

**BIOLOGY OF ATLANTIC BONITO, *SARDA SARDA* (BLOCH, 1793),
IN THE WESTERN AND CENTRAL MEDITERRANEAN
A SUMMARY CONCERNING A POSSIBLE STOCK UNIT**

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SUMMARY

Biological parameters of Atlantic bonito are summarized from the literature taking into account up to date genetic observations: a population unit is apparently distributed in the Central and Western Mediterranean. There are several spawning areas, but fish movements along the coasts probably maintain the mixing of the population.

RÉSUMÉ

Les paramètres biologiques de la bonite à dos rayé sont récapitulés à partir de la documentation en tenant compte des observations génétiques actualisées : une unité de population est apparemment distribuée dans le centre et l'ouest de la Méditerranée. Il existe plusieurs zones de frai, mais les déplacements des poissons le long du littoral maintiennent probablement le mélange de la population.

RESUMEN

Se resumen los parámetros biológicos del bonito de la bibliográfica considerando las observaciones genéticas actualizadas: aparentemente una unidad de población se extiende el Mediterráneo central y occidental. Hay varias zonas de desove, pero es probable que los movimientos de los peces a lo largo de las costas mantengan la mezcla de la población.

KEYWORDS

*Atlantic bonito, *Sarda sarda*, Sex ratio, Breeding season, Breeding sites, Juveniles, Growth curves, Migrations.*

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1. Introduction

Among four allopatric species (*S. australis*, *S. chiliensis*, *S. orientalis* and *S. sarda*), *Sarda sarda*, the Atlantic bonito, is the only inhabiting Atlantic (both sides) and Mediterranean waters; it is distinguished by the higher meristic characters, such as 50-55 vertebrae instead of 43-46 and 20-23 rays in the first dorsal fin instead of 17-19.

The distribution in the Mediterranean extends to the Black Sea, where the most important catches are obtained; in fact of an estimated total Mediterranean catch of 22961 MT (ICCAT SCRS 2003), 13460 MT are due to Turkey, while there is a lack of data for Russian countries. Many studies on the fishery biology of this species begun in this Eastern area (Zusser 1954; Nümann 1955; Slastenenko 1956; Demir 1957, 1963, 1964; Krotov, 1957; Mayorova and Tkacheva 1959; Nikolov 1960; Demir and Demir 1961; Kutaygil 1967; Porumb and Porumb, 1959; Faruk Kara 1979).

Synopses dedicated to Atlantic bonito are available both in a world wide approach (Yoshida 1980) and concerning the Mediterranean fish (Demir 1963; Rey *et al.* 1984; Orsi Relini *et al.* 1999). The latter were prepared when the information about the genetic structure of the Mediterranean populations were absent or in progress. At present both genetic results (Pujolar *et al.* 2001; Vinas *et al.* 2004) and reproductive data suggest to limit the present summary of biological parameters to the Western and Central Mediterranean, where the occurrence of a population unit (or unitary stock) can be envisaged.

2. The genetic framework and the location of spawning grounds

Recent genetic studies have ascertained some differences among fish of the Marmara Sea, the Aegean and the Ionian (Roberti *et al.* 1993 a and b), with the Aegean population sharing characteristics both of the Ionian and, to a lesser extent, of the Marmara Sea; on the contrary the Italian seas, Ligurian, Tyrrhenian and Ionian, seem to have an homogeneous population (Cimmaruta *et al.* 1998). In line with the above mentioned interpretations, a sampling carried out during the E.C. programme “Characterization of large pelagic stocks in the Mediterranean (1993-1996)” in three areas, Ligurian, Ionian and Aegean seas, has allowed to separate two different groups of *S. sarda*: one in the Ligurian and Ionian Sea and the other in the Aegean Sea (Pujolar *et al.* 2001). The authors explained this result assuming that two discrete spawning grounds exist in the Mediterranean: in the East spawning occurs from May to June in the Black and Marmara Seas; in the Western Mediterranean spawning concentrations occur from June to July between Gibraltar, Balearic Islands and Algeria. However, the existence of this spawning ground for the fish of the Western and Central Mediterranean was apparently only conjectural: it was based on the fact that extensive surveys for scombroid eggs and larvae gave only few records of *S. sarda*, located at the Balearic Islands and along the Algerian coast (Duclerc *et al.* 1973; Piccinetti *et al.* 1981, 1994, 1996). This supposition overlooks the fact that mature eggs were described by Sanzo (1910) at Messina and the abundant materials collected in the same area allowed to describe also the embryonic development, the hatchling and the first larval stages (Sanzo 1931, 1932), establishing a continuity with the postlarval stage (7.2 mm) described by Ehrenbaum (1924) and the juveniles (26.5 and 32 mm) of De Buen (1930; 1932). At a total length of about 3.5 cm the young fish present vertical dark stripes and the peculiar meristics of the first dorsal fin (22 spines) which distinguish it from the Thunninae (Padoa 1956).

Young fish (7.5-20 cm) with 10-11 vertical dark stripes were also described by Lo Bianco (1909) at Naples: these juveniles were observed in the months of July and August and, in some years, were abundant in the catches of beach seines. So the Ionian and the Tyrrhenian Seas can be added to the spawning areas and recently also the Catalan coast has given interesting numbers of larvae (Sabates 1990; Sabates and Recasen, 2001). On the basis of our observations in the Ligurian Sea, we can add that fluent specimens are present in the Gulf of Genoa in the period June-July, suggesting that also the most northern part of the western Mediterranean has its own spawning grounds.

The most recent genetic study (Vinas *et al.* 2004) is based on samples of western, central and eastern Mediterranean, but unfortunately no sampling concerned the Marmara Sea. Two clades were found, mixed in proportions figuring an east-west cline (**Figure 1**); they were named “Atlantic” and “Mediterranean” respectively, but, as no Atlantic samples were analysed, these two clades, saving the analogies with the previous studies, could also be called simply “western” and “eastern Mediterranean”. It is interesting to note that differences among Italian seas, such as Ligurian and Ionian, also in this study result scarce.

3. Migrations

In the western and central Mediterranean, Atlantic bonitos are mainly fished in coastal waters, but large specimens (60-85 cm FL) are sporadically present offshore; observations made in our study area, the Ligurian Sea, analysing the swordfish fisheries by-catch, ascertained a distance from the coast of about 15 NM at least, on a depth more than 2000m.

Atlantic bonitos tagged on the Mediterranean Spanish coast (Rey *et al.* 1984) have shown that: 1) the fish can move along the coast in both South and North directions; 2) a specimen covered about 370 NM in less than 4 months, travelling toward Gibraltar from Castellon to Estepona, (Rey and Cort, 1978). A consistent fraction of fish tagged at the tuna trap of Ceuta were recovered in the Atlantic, both South and North of the Strait, from Morocco to Portugal (Rey and Cort 1981). So the Western-Central Mediterranean *S. sarda* are apparently not confined to this Sea, but it is so far unknown if also Atlantic specimens (which have their spawning grounds along the Atlantic coast of Morocco (Dardignac 1962) move across the Strait toward the Mediterranean.

4. Size and age structure of the fished stock

Length/frequency distributions generally show a few gaussian groups, which frequently have been followed in their growth by temporal series of samples (**Figure 2**, from Rey *et al.* 1984).

Fish of three age groups (0, 1 and 2) are apparently easily identified, but, as shown later, ageing by growth bands on skeletal hard structures (otoliths, vertebrae, fin rays) seems to give different results (**Table 1**) in respect of l/f distributions.

5. Growth

Studies about the growth of fish of the genus *Sarda* seems to be somewhat problematic. In fact, in his exhaustive monograph, Yoshida (1980) noted that:

1) Nothing was available on age and growth of *S. australis*, except a maximum size of 91.4 cm.

2) The growth of *S. chiliensis*, whose maximum size in the Northern hemisphere is about 101.6 cm and 11.3 kg, had been described by two quite different curves, obtained by Kuo (1970) and Campbell and Collins (1975). The former curve suggests an almost linear growth from age 1 (15 cm) to age 8 (75 cm); the latter curve indicates a rapid growth rate during the first 3 years (age 1 = 45 cm; age 2 = 59 cm; age 3 = 67 cm) and a tapering to a relatively low rate thereafter.

3) Albeit a growth curve was not available, *S. orientalis* juveniles, obtained by artificial fertilization, grew in culture at a rate of 2.9 mm/day, reaching 290 mm in 99 days after hatching. A segment of natural growth, obtained plotting the mean length of samples of juveniles (max 24.8 cm) against sampling date, showed a mean growth of about 2.6 mm/day.

4) Many studies were available for *S. sarda* of the Black Sea, including both “slow” series of length at age with a longevity of 9 years (74-85 cm at age 9 according to Zusser, 1954) and fast growth performances, e.g. 67 cm, at age 4 (Nikolov 1960). The maximum size was 85 cm.

Apparently Yoshida had no information about studies on growth in the Eastern Atlantic and Mediterranean.

Very abundant samples of Atlantic bonitos were studied, from the sixties onward, near the Gibraltar Strait, at the tuna traps of Barbate and Tarifa (Gulf of Cadiz). Rodriguez-Roda (1966) illustrated bimodal l/f distributions, obtained in the months of May-June-July (**Figure 3B**) i.e. in coincidence with the reproductive season. He showed also a l/f distribution per sex (**Figure 3C**), where the sexual dimorphism is small. So the three modes observed in 1963 and the two modes observed in 1964 (**Figure 3A**) represented cohorts, with average lengths of 43.48 – 51.54 and 62 cm fork length (Rodriguez-Roda 1966). In another paper, Rodriguez-Roda (1981) reconsidered in more details the 1963-64 data (size classes of 1 cm) (**Figure 3D**) and named the concerned age groups (the first and the second) as age 0 and age 1, but in this way he did not remark that exactly at the time of sampling (June-July) the fish are spawning, so age 0 is becoming age 1 and age 1 is becoming age 2.

Rey *et al.* (1984), assuming that a sole population of Atlantic bonitos is distributed on the Mediterranean and Atlantic coasts of Spain and Morocco, and using materials such as otoliths, vertebrae and fin rays, gave the following interpretation of lengths at age and growth parameters :

Age class	Mean FL (cm)	St. dev. (cm)	$L_{\infty} = 80.87$ cm
0	37.03	6.12	$t_0 = -1.7$
1	51.71	3.07	$k = 0.352$
2	57.04	2.79	
3	63.15	3.28	
4	71	0	

In the same paper the Authors followed the growth of a cohort from September 1982 (25 cm) to September 1983 (about 48 cm) in a dedicated graph (**Figure 22** of their synopsis, **Figure 3E** of the present paper). If in this graph the length of July is taken as length at age 1, the measure of length concerned should be about 43 cm FL.

The Authors did not comment these contrasting results; they only noted that there is a variability of sizes from one year to another.

A recent paper (Santamaria *et al.*, 1998) gives growth parameters very similar to those of Rey *et al.* (1986): $L_{\infty} = 80.6$ cm; $K = 0.36$; $t_0 = -1.37$ (**Table 1**).

Two tagged and recaptured specimens gave interesting results concerning growth: the specimen which travelled from Castellon to Estepona, was tagged at a length of 29 cm on 14 October and recaptured, after 118 days, at a length of 36 cm (Rey and Cort 1978); a fish tagged at age 0 was recaptured after 1281 days, when it weighed 5000 g, which is equivalent to a fork length of 70.72 cm (Rey *et al.* 1986). This growth performance well fits the above mentioned parameters (age 4 = 71 cm) (Rey *et al.*, 1986).

In the Gulf of Genoa the maximum observed fork length was 90 cm and the maximum weight 8 kg. We suppose therefore that the longevity of *S. sarda* could be extended to some more years and the L_{∞} increased in conformity of this datum.

Different length/weight relationships are summarized in **Table 2**.

6. Reproduction

All the species of genus *Sarda* are heterosexual and without any dimorphism, however some Turkish fishermen are able to recognize male from female by the rugosity of the ventral skin in proximity of the anus (Demir, 1963).

S. sarda inhabits neritic and offshore waters, but spawning generally occurs in more coastal areas. In the Western Mediterranean there are several spawning grounds: the Algerian coasts, Sicily and the Balearic islands, the Tyrrhenian, the Ligurian and the Catalan Sea. On the Atlantic coast of Morocco spawning areas have been recognized near Agadir and Casablanca-Fedala (Dardignac 1962; Rodriguez-Roda and Dicenta 1980).

The spawning season in the Mediterranean usually occurs between May and July, with a maximum in June; in the southern part of the Mediterranean, such as Algerian coasts, it may occur between March and May (Dieuzeide 1954). In the **Table 3** we summarized the spawning periods from different geographical areas.

Many studies on reproductive parameters of the Atlantic bonito were carried out in the past; they can be summarized in the following scheme:

a) The sex ratio of the Mediterranean *S. sarda* has been studied since 1966 (Rodriguez-Roda): in this paper data from Spanish landings of two different periods –June 1963 and May/July 1964– are reported. Studying all the data set, generally the sex-ratio was near parity; it was possible to find some difference between the two sexes only in May 1964: 1 male per 0.35 female.

The sex ratio obtained in the Ionian Sea in the period 1992–1994 (AAVV 1995) (**Table 4**) is also close to parity, with a total of 374 males and 360 females.

b) Gonadosomatic indexes were studied by the functions:

$$GI = Pg / P \times 100 \quad (\text{Rey } et al. 1984; \text{Rodríguez-Roda } 1966)$$
$$GI = (Pg / L3) \times 104 \quad (\text{AAVV, } 1995)$$

The maximum values are reported in June-July, with a GI of 12.15 for females and 7.05 for males.

c) Rey *et al.* (1984) described six different stages of maturity in *S. sarda*, based on macroscopic observation of gonads (**Table 5**). The relationship between the maturity stages of gonads and GI (Rey *et al.* 1984) are reported in **Table 6**.

d) About the size and age at first maturity results appear a little contradictory (**Table 7**). In any case the proposed sizes indicate an early maturation.

e) Fecundity is calculated as the number of oocytes in the mature ovary (or next to maturity) (**Table 8**). Rey *et al.* (1984) reported the equation that gives the relation between the fecundity and the length of fish:

$$F = 0,01 \times L_F^{4,59}$$

In conclusion, *S. sarda* in the Western Mediterranean has a plurality of spawning areas, where the reproduction occurs at rather precise times ; albeit there is a gradient South-North in the reproductive season, in each area the spawning seems to last less than two months, generating well identified cohorts, at least for the first three years of life. Ample migrations along the coast were ascertained by tag-recapture experiments; these migrations probably maintain the mixing of the population.

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Table 1. Length at age, in cm, of *Sarda sarda*.

Author	Age group					Method	Area
	0	1	2	3	4		
Dardignac, (1962)	40	52	58	62-64	-	l/f distribution	Atlantic Morocco
Rodriguez-Roda, (1966)	-	43.48	51.46	62	-	l/f distribution	Gibraltar
Rodriguez-Roda, (1981)	42.59	50.51	60.50	64.00	-	vertebrae	Gibraltar
Rey <i>et al.</i> , (1984)	46.0	51.71	57.04	63.15	-	-	Gibraltar
Rey <i>et al.</i> , (1986)	37.03	51.71	57.04	63.15	71.00	otoliths, vertebrae, fin rays	Gibraltar
Santamaria, (1998)	34.8	50.9	57.5	64.8	70.4	Fin rays, vertebrae	Italy (Ionian Sea)

Table 2. Length/weight relationships.

Function	N°	Range	Author	Area	Notes
$W = 0.01486 L^{2.9719}$	165	40-55.5cm -	Rodriguez-Roda, 1966	Gibilterra	-
$W = 0.00797 L^{3.1427}$	-	- -	Dardignac, 1962	Atlantic Morocco	Estrapolato
$W = 0.00724 L^{3.1644}$	878	19-72cm 200-5500g	Rey <i>et al.</i> , 1984	Mediterranean Atlantic	♂+♀+Indet.
$W = 0.00653 L^{3.1865}$	242	33-65.2cm 436-4040g	Rey <i>et al.</i> , 1984	Mediterranean Atlantic	♂
$W = 0.00844 L^{3.1218}$	229	33-70.5cm 460-4866g	Rey <i>et al.</i> , 1984	Mediterranean Atlantic	♀
$W = 0.0351 L^{2.755}$	663	34-78cm	AAVV, 1995	Gulf of Taranto	1992 total
$W = 0.0311 L^{2.789}$	130	39-69cm	AAVV, 1995	Gulf of Taranto	♂ 1992
$W = 0.0574 L^{2.633}$	105	38-71cm	AAVV, 1995	Gulf of Taranto	♀ 1992
$W = 0.0190 L^{2.909}$	158	38-81cm	AAVV, 1995	Gulf of Taranto	1993 total
$W = 0.0149 L^{2.963}$	33	-	AAVV, 1995	Gulf of Taranto	♂ 1993
$W = 0.0177 L^{2.924}$	44	-	AAVV, 1995	Gulf of Taranto	♀ 1993
$W = 0.0071 L^{3.151}$	833	36.5-80cm	AAVV, 1995	Gulf of Taranto	1994 total

Table 3. Spawning periods and grounds of *S. sarda* (from Rey *et al.*, 1984, with addition).

<i>Area</i>	<i>Period</i>	<i>Author</i>
Sicily	May 20 – June 30	Sanzo, 1932
Algerian coasts	March - May	Dieuzeide, 1955
Gibraltar	May - July	Rodriguez-Roda, 1966
Atlantic Morocco	June - July	Fournestin, 1958
Tropical East Atlantic	February - March	Frade and Postel, 1955
Dakar	December - June	Postel, 1955
Western Atlantic, USA coasts	June	Bigelow and Schroeder, 1953
Western Atlantic	July	Sette, 1943
Mediterranean and Atlantic Morocco	June - July	Rey <i>et al.</i> , 1984
Ligurian Sea	June - July	Present note
Catalan coast	July	Sabates and Recasens, 2001

Table 4. Sex ratio of *S. sarda* in the Ionian Sea (from AAVV, 1995).

<i>Year</i>	<i>Sex</i>	<i>Samples</i>	<i>Sex-Ratio</i>
1992	Males	130	1.24
	Females	105	
1993	Males	33	0.73
	Females	44	
1994	Males	24	0.77
	Females	31	
Total	Males	187	1.04
	Females	180	

Table 5. Stage of maturity and relative gonadal description (Rey *et al.*, 1984).

<i>Stage of maturity</i>	<i>Morphology of gonads</i>
Stage 1: indeterminated	Gonads pinkish, in shape of narrow ribbon.
Stage 2: immature	Gonads thin but it's possible to determine sex. Female with enlarged and subcilindrical gonads; pinkish colour. Male with thin gonads in shape of ribbon; pinkish colour. Testicular arteries easily visible in the median portion.
Stage 3: beginning of maturation or recovering	Female have subcilindrical gonads, from dark pink to light red. Oocytes aren't yet visible. Male with whitish gonads, with bigger size than in the female. Testicular arteries visible.
Stage 4: maturation	Female with developed gonads; yellow orange colour. Oocytes visible. Male with very developed gonads; whitish colour. It is possible to observe some spermatic fluids after incision.
Stage 5: mature fishes – spawning	Female with gonads at maximum development, filling all the abdominal cavity. The oocytes, very large and translucent, are detached by simple pressure on the abdomen. Male with gonads at maximum development; it is possible to observe few red spots on the gonads surface. Seminal fluid spouts by simple pressure.
Stage 6: post spawning	Female gonadal aspect is different according to more or less recent deposition (ovary empty, very vascularized or contracted). Male have soft gonads, with the presence of scarce seminal fluid, owing recent deposition. Pinkish colour at the end of the deposition, whitish onward.

Table 6. Relationship between maturity stages of gonads and GSI (from Rey *et al.*, 1984).

	<i>Male</i>		<i>Female</i>	
	<i>IGS</i>	<i>Range</i>	<i>IGS</i>	<i>Range</i>
1	-	-	-	-
2	0.23	0.15-0.33	0.75	0.52-2.10
3	0.91	0.47-1.44	1.38	0.63-1.98
4	3.65	1.70-6.53	5.46	1.84-9.34
5	3.50	1.81-7.05	6.11	3.27-12.64
6	2.27	1.73-2.91	3.28	3.18-4.0

Table 7. Age of first maturity according to different authors (from Rey *et al.*, 1984, modified).

<i>Area</i>	<i>Age</i>	<i>Size (cm)</i>	<i>Author</i>
Tropical Atlantic (Dakar)	0+	Male: 39.2 Female: 37	Postel, 1955
Mediterranean and Atlantic Morocco	0+	Male: 38 Female: 39	Rey <i>et al.</i> , 1984
Atlantic Morocco (minimum spawning size)	1 year	Male: 40 Female: 45	Dardignac, 1962

Table 8. Fecundity of *S. sarda* according different authors (from Rey *et al.*, 1984, modified).

<i>Area</i>	<i>Size</i>	<i>Fecundity</i>	<i>Author</i>
East Atlantic Tropical	60	900000	Postel, 1955
Mediterranean and Atlantic Morocco	47 - 71	220000 - 1500000	Rey <i>et al.</i> , 1984

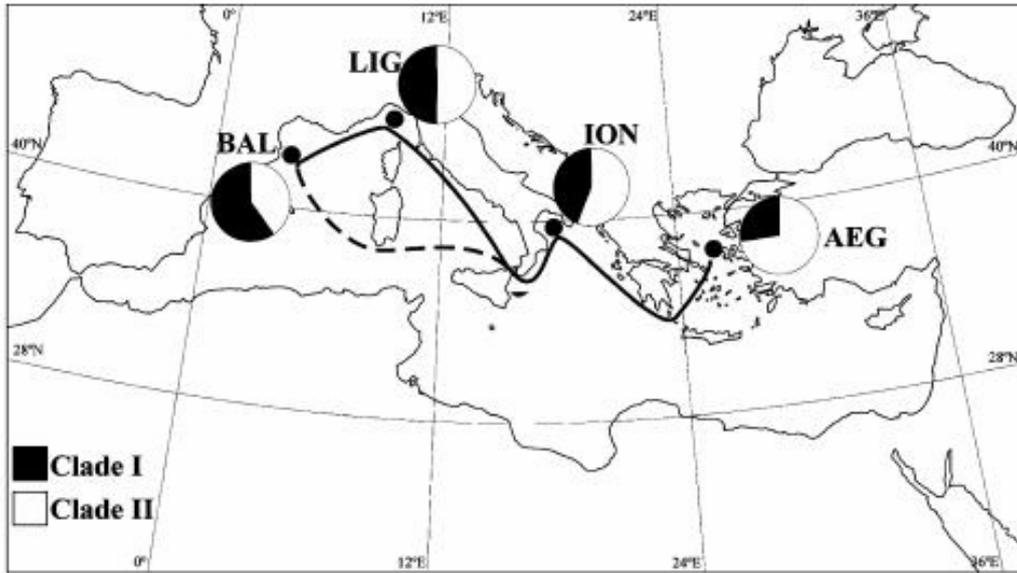


Figure 1. Sampling locations and pie diagrams of distribution of the two mitochondrial control region clades studied by Vinas *et al.* (2004).

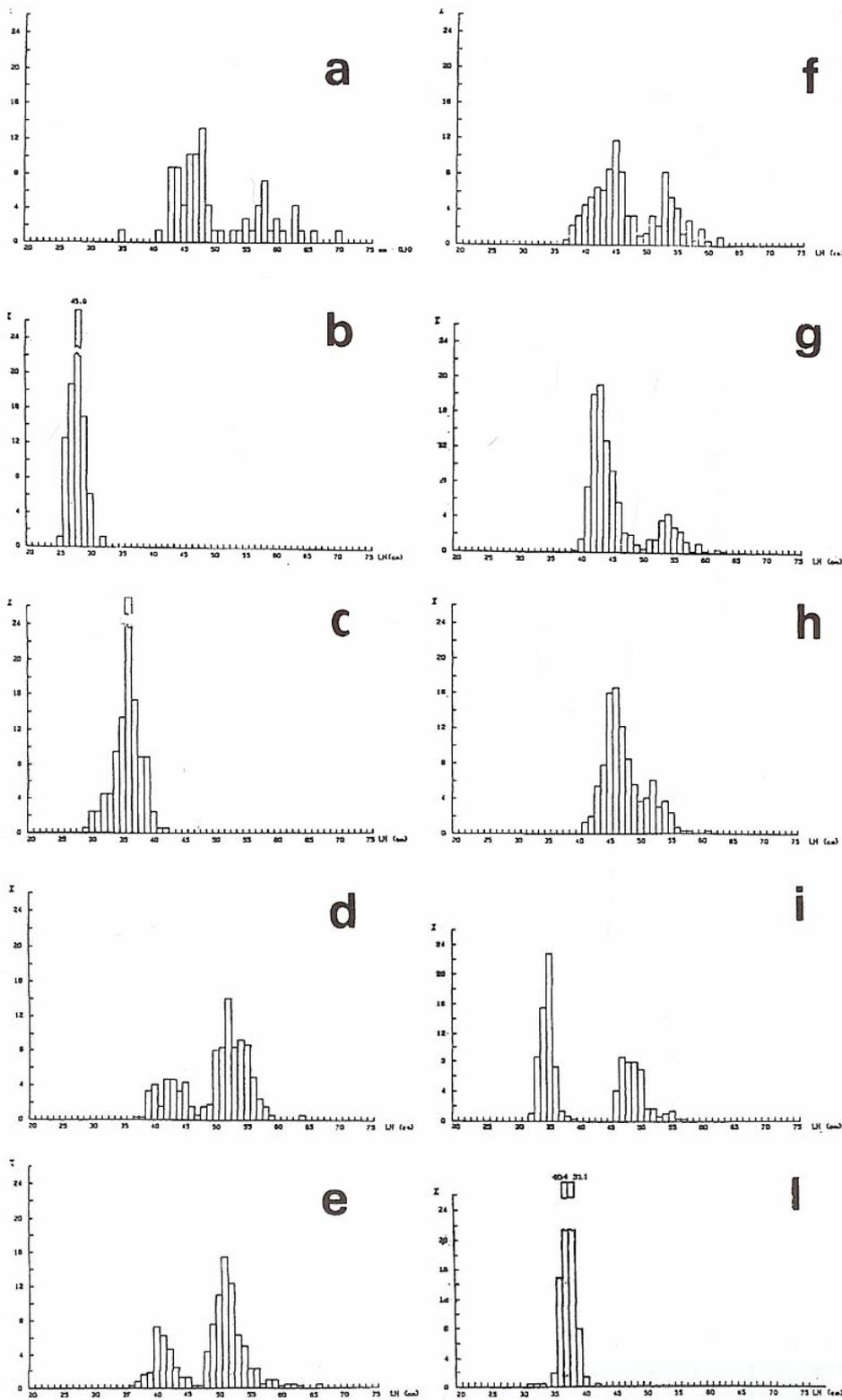


Figure 2. Monthly length/frequency distributions of *S. sarda* in Spanish waters in 1982-83: a) July '82 – n=68; b) September '82 – n=80; c) October '82 – n=157; d) March '83 n=320; e) May '83 – n=382; f) June '83 – n=348; g) July '83 – n=453; h) August '83 – n=296; i) September '83 – n=291; l) October '83 – n =151 (from Rey *et al.*, 1984).

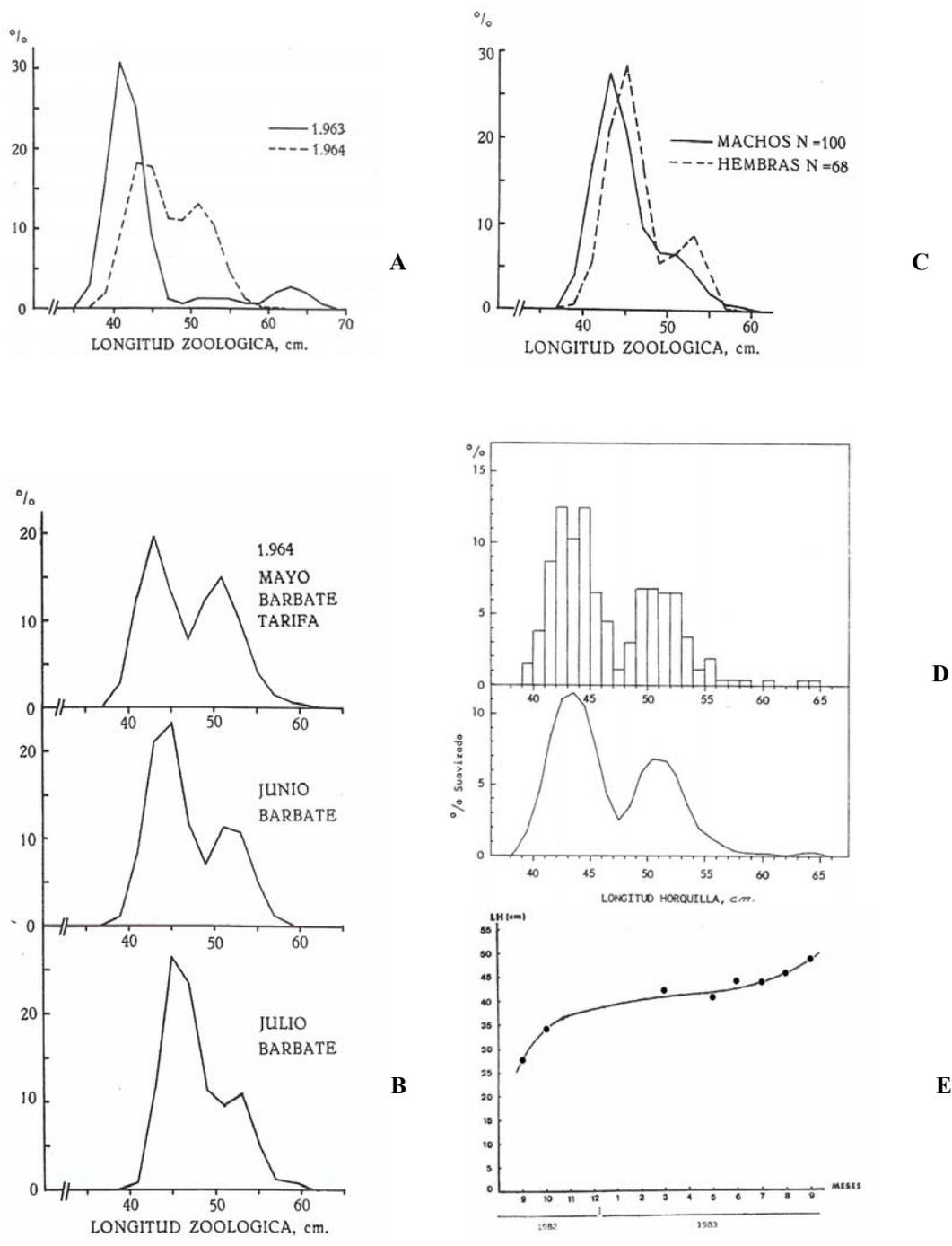


Figure 3. A, B, C, D) Length/frequency distributions of *Sarda sarda* in Spanish waters (Rodríguez-Roda 1966; 1981); E) Growth of 1982 cohort (Rey *et al.* 1984): the points of June and July, should indicate the length at age 1; however the Authors assigned to age 1 the length of 51.7 cm.