How fast does hake grow? A study on the Mediterranean hake (*Merluccius merluccius* L.) comparing whole otoliths readings and length frequency distributions data*

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SUMMARY: The hake (*M. merluccius*) is a target species of the Mediterranean trawl fleets. In this study, its growth was compared by two means: whole otolith readings and length frequency distribution analysis. Two growth hypotheses, fast and slow, were assumed using the results of otolith readings: (1) two rings were formed every year and (2) a single ring was formed every year. The monthly length distributions covered the period from 1992 to 1998, and the otoliths were obtained from monthly samplings between 1992 and 1995. The variability observed in the results for the number of rings counted was shown especially in the range of lengths for each group of individuals that had the same number of rings. A high correlation was found between the rings counted in the otoliths and the length of the individual in cm. The sex factor did not influence the relationship, unless the sexually undifferentiated individuals were included. The best fit with the growth data according to the length frequencies occurred in the two-ring hypothesis (*Hypothesis 1*), meaning faster growth rates than had been accepted till now, especially in females. We suggest the consideration of the hypothesis of faster growth in future studies.

Key words: growth, hake (*Merluccius merluccius*), Mediterranean.

INTRODUCTION

The hake *Merluccius merluccius* (Linnaeus, 1758) is a demersal species widely distributed on the European and Mediterranean coasts. In the study port of Santa Pola, most of the fishing activity from the Gulf of Alicante is concentrated. The hake landings caught by trawling, for the 1991-1994 period, averaged 385 t/year, while the monthly catches obtained varied around an average of 48 t/month, with the small sizes dominating (García-Rodríguez and Esteban, 1995). In other areas of the Mediterranean, it is also a target species for trawling, as well as for the long-line and gillnet fleets. In the case of trawling, the catches are characterised, as in the port of Santa Pola, by the dominance of a large proportion of small sizes (Martín *et al*., 1999; Aldebert and Recasens, 1996; Recasens *et al*., 1998).

In the Spanish Mediterranean the hake constitutes an important resource and consequently its biology has been widely studied. In addition to the population structure being determined (Recasens *et al*., 1998), some analyses of the exploitation patterns (Martín *et al*., 1999) and their rate in different areas

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have also been carried out (Recasens, 1992; Aldebert and Recasens, 1995; García-Rodríguez and Recasens, 1994; Oliver *et al.*, 1994; Recasens *et al.*, 1994; García-Rodríguez and Esteban, 1995; Aldebert and Recasens, 1996).

In these later studies specifically, the necessity to adopt uniform criteria has been demonstrated for the growth rates of the species, since this is a fundamental parameter for determining the age structures of the catches with any accuracy and for undertaking Virtual Population Analysis (VPA). Traditionally, growth studies have been carried out with two different methodologies: following the length structure through a period of time (distribution of length frequencies, LFD) and the study of hard structures, fundamentally otoliths, which gives growth ring counts from the complete otolith or from transverse sections.

Some growth studies using otolith readings have been carried out on the Mediterranean hake (Oliver *et al.*, 1989; Aldebert and Morales-Nin, 1992; Morales-Nin and Aldebert, 1997). In addition, some comparative studies have also been undertaken between the validity of the growth data obtained by the different methods (length frequencies distribution, complete otoliths and otolith sections readings) and it has been observed that there are differences between the data obtained from the study of the sections and the complete otolith, with a marked fit of the data from sections and the modal length frequencies (Piñeiro and Hunt, 1989) or whole otolith readings and length frequency distributions (Piñeiro and Pereiro, 1993). More recently, Morales-Nin *et al.* (1998) carried out a study of otolith growth and an estimate of Mediterranean hake age from sections, but concluded that there was no interpretable pattern in the detected rings that could be applied to age determination.

However, in spite of the existence of these studies, it was considered useful to carry out this particular study in order to compare age assessment methods for *M. merluccius* from growth ring counts in complete otoliths and by analysis of length frequency distributions, based on the length compositions by sex from landings during an extensive period and assuming two hypothetical growth patterns: rapid growth (*Hypothesis* 1) and slow growth (*Hypothesis* 2).

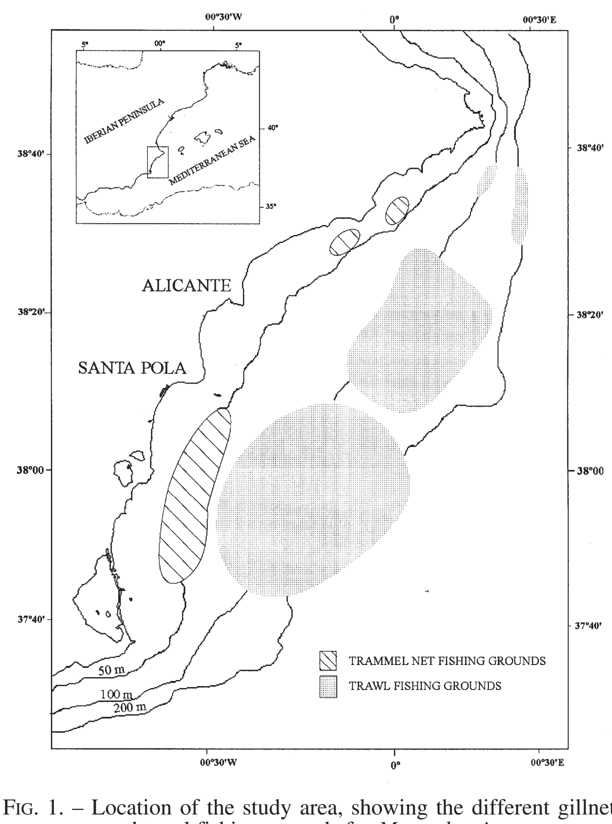

FIG. 1. – Location of the study area, showing the different gillnet and trawl fishing grounds for *M. merluccius*.

MATERIALS AND METHODS

Length compositions

The length frequency distributions used in this study were obtained from monthly samplings of hake carried out in the Port of Santa Pola from January 1992 to December 1998 on catches from the Gulf of Alicante (Fig. 1). Each sampling operation followed a random scheme stratified by the actual commercial categories present in the catch. The individuals were measured by total length to the nearest lower 0.5 cm The sampled individuals from each commercial category were weighed and the figures were extrapolated to the total number of individuals by commercial category caught by the sampled boat. In addition, the total daily catch for each boat of the trawling fleet was recorded by commercial category, giving the total monthly catch for the port by commercial categories. The monthly results were averaged, since not all the boats landed all the commercial categories daily. The results of the daily samplings were expanded to the monthly catch by commercial categories, thus giving a single monthly length frequency distribution for all months separately during the sampling period. The separation into sexes was carried out by applying a sex ratio by length class to each monthly length distribution. The sex ratio was obtained from the maturity by length curves calculated by García-Rodríguez and Esteban (1995), with data adjusted to a normal; the lengths at 50% maturity coincided with those found by Larrañeta (1970) for the species in a neighbouring area. To estimate the accuracy of the sampling, the official total landed weight was compared with the calculated weight. The latter was obtained by applying the corresponding length-weight relationship calculated by García-Rodríguez and Esteban (1995) to each length class of each sex.

The length-age relationship was expressed by the Von Bertalanffy Growth Function model (VBGF), and the parameters were calculated from the monthly length structure, smoothed with a running mean of 3 consecutive classes for the 1992-1998 period and for each sex separately. The analyses were performed over different groupings, the quarterly length distributions grouping and annual length distributions grouping, and finally following the length distributions of the summer cohort; the "best combination" being taken from the parameters obtained. The growth Performance Index (ϕ'), considering the asymptotic length, was also calculated for each group. All the calculations were made using the automatic FISAT calculation programme (subp. ELEFAN) (Gayanilo *et al.*, 1988).

Otoliths

The otoliths were extracted from one part of the sampled specimens. Subsequently, the growth rings were read from the collection of hake otoliths, sharing out undifferentiated individuals at 50% between males and females, which was composed of 3,522 pairs collected monthly between 1992 and 1995 using reflected light optical microscopy against a dark background. The readings were made on the complete otolith after it had been polished on its interior surface (sulcus) and placed for 24 h in a glycerine solution, and the opaque rings had been counted. Growth rings were taken as the opaque-hyaline pairs in each otolith.

Two independent readings were carried out and 1,235 otoliths, whose readings coincided for both, were used for the calculations, which represented 35% of the total number of processed otoliths. The mean length was calculated for each group in which the same number of rings was counted. Also, prior to the preparation for reading, the major and minor axes were measured (to the nearest 0.1 mm), with each otolith being weighed to the nearest 0.001 gram after drying to constant weight in an oven at 80º for 24 h.

Different regressions were established between otolith variables (major axis, minor axis and weight), as well as against the variables belonging to the individual (total length and total weight), by applying an allometric power equation (Lleonart *et al*, 2000). The border type, opaque or hyaline of each otolith was also recorded. For this, a total of 1,388 otoliths with two coincident readings of border type were used, and the data from the whole period were grouped into months. A significance test (Sokal and Rohlf, 1969) was also carried out to assess the monthly predominance of each border type. In addition, a linear regression was undertaken to express the number of rings that were counted against the total length of the individual in cm.

The covariance analysis (ANCOVA) was used to determine the influence of the sex of the individual and the quarterly period of the year on the different relationships found for length-length and weight-length. The ANCOVA analysis consisted of two tests: a test for the slopes and a test for the adjusted means. The first one was applied to detect whether the slopes of the regressions were different to each other and the second was applied, mainly if the test of the slopes was not significant, in order to verify the results. The selected model for the test of the slopes was $Y = A + X + (A*X)$, with Y being the dependent variable, X the covariant and A the chosen factor. If the factor had a positive effect, the null hypothesis was rejected (the factors did not influence the regressions). The second test analysed the adjusted means for each group of measurements for each factor ($Y_1 = a + bX_1$), which essentially validated the cases in which the null hypothesis was not rejected in the first analysis. These analyses were carried out by means of the SYSTAT 8.0 programme.

In addition, a series of VBGF parameters (L_∞, K and t_0) were calculated from the results of the otolith readings, using the mean lengths obtained for each group based on the number of rings counted with the FISHPARM iterative calculation programme (Prager *et al.*, 1987).

Growth

In order to establish comparisons between growth results obtained both from the length frequency distributions (LFD) and the otolith readings, two hypothesis were assumed: *Hypothesis 1*, that two rings were formed every year (fast growth); or *Hypothesis 2*, that one ring was formed

TABLE 1. – Characteristics of the trawl catches of *M. merluccius* from the study area landed in the port of Santa Pola, by sex and year.

		1992	1993	1994	1995	1996	1997	1998
MALES	Individuals (n*1000)	11 663.12	12 798.39	9 364.24	5 785.06	28 142.84	9 021.16	9 930.28
	Min. Length (cm)	4.0	4.0	4.0	4.0	4.0	4.0	4.0
	Max. Length (cm)	56.0	60.0	60.0	60.0	60.0	60.0	60.0
	Mean length (cm)	11.73	12.52	9.99	11.75	9.14	10.35	10.32
	Total weight (t)	239.034	322.399	166.238	114.287	220.460	121.270	122.043
FEMALES	Individuals (n*1000)	12 110.98	13 380.35	9 625.27	5 964.31	28 333.48	9 199.25	1 0081.92
	Min. Length (cm)	4.0	4.0	4.0	4.0	4.0	4.0	4.0
	Max. Length (cm)	58.0	68.0	68.0	68.0	74.0	78.0	78.0
	Mean length (cm)	12.30	13.28	10.71	12.29	9.28	10.72	10.60
	Total weight (t)	307.292	474.838	269.746	160.079	271.989	159.330	154.347
	Official total catch (t)	545.65	647.72	352.79	379.54	626.34	359.14	255.21
	Specimens measured	5255	6687	3267	4067	5477	7775	8933

every year (slow growth). Firstly, the series of lengths obtained in the different age-length relationships, without considering the ages, were checked to see whether the normality hypothesis was accepted (Kolmogorov-Smirnov test of Composite Normality). Then each one was compared against another other by pairs, using various tests (Kolmogorov-Smirnov, "t" test and F test for equality of variances) in order to detect the differences in means and variances between groups and asses the incidence of the "data origin" factor (ANCOVA) in a similar way to that carried out for the meristic variables of the otoliths. Finally, the different curves obtained in the two hypotheses were compared: *Hypothesis 1* (the curves obtained by assuming that two growth rings were formed every year against the curve constructed with the parameters obtained from the LFD); and *Hypothesis 2* (the curves obtained by assuming that one growth ring was formed every year against the curve constructed with the parameters obtained from the LFD). The null hypothesis (no differences between the curves) was accepted or rejected according to the results obtained. These analyses were carried out using the SYSTAT 8.0 programme.

RESULTS

Length Compositions

In the monthly length samplings a total of 41,461 specimens were measured (Table 1). The trawl catches were composed of a large proportion of juvenile individuals, 94% of the annual total catch in number being below 20 cm in length. By weight, the individuals that were below 20 cm in length represented 44% of the yearly total catch. The lengths in the trawl ranged between a minimum length of 4 cm and a maximum of 60 cm in males and 78 cm in females. The mean lengths of the catches varied between 9.14 cm and 12.5 cm, with a mean of 10.8 cm in males and 9.28 cm to 13.28 cm, with a mean of 11.31 cm, in females.

The comparison of the sum of the total landings, calculated by sex, with the official data of the total landings in the port showed a difference of between 0.1% and 38%, with a 22% average error for the whole period, which indicated the level of accuracy achieved by the sampling scheme and the parameters (sex ratio, length-weight relationship) used in the study.

Seasonally, an increase over the mean in the proportion of small-sized individuals was observed in the summer, and was repeated on a smaller scale in the autumn. Those events can be attributed to the massive incorporation of very small-sized individuals to the fishery, representing two main cohorts in the continuos annual recruitment (Fig. 2).

The results of the different estimates of the Von Bertalanffy growth parameters on the distribution of length frequencies obtained by the application of the FISAT statistical package (subp. ELEFAN) are shown in Table 2.

Otoliths

Figure 3 shows the evolution of the monthly percentage border type found in the otoliths. It was observed that those with an opaque border were greater than 50% in June, October and November. This was significant in the first two months, which supposedly would correspond to two periods of

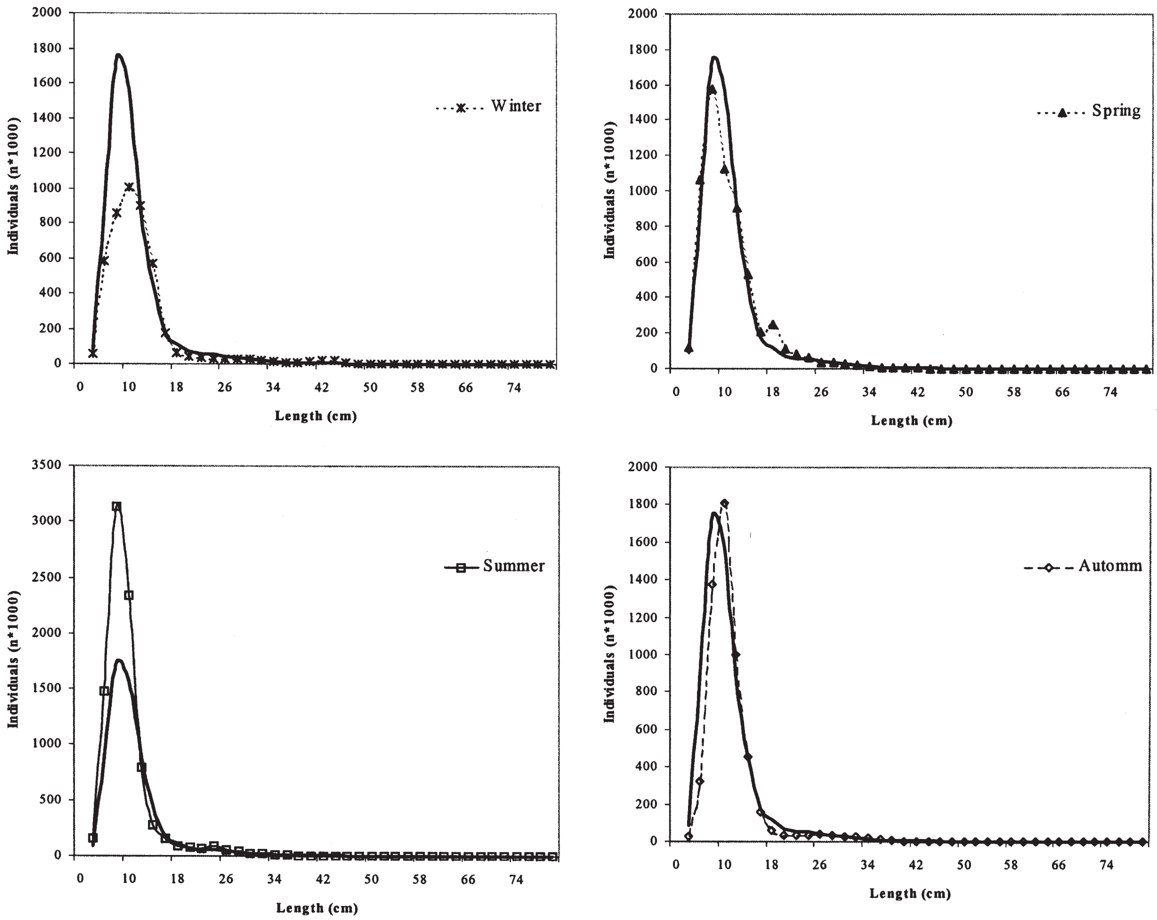

FIG. 2. – Representation of the length frequency average for each quarter against the mean value of all the quarters for the landings of *M. merluccius* in the port of Santa Pola during the 1992-1998 period.

TABLE 2. – Results of the VBGF growth parameters (length-age relationship) obtained using the FISAT program (subp. ELEFAN), from a record of quarterly, annual and summer cohort groupings in the 1992-1998 period, for the different groups (males, females and both sexes together) of *Merluccius merluccius.* The values selected for the comparisons are indicated *.

Group	Grouping	L_∞ (cm)	K	t_0	Φ'
males	quarterly	94.0	0.27	0.199	3.38
males	annual	93.0	0.20	-0.091	3.24
males*	summer cohort	86.0	0.23	-0.035	3.23
females	quarterly	102.0	0.22	0.094	3.36
females	annual	108.0	0.21	0.115	3.42
females*	summer cohort	116.0	0.17	-0.018	3.36
both sexes	quarterly	100.0	0.23	0.119	3.36
both sexes*	annual	108.0	0.21	0.115	3.39

more intense growth in the hake, while in February-April, July-September and in December the borders were significantly hyaline. This suggests that since the growth of the hake occurs fundamentally in the months when the opaque border dominates significantly, which in this case would be June and October, two annual growth rings would be formed, instead of one as is usually accepted.

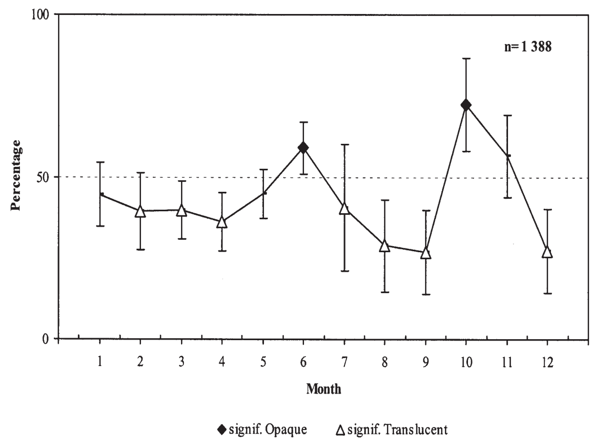

FIG. 3. – Monthly percentage evolution of the otolith border types; accumulated data for the 1992-1995 period, showing the significance level.

Table 3 shows the parameters of the different relationships found for both morphometrics and relative growth. Relationships between longitudinal otolith axes, and with fish length, were isometric. The weight increase of the otolith (g), both

TABLE 3. – Parameters of different relationships found for the otoliths of *Merluccius merluccius*; level of signif. = ***<0.001, **<0.01, *<0.05 and NS <0.1 in a "t" Test.

Dep. Var.	Ind. Var.	Constant	Coef. B	Err B	Signif.	r^2	n
Minor axis	Major axis	0.411	0.951	0.003	ns	0.973	1377
Major axis	Fish length	0.052	0.982	0.003	ns	0.978	1377
Otol. weight	Major axis	0.0001	2.562	0.009	***	0.984	1377
Otol. weight	Fish length	6.00E-08	2.517	0.012	***	0.970	1377

TABLE 4. – Results of the covariance analyses carried out for the regressions of the different variables selected. (Sex = Undifferentiated + Males + Females; Sex* = Males + Females); R = rejection of the null hypothesis, NR = non rejection of the null hypothesis.

			SLOPES			ADJUSTED MEANS			
Dep. Var.	Ind. Var.	Factor	f	p	effect	f	p	effect	Final effect
Minor axis	Major axis	Sex	13.490	0.000	r	168.286	0.000	r	r
Major axis	Fish length	Sex	9.811	0.000	r	28.167	0.000	r	r
Otolith weight	Major axis	Sex	2.217	0.109	nr	30.074	0.000	r	r
Otolith weight	Fish length	Sex	28.785	0.000	r	41.596	0.000	r	r
Number of rings	Fish length	Sex	3.815	0.022	r	71.006	0.000	r	r
Minor axis	Major axis	Sex*	7.036	0.008	r	13.274	0.000	r	r
Major axis	Fish length	Sex*	3.226	0.073	nr	0.360	0.549	nr	nr
Otolith weight	Major axis	Sex*	0.041	0.840	nr	20.277	0.000	r	r
Otolith weight	Fish length	Sex*	1.098	0.272	nr	17.672	0.000	r	r
Number of rings	Fish length	Sex*	2.563	0.110	nr	1.402	0.237	nr	nr
Minor axis	Major axis	Quarter	4.277	0.005	r	0.588	0.623	nr	r
Major axis	Fish length	Quarter	6.913	0.000	r	2.330	0.073	nr	r
Otolith weight	Major axis	Quarter	0.659	0.577	nr	3.229	0.022	r	r
Otolith weight	Fish length	Quarter	7.042	0.000	r	2.531	0.056	r	r

with regard to the major otolith axis (mm) and to the individual's length (mm), showed a negative allometry (b<3) which was significant in both cases.

In Table 4, the results of the covariance analyses are shown for the regressions of the different variables selected, with their effect estimated for the factors sex (including or not including the undifferentiated individuals) and quarterly period of the year in which the specimen was caught, and acceptance or rejection of the null hypothesis (the factors do not affect the variables).

According to the results of the analyses, the correlations between the variables were positive and high. All the relationships obtained were affected both by the sex factor and by the quarterly factor. Two exceptions were found if only sexually differentiated individuals were considered: for the relationships between the longitudinal growth of the otolith and that of the individual to which it belonged; and the number of rings counted and the individual's length. Table 5 lists the number of rings per individual according to length for males and females, taken from the otolith reading data. The regression number of number of rings against length of fish is in the form: Nº rings = - 0.967 + 0.113 * Length (cm). A high correlation was observed between the rings counted in the otoliths and the length of the individual in cm (Fig. 4). The parameters of the Von Bertalanffy equation were calculated from the mean lengths found in each age class, assuming that each growth ring represented half a year or one year. In the case of the males, it was not possible to fit the data using the FISHPARM program, and the parameters are therefore not shown (Table 6).

Growth

The tests carried out between the lengths obtained in the age-length tables for each case (Fig. 5) indicated that the hypothesis of normality was accepted in all cases. Significant differences were shown between samples (at the 95% level) obtained by *Hypothesis 2* and the LFD, particularly when both sexes were considered as a whole. The smallest differences (p values of 0.9) were observed in the comparison between the samples obtained in *Hypothesis 1* and the LFD.

The results of the comparison between curves (ANCOVA) are shown in Table 7, and it was observed that these samples were affected by the "origin" factor. The null hypothesis was rejected, since significant differences existed in all cases (General and *Hypothesis* 2), except in *Hypothesis 1* in which there were no significant differences between the compared curves; one assuming that two annual rings were formed (1 ring = 0.5 years) and the other constructed with the parameters obtained in the length frequency analyses (LFD). In Figure 6, a comparison of the different growth curves is shown for both those obtained from the assumptions between otolith formation and temporal scale, and between the different parameters obtained by the two methodologies used. It was observed that the curves obtained by assigning a

TABLE 5. – Number of rings according to length for *Merluccius merluccius* males and females from the otolith readings.

	Males Number of rings								
Length	0	1	2	3	4	5	6	7	TOTAL
7	4	-	-	-	-	-	-	-	4
8	8	-	-	-	-	-	-	-	8
9	10	-	-	-	-	-	-	-	10
10	16	-	-	-	-	-	-	-	16
11	17	1	-	-	-	-	-	-	18
12	16	1	-	-	-	-	-	-	17
13	16	3	-	-	-	-	-	-	19
14	13	3	-	-	-	-	-	-	16
15	11	4	-	-	-	-	-	-	15
16	8	6	-	-	-	-	-	-	14
17	2	8	-	-	-	-	-	-	10
18	1	5	1	-	-	-	-	-	7
19	-	6	5	-	-	-	-	-	11
20	-	4	3	-	-	-	-	-	7
21	-	5	3	-	-	-	-	-	8
22	-	4	7	-	-	-	-	-	11
23	-	3	6	2	-	-	-	-	11
24	-	3	15	2	-	-	-	-	20
25	-	-	17	1	-	-	-	-	18
26	-	1	14	4	-	-	-	-	19
27	-	-	6	10	2	-	-	-	18
28	-	-	9	11	-	-	-	-	20
29	-	-	6	5	1	-	-	-	12
30	-	-	5	15	1	-	-	-	21
31	-	-	7	15	1	-	-	-	23
32	-	-	2	18	2	-	-	-	22
33	-	-	1	13	1	-	-	-	15
34	-	-	1	12	-	-	-	-	13
35	-	-	2	5	-	-	-	-	7
36	-	-	3	13	-	-	-	-	16
37	-	-	2	6	2	-	-	-	10
38	-	-	-	3	1	1	-	-	5
39	-	-	-	-	1	-	-	-	1
40	-	-	-	3	3	-	-	-	6
41	-	-	-	1	2	-	-	-	3
42	-	-	-	1	2	-	-	-	3
43	-	-	-	1	1	-	-	-	2
44	-	-	-	2	-	-	-	-	2
45	-	-	-	-	-	-	-	-	-
46	-	-	-	-	1	-	-	-	1
47	-	-	-	-	-	-	-	-	-
48	-	-	-	-	-	-	-	-	-
49	-	-	-	-	-	-	-	-	-
50	-	-	-	-	-	1	-	-	1
51	-	-	-	-	-	-	-	-	-
52	-	-	-	2	-	1	-	-	3
53	-	-	-	1	1	-	-	-	2
54	-	-	-	-	1	-	-	-	1
55	-	-	-	-	-	-	-	-	-
56	-	-	-	-	-	-	-	-	-
57	-	-	-	-	-	1	-	-	1
58	-	-	-	-	-	-	-	-	-
59	-	-	-	-	1	-	-	-	1
60	-	-	-	-	-	-	-	-	-
TOTAL	117	53	113	146	24	4	-	-	457
MEAN LENGTH	11.90	18.29	26.30	32.49	38.87	49.25	-	-	

TABLE 5. (Cont.) – Number of rings according to length for *Merluccius merluccius* males and females from the otolith readings.

Length	Females 0	1	2	3	4	5	6	7	TOTAL
7	4	-	-	-	-	-	-	-	4
8	8	-	-	-	-	-	-	-	8
9	11	-	-	-	-	-	-	-	11
10	18	-	-	-	-	-	-	-	18
11	19	1	-	-	-	-	-	-	19
12	18	2	-	-	-	-	-	-	20
13	17	4	-	-	-	-	-	-	21
14	15	4	-	-	-	-	-	-	19
15	11	6	-	-	-	-	-	-	16
16	10	7	-	-	-	-	-	-	16
17	2	13	-	-	-	-	-	-	14
18	2	6	1	-	-	-	-	-	9
19	1	6	4	-	-	-	-	-	10
20	-	7	4	-	-	-	-	-	10
21	-	4	6	1	-	-	-	-	11
22	-	2	13	-	-	-	-	-	14
23	-	1	12	-	-	-	-	-	13
24	-	-	8	3	-	-	-	-	11
25	-	1	10	4	-	-	-	-	15
26	-	1	11	3	-	-	-	-	15
27	-	-	6	2	-	-	-	-	8
28	-	-	10	8	-	-	-	-	18
29	-	-	3	9	1	-	-	-	13
30	-	-	3	5	-	-	-	-	8
31	-	-	3	8	1	-	-	-	12
32	-	-	2	10	1	-	-	-	13
33	-	-	1	16	1	-	-	-	18
34	-	-	2	10	4	1	-	-	17
35	-	-	-	12	-	-	-	-	12
36	-	-	-	9	4	-	-	-	13
37	-	-	-	9	6	-	-	-	15
38	-	-	-	13	4	-	-	-	17
39	-	-	-	14	9	1	-	-	24
40	-	-	-	12	12	1	-	-	25
41	-	-	-	2	10	3	-	-	15
42	-	-	-	2	17	4	-	-	23
43	-	-	-	5	9	7	-	-	21
44	-	-	-	1	16	5	1	-	23
45	-	-	-	3	15	4	1	-	23
46	-	-	-	1	11	9	1	-	22
47	-	-	-	-	10	5	2	-	17
48	-	-	-	2	8	-	2	-	12
49	-	-	-	-	3	5	-	2	10
50	-	-	-	-	3	5	1	-	9
51	-	-	-	1	6	9	-	-	16
52	-	-	-	-	5	11	1	1	18
53	-	-	-	-	3	4	3	3	13
54	-	-	-	1	3	6	4	-	14
55	-	-	-	-	1	4	2	1	8
56	-	-	-	-	-	8	3	-	11
57	-	-	-	-	1	3	1	1	6
58	-	-	-	-	1	2	1	-	4
59	-	-	-	-	1	2	1	-	4
60	-	-	-	-	1	4	2	-	7
61	-	-	-	-	1	-	-	-	1
62	-	-	-	-	1	-	-	1	2
63	-	-	-	-	2	2	-	-	4
64	-	-	-	-	-	-	1	-	1
65	-	-	-	-	1	1	-	1	3
66	-	-	-	-	-	1	-	-	1
67	-	-	-	-	-	1	-	-	1
68	-	-	-	-	-	-	1	-	1
69	-	-	-	-	-	2	1	-	3
70	-	-	-	-	-	-	-	-	-
71	-	-	-	-	-	-	1	-	1
72	-	-	-	-	-	-	-	-	-
73	-	-	-	-	-	-	-	-	-
74	-	-	-	-	-	-	-	-	-
75	-	-	-	-	-	-	-	1	1
TOTAL	131	61	97	166	172	110	30	11	778
MEAN LENGTH	12.04	17.37	24.99	34.94	44.46	50.83	54.87	56.64	

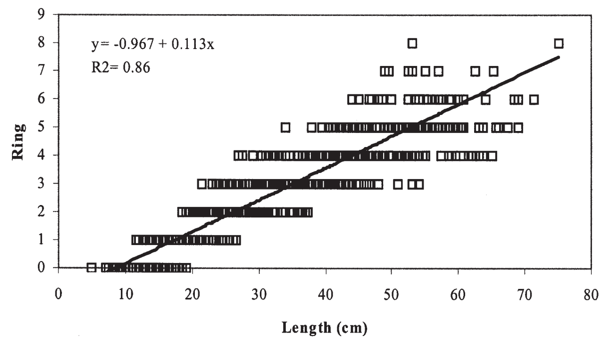

FIG. 4. – Linear regression for the number of rings-length of Mediterranean hake individuals in cm, produced from the data of whole otolith readings shown in Table 5.

TABLE 6. – Results for the VBGF growth parameters (length-age relationship) obtained using the FISHPARM program, for the different groups (males, females and both sexes) of *Merluccius merluccius*, from the mean lengths found in each age class of the otolith readings. The values of K and t_0 are shown where two rings (*Hypothesis 1*) or one ring (*Hypothesis 2*) are formed for each year.

Group	L_∞	K		t_0	
		H1	H2	H1	H2
Females	103.9	0.212	0.106	0.0307	-0.94
Both sexes	106.8	0.20	0.10	0.0028	-0.994

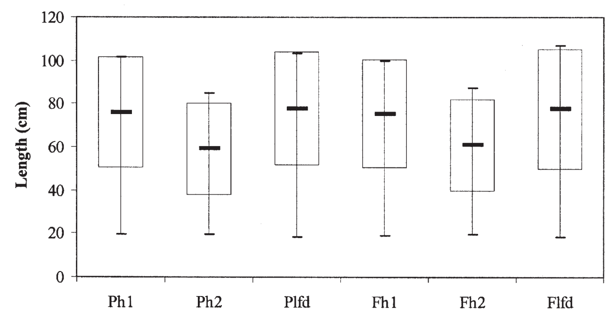

FIG. 5. – Representation of the maximum, minimum and mean values, with their SD (box), of the series of lengths obtained by the length-age relationship for the Mediterranean hake, for females (F) and males + females + undefined (P), obtained for *Hypothesis* 1 (h1) and *Hypothesis* 2 (h2) and for the length frequency distributions (lfd), over a series of 0 to 15 years.

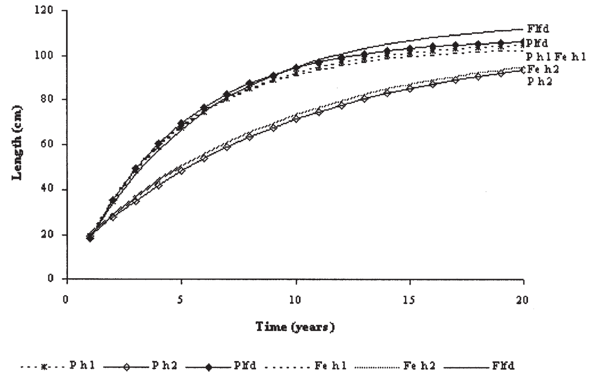

FIG. 6. – Comparison of the absolute growth curves (length-age relationship) for Mediterranean hake females (Fe) and males + females + undefined (P), obtained for Hypotheses 1 (h1) and Hypothesis 2 (h2) and for the length frequency distributions (lfd).

periodicity of 6 months to each ring (*Hypothesis* 1) occurred above those obtained by assigning a single year (*Hypothesis* 2), and that when they were compared with those constructed for the parameters obtained in the length frequency analysis (LFD), those obtained from *Hypothesis* 1 and the LFD were in agreement with each other, although they were lower for the males.

For the estimates carried out from the VBGF parameters, the results obtained by the application of both LFD and otolith readings, using different packages, FISAT (subp. ELEFAN) and FISHPARM, were similar both in the L_∞ and in the growth rate values, with the growths between the sexes differing from the second year.

DISCUSSION

The lengths of the catches show a large proportion of juvenile individuals in their composition. Seasonally, an increase in the proportion of small sized individuals is observed in the summer with a

TABLE 7. – Results of the ANCOVA analyses carried out for the different growth curves considered: Model = (Age = Factor + Length + (Factor * Length); Factor = Origin of the data; General = *hypothesis* 1, *hypothesis* 2 and LFD; *Hypothesis 1*= *hypothesis 1* vs LFD; *Hypothesis 2*= *hypothesis 2* vs LFD; (R = rejection of the null hypothesis, NR = non rejection of the null hypothesis).

Group	Data	SLOPES f	p	effect	ADJUSTED MEANS f	p	effect	Final effect
General	Males + females + undefined.	2.257	0.057	r	14.315	0.000	r	r
General	Males + females.	2.738	0.077	r	18.930	0.000	r	r
General	Females	2.900	0.067	r	16.056	0.000	r	r
Hypothesis 2	Males + females + undefined.	4.410	0.008	r	22.249	0.000	r	r
Hypothesis 2	Males + females	5.661	0.025	r	33.730	0.000	r	r
Hypothesis 2	Females	7.667	0.010	r	31.767	0.000	r	r
Hypothesis 1	Males + females + undefined.	0.138	0.937	nr	0.180	0.909	nr	nr
Hypothesis 1	Males + females	0.060	0.809	nr	0.181	0.674	nr	nr
Hypothesis 1	Females	0.365	0.551	nr	0.335	0.568	nr	nr

smaller replica in the autumn, which can be attributed to increases in the incorporation of recruits to the fishery. Although recruits can be found throughout the year, the magnitude of these two increases suggests the existence of two main cohorts in the recruitment of each year, one toward the summer and a weaker one in autumn. Nevertheless, the variability of those events observed between years is high. However in some years they can be delayed or advanced slightly, coinciding more or less with similar events observed in other areas: in spring and in autumn, described by Orsi-Relini *et al.* (1986) for the Ligurian Sea, by Abella *et al.* (1995) in autumn and late winter (Tyrrenian), in spring and summer for the Gulf of Lions, according to Aldebert and Recasens (1996) and by Alemany *et al.* (1994) for the Balearic area. The results could allow us to establish a relationship between the appearance of these recruitments and the existence of the two most important spawning periods of *M. merluccius,* which would be in February-March and in June (García-Rodríguez and Esteban, 1995), with the existence of an out of step 4 or 5 month spawning-recruitment. However, Recasens *et al.* (1998) have only detected one spawning season, for the Gulf of Lions, in autumn.

The growth of the otolith axes demonstrates differences between males and females, although it does not show variations throughout the year. The longitudinal axis, with regard to the length of the individual to which it belongs, shows differences in growth in the undifferentiated individuals that disappear after sexual differentiation, with growth afterwards being the same in males and in females. This coincides with the observations made by Piñeiro and Hunt (1989) on the Atlantic hake. The lowest mean values of longitudinal growth were detected in winter. However its increase in weight, which shows a negative allometry and is also different in males and females, displays a seasonal variation with smaller mean values in spring.

The type of otolith border was related to the rapid or slow growth periods of the individuals, giving opaque or hyaline borders. This could indicate that the growth of the Mediterranean hake occurs mainly in the months when the opaque border is significantly dominant, which are June and October (Spring and Autumn), meaning that two annual growth rings would be formed, instead of one as has usually been accepted. The periodicity of the predominance of the opaque border could be related to the presence of two periods of high primary productivity in the western Mediterranean, which occur exactly in these periods (Fernández, 1990). However, some authors relate ring formation more to internal events than to the external environment (Morales-Nin *et al.*, 1998).

There is no evidence to support the assumption that opaque and translucent zones in whole otoliths of *M. merluccius* are annual events (Morales–Nin *et al.*, 1998). Moreover, te same authors working on otolith sections concluded that the internal sulcal rings in *M. merluccius* otoliths cannot be considered as annuli. Despite this, otolith readings for ageing *M. merluccius* are still widely used. In our case the variability observed in the results for the number of rings counted is reflected especially in the range of lengths contained in each group of individuals that have the same number of rings. However, there is a high correlation between the rings counted in the otoliths and the length of the individual in cm. The sex factor does not influence the relationship unless the sexually undifferentiated individuals are included, since the differences in the undifferentiated ones disappear after sexual differentiation. Consequently, the number of rings depends only on the individual's length, with males showing the same number as females of the same length. The best fit for the curves constructed from the mean lengths of the otolith readings with the growth data according to the length frequency is observed for the two-ring hypothesis (*Hypothesis 1*), which suggests that the hypothesis of rapid growth could be considered in future studies.

Growth patterns obtained by otolith readings considering hypothesis 2 (one ring per year were similar to those obtained in previous works on Mediterranean hake (Oliver *et al*., 1989; Aldebert and Morales-Nin, 1992; Morales-Nin and Aldebert, 1997) carried out on the basis of the same hypothesis over otoliths readings, considering complete otoliths, sections and daily increments, and obtaining K values around 0.1. Nevertheless, in our study, patterns obtained by the acceptance of hypothesis 1 (two rings per year) and those from LFD show high growth rates. In this cases the estimates of the growth parameters indicated high growth rates (K), twice those of hypothesis 2, regarless of the selected method. When we considered the values of the Growth Performance Index (ϕ'), the females ($\phi' = 3.36$) appeared to have faster growth rates than the males ($\phi' = 3.23$), which would explain the accumulation of females in the larger lengths. On the other hand K values of males are greater than those of females whether obtained by LFA or by ELEFAN, while L_∞ values are lower in males. If we consider that there is an inverse covariation between the parameters considered in a data series, with higher K values for diminishing L_∞ values, we can conclude that growth differences between sexes are not so great, being conditioned more by the maximum length that sexes are able to reach (life expectancy) than by growth efficiency. The lack of adjustment of the male mean lengths obtained by otolith readings may be attributed to the existence of few individuals having 5 rings (biggest sizes), giving biased mean lengths and thus disturbing iterations of the FISH-PARM program.

In general, the estimates obtained from the VBGF parameters emphasised the similarity of the results obtained by the application of both methods, following the length frequencies and otolith readings (*Hypothesis* 1), using different statistical packages for both L_∞ and the growth rate values, with the growth between the sexes differing from the second year. These high values of K have already been observed previously (Piñeiro and Pereiro, 1993; Alemany *et al.*, 1994; García-Rodríguez, 1994; García-Rodríguez and Esteban, 1995; Alemany and Oliver, 1995; Abella *et al.*, 1995; García-Rodríguez and Esteban, 1998) for similar L_∞ values. Excepting the former work, all these studies were made on modal progression analysis over quarterly length frequency data, using different packages and obtaining similar results. Piñeiro and Pereiro (1993) used booth commercial and surveys data, for whole otolith readings and length frequency distributions. They proposed a "fast growth" hypothesis assuming that several rings were formed in the first year of life because growth undergoes a series of "intermittent" interruptions in the first winter. Comparatively our *Hypothesis* 1 is simpler and reaches the same conclusions, reinforcing the results of all these works that propose high K values (around 0.2) for hake growth. Therefore, we recommend the consideration of the rapid growth hypothesis in future studies, hoping that it will help to understand some peculiarities of the hake trawl fishery in the Mediterranean.

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