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RESEARCH ARTICLE

Length-weight relationship and condition factors of European perch, *Perca fluviatilis*, from 38 lakes in northeastern Poland

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Abstract. Length-weight relationships and condition factors of various fish species depend on food resources, habitat, season, water quality, and the size, age, and sexual maturity of fishes. The aim of this study was to determine the length-weight relationships (LWR) and the values of the Fulton condition factor (K_f), the allometric condition factor (K_a), and the relative condition factor (K_r) of European perch *Perca fluvatilis* from 38 lakes located in northeastern Poland. The total length (TL) of the perch ranged from 3.9 to 41.4 cm. The body weight of the fish caught ranged from 0.4 to 1,162.1 g. The linear regression coefficient of the LWR was highly significant (r^2=0.99). Parameter *b* (3.1859) indicated positive allometric growth. The mean values of K_f (0.996 ± 0.154) and K_r (1.003 ± 0.121) indicated that the fish from the Polish lakes were in good condition. None of the condition coefficients differed significantly among the various maximum depth ranges of the lakes (P > 0.05). RDA analysis indicated a weak positive correlation between K_r and morphometric parameters of lakes. K_a was strongly correlated with lake surface area, while K_f was weakly correlated with the depth of the lakes studied. The results of this study are very important for updating data regarding the fish fauna of Polish lakes and for the management of commercial and recreational fisheries.

Keywords: eutrophication, morphometric parameters, Nordic multi-mesh, trophic state index

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Introduction

Fish growth rates depend on many factors both biotic (e.g., food availability, interspecific competition, the presence of predators, fish condition) and abiotic (e.g., water temperature, salinity, and pH; the availability of oxygen and other chemicals in the water; light intensity and daily duration) (Jisr et al. 2018, Ragheb 2023, Rodriguez et al. 2023). Measurements of body length and weight are used to determine growth in various fish species (Froese 2006, Reis and Ateş 2020). Relationships between body length and weight (LWR) provide much important information regarding fish population dynamics, estimates of the state of resources, mortality, and seasonal changes in fish growth, all of which are key for ecological studies and fish stock management (Richter et al. 2000, Morey et al. 2003, Froese 2006, Froese et al. 2014, Jisr et al. 2018, Eagderi et al. 2020, Reis and Ateş 2020, Sánchez-González et al. 2020). Length-weight relationships are also useful for estimating weight based on known or predicted fish lengths (Bagenal and Tesch 1978). Therefore, determining LWR values is extremely important for managing and protecting natural fish populations. Condition factors allow for rough assessments of the nutritional status of fishes (Simon et al. 2023). They are also used as indicators of fish welfare and health in their habitats (Froese

2006, Jisr et al. 2018, Indrayani et al. 2023, Ragheb 2023). Condition factors are based on the assumption that fish of the same lengths with higher body weights are in better condition (Bagenal and Tesch 1978, Omogoriola et al. 2011, Ragheb 2023). Fulton's condition factor (K_f) (Fulton 1911), the allometric condition factor (K_a) (Bagenal and Tesch 1978), and the relative condition factor (K_r) (Le Cren 1951) are effective tools in biological and ichthyological research and fisheries management (Froese 2006, Verreycken et al. 2011, Sánchez-González et al. 2020). The LWR and condition factors of various species depend on many parameters that include food availability, habitat, season, water quality, fish size, and sexual maturity (Holubova et al. 2022, Ragheb 2023).

European perch (*Perca fluviatilis* L.) is a predatory fish that inhabits various freshwater and brackish ecosystems throughout most parts of Europe and Asia (Kottelat and Freyhof 2007). Growth rates and sexual maturation of perch vary depending on geographical region primarily because of differences in climatic conditions. Populations in warmer regions of the southern hemisphere tend to have faster growth rates and mature sexually earlier than those occurring in the cooler regions of Eurasia (Ning et al. 2025). Perch is known as a keystone species (Power et al. 1996) and as a strong interactor (Carpenter et al. 1996) that can cause fundamental changes in the structure and functioning of aquatic ecosystems. From 2012 to 2022, the global supply of perch from commercial fisheries increased from approximately 26,000 to 37,000 tons (FAO, 2025). Recreational catches of perch have become popular thanks to the fighting ability, its availability (Kalinowska et al. 2023), and the low fat content in muscle tissues (Orban et al. 2007). This species is of great importance to both commercial and recreational fisheries (Skov et al. 2017, Lyach and Remr 2019).

The diet of perch changes as body length and mouth size increase (Ceccuzzi et al. 2011). In the larval stage, this species often occupies the pelagic zone before moving to the littoral zone where it feeds on zooplankton and organisms inhabiting lake bottoms (Amundsen et al. 2003, Bowszys et al. 2012). Adult perch eventually switch to diets composed mainly of fishes (Yazıcıoğlu et al. 2016). Perch populations usually vary depending on lake morphometry and the availability of food (Bogacka-Kapusta and Kapusta 2010). The wide ontogenic complexity and plasticity of perch mean that its growth can be influenced by various environmental factors (Ylikarjula et al. 1999, Persson et al. 2000).

The relationship between total length and body weight (LWR) is estimated for many fish species, and its variation within species and populations is high (Froese et al. 2014). The current FishBase (Froese and Pauly 2025) includes no information regarding LWR values for perch in Poland. Data on the state of populations and their condition are extremely important for the effective and safe management of perch resources in aquatic ecosystems. This is why the aim of this study was to determine the relationship between total length and body weight (LWR) and the three condition factors (K_f, K_a, and K_r) for perch from 38 lakes located in northeastern Poland. We hypothesized that perch condition could depend on the trophic status of the lakes studied.

Material and Methods

Study area and sample collection

The study was conducted in 38 lakes in northeastern Poland with surface areas of 50.5–1,887.7 ha and maximum depths of 1.8–55.8 m (Table 1). Catches were conducted from July 1 to October 17 in 2023 and 2024. Water temperature, dissolved oxygen concentration, oxygen saturation, and electrical conductivity were measured *in situ* in the water column at 1 m intervals with a YSI multiparameter meter (Yellow Spring Instruments, USA). Water transparency was measured with a Secchi disk. Chlorophyll a concentrations were determined by the spectrophotometric analysis of acetone extracts of algae and cyanobacteria retained on Whatman GF/C filters (Golterman 1969). The trophic state index (TSI) of the lakes was calculated based on chlorophyll *a* concentration and Secchi disk visibility (SDV) according to Carlson (1977). It was assumed that lakes with TSI < 40 were oligotrophic, 40–45 mesotrophic, 45–50 meso-eutrophic, 50–70 eutrophic, and > 70 hypereutrophic (Kalinowska et al. 2023). Catches were conducted in accordance with European Standard EN 14757 for sampling fish with Nordic multi-mesh gillnets (CEN 2015). The bottom nets were 30 m in length, 1.5 m in height, and composed of 12 panels (each 2.5 m in length) with mesh sizes of 5, 6.25, 8, 10, 12.5, 15.5, 19.5, 24, 29, 35, 43, and 55 mm. The pelagic nets were 27.5 m in length, 6 m in height, and composed of 11 panels with mesh sizes ranging from 6.25 to 55 mm. The nets were deployed in the deepest parts of the lakes, the maximum depth of which exceeded 7.5 m. The bottom nets were deployed at depths of 0–2.9, 3–5.9, 6–11.9, 12–19.9, 20–34.9, and 35–49 m. Pelagic nets were deployed at depth layers of 0–6, 6–12, 12–18, 18–24, 24–30, 30–36, 36–42, and 42–48 m. The exposure time was 12 h (from 18:00 to 6:00). All of the fishes caught were identified to the species, weighed, and measured immediately after catching. The total length (TL) of each specimen was measured from the snout to the tip of the caudal fin to the nearest 0.1 cm, and fish weight (W) was determined to the nearest 0.1 g.

Length-weight relationship

The LWR was calculated with the following formula:

$$W = a \times L^b,$$

where W is fish weight in g, L is total fish length in cm, *a* is the intercept and *b* is the slope of the linear regression above (LeCren 1951, Ricker 1973). The formula was transformed logarithmically to:

$$W = \log a + b \log L,$$

which fitted the least squares regression using W and the dependent variable. Parameters *a* and *b* were calculated after log-transformed weight and length data. Applying this formula to the fish in the study, *b* may deviate from the "ideal value" of 3, which indicates isometric growth due to environmental conditions or the condition of the fish. Parameter *b* values of less than 3 indicate that the fish are growing faster in length than they are in weight and that growth will be negatively allometric. However, *b* values higher than 3 indicate that the fish are growing faster in weight than length, which is positive allometric growth that reflects optimal conditions for growth. Additionally, a 95% confidence interval (CL) for *b* was estimated (Froese 2006, Sánchez-González et al. 2020):

$$CL = b \pm (1.96 \times SE),$$

where *b* is the length-weight constant, and SE is the standard error of constant *b*. The same procedure was applied to *a*, and the coefficients of determination (r^2) were also estimated in LWR.

Condition factors

Fish condition was evaluated with Fulton's condition factor (K_f), the allometric condition factor (K_a), and the relative condition factor (K_r). Fulton's condition factor (K_f) was calculated with the following formula:

$$K_f = 100 \times W/L^3,$$

where W is total fish weight (g) and L is total fish length (cm). Fulton's condition factor assumes isometric growth (b = 3) in which fish shape does not change as fish length increases.

The allometric condition factor (K_a) was estimated according to the following formula with exponent *b* derived from the LWR of each species:

$$K_a = 100 \times W/L^b,$$

where W is total fish weight (g), L is total fish length (cm), and *b* is the length-weight constant. This factor is used much less frequently even though it is theoretically more significant. Higher values of K_f and K_a indicate higher fish condition.

The relative condition factor (K_r) was estimated with the following formula:

$$K_r = W_o/W_c,$$

where W_o is the observed fish weight and W_c is the calculated fish weight as $W_c = a \times L^b$ (Le Cren 1951). K_r values of 1 or greater indicate that the fish is in good growth condition, while a K_r value of less than 1 indicates that the fish is in poor growth condition.

Statistical analyses

Before regression analysis, log-log plots of length-weight were performed to identify outliers (Froese et al. 2011). The outliers on the log-log plots were excluded form the regression. The degree of correlation among the variables was calculated with the r^2 coefficient of determination, and the level of significance was estimated with analysis of variance. Additionally, differences among K_f, K_a, and K_r were calculated among the different maximum lake depth ranges with Tukey's test (for different N). Differences were significant at $P \leq 0.05$. Relationships among condition factors and morphometric (surface area and maximum and mean depth) and trophic (chlorophyll *a*, SDV, and TSI) parameters of the lakes were determined with Pearson's linear correlation analysis, redundancy analysis (RDA), and the Monte Carlo test (999 permutations). All data were transformed logarithmically prior to analysis. Gradient length was 0.8 units SD. Statistical analysis was performed with STATISTICA 12 PL (StatSoft, Poland). RDA analysis was performed with CANOCO 5.0 (Microcomputer Power, Ithaca, NY, USA).

Results

Environmental characteristics of the lakes studied

The surface layer water temperatures in the lakes studied ranged from 12 to 28°C. The oxygen content ranged from 7.4 to 15.0 mg l^{-1}, which corresponded to 83.2 and 164.8% oxygen saturation. Electrical conductivity ranged from 46.7 to 490.4 µS cm^{-1}. Water transparency ranged from 0.3 to 4.9 m, while chlorophyll *a* concentration ranged from 1.6 to 121.1 µg l^{-1} (Table 1). Most of the lakes were eutrophic (25 lakes or 65.8% of all lakes studied), while oligotrophic and hypereutrophic lakes were the least common (two each).

Perch morphometric parameters

A total of 8,904 perch specimens caught in the 38 lakes were examined. The number of specimens in the lakes ranged from 58 to 338. The total length (TL) range of the perch was 3.9–41.4 cm, while the mean for all the lakes was 9.4 ± 2.6–18.2 ± 9.4 cm (Table 2). Most specimens (1,141) had total lengths within the 9.0–9.9 cm range (Fig. 1). The body weights of the fish caught ranged from 0.4 to 1,162.1 g, with mean values of 10.4 ± 14.6 to 143.7 ± 182.5 g in individual lakes.

The relationship between perch length and body weight was highly significant ($P < 0.0001$) with a high coefficient of determination (r^2) in the 0.974–0.998 range (Table 2). The linear regression intercept (*a*) was 0.0039–0.0111, while slope parameter (*b*) was 2.965–3.353.

Fulton's condition factor (K_f) was 0.386–1.934. The mean K_f value calculated for all the lakes ranged from 0.891 ± 0.126 to 1.101 ± 0.127 (Table 3). The allometric condition factor (K_a) values ranged from 0.252 to 2.106 (the mean for all lakes was 0.393 ± 0.035–1.118 ± 0.104), while the relative condition factor (K_r) was 0.403–2.039 (mean 0.872 ± 0.098 – 1.015 ± 0.180).

The mean total perch length and body weight calculated for all 38 lakes were 12.0 ± 5.8 cm and 38.9 ± 94.4 g, respectively (Table 4). The linear regression coefficient was 0.99 (Figs. 2 and 3). Parameters *a* and *b* were 0.0063 and 3.1859, respectively. The mean K_f value for perch was 0.996 ± 0.154, for K_a – 0.693 ± 0.191, and for K_r – 1.003 ± 0.121 (Table 4). The LWR was $y = 0.0063x^{3.1859}$, while for the logarithmic form of the LWR it was $y = 3.1859x–2.1994$ ($r^2 = 0.9907$, Figs. 2 and 3). The values of K_f, K_a, and K_r did not differ significantly ($P > 0.05$) among the maximum depth ranges of the lakes (Table 5).

Among K_f, K_a, and K_r for perch, only K_a showed negative correlations with the surface areas and maximum and mean depths of the lakes (Table 6), while

Table 1
Morphometric and trophic characteristics of the studied lakes. SDV – Secchi disc visibility, Chl – chlorophyll *a*

Lake	Area (ha)	Max depth (m)	Mean depth (m)	SDV (m)	Chl ($\mu g\ l^{-1}$)	Trophic status
Arklickie	58.0	2.0	0.9	1.3	7.1	Eutrophy
Bałądź	58.2	22.0	8.2	3.8	1.7	Oligotrophy
Boczne	58.3	33.5	15.0	1.8	2.0	Mesotrophy
Bolesty	138.8	16.2	7.0	0.6	3.8	Eutrophy
Brzozolasek	155.9	17.2	5.1	2.1	7.7	Eutrophy
Buwełno	360.3	49.1	12.4	1.1	10.0	Eutrophy
Długie	89.6	18.0	6.0	1.9	4.2	Meso-eutrophy
Długie Wigierskie	80.0	14.8	6.4	4.9	4.6	Mesotrophy
Dłużek	100.7	14.9	7.4	2.8	1.6	Mesotrophy
Ełckie	382.4	55.8	15.0	1.2	8.4	Eutrophy
Głębockie	87.5	10.5	4.5	1.2	18.0	Eutrophy
Gremzdel	59.3	10.0	2.9	0.9	27.0	Eutrophy
Guzianka Wielka	59.6	25.5	6.5	1.1	14.5	Eutrophy
Hołny	158.1	15.2	5.8	2.3	10.4	Eutrophy
Iławki	123.4	6.5	2.9	0.5	56.4	Eutrophy
Inulec	178.3	10.1	4.6	0.9	15.9	Eutrophy
Jegocin	127.4	36.1	9.0	2.9	1.6	Oligotrophy
Kinkajmskie	95.5	1.8	0.9	0.4	121.1	Hypereutrophy
Kirsajty	207.0	7.0	3.2	2.8	3.6	Mesotrophy
Krzywe Filipowskie	50.5	19.9	7.9	1.2	21.9	Eutrophy
Mikołajskie	497.9	25.9	11.2	1.5	23.3	Eutrophy
Necko	400.0	25.0	10.1	1.3	22.9	Eutrophy
Okmin	11.8	42.4	12.8	2.7	2.1	Mesotrophy
Ołówka (Haleckie)	93.5	7.2	3.4	0.8	62.2	Eutrophy
Orzysz	1070.7	36.0	7.0	2.3	3.8	Meso-eutrophy
Płaskie	620.4	5.7	2.6	0.6	17.5	Eutrophy
Pobondzie	53.1	10.0	3.6	2.1	8.0	Eutrophy
Roś	1887.7	31.8	8.1	1.7	20.1	Eutrophy
Sejny	64.3	3.8	1.8	1.2	31.1	Eutrophy
Sejwy	85.6	21.5	4.8	0.9	10.2	Eutrophy
Symsar	135.5	9.6	4.8	0.3	102.5	Hypereutrophy
Szelment Wielki	356.1	45.0	15.0	2.9	2.5	Mesotrophy
Szwałk Mały	70.4	6.7	4.3	0.7	38.2	Eutrophy
Szymbarskie	165.2	25.1	6.1	1.0	14.2	Eutrophy
Tobołowo	51.4	9.4	4.1	1.4	14.1	Eutrophy
Toczyłowo	101.8	9.9	4.8	3.0	10.3	Meso-eutrophy
Ustrych	93.1	11.6	5.5	0.8	14.7	Eutrophy
Wiartel	179.6	29.0	4.5	1.3	13.5	Eutrophy

Table 2

Morphometrics and length-weight relationships for P. *fluviatilis* from 38 Polish lakes. N – number of individuals, TL – total length, BW – body weight, SD – standard deviation, *a* – intercept, *b* – coefficient of regression (slope), CL – confidence limit, r^2 – coefficient of determination

Lake	N	TL (cm)	BW (g)	Regression parameters				
		mean±SD (range)	mean±SD (range)	*a*	*b*	95% CL of *a*	95% CL of *b*	r^2
Arklickie	203	11.0 ± 4.8 (5.0-31.1)	25.3 ± 47.0 (1.5-406.6)	0.0111	2.988	0.0103-0.0120	2.954-3.021	0.995
Bałądź	303	11.4 ± 4.5 (4.5-26.5)	23.8 ± 32.0 (0.7-230.3)	0.0058	3.223	0.0053-0.0063	3.188-3.258	0.991
Boczne	179	12.5 ± 4.7 (3.9-31.2)	31.0 ± 38.1 (0.6-373.3)	0.0065	3.185	0.0059-0.0071	3.147-3.222	0.989
Bolesty	262	12.2 ± 3.6 (4.9-35.9)	24.7 ± 53.8 (1.2-496.3)	0.0081	3.055	0.0068-0.0095	2.988-3.122	0.977
Brzozolasek	226	13.8 ± 7.0 (7.1-39.2)	69.7 ± 157.1 (3.2-834.1)	0.0067	3.185	0.0062-0.0073	3.152-3.218	0.993
Buwełno	338	9.6 ± 4.8 (4.3-33.0)	18.0 ± 46.3 (0.5-483.1)	0.0065	3.141	0.0060-0.0071	3.101-3.182	0.985
Długie	311	11.0 ± 4.2 (5.8-35.9)	22.6 ± 62.7 (1.9-595.3)	0.0088	3.049	0.0074-0.0105	2.974-3.124	0.978
Długie Wigierskie	144	11.8 ± 4.0 (6.0-23.6)	25.1 ± 26.9 (2.1-176.6)	0.0099	3.038	0.0089-0.0109	2.997-3.080	0.991
Dłużek	302	9.4 ± 2.6 (6.6-23.1)	10.4 ± 14.6 (2.1-128.6)	0.0085	3.059	0.0075-0.0097	3.001-3.116	0.974
Ełckie	306	12.2 ± 6.5 (4.6-37.1)	41.6 ± 75.9 (0.7-589.0)	0.0054	3.245	0.0051-0.0057	3.222-3.267	0.996
Głębockie	304	14.3 ± 5.9 (6.4-38.5)	62.6 ± 148.1 (1.7-870.1)	0.0049	3.282	0.0045-0.0054	3.245-3.319	0.990
Gremzdel	154	10.8 ± 4.7 (6.9-32.6)	25.9 ± 68.3 (3.0-467.4)	0.0055	3.234	0.0046-0.0065	3.159-3.309	0.986
Guzianka Wielka	211	11.4 ± 5.5 (5.8-39.3)	30.7 ± 83.8 (1.7-875.0)	0.0061	3.166	0.0055-0.0067	3.124-3.208	0.992
Hołny	187	10.5 ± 5.1 (5.2-41.0)	28.1 ± 94.9 (1.6-1162.1)	0.0073	3.152	0.0067-0.0079	3.115-3.190	0.993
Iławki	142	12.2 ± 3.5 (7.2-34.0)	26.7 ± 55.2 (4.1-548.2)	0.0102	3.009	0.0088-0.0118	2.951-3.068	0.988
Inulec	303	9.7 ± 4.9 (4.7-33.4)	20.6 ± 51.2 (0.8-523.0)	0.0070	3.127	0.0066-0.0075	3.096-3.158	0.992
Jegocin	304	13.4 ± 3.0 (6.3-30.0)	26.8 ± 24.1 (1.8-339.6)	0.0106	2.965	0.0094-0.0119	2.920-3.011	0.982
Kinkajmskie	58	15.4 ± 6.0 (5.2-31.7)	64.8 ± 86.7 (1.6-551.6)	0.0080	3.120	0.0070-0.0091	3.071-3.169	0.995
Kirsajty	255	13.5 ± 6.8 (5.2-33.9)	52.5 ± 94.6 (0.9-511.9)	0.0098	3.017	0.0090-0.0108	2.981-3.052	0.991
Krzywe Filipowskie	348	10.3 ± 4.3 (4.2-35.1)	20.2 ± 53.2 (0.5-666.5)	0.0065	3.173	0.0060-0.0070	3.140-3.205	0.991
Mikołajskie	326	13.0 ± 5.3 (6.4-30.2)	39.4 ± 59.0 (2.3-338.9)	0.0051	3.250	0.0047-0.0054	3.222-3.278	0.994
Necko	308	12.1 ± 6.9 (5.7-41.4)	58.2 ± 177.3 (1.1-1054.2)	0.0055	3.247	0.0050-0.0061	3.205-3.289	0.986
Okmin	200	10.4 ± 4.5(5.1-28.7)	21.0 ± 38.3 (1.2-301.2)	0.0065	3.185	0.0062-0.0067	3.161-3.209	0.995
Ołówka (Haleckie)	238	13.7 ± 5.1 (6.7-33.3)	43.3 ± 72.9 (3.0-472.9)	0.0060	3.196	0.0055-0.0066	3.162-3.230	0.993
Orzysz	307	13.6 ± 7.4 (6.0-38.0)	64.7 ± 120.5 (1.6-761.8)	0.0052	3.265	0.0048-0.0055	3.240-3.290	0.995
Płaskie	276	11.3 ± 5.9 (4.2-27.2)	32.0 ± 49.6 (0.4-285.8)	0.0068	3.176	0.0063-0.0074	3.139-3.212	0.990
Pobondzie	206	10.5 ± 3.6 (6.5-27.0)	17.4 ± 31.6 (2.3-245.1)	0.0071	3.142	0.0060-0.0084	3.069-3.214	0.977
Roś	155	18.2 ± 9.4 (5.4-38.4)	143.7 ± 182.5 (1.3-867.1)	0.0039	3.353	0.0037-0.0041	3.337-3.369	0.998
Sejny	98	9.6 ± 2.9 (6.9-22.0)	12.2 ± 19.7 (2.7-138.6)	0.0071	3.134	0.0060-0.0084	3.061-3.207	0.987
Sejwy	221	10.7 ± 4.5 (5.9-32.0)	21.3 ± 42.7 (1.8-407.8)	0.0069	3.143	0.0064-0.0074	3.110-3.176	0.994
Symsar	103	10.7 ± 4.3 (6.4-33.5)	24.7 ± 78.0 (2.3-552.9)	0.0070	3.154	0.0054-0.0090	3.046-3.262	0.979
Szelment Wielki	292	10.1 ± 4.2 (4.9-33.5)	18.1 ± 44.7 (0.9-526.3)	0.0052	3.213	0.0053-0.0062	3.176-3.250	0.992
Szwałk Mały	233	11.7 ± 5.9 (6.0-32.2)	37.6 ± 81.0 (2.3-488.8)	0.0075	3.127	0.0067-0.0086	3.074-3.179	0.989
Szymbarskie	268	11.4 ± 5.2 (5.2-40.9)	34.3 ± 111.4 (1.1-1158.8)	0.0087	3.074	0.0080-0.0095	3.039-3.108	0.991
Tobołowo	151	10.2 ± 5.2 (5.5-28.8)	22.6 ± 50.0 (0.8-293.1)	0.0058	3.188	0.0053-0.0063	3.150-3.227	0.993
Toczyłowo	126	16.6 ± 8.7 (5.3-40.1)	110.0 ± 147.0 (1.2-896.2)	0.0055	3.253	0.0051-0.0060	3.222-3.284	0.996
Ustrych	304	9.6 ± 2.7 (6.5-26.7)	10.7 ± 18.3 (1.5-224.5)	0.0083	3.039	0.0070-0.0098	2.964-3.113	0.956
Wiartel	181	13.9 ± 8.1 (5.7-40.5)	81.9 ± 183.3 (1.6-947.5)	0.0058	3.222	0.0054-0.0064	3.189-3.255	0.995

RDA analysis showed a weak positive relationship between K_r and the morphometric parameters of lake (surface area and maximum and mean depth) (Fig. 4). There was a strong negative correlation between K_a values and lake surface area, while K_f showed a weak negative relationship with the depths of the lakes studied.

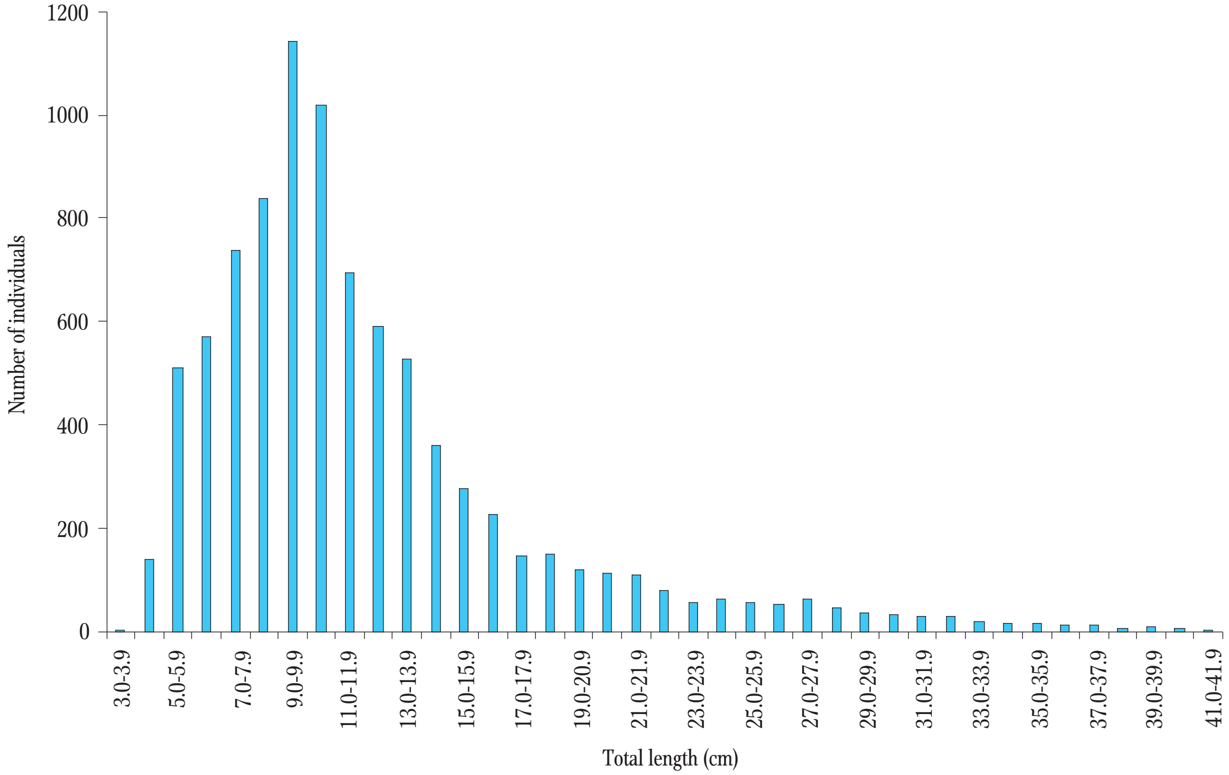

Figure 1. Total length distribution of European perch from 38 lakes in northeast Poland.

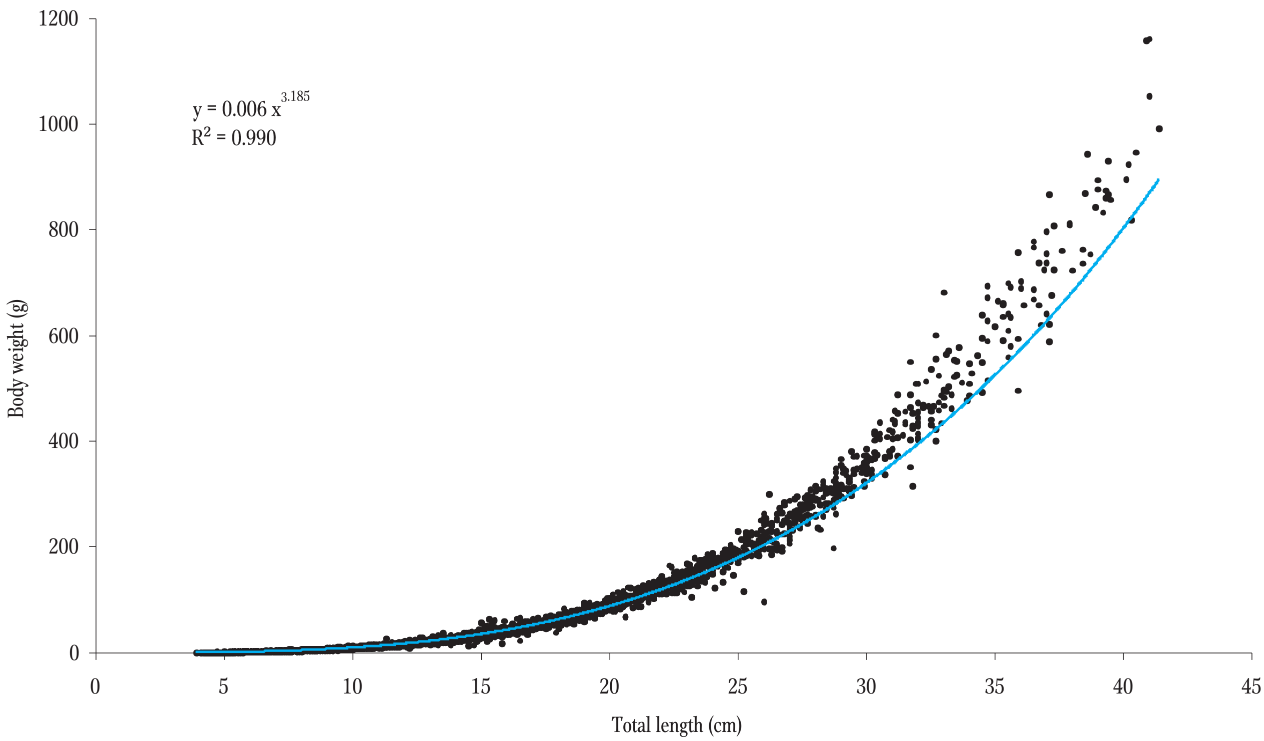

Figure 2. Length-weight relationship of European perch from 38 lakes in northeast Poland.

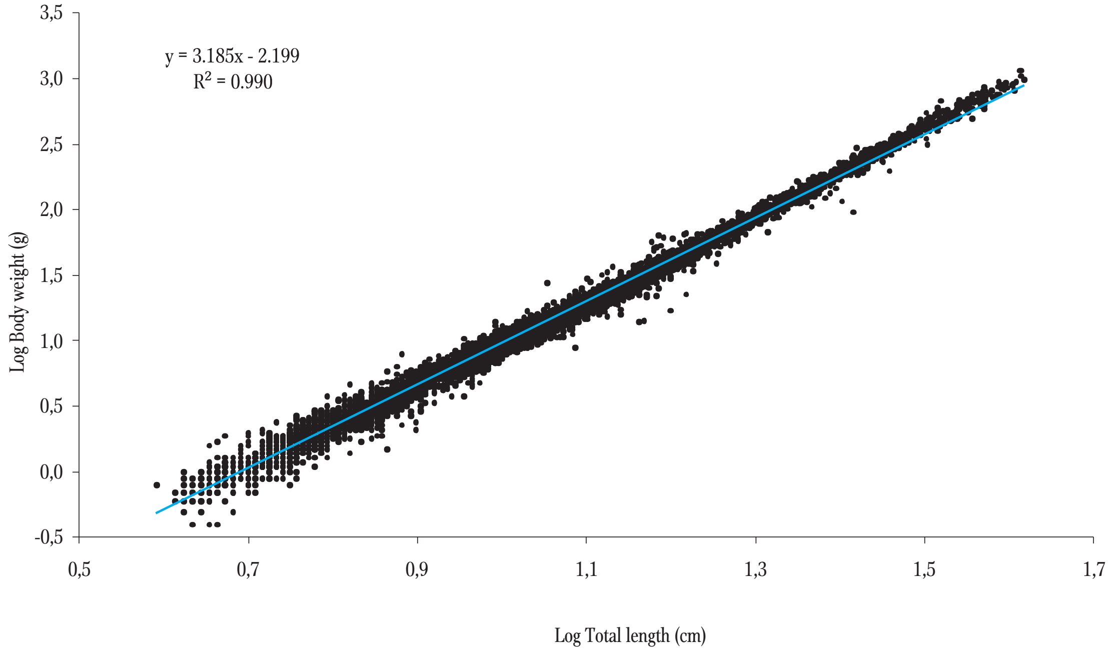

Figure 3. Logarithmic length-weight relationship of European perch from 38 lakes in northeast Poland.

Table 3

Fulton's condition factor (K_f), allometric condition factor (K_a), and relative condition factor (K_r) for *P. fluviatilis* from 38 Polish lakes. SD – standard deviation

	Fulton (K_f)		Allometric (K_a)		Relative (K_r)	
Lake	mean ± SD	range	mean ± SD	range	mean ± SD	range
Arklickie	1.087 ± 0.102	0.694-1.422	1.118 ± 0.104	0.710-1.451	1.004 ± 0.094	0.637-1.303
Bałądź	0.984 ± 0.145	0.545-1.495	0.581 ± 0.075	0.363-0.894	1.008 ± 0.130	0.630-1.552
Boczne	1.032 ± 0.137	0.436-1.349	0.654 ± 0.078	0.262-1.049	1.008 ± 0.120	0.403-1.615
Bolesty	0.931 ± 0.092	0.450-1.274	0.812 ± 0.078	0.388-1.128	1.005 ± 0.097	0.480-1.396
Brzozolasek	1.086 ± 0.154	0.774-1.899	0.679 ± 0.072	0.474-0.995	1.005 ± 0.106	0.703-1.474
Buwełno	0.900 ± 0.166	0.452-1.793	0.661 ± 0.114	0.362-1.218	1.014 ± 0.175	0.555-1.868
Długie	1.003 ± 0.158	0.509-1.635	0.894 ± 0.141	0.462-1.490	1.012 ± 0.159	0.523-1.687
Długie Wigierskie	1.088 ± 0.103	0.700-1.487	0.991 ± 0.093	0.632-1.363	1.004 ± 0.094	0.640-1.381
Dłużek	0.978 ± 0.110	0.487-1.517	0.859 ± 0.096	0.431-1.350	1.006 ± 0.112	0.505-1.581
Ełckie	0.983 ± 0.153	0.601-1.430	0.546 ± 0.054	0.320-0.706	1.005 ± 0.099	0.589-1.300
Głębockie	1.041 ± 0.149	0.510-1.609	0.497 ± 0.049	0.231-0.676	1.005 ± 0.099	0.467-1.368
Gremzdel	0.954 ± 0.141	0.595-1.394	0.553 ± 0.068	0.362-0.814	0.913 ± 0.142	0.634-1.484
Guzianka Wielka	0.907 ± 0.118	0.551-1.442	0.612 ± 0.063	0.320-0.933	1.005 ± 0.104	0.526-1.533
Hołny	1.036 ± 0.121	0.709-1.686	0.732 ± 0.070	0.492-0.977	1.005 ± 0.096	0.675-1.340
Iławki	1.049 ± 0.090	0.803-1.457	1.026 ± 0.088	0.783-1.413	0.990 ± 0.086	0.766-1.383
Inulec	0.936 ± 0.119	0.722-1.404	0.709 ± 0.079	0.541-0.930	1.006 ± 0.113	0.767-1.320
Jegocin	0.973 ± 0.105	0.655-1.934	1.063 ± 0.114	0.716-2.106	1.005 ± 0.108	0.677-1.988
Kinkajmskie	1.101 ± 0.127	0.935-1.732	0.799 ± 0.079	0.672-1.143	1.005 ± 0.099	0.845-1.437
Kirsajty	1.038 ± 0.153	0.569-1.524	0.995 ± 0.147	0.549-1.481	1.011 ± 0.149	0.558-1.504
Krzywe Filipowskie	0.968 ± 0.128	0.528-1.541	0.654 ± 0.078	0.398-1.026	1.007 ± 0.119	0.613-1.580
Mikołajskie	0.959 ± 0.135	0.616-1.449	0.508 ± 0.049	0.362-0.701	1.005 ± 0.097	0.716-1.386
Necko	1.012 ± 0.176	0.487-1.822	0.557 ± 0.082	0.306-1.104	1.010 ± 0.148	0.554-2.003
Okmin	0.997 ± 0.108	0.713-1.388	0.655 ± 0.053	0.509-0.807	1.003 ± 0.081	0.780-1.236
Ołówka (Haleckie)	1.004 ± 0.116	0.771-1.454	0.606 ± 0.053	0.454-0.788	1.004 ± 0.088	0.752-1.304

Table 3. To be continued

Lake	Fulton (K_f)		Allometric (K_a)		Relative (K_r)	
	mean ± SD	range	mean ± SD	range	mean ± SD	range
Orzysz	1.012 ± 0.175	0.490-1.594	0.519 ± 0.058	0.252-0.983	1.006 ± 0.112	0.489-1.905
Płaskie	1.040 ± 0.189	0.411-1.830	0.694 ± 0.123	0.314-1.394	1.015 ± 0.180	0.460-2.039
Pobondzie	0.991 ± 0.137	0.524-1.379	0.714 ± 0.096	0.393-1.005	1.009 ± 0.135	0.555-1.421
Roś	1.060 ± 0.237	0.633-1.698	0.393 ± 0.035	0.292-0.550	1.004 ± 0.091	0.745-1.404
Sejny	0.961 ± 0.091	0.723-1.302	0.712 ± 0.062	0.550-0.860	1.004 ± 0.087	0.775-1.212
Sejwy	0.959 ± 0.097	0.700-1.343	0.959 ± 0.097	0.530-1.034	1.004 ± 0.089	0.772-1.507
Symsar	1.009 ± 0.157	0.700-1.471	0.706 ± 0.105	0.520-1.003	1.011 ± 0.151	0.744-1.436
Szelment Wielki	0.931 ± 0.121	0.540-1.402	0.576 ± 0.061	0.373-0.753	1.006 ± 0.107	0.651-1.316
Szwałk Mały	1.029 ± 0.145	0.463-1.534	0.761 ± 0.097	0.330-1.107	1.008 ± 0.128	0.437-1.466
Szymbarskie	1.047 ± 0.123	0.657-1.694	0.879 ± 0.096	0.548-1.289	1.006 ± 0.110	0.627-1.474
Tobołowo	0.891 ± 0.126	0.456-1.252	0.584 ± 0.066	0.329-0.729	0.872 ± 0.098	0.491-1.180
Toczyłowo	1.095 ± 0.200	0.648-1.527	0.553 ± 0.059	0.321-0.749	1.006 ± 0.108	0.584-1.361
Ustrych	0.912 ± 0.139	0.386-1.428	0.836 ± 0.128	0.357-1.293	1.013 ± 0.155	0.432-1.565
Wiartel	1.032 ± 0.172	0.733-1.663	0.589 ± 0.065	0.415-0.757	1.006 ± 0.111	0.709-1.295

Table 4
Mean values ± standard deviations of total length, body weight, regression parameters, and condition factors for *P. fluviatilis* from 38 Polish lakes

Parameter	*P. fluviatilis*
Morphometric	
Total length (cm)	12.0 ± 5.8
Body weight (g)	38.9 ± 94.4
Regression	
a	0.0063
b	3.1859
r^2	0.9907
95% CL of a	0.0062 – 0.0064
95% CL of b	3.1795 – 3.1923
Condition	
Fulton (K_f)	0.996 ± 0.154
Allometric (K_a)	0.693 ± 0.191
Relative (K_r)	1.003 ± 0.121

Discussion

The LWR of fishes is an important tool in the management of fisheries and in scientific research, because it provides information about fish condition and growth (Bagenal and Tesch, 1978, Verreycken et al. 2011). In the current study, the LWR of perch from northeastern Poland was highly significant. The study was based on a large number of perch specimens of a wide size range caught in 38 lakes. The use of Nordic multi-mesh gillnets ensured obtaining reliable, comparable data on the fish assemblage structures in the lakes monitored (Tsionki et al. 2021, Kalinowska et al. 2023).

Table 5
Values of three condition factors in lakes of different maximum depths. Differences in all factors between groups of lakes of different depth were not statistically significant ($P > 0.05$)

Depth (m)	Fulton (K_f)	Allometric (K_a)	Relative (K_r)
< 6.0	1.039 ± 0.066	0.831 ± 0.197	1.007 ± 0.005
6.0–11.9	0.996 ± 0.061	0.712 ± 0.171	0.987 ± 0.046
12.0–19.9	1.013 ± 0.060	0.803 ± 0.122	1.006 ± 0.003
20.0–34.9	0.999 ± 0.050	0.637 ± 0.177	1.006 ± 0.002
≥ 35.0	0.966 ± 0.042	0.670 ± 0.201	1.007 ± 0.004

Table 6

Pearson's correlation coefficients (r values) between condition factors of *P. fluviatilis* and abiotic parameters in the studied 38 Polish lakes. Chl-*a*– chlorophyll *a*, SDV – Secchi disc visibility, TSI – trophic state index, n = 38, ns – not significant correlation, * – P < 0.05, ** – P < 0.01

Condition factor	Area	Max depth	Mean depth	Chl-*a*	SDV	TSI
Fulton	ns	ns	ns	ns	ns	ns
Allometric	-0.43**	-0.33*	-0.34*	ns	ns	ns
Relative	ns	ns	ns	ns	ns	ns

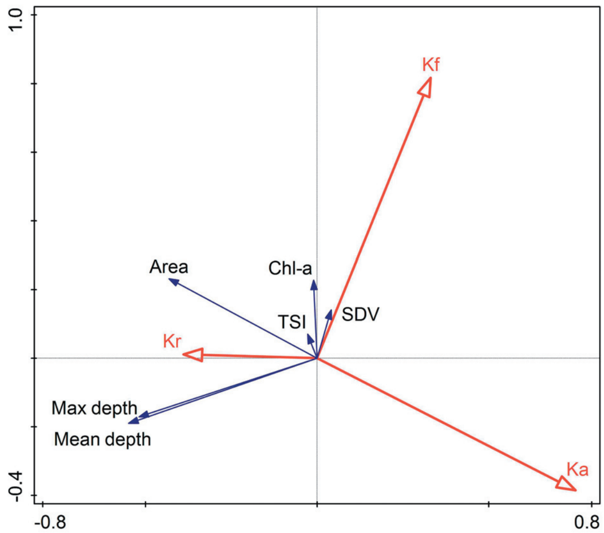

Figure 4. Redundancy diagram (RDA) of relationships among K_f, K_a, and K_r and morphometric (surface area, maximum and mean depth) and trophic (Chl-*a* - chlorophyll *a*, SDV- Secchi disc visibility, TSI - trophic state index) parameters. The cumulative explained variability for the first two axes is 18.0% (13.6 and 4.4%, respectively).

Parameter *a* can vary daily, seasonally, and among habitats (Le Cren 1951, Bagenal and Tesch 1978, Froese 2006, Bobori et al. 2010, Simon et al. 2023), while parameter *b* does not vary substantially over the year, ranging from 2.5 to 3.5 (Froese 2006). The mean value of *a* for the perch from the 38 lakes was 0.0063, and the mean value of *b* was 3.1859 and indicated positive allometric growth, which means that as fish size increases, its weight increases at given lengths (Omogoriola et al. 2011, Indrayani et al. 2023, Ragheb 2023) and its shape becomes more "short and deep" (Verreycken et al. 2011). Only in the eutrophic lakes Arklickie and Iławki was perch growth almost isometric (2.99–3.01), while perch growth was minimally allometric (2.96) in the mesotrophic Lake Jegocin. De Giosa and Czerniejewski (2016) reported *a* and *b* values of 3.83×10^{-6} and 3.238, respectively, for perch from the Polish coast of the southern Baltic. Similar values to parameters *a* and *b* from the present study were reported in perch from other regions of Europe, for example, 0.0075 and 3.186 from lakes in Flanders, Belgium (Verreycken et al. 2011), 0.0076 and 3.213 in all regions of Croatia (Treer et al. 2008), 0.0080 and 3.200 in the region of Marmara in Turkey (Tarkan et al. 2006), and 0.0080 and 3.012 in the lakes of Kirkkojärvi in Finland (Gama and Nyberg 2017). Bobori et al. (2010) reported that the values of parameters *a* and *b* in perch from Lake Volvi in Greece fluctuated seasonally in the ranges of 0.0058–3.294 in spring, 0.0108–3.094 in summer, 0.0067–3.298 in fall, and 0.0023–3.639 in winter. Connor et al. (2017) noted different values of these parameters in three alkalinity classes in Irish lakes (0.023–3.083, 0.038–3.149, and 0.025–3.417 in low, moderate, and high alkalinity, respectively).

Studies indicate that the value of parameter *b* can fluctuate depending on various factors such as the availability of food, temperature, competition, sex, gonadal development, disease, seasonality, habitat, spawning season, body length range, and the number of specimens examined (Le Cren 1951, Bagenal and Tesch 1978, Froese 2006, Ragheb 2023, Simon et al. 2023). Differences in the fish growth can also be attributed to the methods applied to collect the study material and the fishing gear used (Rodriguez et al. 2023). In the present study, the small differences in the values of parameter *b* in the perch can be attributed to the number and size range of the specimens examined and the health and overall condition of the fish (Le Cren 1951, Froese 2006, Eagderi in. 2020, Simon et al. 2023).

Knowing LWRs eliminates the need to weigh fishes in the field and can provide estimated fish weights. In reality, applying LWRs should be strictly limited only to the length ranges used in linear regressions (Wang et al. 2017). Additionally, LWRs shorten the handling time of fishes while limiting fish skin contact with objects and decreasing possible mucosal damage. They also minimize stress, which is especially important for rare and protected fish species, while simultaneously reducing manipulations and costs thanks to the time saved (Simon et al. 2023). Furthermore, adverse weather conditions, such as wind or rain, can influence the accuracy of body measurements, while water or debris on the fishes or on the hands of personnel working in the field and uneven terrain can result in fluctuations in the weights recorded (Connor et al. 2017). In field study, imprecise weight measurements of juvenile or small specimens can be the result of water adhering to bodies or the accuracy limits of the scales (Kimmerer et al. 2005).

The condition factors K_f, K_a and K_r are used to determine the condition, health, and welfare of fishes (Indrayani et al. 2023, Ragheb 2023). Deviations from 1 in condition factor values can provide information on the differences in food availability for each fish species (Le Cren 1951). In the present study, Fulton's condition factor values of perch differed among the studied lakes. This indicated that the conditions, growth rates, and foraging abilities of each specimen were different even within the same species. Mean K_f values were <1 in 18 lakes, while in the other 20 lakes they were >1, indicating high food availability for perch. In the current study, Fulton's condition factor values (0.996 ± 0.154) were lower in comparison to those of perch from Lake Miedwie, in which values of K_f were 1.128 ± 0.02 and 1.203 ± 0.02 for catches made in May and November, respectively (Stepanowska et al. 2012). However, the results of the studies mentioned above must be treated cautiously because of the small number of fish specimens analyzed (25 specimens from each catch) and the use of only one type of net with a relatively large mesh size of 40–45 mm. In Lake Skomielno the mean K_f was 2.3, and there was high variability in the group of perch studied that ranged from an average of 1.7 for three-year-old specimens to even 3.8 for one-year-old specimens (Rechulicz 2008). In the Solińskie and Rożnowski reservoirs, the Fulton condition factor was 1.23–1.55 and 1.27–1.62, respectively (Epler et al. 2005). In comparison to results from the second half of the twentieth century, Fulton condition factors of perch in various Polish water bodies were as follows: 1.9 in Lake Tajty (Zawisza 1953), 1.6 in Lake Wdzydze (Zawisza and Karpińska-Waluś 1961), 2.0 in the Kozłowa Góra Reservoir (Skóra 1964), and 1.8 in the Vistula Lagoon (Krawczak 1965). The K_f value depends mainly on the qualitative and quantitative composition of food, its availability, and utilization. However, the condition of the fish examined reflects the environmental conditions of a given water body, which is why differences in the value of this coefficient are most likely linked to ontogenetic changes in the diets of older fishes (Żuromska 1961, Rechulicz 2008) and to climate change.

The values of Fulton's condition factor may differ for each population of the same fish species or for the same species in the same area in different years, depending on their feeding activity (Ricker 1973, Indrayani et al. 2023). If fishes are present in an environment that provides an adequate quantity of food, this can result in optimum growth (Jisr et al. 2018). However, various biotic and abiotic factors can influence the availability of food, fish condition and growth, and the reproductive cycle (Morato et al. 2001, Jisr et al. 2018, Indrayani et al. 2023).

The allometric condition factor (K_a) is used most frequently to determine fish feeding intensity (Omogoriola et al. 2011, Ragheb 2023). If a species exhibits allometric growth or if value *b* is calculated using sufficient data, calculation error is reduced (Bagenal and Tesch 1978). The allometric condition factor is likely more appropriate when differences are directly related to differences in fish weight or feeding intensity (Ragheb 2023). In the present study, the values of K_f were higher than those of K_a, when *b* was >3, but when *b* was <3 the values of K_a were higher than those of K_f. Ragheb (2023) reported the same observations for 33 fish species caught with

Nordic nets in the waters of the Mediterranean Sea off the coast of Egypt. In our study, only the perch caught in the eutrophic Lake Sejwy had the same K_f and K_a values.

The lowest values of the relative condition factor (K_r) were noted in perch from the eutrophic lakes Gremzdel and Tobołowo (0.913 and 0.872, respectively), indicating that these fish live in poor conditions. In the remaining lakes studied, K_r values were ≥ 0.99, which is evidence of good perch condition. Deviations of K_r from 1 indicate the influence of food availability and physicochemical conditions on the fish life cycle (Le Cren 1951, Jisr et al. 2018). According to Muchlisin et al. (2017), K_r values of <1 indicate poor prey availability or high predator density, while K_r values of >1 indicate prey surplus or low predator density. However, when $K_r = 1$, there is still balance between prey and predators, and the water is in a good state, which may favor fish growth. The disadvantage of K_r is that it is limited to homogeneous data in terms of the *b* value in the LWR (Bolger and Connolly 1989), since mean slopes can differ depending on geographic range (Anderson and Neumann 1996). Consequently, different W_c equations are required for each region or maybe even each population, which makes comparisons difficult among water bodies (Blackwell et al. 2000).

Differences in perch growth and abundance among different lakes might be linked with differences in perch feeding niches, which are influenced by lake productivity (Persson 1991), habitat diversity and complexity (Höhne et al. 2020), and lake depth (Kahl and Radke 2006, Trudeau et al. 2024). Data from the literature indicate that perch is the dominant species in deeper, mesotrophic lakes (Jeppesen et al. 2000, Mehner et al. 2005). Lake depth is a primary structural factor, and it may shape niche partitioning opportunities between perch and competing cyprinid species, which can influence food competition regardless of density (Kahl and Radke 2006). In shallow lakes with gravel bottoms, perch occupies a higher trophic level than do small perch in deeper lakes. This suggests that juvenile perch in deeper lakes feed on zooplankton more than benthic macroinvertebrates. However, larger perch in shallow lakes occupy a lower trophic position than they do in deeper lakes; this suggests that perch populations in shallow water bodies still consume benthic macroinvertebrates as a major dietary component as they grow, while perch in deeper lakes transition to a more piscivorous diet (Trudeau et al. 2024). The present study demonstrated that lake morphometric parameters can significantly influence perch condition. However, the study did not demonstrate that different maximum depth ranges influenced perch condition significantly.

In summary, the present study provides a robust regression equation for LWR among perch from lakes in northeastern Poland. All of the study material was obtained with Nordic multi-mesh nets, which guarantee catching a wide size range of fish and the possibility of comparing fishing effort among different lakes. The results of the current study provide valuable information regarding perch LWR and condition in 38 lakes in northeastern Poland. The results of the study may be significant for updating data on the fish fauna of Polish waters and the management of commercial and recreational fisheries.

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Author contributions. M.K. designed the study, analyzed the data, and drafted the manuscript; P.T. analyzed the data and revised a draft version of the manuscript; K.K. analyzed the data and revised a draft version of the manuscript.

Conflicts of interest. K.K. is on the editorial board of Fisheries & Aquatic Life but was not involved in the handling of the manuscript.

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