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On the population dynamics of sardine, *Sardina pilchardus* Walbaum, 1792, from the Catalan sea (northwestern Mediterranean)*

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SUMMARY: In this paper, the sardine resources of Catalan coastal waters are analyzed. The period studied covers the years between 1988 and 1991. The resource has a stable biomass and the fish stock is under exploited. Current fishing gear seems to be adequate in selectivity. The natural mortality rate and fishing mortality are estimated.

Key words: Sardine, *Sardina pilchardus*, northwestern Mediterranean, population dynamics, analytical models, biomass estimates.

RESUMEN: SOBRE LA DINÁMICA POBLACIONAL DE LA SARDINA, *Sardina pilchardus* Walbaum, 1782, DEL MAR CATALÁN (MEDITERRÁNEO NOROOCCIDENTAL). — En el presente trabajo se analiza la situación del recurso sardina dentro del litoral Catalán en el período 1988 a 1991 inclusive. Presentando una biomasa estable y un estado de subexplotación del stock, así como también una adecuada selectividad del arte de pesca empleado. Se estiman las tasas de mortalidad natural y por pesca.

Palabras claves: sardina, *Sardina pilchardus*, Mediterráneo Noroccidental, dinámica poblacional, modelos analíticos, estimaciones de biomasa.

INTRODUCTION

Small pelagic fish populations fluctuate markedly, mainly on account of variations in recruitment. Fisheries activity affects these fluctuations, it is necessary to accumulate extensive series of data regarding fish capture, fishing effort, biological data, etc. This allows us to gain an understanding of the historical evolution of these fisheries and to understand their dynamics and hence make future forecasts.

The sardine of the Spanish Mediterranean began to be studied in 1950. For the most part, data was taken from fish catches unloaded at the ports of Castelló and Vinaròs in València (LARRAÑETA *et al.*, 1958; SUAU, 1973; LARRAÑETA, 1979). LÓPEZ (1963) also carried out an extensive study of the growth of this species from catches unloaded in Barcelona. LARRAÑETA (1968) has established different stocks within the western Mediterranean and compared their biometrical and physiological characteristics.

In a recent report describing the fisheries of Catalunya and València (LLEONART, 1990), aspects of the growth and population dynamics of sardine were analyzed. PERTIERRA and MORALES-NIN (1989) studied the growth of this species in the nortwestern Mediterranean. MORALES-NIN and PERTIERRA (1990)

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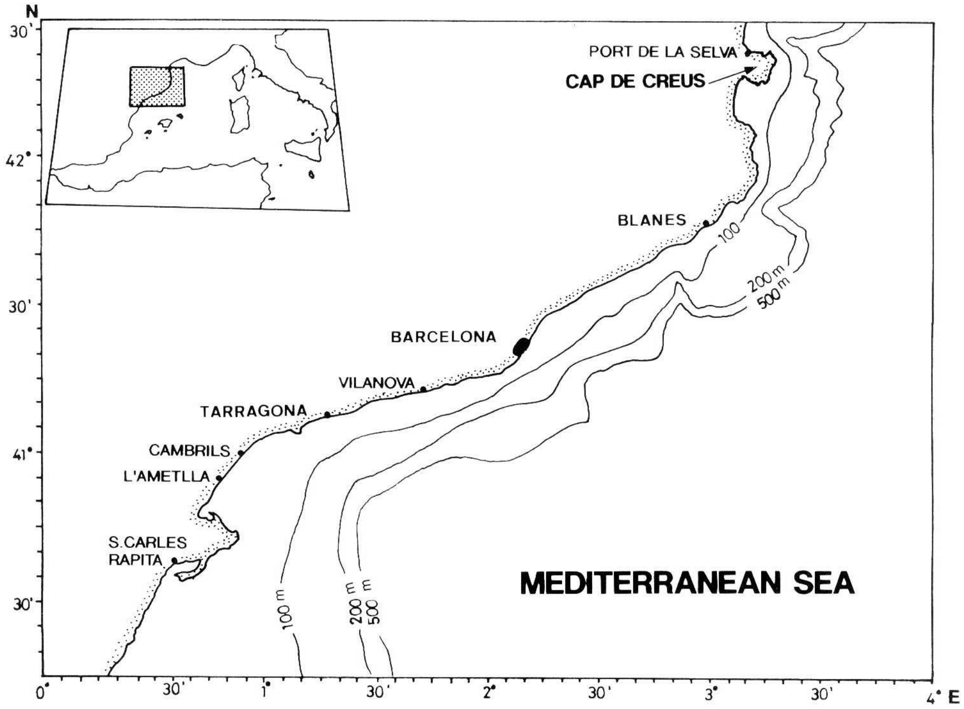

FIG. 1. — Ports where samples were collected.

compared the growth rates of sardine and anchovy in the Mediterranean and in important upwelling areas, and stated that the differences in the former region are due to the more stable environment.

Sardine constitutes 40 % of the total catch of pelagic and demersal fish, which calls for the regular monitoring of this resource. For this purpose, the Instituto Español de Oceanografía (IEO) regularly gathers acoustical data along the entire Mediterranean littoral zone to estimate the biomass of this population. Sardines are mainly fished by the purse seiner fleet, though bottom trawlers have been fishing pelagic resources recently with a wide vertical bottom trawl gear (ÁLVAREZ, 1990), especially from the southern ports (Sant Carles de la Ràpita, Cambrils and L'Ametlla).

The present study helps broaden the understanding of the population dynamics of sardine in the northwest Mediterranean Sea, along the Catalan coast, and contributes to optimizing the management of this resource. The stock fished in this area is part of a larger stock unit which inhabits the Spanish northern Mediterranean coast between Castelló, in València, and Cap de Creus, in Catalonia (LARRAÑETA, 1968).

MATERIALS AND METHODS

The sardine samples were obtained fornightly from the fish catches unloaded in Barcelona, Vilanova, Blanes, and Port de La Selva from 1988 to 1991 (Fig. 1). A total of 94 samples were taken from the purse seiners landings, which average 26.4 tons and 250 HP (PERTIERRA, 1992).

In each sample, total lengths of sardines were measured and grouped into 0.5 cm intervals for each year studied. Total catch was also recorded and the number of individuals in the catch calculated by length classes. The frequency of each length in the sample was multiplied by the coefficient between the total weight of the catch and the weight of the sample, calculated from the length-weight relationship. To smooth the annual raw length frequency, we used a standard algorithm that minimizes the difference between each class and their contiguous size classes by subtracting 25 % of its own value, then adding 25 % of those length classes immediately higher and lower. A class plus was considered above 19.5 cm in all years.

The evolution of catches throughout the entire Catalan coast from 1971 to 1991 included, is shown in Fig. 3. The data were supplied by the "confraries" of each port.

The VIT programme (LLEONART and SALAT, 1992) was used for all calculations. The program uses the length frequency distribution smoothed with the algorithm mentioned above, annual catch, and growth parameters as input data. The following values of the growth parameters were used based on

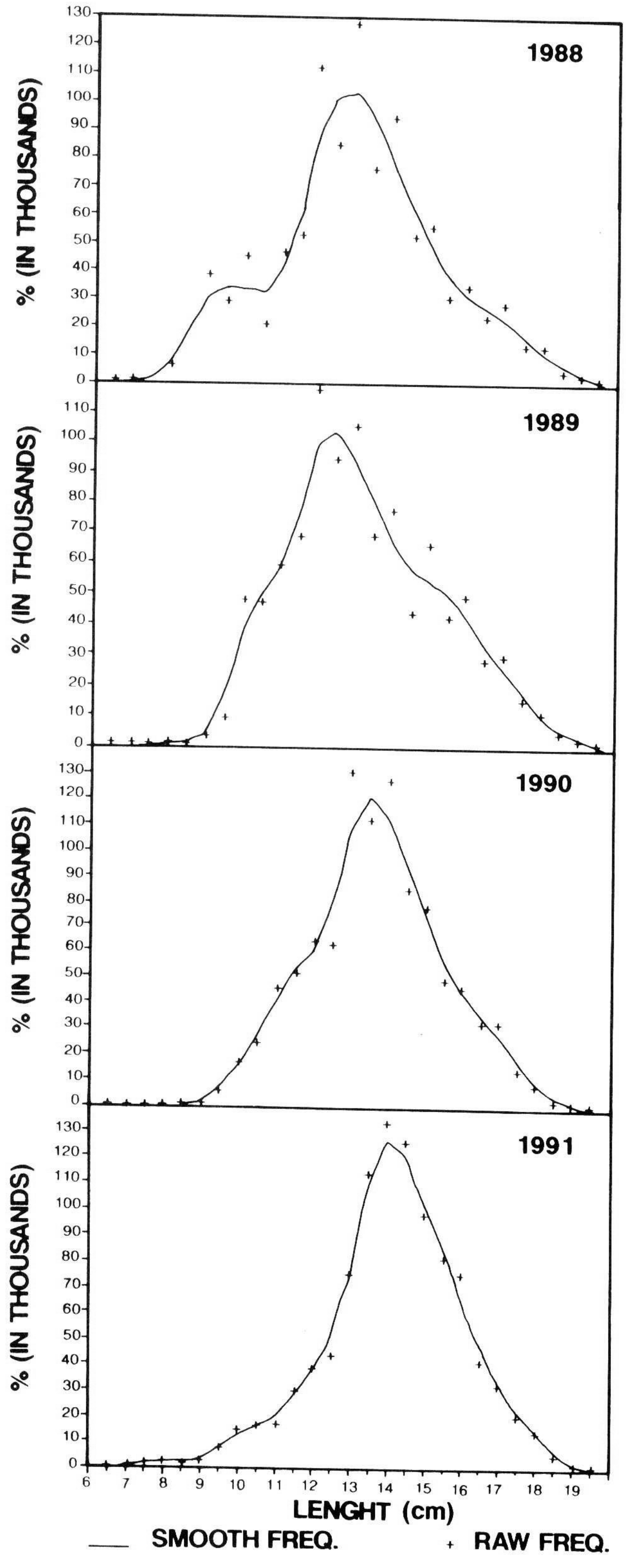

FIG. 2. — Length frequency distribution for each of the years studied.

PERTIERRA and MORALES-NIN (1989) and LLEONART (1990) for the Catalan Sea:

V. Bertalanffy's parameters : $L\infty = 22.0$ cm ; $k = 0.26$ year^{-1}; $t_o = -1.1$ year

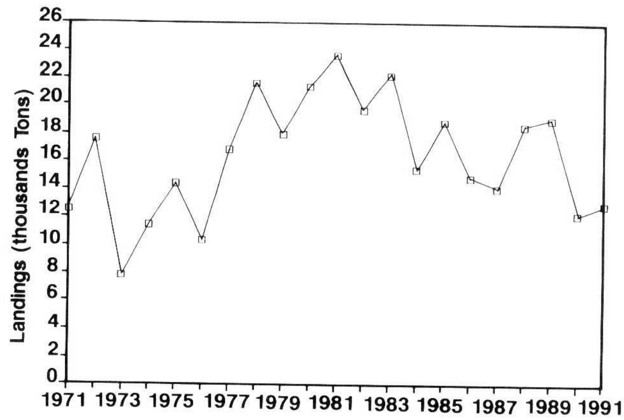

FIG. 3. — Evolution of landings of Catalan catches (1971-1991).

Length-Weight ratio: $a = 6.667\ 10^{-3}$ g; $b = 3.0525$ (total length in centimeters and total weight in grams).

The biomass of the resource was estimated by means of Length Cohort Analysis (LCA) using the catch equation (GULLAND, 1964). The yield per recruit (*Y/R'*) was estimated empirically for different mortality rates in order to have a frame of reference to compare the current rate of exploitation. Then we carried out a sensitivity analysis which consisted of changing the input parameters by 10 % of their original value. Variations on *Y/R'* values could then be analysed with respect to possible over or under estimates of input parameters.

VIT was run with different natural mortality rates (*M*) to observe their effects on the final results. The *M* estimates were obtained by different methods (BEVERTON and HOLT, 1957; TAYLOR 1962; BEVERTON 1963; PAULY 1980; HOENING, 1983) that allowed working with a range of values in which different stock situations were considered.

The corresponding terminal *F* values of each year were chosen in such way as to continue the general tendency of their values, matching an initial estimate which was the result of the difference between the total mortality rate (*Z*) and *M*. *Z* was previously calculated with the formula of BEVERTON and HOLT (1957), assuming an average catch length of 13.0 cm and a minimum length of 12.0 cm at recruitment (LLEONART, 1990).

RESULTS AND DISCUSSION

Length frequency

Fig. 2 shows both the raw and smoothed length distributions of the catches for each year studied. A well marked mode is apparent in each year studied around 13 cm, with an increase tendency towards higher length classes. Fig. 2 also shows that fishing mainly affects fish of approximately 12 cm or larger. This means that individuals that have matured at least once are most affected by fishing, since fish in the 11.9 cm length class in which 60 % of mature individuals appear (PERTIERRA and MORALES-NIN, 1989; ICES, 1991), are in the first year of life.

Length Cohort Analysis. (LCA)

One of the most important parameters in the application of Cohort Analysis models is the natural mortality rate (M), which affects final results to a large extent.

LARRAÑETA (1979), studying the sardine of Castelló, obtained various estimates of M. He considered that values of 0.36 and 0.45 were low and values greater than 0.9 overestimates. He proposed, nevertheless, that the natural mortality of this population of sardine is high and that estimates between 0.8 and 1.0 could be the most accurate.

In the case of the intensely exploited sardine of the Cantabrian Sea, M was calculated at 0.30, 0.33, and 0.35 (ICES, 1991). This suggests that increased fishing activity will result in a decrease in the numbers of older individuals, so that the age range will be narrower. The maximum age observed was 5 years, reflecting intense exploitation of that stock. In contrast, individuals of up to 9 years of age are found in the Mediterranean Sea (PERTIERRA and MORALES-NIN, 1989).

Table 1 shows estimates of M obtained using different methods. M varies widely between 0.29 and 0.62. According to these results and those mentioned above, we decided to work with the extreme values of 0.3 and 0.6 and an intermediate value of 0.45. Using this value, the calculations show that the resource is underexploited, but close to optimal yield. On the other hand, when we worked with a natural mortality rate of 0.30, it appears that the resource is clearly over exploited. With M at 0.60, analysis reveals under-exploitation, much lower than the optimal yield, to reach which fishing should be increased by 300 %.

Three facts further support this level of underexplotation: a) the size frequency distribution mainly consists of adults, and does not vary significantly from year to year; b) the size and age averages in sardine catches are above the size and age of first maturation (Table 2 and Fig. 2); and c) the values of the catches, with the exception of the period between 1978 and 1983 and during the years 1985, 1988, and

TABLE 1. – Estimated Natural Mortality rates (M).

Method	M (years^{-1})
BEVERTON and HOLT, 1956	0.55
TAYLOR, 1958	0.29
BEVERTON, 1963	0.42
PAULY, 1980	0.62
HOERING, 1983	0.47

TABLE 2. – Landings and Population Description corresponding to each sampled year and mean values. Numbers are expresed in millons of individuals, biomass and weights in tons, lenght in cm and ages in years.

	1988	1989	1990	1991	1988/1991
LANDING					
Capture mean number	1019	993	651	559	806
Capture in weight	18502	19007	12163	12860	15633
Mean age of capture	2.45	2.57	2.52	2.99	2.63
Mean Length	12.96	13.24	13.21	14.18	13.40
% Total Biomass	42	44	46	36	42
POPULATION					
Recruitment (in numbers)	3346	2950	1814	2176	2572
Annual mean number	5176	4348	2584	3593	3925
Annual mean biomas	44718	43381	26214	35899	37553
Mean age	1.25	1.58	1.49	1.44	1.44
Mean Lenght	9.71	10.72	10.54	10.28	10.31

TABLE 3. – Fishing Mortality by lengths and year.

Year Length (cm)	1988	M=0.45 1989	1990	1991	Avg
6	0.000	0.000	0.000	0.000	0.000
6.5	0.000	0.000	0.000	0.000	0.000
7	0.001	0.000	0.000	0.001	0.000
7.5	0.004	0.001	0.000	0.004	0.002
8	0.021	0.002	0.001	0.007	0.008
8.5	0.060	0.005	0.006	0.004	0.019
9	0.094	0.013	0.022	0.006	0.034
9.5	0.111	0.053	0.050	0.020	0.058
10	0.115	0.118	0.092	0.039	0.091
10.5	0.115	0.163	0.145	0.043	0.117
11	0.155	0.203	0.196	0.049	0.151
11.5	0.265	0.294	0.240	0.088	0.222
12	0.401	0.412	0.345	0.121	0.320
12.5	0.517	0.484	0.531	0.146	0.420
13	0.618	0.508	0.695	0.268	0.522
13.5	0.667	0.508	0.801	0.463	0.610
14	0.689	0.497	0.844	0.645	0.669
14.5	0.686	0.508	0.844	0.759	0.699
15	0.656	0.585	0.850	0.757	0.712
15.5	0.643	0.677	0.901	0.834	0.764
16	0.673	0.754	0.071	1.100	0.900
16.5	0.821	0.842	1.315	0.902	0.970
17	1.052	0.957	1.461	1.099	1.142
17.5	1.335	1.084	1.448	1.180	1.262
18	1.898	1.126	1.510	1.737	1.568
18.5	5.983	1.191	1.619	1.795	2.647
19	1.872	1.393	2.257	1.427	1.737
19.5 +	1.700	1.700	2.200	1.700	1.825

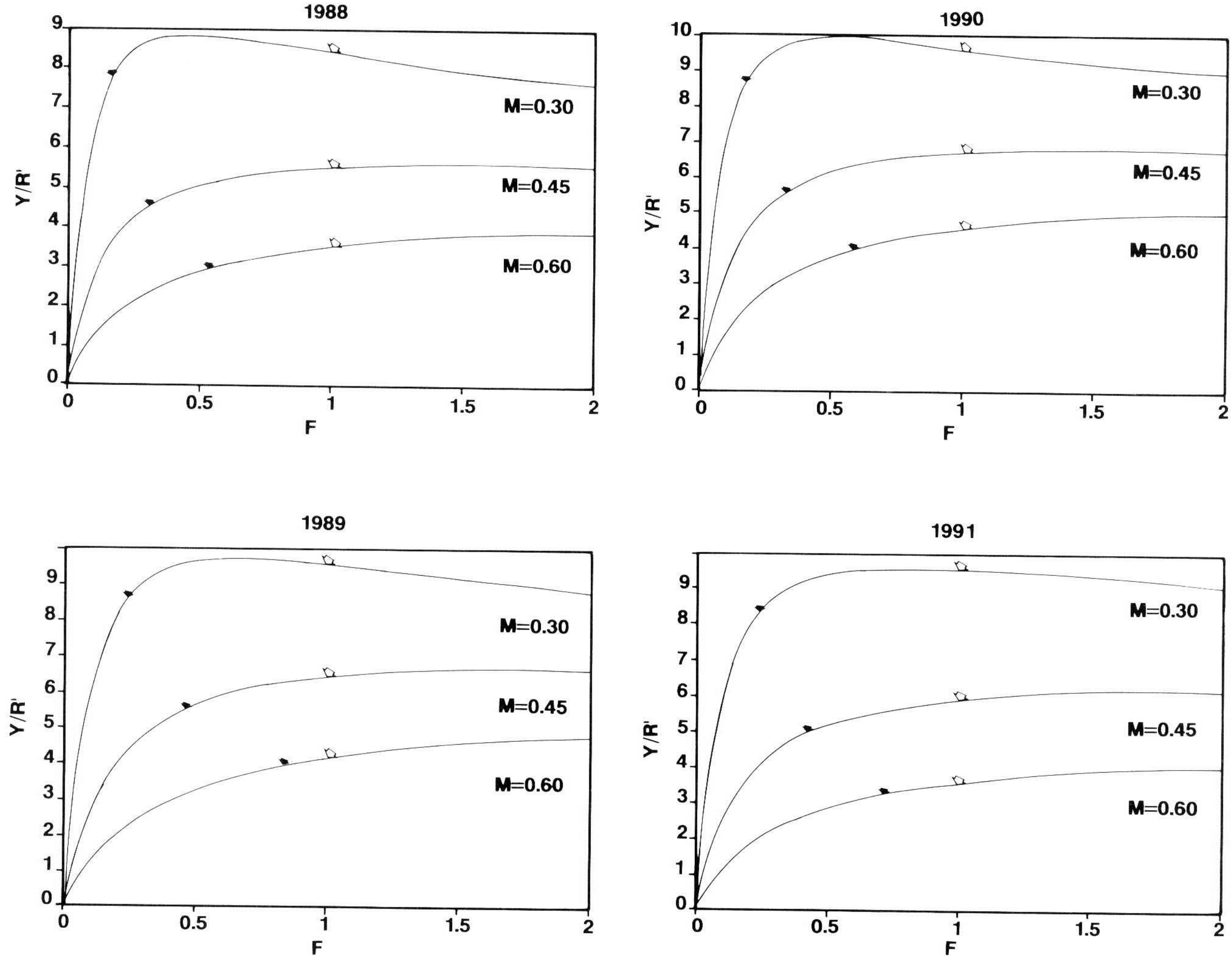

FIG. 4. — Yield per Recruit Analysis (*Y/R'*) for last year. Note: Strategy 0.1 and Actual strategy values are indicated for each different *M* value.

1989, when they were lower than the historical average of 15600 metric tons (Table 2 and Fig. 3).

The total biomass obtained for each year studied is shown in Table 2. The lowest value, in 1990, coincides with the lowest recruitment during the studied period.

In general, the highest *F* rates per length class corresponded to 1990 showing the highest terminal value (see Table 3) eventhough a value of 5.9 for 18.5 cm during 1988 was achieved. Size classes between 6 and 10.5 cm were rare throughout the entire period studied. Judging by the average *F* values in Table 3, fishing on juveniles is low and results in a well focused fishing activity on higher length classes.

Yield per Recruit Analysis and Sensitivity Analysis

The curves obtained for 1991 for each value of *M*: 0.3, 0.45, and 0.60 are shown in Fig. 4; these curves are similar for each level in each of the previous years and with a similar shape. Note the first arrow corresponds to the strategy 0.1 value while the second indicates the actual strategy. The gradual increase of *Y/R'* with different *M* values upon increasing the fishing rate, and always considering the same age of first capture, is interpreted as a good selectivity of the fishing gear employed.

Table 4 is a summary of the numerical results which correspond to the analysis for each year. Here it is apparent that the optimal fishing rate, for $M = 0.45$, is higher than the actual rate. That is to say that the resource is under exploited. The highest fishing rate obtained for 1991 stands out in relation to the rest. This fact is accompanied by an increase in the value of the average length found in the catches over the studied period, a lower percentage of biomass caught (Table 2), and an unloaded catch level that is lower than the average one (Fig. 3). The opti-

TABLE 4. – Yield per Recruit Analysis Results for the corresponding years (for M=0.45).

YEAR	1988	1989	1990	1991
Yield per Recruit (gr / recruit)	5.50	6.443	6.707	5.908
Maximum Sustainable Yield (gr / recruit)	5.90	6.668	6.796	6.214
Optimum strategy (actual effort unities)	1.59	1.93	1.57	2.64
Strategy 0.1 (actual effort unities)	0.30	0.45	0.33	0.41

mum strategy is always above the actual value, especially for 1991 where it more than doubles the original actual effort. If a very conservative 0.1 strategy is to be considered, actual effort should be reduced to almost half its value.

Table 5 gives the results of the sensitivity analysis applied to each individual parameter, and shows how *Y/R'* values vary. Note the highest rate of variation in general terms correspond to under estimates of $L\infty$ compared with the rest. However parameters do not vary individually and a more realistic situation would consider simultaneous variation of all parameter considered.

Table 6 shows the combined effect of parameter variation on *Y/R'*. Simultaneous under or over estimates of $L\infty$ and k, i.e. both with the same sign, give the widest range of variation in all situations considered, yet when M varies with the opposite sign to the former, *Y/R'* achieves the most extreme values of all. In the contrast, least variation was noted in the sixth case ($L\infty$+, K− and M+) where the effect of each variation seem to balance the final *Y/R'* value. Finally we may say that slight variations in input parameters cause significant variations in final *Y/R'* results, hence their importance in this analysis. Sardine growth parameters vary along the Spanish Mediterranean coast (ALEMANY and ÀLVAREZ, 1993). This fact, together with the uncertain natural mortality value, give these results a first idea of the present population dynamics and should be considered as so.

TABLE 5. – Sensitivity Analysis on the *Y/R'* results with single input parameters at a 10 % change of its value (+ means overestimation, and − underestimation). In brackets the percentage of variation with respect to the original value.

YEAR		1988	1989	1990	1991
Original *Y/R'*		5.50	6.53	6.71	5.91
Parameter value					
$L\infty$	+	6.91 (25)	8.09 (24)	8.18 (22)	7.71 (30)
	−	3.32 (−40)	3.67 (−64)	4.51 (−33)	3.38 (−43)
K	+	6.23 (12)	7.20 (10)	7.42 (11)	6.74 (11)
	−	4.74 (−15)	5.60 (−14)	5.91 (−12)	5.01 (−15)
M	+	4.81 (−17)	5.68 (−13)	5.99 (−11)	5.10 (−14)
	−	6.27 (13)	7.28 (11)	7.50 (12)	6.83 (16)

TABLE 6. – Sensitivity Analysis on the *Y/R'* results with combined input parameters at a 10 % change (+ means overestimation, and − underestimation). In brackets the percentage of variation with respect to the original value.

YEAR	1988	1989	1990	1991
Original *Y/R'* value	5.50	6.53	6.71	5.91
Parameters				
$L\infty - K - M -$	3.32 (−40)	3.67 (−44)	4.51 (−33)	3.38 (−43)
$L\infty - K - M +$	1.99 (−64)	2.08 (−68)	2.98 (−56)	1.95 (−67)
$L\infty - K + M -$	4.83 (−12)	5.42 (−17)	6.11 (−9)	5.07 (−14)
$L\infty - K + M +$	3.32 (−40)	3.66 (−44)	4.51 (−33)	3.38 (−43)
$L\infty + K - M -$	6.91 (25)	8.09 (24)	8.18 (22)	7.71 (31)
$L\infty + K - M +$	5.53 (1)	6.54 (0)	6.71 (0)	5.96 (1)
$L\infty + K + M -$	8.15 (48)	9.57 (47)	9.58 (43)	9.48 (60)
$L\infty + K + M +$	6.89 (26)	8.09 (24)	8.18 (22)	7.71 (30)

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