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Growth and mortality estimates of *Sardinella brasiliensis* in the southeastern brazilian bight

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• *Abstract:* Length frequency analisys were applied for sardine data collected from commercial catches throughout the southeastern Brazilian coast in 1977-1987. Age/length keys were obtained by otolith ring countings and utilized to transform length into age composition. Growth parameters were estimated by the von Bertalanffy growth equation using age and length data for each year and for all the period of investigation. The mean growth parameters for the entire period were estimated as $L\infty$ = 271 mm and K = 0.59 year^{-1}. Instantaneous total mortality (Z) coefficients per year were estimated using catch curves and methods based on the mean length of the fish caught. Total mortality rate for the entire period was obtained through the average of the annual values. Natural mortality (M) was estimated using the Pauly's empirical equation (1980a), and fishing mortality (F) by the difference between total and natural mortality values.The results were Z = 3.6 year^{-1}; M = 0.96 year^{-1}; and F = 2.6 year^{-1}.

• *Resumo:* Estudo sobre o crescimento e a mortalidade de *Sardinella brasiliensis*, da costa sudeste do Brasil, foi realizado para o período 1977 a 1987. As análises foram efetuadas a partir de dados existentes sobre distribuições de freqüência de comprimento de amostras da captura comercial. Chaves idade/comprimento, construidas a partir de leitura de anéis de crescimento em otólitos, dentro do Programa Integrado de Estudos Biológicos sobre a Sardinha - PIEBS, foram utilizadas para transformar as distribuiçes de comprimento em idade. Os parâmetros de crescimento da equação de von Bertalanffy foram estimados, anualmente e para o período como um todo, a partir de métodos que utilizam dados de idade e comprimento. Os parâmetros médios encontrados para o período foram: $L\infty$ = 271 mm e K = 0,59 ano^{-1}. Os coeficientes instantâneos de mortalidade total (Z) anuais foram calculados pelas curvas de captura e por métodos baseados no comprimento médio dos indivíduos nas capturas. A mortalidade total para todo o período foi obtida pela média dos valores anuais. O coeficiente instantâneo de mortalidade natural (M) foi estimado pela equação empírica de Pauly (1980a), usando um fator de correção de 0,8 para clupeoides, e o coeficiente instantâneo de mortalidade por pesca (F), pela diferença entre a mortalidade total e a natural. Os valores encontrados foram: Z = 3,6 ano^{-1}, M = 0,96 ano^{-1} e F = 2,6 ano^{-1}.

• *Descriptors:* Growth, Mortality, Catch, *Sardinella brasiliensis*, SW Atlantic, Brazil, Brazilian Bight.

• *Descritores:* Crescimento, Mortalidade, Captura, *Sardinella brasiliensis*, Atlântico Sul Ocidental, Brasil, Costa sudeste.

Introduction

Among the economically important pelagic species in Brazil, the Brazilian sardine, *Sardinella brasiliensis,* is the one that undergoes strong fishing effort of the commercial fleet. As any clupeoids, the exploitation of this species is characterized by instability of the total catch. Recently, total landing of this species along the southeastern Brazilian coast has experienced a sharp decline resulting in considerable impacts on all sectors of the fishing industry.

Fishing of the Brazilian sardine takes place along the coast of Brazil between the Cape São Tomé (22°S) and the

Cape Santa Marta Grande (28°30'S) up to the depth of 70m (Fig. 1).

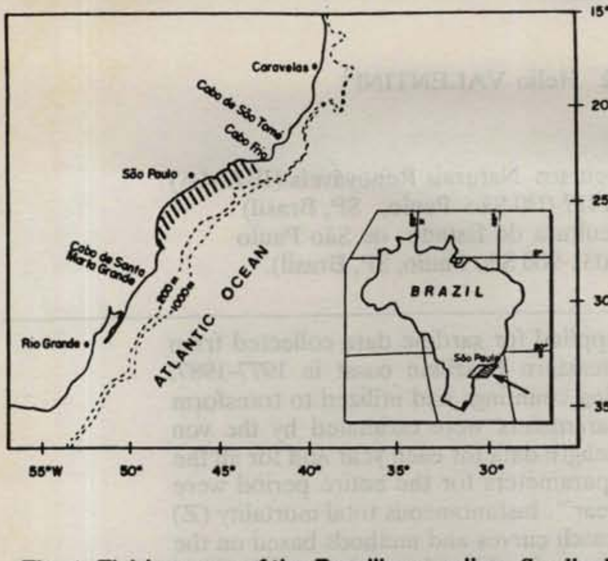

Fig. 1. Fishing area of the Brazilian sardine, *Sardinella brasiliensis*.

Biological data on *S. brasiliensis* obtained until 1988 were summarized by Saccardo & Rossi-Wongtschowski (1991). After this review, some scientific studies were carried out by Matsuura (1988, 1990); Bakun & Parrish (1990); Spach (1990), Ekau & Matsuura (1991); Rossi-Wongtschowski & Saccardo (1991); Lin (1992); and Matsuura *et al.* (1992).

These studies provided information on: distribution and abundance of eggs and larvae; growth and survival rates of larvae; maturity and fecundity; area, season and type of spawning; larvae and adult feeding; age determination and growth rate; weight/length relationship; sex ratio and mortality estimate by indirect methods.

Growth parameters have already been estimated for sardine, both by length frequency distribution (Richardson *et al.*; 1960; Santos & Fratzen, 1965; Matsuura, 1977, 1983; Rijavec *et al.*, 1977) and by growth rings reading in scale (Richardson *et al.*, 1960) and in otolith (Rossi-Wongtscowski *et al.*, 1982; Vazzoler *et al.*, 1982, 1987; Saccardo *et al.*, 1988a,b). However the results could not be readily incorporated into stock assessment models. The main problem was that all the estimates of the asymptotic length ($L\infty$) were inferior to the maximum length observed from the samplings (L_t=270mm) except for the $L\infty$ estimated by Rijavec *et al.* (*op cit.*) which, on the contrary, was much superior.

The objectives of this study are: a) to verify the applicability of sardine length data to estimate growth parameters; b) to estimate growth parameters of the von Bertalanffy equation, the asymptotic length ($L\infty$), the growth rate (K) and the age at zero length (t_0) for the Brazilian sardine, during the period 1977-1987, applying several methods based on age and length data; and c) to estimate the natural and total mortality as well as the fishing mortality using the growth parameters.

Material and methods

Data from commercial landings of *Sardinella brasiliensis* were derived from the catches along the coasts of Rio de Janeiro, São Paulo and Santa Catarina States during the 1977-1992 period. The basic data used were as follows: weight in tons of the total landings per month for each state separately and monthly length frequency distributions from the materials collected at each state.

Catch data from the states of Rio de Janeiro and Santa Catarina were collected by IBAMA (Brazilian Institute for Environmental and Renewable Natural Resurces) based on boarding map system; in the state of São Paulo, the Marine Fishery Division of the Fishery Institute collected the data obtained by interviewing the fishermen.

The length frequency samples were raised to monthly catch for each state which were later summed up to account for the total length frequency distribution of the month for the entire area. For such, the raising factor (total catch weight/sample weight) and the weight/length relationship were used. These steps were executed with the aid of the "Compleat ELEFAN" program package (routine ELEFAN 0, Gayanilo *et al.*, 1989).

The growth and mortality studies were carried out only for the 1977-1987 period when the Brazilian sardine stock has been in a relative equilibrium phase (Cergole, 1993).

The biological parameters considered here were extracted from literature references derived from the collections of the research programme "PIEBS" (Integrated Programme of Biological Studies on Sardine): a) the mean length at sexual maturity, L_t = 168 mm; b) the weight/length relationships as follows: $W_t = 0.0000018 \cdot L_t^{3.29}$ (expression considered for the 1977-1982 period), $W_t = 0.0000023 \cdot L_t^{3.24}$ (1983), $W_t = 0.0000028 \cdot L_t^{3.21}$ (1984), $W_t = 0.0000022 \cdot L_t^{3.26}$ (1985), $W_t = 0.0000016 \cdot L_t^{3.31}$ (1986) e $W_t = 0.0000017 \cdot L_t^{3.30}$ (1987); and c) the age/length keys. The mean length and weight of the captured specimens for the entire area, were estimated by each year; the mean individual weight per year were estimated for each length class.

Growth parameters

The growth parameters of the von Bertalanffy growth equation ($L\infty$ and K) were estimated annually and for the period 1977-1987 as a whole, using length and age data.

Length frequency data

The length frequency distribution data were analysed by means of the Compleat ELEFAN (Gayanillo *et al.*, *op. cit*).

The annual growth parameters for each state and for the entire area were estimated through the seasonalized von Bertalanffy growth equation (Pauly & Gaschutz, 1979) by means of ELEFAN I method (ELEFAN I routine).

Bhattacharya's method (Bhattacharya, 1967) was also applied (using the MPA routine) for splitting the length frequency distribution of the entire area into separate normal distributions, according to age groups; afterwards, the growth parameters were estimated using the FISHPARM program (Saila *et al.*, 1988).

The Wetherall method (Wetherall, 1986) modified by Pauly (1986) was used for estimating $L\infty$; ELEFAN II routine was used in the computations.

Age data

The mean length at age per year data were used in order to estimate the growth parameters by the Ford-Walford plot (Beverton & Holt, 1957) and by means of the FISHPARM program(Saila *et al.*, *op. cit*).

Length and age data

The same mean length at age data of the item b above were also evaluated by means of the ELEFAN V routine from the Compleat ELEFAN , which deals with the analysis of age and length frequency distribution at the same time.

Therefore, the mean growth parameters were calculated according to the values obtained in the different methods; the mean annual values were used for estimating the mortality rates.

The growth equation parameter t_0 was estimated separately through Pauly's empirical formula, using the growth parameters obtained by the ELEFAN I method and also by the mean parameters resultant of all the methods employed.

Mortality rates

The instantaneous total, natural and fishing mortality coefficients were estimated, when possible, by several methods.

The instantaneous total mortality coefficient (Z) was estimated for each year of the 1977-1987 period and for the entire period by the catch curve method based on length at age data (Pauly, 1983, 1984b and 1984c) and also by means of two empirical formulas: Beverton & Holt's (1956) equation and Ssentengo & Larkin's (1973) equation based on the mean length of fish in the catches.

The catch curve was obtained by means of ELEFAN II from the Compleat ELEFAN, and Z was estimated from the descending part of the curve using length data and mean annual growth parameters.

The mean length for which 25%, 50%, 75% and 100% of the fish are under exploitation, were obtained by probability of catch curves using ELEFAN II. The $L_{100\%}$ value, or L', was used in the empirical formulas for calculating Z.

The instantaneous natural mortality coefficient (M) was estimated by Pauly's (1980a) equation , which relates M to the growth rate, K, annually, to the asymptotic, $L\infty$, in centimeters, and to the water temperature, T, in °C. M was also estimated by Rikhter & Efanov's (1976) formula , which relates M to the length at sexual maturity, L_{50}.

Using the Pauly's formula (*op. cit*), M was estimated with the average values for $L\infty$ and K and the temperature 24°C, through the ELEFAN II program. According to Pauly (1980a,b; 1984a), a correction factor of clupeoid fish 0.8 was used to obtain the M. The mean temperature value (T = 24°C) was chosen based on Matsuura's (1983) consideration for the same area.

The value of T_{50} introduced in Rikhter & Efanov's formula correspondent to age at sexual maturity was obtained by the von Bertalanffy equation, using mean growth parameters for the whole period of study, the t_0 obtained from the Pauly's empirical formula (Pauly, 1979), and length at sexual maturity.

The instantaneous fishing mortality coefficient (F) was obtained by $F = Z - M$, where the total (Z) and natural (M) mortality coefficients used correspond to the mean values obtained for the period.

Recruitment pattern

The recruitment pattern was derived from the length frequency distribution by means of ELEFAN II, from the Compleat ELEFAN, using the mean growth parameters of ELEFAN I method and corresponding t_0.

Results

Since 1964, total sardine landings gradually increased reaching a maximum of 228 thousand tons in 1973. From the following year on, there was a reduction in yield exibiting two maximum points: between 1977 and 1980 with oscilations around 140 thousand tons and between 1983 and 1986, with oscilations around 125 thousand tons. After 1986 the catches decreased rapidly to about 32 thousand tons in 1990, being around 65 thousand tons in 1991 and 1992 (Fig. 2).

It can be noticed that after each period of reduction, the stock came to a new level of equilibrium, which was always inferior to the previous one.

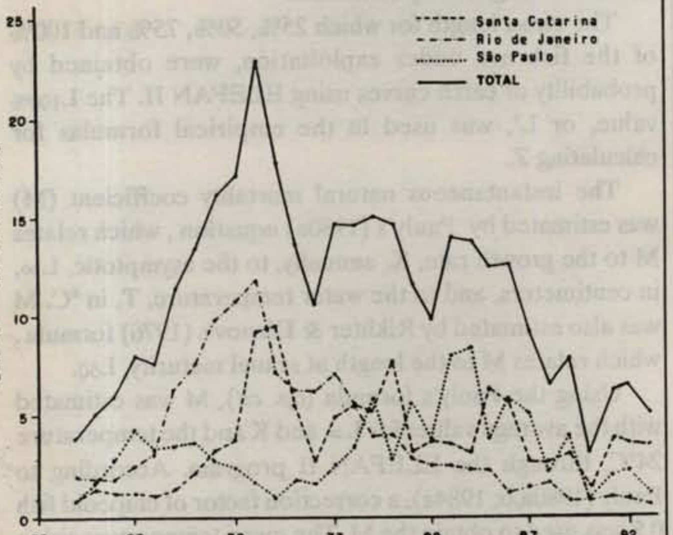

Fig. 2. Total catch of the Brazilian sardine, *Sardinella brasiliensis*, in each state and in the whole area.

Length and weight composition

The fish length in the commercial catches ranged from 90 to 270 mm, most of them between the 150 and 220 mm total length. Large fishes from 260 and 270 mm classes were found during the years 1984 to 1986. Length of recruitment can be considered 90 mm (Table 1).

The mean length of fish landed each year is presented in Table 1 and Figure 3. No abrupt variation in mean length is really noticed. The mean weight of the landed fish shows again no noticeable variation (Table 1, Fig. 4).

Growth parameters

Length frequency data

Growth parameters obtained by ELEFAN I for each year, and state, and for the whole area and period are shown in Table 2.

The C values (range of growth oscilations) showed practically no variation, being equal to 0.6 except in 1987 when it reached 0.4. The value obtained for C is acceptable for the surface water temperature range (21°C to 27°C) observed in the Southeast region of Brazil (Matsuura, 1983, 1986b).

Table 1. Annual length frequency distribution (x 1000) for the Brazilian sardine (*Sardinella brasiliensis*)

LENGTH CLASS (mm)	Wt	YEAR 1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
90	0.006	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0
100	0.008	0	0	0	0	60	0	56	259	0	24	83	0	0	0	0	0
110	0.011	0	0	456	7	661	19	901	110	11751	74	626	0	0	0	25	116
120	0.014	154	212	3028	3846	2967	6791	2321	2160	21854	10002	12644	0	0	0	759	174
130	0.019	2545	3112	20472	18426	7448	19763	12516	21632	57316	39208	45149	0	0	262	2855	515
140	0.023	19042	21516	37749	72088	32148	76554	79843	58456	92082	82043	113702	1539	1186	129	6271	7946
150	0.029	63222	69934	53556	240168	150860	217194	235824	138179	124954	148412	162698	49853	32538	21100	18905	84057
160	0.036	166662	121040	146571	589293	293857	381010	416218	188137	208881	247796	249925	131698	287511	121932	74920	104116
170	0.043	392853	233613	283266	879447	437143	543769	496141	264674	379450	436630	327070	330897	622659	189177	228009	257900
180	0.052	574665	428198	474894	728060	618461	460181	633278	303768	496945	569853	363677	473357	461793	131776	415410	375343
190	0.062	555506	562097	726696	461697	460192	308546	525714	419003	434475	477621	329067	241576	173062	123258	419257	239709
200	0.073	385654	570180	493442	203523	166122	115478	311510	520260	266356	363430	248865	52281	49227	46473	272885	211680
210	0.085	174994	308871	206913	59524	50158	21050	87321	282097	132822	187652	72899	8797	16742	9882	110735	163627
220	0.099	83766	113343	50104	7331	8837	2032	9961	54515	34885	44157	7997	659	3263	1230	18968	62515
230	0.114	35082	28000	10784	725	489	195	929	9876	6062	6660	560	73	85	64	892	8613
240	0.130	8635	4957	1334	74	0	0	32	3688	1522	1346	0	0	0	0	49	344
250	0.148	203	839	37	0	0	7	0	1029	479	251	0	0	0	0	0	0
260	0.168	0	0	0	0	0	0	0	512	147	147	0	0	0	0	0	0
270	0.190	0	0	0	0	0	0	0	68	27	27	0	0	0	0	0	0
TOTAL		2462983	2465912	2509302	3264209	2229403	2152589	2812565	2268438	2270008	2615333	1934962	1290730	1648066	645283	1569940	1516655
Mean Lt (mm)		190.72	195.02	191.32	178.56	181.93	176.68	181.50	190.26	182.84	185.10	179.85	182.10	179.15	181.17	190.73	189.58
S		17.341	17.624	17.034	15.406	15.466	15.975	17.285	20.560	20.986	19.541	20.129	11.692	11.274	13.641	14.317	18.250
Mean Wt (kg)		0.059	0.064	0.060	0.048	0.051	0.046	0.051	0.059	0.052	0.054	0.050	0.050	0.047	0.050	0.059	0.058
S		0.0179	0.0181	0.0164	0.0135	0.0138	0.0134	0.0153	0.0196	0.0183	0.0179	0.0172	0.0105	0.0102	0.0125	0.0141	0.0183

Lt = total length (mm)
Wt = total weight (kg)
S = standart deviation

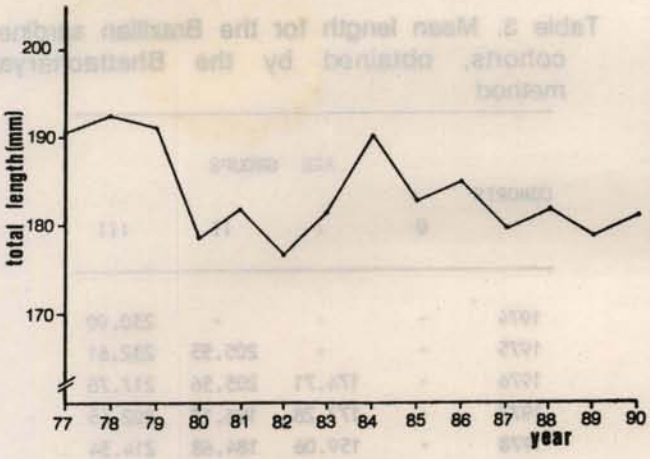

Fig. 3. Annual mean length (mm) for the Brazilian sardine.

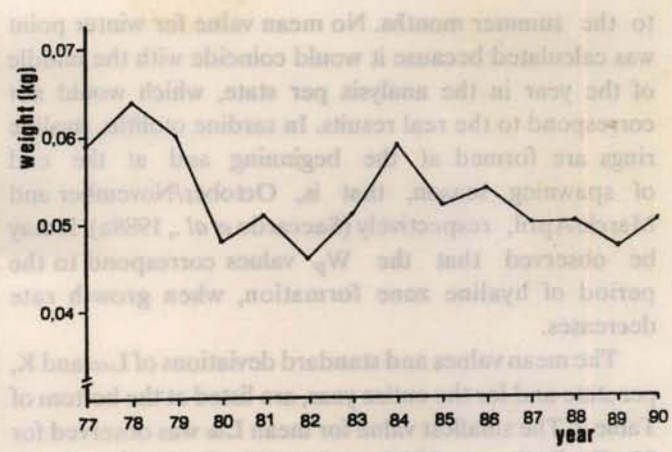

Fig. 4. Annual mean weight (Kg) for the Brazilian sardine

Table 2. Annual growth parameters for the Brazilian sardine obtained by the ELEFAN I program

YEAR	São Paulo				Rio de Janeiro				Santa Catarina				WHOLE AREA			
	L∞	K	C	WP	L∞	K	C	WP	L∞	K	C	WP	L∞	K	C	WP
1977	275	0,73	0,60	0,00	276	0,70	0,60	0,03	288	0,69	0,60	0,00	278	0,69	0,60	0,10
1978	278	0,67	0,60	0,30	276	0,70	0,60	0,30	285	0,67	0,60	0,30	280	0,68	0,60	0,30
1979	284	0,65	0,61	0,45	276	0,68	0,60	0,40	280	0,69	0,60	0,40	288	0,72	0,60	0,30
1980	288	0,70	0,60	0,40	291	0,74	0,60	0,80	282	0,70	0,60	0,40	280	0,68	0,60	0,50
1981	272	0,62	0,60	0,90	282	0,69	0,60	0,90	276	0,65	0,60	0,10	279	0,69	0,60	0,10
1982	271	0,59	0,60	0,95	288	0,71	0,60	0,10	272	0,64	0,60	0,90	280	0,69	0,60	0,00
1983	269	0,65	0,60	0,40	285	0,71	0,60	0,30	270	0,65	0,60	0,50	276	0,68	0,60	0,20
1984	282	0,70	0,60	0,30	294	0,74	0,60	0,30	266	0,69	0,60	0,40	297	0,73	0,62	0,32
1985	272	0,68	0,60	0,40	288	0,71	0,60	0,10	285	0,70	0,60	0,10	291	0,70	0,60	0,40
1986	285	0,70	0,60	1,00	294	0,73	0,60	0,90	291	0,71	0,60	0,70	285	0,69	0,60	0,00
1987	282	0,69	0,60	0,90	287	0,69	0,60	0,49	276	0,69	0,60	0,10	272	0,62	0,40	0,00
Mean values	278,00	0,68	0,60	-	285,20	0,71	0,60	-	279,20	0,68	0,60	-	282,40	0,69	0,58	-
S	6,542	0,042	0,002	-	6,868	0,020	0,000	-	7,897	0,024	0,000	-	7,229	0,028	0,061	-

L∞ = asymptotic length (mm)
K = growth rate (year^{-1})
Wp = "winter point"
C = amplitude of the growth oscillations
S = standard deviation

The winter point (W_P), that is, the season of the year of minimum growth rate, exhibited a greater variation though most of the values were concentrated within spring-summer, mainly at the end of spring (W_P = 0.8 to 1.0) and at the end of summer (W_P = 0.2 to 0.3). For the global area, the obtained values corresponded principally to the summer months. No mean value for winter point was calculated because it would coincide with the middle of the year in the analysis per state, which would not correspond to the real results. In sardine otoliths, hyaline rings are formed at the beginning and at the end of spawning season, that is, October/November and March/April, respectively (Saccardo *et al*., 1988a). It may be observed that the W_p values correspond to the period of hyaline zone formation, when growth rate decreases.

The mean values and standard deviations of L_∞ and K, per state and for the entire year, are listed at the bottom of Table 2. The smallest value for mean L_∞ was observed for São Paulo (L_∞ = 278.0 mm) and the largest for Rio de Janeiro (L_∞ = 285.2). The mean values for the entire area were L_∞ = 282.4 mm and K = 0.69 $year^{-1}$.

Figure 5 shows the growth curves obtained by ELEFAN I for 1977 considering the entire area, which were plotted over histograms of length frequency using the growth parameters that presented the best results. Four age groups, three of them complete cohorts, and one formed by a few months, can be observed indicating that the species reaches a life span of little more than 3 years. This result agrees with studies on age based on otolith readings by Saccardo *et al.* (1988a, b).

By Bhattacharya's method (Bhattacharya, 1967) four modal groups were also identified. The average length for each modal group and the monthly increments in length of the cohorts are shown in Table 3 and Figure 7 respectively. The growth parameters estimated through this method were: L_∞ = 296.6 mm and K = 0.46 $year^{-1}$.

The annual L_∞ values obtained by the Wetherall method (Wetherall, 1986) modified by Pauly (1986) were in Table 4; the average L_∞ value was 271.7 mm. The curves plotted for 1977 as an example is in Figure 6.

Table 3. Mean length for the Brazilian sardine cohorts, obtained by the Bhattacharya method

COHORTS	AGE GROUPS 0	I	II	III
1974	-	-	-	230.90
1975	-	-	205.55	232.61
1976	-	174.71	205.56	217.76
1977	-	177.28	196.17	202.65
1978	-	159.06	184.68	214.34
1979	-	166.52	191.30	209.73
1980	164.72	172.80	190.03	216.97
1981	161.76	169.86	199.08	235.70
1982	-	169.99	203.84	226.98
1983	126.26	180.68	197.17	230.69
1984	156.77	175.59	209.84	220.00
1985	144.69	180.24	204.46	-
1986	-	195.95	-	-

Age data

In relation to the growth parameters estimated by the average length at age, the values for the entire period were L_∞ = 228.5 mm and K = 0.53 $year^{-1}$ (using the Ford-Walford plot) and L_∞ = 272.5 mm and K = 0.55 $year^{-1}$ (using FISHPARM program).

Length and age data

The results of the combined analysis of age and length data using ELEFAN V are listed in Table 4; the mean values for the period were L_∞ = 274.3 mm and K= 0.72 $year^{-1}$.

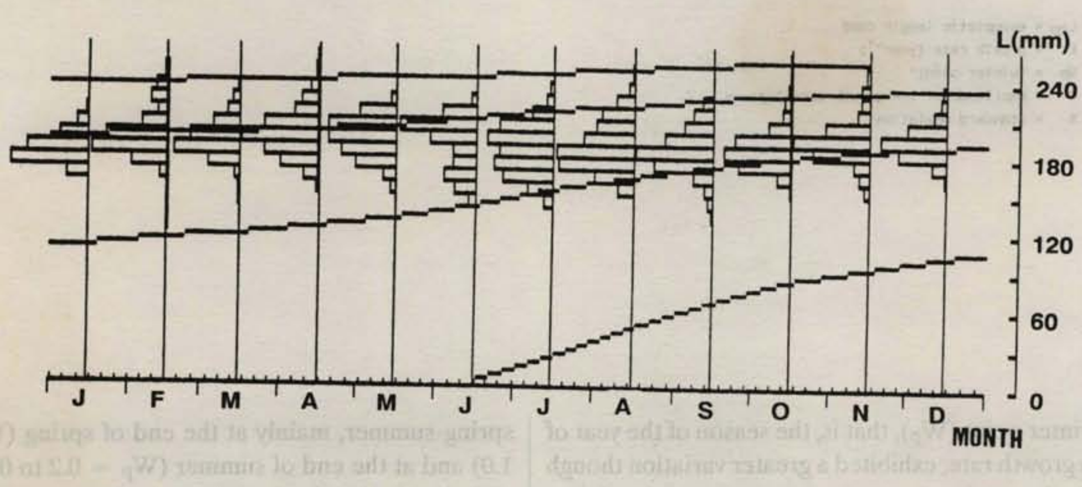

Fig. 5 - Growth curves of the Brazilian sardine based on ELEFAN I. Data from 1977

Table 4. Annual growth parameters obtained for the 1977-1987 period, considering different methods, for the Brazilian sardine

YEAR	ELEFAN I		ELEFAN V		AGE (Ford-Waldord)		WETHERALL	MEAN VALUES	
	K	L∞	K	L∞	K	L∞	L∞	K	L∞
1977	0.60	278.0	0.78	240.0	0.56	234.0	272.6	0.68	256.2
1978	0.68	280.0	0.76	292.0	0.62	229.0	290.3	0.69	272.8
1979	0.72	288.0	0.70	280.0	0.63	222.0	271.6	0.68	265.4
1980	0.68	280.0	0.70	290.0	0.32	246.0	268.6	0.57	271.2
1981	0.69	279.0	0.71	294.0	0.43	225.0	261.9	0.61	265.0
1982	0.69	280.0	0.71	276.0	0.36	233.0	-	0.59	263.0
1983	0.68	276.0	0.71	265.0	0.47	227.0	261.5	0.62	257.4
1984	0.73	297.0	0.68	295.0	0.62	227.0	297.2	0.68	279.0
1985	0.70	291.0	0.74	240.0	0.46	232.0	281.8	0.63	261.2
1986	0.69	285.0	0.74	255.0	0.72	219.0	253.6	0.72	253.2
1987	0.62	272.0	0.71	290.0	0.59	220.0	257.7	0.64	260.0
Mean values	0.69	282.4	0.72	274.3	0.53	228.5	271.7		
Standard deviation	0.270	6.892	0.028	20.159	0.120	7.328	12.906		

L∞ = asymptotic length (mm)
K = growth rate ($year^{-1}$)

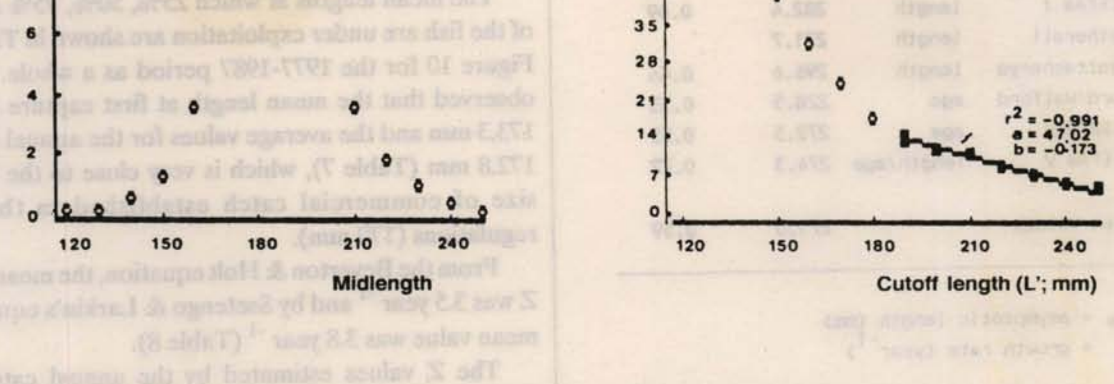

Fig. 6. Estimation of L∞ value for the Brazilian sardine based on Wetherall method. Data from 1977.

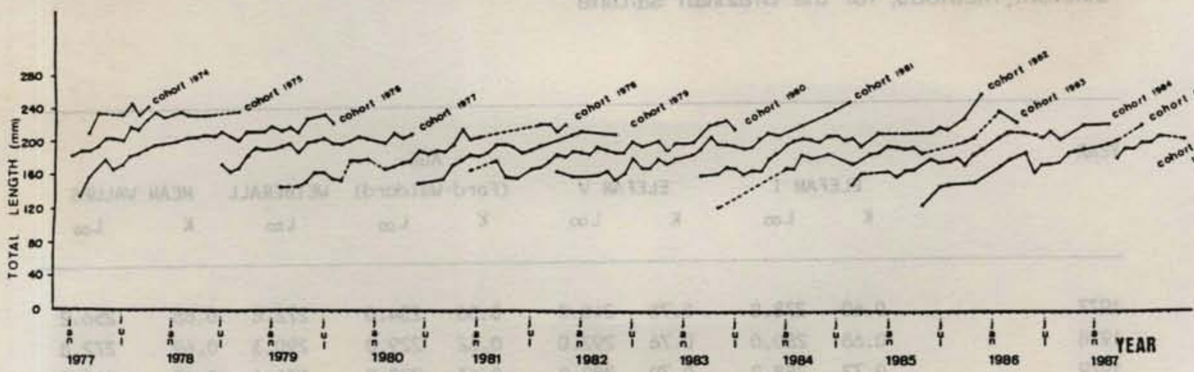

Fig. 7. Monthly length increments for the 1977-1987 Brazilian sardine cohorts, obtained with Bhattacharya method.

The growth parameters obtained annually by all the methods employed are listed in Table 4. When the results are compared based on the maximum length, some methods result in low values for L∞ and high for K, while others lead to opposite results, that is high L∞ and low K. For this reason, average values were estimated in order to counterbalance the effects of each method.

Table 5 shows the results obtained by several methods, considering the entire period under study. The average values were L∞ = 271 mm and K = 0.59 $year^{-1}$.

Table 6 and Figure 8 show the age composition and average length for each age class, based on the data of each semester. When the points are connected following the cohorts, it appears that there are two cohorts per year.

Table 5. Mean growth parameters values for the Brazilian sardine obtained by different methods

METHODS	IMPUT DATA	L∞ (mm)	K($year^{-1}$)
ELEFAN I	length	282.4	0.69
Wetherall	length	271.7	
Bhattacharya	length	296.6	0.46
Ford-Walford	age	228.5	0.53
FISHPARM	age	272.5	0.55
ELEFAN V	length/age	274.3	0.72
Mean values		271.0	0.59

L∞ = asymptotic length (mm)
K = growth rate ($year^{-1}$)

The growth curves for the several year classes plotted per semester, using the average length values estimated by the mean annual parameters and corresponding t_0, obtained by Pauly's equation (Pauly, 1979), are shown in Figure 9. In order to plot the growth curve of the year-classes, a single cohort with birthday on 1_{st} January (such as those obtained by Bhattacharya's method and ELEFAN) was considered.

No significant variation in the mean growth rates was observed for the period under study, but a decrease in the mean lengths for 0.0; 0.5 and 1.0 year-old classes, which can be interpreted as an increase in catch of younger fish, can be observed in Figure 8.

The values for the parameter t_0, age at zero length, estimated by Pauly's equation (Pauly, 1979), were: t_0 = -0.13 for L∞ = 282.4 mm and K = 0.69 $year^{-1}$ (average values estimated by the ELEFAN I method) and t_0 = -0.15 for L∞ = 271 mm and K = 0.59 $year^{-1}$ (average values for all the methods).

Mortality rates

The mean lengths at which 25%, 50%, 75% and 100% of the fish are under exploitation are shown in Table 7 and Figure 10 for the 1977-1987 period as a whole. It can be observed that the mean length at first capture (L_{50}) was 173.3 mm and the average values for the annual mean was 172.8 mm (Table 7), which is very close to the minimum size of commercial catch established in the fishing regulations (170 mm).

From the Beverton & Holt equation, the mean value for Z was 3.5 $year^{-1}$ and by Ssetengo & Larkin's equation, the mean value was 3.8 $year^{-1}$ (Table 8).

The Z values estimated by the annual catch curves (Table 8) ranged from 2.5 $year^{-1}$ (1977) to 5.2 $year^{-1}$ (1980), the calculated mean being 4.0 $year^{-1}$. As the sardine stock

Table 6. Total catch (in number x 1000) and mean length (mm) for each age group for the Brazilian sardine

AGE	1977 N	1977 Lt	1978 N	1978 Lt	1979 N	1979 Lt	1980 N	1980 Lt	1981 N	1981 Lt	1982 N	1982 Lt
0.00	1128	141.93	0	137.39	3376	134.48	13478	137.83	4213	133.16	8738	135.42
0.50	1833	156.85	2852	153.23	6038	140.18	3478	161.31	4215	151.93	7055	148.34
1.00	402118	177.06	164566	188.71	354700	180.46	976780	168.48	424802	176.23	492432	168.86
1.50	559070	178.95	599465	175.62	491212	175.16	1021383	175.55	744115	171.66	869070	170.57
2.00	829722	197.17	977036	202.19	1059383	197.30	655215	187.64	711816	191.96	457199	189.64
2.50	585457	198.87	600130	200.94	506812	200.02	566758	190.63	306476	190.16	300217	187.80
3.00	65150	211.11	101541	209.93	79080	206.86	26277	205.70	32075	202.37	17411	201.57
3.50	18502	231.08	20322	229.59	8699	226.29	839	219.71	1691	222.56	468	221.02

AGE	1983 N	1983 Lt	1984 N	1984 Lt	1985 N	1985 Lt	1986 N	1986 Lt	1987 N	1987 Lt
0.00	313	122.00	568	136.29	-	-	6	105.00	21	105.00
0.50	5809	138.35	820	121.55	846	130.40	23	128.91	407	124.65
1.00	294253	173.18	208697	181.60	186006	153.70	293338	155.47	316145	152.87
1.50	1208221	170.94	679130	170.64	773750	170.82	702224	175.44	585065	173.13
2.00	793925	194.51	670381	202.17	611004	191.70	867987	193.48	535453	190.43
2.50	487702	190.93	583035	198.22	551344	193.44	513391	190.52	385174	190.75
3.00	19126	205.39	101428	208.14	135006	205.31	233370	207.68	108346	202.69
3.50	3217	213.86	24377	222.68	12053	221.73	4994	216.25	4351	214.43

N = number of fishes
Lt = mean total length (mm)

was under equilibrium during the period considered, it is convenient to use the combined data as a whole and plot a single catch curve, instead of estimating Z year-to-year and calculate the mean. So, considering the data altogether for the entire period, the Z was equal to 3.0 year^{-1} (Fig. 11).

The average total mortality coefficient considered for the 1977- 1987 period as a whole was the mean calculated for the 4 values above, that is, Z = 3.6 year^{-1}.

The instantaneous natural mortality coefficients obtained from Pauly's equation (Pauly, 1980a) was M = 0.96 year^{-1} using the mean values of the growth parameters (L_∞ = 271 mm and K = 0.59 year^{-1}) and T = 24°C.

The estimation of the natural mortality obtained by Rikhter & Efanov's equation (1976) was 0.98 year^{-1}, considering the first maturation as 1.5 years. This value is very similar to the previous result obtained by Pauly's empirical formula.

The fishing mortality coefficient was estimated as 2.6 year^{-1} by the difference between the values of total (Z = 3.6 year^{-1}) and natural (M = 0.96 year^{-1}) mortality coefficients.

Recruitment pattern

The greatest percentage of recruitment occurred in the month of July (17.38%). This agrees with the observed field exploitation of the young fish, that is more intensively during the winter months of June to August.

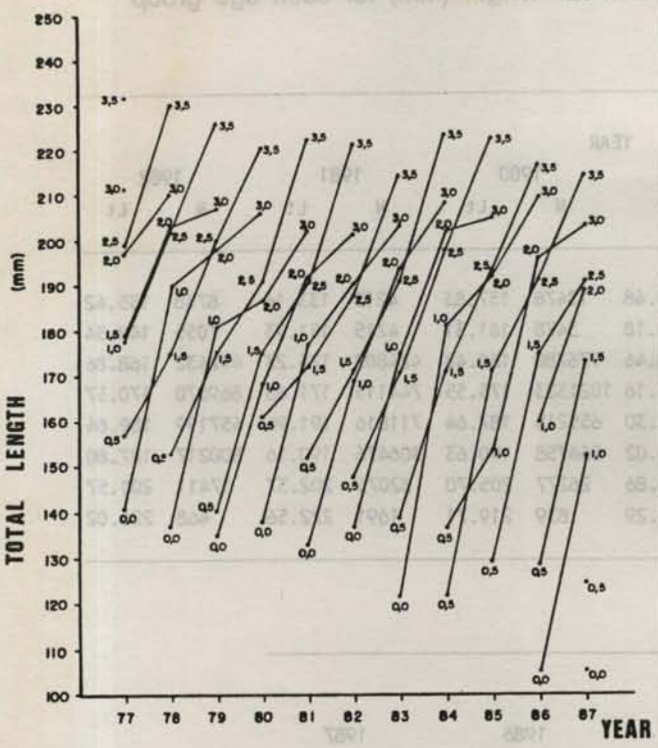

Fig. 8. Mean annual length at age for the Brazilian sardine.

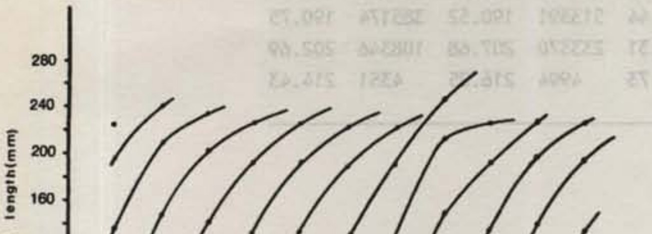

Fig. 9. Annual growth curves for the Brazilian sardine.

Discussion

After 1985, there has been an increase in fishing effort over the sardine stock due to the use of new modern boats, and also to an intensive exploitation of juveniles by fishermen (IBAMA, 1991a, b;1992). It is possible that these changes in the fishing vessels, with a consequent increase in the fishing power, had contributed with the reduction of the sardine stock. Apparently it did not reflect in the density-dependent parameters. Only a decrease in the mean length of the young fish (0.5 year) was observed during the period.

Table 7. Mean length values obtained by catch probability curve for the Brazilian sardine

YEAR	L25 (mm)	L50 (mm)	L75 (mm)	L100 (mm)
1977	170.6	171.1	183.6	190.0
1978	185.5	193.5	201.6	200.0
1979	185.2	194.0	202.9	200.0
1980	168.0	173.1	178.1	180.0
1981	175.2	182.0	188.9	190.0
1982	155.2	160.3	165.5	180.0
1983	178.4	185.3	192.1	190.0
1984	165.0	172.9	180.7	210.0
1985	161.6	172.7	183.7	190.0
1986	173.6	180.9	188.2	190.0
1987	168.3	176.1	183.9	180.0
Mean values	163.0	172.8	182.4	190.0
Standard deviation	8.937	9.346	10.021	9.000

L25 = mean length for which 25% of the fish are under exploitation
L50 = mean length for which 50% of the fish are under exploitation
L75 = mean length for which 75% of the fish are under exploitation
L100 = L' = mean length for which 100% of the fish are under exploitation

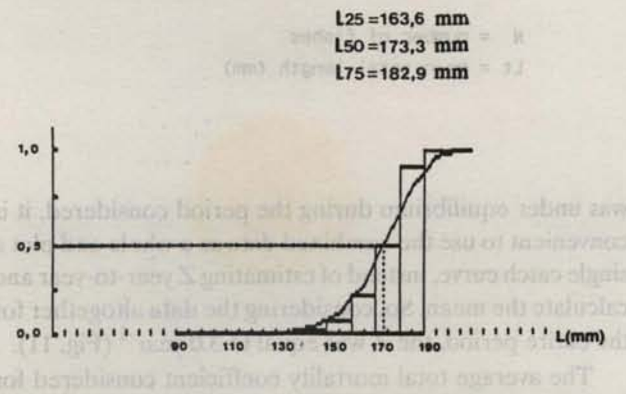

Fig. 10. Catch probability curve for the Brazilian sardine.

Table 8. Annual total mortality coefficients for the Brazilian sardine obtained by different methods

	TOTAL MORTALITY		
YEAR	Beverton & Holt (1956)	Ssentengo & Larkin (1973)	Catch curve
1977	2.468	2.794	2.504
1978	3.716	4.052	4.266
1979	3.952	4.284	4.585
1980	3.656	3.934	5.187
1981	4.257	4.555	4.884
1982	3.632	3.919	3.602
1983	3.322	3.623	4.776
1984	5.414	5.747	3.431
1985	2.902	3.207	2.751
1986	2.701	3.047	3.567
1987	2.751	3.060	3.954
Mean values	3.525	3.838	3.955
Standard deviation	0.808	0.808	0.834

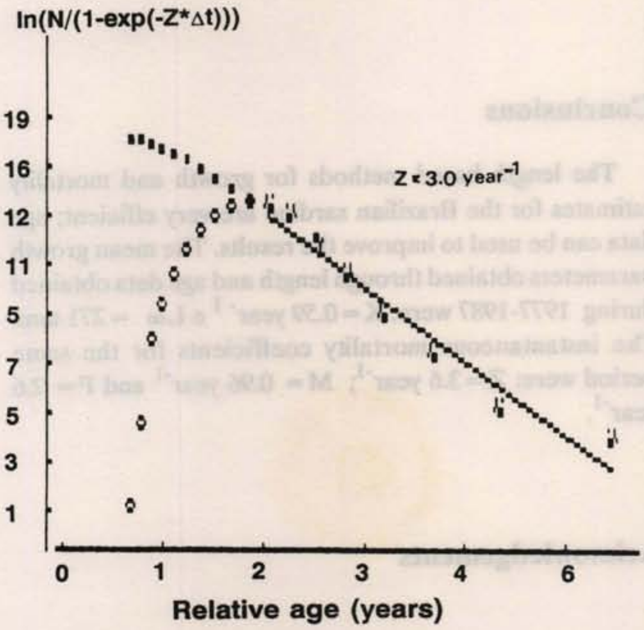

Fig. 11. Length converted catch curve for the Brazilian sardine. Data from 1977-1987 period.

Considering only the analysis of the variations of the density- dependent parameters (mean length and weight, and growth rate), for the period under study, they showed no signs of a future fishing collapse of *S. brasiliensis*.

In the previous studies concerning age and growth of the Brazilian sardine, growth parameters were estimated using length and age data obtained from countings of growth rings in otoliths and scales. The results were not satisfactory because the asymptotic length estimated was smaller than lengths obtained in the commercial fishery.

In the present study, with the use of microcomputer and softwares in the analysis of length frequency distributions and non- linearized adjustments in analysis of age data, the estimated average growth parameters (L_∞ = 271 mm and K = 0.59 year^{-1}) were satisfactory. Also, the methods (ELEFAN I, Bhattacharya, Wetherall and ELEFAN V) based on length frequency data were very efficient on the estimate of the parameters because they were applied to the species on a balanced equilibrium of the stock, where the annual variations on the recruitment were small. In addition, the availability of the age data was important to improve the estimate of the parameters.

When Saccardo *et al*. (1988a, b) analyzed the growth of the Brazilian sardine, they considered two groups per year: one composed by the fish that were born in the beginning of spawning season and the other in the end of it. By application of Bhattacharya's method to the length frequency distribution it became evident that a single cohort is formed each year, which agrees with the growth curves obtained by the ELEFAN I method. Although the spawning season is long (from October to March), the intensive spawning takes place within a relative short period, generally in December-January (Matsuura, 1977, 1988).

For stock assessment purposes only one cohort with the birthday date of January 1st can be considered (Cergole, 1993).

The growth performance index, Phi prime ϕ' (Munro & Pauly, 1983; Pauly & Munro, 1984), was used for comparison of the several estimates of the growth parameters presented in literature and our results. Table 9 shows the values for L_∞ and K and correspondent ϕ'. The highest value calculated was ϕ' = 4.99, for the growth parameters estimated by Rijavec *et al*. (1977) (in the 23°-25°S area) and the lowest ϕ' = 4.13, for parameters obtained by Vazzoler *et al*. (1987), for the area between 25° and 26°S (Cananéia, SP - Paranaguá, PR). The former authors estimated the growth rate (K = 0.87) and the asymptotic length (L_∞ = 335 mm), using the modal progression method of length frequency distributions, resulting a very large value for L_∞. On the other hand, Vazzoler *et al*. (*op. cit*) estimated the growth parameters (L_∞ = 115.16 mm and K = 1.02 year^{-1}) using the Ford-Walford plot applied to the mean length at age data obtained by otolith readings; in this case, the estimation was made based on samples of young fish, which could have influenced the calculations, resulting in an underestimate asymptotic length.

Table 9. Growth Performance Index (ϕ') values for the Brazilian sardine, for different sets parameters

AUTHORS	AREA	L∞ (mm)	K(year^{-1})	ϕ'
Richardson et al., 1960	22-23°S	254.20	0.31	4.30
Santos & Fratzen, 1965	22-23°S	243.00	0.50	4.47
Matsuura, 1977	22-23°S	244.00	0.44	4.42
Rijavec et al., 1977	23-25°S	335.00	0.87	4.99
Matsuura, 1983	22-28°S	260.00	0.62	4.62
Vazzoler et al., 1987	22-23°S	232.94	0.62	4.53
Vazzoler et al., 1987	23-25°S	229.86	0.37	4.29
Vazzoler et al., 1987	25-26°S	115.16	1.02	4.13
Saccardo et al., 1988a	22-28°S	230.99	0.72	4.58
Saccardo et al., 1988a	22-28°S	226.09	0.72	4.56
Cergole (average values)*	22-28°S	271.00	0.59	4.64
Cergole (ELEFAN I)*	22-28°S	282.40	0.69	4.74

L∞ = asymptotic length (mm)
K = growth rate (year^{-1})
* = results of this work

The values of ϕ' for the growth parameters estimated by the various authors did not demonstrate significant variation except for those mentioned and discussed above, which are considered extreme values.

Once the growth parameters were known, it was possible to estimate the instantaneous total ($Z = 3.6$ year^{-1}) and natural ($M = 0.96$ year^{-1}) mortality coefficients.

The best estimates for Z using the catch curve method for the sardine stock was those based on pooled data (from 1977 to 1987). In this manner, annual variations in recruitment were eliminated, simulating a true equilibrium situation.

The methods for estimating natural mortality in fish population include the analysis of data from commercial catch or from sampling programs specific for stock assessment. The M values can be estimated by catch per unit fishing effort data, by correlation with other parameters of the life cycle and by predation studies (Vetter, 1988).

Since there were some problems with the data on catch per unit of effort (CPUE) and no data of predation was available for the Brazilian sardine, it was only possible to apply the empirical methods. The results, when comparing the one derived from the use of Pauly's equation (Pauly, 1980) raised for clupeoids with the one derived from Rikhter & Efanov's equation, were very similar. This provided reliabity to the results, since they are based on different criteria.

Beverton (1963) estimated M/K for 13 species of engraulidids and clupeids including the genus *Sardinella* , and the values ranged between 1.0 and 2.0. In the present study the values of M/K estimated for the Brazilian sardine ($M/K = 1.63$) occur within the range observed by the author cited above.

The fishing mortality rate gives an idea of the exploitation rate ($E = F/Z$) of the Brazilian sardine, which is 0.72 year^{-1}. This value can lead to the conclusion that the sardine stock is being intensively exploited. It is considered here that this may be the main cause of the stock reduction.

The fishing mortality rates per age, per year, was calculated through Virtual Populations Analysis (Cergole, 1993). An increase of the mortality rates after 1985 was observed; this variation can be correlated with an increase in the fleet size and in the fishing power.

Conclusions

The length based methods for growth and mortality estimates for the Brazilian sardine are very efficient; age data can be used to improve the results. The mean growth parameters obtained through length and age data obtained during 1977-1987 were: $K = 0.59$ year^{-1} e $L_\infty = 271$ mm. The instantaneous mortality coefficients for the same period were: $Z = 3.6$ year^{-1}; $M = 0.96$ year^{-1} and $F = 2.6$ year^{-1}.

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