MEDITERRANEAN MARINE DEMERSAL RESOURCES: THE MEDITS INTERNATIONAL TRAWL SURVEY (1994-1999).
P. ABELLÓ, J.A. BERTRAND, L. GIL DE SOLA, C. PAPACONSTANTINOU, G. RELINI and A. SOUPLET (eds.)

Distribution of the Mediterranean hake populations (*Merluccius merluccius smiridus* Rafinesque, 1810) (Osteichthyes: Gadiformes) based on six years monitoring by trawl-surveys: some implications for management*

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SUMMARY: On the basis of trawl survey data collected during the MEDITS project (1994-1999), the distribution of Mediterranean hake populations was described in coastal areas corresponding to about three quarters of both the latitudinal and longitudinal extensions of the Mediterranean Sea, and in the 0-800 m range. Abundance and biomass indices (in terms of number and kg per km^2) are presented in 15 geographical sectors and 40 subareas from the Alborán Sea to the Aegean Sea. A statistical analysis by generalized linear modelling performed on such indices per main national blocks (Greece, France, Italy and Spain), and considering the effects of the six years of sampling and the depth, showed that biomass increased from west to east, while for all areas the most significant depth effect appeared between 100 and 200 m, corresponding to the depth range that hosts most of the summer nursery areas. The overall size-frequency distributions in shelf and slope waters, average sizes and total mortality coefficient Z per sector showed that the bulk of the MEDITS samples consisted of young individuals and, with only a few exceptions (western Sardinia, central Aegean), a generalized condition of growth overfishing was apparent. However, no negative trend was found, either in biomass or in average size of fishes, during the six years of the present study. Recruitment patterns were studied by distinguishing the youngest fish as Gaussian groups (modal length from 6 to 9 cm total length) in length-frequency distributions of each subarea and main stratum (shelf and slope). Considering the timing of MEDITS surveys (May-July), this approach emphasised the nurseries in the northern part of the western Mediterranean (Gulf of Lions, Ligurian Sea, northern Tyrrhenian Sea) and in the northern central Mediterranean, where recruitment occurs mainly during spring. On the other hand, few recruits were found in part of the central and particularly in the eastern Mediterranean, where recruitment occurs mainly in summer. MEDITS recruitment patterns therefore gave support to distinctions among Mediterranean hake populations, previously suggested on the basis of vertebral counts and other morpho-physiological, albeit fragmentary, data. In particular the central Mediterranean hake populations do not seem to be homogeneous, with an Adriatic unit very close to the northwestern one. The MEDITS experience therefore suggests that future management measures could take into account both general and regional patterns, the latter concerning mainly the younger fraction of the populations.

Key words: hake, *Merluccius merluccius*, Mediterranean subspecies, biomass, abundance, size structures, spring recruitment patterns, stock identification.

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INTRODUCTION

Fish of the genus *Merluccius* constitute very important demersal resources both worldwide and in the Mediterranean. In the last thirty years the world catches have oscillated between 1 and 2 million tonnes, while Mediterranean catches have doubled to more than 44,500 tonnes (Fiorentini *et al.*, 1997). The contribution of the three sectors, western, central and eastern Mediterranean (sensu FAO), as well as the catches since 1972 are shown in Figure 1. In recent years the central Mediterranean, which is formed by the Sicilian Channel and the Ionian and Adriatic seas, has provided the most relevant quantities.

The various species of hake are a difficult subject for fishery biology (Jones, 1974) owing to their biological characteristics. The morpho-physiological model of *Merluccius* is long-standing and successful, probably due to its flexibility with regard to environmental constraints. Fossil hake have been found dating back to the Eocene in the Pacific and the Oligocene in Europe (Alheit and Pitcher, 1995). Among the recognised reasons for their success some significant biological and ecological characteristics can be listed, such as: the broad extension of the vertical distribution which covers both shelf and slope, the prolonged period of reproduction (thus eggs and larvae can experience very different sets of environmental conditions) and the possibility of cannibalism (if density is too high, part of the population dies, thus giving support to its conspecifics) (Payne and Punt, 1995).

At present, of twelve known species of hake (Inada, 1981), only one is found along the eastern North Atlantic and the Mediterranean: *Merluccius merluccius* (L.), the "European hake" with two subspecies, one in the Atlantic and one in the Mediterranean (Cohen *et al*., 1990). Therefore, the target of the MEDITS project was *Merluccius merluccius smiridus,* the Mediterranean subspecies, possibly with a plurality of stocks, given the variety of the observed biological patterns regarding reproduction and growth. It should be remembered that, on a simple meristic basis (i.e. vertebral number), differences were detected between Atlantic and Mediterranean (Cadenat, 1950) as well as among western, central and eastern Mediterranean hakes (Maurin**,** 1965). Genetic studies confirmed the former distinction (Pla *et al.*, 1991; Roldán *et al.*, 1998) and first results in the central Mediterranean are confirming the latter (Lo Brutto *et al*., 1998).

In the Mediterranean subspecies, the characteristics which form the basis of the success of hake have been repeatedly recorded. In particular, regarding the long reproductive period, several different cases have been pointed out, which could represent a first basis for the identification of stocks: in the Adriatic, Zupanovic (1968) showed two peaks of recruitment, in spring and in autumn, probably linked to winter and summer spawning peaks; the same recruitment pattern was observed in the Ligurian Sea (Orsi Relini *et al.*, 1986); in the adjacent Tyrrhenian Sea two spawning peaks were found, one in February-March and another in September (Biagi *et al.*, 1995). Bouhlal (1973) observed three spawning peaks off Tunisia in summer, winter and spring; off the Balearic Islands, the spawning period is from November to May (Bruno *et al.*, 1979); along the Catalan coast and Gulf of Lions, the spawning season lasts all year long with

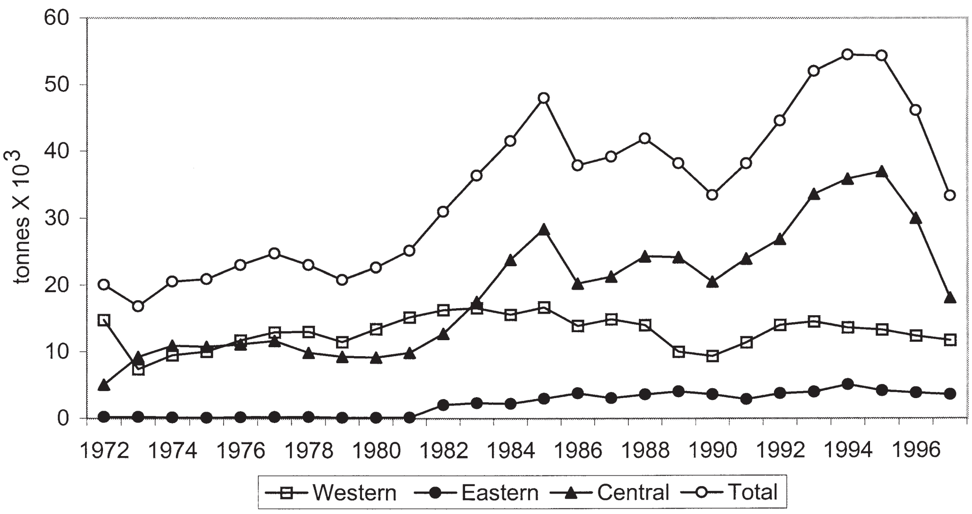

FIG. 1. – Mediterranean catches of hake (in tons) based on FAO data.

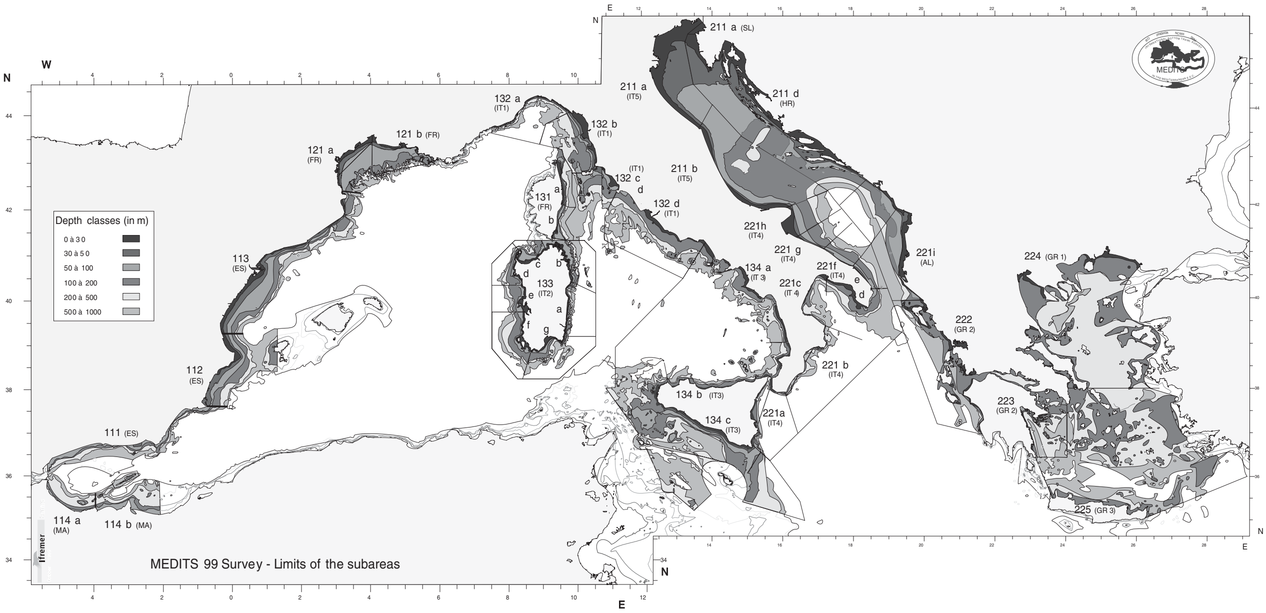

FIG. 2. – MEDITS geographical sectors (111 to 225) with indications of partner countries (in parenthesis) and their shelf and slope surfaces.

a peak in autumn (Recasens *et al.*, 1998). In the Eastern Mediterranean different authors have presented a variety of results (Papaconstantinou and Stergiou, 1995): spawning periods are long, frequently lasting throughout the year, with autumn-winter and spring peaks. In the Greek seas, recruits appear in trawl catches in summer and through to early autumn, in well-defined areas such as Saronikos, Patroikos, Siggitikos and also in certain locations in the north and south Aegean Sea and the Ionian Sea (Papaconstantinou, 1999). Also, reproductive sizes and growth rates vary in different Mediterranean sectors. The biological parameters assumed in numerous stock assessments can be found in Fiorentino (2000).

In relation to fishing exploitation, such assessments generally agree with the opinion that hake populations are fully exploited or over-exploited (Fiorentino, 2000). However, given that in some areas yields have apparently been stable for some time (see Bertrand *et al.*, 2000a, for the Gulf of Lions), the "refuge theory" has been proposed (Caddy, 1993). According to this theory, the fact that the spawners are caught in small numbers ensures the rich recruitment which sustains the fishery. Therefore, an assessment framework which puts the emphasis on maintaining spawning stock biomass and on the stock-recruitment relationship, rather than on maximising yield per recruit, has been suggested as a more appropriate basis for scientific management (Caddy, 1993). Until now, the stock-recruitment relationships (Alegría Hernández and Jukic, 1992) have not been exhaustively studied.

The MEDITS trawl survey represented an important occasion to work on homogeneous data from a series of surveys which were accurately standardised and covered the western, central and eastern Mediterranean. This paper deals with some general results. Biomass and abundance indices, recorded from the Alborán Sea to the Aegean Sea and in a depth range of 800 m during six consecutive years, are illustrated as well as their general trends.Size structures of the fished stocks are analysed in two main strata (continental shelf and slope) and total mortality coefficients are derived. The distribution of very young individuals (6-9 cm total length) is studied in order to show the most important summer nursery areas. As in few cases in the Mediterranean literature, the explored area is large enough to give evidence to regional differentiations; those concerning recruitment patterns represent an interesting contribution to the problem of stock identification.

MATERIAL AND METHODS

Within the framework of the "MEDITS" project six annual bottom trawl surveys were performed from 1994 to 1999 in the Mediterranean Sea, covering 40 sub-areas belonging to 15 geographical sectors (Bertrand *et al.*, 2000b, 2002) (Fig. 2). At the beginning (1994), the project included four Euro-

TABLE 1. – Area name, code, total surface and percentage of the total area for the shelf and slope strata in the different surveyed geographic sectors.

	shelf	area (km^2)	%	slope	area (km^2)	%
Alborán Sea	11101	3809	1	11104	8944	4
Alicante Sector	11201	8527	3	11204	7401	4
Catalan Sea	11301	12702	5	11304	3876	2
Gulf of Lions	12101	6212	2	12104	2608	1
Ligurian and Northern-Central Tyrrhenian Sea	13201	20588	8	13204	19778	10
Sardinian Sea	13301	16186	6	13304	9879	5
Southern Tyrrhenian Sea	13401	7362	3	13404	12893	6
Sicilian Channel	13411	19621	7	13414	29077	14
Central-Northern Adriatic Sea-Slovenia	21101	55684	20	21104	4850	2
NE Adriatic-Croatia	21116	29318	11	21119	2409	1
Southern Adriatic Sea	22121	11464	4	22124	2617	1
South-Eastern Adriatic Sea - Albania	22141	4985	2	22144	3750	2
Eastern Ionian Sea	22201	9817	4	22204	7006	3
Argosaronikos	22301	10197	4	22304	14719	7
Northern Aegean Sea	22401	32957	12	22404	35200	17
Southern Aegean Sea	22501	22277	8	22504	40324	20
Total		271706			205331	

TABLE 2. – *Merluccius merluccius*: Mean biomass (in kg km^{-2}) estimated from the MEDITS trawl surveys by depth stratum, geographical sector and year (1994-1999). Not sampled strata are indicated by *. Values higher than 100 kg km^{-2} are presented in bold.

		1994 Depth (m)					1995 Depth (m)					1996 Depth (m)				
Sector code	Sector	10-50	50-100	100-200	200-500	500-800	10-50	50-100	100-200	200-500	500-800	10-50	50-100	100-200	200-500	500-800
111a	Alborán Sea	13.0	27.3	19.2	9.8	0	41.9	2.4	13.5	1.8	1.2	18.7	23.1	30.2	16.4	3.8
112a	Alicante	5.9	11.0	35.2	1.9	0	1.7	3.7	17.2	4.5	2.8	5.6	23.0	50.7	7.0	7.2
113a	Catalan Sea	11.1	23.7	50.5	5.0	0	5.5	6.3	23.6	2.7	3.5	37.8	35.4	34.9	14.7	2.1
114a	W Morocco	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
114b	E Morocco	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
121a	W Gulf of Lions	23.7	32.3	71.7	22.9	0	23.5	30.3	51.3	37.7	5.9	20.5	24.8	24.5	6.9	16.6
121b	E Gulf of Lions	64.7	46.8	58.9	4.6	6.5	28.8	29.2	96.7	74.9	38.0	9.4	19.1	36.6	83.9	0
131a	NE Corsica	*	0.0	56.9	25.6	1.1	*	0.0	15.7	50.7	13.5	*	1.6	10.9	14.6	4.5
131b	SE Corsica	*	4.6	15.7	4.3	0	*	1.1	0.4	22.4	0	*	1.6	2.7	13.3	16.0
132a	N Ligurian Sea	1.8	34.2	**104.1**	5.6	8.2	17.6	41.0	**113.7**	14.4	5.0	1.7	19.7	66.3	8.0	3.3
132b	E Ligurian Sea	9.5	24.9	53.0	40.9	0	7.5	29.6	49.3	13.4	0	7.8	37.4	56.5	38.3	2.1
132c	N Tyrrhenian	9.1	32.5	21.2	37.0	0.4	12.4	43.9	118.4	89.0	4.7	5.2	22.6	40.3	29.3	5.2
132d	C Tyrrhenian	3.6	20.5	22.2	25.8	1.5	14.7	35.0	56.6	48.0	4.9	7.5	19.1	60.0	19.1	4.9
133a	SE Sardinia	3.3	13.0	53.6	33.3	7.2	0	4.2	10.7	10.5	6.7	1.0	0.0	31.8	41.9	14.0
133b	NE Sardinia	0	5.0	50.9	7.5	2.7	0	1.8	1.2	27.4	2.5	0.3	3.4	7.5	7.6	5.0
133c	N Sardinia	6.3	54.3	**262.9**	22.8	50.7	6.4	12.8	26.5	63.8	0.8	0.8	37.5	31.6	48.6	0.9
133d	NW Sardinia	0	**307.5**	**245.6**	52.7	0.7	*	67.6	67.4	1.8	18.7	3.7	**137.0**	85.3	42.2	6.8
133e	W Sardinia	1.8	*	**110.7**	81.7	4.4	1.0	80.6	77.2	56.0	15.1	1.7	70.7	**119.2**	49.0	9.7
133f	SW Sardinia	1.6	58.6	**145.9**	**457.5**	13.7	46.2	77.5	56.1	18.9	7.9	36.2	17.1	**125.9**	**175.4**	17.7
133g	S Sardinia	4.6	8.0	6.7	39.6	5.8	0	*	75.8	68.4	12.2	0	1.3	48.4	61.4	27.1
134a	SE Tyrrhenian	8.2	20.4	35.2	13.0	3.7	12.2	22.3	55.2	16.8	0.6	11.5	14.8	25.2	12.6	0.9
134b	SW Tyrrhenian	0	12.0	27.0	22.0	0	1.4	45.3	59.0	43.1	2.0	0.3	37.2	46.7	12.0	4.0
134c	Sicilian Chan.	25.5	45.6	32.9	40.5	8.6	18.2	50.8	32.1	31.6	6.3	3.3	30.4	19.2	20.4	7.8
211a	N Adriatic Sea	44.9	45.8	*	*	*	38.0	50.9	*	*	*	14.1	31.7	*	*	*
211b	Central Adriatic	23.1	37.7	45.5	85.5	0	36.0	58.2	88.3	65.1	0	19.3	36.9	66.3	52.7	60.0
211c	N Adriatic-Slov	*	*	*	*	*	64.8	*	*	*	*	3.9	*	*	*	*
211d	NE Adri Croatia	*	*	*	*	*	*	*	*	*	*	44.0	80.3	**123.9**	85.9	*
221a	E Sicily	4.7	**123.2**	30.8	7.9	0	50.1	36.6	22.7	1.4	0	13.9	61.8	35.3	13.7	0
221b	NW Ionian Sea	0.5	73.6	35.7	56.6	8.7	30.2	63.4	41.1	26.1	4.4	21.8	62.1	23.2	24.6	3.1
221c	N Ionian Sea	27.5	62.8	79.5	25.9	10.2	20.7	40.5	59.2	6.0	0	1.0	**140.1**	28.6	7.8	0
221d	N Ionian Sea	*	57.5	18.4	19.6	5.6	41.9	8.9	40.5	18.5	0	73.4	77.7	21.9	17.5	4.9
221e	SW Adriatic	0	48.8	17.3	26.8	48.5	*	67.8	71.3	32.4	6.9	*	77.1	66.5	31.4	15.6
221f	SW Adriatic	21.8	26.8	26.2	6.2	17.9	7.3	20.7	34.0	0.6	0	18.0	30.8	21.8	14.1	0
221g	SW Adriatic	0	8.6	7.1	*	**105.8**	3.0	17.2	14.3	*	21.2	8.1	14.0	9.3	*	0
221h	SW Adriatic	7.0	13.1	27.8	24.5	**103.9**	29.6	32.9	63.5	54.5	1.5	22.5	10.1	42.7	74.6	11.0
221i	SE Adriatic	*	*	*	*	*	*	*	*	*	*	31.0	52.8	69.1	23.7	10.2
222a	E Ionian Sea	18.8	31.2	21.7	18.1	8.2	64.5	31.3	**126.4**	**112.3**	43.3	2.4	24.0	59.5	65.6	12.9
223a	Argosaronikos	0	**196.2**	9.3	29.5	0	0	**155.7**	**262.6**	38.6	0	0	**179.4**	**251.9**	34.5	31.4
224a	N Aegean Sea	15.6	39.2	35.3	37.6	15.1	12.6	21.0	4.8	11.6	13.2	13.0	28.2	27.0	48.7	3.3
225a	S Aegean Sea	0	25.6	**126.0**	54.6	10.2	0	4.8	33.0	30.5	25.5	0	11.1	42.5	32.3	0.7

TABLE 2 (Cont.). – *Merluccius merluccius*: Mean biomass (in kg km $^{-2}$) estimated from the MEDITS trawl surveys by depth stratum, geographical sector and year (1994-1999). Not sampled strata are indicated by *. Values higher than 100 kg km $^{-2}$ are presented in bold.

		1997 Depth (m)					1998 Depth (m)					1999 Depth (m)				
Sector code	Sector	10-50	50-100	100-200	200-500	500-800	10-50	50-100	100-200	200-500	500-800	10-50	50-100	100-200	200-500	500-800
111a	Alborán Sea	44.8	6.9	19.2	20.1	4.0	52.0	9.5	5.5	7.2	1.1	10.4	7.6	29.9	1.2	0
112a	Alicante	17.8	19.9	39.0	4.9	0	12.2	22.6	20.9	4.9	0	7.2	14.7	29.3	2.5	0
113a	Catalan Sea	14.6	41.1	54.1	14.8	0	10.3	29.0	94.1	*	0	18.0	34.5	48.5	1.6	0
114a	W Morocco	*	*	*	*	*	*	*	*	*	*	*	37.1	13.9	8.2	0
114b	E Morocco	*	*	*	*	*	*	*	*	*	*	1.2	0.0	12.6	3.6	3.9
121a	W Gulf of Lions	7.1	15.5	13.6	3.3	5.5	34.9	56.6	16.4	25.7	5.8	22.3	34.2	20.2	2.6	0.1
121b	E Gulf of Lions	5.6	28.2	17.4	**157.4**	8.7	94.0	57.4	**136.5**	**139.6**	30.8	23.8	49.8	89.2	30.1	*
131a	NE Corsica	*	0	*	18.5	10.1	*	3.0	1.0	17.1	0	*	2.9	16.8	15.2	0
131b	SE Corsica	*	0	23.9	12.3	*	*	0.3	0.4	9.1	0	*	0	2.8	13.5	11.0
132a	N Ligurian Sea	19.9	30.4	26.2	10.7	7.7	19.5	62.5	**117.6**	13.0	1.4	18.2	19.6	52.8	14.5	8.7
132b	E Ligurian Sea	3.7	37.4	71.1	55.2	0	8.5	19.2	61.5	77.1	3.6	16.8	31.0	76.4	54.7	0
132c	N Tyrrhenian	9.5	33.1	**146.8**	58.3	5.0	12.9	34.6	62.5	**128.3**	3.5	12.2	59.6	**130.7**	**231.3**	10.0
132d	C Tyrrhenian	9.1	16.9	58.4	34.2	3.5	7.4	23.5	160.1	47.4	1.8	17.2	37.7	97.6	75.7	1.7
133a	SE Sardinia	0	1.6	63.7	31.8	13.2	0	1.4	7.8	21.9	17.4	12.5	2.3	54.4	40.4	12.8
133b	NE Sardinia	0	21.2	10.5	9.8	1.7	3.9	10.6	11.2	9.6	0	0.6	10.7	7.4	22.5	12.6
133c	N Sardinia	14.7	16.5	48.7	35.4	0	13.7	13.7	75.9	20.3	0	48.0	71.7	**260.3**	**240.8**	11.4
133d	NW Sardinia	0	**140.1**	**201.4**	12.8	1.9	0	14.3	94.2	1.9	6.1	0	**546.6**	**145.6**	**123.3**	0
133e	W Sardinia	61.8	0.0	68.2	86.4	7.5	2.2	84.7	28.8	18.3	13.6	0.5	**541.3**	**429.5**	**108.2**	17.2
133f	SW Sardinia	19.8	64.0	82.5	38.7	11.6	10.9	30.4	36.4	**158.0**	3.6	59.2	**168.9**	**209.1**	**235.9**	2.7
133g	S Sardinia	0.5	6.8	42.3	39.0	13.4	2.2	3.5	37.6	28.5	4.9	3.0	6.3	**326.9**	76.4	2.7
134a	SE Tyrrhenian	33.2	36.7	46.6	22.1	1.0	0.7	14.2	33.6	9.9	0.9	2.1	34.4	54.9	24.6	0.8
134b	SW Tyrrhenian	2.0	15.3	29.0	15.6	0.6	0.3	14.9	18.5	25.4	1.6	0	54.3	54.2	23.7	0
134c	Sicilian Chan.	7.0	35.0	32.7	26.7	3.1	13.1	25.2	23.1	28.4	2.0	12.8	26.0	23.2	30.4	8.4
211a	N Adriatic Sea	11.1	42.5	*	*	*	8.1	28.2	*	*	*	5.9	29.3	*	*	*
211b	Central Adriatic	7.6	27.5	57.3	53.6	14.1	13.7	21.7	36.2	23.1	*	23.8	60.3	49.0	34.7	*
211c	N Adriatic-Slov	8.9	*	*	*	*	0	*	*	*	*	0	*	*	*	*
211d	NE Adri Croatia	40.6	**101.2**	97.3	28.0	*	30.7	**109.2**	36.0	15.1	*	0	*	*	*	*
221a	E Sicily	0	4.0	63.7	50.2	4.5	6.7	44.3	3.2	27.2	0	0	20.1	33.4	38.0	0
221b	NW Ionian Sea	3.0	15.8	15.0	19.0	4.2	13.9	22.6	24.8	4.3	1.1	3.4	14.0	24.8	2.1	1.8
221c	N Ionian Sea	9.8	32.8	29.0	6.0	0	41.5	24.6	11.7	0.5	0	5.5	38.2	46.3	7.6	0
221d	N Ionian Sea	51.9	74.6	29.3	16.4	8.5	**115.3**	20.6	12.3	21.2	0.7	19.6	3.4	7.8	4.8	2.2
221e	SW Adriatic	*	80.3	74.8	57.3	10.1	*	41.8	42.2	8.2	22.4	*	48.6	12.3	45.3	2.8
221f	SW Adriatic	7.1	6.1	18.2	38.2	28.4	2.9	17.7	22.2	2.4	0	0	22.6	20.4	33.3	0
221g	SW Adriatic	6.5	9.0	12.0	*	3.1	2.8	6.4	13.7	*	**133.2**	2.2	10.4	11.9	*	19.8
221h	SW Adriatic	9.5	5.8	27.0	42.0	31.9	8.4	7.7	32.8	16.2	15.9	14.2	21.8	33.4	9.1	22.7
221i	SE Adriatic	17.9	59.8	45.4	26.7	5.9	11.3	29.9	18.9	10.3	6.6	16.4	19.1	11.6	9.2	17.9
222a	E ionian Sea	0	18.1	37.4	52.4	16.5	13.7	24.6	17.9	15.1	3.2	5.2	22.9	6.0	8.3	20.3
223a	Argosaronikos	24.7	**114.5**	**141.5**	87.9	20.8	13.4	**168.0**	50.2	77.1	14.8	5.9	**236.4**	**182.5**	9.9	34.9
224a	N Aegean Sea	55.5	37.1	27.7	92.1	44.3	37.7	31.5	28.0	77.6	30.3	**101.0**	68.5	56.5	73.1	4.0
225a	S Aegean Sea	0	17.1	29.9	24.5	22.8	0	5.7	35.1	44.9	55.0	0	11.7	19.4	33.2	62.1

pean Union countries: Spain, France, Italy and Greece. In 1996 it was enlarged to Croatia, Slovenia and Albania, and in 1999 to Morocco. Consequently, some trends will be illustrated for most but not all partners. The surveys, which were aimed primarily at obtaining estimates of abundance indices for a series of target species, were carried out from late spring to mid summer, and each of them included sampling at approximately 1000 pre-defined stations (total number sampled in six years = 6,336). The selection of stations was based on a depth-stratified sampling scheme that included five depth strata: 10-50, 50-100, 100-200, 200-500 and 500-800 m. Hauls were positioned randomly in each stratum in number proportional to the area of the stratum. The areas of shelf and slope of each sector are shown in Table 1. The net had 20 mm stretched meshes in the codend. Hauls were performed during daylight hours and their duration was fixed to half an hour on the shelf trawling grounds and to one hour on the slope. Collected data included number, weight, gonad maturation stage and total length measurements for the target species (a total of 30, including *M. merluccius*). The same gear and sampling protocol were used in all cases (for more details see Anonimous, 1998, Bertrand *et al.*, 2000b, 2002).

Data analysis

From the collected data, abundance indices by sub-area, year and depth stratum were computed and expressed in terms of both number of individuals (N) and weight (kg) per square kilometre.

Generalized linear modelling (GLM) (McCul-

TABLE 3. – *Merluccius merluccius*: Mean abundance (ind. km $^{-2}$) estimated from the MEDITS trawl surveys by depth stratum, geographical sector and year (1994-1999). Not sampled strata are indicated by *. Values higher than 10000 ind. km $^{-2}$ are presented in bold.

		1994 Depth (m)					1995 Depth (m)					1996 Depth (m)				
Sector code	Sector	10-50	50-100	100-200	200-500	500-800	10-50	50-100	100-200	200-500	500-800	10-50	50-100	100-200	200-500	500-800
111a	Alborán Sea	238	429	627	50	0	467	83	696	16	1	241	377	1189	533	3
112a	Alicante	288	568	2883	9	0	200	174	1645	108	2	309	621	5292	290	8
113a	Catalan Sea	682	2392	4728	198	0	156	588	1672	12	3	1191	2670	1907	186	3
114a	W Morocco	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
114b	E Morocco	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
121a	W Gulf of Lions	1327	3310	**10922**	168	0	1703	2504	4418	209	6	2260	1515	218	91	11
121b	E Gulf of Lions	1491	2908	3007	15	7	1267	1816	**15180**	362	27	1168	1762	5875	1023	0
131a	NE Corsica	*	0	844	696	3	*	0	143	405	11	*	28	158	215	8
131b	SE Corsica	*	54	171	9	0	*	11	19	45	0	*	27	44	40	16
132a	N Ligurian Sea	46	1481	4936	99	10	463	1153	8354	343	18	31	318	5687	100	3
132b	E Ligurian Sea	196	533	5081	990	0	123	1140	2536	474	0	184	1889	5489	2690	2
132c	N Tyrrhenian	249	656	1588	2113	2	341	2872	**17840**	7211	3	173	1112	4633	1847	8
132d	C Tyrrhenian	104	493	2223	2278	3	705	3380	6865	6022	97	325	1380	7051	2035	3
133a	SE Sardinia	46	177	524	298	5	0	30	104	146	5	16	0	330	290	26
133b	NE Sardinia	0	58	409	80	3	0	11	21	36	5	6	60	43	158	8
133c	N Sardinia	59	527	4313	473	324	48	113	349	722	30	24	280	833	3334	134
133d	NW Sardinia	0	4492	4793	894	12	*	1266	1133	52	38	85	3011	2563	1798	22
133e	W Sardinia	27	*	1449	869	13	13	1478	1452	1627	716	21	1552	5102	4280	54
133f	SW Sardinia	41	929	1255	**18076**	63	983	1163	2431	368	144	1011	354	3510	**10201**	218
133g	S Sardinia	29	64	57	763	118	0	*	1203	729	81	0	46	955	862	191
134a	SE Tyrrhenian	234	1159	3435	529	9	467	698	4807	412	2	442	1232	2766	444	2
134b	SW Tyrrhenian	0	385	969	480	0	45	1148	2813	2572	61	6	455	1500	374	6
134c	Sicilian Chan.	987	443	1655	1775	21	414	562	594	944	20	63	380	915	812	20
211a	N Adriatic Sea	672	523	*	*	*	396	562	*	*	*	125	432	*	*	*
211b	Central Adriatic	828	843	1084	823	0	754	1188	2784	1294	0	314	812	2051	1052	32
211c	N Adriatic-Slov	*	*	*	*	*	301	*	*	*	*	24	*	*	*	*
211d	NE Adri Croatia	*	*	*	*	*	*	*	*	*	*	634	1054	3128	6355	*
221a	E Sicily	79	1606	475	67	0	623	643	1683	37	0	175	1101	2455	136	0
221b	NW Ionian Sea	16	2097	1437	1867	8	410	1057	508	500	13	348	1285	429	387	4
221c	N Ionian Sea	526	1058	3071	345	7	405	773	1508	19	0	14	1628	1123	31	0
221d	N Ionian Sea	*	1276	49	232	10	566	116	919	259	0	1363	1688	235	223	4
221e	SW Adriatic	0	1107	554	284	84	*	1535	1555	430	5	*	1837	1059	168	18
221f	SW Adriatic	335	535	707	22	29	406	445	677	12	0	990	1896	347	44	0
221g	SW Adriatic	0	218	216	*	129	145	411	294	*	20	774	825	296	*	0
221h	SW Adriatic	208	230	804	852	84	908	790	2529	1211	2	1230	448	1273	1495	5
221i	SE Adriatic	*	*	*	*	*	*	*	*	*	*	336	539	1549	247	6
222a	E Ionian Sea	274	289	180	68	19	884	363	615	420	29	27	462	956	817	6
223a	Argosaronikos	0	1723	359	215	0	0	3972	9887	735	0	0	1459	8587	235	27
224a	N Aegean Sea	132	265	377	202	20	142	245	75	82	7	334	269	440	284	3
225a	S Aegean Sea	0	273	961	323	24	0	95	533	309	53	0	209	1473	866	5

lagh and Nelder, 1989) was used to analyse trends of hake biomass and abundance (number of specimens) in relation to country, year and depth stratum area. Given the complexity of the data (in terms of strata and years), only the four countries forming the initial MEDITS team were studied: Spain, France, Italy and Greece. A GLM provides a way of estimating a function of the mean response (called the link function) as a linear function of the values of some set of predictors. The model used was:

glm [Log_{10}(hake biomass)] = β + Country + Year + Depth zone + Country*Year + Country * Depth zone + Year * Depth zone

with β being an intercept term. In GLMs the standard linearity assumption is extended to include any underlying probability distribution from the exponential family (including the Poisson, gamma, normal and binomial distributions). Appropriate link functions and error distributions were chosen on the basis of residual plots (McCullagh and Nelder, 1989). The probability distribution of the variables (biomass and abundance) was found to be log normal. We used Gaussian error distribution following an examination of diagnostic plots of the deviance residuals. All available variables and their first order interactions were initially included in the model. The models were considered as adequate to describe the trends for both variables, since the unexploited structure left in the residuals appeared only as noise. Backward stepwise elimination was used to select a set of significant covariates. In each model, only significant parameters were included, at the signifi-

TABLE 3 (Cont.). – *Merluccius merluccius*: Mean abundance (ind. km $^{-2}$) estimated from the MEDITS trawl surveys by depth stratum, geographical sector and year (1994-1999). Not sampled strata are indicated by *. Values higher than 10000 ind. km $^{-2}$ are presented in bold.

		1997					1998					1999				
		Depth (m)					Depth (m)					Depth (m)				
Sector code	Sector	10-50	50-100	100-200	200-500	500-800	10-50	50-100	100-200	200-500	500-800	10-50	50-100	100-200	200-500	500-800
111a	Alborán Sea	2080	381	1241	266	5	200	230	506	261	1	221	335	1749	15	0
112a	Alicante	411	951	5473	67	0	566	1386	2080	153	0	201	1124	4779	92	0
113a	Catalan Sea	1056	4081	5555	212	0	474	1898	9828	*	0	1131	2971	4933	63	0
114a	W Morocco	*	*	*	*	*	*	*	*	*	*	*	3088	60	14	0
114b	E Morocco	*	*	*	*	*	*	*	*	*	*	20	0	180	7	4
121a	W Gulf of Lions	212	456	398	748	3	1959	4346	1164	2261	12	1417	2312	1392	17	103
121b	E Gulf of Lions	613	943	905	5749	6	4285	2951	**12807**	6615	16	540	1187	2972	425	*
131a	NE Corsica	*	0	*	305	6	*	47	19	229	0	*	33	342	297	0
131b	SE Corsica	*	0	254	92	*	*	9	9	15	0	*	0	75	16	10
132a	N Ligurian Sea	312	1013	1442	180	11	488	7236	**23667**	84	2	514	770	2453	83	9
132b	E Ligurian Sea	111	830	3286	5123	0	634	556	**12194**	**14474**	5	519	487	5245	2280	0
132c	N Tyrrhenian	176	1684	**18720**	7377	3	561	4821	9818	**26482**	5	292	1928	**12553**	**15109**	10
132d	C Tyrrhenian	375	471	6215	3546	7	328	867	**16156**	2660	2	591	1459	**12832**	6552	2
133a	SE Sardinia	0	11	517	206	12	0	12	69	106	12	74	23	367	549	14
133b	NE Sardinia	0	255	88	136	3	26	74	94	145	0	7	78	231	363	7
133c	N Sardinia	422	220	3381	515	0	123	99	2551	1016	0	426	610	**17575**	2701	52
133d	NW Sardinia	0	2126	3453	216	4	0	252	1427	60	7	0	9102	4392	1448	0
133e	W Sardinia	1021	0	2786	2598	41	30	1136	875	234	45	7	7914	**11898**	2168	196
133f	SW Sardinia	307	1011	1855	1363	13	202	383	667	**11589**	10	2388	4152	7246	**14718**	6
133g	S Sardinia	15	147	1019	1160	201	43	23	473	484	6	52	95	**12156**	760	5
134a	SE Tyrrhenian	1453	2548	4572	1117	3	17	880	2247	140	1	51	681	4111	706	1
134b	SW Tyrrhenian	23	169	1563	553	3	12	258	475	1234	5	0	1141	1764	546	0
134c	Sicilian Chan.	377	429	1915	815	10	327	329	813	1098	4	154	348	750	1033	10
211a	N Adriatic Sea	88	360	*	*	*	76	300	*	*	*	38	274	*	*	*
211b	Central Adriatic	121	378	1400	1202	10	300	409	1479	719	*	606	767	1249	1028	*
211c	N Adriatic-Slov	24	*	*	*	*	0	*	*	*	*	0	*	*	*	*
211d	NE Adri Croatia	376	1327	3204	892	*	323	1498	1620	1198	*	0	*	*	*	*
221a	E Sicily	0	42	535	354	6	170	1256	291	255	0	0	110	502	216	0
221b	NW Ionian Sea	12	120	107	46	5	388	925	1187	18	1	34	204	172	31	1
221c	N Ionian Sea	111	654	694	15	0	904	544	979	5	0	112	631	5198	33	0
221d	N Ionian Sea	757	829	246	171	7	4916	524	346	422	2	709	94	1027	35	2
221e	SW Adriatic	*	1650	1112	327	14	*	753	1390	78	13	*	829	233	97	3
221f	SW Adriatic	86	138	280	78	44	233	316	898	21	0	0	461	284	237	0
221g	SW Adriatic	274	275	225	*	14	131	168	961	*	80	71	93	300	*	11
221h	SW Adriatic	158	88	554	1646	29	217	276	1365	210	18	383	363	717	328	14
221i	SE Adriatic	275	761	1427	209	5	131	384	285	40	10	719	373	372	205	17
222a	E Ionian Sea	0	125	177	314	41	89	326	317	257	7	81	404	195	317	33
223a	Argosaronikos	199	4028	3067	607	71	91	5070	1494	958	47	119	7737	6835	753	137
224a	N Aegean Sea	451	650	377	482	64	349	305	644	476	39	2719	1736	1096	446	9
225a	S Aegean Sea	0	89	622	403	95	0	48	389	486	188	0	91	272	480	232

cance level of 0.05, and using a stepwise backward method.

In addition, on the basis of the total length (cm) measurements taken from a representative number of individuals, the summary statistics together with the yearly percentage length-frequency distributions were estimated for each sub-area and major depth stratum (10-200, 200-800 m), corresponding to shelf and slope areas. Estimates were made using specifically developed software that takes into account the surface of each sub-area and depth stratum (Cochran, 1977; adapted by A. Souplet).

Mean lengths, standard deviation and coefficient of variation (CV) were derived from length-frequency distributions. Using LCCC (Length Converted Catch Curves, Gayanilo *et al.*, 1994), the coefficient Z of instantaneous total mortality was calculated for the 15 studied geographical sectors: this was a rough estimate in which sex distinction was not made and the growth function was common for all areas: parameters L_{inf} = 73 cm and K= 0.15 were estimated as average values taking into account Fiorentino's (2000) compilation in the context of the FAO-GFCM Stock Assessment Committee.

Length-frequency distributions were also used to point up recruitment events occurring shortly before the period during which the MEDITS surveys were carried out (May-July). The MEDITS recruitment patterns represent only part of the general recruitment processes in the Mediterranean hake populations, given the temporal limits of the surveys and the already mentioned variety of the reproductive seasons (see Introduction). Another limit of MEDITS data for recruitment studies is due to the fact

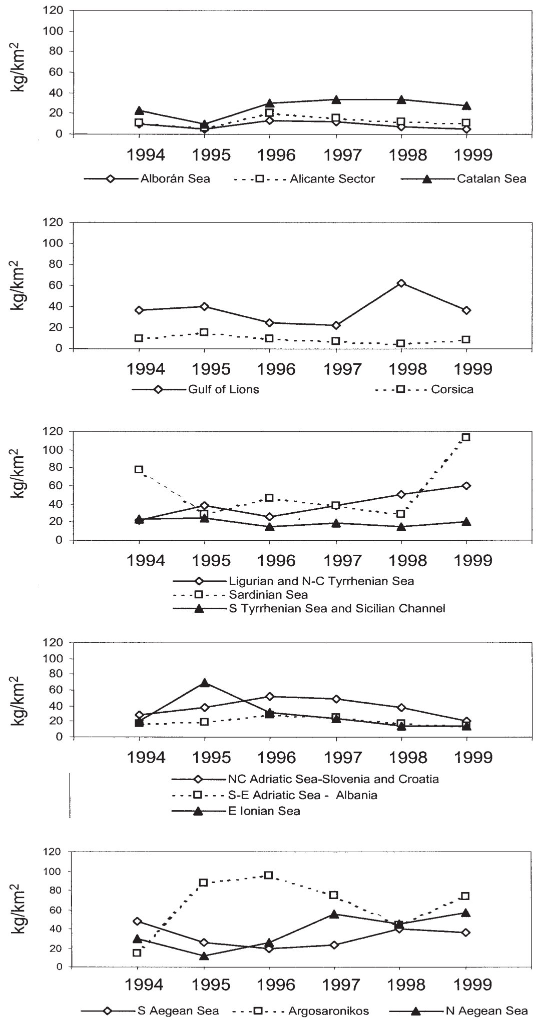

FIG. 3. – Average biomass recorded in the total depth range (10-800 m) in different sectors. Table 4 gives the result of the research of trends by the Pearson's correlation coefficient: only one, in bold, is significant (r = 0.89; p = 0.05).

that trawl surveys which are aimed at the youngest hake require a specific timetable of sampling in respect of the factor light (Orsi Relini *et al.*, 1997). So the following quantitative aspects must be considered only provisionally, in the sense that they are probably underestimated. On the other hand, given that MEDITS procedures were applied in the same way over a very large area and during several years, these provisional results assume a great relevance when they show patterns of regional differences.

In each geographical sector the Gaussian components of fish whose modal length was in the range 6-9 cm were isolated using Bhattacharya's method. The extracted numbers of juveniles were transformed in mean numbers per square kilometres for comparison among sectors. The same groups were also figured by geographical sector, year and main

TABLE 4. – Pearson's correlation coefficient between sampling year and hake biomass for the different geographical sectors studied. The only significant trend is presented in bold.

CODE	GEOGRAPHICAL SECTOR	r
111	Alborán Sea	-0.25
112	Alicante Sector	0.15
113	Catalan Sea	0.59
121	Gulf of Lions	0.23
131	Corsica	-0.65
132	Ligurian and N-C Tyrrhenian Sea	**0.89**
133	Sardinian Sea	0.27
134	S Tyrrhenian Sea and Sicilian Channel	-0.56
211	N-C Adriatic Sea	-0.19
221	S Adriatic and Ionian Sea	-0.25
222	E Ionian Sea	-0.51
223	Argosaronikos	0.24
224	N Aegean Sea	0.79
225	S Aegean Sea	-0.04

stratum (shelf and slope), after a standardization based upon a factor proportional to the area of each sector.

RESULTS

Biomass and abundance

The biomass and abundance of hake presented, respectively, as kg per km^2 and number of individuals (N) per km^2 in each sub-area, caught in the six MEDITS surveys per stratum and per year, are shown in Tables 2 and 3 (tables are presented along a west to east geographical gradient). Catch variability was high. The highest values of biomass (Table 2) were recorded in Sardinia, with peaks of more than 540 kg per km^2 and in the eastern sector, especially in Argosaronikos, with peaks of more than 260 kg per km^2. Significant quantities also appeared in the Tyrrhenian Sea, the Gulf of Lions, and in Croatian, Apulian and Ionian waters. Throughout the period studied, no figure higher than 100 kg/km^2 was registered in Spanish, Moroccan, Sicilian or northwestern and central Adriatic waters. Average biomass in the main geographical sectors showed increases and decreases (Fig. 3), but the research of statistically significant trends on the basis of the Pearson's correlation coefficient was generally negative; the only exception was found in sector 132 (Ligurian and north central Tyrrhenian Sea) (Table 4) where biomass slowly increased.

Maximum values of abundance in N per km^2 (> 20,000) were recorded in Ligurian-Tyrrhenian waters (Table 3). In general all values higher than

TABLE 5. – Number and size characteristics of hake sampled on the continental shelf and slope of each sector (1994-1999), with main size characteristics (minimum and maximum size recorded, average length with standard deviation and variability coefficient).

MEDITS code	SECTOR	Number (N)		Total length (cm) Min and Max				Average length (cm)		Stdev		CV (%)	
				shelf	slope	shelf	slope	shelf	slope	shelf	slope	shelf	slope
111	Alborán	1901	945	4	57	7	78	12.50	14.38	5.83	8.09	46.63	56.27
112	Alicante	7401	446	4	24	4	61	9.72	14.34	3.84	7.96	39.48	55.55
113	Catalan	20681	282	4	24	1	70	10.18	13.91	3.48	9.57	34.22	68.82
114	Morocco	640	25	7	31	27	60	12.37	37.31	4.58	8.18	37.05	21.93
121	Gulf of Lions	46602	5422	5	33	5	86	10.53	12.24	4.07	7.28	38.69	59.51
131	Corsica	206	1125	9	95	8	67	22.33	21.05	13.18	8.43	59.05	40.07
132	Ligurian and N Tyrrhenian	110084	120878	4	23	5	22	9.68	10.12	3.55	3.31	36.70	32.74
133	Sardinia	29532	49656	5	32	7	44	16.13	13.41	5.89	5.93	36.52	44.19
134	Sicily & S Tyrrhenian	22176	18560	4	38	5	32	11.77	13.26	5.00	6.02	42.44	45.41
211	N Adriatic	27239	5584	5	33	5	66	15.91	12.80	6.33	6.63	39.81	51.82
221	S Adriatic & W Ionian	18275	5567	5	37	1	82	15.31	18.94	6.21	9.78	40.59	51.63
222	E Ionian	1091	908	2	44	5	78	18.04	18.59	7.63	10.73	42.29	57.74
223	Argosaronikos	10282	1404	7	41	6	56	14.47	17.50	4.20	9.95	29.00	56.83
224	N Aegean	4400	3442	1	48	2	65	16.96	24.07	7.03	11.49	41.42	47.73
225	S Aegean	2338	4597	6	47	5	57	17.45	17.39	7.03	9.75	40.28	56.03
	TOTAL NUMBER 521687	302848	218839										

10,000 derived from areas 121 (Gulf of Lions), 132 (Ligurian and north central Tyrrhenian) and 133 (Sardinia).

Pooling the catches of the 15 main sectors to obtain absolute numbers, a total of 521,687 individuals were collected during the samplings, of which 302,848 on the continental shelf and 218,839 on the slope (Table 5). It is remarkable that 44.3% of these fishes were found in sector 132 (Ligurian and north central Tyrrhenian Sea), which represents, respectively, 8% and 10% of the overall shelf and slope of the MEDITS sea beds (Table 1). Second in terms of abundance (15.2% of the total catches) was area 133 (Sardinia), adjacent to the former, with, respectively, 6% and 5% of the overall shelf and slope MEDITS trawlable surface (Table 1). On the other hand, samples from one or both levels, shelf and slope, were very scanty in some areas.

GLM analysis of biomass, abundances, European Union countries, depth and years of sampling

Results of the GLM analysis are given in Tables 6 and 7. The significance level was set to 0.05. The model was considered to be strong, explaining more than 82% (in the case of biomass) and 90% (in the case of abundance) of the observed variation in the data (adjusted R squared statistic = 0.824 and 0.920, respectively). From the variables examined and their first order interactions, the main effect of year as well as its interactive effect with depth zone were not found to be statistically significant. *Depth zone*, *country*, *country*depth zone* interaction and *country*year* interaction were all statistically highly significant.

Figures 4-7 present the profiles of the estimated marginal means of the generalized linear model. Figure 4 shows the estimated marginal mean of the inter-

TABLE 6. – General results of the GLM analysis. Dependent variable: $\log_{10}$ (kg/km^2 + 1).

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Corrected Model	18.827	59	319	10.412	.000	.911
Intercept	211.619	1	211.619	6905.154	.000	.991
Year	7.538E-02	5	1.508E-02	.492	.781	.039
Country	4.296	3	1.432	46.731	.000	.700
Depth Zone	8.550	4	2.138	69.748	.000	.823
Country * Year	1.368	15	9.122E-02	2.977	.001	.427
Country * Depth Zone	3.530	12	.294	9.599	.000	.658
Year * Depth Zone	1.006	20	5.031E-02	1.642	.072	.354
Error	1.839	60	3.065E-02			
Total	232.284	120				
Corrected Total	20.665	119				

R Squared = .911 (Adjusted R Squared = .824)

TABLE 7. – General results of the GLM analysis. Dependent variable: $\log_{10}$ (N/km^2+1).

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Corrected Model	90.113	59	1.527	24.081	.000	.959
Intercept	774.154	1	774.154	12205.578	.000	.995
Year	.649	5	.130	2.045	.085	.146
Country	2.578	3	.859	13.549	.000	.404
Depth Zone	73.404	4	18.351	289.329	.000	.951
Country * Year	2.309	15	.154	2.427	.008	.378
Country * Depth Zone	9.914	12	.826	13.026	.000	.723
Year * Depth Zone	1.259	20	6.295E-02	.992	.484	.249
Error	3.806	60	6.343E-02			
Total	868.072	120				
Corrected Total	93.918	119				

R Squared = .959 (Adjusted R Squared = .920)

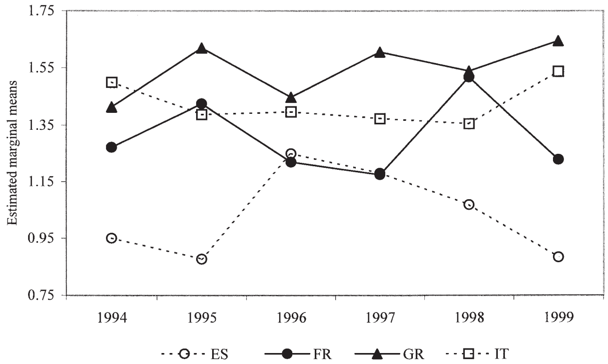

FIG. 4. – Results of the GLM analysis. Effect: *Country * Year*. Estimated marginal means of $\log_{10}$(kg/km^2+1) (ES=Spain; FR=France; GR=Greece; IT=Italy) (Lines are used to join scatter plots of each country only for easier interpretation).

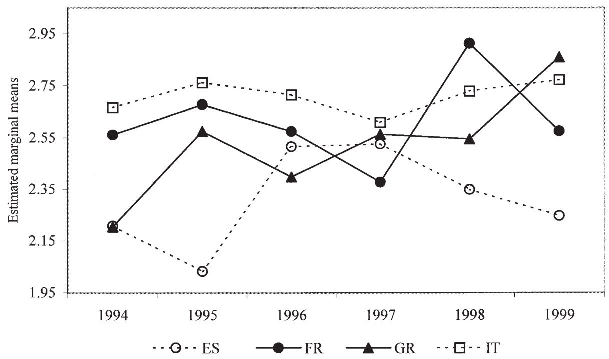

FIG. 6. – Results of the GLM analysis Effect: *Country * Year*. Estimated marginal means of $\log_{10}$(N/km^2+1) (ES=Spain; FR=France; GR=Greece; IT=Italy) (Lines are used to join scatter plots of each country only for easier interpretation).

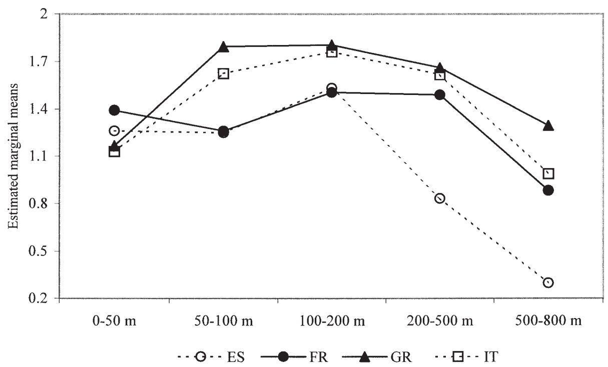

FIG. 5. – Results of the GLM analysis Effect: *Country * Depth Zone*. Estimated marginal means of $\log_{10}$(kg/km^2+1) (ES=Spain; FR=France; GR=Greece; IT=Italy (Lines are used to join scatter plots of each country only for easier interpretation).

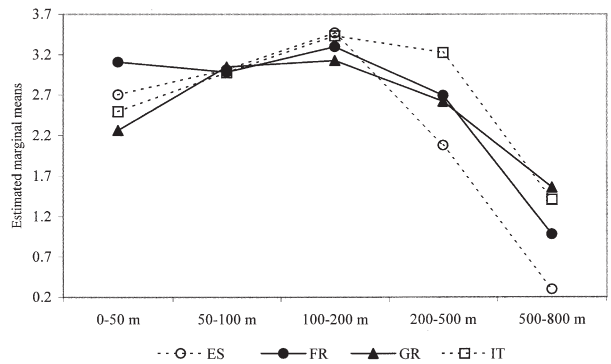

FIG. 7. – Results of the GLM analysis Effect: *Country * Depth Zone*. Estimated marginal means of $\log_{10}$(N/km^2+1) (ES=Spain; FR=France; GR=Greece; IT=Italy). (Lines are used to join scatter plots of each country only for easier interpretation).

active effect of *country*year* on hake biomass. Results demonstrate that the range of values of the estimated marginal means of the *country*year* effect in Italy (0.476) and Greece (0.544) were less dispersed than those in Spain (0.657) and France (0.610). This supports the idea that smaller interactive effects might be observed within, rather than between, these two groups of countries (i.e., IT-GR and ES-FR).

The interactive effect of *country*depth* zone is presented in Figure 5. Results show that the range of values of the estimated marginal means of the latter effect in Italy (0.776), Greece (0.641), and France (0.623) were less dispersed than those in Spain (1.236). In all three countries (Spain, France and Italy) the 500-800 m depth zone was found to carry the lowest hake biomass; in Greek waters this was observed in the 0-50 m depth zone. With the exception of its shallower waters (<50 m), Spain was found to have the lowest hake biomass compared to other countries. On the other hand, Greek waters with depths greater than 50 m carried the highest hake biomass. The 0-50 m depth zone had the least dispersed variation in the estimated marginal means of hake biomass.

Figure 6 gives the estimated marginal mean of the interactive effect of *country * year* on hake abundance, indicating significant interactions between years. With the exception of Italy, all other countries showed significant interannual variability in total hake abundance. Figure 7 shows that the 500-800 m depth zone had the lowest level of hake abundance in all countries. Thus, eliminating the factor z800 (depth zone 500-800 m), the range of values of the estimated marginal means between the four countries presents two groups of countries. The first is formed by France (0.606), Greece (0.865) and Italy (0.94), and the second is Spain (1.392). On the other hand, the 100-200 m depth zone carried the highest numbers of hake specimens. In general, the 50-200 m depth zones in all countries were characterised by the highest levels of hake abundance. These depth zones (i.e., 50-100 and 100-200 m) were also characterised by the lowest variability in hake abundance between countries.

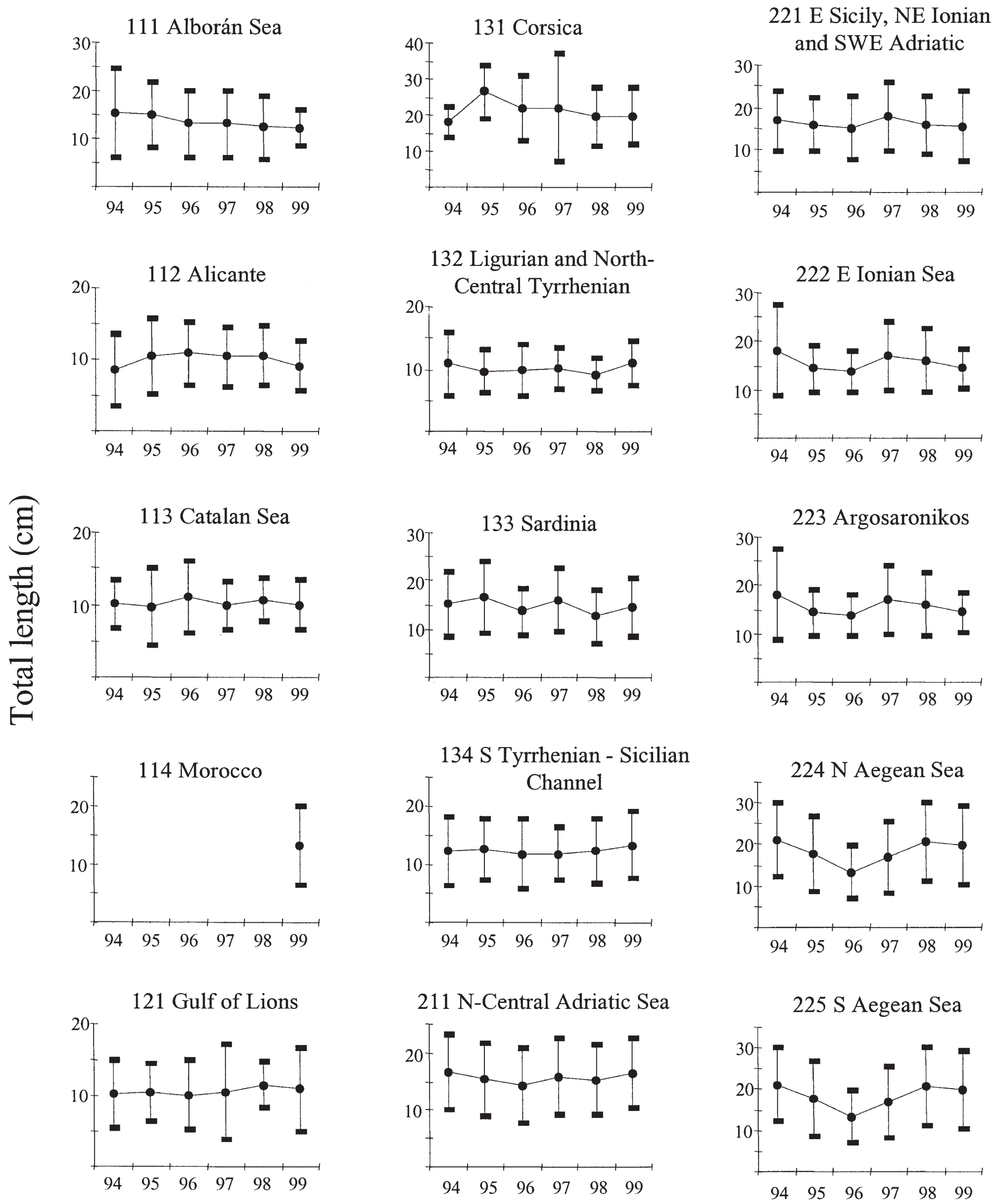

FIG. 8. – Trends of average length values (with standard deviation) recorded in the MEDITS geographical sectors during 1994-1999.

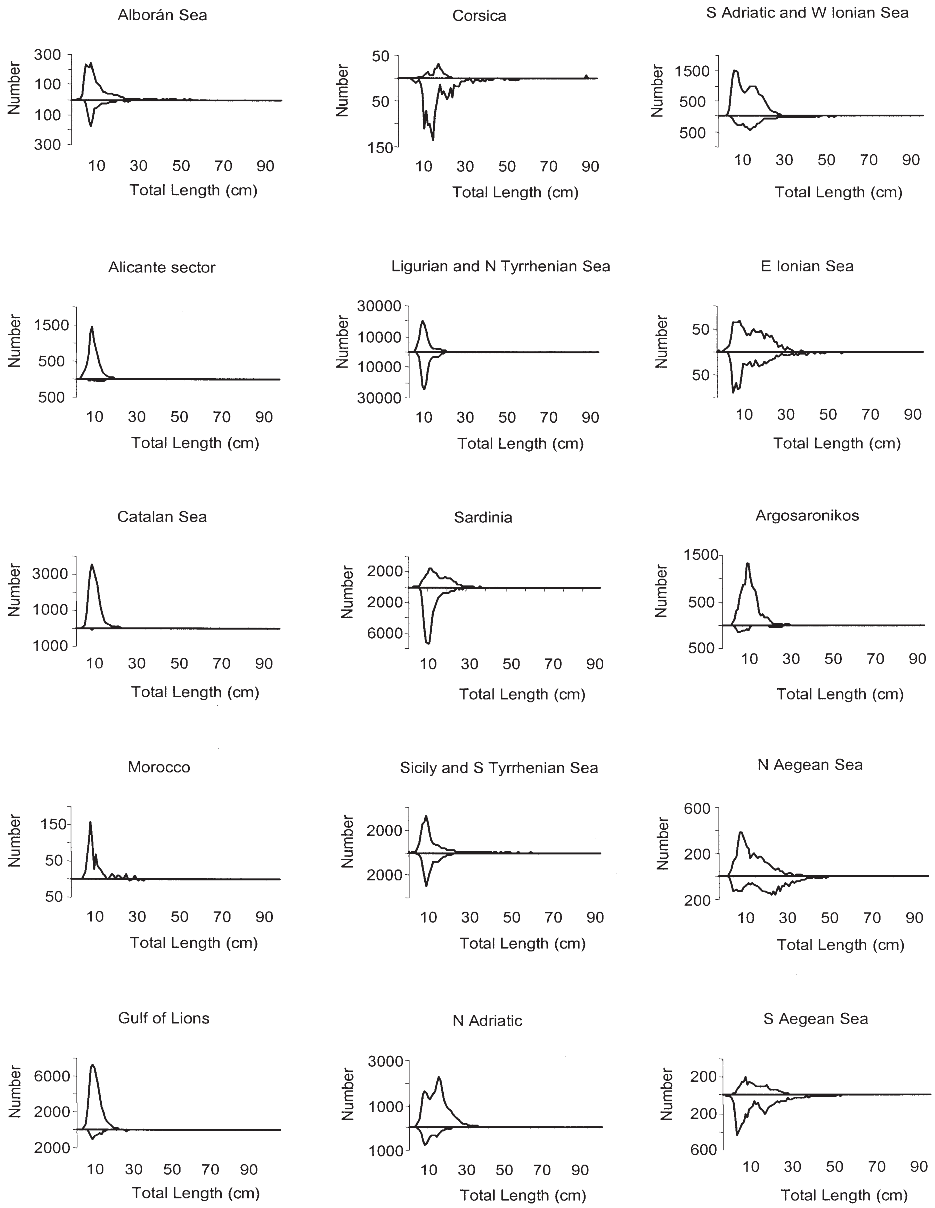

FIG. 9. – Length frequency distributions (TL in cm) of hake sampled on the continental shelf (upper values) and slope (lower values) in the MEDITS geographical sectors during 1994-1999.

Size analysis

Length analysis showed that in all surveyed areas, with the exception of Corsica, Sardinia, the northern Adriatic and southern Aegean Seas, average lengths on the slope were higher than on the shelf (Table 5). In the western Mediterranean, with the exception of Corsica and Sardinia, average lengths were lower than in the Adriatic, Ionian and Aegean Seas. Definite trends in average length were not detected, except in area 111, Alborán (a=-0.6681; b=15.833; R^2= 0.8789; Fig. 8).

Length-frequency distributions (Fig. 9) showed a general prevalence of small sizes, confirming the fact that the first age classes form the bulk of the fished stock. A considerable portion of larger sizes appeared in Corsica and Sardinia, and in the Ionian and Aegean Seas. On the other hand, a deficit of slope population seemed to characterize some segments of the Spanish coast.

Mortalities

The values of Z obtained for all MEDITS sectors are given in Table 8. They were, for all the investigated areas, fairly high. In some areas Z values exceeded 1, mostly in the case of western Mediterranean sectors: Alborán (1995; 1999), Alicante

TABLE 8. – Values of instantaneous coefficient of mortality (Z) estimated from length converted catch curve and correlation coefficient (r) of hake for the MEDITS area during 1994-1999. Values >1 are presented in bold.

MEDITS sector	1994 Z	1994 r	1995 Z	1995 r	1996 Z	1996 r	1997 Z	1997 r	1998 Z	1998 r	1999 Z	1999 r	average Z
Alborán	0.91	-0.94	**1.20**	-0.96	0.63	-0.93	0.96	-0.96	0.60	-0.75	**2.10**	-0.97	**1.07**
Alicante	0.82	-0.95	0.78	-0.89	0.79	-0.89	**1.48**	-0.93	**1.50**	-0.94	0.51	-0.95	0.98
Catalan	**1.45**	-0.91	**1.20**	-0.93	**1.01**	-0.96	**1.59**	-0.96	**1.44**	-0.90	**1.10**	-0.93	**1.30**
Morocco											0.91	-0.97	-
Gulf of Lions	0.83	-0.92	0.77	-0.91	0.59	-0.93	0.79	-0.92	0.74	-0.90	0.99	-0.97	0.79
Corsica	**1.58**	-0.90	0.57	-0.88	0.67	-0.88	0.46	-0.84	0.55	-0.82	0.79	-0.86	0.77
Ligurian and N Tyrrhenian	0.65	-0.89	0.76	-0.91	0.95	-0.95	0.83	-0.90	**2.48**	-0.97	**1.30**	-0.93	**1.16**
Sardinia	0.98	-0.95	0.84	-0.98	0.85	-0.93	0.97	-0.85	**1.19**	-0.96	0.88	-0.95	0.95
Sicily andS Tyrrhenian	0.71	-0.94	0.78	-0.95	0.86	-0.95	0.74	-0.87	**1.05**	-0.98	0.79	-0.96	0.82
N Adriatic	0.82	-0.97	**1.02**	-0.94	0.89	-0.96	0.94	-0.97	**1.30**	-0.99	0.98	-0.98	0.99
S Adriatic andW Ionian	0.51	-0.93	0.91	-0.94	0.61	-0.92	0.60	-0.96	0.82	-0.93	0.54	-0.91	0.67
E Ionian	0.57	-0.74	**1.01**	-0.97	0.67	-0.91	**1.44**	-0.99	0.79	-0.95	0.77	-0.97	0.88
Argosaronikos	0.88	-0.92	**1.02**	-0.91	**1.07**	-0.86	0.51	-0.95	**1.08**	-0.98	0.92	-0.84	0.91
N Aegean	0.62	-0.97	0.5	-0.89	0.57	-0.97	0.51	-0.95	0.54	-0.95	0.82	-0.97	0.59
S Aegean	0.82	-0.95	0.78	-0.98	0.96	-0.95	0.85	-0.98	0.9	-0.99	0.68	-0.98	0.83

(1997; 1998), Catalan (1994-1999), Corsica (1994), Ligurian (1998; 1999), Sardinia (1998), northern Adriatic (1995; 1998), east Ionian (1995; 1997) and Argosaronikos (1995; 1996; 1998). However, some of these values were probably influenced by the massive presence of juveniles; the absolute maximum value of 2.48 in the Ligurian and northern-central Tyrrhenian Seas in 1998 was clearly linked to the large number of recruits found in the area (Table 9 and Figs. 10 and 11). In the case of the Morocco sector, where assessment of Z was made on only one set of annual data, the obtained value (Z=0.91) also describes significant fishing pressure in bottom trawl fisheries.

Recruitment patterns

In the MEDITS length frequency distributions, groups of fish identified by their small modal length were recorded from 6 cm total length onward. Findings of recruits varied considerably from year to year (Table 9) and only on the shelf of two sectors, Alicante and Ligurian-Tyrrhenian, were recruits recorded every year. However, this variability was offset by taking six years into account and in every sector did recruits appear at least one time. In total, 50 distinct groups of recruits were found on shelf fishing grounds and 29 on those of the slope (Figs. 10 and 11). The groups on the shelf were formed by

Table 9. – Numbers of recruits (groups of fish identified by a modal length of 6-9 cm in length frequency distributions) derived from each geographical sector and year on shelf and slope fishing grounds. Estimated mean n/km^2 are also indicated.

SHELF	Alborán	Alicante	Catalan	Gulf of Lions	Ligurian and N-C Tyrrhenain	Sardinia	S Tyrrhenian	Sicily Channel	N-C Adriatic	Croatia	S -W Adriatic	Albania	E Ionian	Argosaronikos	N Aegean	S Aegean
1994	88	480	2056	4399	3700	0	1459	0	841		0		0	0	0	0
1995	0	227	824	0	13290	0	0	0	3379		1039		0	362	0	55
1996	50	993	1499	5421	6616	0	0	238	2515	1967	974	0	81	65	87	0
1997	259	785	3991	1711	9831	415	0	0	0	3009	0	277	0	0	0	0
1998	75	807	0	0	13303	0	712	203	0	0	770	0	34	0	0	0
1999	0	347	2752	2101	17209	1745	1576	0	1894	0	0	0	22	0	0	48
Estimated mean n/km^2	121	713	1196	770	2665	97	357	67	327	529	157	60	20	119	9	17
SLOPE																
1994	0	0	0	0	2186	0	0	0	0		0		0	0	0	0
1995	0	0	0	0	11441	0	0	0	165		0		0	0	0	80
1996	0	40	0	116	0	0	456	677	139	1702	0	0	0	0	122	524
1997	0	0	56	1717	0	173	1117	124	0	0	0	0	0	0	102	0
1998	0	10	0	818	34560	0	0	0	0	0	0	0	29	165	37	173
1999	0	34	0	25	0	0	0	0	0	0	0	0	113	0	0	210
Estimated mean n/km^2	0	12	8	446	1100	6	52	39	46	1418	0	0	14	23	15	78

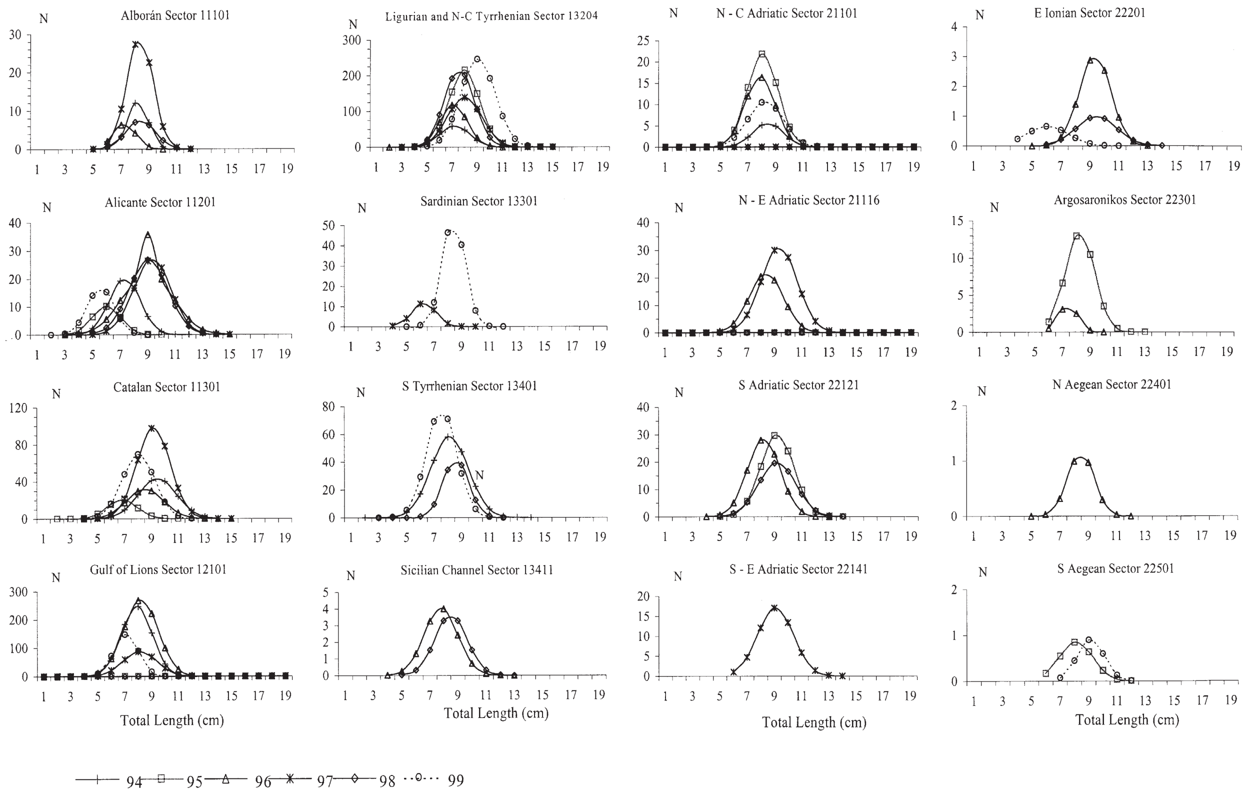

FIG. 10. – Gaussian components by year of the groups of recruits identified in length frequency distributions recorded on shelf fishing grounds. N are relative numbers, obtained by a factor proportional to the area of each sector.

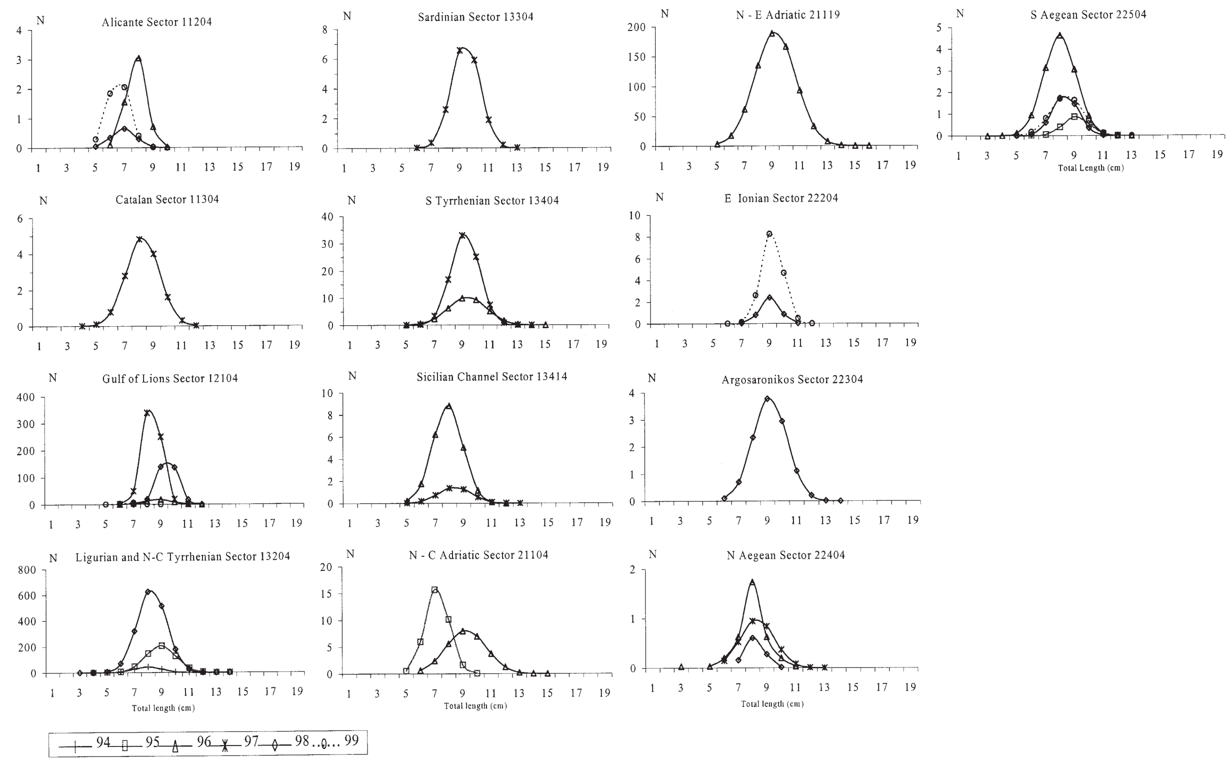

FIG. 11. – Gaussian components by year of the groups of recruits identified in length frequency distributions recorded on slope fishing grounds. N are relative numbers, obtained by a factor proportional to the area of each sector.

smaller fish and their absolute numbers were generally higher than on the slope (Table 9), indicating the fact that recruitment occurs in shelf waters and the fish, after some growth has taken place, move to the slope.

Analysis of the geographical distribution of recruits on the shelf in the western Mediterranean (Table 9 and Fig. 10) showed numbers increasing from Alborán (note the scales of the individual graphs in Fig. 10) to a maximum in the northern sectors (Catalan, Gulf of Lions and Ligurian-Tyrrhenian Sea); thereafter they decreased in the southern Tyrrhenian Sea and northern Sicily. In the central Mediterranean, only the northeastern Adriatic presented high numbers; those in the eastern sectors were poor. Slope fishing grounds adjacent to the most crowded shelf areas presented important numbers of recruits. On the slope (Fig. 11) of area 132 (Ligurian-Tyrrhenian) in 1998, recruits of a modal length of 8 cm reached considerable densities, including the absolute maximum.

DISCUSSION

On a basis of a total of 4,800 positive hauls, the MEDITS surveys have made it possible, for the first time, to study hake in an area corresponding approximately to three quarters of both the latitudinal and the longitudinal range of the Mediterranean. The study of such rich material has developed knowledge of the distribution and abundance patterns, thus highlighting general management implications which are in line with the MEDITS purposes. The study also has shown aspects revealing the biological diversity of the Mediterranean hake populations.

GLM results

The bathymetric distribution of hake in the Mediterranean Sea displays a wide range stretching from 25 to 1000 m depth. The species is mainly abundant, however, at depths ranging from 100 to 400 m. Hake abundance increases with depth, depending on size and latitude, while average body size of hake increases, in general, as depth increases.

Different authors have studied the bathymetric distribution of hake in the Mediterranean Sea, such as Massutí and Daroca (1976) off the Spanish coast, Tsimenidis *et al*. (1978) in the Aegean Sea, Vassilopoulou and Papaconstantinou (1987) in the Ionian, Zupanovic and Jardas (1986) in the Adriatic, Orsi-Relini *et al*. (1989) in the Ligurian Sea, Sartor *et al*. (1990) in the Tyrrhenian Sea, and Campillo *et al.* (1991) in the Gulf of Lions. Studies in the Ligurian Sea demonstrated that the nursery areas are situated from 50 to 250 m depth (with the main concentration located around 100 m), while the eggs and larvae appear in the pelagic environment at depths ranging from 50 to 150-200 m (Orsi-Relini *et al*. 1989). In the Gulf of Lions, distribution and abundance of age class 0, I and II have been studied using catch data from the trawler fleet (Campillo *et al.,* 1991). Main concentrations of group 0 were found from 100 to 150 m depth, whereas groups I and II appeared to be distributed along the continental shelf from 30 to 150 m. Regarding the distribution of young hake (age 0) in the Greek Seas, it was found that they appear in trawl catches in summer through early autumn, in well defined areas such as the Saronikos, Patraikos, Siggitikos and also in certain locations of the northern and southern Aegean and the Ionian (Vassilopoulou and Papaconstantinou, 1987; Papaconstantinou and Stergiou, 1995; Papaconstantinou, 1999), in depths varying between 110 and 250 m.

The results of the present study provided a quantitative basis for the division of the bathymetric distribution of hake in the Mediterranean Sea, since the depth zones, as well as the *Country * Depth Zone* interaction was found to be statistically significant. From Figures 5 and 6 it is obvious that both the abundance and the biomass exhibit minimum values in the 500-800 m depth zone, which is in accordance with the findings of other studies, indicating that the species displays a rather limited abundance in the Mediterranean in waters deeper than 500 m (Papaconstantinou and Stergiou, 1995; Oliver and Massutí, 1995). Highest abundance values coincide with the 100-200 m depth zone in which most nursery grounds in the Mediterranean are located, according to the results of the various studies, as well as of the findings from the present MEDITS programme. In relation to the distribution of the biomass and abundance in other depth zones, the greatest difference is found between biomass values in Spain and in the rest of countries, while in relation to abundance, minor differences appear. In general, it could be suggested that higher biomass/abundance values are found in Greece and Italy and then France, while lower values are shown in Spain.

The main determining feature associated with the structure of hake abundance is depth since it reflects the changes from the continental shelf to the continental slope. However, other biotic and abiotic characteristics do play a role in the depth distribution of hake between the four areas/countries. The main factors which possibly contribute to such a geographical differentiation is the fishery status in each area/country, correlated directly to the applied management scheme and the extent and bottom type of the continental shelf and slope in these countries. Nevertheless, the most important quantitative boundary for all areas was located at around 200 m, which separated the hake distribution between continental shelf and upper slope. At this depth, a remarkable increase with respect to hake biomass has been noted in Spain, Greece and Italy, while concerning abundance, the highest values were found in Spain, Greece and France. On the other hand, hake found in deep waters tend to have a much broader length range than those inhabiting the shallow depths.

Taking into consideration the smaller interactive effects which have been observed for the *country*year* effect on biomass and *country*depth zone* on abundance between Italy and Greece, it is suggested that the status of the hake stocks in the two countries is more similar in relation to other Mediterranean countries. This similarity could be possibly connected with certain abiotic and biotic factors prevailing in the eastern Mediterranean, as well as to the fishery management systems of the two countries. In fact, the management systems of Greece and Italy are quite close, exhibiting considerable differences, as compared to those established in Spain and France (ACC, 1994).

Nevertheless, in general, management measures (i.e. closed seasons and areas, limited issue of licenses, minimum legal landing sizes and mesh size regulation) seem to be inadequate. In fact, despite the enforcement of such measures, these resources appear currently overfished (Papaconstantinou and Stergiou, 1995; Oliver and Massutí, 1995). This must be attributed mainly to the multi-species, multi-gear nature of the Mediterranean fisheries, which pose certain difficulties in designing and implementing uniform protective measures. Based on the results of the MEDITS programme since 1994, the derived debate suggested a network of marine protected areas, established on nursery and spawning grounds of hake in the Mediterranean Sea. This should ensure that both juvenile and adult hake are protected against exploitation, as long as those areas amount to a "significant" proportion of the total habitat. Management options in those areas would include the creation of "no-takes" zones, limited access zones, control of fishing gears, introduction and management of fishing permissions etc.

Biomass and size structures

Considering the distribution of biomass and the observed size structures, where there is a dominance of young fish, as well as the calculated (albeit rough) estimates of Z, a general condition of growth overfishing is apparent. Fishing grounds which presumably are correctly fished, or at least less overfished and thus show rich biomass values, appear limited to some subareas of the central and eastern Mediterranean. On account of their high biomass indices, some western Sardinian fishing grounds, where trawling has developed more recently than in other Italian seas, would seem to represent the potential yield of hake when not overfished.

However, when trends of biomass and average size have been analysed – albeit in the brief time range of six years – no negative trend has been found (with the exception of the Alborán Sea). Consequently, the refuge theory (Caddy, 1993) is supported and also can be extended to large scale patterns. In fact, the slope around Sardinia could host a consistent number of spawners and the derived larval flow, given that main currents move toward the north, could enrich the Liguro-Tyrrhenian sector with unparalleled densities of juveniles. But in the eastern Mediterranean, the rich biomass of Argosaronikos is apparently not related, as shown later, to significant concentrations of young individuals in adjacent areas. Different reproductive seasons must be taken into account.

Recruitment patterns

Recruitment patterns have been analyzed on a detailed basis of areas and subareas, taking into account the fact that quantitative aspects registered in the MEDITS surveys are only facets of a more complex reality. Nevertheless, the analysis of recruitment processes has pointed out important regional differences in the surveyed area. Since the study carried out by Maurin (1965), very few papers have considered Mediterranean hake in relation to large areas of their distribution. In their review of world hake, Alheit and Pitcher (1995) considered two units: a western Mediterranean hake (Oliver and Massutí, 1995) and an eastern Mediterranean hake (Papaconstantinou and Stergiou, 1995), probably on the basis of the differences in growth rates which were available at that time in the literature (Oliver *et al.*, 1992; Tsimenidis *et al*., 1978). In this approach, the eastern Mediterranean hake was supposed to include the Ionian and the Adriatic Seas in its distribution area. MEDITS surveys, which take place in late spring-early summer, have exhaustively sampled recruits in the northwestern Mediterranean and in the northern Adriatic but not in the eastern Mediterranean and the southernmost explored areas of the central sector. This feature is in accordance with the different timing of recruitment already reported. In the Ligurian Sea, two recruitments per year, in spring and in autumn, were observed, with the former generally stronger than the latter. During spring, the 100-150 m depth interval hosted the most substantial densities of juveniles and during summer, the spring recruits began their descent along the slope (Orsi Relini *et al*., 1989 a and b). Also, recruitment in the Adriatic takes mainly place in spring, while in the eastern sector, at the time of the MEDITS survey, recruitment was only at its start and the fish were probably still dispersed and too small to provide significant samples.

So, MEDITS surveys have (1) highlighted the main nurseries of the western hake population. Positioned above 42° latitude N, in the Gulf of Lions and the Ligurian-Tyrrhenian Seas, these nursery areas correspond exactly to the core of the population subunit identified on the basis of the highest vertebral number in the Mediterranean (higher than 52, according to Maurin, 1965).

Moreover, MEDITS data suggest that (2) the population of the central Mediterranean is not homogeneous and the Adriatic is to be considered a northwestern “enclave”. The Adriatic hake, with its peaks of recruitment in spring (recorded by MEDITS) and autumn and a vertebral number of 51.99 (Piccinetti and Piccinetti Manfrin, 1971) is very close to the northwestern hake. Both recruitment patterns (hence reproduction) and vertebral numbers could be linked to latitudinal gradients, i.e. to physical factors such as temperature and light. In the case of hake, which generally lives under the thermocline, light is probably the most important factor. If these differences are phenotypic or genotypic is a matter for future research, but a recent study of four polymorphic loci in hake sampled in the Adriatic, Tyrrhenian, southern Sardinia and Sicily Channel (Lo Brutto *et al*., 1998) is apparently in line with the second hypothesis: in fact no differences were found, except in the case of one sample collected near Malta (which was interpreted as a casual effect, but could be referred to the Ionian hake, i.e. a transitional form to the eastern hake (vertebral number 51.87) according to the racial groups proposed by Maurin (1965). If such genetic results are confirmed, the Adriatic hake, and more in general the Italian hake populations, could be older than the present distribution of Italian seas i.e. than the last steps of the orogenesis of the Apennine Chain which isolated the Adriatic Sea.

In any case, the observed differences in the biology of hake populations have important management implications, especially if measures specifically addressed to juveniles are to be envisaged.

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