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RESEARCH ARTICLE

Length-weight relationship and condition factor of sea trout from the Słupia River (Poland), during the spawning migration

Tomasz Błądek, Marek Matras, Andrzej Posyniak, Michał Reichert

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Abstract. Ulcerative dermal necrosis (UDN) has been observed in sea trout (*Salmo trutta* L.) entering the Słupia River to spawn. During this time, various biotic and abiotic factors can disrupt homeostatic balance, leading to severe pathological changes, including those on the skin surface. The aim of the study was to determine whether the symptoms of ulcerative dermal necrosis affect the growth and condition of sea trout migrating to spawning areas in the Słupia River. Between 2021 and 2024, 63 fish ascending the fish ladder in the Słupia River were tested. The length-weight relationship (LWR) and Fulton's condition factor (*Kc*) were estimated. A comparison of the slopes and intercepts of the LWR regressions for both healthy and diseased males and females indicated no statistically significant differences among the groups examined. Consequently, this suggests that UDN infection does not have a relevant impact on linear regression. Additionally, a comparison of *Kc* values between the studied groups did not reveal a statistically significant effect of UDN in sea trout. The current study provides basic biometric data on spawning stocks of sea trout in the Słupia River, where UDN is observed, thereby expanding knowledge on this subject.

T. Błądek [✉], A. Posyniak
Department of Chemical Research of Food and Feed, National Veterinary Research Institute, 24-100 Puławy, Poland
E-mail: tomasz.bladek@piwet.pulawy.pl

M. Matras, M. Reichert
Department of Parasitology and Invasive Diseases, Bee Diseases and Aquatic Animal Diseases, National Veterinary Research Institute, 24-100 Puławy, Poland

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Introduction

The sea trout (*Salmo trutta* L.) is an anadromous fish belonging to the species brown trout (*Salmo trutta* L.), a polytypic species of the Salmonidae family distributed over a wide geographic range, which periodically migrate from the Baltic Sea up rivers to spawn (Bernaś et al. 2009, Degerman et al. 2012, Dębowski 2018). In Poland, most sea trout return into Pomeranian rivers (Rega, Parsęta, Wieprza, and Słupia) and their tributaries after a two-year stay in the sea waters (Bartel et al. 2010, Dębowski 2018). During the transition from seawater to freshwater for spawning, sea trout undergo significant changes that adapt the fish's organism to new environmental conditions. During this time, various biotic and abiotic factors can disrupt homeostatic balance, leading to serious pathological changes, including those on the skin surface (Kazuń et al. 2023).

For many years, skin lesions observed in fish migrating upstream in autumn have been described as ulcerative dermal necrosis (UDN) (Munro 1970, Roberts 1993, Grudniewska et al. 2011). Symptoms observed during early infection consist of small grey lesions on the skin, which gradually ulcerate and become infected with opportunistic pathogens. In the advanced stage of the disease, ulcers and molds cover large areas of the affected fish skin. According to Noga (2000), if skin changes cover 10% of the fish body surface, mortality can reach 50%. It is difficult to identify a single etiological factor causing UDN, as the disease seems to be polyetiological in nature. Additionally, factors related to water quality may influence the etiology of UDN, and its occurrence is predisposed by the reproductive period and the change in environment from marine to freshwater (Rajkowska-Myśliwiec et al. 2022, Stokowski et al. 2023, Matras et al. 2024).

Biometric analysis is an important tool for assessing fish condition, as it provides information on growth, general health, habitat conditions, life history, fatness and condition of fish, morphological characteristics, and others. Biometric tests determine growth related to the weight and length of fish, as well as welfare, which is influenced by various biological and environmental factors (Froese 2006).

The importance of determining the length-weight relationship (LWR) in fish has been emphasized in many studies (Jisr et al. 2018, Mazlum and Turan 2018, Das et al. 2023, Ragheb 2023). The LWRs are expressed in a formula that allows for the estimation of the fish weight (W) using a particular length (L). It can also be applied to studies on gonadal development, feeding rates, and maturity conditions. However, it should be noted that the LWRs differ among fish species depending on the inherited body shape, and physiological factors such as maturity and spawning relationships might change over seasons or even days. Relationships may change during different periods, illustrating the fullness of the stomach, general feeding status, and gonadal stages. In addition, the growth process can differ in the same species dwelling in diverse locations and is influenced by numerous biotic and abiotic factors.

Another important biometric tool is the condition factor, which is used as an indicator of fish welfare and the health of fish populations in their habitats. They provide information on environmental quality and suitability, and as indices, they reflect an interaction between biotic and abiotic factors in fish physiological conditions (Le Cren 1951, Aminisarteshnizi and Moyo 2022, Latiu et al. 2022, Shah et al. 2022). Condition factors compare fish fatness or well-being, where heavier fish of a given length are in a better condition. Three identified factors are known: Fulton's condition factor (*Kc*), the allometric condition factor (*Ka*), and the relative weight condition factor (*Kn*) (Ragheb 2023). *Kc* measures individuals in the form of hypothetical fish, *Ka* measures deviations from the form of hypothetical fish, and *Kn* measures deviations from an average weight in a given sample of fish. Variations in the condition primarily reflect the degree of nourishment and state of sexual maturity. The values of the condition may also vary with fish age and sex in some species (Froese 2006).

Data on population size and conditions are crucial for the effective and safe management of sea trout resources in aquatic ecosystems. Many studies have determined the LWRs and condition factors in brown trout (Rawat et al. 2014, Tanir and Fakioglu 2017, Muddasir et al. 2018, Durrani 2023). In Poland, studies on sea trout biology in Pomeranian rivers (Pilecka-Rapacz 2011) and the Vistula (Borzęcka 2001, Bernaś et al. 2019), and its tributary, the Drwęca (Borzęcka 2003), have shown changes in size and fluctuations in condition. However, these studies have mainly focused on healthy fish. Considering the above aspects, this study aimed to determine whether the symptoms of UDN affect the growth and condition of sea trout during their migration to spawning in the Słupia River in Poland.

Material and Methods

Fish sampling

Sea trout were collected from the Słupia River (54°27'37.8"N; 17°02'21.1"E) using chamber traps, 36 km from the mouth of the Słupia River to the Baltic Sea, with the help of local fishermen and the

Polish Angling Association trap in Słupsk (Poland). All specimens were trapped during their spawning migration in November 2021-2024. A total of 63 fish were obtained and used in this study. After euthanasia by immersion in a bath of 0.5 g l^{-1} tricaine solution (Sigma-Aldrich, St. Louis, MO, USA), and the total length of each fish was measured with an accuracy of 0.5 cm. The caught fish were observed for skin lesions and divided into two groups: healthy (without lesions) and diseased (with lesions). Additionally, each group was divided into males and females, and 16 healthy fish (9 males and 7 females) and 47 fish with pathological lesions (25 males and 22 females) were collected. The fish bodies were then dried with a paper towel to remove excess water, placed in iceboxes, and transported to the laboratory, where their weight was immediately measured to the nearest 1.0 grams.

The length-weight relationship

The LWR of fish was calculated using the equation originally proposed by Le Cren (1951):

$$W = aL^b$$

where W is the weight of the fish (g), L is the total length of the fish (cm), a is the intercept, and b is the slope.

The logarithmic transformation of this equation linearizing it, facilitating the analysis with linear regression and interpretation of the slope and intercept of the line of best fit. The formula after logarithmic transformation is as follows:

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

Applying this formula to the fish in the study, the b coefficient helps infer the growth patterns and general body shapes of particular species (Froese 2006). The threshold value of $b = 3$ represents isometric growth. This value indicates an ideal growth relationship in which fish body parts grow at similar rates. When the b value deviates from 3, it indicates allometric growth, which may be caused by specific environmental or growth conditions. If $b > 3$, individuals of larger size increase their weight by a greater proportion than their length, indicating positive allometric growth. In contrast, when $b < 3$, individuals increase their relative length more than their weight (Froese 2006).

The condition factor

To evaluate the condition of sea trout and assess the well-being of the population in relation to its health state, Fulton's condition factor (*Kc*) (Ricker 1975, Nash et al. 2006) was applied as follows:

$$Kc = W \times L^{-3} \times 100$$

where W is the weight of the fish (g) and L is the total length of the fish (cm). The index uses 1 as a benchmark for the condition of a standard fish: fish above or below 1 are considered to be in relatively better or worse condition, respectively, depending on their distance from the benchmark value. Nevertheless, it is essential to note that the stated formula assumes isometric growth in fish.

Data Analysis

All LWR and *Kc* analyses were performed as described by Ogle (2016) and were run in RStudio (version 2025.09.0 Build 387) (R Core Team 2025). The FSA (Ogle et al. 2025), car (Fox and Weisberg 2019), magrittr (Bache and Wickham 2025), and dplyr (Wickham et al. 2023) packages were used for the analyses. LWR curves were fitted from log-transformed variables for each analyzed group using the lm() function in R. Parameters a and b, 95% confidence intervals (95% CI), and coefficients of determination (R^2) were estimated from the linear regressions of the log-transformed W and L. Anova and summary functions from the car package (Fox and Weisberg 2019) were used to test the significance levels (type II test, two-tailed test) of the fitted linear regression models to confirm that parameters a and b significantly explained the majority of the variability of the response variable (W). We assessed the assumptions of linear regression (linearity, normality, and constant variance) by analyzing residual plots and histograms using the residPlot function from the FSA package (Ogle et al. 2025). To test the null hypothesis (*H*) that $b = 3$, indicating isometric growth, against the alternative hypothesis (*HA*) of allometric growth ($b \neq 3$), we used *t*-tests implemented in the 'hoCoef' function of the FSAmisc package (Ogle 2022). To examine the differences in LWR parameters between healthy and diseased females and between healthy and diseased males, a dummy variable regression (DVR), also known as analysis of covariance (ANCOVA), was performed. A DVR constituting the difference in parameters amongst the two groups (Ogle 2016) was transformed from the LWR equation with the inclusion of the quantitative variable *f*UDN and the interaction between the covariate log *L* and the quantitative variable. Factor (*f*UDN) and DVR model significance of interaction variables were determined by ANOVA from car (Fox and Weisberg 2019). Assumption checking followed the same process described above for linear regression. For the *Kc* data analysis, we used the dplyr package (Wickham et al. 2023) to generate summary statistics, including ranges, means, and confidence intervals. An ANOVA test was used to assess statistical significance within grouping variables, as implemented in Anova from car (Fox and Weisberg 2019). Levene's test for equal variances among groups was performed using the car package (Fox and Weisberg 2019).

Results

The length weight relationship

In this study, 63 specimens of *S. trutta* were collected between 2021 and 2024 and examined to evaluate their length-weight data. Due to technical logistics and permit restrictions (sampling during spawning migration), we obtained limited sample sizes, especially for healthy male and female groups in this study. Consequently, this limitation affects the overall representativeness and statistical power of the study. The body size of fish gathered from all groups was chosen randomly; however, efforts were made to match their body lengths and weights to be comparable between the sampled groups. The range of total length of the investigated fish was 48-82 cm, with mean values from 53 ± 3.34 to 63 ± 9.70 cm. The body weights of the fish caught ranged from 1001-7000 g, while the mean ranged from 1382 ± 386 to 2935 ± 1596 g (Table 1). In our study, we quantified the LWR equations separately for healthy and diseased male and healthy and diseased female sea trout (Table 2). The linear regression analysis plot represents each set of regression analyses shown in Fig. 1. The parameter *b* value ranged from 2.6334 for healthy male fish to 3.3791 for diseased female fish. The values of intercept a ranged between 0.002 and 0.0418. The results of the *t*-test of the *b* value revealed that the differences between the groups of fish were statistically insignificant ($P > 0.05$) from the hypothetical value of 3, leading to the rejection of *H*. Therefore, the overall growth patterns of the investigated groups were isometric. In contrast, the R^2 values for the different fish groups ranged from 0.5743 for healthy female fish to 0.9423 for healthy male fish (Table 2). High coefficient of determination values ($R^2 \geq 0.80$) for healthy and diseased males signified that the predictor variable (log *L*) effectively explained (more than 80%) the predicted value (log *W*), suggesting a strong model fit. In contrast, the moderate $R^2 = 0.5743$ value for healthy females indicates a lower explanatory power and greater variability in the relationship. Overall, the three LWR models were more robust and reliable than those in the healthy female group. ANOVA of the linear regression LWR for all groups showed a significant relationship between fish length and weight. The regression models had large *F*-values and very small p-values, indicating that the model with both an intercept and log *L* better described the variability in log *W* than the model with only an intercept (Table 2). However, for the *F*-statistic for healthy females, the p-value was quite large (0.0484), indicating that log *L* still significantly interprets log *W*. The results for the *t*-test statistics and p-values (two-tailed test) showed a highly significant difference between the slope of the linear regression model and the hypothesized value of zero. These significant relationships were evident in all models, indicating that the slope was significantly different from zero and that there

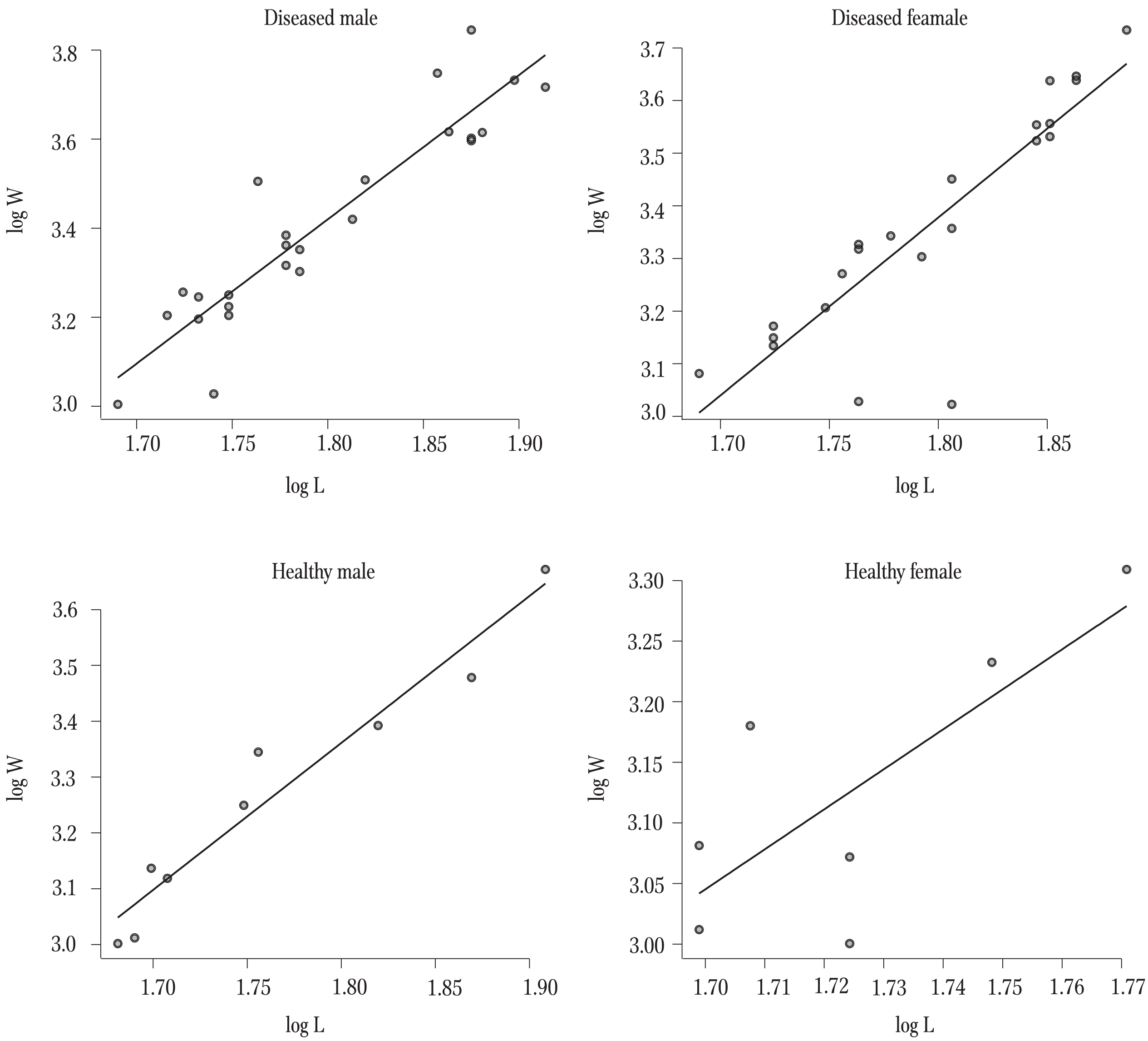

Figure 1. Linear regression analysis graphs showing log weight against log length (LWR) for sea trout from the Słupia River.

was a significant relationship between log *W* and log *L* for all the species. The results of the DWR showed that the interaction term, *f*UDN × log *L*, was insignificant in the male (P = 0.174) and female (P = 0.962) groups; thus, there was no significant difference in slopes between healthy and diseased male and female groups, respectively. In addition, the *f*UDN variable was insignificant in the male (P = 0.191) and female (P = 0.955) groups, suggesting that the intercepts of the compared LWR models were similar.

The condition factor

Because the LWR analysis showed that all analyzed groups exhibited isometric growth, the condition of the fish was estimated using only Fulton's condition factor. The mean *Kc* values for the diseased male and female groups were 1.07 ± 0.23 and 0.97 ± 0.19, respectively, and for the healthy groups, 0.95 ± 0.14 and 0.91 ± 0.16, respectively (Table 3). The mean *Kc* value was > 1 only in diseased male sea trout.

Table 1
Descriptive statistics of total length and weight of sea trout from the Słupia River. n – number of specimens, length in cm, and weight in g (Min – minimum, Max – maximum, mean, SD – standard deviation, median, SE – standard error of the mean)

Health status	Sex	n	Length (cm)						Weight (g)					
			Min	Max	Mean	SD	Median	SE	Min	Max	Mean	SD	Median	SE
Diseased	Male	25	49	82	63	9.70	60	1.94	1010	7000	2935	1596	2300	319
	Female	22	49	77	63	8.03	63	1.71	1054	5420	2592	1274	2162	272
Healthy	Male	9	48	81	59	11.9	56	3.97	1004	4700	2098	1191	1776	397
	Female	7	50	59	53	3.34	53	1.26	1001	2038	1382	386	1206	146

Table 2
Estimated parameters of weight-length relationships and statistical description for sea trout from the Słupia River. n – number of specimens, a – intercept, b – slope, 95% CI – 95% confidence interval, R^2 – coefficient of determination, H_0 – null hypothesis to verify if b between the groups of fish is statistically significantly different from the b = 3, indicating isometric growth

Health status	Sex	n	a	$log\ a$	95% CI of $log\ a$	b (95% CI)	R^2	ANOVA F-test statistic		Two-tailed t-test statistic		t-test (H_0=3)		Growth type
								F-value	p-value	t-value	p-value	t-value	p-value	
Diseased	Male	25	0.0038	-2.4148	(-1.3831 to -3.4465)	3.2415 (2.6676 to 3.8153)	0.8558	136.5	$3.75e^{-11}$	11.68	$3.75e^{-11}$	0.871	0.393	Isometric
	Female	22	0.0020	-2.7047	(-1.1068 to -4.3026)	3.3791 (2.4897 to 4.2686)	0.7585	62.80	$1.35e^{-7}$	7.925	$1.35e^{-7}$	0.889	0.385	Isometric
Healthy	Male	9	0.0418	-1.3789	(-0.3501 to -2.4077)	2.6334 (2.0509 to 3.2159)	0.9423	114.3	$1.38e^{-5}$	10.69	$1.38e^{-5}$	1.488	0.180	Isometric
	Female	7	0.0027	-2.5645	(-8.1977 to 3.0688)	3.2998 (0.0339 to 6.5656)	0.5743	6.746	0.0484	2.597	0.0484	0.236	0.823	Isometric

Table 3
Range, mean, standard deviation (SD), confidence intervals (95% CI), and ANOVA *F*-test statistics values of Fulton's (*Kc*) condition factors of sea trout from the Słupia River

		Kc				ANOVA *F*-test statistic	
Health status	Sex	Range	Mean ± SD	95%CI (Lower)	95%CI (Upper)	*F*-value	p-value
Diseased	Male	0.64 – 1.66	1.07 ± 0.23	0.98	1.15	1.955	0.172
	Female	0.40 – 1.21	0.97 ± 0.19	0.89	1.05	0.622	0.437
Healthy	Male	0.74 – 1.19	0.95 ± 0.14	0.81	1.10	-	-
	Female	0.67 – 1.14	0.91 ± 0.16	0.77	1.05	-	-

However, there were no statistically significant differences in the mean *Kc* values between healthy and diseased males (P = 0.172) or betwen healthy and diseased females (P = 0.437).

Discussion

The UDN in salmon and sea trout migrating along the Słupia River was confirmed in 2007 (Ciepliński et al. 2018). The occurrence of UDN may be significantly influenced by the poor condition of spawning fish caused by environmental conditions and gonad maturation. Diseased skin poorly protects fish against bacterial and/or viral infections (Ciepliński et al. 2018, Henard et al. 2022). The pathophysiological mechanism of UDN is associated with a decrease in the most important antioxidant enzymes (Kurhalyuk et al. 2009, 2011). Additionally, our previous research showed that the levels of male and female hormones in fish with UDN are lower than those in healthy individuals (Matraszek-Żuchowska et al. 2022). This may significantly affect the quality of fry hatching from fertilized eggs.

The relationship between fish length and body mass is important in fish biology because it can be an indicator of reproductive activity, food intake, and temperature changes (Nehemia et al. 2012, Mazumder et al. 2016, Shah et al. 2022, Durrani 2023). As the value of this indicator changes seasonally, sampling was conducted only in autumn (November), during the spawning period. In these studies, the total weight of the sea trout included the weight of the gonads. Since biotic and abiotic factors significantly affect the assessed parameters of fish, it is challenging to compare the obtained results with existing literature data. Such studies have not been conducted to date in the case of sea trout with clear pathological skin changes. Nevertheless, it is worth noting that numerous studies have been conducted on brown trout related to sea trout. The differences in the length and weight of fish collected from different aquatic environments are quite large. However, in many cases, the authors of these studies indicate significant correlations between the length and weight of the fish studied (Nowak et al. 2009, Mazlum and Turan 2018, Latiu et al. 2022, Durani 2023). Moreover, for brown trout, they reported isometric growth (Arslan et al. 2004, Verreycken et al. 2011, Durani 2023), which is consistent with the findings of the present study. In addition, we compared our regression parameter results with those in the FishBase database (Froese and Pauly 2025). In all cases, coefficients *a* and *b* varied in the range for sea trout populations (*a*: 0.00152 – 0.06918; *b*: 2.535 – 3.495). Comparing the parameters of the *b* coefficient obtained in this study with those obtained for sea trout in other Polish rivers, we noticed some differences. In the case of female winter and summer sea trout obtained in the 1960s from the Vistula River (Borzęcka 2001), *b* values of 2.707 and 2.975 were obtained, respectively. In another study in the Vistula River (Bernaś et al. 2019), the values *b* = 2.5802 and *b* = 2.8353 were calculated for sea trout without division by sex caught in spring-summer and autumn 2018, respectively. On the other hand, in the Drwęca, a tributary of the Vistula, the *b* coefficient for the migrating sea trout breeding stock was 2.987 for males and 3.504 for females collected between 1988 and 1992 (Borzęcka 2003). These data indicate the variability of this parameter depending on both the time period and location of sea trout sampling.

Condition coefficient values can provide information about the physiological state and welfare of fish. Thus, they may indicate the development of the gonads and the ability to reproduce (Muddasir et al. 2018, Latiu et al. 2022, Das et al. 2023, Durrani 2023). The Fulton's condition factor (*Kc*) is most often used to assess fish well-being. This is based on the hypothesis that heavier fish of a particular length are in better physiological condition. It assumes isometric growth, in which the shape of the fish does not change with increasing length of the fish. If the population of fish being examined does not exhibit isometric growth, as is often the case (Froese 2006), then *Kc* depends on the fish length. Thus, comparisons of *Kc* are restricted to fish of similar lengths to those in the population. *Kc* is also a helpful index for monitoring feeding, age, and growth rates in fish and can be used to assess the status of the aquatic ecosystem in which fish live (Ahmed et al. 2011). The *Kc* value is influenced by age of fish, sex, season, stage of maturation, fullness of the gut, type of food consumed, amount of fat reserved, and degree of muscular development. Moreover, the *Kc* value is greatly affected by the stage of development of the reproductive organs. In some fish species, the gonads may weigh up to 15% or more of the total body weight (Barnham and Baxter 1998). Knowing the fact that the development of the reproductive organs greatly influences the *Kc* value, and there is a relation between the *Kc* value and the fish shape, where each family has its range depending on their shape, type growth pattern, and *b* value, we followed recommendation from literature (Barnham and Baxter 1998) that points out that the sampling of the fish should be carried out at the same time of year, so that the individuals or populations are at the same stage of the reproductive cycle, as it was done in the frame of this project. For salmonids, the *Kc* values typically fall within the range of 0.8 to 2.0. Salmonidae with a *Kc* of 1.60 presented excellent body condition, and those with a *Kc* of 1.40 were well proportioned. A fair state occurred in fish having a *Kc* of 1.20, and fish with a *Kc* of 1.00 and 0.80 showed poor and extremely poor body states, respectively (Barnham and Baxter 1998). The obtained results for the *Kc* value in all groups of sea trout were close to 1 (Table 3), indicating that the fish were in poor condition. The relatively low *Kc* values in our study are even more indicative of the fish's poor condition, as *Kc* should reach its higher values during the spawning period in both sexes due to the weight of the developed gonads. Our mean *Kc* results are similar to the mean condition data (0.89 – 1.06) for sea trout from other rivers in the Pomeranian region (Pilecka-Rapacz 2011). In a study by Pilecka-Rapacz (2011) conducted on the Słupia River, only male sea trout were collected, and the average *Kc* value was 1.03. In our study, we obtained similar *Kc* values for healthy and diseased males, 0.95 and 1.07, respectively. Slightly higher *Kc* values were recorded for sea trout in the Drwęca River, with values of 1.08 for females and 1.09 for males (Borzęcka 2003). In contrast, fish captured in the Vistula River exhibited higher condition indices, with *Kc* values of 1.17 and 1.16 for sea trout sampled in spring and summer and autumn, respectively (Bernaś et al. 2019). Even higher *Kc* values were observed for female specimens, reaching 1.27–1.32 in winter sea trout and 1.26–1.32 in summer fish (Borzęcka 2001). When comparing these data to our findings, it appears that the sea trout we collected were in a poorer condition.

In our comparison of the influence of UDN on LWR and *Kc* parameters in males and females, we did not observe any statistically significant effect of UDN on the morphometric parameters of sea trout. On the other hand, obtaining statistically nonsignificant results does not necessarily imply that there are no effects of UDN, especially given the small sample size and the associated high uncertainty. The results obtained in our study are comparable to those reported in the literature, suggesting that including individuals with small sample sizes is useful.

Despite the insights provided by this study, its limitations should be acknowledged. First, we cannot deny that the small sample size may have influenced the estimations. As mentioned earlier, due to permit restrictions (spawning season), sample sizes, especially for healthy groups, were small, which may have affected the accuracy of LWR and *Kc* evaluations. Quantifying mean values and identifying outliers is more effectively achieved with larger sample sizes. However, Rodriguez-Garcia et al. (2023) argued that, even with small sample sizes, the weight-length data can be a valuable tool in fisheries research when combined with appropriate statistical methods and careful attention to potential errors. Sampling fish with narrow size ranges may also bias the estimates (Froese 2011). Moreover, this study focused exclusively on adult individuals, which do not fully represent the sea trout population in the Słupia River. Finally, this study did not account for possible seasonal variations that may have influenced the results. Therefore, caution should be exercised when using these data, as the estimates of LWRs and *Kc* for sea trout may be less precise. Additional studies with larger sample sizes are needed to confirm the results and increase the precision of the estimates. Regardless of these considerations, studies such as this one are essential for understanding the condition of sea trout infected with UDN disease.

In conclusion, the results reported in this study contribute to a better understanding of the influence of UDN on the general condition of sea trout, which periodically move from the Baltic Sea to rivers for spawning. This problem is even more important because, despite many studies, the cause and mechanism of these lesions remain unclear.

Conflict of Interest Statement. The authors declare no conflicts of interest regarding the publication of this article.

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Author contributions. T.B. – data collection, statistical analyses, drafting the paper; M.M. – sampling collection, manuscript correction, and final manuscript approval; A.P. – funding acquisition, drafting the paper; M.R. – funding acquisition, manuscript correction, and final manuscript approval.

ORCID iD

Tomasz Błądek https://orcid.org/0000-0002-6716-8436

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