Belg. J. Zool., 138 (1) : 90-94 January 2008

Allometry of external morphology and sexual dimorphism in the red porgy (*Pagrus pagrus*)

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ABSTRACT. Body weight (W), nine morphometric variables and total length (TL) were estimated for each sex in the protogynous red porgy, (*Pagrus pagrus)* reared in captivity. The power function $Y=aX^b$ was used to evaluate growth-related changes in morphology. The first derivative, $dY/dTL=abTL^{b-1}$, where Y is each morphometric character, was used to study the growth pattern of each character relative to growth in length (TL). The length-weight relationship showed isometric growth and no inter-sex variability. The analysis of the morphometric variables demonstrated the existence of a substantial degree of differences between the sexes. Males showed an isometric growth pattern (I) for head height and an accelerated (+A) or retarded (-A) growth pattern for the preorbital and post-orbital distance, respectively. However, females showed a retarded (-A) growth rate of the head height and an isometric growth pattern (I) for pre-orbital and post-orbital distances. Thus, the male red porgy appears to have a taller head compared to females. Additionally, the head in males is wider and the orbits are positioned more posteriorly in the head. The adaptive significance of these differences remains currently unclear but should be studied in relation to protogynous hermaphroditism and the specific features of male biology in the red porgy.

KEY WORDS : *Pagrus*, porgy, morphometry, allometry, sexual dimorphism

INTRODUCTION

The red porgy (*Pagrus pagrus*, L., 1758) is a marine fish of great economic importance in both the Mediterranean Sea and the Atlantic Ocean (Vassilopoulou & Papaconstantinou, 1992; Harris & McGovern, 1997). Due to its wide geographical distribution, high market demand and good growth rates (Pajuelo & Lorenzo, 1996; Maragoudaki et al., 1999; Fostier et al., 2000) there is a strong interest in breeding this species commercially (Kolios et al., 1997; Bodington, 2000). Thus, it is considered as a new candidate species for the diversification efforts of the Mediterranean aquaculture.

The red porgy is a protogynous hermaphroditic species. In captivity, it reaches sexual maturity at the age of 3-4 years (Kokokiris et al., 1999; 2001). Depending on latitude, spawning occurs from February to mid-June (Pajuelo & Lorenzo, 1996; Kokokiris et al., 2001). Although some immature individuals develop testicular tissue and function as males throughout their life (primary males), the majority of males derive from the sex change of adult females after sexual maturation (Kokokiris et al., 1999). Adult females cannot be distinguished from males in view of their external morphology. Although there is an interest for external morphometric characters to distinguish sexes, (mainly for aquacultural purposes), the allometry of its external morphology has not been studied so far. The present study examines the allometric growth pattern of a number of morphometric characters searching for any dimorphism useful to distinguish sexes.

MATERIALS AND METHODS

Fish were caught by bottom trawls at Heraklion Bay (Crete, Greece) and were acclimatized to rearing conditions in outdoor tanks ($10m^3$) under natural photoperiod and water temperature (National Center of Marine Research). Fish were fed with commercial pellets (sea bream pellets, Biomar), provided by self-feeders (Kokokiris et al., 1999; 2001).

Sampling was carried out five times throughout the year (April, May, July, August and September). Two hundred ninety five (295) individuals were examined for morphometric analysis (0.09-2.5Kg, total body weight, 17.5-49cm, total length). Fish were killed with an overdose of 2-phenoxyethanol. Total length (TL) and nine other morphometric variables were measured with a caliper to the nearest 0.1mm. Abbreviations of the morphometric variables measured and their indications on the fish body are given in Table 1 and Fig. 1.

After measuring, the fish were dissected and the gonads removed. A tissue sample from the middle of the right gonad was fixed in Bouin solution, prepared for analysis using routine histological techniques (sections of 4-6μm stained with Harris haematoxylin and eosin) and observed under light microscopy for sex identification (Kokokiris et al., 1999; 2001).

The structure of the sampled population according to the length of females and males is presented in Fig. 2. The TL frequency distribution and mean TL values differed significantly between females and males (t-test, $P<0.05$). In order to meet the assumptions necessary to carry out the comparisons of the morphometric variables between sexes (same TL frequency distribution and same size

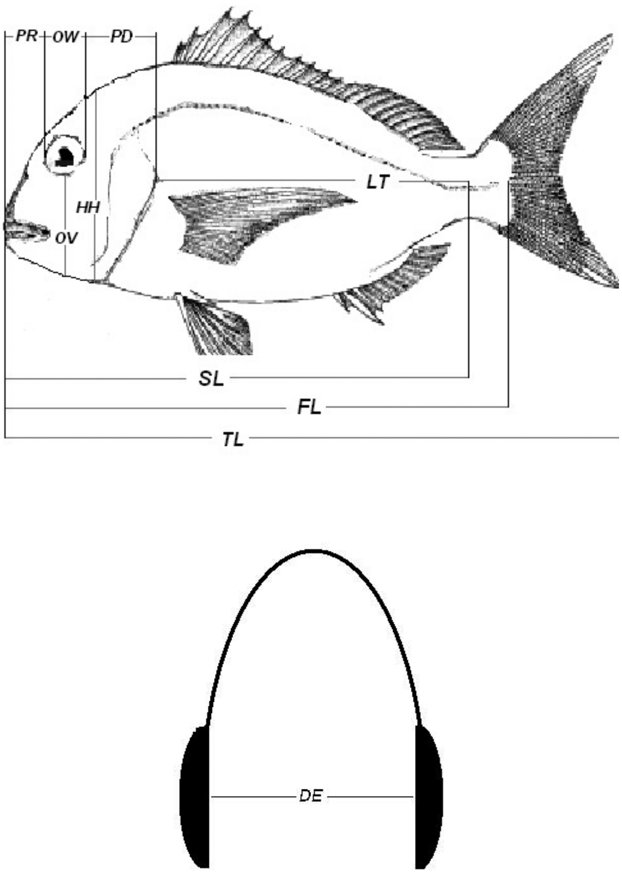

Fig. 1. – Identification of the different morphometric characters on the fish body.

TABLE 1

Morphometric measurements made on *P. pagrus*. Abbreviations and names of variables are those used in text.

Term	Description
Head width	Upper distance between the tip of the orbits
Fork length	Distance from the tip of the nose to the middle part of the caudal fin
Head height	Distance from the lower end to the upper end of the head
Trunk length	Distance from the tip of the posterior margin of the opercula to the end of the vertebral column
Vertical position of the orbit	Distance from the tip of orbit to the lower end of the jaw
Orbit width	Diameter of the orbit
Post-orbital distance	Distance from the end of the orbit to the posterior margin of the opercula.
Pre-orbital distance	Distance from the tip of the nose to the front end of the orbit
Standard length	Distance from the tip of the nose to the end of the vertebral column
Total length	Distance from the tip of the nose to the longest caudal fin ray

DE: Head length, FL: Fork length, HH: Head height, LT: Trunk length, OV: Vertical position of the orbit, OW: Orbit width, PD: Post-orbital distance, PR: Pre-orbital distance, SL: Standard length, TL: Total length.

range), individuals were taken randomly from each 5cm TL group of females and males, within the TL size range from 25 to 50cm (MINOS et al., 1995). TL values were tested for normality and homogeneity of variances and then frequency distributions and mean values were compared between sexes by means of Kolmogorov-Smirnov and t-test, respectively (ZAR, 1999). This procedure was repeated until TL mean values were similar (t-test, P>0.05) between sexes (Fig. 3, MINOS et al., 1995; TIDU et al., 2004). Finally, one hundred seven females (107) and fourty eight males (48) were used for the morphometric analysis.

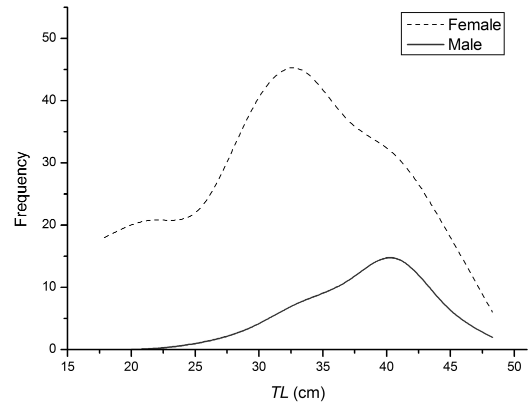

Fig. 2. – Total length frequency distributions of male and female individuals of *P. pagrus*.

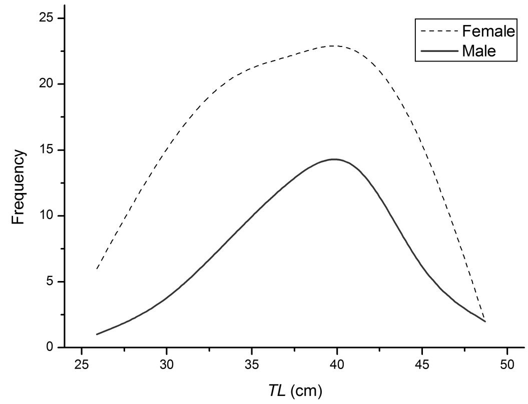

Fig. 3. – Total length frequency distributions of male and female individuals of *P. pagrus* from the selected specimen per total length class size.

The allometric growth (differential increase) of each variable relative to TL was calculated from the function $Y=aTL^b$ using the first derivative with respect to the total length $dY/dTL=axbxTL^{b-1}$, where a and b are constants and Y is the morphometric variable (MINOS et al., 1995). Data were $\log_{10}$ transformed and least-square regression analysis was applied to calculate the parameters of the allometric equation of each variable versus TL. The significance of the slope was tested by means of a t-test (ZAR, 1999). The morphometric variables were then divided into three categories: positive allometry (+A), when the slope (b, allometry coefficient) was significantly higher than 1 and the variable increased relatively to TL; negative allometry (-A), when the slope was significantly lower than 1 and the variable decreased relative to TL; and isometry (I) when the slope showed a non significant difference from 1, indicating direct proportionality between the variable and TL.

The relationship between the length and the weight was estimated using also the equation $W=aTL^b$, where W is the body weight in grams (g). The W was plotted against TL and a least-square regression analysis was applied to calculate the coefficients a and b. The significance of the slope was tested by comparing the slope with the expected slope of 3.0 under isometric growth using a t-test (ZAR, 1999).

To examine differences in morphometric dimensions between females and males, the regression slopes of each variable versus TL were tested by means of t-tests (MINOS et al., 1995; BRACCINI & CHIARAMONTE, 2002).

RESULTS

Weight versus total length

Regression analysis showed that the slope (b) was not significantly different from 3.0 (t-test, P>0.05), in both females and males, indicating an isometric growth pattern for both sexes ($b_{Females}$=2.958, b_{Males}=2.989, Table 4).

Morphometric variables versus total Length (TL)

The parameters of the equation of each morphometric variable versus total length (TL) of females and males are presented in Table 2. In females, three dimensions (trunk length, vertical position of the orbit, standard length) revealed a positive allometric relationship (+A, t-test, P<0.05) and three (head width, orbit width, head height) had a negative allometric relationship (-A, t-test, P<0.05) (Table 2). Three dimensions (fork length, pre-orbital distance, post-orbital distance) had an isometric relationship (I) with TL (P>0.05).

In males, two dimensions (trunk length, pre-orbital distance) had a +A relationship and two dimensions (orbit width, post-orbital distance) a –A relationship (t-test, P<0.05). Five dimensions (head width, fork length, head height, vertical position of the orbit, standard length) increased isometrically with TL (P>0.05, Table 2).

Regression analysis (comparison of slopes between sexes) revealed that six morphometric characters, (standard length, fork length, trunk length, post-orbital distance, pre-orbital distance and head height) were significantly different between females and males (t-test, P<0.05, Table 3). The non-dimorphic measurements were head height, orbit width and vertical position of the orbit. Especially, the dimensions measured on the head (head height, pre-orbital distance, post-orbital distance) had not only different growth patterns between sexes, but head height and pre-orbital distance had a higher rate of change during growth in males and only post-orbital distance in females. Body dimensions including trunk length and standard length had a higher rate of change in females but the fork length dimension had a higher growth rate in males (Table 3).

TABLE 2

Ontogenetic changes in morphometric measurements (see Table 1) for female and male red porgy. Values given are from the equation $Y=aTL^b$. a, b, parameters of the equation; r^2, coefficient of determination; SE_b, standard error of b; SE_e, standard error of estimation; * as P< 0.05. Slope patterns are: +A, positive allometry; –A, negative allometry; I, isometry.

Dimension	a	b	r^2	SE_b	SE_e	Slope (b)
Females						
DE	0.114	0.911	0.96	0.021	0.031	**-A ***
FL	0.940	0.976	0.96	0.021	0.033	**I**
HH	0.372	0.903	0.95	0.020	0.033	**-A***
T	0.354	1.119	0.98	0.014	0.023	**+A ***
OV	0.089	1.068	0.95	0.025	0.041	**+A ***
OW	0.335	0.543	0.86	0.013	0.052	**-A ***
PD	0.098	0.974	0.92	0.028	0.045	**I**
SL	0.727	1.028	1.00	0.007	0.012	**+A ***
PR	0.103	1.015	0.94	0.024	0.039	
Males						
DE	0.099	0.948	0.93	0.044	0.027	**I**
FL	0.733	1.042	0.95	0.034	0.031	**I**
HH	0.204	1.068	0.82	0.073	0.066	**I**
LT	0.409	1.077	0.98	0.024	0.022	**+A ***
OV	0.114	1.001	0.92	0.042	0.038	**I**
OW	0.301	0.573	0.68	0.058	0.052	**-A ***
PD	0.355	0.622	0.66	0.066	0.060	**-A ***
PR	0.065	1.140	0.88	0.062	0.056	**+A ***
SL	0.835	0.989	0.99	0.015	0.013	**I**

TABLE 3

Regression slopes and t-test analysis of sexual differences in morphometric measurements (see Table 1). P, statistical difference (α=0.05).

Dimension	Females	Males	P
	Equation	Equation	
DE	$Y=0.114\ TL^{0.911}$	$Y=0.099\ TL^{0.948}$	>0.05
FL	$Y=0.940\ TL^{0.976}$	$Y=0.733\ TL^{1.042}$	<0.05
HH	$Y=0.372\ TL^{0.903}$	$Y=0.204\ TL^{1.068}$	<0.05
LT	$Y=0.354\ TL^{1.119}$	$Y=0.409\ TL^{1.077}$	<0.05
OV	$Y=0.089\ TL^{1.068}$	$Y=0.114\ TL^{1.001}$	>0.05
OW	$Y=0.335\ TL^{0.543}$	$Y=0.301\ TL^{0.573}$	>0.05
PD	$Y=0.098\ TL^{0.974}$	$Y=0.355\ TL^{0.622}$	<0.05
PR	$Y=0.103\ TL^{1.015}$	$Y=0.065\ TL^{1.140}$	<0.05
SL	$Y=0.727\ TL^{1.028}$	$Y=0.835\ TL^{0.989}$	<0.05

DE: Head length, FL: Fork length, HH: Head height, LT: Trunk length, OV: Vertical position of the orbit, OW: Orbit width, PD: Post-orbital distance, PR: Pre-orbital distance, SL: Standard length, TL: Total length.

TABLE 4

Parameters of the length-weight relationship ($W=aL^b$) between body weight (g) and total length (cm) of *P. pagrus* at various regions in Mediterranean and adjusted areas or rearing conditions. n, sample size; min and max, minimum and maximum length (cm); a and b, parameters of the equation; SE_b, standard error of b; r^2, coefficient of determination; M, male; F, female; A, all individuals, * Length measured was Fork Length; P: statistical significance.

Location	Author	Sex	n	Length		A	b	SE_b	r^2	P
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Canary Islands, Eastern Atlantic	Pajuelo & Lorentzo (1996)	F	758	16.8	56.2	0.0132	3.032	0.026	0.98	>0.05
		M	230	22.8	57.2	0.0133	3.043	0.018	0.98	<0.05
		A	1858	4.7	57.2	0.0179	2.958	0.023	0.99	>0.05
South-West coast of Portugal.	Concalves et al. (1997)	A	23	13.5	36.2	$3.5x10^{-5}$	2.866	0.077	0.98	>0.05
Eastern Adriatic (Croatian waters)	Dulcic & Kraljevic (1996)	A				$5.3x10^{-6}$	3.343	0.127	0.98	<0.05
Western Mediterranean	Morey et al. (2003)	A	127	4.8	33.4	0.0282	2.800	0.248	0.95	>0.05
Aegean Sea, Eastern Mediterranean	Moutopoulos & Stergiou (2002)	A	35	13.0	51.7	0.0152	3.005	0.067	0.98	>0.05
Kastelorizo island, Eastern Mediterranean	Vassilopoulou (1989)	F	95	13.3*	41.8*	$1.9x10^{-5}$	3.020		0.98	
		M	23	13.3*	41.8*	$3.4x10^{-5}$	2.920		0.99	
		A	142	13.3*	41.8*	$2.4x10^{-5}$	2.980		0.98	
Kastelorizo island, Eastern Mediterranean	Vassilopoulou & Papaconstantinou (1992)	F		10*	46*	$3.3x10^{-5}$	2.928		0.98	
		M		10*	46*	$4x10^{-5}$	2.897		0.99	
Crete island, Eastern Mediterranean	Machias et al. (1998)	A	1817	11*	37*	0.020	3.105		0.99	
Crete island, Eastern Mediterranean, Reared populations	Machias et al. (1998)	A	1142	8.5*	39.5*	0.016	3.205		0.99	
Crete island, Eastern Mediterranean, Reared populations	Present study	F	107	25.5	48.4	0.0239	2.958	0.049	0.97	>0.05
		M	48	25.8	49	0.0206	2.989	0.135	0.93	>0.05

DISCUSSION

The relationship of body weight versus length showed an isometric growth pattern for both female and male red porgy. Similarly to this study, an isometric growth pattern has been also reported for the wild populations in various geographic areas where this species has been studied (see Table 4).

The analysis of morphometric variables demonstrated a substantial degree of differences between the sexes concerning either the growth pattern or the rate of change of some cranial variables. Males showed an isometric (I) growth pattern for head height (HH) and an accelerated (+A) or retarded (-A) growth pattern for the pre-orbital (PR) and post-orbital (PD) distance respectively. However, females showed a retarded (-A) growth rate of the head height (HH) and an isometric growth pattern for the pre-orbital (PR) and post-orbital (PD) distances (length of the head, I). These results indicate a sexual dimorphism of the skull. Males tend to have a taller head, and a longer pre-orbital area than females. Significant changes in the morphology of the head have also been reported in the red snapper, *Chrysophrys auratus* and the redbanded porgy, *Pagrus auriga*. In the red snapper, as individuals age, a large hump grows on their forehead, apparent in both sexes but more prominently so in males. The formation of the hump is due to the enlargement of particular areas of supraoccipital and frontal bones of the skull (hyperostosis, Gauldie & Czochanska, 1990; Smith-Vaniz et al., 1995) but the cause of its presence is still unclear. It has recently been suggested that it possibly has a genetic basis (Smith-Vaniz et al., 1995). Also, in males of this species, the snout may become fleshy and pronounced, sometimes with another distinct hump or bump. Similarly, the adults of the redbanded porgy (*Pagrus auriga)* have a slight hump above eyes and the snout becomes more bulbous (Fisheries Global Information System, 2004).

Due to protogyny of the red porgy, male individuals derive from females after a sex change (Kokokiris et al., 1999). The dimorphic characters in *P. pagrus* may reflect the adaptation of males and females to different social or/and reproductive roles rather than different niche utilization as both sexes were grown under the same artificial environment (rearing conditions). They are possibly related to protogynous hermaphroditism and to behavioral or/and social (demographic) changes of the social system, which induce the sex change process in hermaphroditic species (Shapiro, 1992). However, further research is required in order to identify any relationship between the sex change of females and the sexual dimorphism in this species.

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Received: April 2, 2007
Accepted: June 29, 2007