

Reproductive aspects of the European anchovy (*Engraulis encrasicolus*): six years of observations in the Strait of Sicily.

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Abstract

Several aspects of anchovy reproductive biology were assessed over a six-year period from commercial landing data from the main spawning ground of the anchovy population off the southern coast of Sicily. This work represents the first attempt to investigate the reproductive features of the anchovy population in this area. The intra-annual and interannual evolution of the gonosomatic index, condition factor, size at first maturity, sex ratio and length–weight relationships were assessed. Monthly gonosomatic index values and corresponding maturity stages show that the spawning season extends from late-March/early-April to August–September, though most of the spawning occurs in July–August. Size at first maturity is reached at 11.27 ± 0.09 cm for males and 11.24 ± 0.09 cm for females. Annual sex ratio differs statistically from the expected 1:1 ratio and shows the predominance of females. Monthly sex ratio values show the same trend, except that, in the spawning period, the females significantly outnumber the males. The sex ratio relative to body size underlines the decreasing number of males with increasing size above 12.0 cm length. Condition status reaches its highest value at the beginning and during the first part of the spawning period, in June, decreasing in August during the peak spawning.

Keywords: reproduction, anchovy, size at first maturity, condition factor, sex ratio, Strait of Sicily, central Mediterranean.

1. Introduction

The purse-seine fishery target species in the study area (hatched in Figure. 1) are small pelagic fishes, mainly anchovies and sardines. The value of the local production is relatively high, as a consequence of the high demand for these resources for direct consumption. The small-pelagic-species production is characterized by high interannual fluctuations that appear to be unrelated to the level of fishing effort. On the contrary, there is strong evidence that yearly production is connected to the success of reproduction, which in turn can be related to the direct or indirect effect of favourable environmental conditions (i.e. the availability of food, as determined by the timing of phytoplanktonic and zooplanktonic blooms). The anchovy resource in this area, according to previous acoustic and DEPM estimates (Azzali *et al.*, 1988; Mazzola *et al.*, 2000, 2002), may represent as much as 15% of the total Italian anchovy biomass estimates. From a socio-economic point of view, the anchovy stock of the Strait of Sicily is a relevant resource, historically exploited by fishermen from the north-western and southern coasts of Sicily. It supports several tens of thousands of families, which are exploiting these resources. In spite of the relevant economic and social impact of small-pelagic fishery resources in the study area, only two recent consecutive studies, funded by the European Commission, were carried out during 1997–2000 on biomass estimation and the

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ecology of the anchovy (Mazzola *et al.*, 2000, 2002). A great deal of information on the anchovy population is lacking, in particular concerning its biological features. Therefore, the present paper is focused on anchovy reproduction, particularly the spawning season, condition factor, size at first maturity, sex ratio and their variability over the six-year study period.

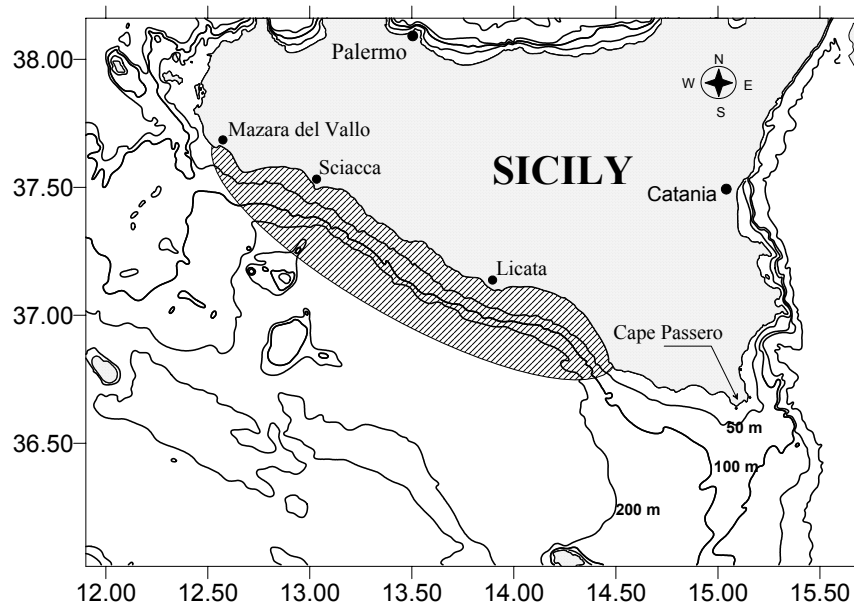


Figure 1. Map of Sicily with the study area (hatched); the 50-m, 100-m and 200-m isobaths are indicated.

2. Methods

The data were from the purse-seine and mid-water pelagic-trawl commercial catches, landed in Sciacca, the most representative port in the study area. For six years (1997–2002) at fortnightly intervals, 106 samples comprising 84,581 specimens were sexed and analysed. The total body length (TL) was recorded to the nearest millimetre and the total body weight, to the nearest gram. It was possible to determine the maturity stage of 64,019 specimens. Gonad weights (GW) were measured to an accuracy of 0.01 g. The sex was determined macroscopically and maturity stages were assigned according to the five-level maturity scale for partial spawners described by Holden and Raitt (1975). The spawning period was determined by evaluating the gonado-somatic index (GSI) and the monthly percentage of mature specimens. Length at first maturity (L_{50}) was computed from the percentage of mature individuals (stages III, IV and V) occurring over the reproductive period. The total length at which 50% of the specimens were mature was estimated by a method based on a logistic non-linear regression model (Hunter *et al.*, 1992; Roa *et al.*, 1999). Formally we have:

$$P(l\%) = \frac{\alpha}{1 + e^{\beta_0 + \beta_1 l}} \quad (1)$$

where $P(l)$ is the proportion of mature at size l , α is the asymptote, β_0 the intercept and β_1 the slope of the logistic regression curve. In order to estimate the confidence limits (c.l.), the procedure recommended by Roa *et al.* (1999) was followed.

Length–weight relationships were computed for males and females and combined sexes on an annual basis by means of the equation:

$$TW = aTL^b \quad (2)$$

where a and b are the slope and intercept of the regression line fitted to the log-transformed data by the least-squares method (Sparre *et al.*, 1989). The combined sexes data included males, females and immature specimens, in order to cover the widest size range possible.

The GSI was calculated on a monthly and a seasonal basis. The corresponding equation was:

$$GSI = \frac{GW}{TW} \quad (3)$$

where GW is the gonad weight and TW is the total weight (Bougis, 1952).

The condition status was investigated on a monthly and a seasonal basis by the condition factor based on the following equation:

$$CF = \frac{TW}{aTL^b} \quad (4)$$

where a and b are the regression parameters of the length–weight relationship estimated for each year, and TL is the total length in centimetres (Le Cren, 1951). The choice of equation for the estimation of CF was based on literature data, which indicated the greater suitability of Le Cren's (1951) equation over Fulton's index (Fulton, 1911 in Tomasini *et al.*, 1989) since the former relates more consistently with size, while that of Fulton increases considerably with larger size (see Giraldez and Abad, 1995; Millan, 1999).

To complete the picture of the reproductive aspects, the sex ratio, expressed as the ratio of the number of males to the number of females in a given sample, was investigated in terms of its intra-annual, interannual and length-class variability.

The significant differences from the expected ratio (1:1) were tested by means of a χ^2 test (Sokal and Rohlf, 1987).

3. Results

Length at first maturity. The estimates of this parameter over six years are shown in Table 1, on an annual basis for males, females and total. Mature specimens were detected starting at 9.4 cm (females and males), whereas complete maturity is reached at 13.5 cm. The analysis of data for the whole period gives values of L_{50} 11.27 cm \pm 0.09 for males and 11.24 cm \pm 0.09 for females (Figure. 2)

Length–weight relationship. The coefficients obtained from regression analysis for each sex and combined, yearly and over the whole period, are given in Table 2. The variations in the allometric parameter (b) between years, suggests differences in the weight of the population, with the highest weight values reached in 2000 and the lowest, in 1997. These differences were tested by analysis of covariance (ANCOVA) taking "length" (log-transformed) as the

covariable and "year" as the factor. Results confirm the statistical significance of the differences ($F_{4, 84574}=1512, p<0.000$).

Table 1. Annual estimates of length at first (L_{50}) and full (L_{95}) maturity, and maturation range (L_{25-75}), total and as function of sex over the period 1997–2002. The 95% confidence limits for the L_{50} estimations (c.l.) are also listed; n number of specimens.

	Males				
Years	L_{25-75}	L_{95}	L_{50}	c.l.	n
1997	9.7–12.6	15.11	11.19	11.02–11.33	4,511
1998	10.3–12.1	13.65	11.18	11.10–11.25	4,485
1999	10.7–11.9	13	11.30	11.24–11.36	4,061
2000	10.5–12.2	13.7	11.34	11.24–11.41	4,157
2001	8.6–14.3	19	11.42	11.13–11.62	3,103
2002	11.0–12.2	13.3	11.64	11.55–11.71	2,139
1997–2002	10.1–12.4	14.4	11.27	11.22–11.31	22,456
	Females				
Years	L_{25-75}	L_{95}	L_{50}	c.l.	n
1997	9.3–12.2	14.7	10.75	10.53–10.93	5,705
1998	10.3–11.9	13.26	11.09	10.99–11.17	4,103
1999	10.8–11.9	12.8	11.33	11.27–11.38	3,850
2000	10.7–12.3	13.6	11.52	11.43–11.59	4,329
2001	9.5–12.9	15.7	11.04	10.70–11.28	2,533
2002	11.3–12.3	13.1	11.79	11.71–11.86	2,400
1997–2002	10.3–12.2	13.8	11.24	11.19–11.28	22,920
	Total				
Years	L_{25-75}	L_{95}	L_{50}	c.l.	n
1997	9.6–12.4	14.8	11.02	10.89–11.13	10,216
1998	10.3–12.0	13.5	11.14	11.08–11.20	8,588
1999	10.7–11.9	12.9	11.31	11.27–11.35	7,911
2000	10.6–12.2	13.6	11.41	11.35–11.47	8,486
2001	8.9–13.6	17.5	11.27	11.07–11.41	5,636
2002	11.1–12.3	13.2	11.71	11.65–11.76	4,539
1997–2002	10.2–12.3	14.1	11.26	11.23–11.29	45,376

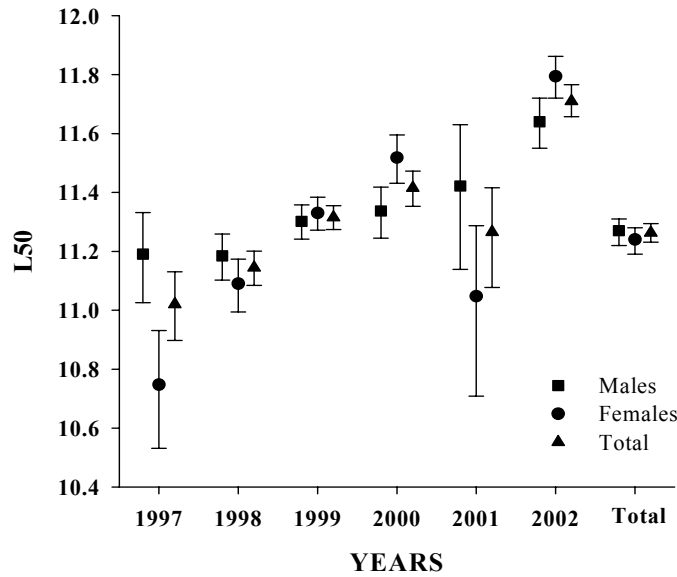


Figure 2. Length at first maturity estimates for each year and for the total, for males and females and combined sexes, with their 95% confidence limits.

Table 2. Values of the regression parameters (*a*, *b*, *r*) of the length–weight relationship, by sex and by year; *TL* total length; *TW* total weight; *n* number of specimens.

Years	Males				Females				Total (<i>M</i> + <i>F</i> + <i>Immature</i>)			
	<i>a</i>	<i>b</i>	<i>r</i>	<i>n</i>	<i>a</i>	<i>b</i>	<i>r</i>	<i>n</i>	<i>a</i>	<i>b</i>	<i>r</i>	<i>n</i>
TL(cm)/TW(g)												
1997	0.0053	3.3160	0.94	4,497	0.0047	3.2203	0.95	5,699	0.0047	3.2196	0.95	10,213
1998	0.0032	3.3497	0.94	6,755	0.0028	3.4082	0.96	7,096	0.0029	3.3838	0.95	13,859
1999	0.0027	3.4120	0.92	5,796	0.0020	3.5241	0.94	5,536	0.0023	3.4748	0.93	12,398
2000	0.0018	3.5540	0.95	5,798	0.0015	3.6224	0.97	7,850	0.0016	3.6005	0.96	15,327
2001	0.0029	3.3719	0.93	8,062	0.0028	3.3881	0.95	9,816	0.0027	3.4047	0.95	21,723
2002	0.0021	3.5179	0.95	4,518	0.0017	3.6001	0.95	5,965	0.0020	3.5298	0.96	11,058

Reproductive cycle. As already highlighted in other similar studies for others areas (Giraldez and Abad, 1995), spawning occurs during spring–summer with an interannual variability of one or two months. From monthly averages of the GSI, coupled with gonad maturity data (Figures. 3a, 4) it is possible to set a threshold value (in 0.01GSI units) indicating the start and the end of the spawning season. The reproductive period ranged from April–May to September–October. The peak of spawning usually occurred in August, except in 1998, when two peaks were recorded; the first in July and the second, lower, in September. Another interesting feature is highlighted in Figure. 3b: the interannual shift in the spawning period, from March–August in 1999 to June–October in 2001.

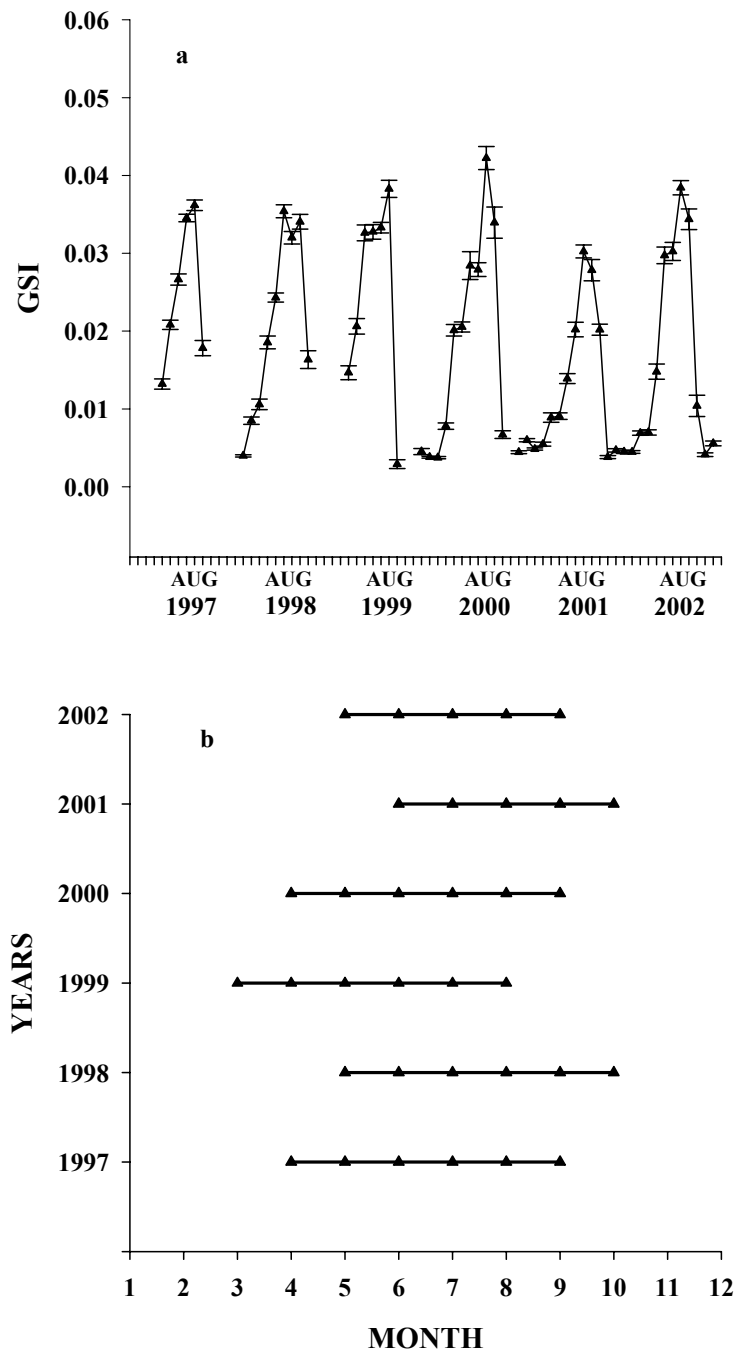


Figure 3. Mean monthly gonosomatic index for males and females (a) and interannual displacement of the spawning period, for females only, between 1997 and 2002 (b)

Maturity stages. A monthly bar graph (Figure. 4) shows the proportion of mature specimens over the whole study period. The maturity pattern confirms results from GSI data on the onset of the spawning period and the timing of the peak spawning.

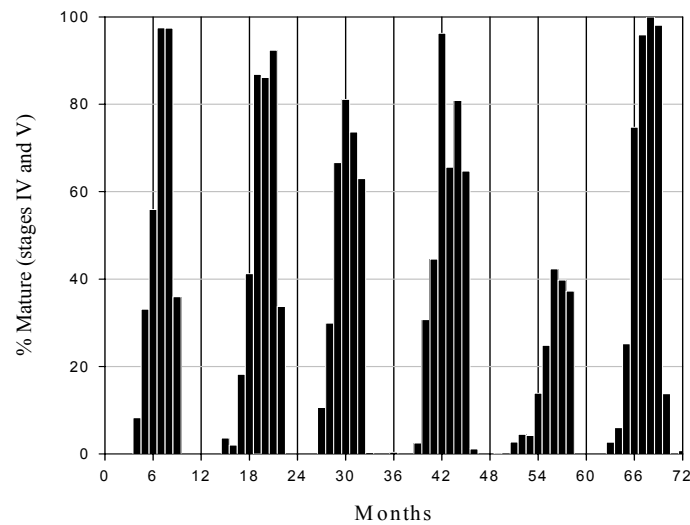


Figure 4. Proportion of mature females (stages IV and V), on a monthly basis, from 1997 to 2002.

Condition factor. There were no significant differences between males and females in respect of the mean monthly CF values; therefore, only the CF of unsexed specimens was analysed. The monthly mean CF values during the study period showed only one clear main peak, in June, but two other minor peaks occurred in spring and autumn (Figure. 5a). It appears that the peak nutritional conditions were met in spring and summer, but later, the energy reserve decreased during the onset of spawning. The breakdown of the thermocline in autumn facilitates the nutrient circulation in the photic zone of the water column, since another annual primary production peak occurs; it could correspond to the late increase in the value of the CF (Giraldez and Abad, 1995). The composite mean seasonal values show better the intra-annual pattern previously described (Figure. 5b) and some degree of interannual variability is more evident in the composite seasonal data.

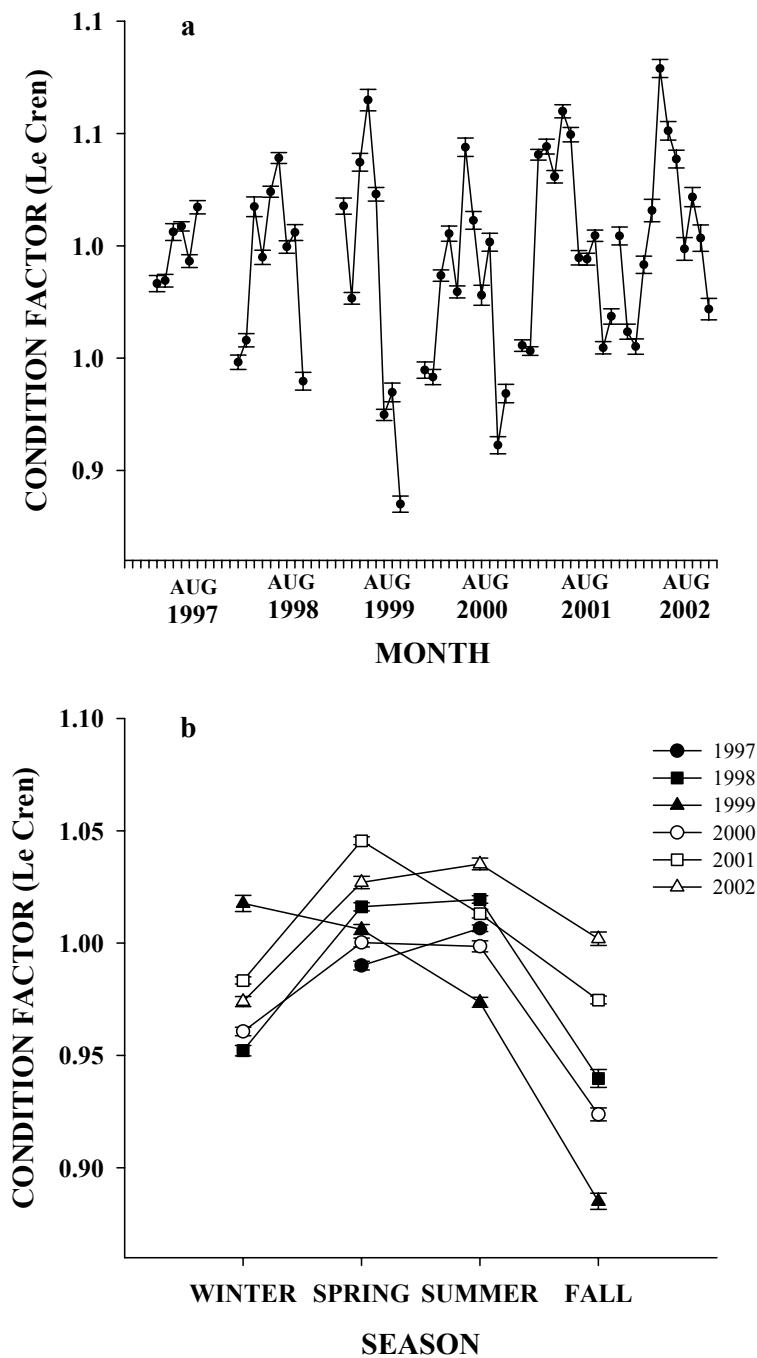


Figure 5. Condition factor by month (a) and by season (b) over the study period.

Sex ratio. The monthly mean values over the six years (Figure. 6a) show similar fluctuations, with male predominance between March–April and September–October; this feature is seen better in the seasonal values (Figure. 6b). The sex ratio by size-class for each year (Figure. 7) showed male predominance, in the size range 115–130 mm (whole period mean); above this size range, females constitute a majority in the catches.

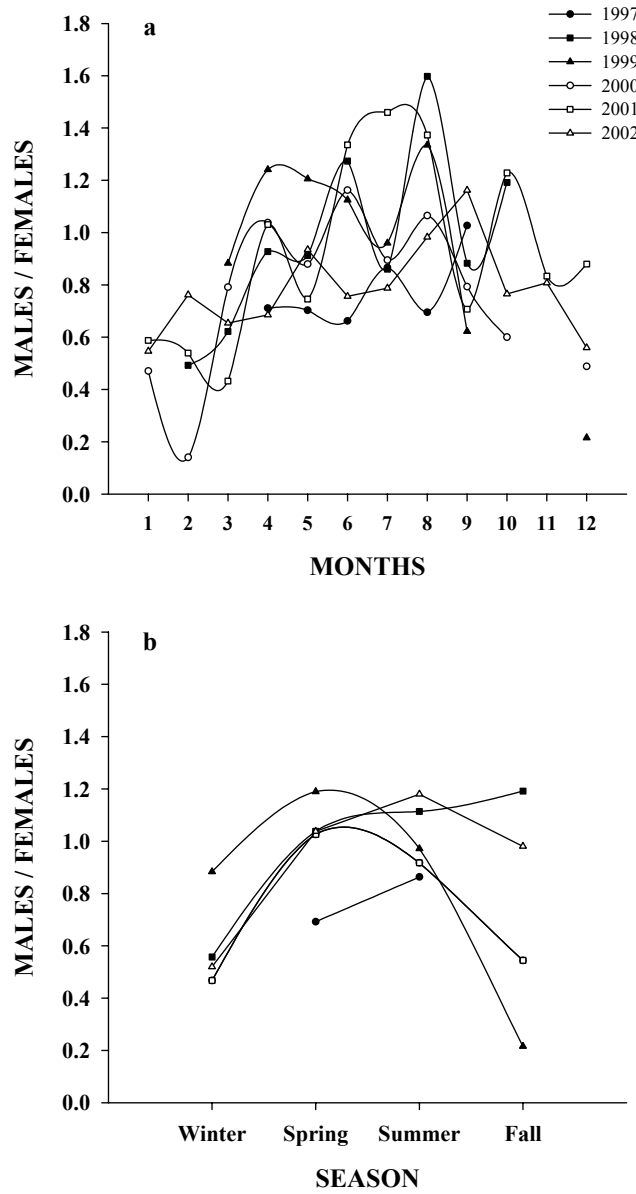


Figure 6. Monthly mean sex ratio by year (a) and seasonal sex ratio (b).

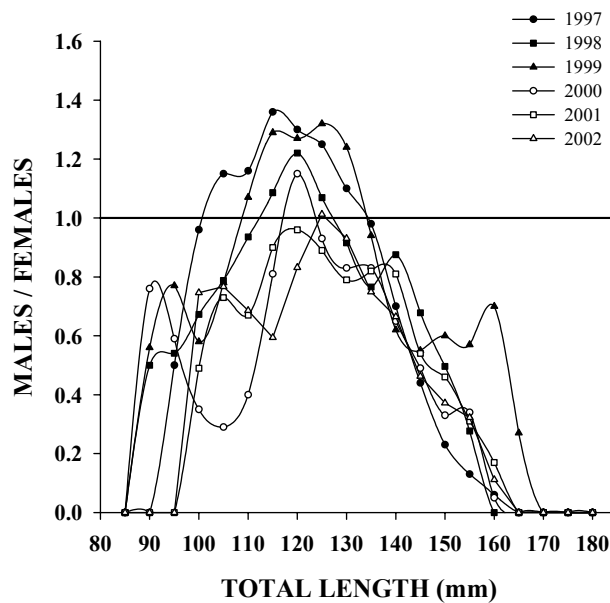


Figure 7. Sex ratio by size-class and by year.

A χ^2 test on monthly and seasonal sex ratios showed the significance of differences between the yearly and seasonally computed values (Table 3). Spring and summer values were more often not statistically different from the expected ratio (1:1), indicating that the catches are more homogeneous than in autumn or winter.

Table 3. Annual and seasonal sex ratios (M/F): χ^2 values with respective significance levels for the period 1997–2002. * $P < 0.05$; ** $P < 0.01$; *n.s.* not significant; *n* number of specimens.

Year		1997	1998	1999	2000	2001	2002
Annual	M/F	0.79	0.95	1.05	0.74	0.82	0.76
	n	10,200	13,855	11,336	13,652	17,882	10,487
	χ^2	141.6	8.4	5.9	308.4	172	199.6
	<i>P</i>	**	**	*	**	**	**
Winter	M/F	-	0.56	0.88	0.47	0.52	0.65
	n		2,674	1,034	3,850	6,306	3,116
	χ^2		235.7	3.9	572	669	141.4
	<i>P</i>		**	*	**	**	**
Spring	M/F	0.69	1.04	1.19	1.03	1.04	0.79
	n	3,828	4,982	4,661	5,189	4,322	3,396
	χ^2	125	13.1	43.6	0.3	0.01	49.4
	<i>P</i>	**	**	**	<i>n.s.</i>	<i>n.s.</i>	**
Summer	M/F	0.86	1.11	0.97	0.92	1.18	0.98
	n	6,372	5,366	5,257	3,297	4,033	2,343
	χ^2	40.8	2.8	2.7	5.2	24.9	2.4
	<i>P</i>	**	<i>n.s.</i>	<i>n.s.</i>	*	**	<i>n.s.</i>
Autumn	M/F	-	1.19	0.22	0.54	0.98	0.71
	n		833	384	1,316	3,221	1,632
	χ^2		6.3	160.1	119.1	0.1	54.4
	<i>P</i>		*	**	**	<i>n.s.</i>	**

4. Discussion and conclusions

The values for size at first maturity lie in the range of the literature data for the Mediterranean Sea. Interannual variability in the L_{50} estimates recorded by several authors (Hunter and Goldberg, 1980; Giraldez and Abad, 1995; Millan, 1999) was attributed to the spawning tactics to ensure survival of the early-life stages (Alheit, 1989). So the environmental conditions affect one or more of the spawning characteristics (batch fecundity, spawning frequency and age/length at maturity). In the Adriatic Sea, the fluctuation in the annual abundance of anchovy eggs coincided with fluctuations in primary production (Regner, 1974). More detailed study of the long-term fluctuations in the anchovy early-life stages showed that there is a positive relationship, with a one-year phase lag, between egg and post-larval abundance, on the one hand, and temperature and productivity, on the other (Regner, 1996).

The interannual variation in the allometric growth parameter b , in the length–weight relationship, follows the same trend as that of the size at first maturity, increasing from 1997 to 2000, regressing in 2001, and increasing again in 2002. This variation could also be related to the same habitat variability that affects size at maturity. Annual sex ratio does not differ from the expected 1:1 ratio, but varies seasonally and shows the predominance of females during the year, except in the spawning period, when it is evident that males significantly outnumber females. Otherwise, the change in the sex ratio with body size shows the decreasing number of males at sizes above 12.0 cm (almost the size at first maturity). As concerns the spawning season, GSI clearly shows a seasonal pattern. The mean spawning season extended from April to September, except during 1999, when it began one month before, and in 2001, when it ended two months later. The spring warming of the water body largely influences the onset of the anchovy spawning season (Furnestin, 1945; Cort *et al.*, 1979) and Motos *et al.* (1996) suggested that the Bay of Biscay anchovy starts spawning (massive occurrence of eggs and larvae in the plankton) when the temperature rises above 14°C, and local spawning peaks were recorded at a sea-surface temperature between 16° and 18.5°C. Anchovy seems to diminish its spawning when the rate of surface-water warming decreases, and stops when this rate becomes zero or negative (Motos *et al.*, 1996).

The interannual shift in the reproductive activity (Figure. 3b) could be related to the habitat variability, expressed as the warming and the food availability, and could explain this shift in spawning time; however, the chlorophyll concentration, even with two or three months lag, could not be strictly considered as food available for anchovy, because the transport by currents heavily affects the zooplankton distribution. Further data on zooplankton availability are needed to explain better the timing of anchovy spawning.

For the future, it will be interesting to investigate these interannual variations in timing (start and end) of the spawning season in relation to changes in environmental conditions (productivity, temperature, upwelling intensity, salinity) and/or to stock fluctuations.

5. References

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