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Growth and reproduction of the gilthead seabream *Sparus aurata* in Mellah lagoon (north-eastern Algeria)

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SUMMARY: Gilthead seabream *Sparus aurata* (L.), a protandrous hermaphrodite, was caught in Mellah lagoon (Algeria) from July 1997 to June 1998. Its age, growth and reproduction were studied. Fish ranged in size from 157 to 610 mm total length and weighed from 60 to 4000 g wet weight. There were fish aged 1^+ to 7^+ years old in the samples. Direct scale readings were made by counting the number of rings. These were compared with the data obtained by backcalculating the lengths at different ages. These two methods were in agreement and showed that the growth rate of gilthead seabream in Mellah lagoon is very high compared to other study areas. The growth parameters of the Von Bertalanffy equation were: $L_\infty = 55.33$ cm, K = 0.513, to = - 0.282, with Φ' = 7.359. The fitted length-weight relationship was $W = 1.292.\ 10^{-2}\ L^{3.06}$. The reproductive season extended from October to January, with a peak in December. Sex inversion occurred at a total length of 44 cm. Sexual maturity was reached at 32.6 cm total length.

Keywords: lagoon, gilthead seabream, growth, reproduction.

RESUMEN: CRECIMIENTO Y REPRODUCCIÓN DE LA DORADA, *SPARUS AURATA* EN LA LAGUNA DE MELLAH (NORDESTE DE ARGELIA). – Se capturaron ejemplares de dorada, *Sparus aurata* (L.), una especie hermafrodita proterándrica, en la laguna de Mellah (Argelia) entre Julio de 1997 y Junio de 1998. Se estudiaron la edad, el crecimiento y la reproducción. La talla de los ejemplares estudiados osciló entre 157 y 610 mm de longitud total, pesando entre 60 y 4000 g (peso fresco). Ejemplares de edades comprendidas entre 1^+ y 7^+ años estuvieron presentes en las muestras. La lectura directa de algunas escamas mediante el conteo del número de anillos fue comparada con los datos obtenidos por retrocálculo de las tallas a distintas edades. Los resultados de los dos métodos fueron similares y mostraron que la tasa de crecimiento de la dorada en la laguna de Mellah es muy alta en comparación con otras áreas de estudio. Los parámetros de crecimiento de la ecuación de Von Bertalanffy fueron los siguientes: $L_\bullet = 55.33$ cm, K = 0.513, $t_0 = - 0.282$, con F' = 7.359. El ajuste de la relación talla – peso fue el siguiente: $W = 1.292.\ 10^{-2}\ L^{3.06}$. La estación reproductiva estuvo comprendida entre Octubre y Enero, con un pico en Diciembre. La inversión de sexo tuvo lugar a una longitud total de 44 cm. La madurez sexual se alcanzó a una longitud total de 32.6 cm.

Palabras clave: laguna, dorada, crecimiento, reproducción.

INTRODUCTION

The euryhaline and eurytherm gilthead seabream *Sparus aurata* (L., 1758) is an inshore species that frequents *Posidonia oceanica* beds and rocky and sandy areas. Adult individuals may migrate into lagoons or estuaries. Gilthead seabream is common in the Mediterranean Sea, but very rare in the Black Sea (Bânârescu, 1964). It is also present in the eastern part of the Atlantic Ocean, from Britain to Cape Verde and the Canaries (Bauchot and Hureau, 1986).

With a yearly production of about 101,598 t in 2002 (Anonyme, 2004) in Europe and the Mediterranean Sea, cultivation of gilthead seabream has benefited from considerable research effort (Chatain, 1997; Shields, 2001). However, research on its biology in its natural environment is out-of-date and limited (Lasserre and Labourg, 1974; Lasserre, 1976; Arnal *et al.*, 1976; Suau and López, 1976; Chauvet, 1979; Ferrari and Chieregato, 1981; Wassef and Eisawy, 1985; Rosecchi, 1987), notably with regard to reproduction (Arias, 1980). Recently, Kraljevic and Dulčić (1997) studied its growth in the Mirna estuary in the north of the Adriatic Sea, whereas Pita *et al.* (2002) studied its dietary pattern within the lagunar system of Ria Formosa in south Portugal. Sex inversion in wild populations is treated from an ultrastructural point of view by Bruslé-Sicard and Fourcault (1997).

In Mellah lagoon, the sparidae family is represented by seven species, with gilthead seabream occupying an important place with a production of 12 t in 1999, that is, 98% of sparid fishes. However, the biology of gilthead seabream in this particular environment has never been studied in this lagoon. The lagoon is characterised by the presence of a bordigue (fixed fishing gear) which transforms it into a big basin for extensive aquaculture based on trapping the fish. Thus, this work presents new data on the growth and reproduction of gilthead seabream in the area of extensive lagoon aquaculture.

MATERIAL AND METHODS

Situated in the extreme east of Algeria (8°20'E, 36°54'N), ''Mellah'' is a lagoon of 865 ha, with an average depth of 3.5 m. A total of 632 gilthead seabream were taken by professional fishermen from July 1997 to June 1998. Some of the fish (65%) were fished with monofilament gillnets that were 3 m high with a stretched mesh size of 3.5 cm. The rest (35%) came from the bordigue, particularly at the time of their migration towards the sea (from October to December).

The fish total length was measured, and their age was determined by scale-reading. Five to seven scales were removed from under the left pectoral fin, cleaned and observed at a low magnification (x 32). With the help of an ocular micrometer, the total scale radius (R) and the radii of the different growth rings (R_1, R_2,..., R_n) along a median vertical line were measured. In order to determine when these rings formed, we analysed the monthly variations of the scale marginal increment (MI), with $MI = R–R_n/R_n–R_{n-1}$, where R_n and R_{n-1} are respectively the radius of the last and the next-to-last growth rings.

The age-length relationship was backcalculated according to the Lee method (1920). The theoretical size of fishes when the first scales formed was obtained by a regression $L_t = f(R)$ based on 100 data pairs ($157 \leq Lt \leq 579$ mm, $1.91 \leq R \leq 8.27$ mm). Sizes-at-age (age-length key) were compared with the results of the backcalculation. These backcalculations were used to estimate the parameters L_∞, K and to of the Von Bertalanffy (1938) growth model, $L_t = L_\infty (1 – e^{-K(t - to)})$, by non-linear least squares regression using the Fishparm program (Prager *et al.*, 1989). This software package was also used to fit the overall total length-total weight relationship, $W = a L_t^b$, using data from July 1997 to June 1998 ($N = 370$, $157 \leq L_t \leq 610$ mm, $60 \leq W_t \leq 4000$ g). The allometry coefficient (b) of this relation was compared to value 3 with $\alpha = 0.001$ with the help of the Student's t test. As we knew parameters of the Von Bertalanffy model and the allometry coefficient of the length-weight relationship, we could calculate the theoretical weight at every age. The growth performance index $\Phi' = \ln K + 2 \ln L_\infty$ (Munro and Pauly, 1983) was used for making comparisons with other studies.

The reproductive period for both sexes combined was determined from the temporal development of the gonadosomatic index: GSI = (weight of gonad / total weight of the body) x 100. The hepatosomatic rate was also calculated monthly: HSI = (weight of the liver / total weight of the body) x 100. Monthly values of GSI and HSI were compared using a one-way ANOVA test completed by a multiple sample comparison of means (Dagnélie, 1970). The size at first sexual maturity was estimated according to the evolution of the proportion of mature fish according to size class during the reproduction period. It was the size at which 50% of individuals were ripe with functional gonads. The frequency of the different sexual states (juveniles, males, females) was also expressed according to size class during the reproduction season in November and December. These states are defined macroscopically according to whether the gonad functions as a testicle or an ovary. Testicles with sperm or granular ovaries with vitellogenic oocytes indicate the sex and activity state of the fish.

RESULTS

The linear regression of total length versus scale radius was $L_t = 85.43\ R - 15.64$ ($r = 0.92$). The ordinate to the origin of this equation (15.64 mm) corresponds to the theoretical size of fish at the time of formation of the first scales. Comparing successive monthly mean marginal increment values (Fig. 1), using mean comparison tests, showed a significant difference ($P \leq 0.001$) between the months of November and December. Thus, we consider the rings to be annual increments. The value of the marginal increment is at its maximum when the ring is forming (November) and its minimum just after this (December).

Seven age classes, from 1 to 7 years old, were found. Backcalculated age-length pairs (Table 1) did not show any differences from the observed mean size-at-age (Table 2). The largest fish, which could not be aged, measured 61 cm (3411 g). The estimated parameters of Von Bertalanffy's model are: L_∞ = 55.33 cm, K = 0.513 year^{-1}, to = - 0.282. The growth performance index Φ is equal to 7.359. The weight-length relationship $W = 1.292\ 10^{-2}\ L^{3.06}$ ($r = 0.96$) shows isometric growth.

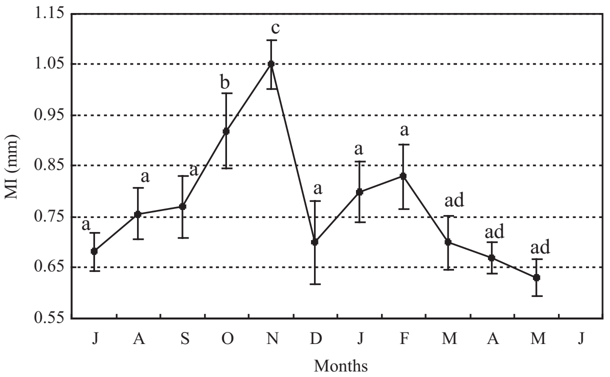

FIG. 1. – Monthly evolution of the marginal increment ($MI = R - R_n / R_n - R_{n-1}$, where R_n and R_{n-1} are the radius of the last and the next-to-last growth rings respectively) of scales of gilthead seabream in Mellah lagoon, Algeria. The different letters indicate significant differences between sampling points.

The GSI increased from October to reach its maximum by December, falling sharply to a minimum in January (Fig. 2). The HSI had a first peak (2.59%) one month before that of the GSI and a second peak (2.69%) in February. A one-way ANOVA

TABLE 1. – Total length (cm) at the appearance of each growth ring in the scales of gilthead seabream from Mellah lagoon, Algeria. Ages I to VII represent the age obtained from direct scale readings. TL1 to TL7 are the backcalculated sizes-at-age.

Age	TL1	TL2	TL3	TL4	TL5	TL6	TL7
I	N = 23 M = 25.48 Sd = 2.78						
II	N = 17 M = 27.21 Sd = 2.25	N = 17 M = 38.82 Sd = 2.68					
III	N = 5 M = 27.72 Sd = 2.00	N = 5 M = 40.72 Sd = 3.43	N = 5 M = 48.26 Sd = 2.92				
IV	N = 4 M = 27.44 Sd = 1.09	N = 4 M = 38.79 Sd = 2.47	N = 4 M = 45.35 Sd = 2.27	N = 4 M = 49.06 Sd = 1.07			
V	N = 3 M = 30.08 Sd = 0.85	N= 3 M = 41.32 Sd = 0.53	N = 3 M = 44.34 Sd = 0.86	N = 3 M = 47.73 Sd = 1.25	N = 3 M = 50.10 Sd = 1.66		
VI	N = 11 M = 25.32 Sd = 4.23	N = 11 M = 37.54 Sd = 2.14	N = 11 M = 44.64 Sd = 2.56	N = 11 M = 48.48 Sd = 1.45	N = 11 M = 51.83 Sd = 2 .15	N = 11 M = 53.35 Sd = 1.52	
Vii	N = 5 M = 26.65 Sd = 1.86	N = 5 M = 37.38 Sd = 1.75	N = 5 M = 44.73 Sd = 1.68	N = 5 M = 47.78 Sd = 0.97	N = 5 M = 51.67 Sd = 1.64	N = 5 M = 52.56 Sd = 1.72	N = 5 M = 54.41 Sd = 1.84
Total	N = 68 M = 26.46 Sd = 2.50	N = 45 M = 38.74 Sd = 2.63	N = 28 M = 45.27 Sd = 2.51	N = 23 M = 48.35 Sd = 1.29	N = 19 M = 51.58 Sd = 1.94	N = 16 M = 53.14 Sd = 1.53	N = 5 M = 54.41 Sd = 1.84

N: number, M: mean, Sd: standard deviation, TL: total length

TABLE 2. – Age-length key for the gilthead seabream in Mellah lagoon, Algeria, sampled between July 1997 and June 1998.

Length interval (cm)	Age (years) 1	2	3	4	5	6	7	Number of fish sampled
19 – 20	2							2
20 - 21	4							4
21 – 22	6							6
22 – 23	7							7
23 – 24	19							19
24 – 25	44							44
25 – 26	44							44
26 – 27	53							53
27 – 28	23							23
28 – 29	4							4
29 – 30	1							1
30 – 31								
31 – 32		1						1
32 – 33		2						2
33 – 34		1						1
34 – 35		2						2
35 – 36		8						8
36 – 37		15						15
37 – 38		8						8
38 – 39		16						16
39 – 40		5	1					6
40 – 41		1	1					2
41 – 42			1					1
42 – 43			1					1
43 – 44			3					3
44 – 45			3					3
45 – 46			1					1
46 – 47			1					1
47 – 48				1				1
48 – 49				2				2
49 – 50				1				1
50 – 51				2				2
51 – 52					2	3		5
52 – 53					1	6	1	8
53 – 54					1	4	1	6
54 – 55					1	3	1	5
55 – 56						5	1	6
56 – 57						1	2	3
57 – 58						3		3
Total samples	207	58	12	6	5	25	6	319
% of number	64.8	18.18	3.76	1.88	1.56	7.83	1.88	
Mean length	25.09	36.93	44.19	50.10	52.40	53.87	54.91	
Stand. deviation	1.75	1.84	2.66	1.05	1.55	1.91	1.51	

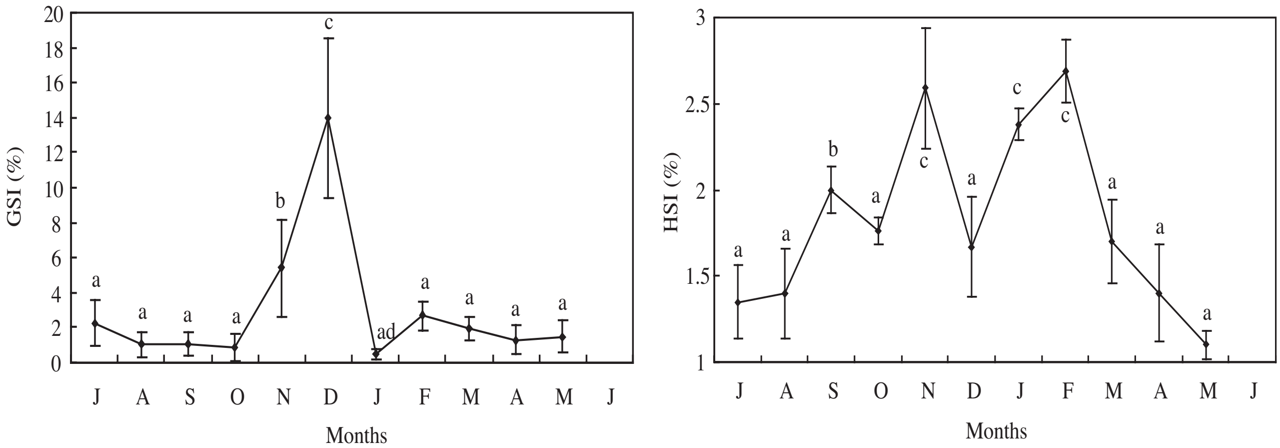

FIG. 2. – Monthly variation of the gonadosomatic index (GSI) and hepatosomatic index (HSI) of gilthead seabream in Mellah lagoon. No separation according to sex was made. The different letters indicate significant differences between sampling points.

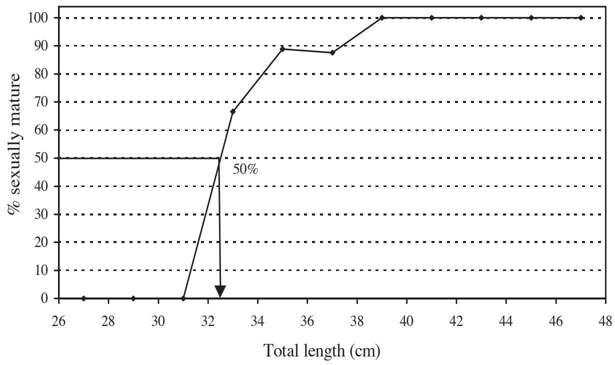

FIG. 3. – Sexual maturity curve of gilthead seabream as a function of total length in Mellah lagoon. The arrow indicates the total length at which 50% of fish were sexually mature. 99 fish were sampled in the months of November and December.

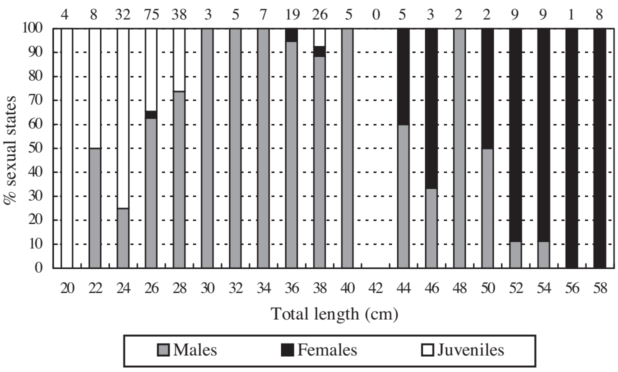

FIG. 4. – Frequency of different sexual states of gilthead seabream in Mellah lagoon as a function of total length. 265 Samples were collected in the months of November and December (see values above).

applied to mean values of GSI indicated their significant heterogeneity (P<0.01). Multiple sample comparisons of means showed that November and December are different from the other months and different between them. In the case of HSI, the difference is also significant (P<0.01). However, November, January and February are not different from each other, but they are different from the other months in the year. Gonad weight was very small in individuals of less than 30 cm. Increasing values, reaching 240 g for 50 cm total length, were obtained from a length of 32 cm. This size corresponds to the length of the smallest ripe individual whose gonad is functional. The size at which 50% of the population reaches maturity is 32.6 cm (Fig. 3).

For a total length less than 20 cm, 100% of the fish were juveniles, which dominate the size classes up to 24 cm (Fig. 4). Males, with a clear dominance of the testes part of the gonad, appeared from 22 cm and dominated until 48 cm. Females were increasingly numerous in the larger size classes, and all fish greater than 56 cm were female.

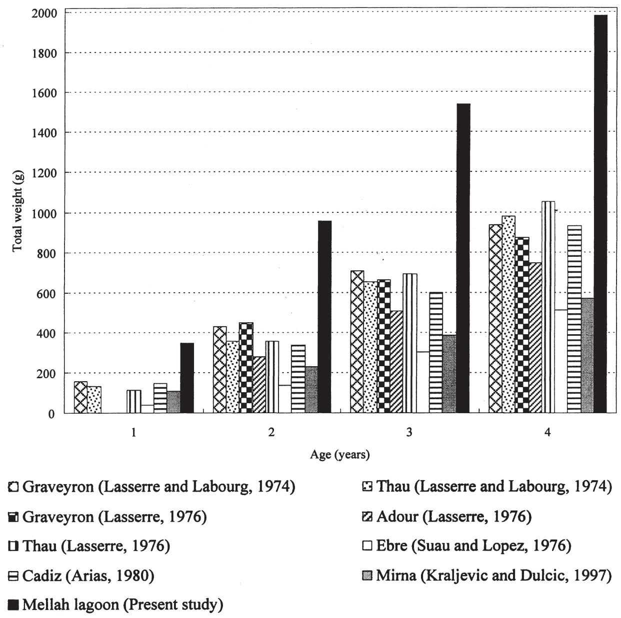

FIG. 5. – Body weight of gilthead seabream as a function of age in different sectors of the Mediterranean Sea and Atlantic Ocean.

DISCUSSION

Scale marginal increment values suggest that only one growth ring is formed in November. This corresponds to the intense gametogenetic activity which starts in October and is completed in December. These months also constitute the period in which the temperatures are lowest, with 14.5°C in November, 12.5°C in December and an annual minimum of 11°C in January. When the water temperature is less than 11.8°C the seabream ceases growing (Kraljević, 1995). However, the energy invested into growing gonads seems to be the main factor responsible for the observed decrease in the somatic growth of gilthead seabream in Mellah lagoon. Temperature appears to affect feeding activity, which ceases completely in January.

About 65% of gilthead seabream belonged to the age group 1^+ year old, 18% to age group 2 years old and 4% to 3 years old. Juvenile individuals of this species are more common in lagoons, as reported by Lasserre (1976) in the Arcachon basin (France) and by Kraljević and Dulčić (1997) in Mirna estuary in the Adriatic Sea. Therefore, this confirms the importance of lagoons as nurseries for seabream.

Compared to other Mediterranean Sea and Atlantic Ocean areas where gilthead seabream are found, Mellah gilthead seabream grow exceptionally fast (Fig. 5) with a growth performance index of

TABLE 3. – Growth parameters (L_∞, K, t_0) and parameters of the weight-length relationship (a, b) of gilthead seabream in different localities (adapted from Kraljević et Dulčić (1997)).

Locality	Age	N	a	b	L_∞	K	t_0	Φ'	Author
Mellah lagoon	1-7	370	0.0129	3.067	55.33	0.513	- 0.282	7.359	Present study
Graveyron (France)	1-4	126	0.0144	3.075	42.29	0.456	- 0.451	6.704	Lasserre and Labourg (1974)
Thau (France)	1-4	713	0.0226	2.886	62.02	0.221	- 0.774	6.745	Lasserre and Labourg (1974)
Segura (Spain)	2-6	135	0.0289	2.907	53.00	0.315	-	6.785	Arnal *et al.* (1976)
Graveyron (France)	2-5	94	0.0541	2.618	53.48	0.264	- 1.340	6.627	Lasserre (1976)
Adour (France)	2-5	79	0.0575	2.590	56.17	0.265	- 0.409	6.729	Lasserre (1976)
Thau (France)	1-4	383	0.0121	3.064	57.66	0.272	- 0.541	6.807	Lasserre (1976)
Ebre (Spain)	1-7	611	$112\ 10^{-7}$*	3.055	62.19	0.171	- 0.531	6.494	Suau and López (1976)
Cádiz (Spain)	1-7	1775	$71\ 10^{-7}$*	3.120	84.55	0.130	- 1.586	6.834	Arias (1980)
South West Portugal		231	$1827\ 10^{-8}$	2.960	-	-	-	-	Gonçalves *et al.* (1997)
Mirna (Croatia)	1-12	314	0.0112	3.052	59.76	0.153	- 1.711	6.303	Kraljević and Dulčić (1997)

* Measurements taken in mm and g (from other authors' measurements taken in cm and g).

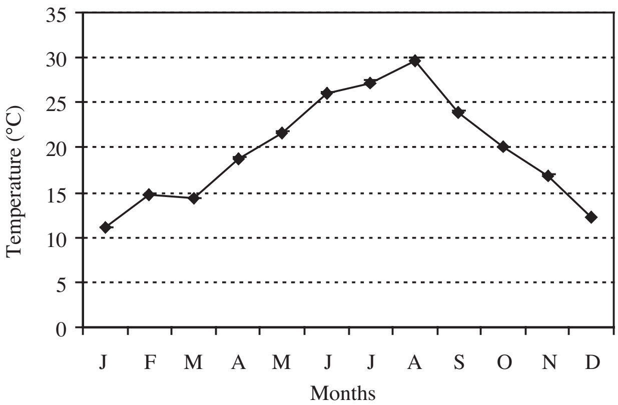

FIG. 6. – Monthly temperature variation in Mellah lagoon during 1998 (Draredja and Kara, 2004).

Φ' = 7.359 (Table 3). It is known that lagoonal environments are highly productive (Sacchi, 1973; Kapetsky, 1984; Labourg *et al.*, 1985), which results in higher growth compared to coastal marine environments (Amanieu, 1973; Chauvet, 1979). In the case of Mellah lagoon, some very favourable thermal conditions partly explain this performance: Temperatures recorded in this area were higher than 15°C during eight months of the year (15-30°C) and did not go lower than 11°C (Fig. 6). They were lower than this value (between 5.5 and 11°C) for at least four months of the year, for example within Thau's pond (France) (Blanchet-Besseon, 1986), where the growth performance was clearly lower (Lasserre and Labourg, 1974; Lasserre, 1976) than that recorded in Mellah lagoon.

The allometry coefficient of the length-weight relationship (b = 3.067) indicates isometric growth. This value is equal to the one recorded in the Arcachon basin, France (Lasserre and Labourg, 1974), in Thau's pond, France (Lasserre, 1976) and in the Ebre, Spain (Suau and Lopez, 1976) and Mirna (Croatia) estuaries (Kraljevic and Dulčić, 1997).

According to the variation in GSI, maturation and reproduction takes place in Mellah lagoon between October and January, with gonad maturation between October and December and spawning during December. Reproduction takes place in the same period in the northern Mediterranean Sea (Lasserre, 1976) and in the Atlantic Ocean (Arias, 1980). HSI increased from August in response to the intensification of dietary activity resulting in an active hepatic metabolism. The first maximal HSI value precedes that of GSI, which indicates an energetic transfer to the gonads. Indeed, fishes which decrease their food intake during gonadal maturation use nutrients originating from endogenous reserves in muscle, adipose tissue and liver (Lal and Singh, 1987; Nassour and Leger, 1989; Matin *et al.*, 1993). During breeding, despite the fact that gilthead seabream females continue feeding during the spawning season, they probably use their liver reserve during the gonadal maturation process (Almansa *et al.*, 2001). The success of reproduction of gilthead seabream in Mellah lagoon could be the result of salinity conditions that are favourable for the osmotic requirements of gametogenesis. Indeed, the increase in salinity of this medium is perceptible with a value of about 35‰ during gonad maturation (October to December) and a yearly mean value of 29.6‰ (Draredja and Kara, 2004).

First sexual maturity was reached at 32.6 cm, at an average age of 18 months. Arias (1980) indicated that between size classes 30 to 32 cm and 34 to 36 cm, 82.2% of males were spermiating. Bi-modal distribution of size frequencies according to the different sexual states (males, females, juveniles), with males occupying the smallest sizes and a sex-ratio in their favour, confirm the protandric hermaphroditism (Sadovy and Shapiro, 1987; Yeung and Chan, 1987), with a sexual inversion that takes place essentially from size class 43 to 45 cm. Zohar *et al.* (1984) came to the same conclusion about first maturity of gilthead seabream in cultivation. He found first maturity to take place at 1 year, but detected 30 to 40% of sex inversions at the end of the second year (Zohar *et al.*, 1978). The sex change of *S. aurata* generally takes place 1 year after the first male activity (D'Ancona, 1941; Lasserre, 1976), but D'Ancona (1941) and Bruslé-Sicard and Fourcault (1997) emphasised the possibility of a later sex inversion. Our results support this hypothesis since only 40% of the field specimens studied changed sex at 2^+ years. Bruslé-Sicard and Fourcault (1997) suggested histocytological criteria that allow the functional sex during the subsequent maturation to be determined. However, sex change may not only be related to individual determinism but could depend on the environmental and social conditions (Happe and Zohar, 1988). This successive hermaphroditism type is different from the one observed in the *Diplodus* species from South African coasts (Mann and Buxton, 1998). The latter are characterised by rudimentary hermaphroditism, with males and females developing before sexual maturation from an immature bisexual gonad.

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