

Age and growth of the sand smelt, *Atherina boyeri* (Risso 1810), in the Mar Menor coastal lagoon (SE Iberian Peninsula)

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Summary

The age and growth of sand smelt, *Atherina boyeri* (Risso 1810), in the Mar Menor (SE Iberian Peninsula) were studied in samples taken from catches of local fishermen obtained between November 1997 and September 1998. The maximum lengths were 94 mm (FL, fork length) in females and 87 mm (FL) in males. Age determination based on scale readings and validated by length frequency analysis shows that the population has a 3-year life cycle. Females were significantly longer than males in each of the age classes. Both sexes of the sand smelt grow allometrically ($b = 3.113$ males; $b = 3.043$ females) and attain approximately 56.2% of their maximum fork length in their immature first year, after which the annual growth rate drops quickly. The highest growth rate was observed from winter to spring ($G_L = 16.01$ males 1+; $G_L = 11.25$ males 2+; $G_L = 17.18$ females 1+; $G_L = 9.62$ females 2+). The condition cycles were similar for both sexes, with a minimum in June–July and two maximums in April and November.

Introduction

The sand smelt, *Atherina boyeri* (Risso 1810), is a small, short-lived, euryhaline atherinid fish which mainly inhabits coastal and estuarine waters, including coastal lagoons, salt marshes and, more rarely, inland waters, over a wide range of salinities from freshwater to hypersaline conditions (110% maximum recorded) (Henderson and Bamber, 1987). Morphologically, it displays several important characters that change in relation to habitat while also being capable of adjusting to wide ranges of environmental conditions (Kiener and Spillmann, 1972, 1973; Tortonesi, 1975). It is common in the Mediterranean and adjacent seas, and is also found in the north-east Atlantic from the Azores to the north-west coast of Scotland (Kiener and Spillmann, 1969; Quignard and Pras, 1986).

Sand smelt fisheries are among the most important on the Spanish Mediterranean coast and represent one of the main fishing resources, along with *Sparus aurata* and species of Mugilidae, in the Mar Menor coastal lagoon (Guevara and Sautier-Casaseca, 1977; Lozano-Cabo, 1979). However, there is no information about the biology of the species applicable to the Spanish Mediterranean coast, and only one work describes some aspects of its life history in the delta of the River Ebro (Sostoa, 1983). In this study, we provide basic information about some biological parameters of sand smelt, including age and growth, for the largest coastal lagoon of this area, which, we hope, will be of use in its management.

Study area

The present study was carried out in the Mar Menor, a saline coastal lagoon located in a semiarid region on the south-eastern coast of the Iberian Peninsula (37°38'N, 0°42'W). Its size (135 km²) and maximum depth (over 6 m) are among the greatest in the Mediterranean (Perez-Ruzafa et al., 1987), and its bottom is covered in part by dense mixed meadows of *Caulerpa prolifera* and *Cymodocea nodosa*. Consequently, the lagoon shows a high degree of habitat diversity and a wide variety of biological assemblages. Its water embayment is approximately 0.58 km³ (Arevalo, 1988) with an estimated residence time between 0.55 and 1.2 years (Perez-Ruzafa, 1989). It is separated from the Mediterranean Sea by a sand bar (21 km long and 100–1500 m wide) with several narrow channels connecting it with the open sea. Several temporal streams flow into the lagoon, which drains a large intensive agricultural area, leading to a substantial input of agrochemicals (via run-off). Due to the regional geomorphology, climatic conditions and hydrological features (evaporation largely exceeds rainfall and run-off), the lagoon acts as a reception basin (Perez-Ruzafa et al., 1987, 1989; Gilabert, 2001). The lagoon shows a salinity range of 39–45‰ and from a morphological and hydrodynamic point of view, *sensu* Kjerfve (1994), it can be classified as a choked lagoon with restricted circulation and long flushing times.

Finally, the Mar Menor coastal lagoon supports important fisheries and is subject to intensive tourist development.

Material and methods

The fish examined ($n = 1936$) were collected weekly from commercial catches taken between November 1997 and September 1998. The fishing gear (*chirretera*) used by the fishermen was a type of fyke-net (11 mm mesh size, 100 m length). The specimens were preserved in neutralized formaldehyde solution (7%) and transported to the laboratory, where their fork length (FL; ± 0.1 mm), standard length (SL; ± 0.1 mm) and total weight (TW; ± 0.1 g) were recorded. All specimens were dissected to obtain eviscerated weight (SW; ± 0.1 g) and to determine their sex by direct observation of the gonads.

Age was determined by two methods, one based on fish scales and the other on length–frequency distributions. For the former, between 8 and 10 scales from the left flank below the first radius of the dorsal fin and above the lateral line were removed from all specimens. These were cleaned using 8% NaOH and placed on two slides for age determination. The modal distributions of length–frequency data were studied

separately over a short period of time (monthly and seasonal periods), to reduce the effects of seasonal growth (Rosenberg and Beddington, 1988). Such methods involving length–frequency distribution and/or modal progression can provide useful estimates of relative age and average growth of fish (Weatherley and Gill, 1987). Age validation was attempted using a length–frequency-based method available in the FiSAT (2000) software (FAO ICLARM Stock Assessment Tools). Size groups which represent age classes in the length–frequency seasonal samples were identified by the method described by Bhattacharya (1967) and contrasted with scale reading data. This was followed by application of modal class progression analysis, where the value of separation index (I_S) must be > 2 to provide meaningfully separated groups (Gayanilo et al., 1988).

The von Bertalanffy growth equation was fitted to all length-at-age data in each age class, separately for males and females, using the method of Ford-Walford (Everhart and Youngs, 1975). The form of the growth curve is (Beverton and Holt, 1957):

$$L_t = L_\infty [1 - e^{-K(t-t_0)}],$$

where L_t is the total length of fish at time t , L_∞ is the asymptotic total length to which fish tend to grow, K is the growth coefficient and t_0 is the hypothetical time when the fish total length is zero.

Over a defined period of time, the specific growth rate (g) (Wootton, 1998) was calculated as:

$$g_L = (\text{Log}_e \text{FL}_f \cdot \text{FL}_i^{-1}) t^{-1}$$

and

$$g_W = (\text{Log}_e \text{SW}_f \cdot \text{SW}_i^{-1}) t^{-1},$$

where FL_f and SW_f are final FL and final SW, respectively, FL_i and SW_i are initial FL and initial SW, and t is the time interval. Frequently, this is expressed as percentage per unit time, i.e. $G_L = 100 \times g_L$ and $G_W = 100 \times g_W$. The relationship between length (FL, SL) and weight (TW, SW) was calculated for all specimens, and for males and females separately. The existence of significant differences between relationships was verified by analysis of covariances (ANCOVA) (Sokal and Rohlf, 1981).

The somatic condition (K_R) was analysed by residuals from the SL–SW relationships (log transformed data), thus removing body length effects (Sutton et al., 2000). To avoid negative values, the variables were previously multiplied by 10^4 , a procedure considered suitable when variables range from 0 to 1 (Garcia-Berthou and Moreno-Amich, 1993). The somatic condition cycle was indexed by residuals from these regressions.

Statistical analyses were performed with SPSS® (SPSS, Chicago, IL, USA) software package and a significant level of 0.05 was accepted.

Results

Age and growth

Due to the frequent occurrence of numerous false *annuli* in the sand smelt (Kiener and Spillmann, 1969; Berrebi, 1978; Hervé, 1978; Fernandez-Delgado, 1987) and because the *annuli* take several months to form (Fernandez-Delgado et al., 1988; Leonardos, 2001), it was difficult to determine age classes for all specimens. However, using the visualization method

recommended by Marfin (1981), the number of suitable specimens for age class determination was 1117 (57.7% of total n ; 519 = 60.6% n males; 598 = 55.4% n females) (Table 1).

When age was determined by scales, three age groups (1+, 2+ and 3+) were identified in both sexes of the population under consideration (Table 1). Maximum lengths observed were 94 mm (FL) in females and 87 mm (FL) in males, both in their fourth year of life (3+). The lower size catches, which were imposed by the sampling gear used, were 42 mm (FL) in females and 39 mm (FL) in males. Females were significantly longer than males in each of the age classes and in the specimens as a whole (two-way ANOVA) (Table 2).

When the method of Bhattacharya (1967) was applied to all captured specimens, whether alone or followed by the modal class progression analysis using the length–frequency seasonal samples, two probable cohorts (in females and males) were identified, with significant separation indices. Probably due to the high degree of overlapping between modes corresponding to the 2+ and 3+ age classes, length–frequency methods indicated one cohort fewer for each sex compared with the scales method. However, to verify the similarity between the length–frequency distribution found for specimens captured as a whole and for specimens used for scale reading (Table 1), we applied chi-squared test with the void hypothesis of non-variation in the proportions of every class of length. No significant differences were found in any of the cases (total: $\chi^2 = 376.9$, d.f. = 1115, $P > 0.05$; males: $\chi^2 = 141.5$, d.f. = 517, $P > 0.05$; females: $\chi^2 = 245.7$, d.f. = 597, $P > 0.05$).

Due to the impossibility of differentiating the 2+ and 3+ age-classes by length–frequency methods, modal progression was examined in monthly and seasonal samples (sexes separately) in the individuals with valid scale reading. According to Pauly (1983, 1984), repetition of the same temporal series of the length–frequency distributions can provide a better visualization of the progression of the modes corresponding to each of the cohorts (Fig. 1). In the present analysis, the beginning of modal progression is in the spring because the *A. boyeri* population in the area under consideration forms the *annulus* in this season.

Von Bertalanffy equation for the theoretical growth of sand smelt in length was: $L_t = 81.90[1 - e^{-0.91(t + 0.45)}]$ for males, and $L_t = 84.58[1 - e^{-0.81(t + 0.61)}]$ for females.

The seasonal growth rate was determined using mean length (FL) increments of the different cohorts (age classes) caught during the study period and extrapolating to eviscerated weight using FL–SW relationships (Table 3). As we analysed a double temporal series, it was possible to show not only the growth rates of every cohort up to the last season of sampling (autumn 1998) but also the hypothetical growth rates of each cohort by extrapolating to a similar growth pattern in consecutive years. The seasonal growth rates of the 3+ cohort are not shown (Table 3) as no significant differences existed between them.

There was little difference in the growth rates between seasons, although the highest growth rate was observed in winter–spring. No age class reflected growth in the spring–summer period, which represented the reproductive period in the area under consideration (unpublished data). The 1+ age-class showed a long growth period (about 9 months), with only the short non-growing period reactivating its growth after summer. Seasonal growth rates tended to decrease with age (Table 3).

There was an evident decrease in annual growth rates with age: the 1+ age class showed $G_L = 30\%$ ($G_W = 98\%$) in

Table 1
Length–frequency distribution of suitable specimens used for scale reading of *Atherina boyeri* in the Mar Menor coastal lagoon (FL = fork length, n = no. of fishes)

FL (mm)	Age-classes								
	Total			Males			Females		
	1+	2+	3+	1+	2+	3+	1+	2+	3+
40	2			2			0		
42	4			4			0		
44	19			17			2		
46	38			32			6		
48	50			37			13		
50	60			37			23		
52	94			54			40		
54	93			42			51		
56	69			40			29		
58	58			28			30		
60	56			28			28		
62	26	1		10			16	1	
64	25	3		13	2		12	1	
66	24	16		15	5		9	11	
68	4	25		2	12		2	13	
70	5	53	1	1	31		4	22	1
72	4	65	2	3	31	1	1	34	1
74		57	4		16	4		41	0
76		50	42		11	15		39	27
78		4	48		0	4		4	44
80		2	47		1	12		1	35
82			24			4			20
84			22			2			20
86			9			2			7
88			7			1			6
90			3			0			3
92			0			0			0
94			1			0			1
n	631	276	210	365	109	45	266	167	165
%	56.49	24.71	18.80	70.33	21.00	8.67	44.48	27.93	27.59

Table 2
Comparison of fish length between sexes obtained from scales

Age class	n	Females FL (mm)	n	Males FL (mm)	F	d.f.	P
1+	266	55.38 ± 0.65	365	53.17 ± 0.64	22.07	1, 629	< 0.0005
2+	167	72.04 ± 0.50	109	70.79 ± 0.53	10.63	1, 274	0.001
3+	165	79.72 ± 0.58	45	78.09 ± 1.05	6.82	1, 208	0.010
Total	598	66.75 ± 0.92	519	59.03 ± 0.93	133.97	1, 1115	< 0.0005

n = no. of fishes; FL = mean FL of each age class, ± 95% confidence limit; P < 0.05, significant differences, ANOVA-test.

males and $G_L = 27\%$ ($G_W = 88\%$) in females, the 2+ age class showed $G_L = 11\%$ ($G_W = 35\%$) in males and $G_L = 8\%$ ($G_W = 26\%$) in females, while the 3+ age class did not show a significant annual growth rate.

Length–weight relationship

The relationships between SL (mm) and SW (g) (dependent variable) showed the best fit between length and weight (regression analysis, P < 0.05):

Total specimens: $SW = 7.2910^{-6}SL^{3.07}; r^2 = 0.97; F(1, 1934) = 71393.6$
 $TW = 3.0410^{-6}FL^{3.26}; r^2 = 0.97; F(1, 1934) = 63815.4$
Males: $SW = 6.2510^{-6}SL^{3.11}; r^2 = 0.97; F(1, 855) = 28442.9$
 $TW = 3.5610^{-6}FL^{3.22}; r^2 = 0.97; F(1, 855) = 29069.9$
Females: $SW = 8.2910^{-6}SL^{3.04}; r^2 = 0.97; F(1, 1078) = 32966.5$
 $TW = 3.3010^{-6}FL^{3.25}; r^2 = 0.96; F(1, 1078) = 26674.5$

There were significant differences between males and females (ANCOVA, $F(1, 1934) = 7.99$, P = 0.005 in the slope), but no differences were obtained with time in these relationships for either sex using season as a factor (males: ANCOVA, $F(3, 855) = 1.750$, P = 0.153 in the slope; females: ANCOVA, $F(3, 1078) = 2.034$, P = 0.106 in the slope).

We obtained significant differences between the b exponent and 3 for isometric growth both in the specimens as a whole and in the sexes separately (total: $t = 6.17$, d.f. = 1932, P < 0.0005; males: $t = 6.27$, d.f. = 854, P < 0.0005; females: $t = 2.53$, d.f. = 1078, P = 0.046). Moreover, because there was a significant difference in the b exponent between males and females ($t = -4.12$, d.f. = 1078, P < 0.0005), females were nearer the isometric growth than males.

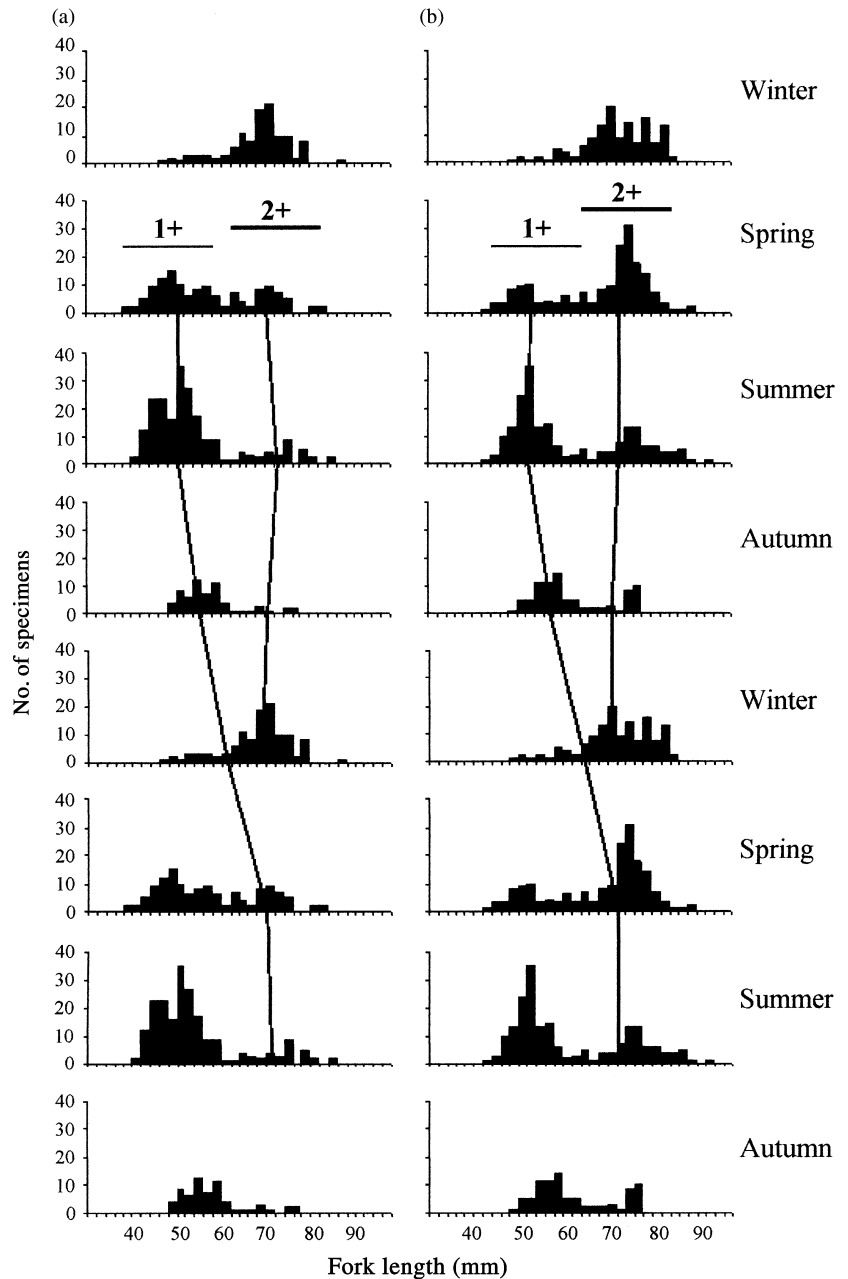


Fig. 1. Length–frequency modal progression of males (a) and females (b) of *Atherina boyeri*, with a valid reading of scales ($N_E = 1117$), caught seasonally in the Mar Menor. The medians of males and females (year classes 1+ and 2+) are joined with lines

Somatic condition

Significant changes were obtained in the temporal variation of somatic condition (Kruskal–Wallis test; males: $H = 128.77$, d.f. = 32, $P < 0.0005$; females: $H = 256.82$, d.f. = 32, $P < 0.0005$) and a similar cycle was evident in both sexes (Pearson's correlation, $r = 0.714$, $P < 0.01$) (Fig. 2). In fact, three phases could be identified in the condition cycle in both sexes: although there were variations between samplings, the first phase (phase I) takes place from autumn to spring, when the residuals (K_R) showed high values, reaching a maximum at the beginning of April (females $K_R = 0.90 \pm 0.28$, males $K_R = 0.70 \pm 0.40$) and another maximum in November (females $K_R = 0.97 \pm 0.28$, males $K_R = 0.90 \pm 0.19$); in the second phase (phase II), from the middle of spring to the beginning of summer, which coincides with the spawning period in the area under consideration (unpublished data), K_R decreased to reach a minimum at the end of June (females $K_R = -0.77 \pm 0.32$, males $K_R = -0.70 \pm 0.25$); finally, in

the third phase (phase III), during summer, sand smelt gradually recover their condition.

A comparison of fish condition between sexes in each of the differentiated phases pointed to significant differences. Females presented significantly higher residual values during phase I (female $K_R = 0.45 \pm 0.10$, male $K_R = 0.23 \pm 0.10$; ANOVA, $F(1, 542) = 8.35$, $P = 0.004$). During phase II, there were no significant differences in condition between the sexes (ANOVA, $F(1, 690) = 3.33$, $P = 0.068$). Finally, during phase III, the males showed a greater ability to recover their condition (female $K_R = -0.31 \pm 0.53$, male $K_R = -0.01 \pm 0.11$; ANOVA, $F(1, 855) = 10.94$, $P = 0.001$).

Discussion

The lifespan of the *A. boyeri* population in the Mar Menor coastal lagoon was short, with only four age groups being evident (maximum age-class: 3+). This is in agreement with

Table 3

Seasonal growth rates in length (G_L) and weight (G_W) of the different cohorts established for the males and females of *Atherina boyeri* in the Mar Menor coastal lagoon. Only growth rates with significant differences ($P < 0.05$, t -test) between seasons in the same cohort and between cohorts are presented (*theoretical rates, see text)

Cohort	Spring– summer	Summer– autumn	Autumn– winter*	Winter– spring
G_L (%)				
Males				
1+	–	8.53	7.66	16.01
2+	–	–	–	11.25
3+	–	–	–	–
Females				
1+	–	7.51	6.18	17.18
2+	–	–	–	9.62
3+	–	–	–	–
G_W (%)				
Males				
1+	–	27.72	24.89	51.99
2+	–	–	–	36.55
3+	–	–	–	–
Females				
1+	–	23.87	19.66	54.63
2+	–	–	–	30.60
3+	–	–	–	–

the general pattern observed in most other *A. boyeri* populations previously studied throughout their distribution range (Table 4). Although in the present study we did not catch any 0+ specimens, their high abundance in the lagoon has been confirmed (unpublished data).

An annulus formation in the stock under consideration took place in spring (about 3 months), which closely reflects the

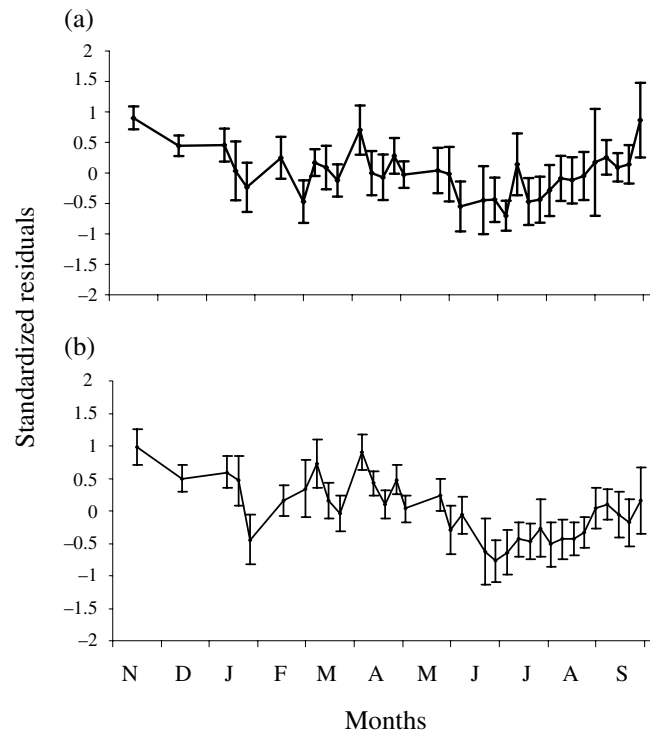


Fig. 2. Temporal pattern in somatic condition for (a) males and (b) females of the *Atherina boyeri* population located in the Mar Menor. Mean \pm 95% CL of SL–SW relationship of standardized residuals

findings of Marfin (1981), Sostoa (1983) and Fernandez-Delgado et al. (1988), although the latter author observed a longer formation period (4–5 months). Palmer and Culley (1983) mentioned winter as the season of annuli formation

Table 4

Maximum age of *Atherina boyeri* in this study and in studies by other authors

Locality	Habitat	Tidal effect	Age	References
Prevost Lagoon (France)	Coastal Lagoon	No	2+	Kohler (1976)
Arcachon Bay (France)	Mainland Coast (Bay)	Yes	2+	Castel et al. (1977)
Aral Sea	Inland Sea	No	2+	Markevich (1977)
Langstone Harbour (England)	Mainland Coast (Salt-marsh)	Yes	3+	Palmer (1979)
Fawley (England)	Mainland Coast (Salt-marsh)	Yes	3+	Turnpenny et al. (1981)
Salses-Leucate Lagoon (France)	Coastal Lagoon	No	3+	Marfin (1981)
Canet-Saint-Nazaire Lagoon (France)	Coastal Lagoon	No	2+	Marfin (1981)
Estuary of the Bourdigou (France)	Estuary	No	2+	Marfin (1981)
Zoñar Lagoon (Spain)	Freshwater Lagoon	No	2+	Fernandez-Delgado and Hernando (1982)
Ebro River Delta (Spain)	Delta	No	3+ (f) 2+ (m)	Sostoa (1983)
Oldbury-upon-Severn (England)	Estuary	Yes	2+	Palmer and Culley (1983)
Bardawil Lagoon (Egypt)	Coastal Lagoon	No	1+	Gon and Ben-Tuvia (1983)
Po River Delta (Italy)	Delta	No	2+	Ferrari and Rossi (1984); Mistri and Colombo (1988)
The Fleet, Dorset (England)	Mainland Coast (Salt-marsh)	Yes	3+	Henderson and Bamber (1986)
Black and Caspian Seas	Inland Sea	No	4+	Henderson and Bamber (1987)
Trasimeno Lake (Italy)	Freshwater Lake	No	2+	Mistri and Colombo (1988)
Ionian Sea (Italy)	Mainland Coast (Gulf)	No	2+	Mistri and Colombo (1988)
Estuary of the Guadalquivir (Spain)	Estuary	Yes	2+	Fernandez-Delgado et al. (1988)
Vaccares Lagoon (France)	Coastal Lagoon	No	4+	Rosecchi and Crivelli (1992, 1995)
Trichonis Lake (Greece)	Inland Lake	No	4+	Economou et al. (1994) Leonardos (2001)
Mesolongi Lagoon (Greece)	Coastal Lagoon	No	3+	Leonardos and Sinis (2000)
Etolikon Lagoon (Greece)	Coastal Lagoon	No	3+	Leonardos and Sinis (2000)
Mar Menor (Spain)	Coastal Lagoon	No	3+ (f) 3+ (m)	Present study

period, although, both differences in latitude and the thermal pollution which affected the habitat under consideration could have had an important effect (Schrieken and Swennen, 1969; Velde and Polderman, 1976; Palmer et al., 1979; Turnpenny et al., 1981).

The largest *A. boyeri* taken in other areas were usually in the 63–190-mm (SL) range: in the Bardawil Lagoon (Gon and Ben-Tuvia, 1983) and Scilly Isles (Henderson and Bamber, 1987). In the stock under consideration, the largest individuals were 87 and 94 mm (FL) for males and females, respectively. However, larger fish [up to 111 mm (FL)] were caught in the study area by Lozano-Cabo (1979). Henderson and Bamber (1987) showed that *A. boyeri* can adapt its life history and morphology to environmental conditions with a trend to reduced growth and hence length-at-age along an oceanic-coastal-estuarine-freshwater habitat range. This trend is not clearly seen in Spanish populations because no decrease in maximum length has been recorded between coastal or estuarine populations (Sostoa, 1983; Fernandez-Delgado et al., 1988 and present study) and freshwater populations (Fernandez-Delgado and Hernando, 1982). Nevertheless, the latter mentioned populations can be regarded as having an introduced status with a possibly marine or estuarine origin (Fernandez-Delgado, 1987), which may mask any such trend.

Sand smelt grow rapidly during the first year of life, attaining approximately 56.2% of their maximum FL. After the first year, the annual growth rate drops rapidly, which is related to sexual maturity, as in the area under consideration individuals mature at the beginning of the second year of life (1+) (unpublished data). Hence, energy is diverted to reproduction, with less energy available for somatic growth (Reznick, 1985). After maturity, the decrease in annual growth observed with longevity was also observed in the pattern of seasonal growth. Thus, the 1+ age class reinitiated growth after summer, reaching its maximum rate between winter and the spring, the 2+ age class only showed growth between winter and spring and, finally, the 3+ age class did not manifest any growth, probably because of a high natural mortality rate and/or migration of the most long-lived individuals from the lagoon.

The non-growing period detected in all age classes (1+, 2+ and 3+) in males and females includes the peak spawning period (unpublished data). Reproductive stress is probably responsible for this cessation of growth between spring and summer (Henderson and Bamber, 1987; Fernandez-Delgado et al., 1988). In the same period, the somatic condition of population under consideration reached a minimum, and then (when reproduction had finished) increased. As already mentioned, this suggests the existence of a trade-off between the energy devoted to reproduction and that devoted to maintenance or growth (Herrera and Fernandez-Delgado, 1994).

Estimates of von Bertalanffy growth parameters indicated that females reach a larger asymptotic size than males. The values of L_{∞} (81.90 mm FL for males and 84.58 mm FL for females) which are lower than the maximum FL should be accepted considering that both few and scattered males and females longer than these asymptotic sizes were caught (Rojas et al., 1993; Megalofonou, 2000) (Table 1).

The somatic condition cycle of the population under consideration is similar to that found by other authors (Marfin, 1982; Fernandez-Delgado et al., 1988), with two periods of maximum values, one in spring when gonads mature, and the other in autumn, which is essential for winter survival. Females showed higher values to males just before the reproductive

period. Subsequently, during the reproductive period the somatic condition falls more sharply in females to reach values similar to those of the males. Finally, in the post-reproductive period, the males show a major recovery of condition which, as suggested previously, might indicate the lower energetic cost of males during reproduction (Rodriguez-Ruiz, 1992).

In conclusion, the age and growth traits of *A. boyeri* in the population under consideration point to a low number of age groups, a high growth rate during the first years of life and a clear decrease in the growth rate with longevity, a short lifespan and seasonal variations in the somatic condition. These life-history tactics are common in productive and/or unstable environments (Stearns, 1976; Mann et al., 1984; Mills, 1987) and do not differ much from those of the other Iberian populations of the species.

Acknowledgements

The authors are very grateful to Leandro Bermudez (Headquarter of Agrarian Production and Fishing of the Council of Agriculture, Water and Environment from the Autonomous Government of Murcia), Julio Mas and Iñaki Franco (both from the Spanish Institute of Oceanography, Region of Murcia) and Andres Escudero (Fishermen's Confraternity of San Pedro of the Pinatar). We also thank all fishermen of the Mar Menor for their assistance in fieldwork. Many thanks to Philip Thomas for the English translation and revision of the manuscript.

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