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Length-weight relationship and growth parameters of the commercial fish *Pagellus erythrinus* (Linnaeus, 1758) (Actinopterygii: Sparidae) from northern and southern Tunisia

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Abstract: Based on length, weight, and age data, we examined allometry and growth parameters for common pandora, *Pagellus erythrinus*, commercially collected seasonally from northern and southern Tunisian coasts in 2007. A total of 370 specimens (14–27.5 cm in length) were used to assess the allometric variation at seasonal scales. The slope *b* values (regression coefficient) of the length-weight relationship varied between 2.494 to 3.237, indicating (roughly) an isometric to negative allometric growth pattern. The allometric relationship, as a proxy for fish condition, seems to be affected by seasons and sex in the northern population, while only seasons seem to have a strong effect in the southern population, as indicated by ANOVA. The von Bertalanffy growth parameters were identified at L_∞ = 34.076 and 28.017 cm, k = 0.153 and 0.150/year, and t_0 = -1.922 and -3.961 years for the northern and southern sample, respectively.

Keywords: allometric coefficient, *Pagellus erythrinus*, common pandora, von Bertalanffy growth model, fish longevity, Tunisian waters

INTRODUCTION

Length, weight, and age are very useful biological data in fish stock assessment and environmental monitoring programs. Such data from individual fish can be combined to provide estimates of population dynamics parameters, notably length and age structures, growth and mortality rates, and well-being of fish (Brown & Guy 2007). They allow also the prediction of fish biomass from length frequency distribution, population stock density, as well as the maximum sustainable yield, and indicate

the vulnerability of fish to overfishing (Beddington & Kirkwood 2005; Cheung et al. 2005). Besides, they are used to compare morphology between different fish species in the same taxonomic group, or between fish populations from different regions or periods, to study the ontogenetic allometric changes (Teixeira de Mello et al. 2006).

Pagellus erythrinus (Linnaeus, 1758) is a common fish species with a wide distribution in the Mediterranean, Black Sea, and the eastern Atlantic Ocean, from Scandinavia to Cape Verde (Fischer et al. 1987). It is found in depths up to 320 m, while most commonly it occupies the depth range between 10 m and 100 m (Somarakis & Machias 2002; Spedicato et al. 2002; Busalacchi et al. 2014). *Pagellus erythrinus* is mainly a protogynous hermaphroditic fish (Buxton & Garratt 1990). Individuals are first females and become males from the third year of life. Spawning season in *Pagellus erythrinus* occurs from spring to early autumn (Tsikliras et al. 2010) and the peak spawning activity varies according to hydrological conditions and regions (Ghorbel 1996; Pajuelo & Lorenzo 1998; Valdes et al. 2004; Coelho et al. 2010; Zarrad et al. 2010; Metin et al. 2011; Ben Smida et al. 2014).

In Tunisia, *Pagellus erythrinus* is an appreciated and valuable fishery resource since it plays an important role in local microeconomics through its capture volume and its high commercial value (Ghorbel 1996). The conservation act and regulations for this species set the minimum size limit at 12 cm for standard length (Law No. 94-13 of 31/1/1994, JORT 8/2/1994, 11: 227-230).

The population structure of *Pagellus erythrinus* along the Tunisian coasts was assessed using isozyme gene markers (Fassatoui et al. 2009; Fassatoui et al. 2011). Two genetically different stocks were identified, the first one in northern Tunisia and the second one in southern Tunisia (the Gulf of Gabes).

Despite the large number of biological studies on *Pagellus erythrinus* in the Mediterranean Sea, few works have examined the length-weight relations over time (Özbilgin et al. 2012). The study aimed to assess the length-weight relationship (as a proxy for fish condition), to investigate their variability at a seasonal scale, and to estimate the growth parameters of the commercial sparid fish *Pagellus erythrinus* from the remote areas off the northern and southern Tunisian coasts.

MATERIAL AND METHODS

A total of 370 specimens of *Pagellus erythrinus* were examined to investigate their length-weight relationship as an indicator of body allometry, and their age-length relationship as an indicator of growth. Samples were collected from northern and southern Tunisia (the open sea of Bizerte and Zarzis, respectively) by a random stratified method from commercial fishing landings at the beginning of each season in 2007 (Fassatoui et al. 2011). The northern Tunisian waters belong to the western Mediterranean basin. The continental shelf is formed there by the extension of mountains, with an abrupt and very narrow slope. The coasts, characterized by an alternation of rocky and movable bottoms, belong to the humid and sub-humid bioclimatic zones. However, southern Tunisia corresponds to the region of the Gulf of Gabes. It is characterized by sandy and sandy-muddy bottoms. The continental shelf is very

extensive there, with a very slight slope. That area is characterized by strong tidal range (up to 2 m) and belongs to an arid bioclimatic zone.

The collected fish were weighed to the nearest 0.01 g and total length was measured to the nearest 0.1 cm. Otoliths (sagittae) were prepared and examined for age determination according to the method of Bagenal & Tesch (1978). Estimation of age from otolith reading was performed for all individuals. No difficulty was encountered in reading sagittal otoliths in *P. erythrinus*, as opaque zones were clear and interpretable. Sex was determined by macroscopic examination of the gonads.

In respect of allometry, the relation of total length (L) to total weight (W) was examined applying the exponential regression function (Le Cren 1951): $W = aL^b$, where a is the intercept parameter or shape coefficient and b is the slope or allometric parameter. The linearized equation was derived with ordinary least squares regression after log-transformation: $\ln(W) = \ln(a) + b \ln(L)$. The length-weight relations were investigated for each locality separately by season, by sex and by combined sexes. These were applied to all samples with more than 10 specimens, as it was recommended by Froese et al. (2011). The comparison of slopes between males and females and between seasons within each locality was carried out using an analysis of variance (ANOVA).

To assess growth, we used the von Bertalanffy growth model to link the observed length and age data of fish by means of a Marquardt algorithm for non-linear least-squares parameter estimation (Saila et al. 1988). The form of the growth equation follows Beverton & Holt (1957): $L_t = L_\infty [1 - e^{-k(t-t_0)}]$, where L_t is the predicted length at time t (years), L_∞ is the asymptotic length to which fish tend to grow, k is the growth coefficient, t is age at time t, and t_0 is the hypothetical age when fish length is zero. The growth performance index was also calculated, using the equation devised by Pauly & Munro (1984): $\varphi' = \log_{10}(k) + 2\log_{10}(L_\infty)$, where L_∞ and k are parameters of von Bertalanffy growth equation. The potential longevity (t_{max}) of the species in each locality was estimated using Pauly & Munro's (1984) formula: $t_{max} = 3/k$, where k is the growth coefficient.

Statistical analyses were performed in the computing environment R version 3.3.0 (R Core Team 2016), using smatr package (Warton et al. 2012) to assess allometry, and both FSA (Ogle 2016) and nlstools (Baty et al. 2015) packages to assess growth parameters. Significance for all statistical tests was taken as $p < 0.05$.

RESULTS

Allometry and growth parameters in *Pagellus erythrinus* were determined in a total of 192 specimens from northern Tunisia and 178 specimens from southern Tunisia. For the estimated parameters of length-weight relations for each season, as well as descriptive statistics by sex and combined sexes for each locality (Table 1), coefficients of determination (r^2) ranged from 0.875 to 0.986 (all p values < 0.001) and b values ranged between 2.494 and 3.237. A negative allometric to isometric growth were observed in seasonal samples for both localities. Only the males of the summer sample from southern Tunisia displayed positive allometric growth. Significant differences in b values were found in the northern sample, suggesting effects of sex

Table 1. Descriptive statistics and estimated parameters of length-weight relations for males, females and combined sexes (total) for seasonal samples of the commercial fish *Pagellus erythrinus* collected in 2007 from northern and southern Tunisia. *N* = sample size; *L* = total length; *W* = body weight; SE = standard error; a = scaling constant; *b* = slope; CI = confidence interval; r^2 = coefficient of determination; TG = type of growth (I = isometry; A+ = positive allometry; A- = negative allometry). Significant *b* values ($p < 0.05$) are shown in bold after evaluation by Student's *t*-test using smatr package under R project environment

		Northern Tunisia								Southern Tunisia							
Season	Sex	*N*	*L* ± SE (cm)	*W* ± SE (g)	a	*b*	95% CI of *b*	TG	r^2	*N*	*L* ± SE (cm)	*W* ± SE (g)	a	*b*	95% CI of *b*	TG	r^2
Spring	female	30	15.95 ± 0.18	48.52 ± 1.77	0.0081	3.135	2.71; 3.56	I	0.892	28	18.09 ± 0.16	81.61 ± 1.99	0.0448	**2.591**	2.26; 2.93	A-	0.906
(Mar	male	2	16.35 ± 0.15	53.63 ± 2.34	nd	nd	nd	nd	nd	32	19.09 ± 0.18	92.16 ± 2.38	0.0475	**2.564**	2.25; 2.88	A-	0.902
2007)	total	32	15.97 ± 0.17	48.84 ± 1.68	0.0077	3.154	2.74; 3.56	I	0.893	60	18.62 ± 0.14	87.24 ± 1.70	0.0588	**2.494**	2.29; 2.69	A-	0.917
Summer	female	11	20.55 ± 0.45	110.00 ± 7.46	0.0205	2.834	2.36; 3.31	I	0.953	9	19.27 ± 0.81	96.64 ± 11.20	nd	nd	nd	nd	nd
(June	male	49	21.98 ± 0.24	133.07 ± 4.24	0.0306	**2.705**	2.53; 2.87	A-	0.956	24	21.99 ± 0.28	138.28 ± 5.71	0.0061	**3.237**	3.07; 3.40	A+	0.986
2007)	total	60	21.72 ± 0.22	128.84 ± 3.87	0.0278	**2.737**	2.59; 2.88	A-	0.960	33	21.25 ± 0.36	126.92 ± 6.03	0.0126	3.006	2.87; 3.14	I	0.986
Autumn	female	50	20.83 ± 0.21	122.36 ± 3.61	0.0176	2.909	2.70; 3.11	I	0.942	7	20.03 ± 0.27	105.62 ± 3.96	nd	nd	nd	nd	nd
(Sept	male	10	21.21 ± 0.46	127.26 ± 8.11	0.0244	2.798	2.36; 3.24	I	0.964	53	20.67 ± 0.16	117.58 ± 2.58	0.0559	**2.523**	2.25, 2.79	A-	0.875
2007)	total	60	20.90 ± 0.19	123.17 ± 3.28	0.0187	2.887	2.70; 3.07	I	0.945	60	20.60 ± 0.15	116.18 ± 2.37	0.0521	**2.545**	2.29; 2.79	A-	0.877
Winter	female	38	17.85 ± 0.20	71.19 ± 2.21	0.0423	**2.574**	2.35; 2.79	A-	0.939	17	19.69 ± 0.32	102.82 ± 4.80	0.0354	2.672	2.21; 3.13	I	0.912
(Dec	male	2	19.15 ± 0.55	85.87 ± 2.88	nd	nd	nd	nd	nd	8	20.26 ± 0.47	109.46 ± 6.80	nd	nd	nd	nd	nd
2007)	total	40	17.91 ± 0.20	71.92 ± 2.16	0.0423	**2.574**	2.36; 2.78	A-	0.940	25	19.87 ± 3.89	104.95 ± 3.89	0.0405	2.625	2.24; 3.01	I	0.897

nd = not determined because of small sample size ($N < 10$), as recommended by Froese et al. (2011)

Table 2. Analysis of variance (ANOVA) results: effects of sex and season on length-weight relations in the commercial *Pagellus erythrinus* collected in 2007 from northern and southern Tunisia. Significant values ($p < 0.05$) are shown in bold

	SS	d.f.	*F*	*p*
Northern Tunisia				
Sex	0.0132	1	19.042	**< 0.001**
Season	0.0052	3	3.716	**0.012**
Season × sex	0.0051	5	2.144	0.062
Southern Tunisia				
Sex	0.0001	1	0.212	0.645
Season	0.0086	3	6.468	**< 0.001**
Season × sex	0.0064	4	3.933	**0.004**

and season on allometry (Table 2). However, no sex effect on allometry was found in the southern sample, only seasons revealed a highly significant effect (ANOVA; $p < 0.001$).

Otolith data allowed us to distinguish 6 age classes in the commercial fishery population from northern Tunisia and 5 age classes from southern Tunisia (Fig. 1).

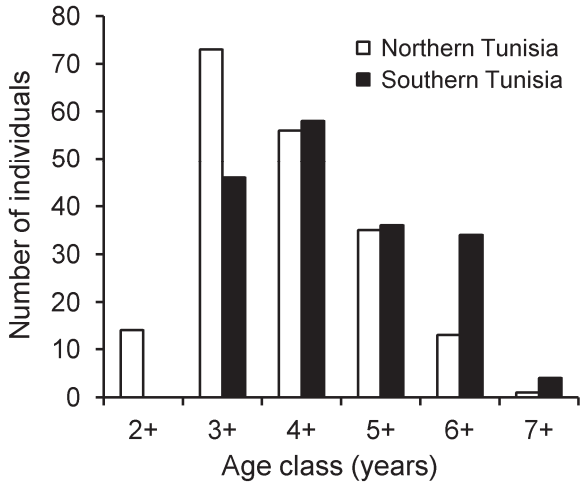

Fig. 1. Age structure of *Pagellus erythrinus* sampled from northern and southern Tunisia

Table 3. Growth parameters, based on typical parameterization of the von Bertalanffy growth model, of the commercial *Pagellus erythrinus* collected in 2007 from northern and southern Tunisia. *N* = sample size; L_∞ = asymptotic total length; k = growth constant; t_0 = hypothetical age at which fish length is zero; CI = confidence interval obtained after 1000 bootstrap iterations using nlstools package in the R environment; r_{max} = maximum absolute value of correlation coefficients among the 3 parameters; r_{mean}= average absolute value of correlation coefficients among the 3 parameters; φ' = growth performance index; and t_{max} = potential longevity

	N	L_∞ (cm)	CI at 95% of L_∞ (cm)	k (yrs^{-1})	CI at 95% of k (yrs^{-1})	t_0 (yrs)	r_{max}	r_{mean}	φ'	t_{max}
Northern sample	191	34.076	27.498 ; 53.292	0.1528	0.066 ; 0.286	-1.9224	0.995	0.980	2.249	19.633
Southern sample	174	28.017	22.831 ; 36.281	0.1505	0.073 ; 0.427	-3.9608	0.997	0.993	2.072	19.933

The estimated parameters of the von Bertalanffy model, the growth performance index φ' and the potential longevity t_{max} for both localities sexes combined (Table 3) excluded individuals aged 7+ because of their small sample size. The growth equations for total length were as follows: $L_t = 34.076\ [1 - e^{-0.153\ (t+1.922)}]$ for the northern sample and $L_t = 28.017\ [1 - e^{-0.150\ (t+3.961)}]$ for the southern sample. From these results, the growth performance index was 2.25 and 2.07, while longevity was 19.63 and 19.93 years for the northern and southern sample, respectively.

DISCUSSION

For an ideal fish, which maintains in perfect equality the dimensions of its body in length and weight, the growth pattern follows the cube law (Le Cren 1951). In such cases, fish grow isometrically and the *b* value (regression coefficient) of the relationship between length and weight is equal to 3. Under natural conditions, most fish do not follow the cube law, and *b* value could be significantly greater or lower than the ideal value 3, indicating that the growth pattern is allometric. There are many internal and/or external factors affecting the *b* value throughout the fish life, e.g. environmental conditions, food availability, gonad development, and fishing pressure, which can strongly influence this growth parameter (Le Cren 1951).

In the present work, the growth pattern in *Pagellus erythrinus* for both locations varies from negative allometry to isometry in the overwhelming majority of cases. The results showed that the expected range of slope *b* values for seasonal samples were globally within the limits 2.5–3.5 reported by Froese (2006) for most fishes. Significant differences between the seasonal slopes of the length-weight relationship may be a reflection of growth variation, as length-weight relationship can fluctuate due to the influence of temperature, salinity, food availability, and reproduction. The fish growth variation in both locations is most notably under the influence of food

availability and environmental fluctuations between seasons and years. However, it is possible that such variations may be due to the influence of reproductive processes on individual growth. Indeed, the differential growth by sex, as shown by ANOVA in the northern Tunisian sample, could be explained e.g. by the hermaphroditism of *Pagellus erythrinus*.

Regarding von Bertalanffy parameters, estimated asymptotic length in the northern Tunisian sample (L_∞ = 34.08 cm) was greater than in the southern sample (L_∞ = 28.02 cm). However, growth coefficient values and the estimated longevity for both locations were closely similar. Differences in estimated asymptotic length for both locations can be attributed to geographical variation. Fish populations of the same species from different geographical regions may exhibit highly variable, individual growth rates. The differences may be due to the differences in the stock population, resulting from genetic factors, environmental variables or their combination.

On the whole, growth performance indices of *Pagellus erythrinus* in the present study were in the same range or slightly smaller than previously published data (e.g. Girardin & Quignard 1985; Pajuelo & Lorenzo 1998; Coelho et al. 2010).

According to our results, the estimated longevity of *Pagellus erythrinus* is about 20 years for both locations. Girardin & Quignard (1985) reported the presence of 2 oldest females in their sample: the first measuring 43.7 cm for fork length at 15 years of age (based on scale reading), and the second appeared to be older but with indeterminable age and had a fork length of 44.5 cm. However, Coelho et al. (2010), on the basis of otolith reading, reported the oldest fish for this species, a 21-year-old male, measuring 40 cm of total length. This suggests that the lifetime of *Pagellus erythrinus* may exceed 20 years.

In conclusion, this study provides basic information on length-weight relations on a_short-term temporal scale, as well as von Bertalanffy growth parameters for *Pagellus erythrinus* from northern and southern Tunisian coasts. The findings can help to enhance the effectiveness of fishery management at the regional level. Moreover, no data currently exist in the FishBase (www.fishbase.se) for this species from northern Tunisia, so our results contribute to this valuable electronic database.

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