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RESEARCH ARTICLE

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Preliminary study of Isometry in pikeperch (*Sander lucioperca*) from Ivars and Vila-sana lake, Spain

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ABSTRACT

The present analysis of sexual allometry is based on the study of 26 adult specimens (12 females and 14 males) of pikeperch (Sander lucioperca) from the same lake. On their left lateral aspect, 19 homologous landmarks were obtained which were studied according to geometric morphometric methods. The utilization of geometric morphometric techniques in assessing allometry in the present study showed that size only accounted for a 4.4% of the shape and that it did not appear allometric relationships neither for males nor for females for the selected most discriminative landmarks. These results may be useful for comparing allometric patterns of pikeperch between geographical populations or ecological variants, fitness, fish movements, spatial scales, and for studying the body-size dependence of energy storage and size-related biokinetics.

Key words: allometry; body shape; *Percidae*; *Sander lucioperca*; zander

INTRODUCTION

Many ichthyological studies have been focused on fish morphometrics. A classic example is the mathematical formula that relates weight to length, as shown by Fulton (1906) [1]. Nowadays, the most commonly used relationship, that has been established for many species of fish (for instance [2], is relating weight to body length. In principle, most types of relationships are allometric, with a trend towards positive allometry. Weight-length relationships are of high importance for fisheries science and can be used in a wide range of applications, such as: (a) estimation of biomass; (b) estimation of a species condition factor; and (c) comparisons among life history and (d) morphologic differentiations of the same species in different areas [1]. In recent years, attempts have been made to relate other morphological characteristics of fish [1].

The geometric morphometric (GM) technique is regarded as a powerful means of analysing external morphology and shape differences among organisms, including fishes [3, 4], and has also been used to identify fishery stocks [5] and species of larval fishes [6], as well as to establish phenotypic variation [7]. It allows also the obtainment of high-resolution phenotypic difference data between populations and related taxons.

In the present study, we use GM analyses to assess the nature of the allometry in pikeperch (*Sander lucioperca*). The pikeperch is a semianadromous, predatory, cool-water percid fish that inhabits both fresh and brackish waters, and is commonly found in estuaries and coastal zones. It is native to Eastern Europe and Western Asia. Either by spreading naturally or by introduction, the species has become established in Northern to Southern Europe, Central Asia, Western China and Northern Africa [8]. Pikeperch is a long, slender fish that weighs up to 20 kg, and has a lifespan of up to 16 years on average. It has two dorsal fins, two pectoral fins, two pelvic fins, one anal fin and a caudal fin. Its back has a greyish-brown coloration with light silvery sides, marked with between 8–12 dark vertical stripes (often broken into spots). Pikeperch reach a maximum length of 100–130 cm which corresponds to a weight of about 15–20 kg. The histological gonad development of pikeperch starts at lengths of 5.7 cm total length [9]. Oogenesis starts at lengths of about 7.9 cm in females, while no spermatogenesis was observed with similarly sized males [9]. To the authors' knowledge, there is to date no analysis of sex dimorphism within pikeperch, based on GM analysis.

For this study, the use of the allometric model, instead of analysis of other types of models (i.e., linear, exponential, and logarithmic), has been focused on the relationship between size and shape in pikeperch (*Sander lucioperca*) using geometric morphometric methods.

MATERIALS AND METHODS

Specimens examined

The present analyses of sexual dimorphism and age-related variation are based on 26 adult specimens of pikeperch (*Sander lucioperca*) (12 females and 14 males) from the permanently flooded Ivars and Vila-sana lake (Catalunya, NE Spain, coordinates: E00º57', N41º40'). This endorheic basin was drained in 1951, but in 2009 it was re-established and pikeperch were introduced. It is equipped with pumping stations and the water system includes an extensive network of canals.

Specimens were randomly collected with fishing nets during one day in November 2013. Body weight and length were obtained and only individuals with a body weight >100 g were considered. Final selected specimens weighed 125.0–912.9 g (total weight: digestive tract included) and measured (forked length: from anterior tip of upper snout to midpoint of caudal edge of the hypural plate) 224.2–422.7 mm, so all of them were considered adults. Sex of specimens was easily determined by macroscopic *post mortem* examination of their gonads, by their posterior dissection. As specimens were captured for research purposes, they were not collected *ex professo* for this investigation.

Image-capturing and landmark digitizing

Image-capturing of geometric morphometric data was performed using a Nikon AF Nikkor® 28–200 mm telephoto lens focused on the left lateral body view. In setting up the digital camera, care was taken to mount it firmly in place, perfectly balanced and attached to a tripod stand and set at maximum zoom. In order to minimize size-related digitizing error, the camera was adjusted so that each fish took up about the same amount of the frame, regardless of its size. A ruler was used in this process. Fish were studied fresh and not dissected for sex determination prior to being photographed. To assure the reliability of this study, any sample that showed marked fin erosion or developmental deformities was also eliminated. The software TPS-Dig, v. 2.16 [10] was used to digitize and save 19 homologous chosen landmarks (Table 1) which provided a comprehensive summary of the general body morphology of the fish (Figure 1). After digitization, landmark coordinates were translated to align the centroids of each individual, and then rotated and rescaled to produce Procrustes shape coordinates (using CoordGen6 by H.D. Sheets, available as part of the Integrated Morphometrics Package (IMP) at:

http://www2.canisius.edu/~sheets/morphsoft.html).

Size was scaled as centroid size (CS), which is the square root of the summed square distance from each landmark to the geometric centre.

Testing for image-capturing precision and landmark digitizing error

The unequal magnification and inaccuracies in landmark digitizing placement on captured images may lead to error because they might distort the apparent shape of the body views due to the potential effects of landmark digitizing error. To assess these potential problems, all pictures were digitized twice on different days by the same observer (LC). A NPMANOVA with Bonferroni corrected p-values, using Mahalanobis distances, was used to assess possible differences between replicas.

Shape variation

In order to compare Procrustes to tangent space distances between individuals, a Generalized Procrustes Analysis superimposition (equivalent to Generalized Least Squares) procedure [11] was performed on each data set using the program TPS-Small 1.20 [12]. The approximation of shape space by tangent space presented with a high correlation (0.999). This high degree of approximation of shapes in the sample (=shape space) by the reference shape (=tangent space) allowed an accurate capturing of the nature and extent of shape deformations in subsequent statistical analyses.

Size dimorphism
As previously stated, size was estimated as CS. The two-tailed (Wilcoxon) Mann-Whitney *U* test was used to determine whether the medians of both sexes were different.

Principal Component Analysis
In order to reduce the number of Procrustes, a Principal Component Analysis (PCA) was performed. Values with loading < [0.2] were discarded. Then, a multiple regression using CS as independent variable was done. This was a linear, one independent (log CS), n (values with loading > [0.2]) dependent (multivariate regression).

All statistical analyses were carried out using the Paleontological Statistics Software Package for Education and Data Analysis [13] and MorphoJ software version 1.05 [14]. Regression was done with *tpsRegr* v. 1.36 (Rohlf, 2009).

RESULTS

Image-capturing device precision
The NPANOVA showed no difference in Procrustes values between the two digitizing trials (p=0.213), thus indicating that final precision was unlikely to constrain the results of subsequent statistical analyses.

Sexual dimorphism
Variation of body weights was equal for both sexes (F=2.310, p=0.153) as well as CS differences (U=59, p=0.209), but there was evidence of sexual shape dimorphism (F=2.613, p=0.036) (Figure 2). The general pattern of sex shape differences was in contrast to the dorsal shape, with females being more rounded and males more slender. Consequently, males and females were treated differently.

PCA
Because of rescaling (i.e. removal of many size effects), the first two components accounted for only 46.1% and 13.6% of the variance, respectively. The respective eigenvalues were 0.00075 and 0.00022. PC I was not correlated with log CS (r^2=0.035, p=0.367) showing many ‘sex overlapped’ specimens, which is likely due to mere shape variability (not associated with size differences). A total of 31 Procrustes coordinates showing loadings < [0.2] were deleted and the remnant coordinates were used to do a second study of the allometry for these highly discriminative landmarks.

Allometry
Pooling both sexes and taking into account all landmarks yielded similar results, size only accounted for a 4.4% of the shape (Goodall test: $F_{36,816}$=1.102, p=0.317) (Figure 3). There also appeared to be no allometric relationships neither for males (R^2=0.042, Wilk’s λ=0.318, p=0.237) nor for females (R^2=0.151, Wilk’s λ=0.483, p=0.733) for the selected most discriminative landmarks.

Table 1. Landmarks used.

Number	Anatomical points
1	Anterior tip of upper snout
2	Anterior point of sphenotic at orbit
3	Top of sphenotic at orbit
4	Posterior point of sphenotic at orbit
5	Base of sphenotic at orbit
6	Dorsal point of gill cover
7	Most posterior point on gill cover
8	Base point of gill cover
9	Anterior basal insertion of first dorsal fin
10	Posterior basal point of first dorsal fin
11	Anterior basal insertion of second dorsal fin
12	Posterior basal point of second dorsal fin
13	Midpoint of caudal edge of the hypural plate
14	Posterior insertion of anal fin
15	Anterior insertion of anal fin
16	Posterior insertion of pelvic fin
17	Anterior insertion of pelvic fin
18	Ventral insertion of pectoral fin
19	Dorsal insertion of pectoral fin

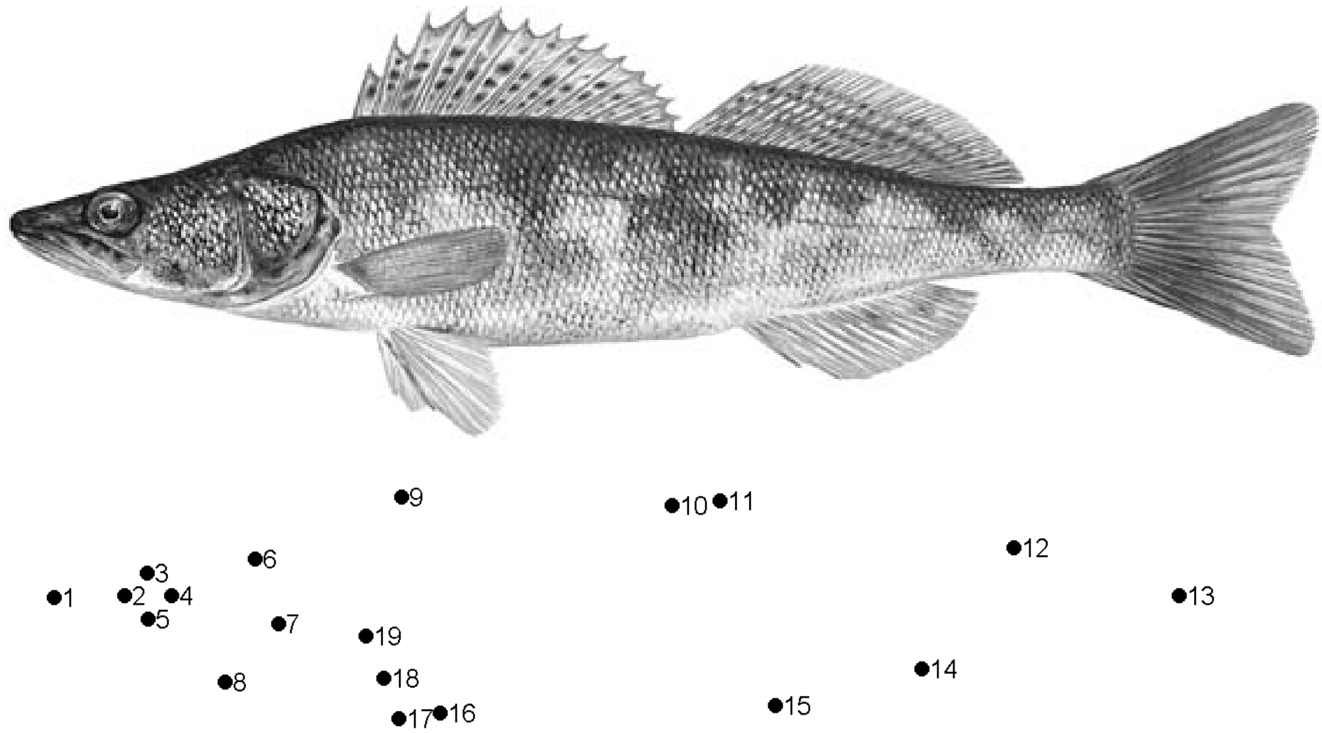

Figure 1. Landmarks used in this study. They were recorded on the lateral left surface of *Sander lucioperca*. Landmarks are marked with circles (projection of the landmark locations for all specimens, after Generalized Least Square alignment). Nineteen homologous and topologically equivalent landmarks were plotted on the body in order to describe the size and shape.

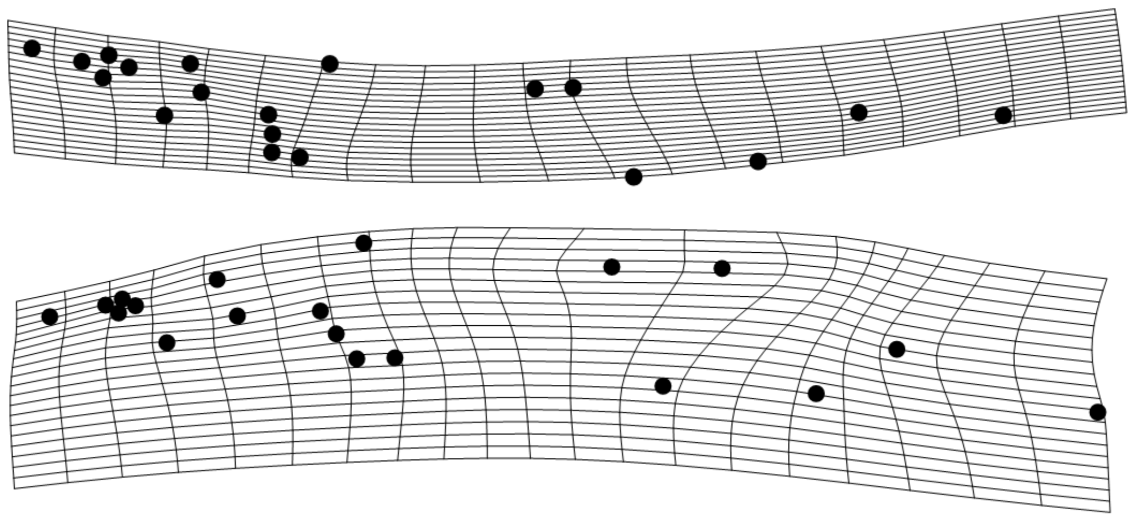

Figure 2. Deformation grids for males (above) and females (below). There was evidence of sexual shape dimorphism. The general pattern of sex shape differences was in contrast to the dorsal shape, with females being more rounded and males more slender.

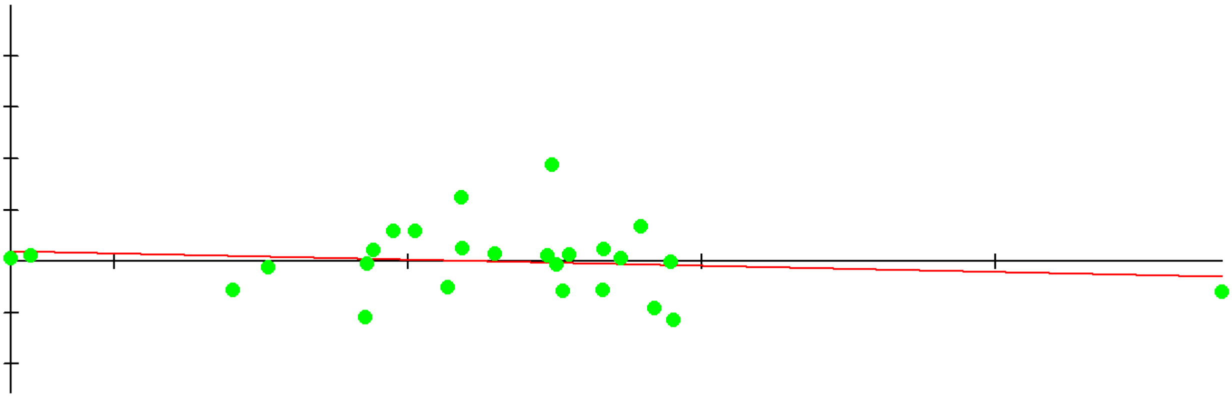

Figure 3. Regression of log CS versus regression score for both sexes, taking into account all landmarks. Size explained only 4.4% of the shape

DISCUSSION

The allometric model seems to be the appropriate for describing morphometrics in fishes and applies to the vast majority of relationships of morphological characteristics with body length. Based on the results of the present study; it seems there is a no effect from body size and shape, so the trunk and fins increased in length proportionally with the body length. Additionally, based on the results presented here, there is no allometric relationship between size and shape in pikeperch, yet, allometric calculations should not be considered optimally applicable to all selected landmarks. This functional relationship implies that larger individuals have the same form, for both sexes, suggesting the form of the fish does not change with growth. Although isometric relationships appear to be infrequent in nature [16], for fishes, a non-linear relationship between mean gonad mass and mean body mass has been described [17]. Results are similar if only the most discriminative landmarks are considered.

Although the results need further investigation, since low number of sampling size doesn't give a real situation of natural fish population, since and the same analysis might have different results in spring before spawning season, as preliminary results they may be useful for comparing allometric patterns between geographical populations or ecological variants, fitness, fish movements, spatial scales, and for studying the body-size dependence of energy storage and size-related biokinetics for pikeperch.

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