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Research Article

Phenotypic and biological variations between the sexes of pike perch, *Sander lucioperca* (Teleostei, Percidae): Emphasizing sexual dimorphism

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Abstract

To phenotypically and biologically characterize the population of pike perch *Sander lucioperca* and to detect any potential variability between sexes, this study focused on analyzing sexual dimorphism and morphological differences based on morphometric and meristic characters, along with examining the length-weight relationships and condition factor. The growth type reveals positive allometry in both sexes. The Fulton's condition factor (K_F) value exceeded 1 for both males and females, suggesting that the fish were in good conditions. No sexual dimorphism was found in the meristic characters of either sex. However, morphometric characteristics show that male individuals are distinguished by deeper bodies and extended pectoral and pelvic fins in comparison to females. The results of this study highlight six morphological differences between male and female *Sander lucioperca*, showing pronounced sexual dimorphism. These findings play a crucial role in the successful management and preservation of this species' population in Morocco, particularly in the Al Massira Dam Lake.

Introduction

Pike perch (*Sander lucioperca*) is a semi-anadromous percid species that occurs in both freshwater and brackish environments (Coad, 2016). It can be found in rivers, lakes, canals, also in estuaries and coastal marine areas with low salinity (Nikolić *et al*., 2023). The pike perch, native to the major rivers of Eastern Europe, is naturally found from the Elbe to the Baltic Sea and southwest Russia (Coad, 2016). Due to its importance for sport and commercial fishing (Nikolić *et al*., 2023) and for regulating phytophagous populations (Ribeiro *et al.,* 2021), it has been introduced to several European countries and the Maghreb, as well as to the Azores and several lakes in the United States (Poulet, 2004). The pike perch was first introduced to Morocco in 1939 by the HCEFLCD, and it has adapted perfectly to the conditions of Moroccan freshwater environments in several water bodies (Mouslih, 1987; Bousseba *et al*., 2025). Due to the quality of its flesh, pike perch holds an important place in the sectoral economy of fisheries resources. It is therefore a species of great significance in the commercial and professional fishing sector, with a notable socio-economic interest. Large predatory fish, like pike perch, play a crucial role as keystone species, and their status can significantly influence ecosystem functioning through important indirect effects (Nikolić *et al*., 2023).

Phenotypic variability within a species can be influenced by environmental, ecological, and ontogenetic factors, as well as by sex-linked changes (Martinez *et al*., 2019). Sex-linked variability frequently appears as sexual dimorphism, typically evident through differences in color, size, or the shape of morphological structures (Zajitschek *et al.,* 2020). This phenomenon is widespread throughout the animal kingdom and is an essential source of intraspecific variability (Berns, 2013; Martinez *et al*., 2019). Natural selection, as well as, Intrasexual and intersexual selection, can play crucial roles in the development of sexual dimorphism within a species (Li and Kokko, 2021).

The length-weight relationship (LWR) and the condition factor (K_R) are important parameters that provide essential information on fish growth and health status, and are therefore widely used in fish biology (Narzary and Khangembam, 2022). These biological parameters have been studied by several authors around the world (M'Hetli *et al.,* 2011; Pérez-Bote and Roso, 2012; Bouamra *et al.,* 2017; Ibănescu *et al.,* 2019; Gago *et al.,* 2021). Analyzing the length-weight relationship is essential for sustainable resource conservation and fisheries research (Azrita *et al*., 2024). It is also essential for developing recommendations regarding aquatic resource management (Sonowal *et al*., 2019; Ergüden, 2021).

Morphological measurements and length-weight relationships are frequently utilized to identify sexual dimorphism (Karadurmuş *et al*., 2022). The allometric variations in the morphological characteristics of fish often reflect differences between the sexes (Kim *et al*., 2008). Several studies have confirmed the phenotypic variation of *S. lucioperca* between the two sexes, resulting in sexual dimorphism marked by morphological differences between males and females,

particularly in terms of head length and body height (Goubier, 1975). The use of geometric morphometric techniques in the study of Parés-Casanova and Cano (2014), from Ivars and Vila-sana lake in Spain, also revealed sexual dimorphism in pike perch morphology, mainly in terms of body length and dorsal fins, with males having a shorter body and more pronounced dorsal convexity. In addition, Turki *et al.* (2009) detected phenotypic variability between the two sexes of the same species in the Nebhana dam reservoir in Tunisia, particularly in terms of different body lengths and ventral and pectoral fin lengths. In terms of coloration, sexual dimorphism in *S. lucioperca* is reflected by a darker belly in the male during the breeding period (Poulet, 2004). This study aims to provide, for the first time in Morocco's Al Massira Reservoir, data on the potential sexual dimorphism in the morphometric and meristic characteristics of *S. lucioperca*. Additionally, it aimed to evaluate the species' biological characteristics, including the length-weight relationship and the condition factor. These findings contribute significantly to future research on the ecology, conservation, and management of *S. lucioperca*.

Materials and methods

Study site and sampling

A total of 83 *S. lucioperca* specimens used in the study were sampled from commercial fisheries in March 2022. These specimens were captured by professional fishermen using gillnets with mesh sizes of 25 and 65 mm in the Al Massira Dam Lake, situated on the Oum Errabia River, and located 120 kilometers south-east of Casablanca (Alaoui *et al*., 2000) (between 32°28'32" N and 7°32'15" W) (Fig. 1). This reservoir represents an important reserve of water for public supply, irrigation, fishing, as well as a significant source of hydroelectric power.

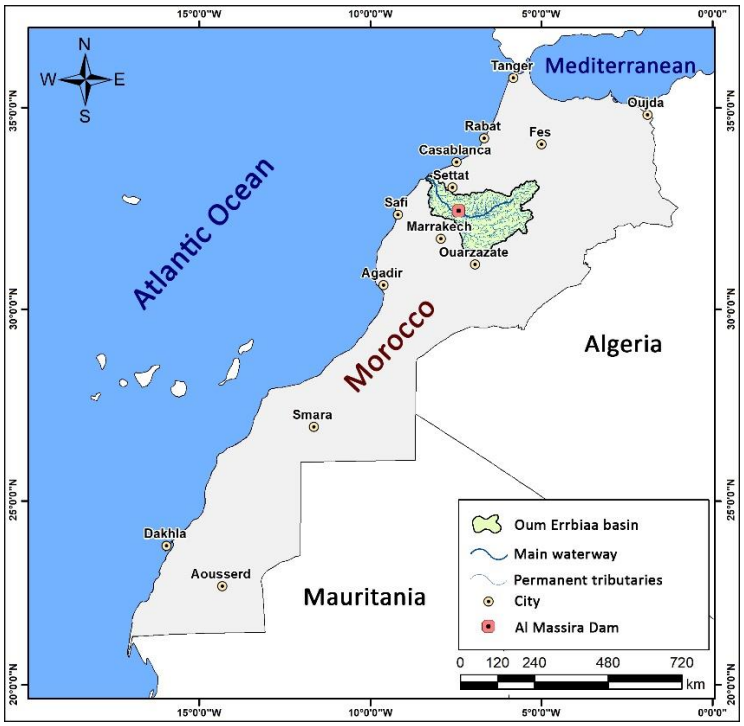

Figure 1: Map of study site: Al Massira Dam Lake, Morocco.

Morphometric analyses

In the laboratory, 20 morphometric characters were measured for each fish using a caliper with a precision of 0.1 mm. These measurements included: Head length (HL), Maximum height (H), Minimum height (h), Snout to eye distance (SE), Snout to pre-operculum distance (SPO), Snout to ventral fin distance (SV), Snout to pectoral fin distance (SP), Snout to first dorsal fin distance (SD1), Snout to second dorsal fin distance (SD2), Snout to anal fin distance (SA), Eye diameter (ED), Eye to post-operculum distance (EPO), Length of first dorsal fin basis (LD1), Length of second dorsal fin basis (LD2), Length of anal fin basis (LA), Ventral fin length (LV), Pectoral fin length (LP), Ventral fin-anal fin distance (VA), Pectoral fin to anal fin distance (PA), Insertion point of the last spine of the first dorsal fin to the tip of the caudal fin distance (PoD). The following meristic counts were registered: Number of gill rakers on the first gill arch (GR), Number of first dorsal fin rays (D1), Number of second dorsal fin rays (D2), Number of ventral fin rays (V), Number of anal fin rays (A), Number of caudal fin rays (C). The body weight (W) of the samples was measured by an electronic balance with a precision of 0.01 g. Morphometric measurements were standardized to eliminate any effects related to size (Lahnsteiner and Jagsch, 2005). Thus, the different morphometric characteristics were represented as a percentage of the standard length (SL).

Sex differentiation was initially determined macroscopically and then confirmed microscopically through histological examination of the gonads. After dissection, the gonads were fixed in a 10% formaldehyde solution for 24 hours and then preserved in 70% ethanol at room temperature until they were analyzed. Portions of the gonadal tissue were cut, dehydrated in increasing ethanol concentrations (70%, 95%, and 100%), embedded in paraffin, and sectioned into 2 to 5 µm thick slices with a microtome. These sections were colored using hematoxylin-eosin, and sex was confirmed by examining the stained tissues under a light microscope.

The regression coefficients *a* and *b* for the relationship between SL and W were estimated using a linearized logarithmic function according to Froese (2006): ln (W)=ln(*a*)+*b* ln (SL). The length-weight relationship indicates isometric growth where $b = 3$ and allometric growth where $b \neq 3$.

The Fulton's condition factor was estimated based on the following formula (Fulton, 1904):

$$KF = 100 \times W/SL^b \qquad (1)$$

Statistical analysis

All represented data were expressed as mean ± SD. The Mann-Whitney test (non-normal data distribution) was used to assess the statistical differences between females and males with regard to length, weight, and meristic characters. Morphometric differences between the sexes were examined according to Student's t-test. In addition, a Student's t-test was conducted to determine if the estimated *b* value significantly differs from 3, which corresponds to the isometric value (Pauly, 1984). The coefficient of determination (r^2) measures the accuracy of a linear regression

model, with values approaching 1 indicating a more precise prediction. All tests were conducted with a significance level set at $p<0.05$. The statistical analyses were conducted with the R-Studio software version (4.3.1).

Results

Histological examination of the gonads of 83 specimens of *S. lucioperca* indicated that 58 were female (275-390 mm SL) and 25 were male (280-380 mm SL) (Table 1). There were no significant differences observed between the sexes in both SL (Mann-Whitney U=246.5, p=0.72) and W (Student test t=0.65, p=0.52).

Table 2 provides the statistical data necessary for evaluating the length-weight relationship of *S. lucioperca* by sex, including the estimated parameters of the regression, the growth type of the population, and the coefficient of determination. The b value obtained for LWR suggests positive allometry in both sexes (b >3, $p<0.05$).

Table 1: Summary of standard length (SL) and weight (W) data for male and female *S. lucioperca.*

Sex	N	SL, mm	W, g
Female	58	347.90±28.04 275.0-390.0	362.37±99.38 149.3-530.7
Male	25	343.23±30.97 280.0-380.0	383.99±116.71 153.4-546.3

Table 2: Descriptive statistics and parameters of the length–weight relationships (LWR) of *S. lucioperca.*

Sex	N	a ± SE	b ± SE	r^2	Growth type	p-value
Female	58	0.031±0.024	3.18±0.162	0.89	A+	1.837e-11***
Male	25	0.021±0.064	3.09±0.42	0.88	A+	2.023e-07***

[a]Intercept, [b]slope, SE standard error, r^2 coefficient of determination, A+ positive allometry, ***$p<0.001$.

The Fulton's condition factor of *S. lucioperca* varied significantly between sex categories ($p<0.05$), and the value was significantly highest in females (1.20±0.12) than in males (1.13±0.06) (Table 3).

Table 3: Summary of parameters condition factors (K_F) of *S. lucioperca.*

Sex	N	K_F
Female	58	1.20±0.12 0.98-1.37
Male	25	1.13±0.064 1.01-1.27

The examination of meristic characteristics of all males and females revealed no significant difference between the sexes ($p>0.05$) (Table 4). However, the examination of morphometric characteristics revealed sex-related differences.

Compared to females, males had greater maximum height (H) and minimum height (h) (t=5.698, 2.378 and p=0.0002, 0.037, respectively), a longer distance between the snout and the second dorsal fin (SD2) (t=2.553, p=0.020), a longer ventral fin length (LV) and pectoral fin length (LP) (t=2.638, 2.360, and p=0.039, 0.032, respectively), and a greater distance between the pectoral fin and the anal fin (PA) (t=2.976, p=0.008) (Table 5).

Here and in Tables 3,4 and 5: Values above the line represent the mean±SD (standard

deviation), while those below the line indicate the min–max range, n is the number of samples.

Table 4: Summary of meristic characteristics and statistical analysis of the rank sum of sexual differences.

Character	Female (*n* = 58)	Male (*n* = 25)	Significance	
			U	*p*
GR	12.55±1.47 9-15	12.55 ±1.13 11-14	187	0.97^{ns}
D1	13.90 ±0.65 13-16	14.00 ±0.71 13-15	205.5	0.645^{ns}
D2	21.26 ±2.04 11-24	21.33 ±0.71 20-22	158	0.414^{ns}
V	5.76 ±0.43 5-6	6.00 ±0.50 5-7	229	0.185^{ns}
A	13.05 ±1.06 9-15	13.55 ±1.13 12-16	223	0.373^{ns}
C	16.50 ±1.09 13-18	17.11 ±1.61 14-19	241.5	0.18^{ns}

GR, Number of gill rakers on the first gill arch; D1, Number of first dorsal fin rays; D2, Number of second dorsal fin rays; V, Number of ventral fin rays; A, Number of anal fin rays; C, Number of caudal fin rays; ns, not significant.

Table 5: Summary of morphometric characters, expressed as percentages of standard length (% of SL), and statistical analysis of the rank sum of sex differences.

Character	Female (*n* = 58)	Male (*n* = 25)	Significance	
			t	*p*
HL	30.89±2.79 25.38-37.27	30.40±0.93 29.39-31.58	-0.718	0.48^{ns}
H	29.78±2.46 24.23-34.04	35.00±1.87 32.65-36.84	5.698	0.0002***
h	12.91±1.31 10.00-16.67	14.01±0.92 12.36-14.92	2.378	0.037*
SE	8.17±1.69 6.15-14.17	7.57±1.17 5.26-8.36	-1.016	0.331^{ns}
SPO	22.31±2.15 18.26-27.73	24.52±3.58 21.22-30.43	1.440	0.200^{ns}
SV	33.05±2.53 28.26-37.55	33.34±0.46 32.65-34.03	0.524	0.604^{ns}
SP	30.73±2.62 26.00-36.36	31.13±1.11 29.82-32.73	0.574	0.572^{ns}
SD1	33.20±2.76 27.39-37.73	32.72±1.59 30.16-34.38	-0.547	0.593^{ns}
SD2	61.71±4.14 54.35-71.43	64.66±1.92 62.54-67.72	2.553	0.020*
SA	62.57±5.59 51.92-72.92	65.16±3.59 58.96-69.56	1.398	0.187^{ns}

Table 5 (continued):

Character	Female (n = 58)	Male (n = 25)	Significance	
			t	p
ED	5.93±0.89 4.35-7.50	5.94±0.69 5.52-7.35	0.039	0.970^{ns}
EPO	20.94±4.13 15.22-31.82	20.00±3.25 16.33-24.21	-0.601	0.562^{ns}
LD2	24.47±2.72 20.00-30.61	25.46±1.14 23.27-26.53	1.360	0.188^{ns}
LA	12.50±1.51 9.20-14.89	13.05±0.70 12.07-14.03	1.306	0.208^{ns}
LV	16.20±1.05 14.54-18.20	18.46±2.01 16.90-22.45	2.638	0.039*
LP	15.75±1.55 12.69-18.64	16.85±0.83 15.86-18.24	2.360	0.032*
VA	31.33±3.44 23.85-36.54	32.74±2.60 30.34-36.96	1.106	0.294^{ns}
PA	33.81±3.86 23.46-40.00	36.97±1.74 34.48-39.13	2.976	0.008**
PoD	63.01±4.64 54.35-74.54	63.75±1.34 62.07-65.31	0.676	0.504^{ns}

HL, Head length; H, Maximum height; h, Minimum height; SE, Snout to eye distance; SPO, Snout to pre-operculum distance; SV, Snout to ventral fin distance; SP, Snout to pectoral fin distance; SD1, Snout to first dorsal fin distance; SD2, Snout to second dorsal fin distance; SA, Snout to anal fin distance; ED, Eye diameter; EPO, Eye to post-operculum distance; LD1, Length of first dorsal fin basis; LD2, Length of second dorsal fin basis; LA, Length of anal fin basis; LV, Ventral fin length; LP, Pectoral fin length; VA, Ventral fin-anal fin distance; PA, Pectoral fin to anal fin distance; PoD, Insertion point of the last spine of the first dorsal fin to the tip of the caudal fin distance; ns, not significant; *p<0.05, **p<0.01, *** p<0.001. All morphometric measures are in mm.

Discussion

Research on the morphometric and meristic characteristics of *S. lucioperca* in Moroccan freshwater environments is non-existent. This study represents the first detailed and informative analysis of the morphometric and meristic characteristics of pike perch in Al Massira Dam Lake. This data is crucial for understanding the dynamics of local populations, assessing their health status, and establishing a solid foundation for the conservation and management of this species in Moroccan aquatic ecosystems.

Sexual dimorphism in growth is a common phenomenon among teleost fish. Generally, it is observed that males reach a larger size than females in adulthood. This phenomenon, for instance, has been documented in various tilapia species (Toguyeni *et al*., 1997), as well as in salmonids including *Salmo trutta* and *Oncorhynchus mykiss* (Bonnet *et al*. 1999). Conversely, several studies have shown that in many species of flatfish, Females are larger than males, This is demonstrated in species such as the dab (*Limanda limanda*) (Lozan, 1992), the carp (*Cyprinus carpio*) (Hollebecq and Haffray, 1994), and the perch (*Perca fluviatilis*) (Fontaine *et al*., 1997). However, our results indicate that there are no significant differences in total length and weight between the sexes.

The length-weight relationship provides crucial baseline data for several biological studies, enabling the assessment of the sustainability of the species' fisheries and the management of its population (Srihari *et*

al., 2018). In this study, the *b* values estimated from the LWR fell within the typical range of 2.5 to 3.5 for teleosts (Froese, 2006). The results indicated positive growth (*b*>3) in the two sexes, indicating that the pike perch increases more in weight than in length, for both males and females. Similarly, positive allometry has been reported for this species in both sexes by M'Hetli *et al*. (2011) in three Tunisian reservoirs, by Perez-Bote and Roso (2012) in the Alcántara Reservoir in Spain, by Bouamra *et al*. (2017) in the Ghrib Reservoir in Algeria, and by Koca and Küçükköse (2023) in Eğirdir and Beyşehir Lakes in Turkey.

Determining the condition factor typically relies on the length-weight relationship, under the principle that fish of a given length are in better condition if they weigh more. The Fulton's condition factor is an effective indicator of the overall health or 'fitness' of the population being considered (Bolger and Connolly, 1989). In general, a high K_R value suggests that the fish exhibit relatively good physiological status (Hossain *et al*., 2017). Variations in kr from 1 offer detailed insights into changes in food supply and the impact of water's physicochemical properties on fish life cycles, as well as their relationship with intrinsic fish characteristics (Le Cren, 1951; Jisr *et al*., 2018). The K_R value in our study exceeded 1 for both sexes, indicating a healthy state (Froese, 2006), which could be related to food availability and habitat quality (i.e. the physiochemical properties of habitat). Indeed, *S. lucioperca* in Al Massira Reservoir feeds on a diverse range of prey fish (Bousseba *et al*., 2020a; Bousseba *et al*., 2020b; Bousseba *et al*., 2024), suggesting a varied diet that supports good health. Although we did not evaluate abiotic factors at this site, the high K_R values observed could be linked to the rich availability of prey and the suitable habitat conditions in this Lake.

The study of meristic variables of pike perch specimens from the Al Massira Reservoir showed that these variables are not influenced by sex. The previous results of Krpo-Ćetković and Stamenković (1996) from the Yugoslav part of the Danube, of Turki *et al*. (2009) in the Nebhana Reservoir (Tunisia), and those of Akbarzadeh *et al*. (2009) in the southern Caspian Sea (Iran) perfectly demonstrate this. Added to these works is that of Poulet (2004), which shows that none of these variables significantly discriminate between pike perch samples, sexes, or even age classes. This is not the case for morphometric variables, which is probably why several other studies indicate that meristic variables are relatively ineffective in detecting variability (Meng and Stocker, 1984; Hurlbut and Clay, 1998; Poulet *et al*., 2004; Akbarzadeh *et al*., 2009).

The analysis of morphometric traits reveals marked variability between the sexes. Males exhibit significantly higher averages for several measurements: maximum height (H), minimum height (h), ventral fin length (LV), and pectoral fin length (LP). Additionally, they are distinguished by a greater distance between the snout and the second dorsal fin (SD2), as well as a greater distance between the pectoral fin and the anal fin (PA). It is therefore clear that males have a greater body depth, and These differences indicate that there are significant variations in maneuverability

between the sexes during foraging (Webb, 1984).

The findings of this study clearly reveal the presence of sexual dimorphism in fin length in *S. lucioperca*. Males possess longer pectoral and pelvic fins compared to females. Similar observations were reported by Turki *et al*. (2009) in the Nebhana Reservoir in Tunisia. This difference in length could be related to the males' reproductive behaviors. Indeed, males of *S. lucioperca* use their pectoral fins to defend the nest and aerate the eggs (Simon, 2015). Additionally, in other fish species, females often prefer males with longer fins (Basolo, 1990; Karino *et al*., 2011), which might also be the case for pike perch. Rival males use fin extension during male-male competitions, indicating that fin length has a role in sexual selection (Mieno and Karino, 2017). Therefore, further studies would be valuable to uncover the role of longer fins in male sexual selection in *S. lucioperca*.

Morphometric characters result from the combined interaction between genotype and environmental factors and are influenced by natural selection (Dobzhansky, 1970). Certain biological factors, such as sexual behavior, body coloration patterns, spawning periods, and external morphology, can also drive changes in morphological characteristics over time (Lythgoe and Lythgoe, 1992; Dulčić *et al*., 2000; Golani *et al*., 2006).

In conclusion, this study describes sexual dimorphism based on morphological characteristics for the first time in *S. lucioperca*. Our results clearly indicate an intra-specific morphological variation favoring males. Sexual dimorphism could be the result of ecological and behavioral variations. Future research should therefore focus on understanding these differences to elucidate the observed sexual dimorphism by supporting morphometric studies with genetic studies, to further develop population management and species conservation strategies for pike perch population in Al Massira Dam Lake.

Conflicts of interest

It is hereby declared that the authors declare no conflict of interest.

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