AGE, GROWTH AND ASPECTS OF REPRODUCTION OF THE MACKEREL, *SCOMBER JAPONICUS* IN SOUTH AFRICAN WATERS (PISCES: SCOMBRIDAE).

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ABSTRACT

The age and growth of the mackerel were determined from 1742 otoliths collected from commercial catches. The time of annulus formation was established from otolith edge examinations. Two zones, one opaque and one hyaline, are laid down during a year. The distance of each annulus from the nucleus of the otolith was measured. Mean measurements were substituted in a linear regression equation which describes the relationship between otolith radius and fish length to obtain back-calculated length at age values. Growth in length and in mass are expressed by the von Bertalanffy growth equation. Length and age at first maturity were established by macroscopic examination of mackerel gonads. All mackerel were found to mature during their fourth year of life, at 42 cm standard body length. Spawning takes place during the period June to September.

INTRODUCTION

The mackerel, *Scomber japonicus* Houttuyn (Pisces: Scombridae), has occurred in the pelagic purse-seine catches of the Republic of South Africa since 1954. Although the annual mackerel catch has shown a fluctuating trend it has nevertheless contributed significantly to the multi-species fishery, as illustrated in Table 1 which shows the catch figures for the period 1966–1975. Other commercially exploited species are the anchovy *Engraulis capensis*, the pilchard *Sardinops ocellata*, the maasbanker *Trachurus trachurus*, the red-eye *Etrumeus terres*, and a lantern fish *Lampanyctodes hectoris* (Myctophidae). During most years since 1967 the mackerel was, next to the anchovy, the most important species of the catch.

Aspects of and trends in the fishery, with emphasis on the role of the pilchard, the maasbanker and the anchovy, have been discussed by Du Plessis (1959), Stander & le Roux (1968), Baird & Geldenhuys (1973), Geldenhuys (1973), Newman (1973), Baird (1973) and Centurier-Harris & Crawford (1974). The biology of the pilchard and anchovy was investigated by Davies (1957), Robinson (1966), Baird (1970 and 1971) and Pollock (1970). Research on the mackerel was initiated during 1971 by the Sea Fisheries Branch, Department of Industries, Sea Point. Preliminary findings on the biology and fishery of the mackerel were published by Baird (1972).

This paper presents the results of studies on the age, growth and aspects of reproduction of the mackerel in South African waters.

COLLECTION OF MATERIAL

Regular sampling of the commercial catches was conducted throughout the pelagic fishing season (1 January to 31 August) each year at three fish-processing plants, situated along the west coast of South Africa. Random samples, which may consist of as many as 200 fish, were collected from boats' holds. Data were obtained on caudal, fork and total length, whole mass, sex, maturity, gonad mass, and degree of stomach repletion; and otoliths were removed for age determination. All mass measurements were taken to the nearest gram and length measurements to the nearest centimetre. Unless otherwise stated, reference to fish length is in terms of standard body length (Lc).

Gonads were classified into maturity stages by macroscopic visual assessment of such criteria as shape, colour, the size of the gonad in relation to that of the body cavity, the size of the eggs and the "freeness" of the milt. The scale of Hjort (1910) recommended by the International Council for the Exploration of the Sea (Ehrenbaum 1930) was adopted. Whenever possible 20 otoliths per 1 cm length class were collected per month.

RESULTS

Growth

The growth of *S. japonicus*, a cosmopolitan, single polytypic species (Matsuì 1967), has been investigated by a number of research workers. Gagliardi & Cousseau (1970) studied the growth of *S. japonicus marplatensis*, occurring in the western Atlantic off Argentine. Fitch (1951) investigated the growth of *S. japonicus* in the Pacific Ocean off the west coast of the United States, while Aikawa (1937) and Iizuka (1967) determined the growth rate of *S. japonicus* in Japanese waters. In addition the growth rate of *Scomber scombrus* from the North Sea has been investigated by Castello & Hamre (1969). All authors used otoliths in the age determination of the mackerel, except Aikawa (1937) who used vertebrae, and Iizuka (1967) who used otoliths and scales. Otoliths were also used in this study on the South African mackerel. Scales of the mackerel are small, cycloid and devoid of any distinctive rings which could be interpreted as year marks. The scales are decidious and easily shed by the fish when caught in the purse-seine net. Few fish were found to contain scales after they had been pumped from the net into the boat's hold.

Mackerel otoliths used for age determination in this study were collected at the field stations during 1968, 1969, 1970 and 1971. The number of otoliths read for age and the percentage readable are shown in Table 2. All otoliths were examined and measured by means of a stereoscopic microscope with X60 and X120 magnification. They were placed in a petri dish, covered with water and studied under reflected light against a black back-

TABLE 1

Total annual pelagic catch and the percentage contribution of the mackerel, *S. japonicus*, 1966–1975

Years	*Total catch (thousands of metric tons)*	*Mackerel (percentage)*
1966	356	15,4
1967	509	27,3
1968	369	24,4
1969	351	26,4
1970	362	21,5
1971	323	16,8
1972	434	12,8
1973	451	12,6
1974	399	7,7
1975	406	16,7

TABLE 2

Number of otoliths examined for age.

Year	*No. examined for age*	*Percentage readable*
1968	573	86,4
1969	480	86,9
1970	244	80,0
1971	445	92,6

ground. Under these conditions hyaline zones appear as dark bands whereas opaque zones are white. Both are concentric to the outer edge of the otolith and are more clearly visible in the region posterior to the otolith centre. Rings are also more clear when otoliths are viewed from the lateral or outer surface, than from the inner or medial side.

Annulus formation

In order to determine whether one hyaline and one opaque zone are formed each year as well as the time of their formation, the edges of otoliths, collected on a monthly basis during the period 1968-1971, were examined. Owing to patterns of availability and to the closed fishing season, which extends from September/October to December, otoliths could not be collected during all the months of any particular year. The number of otoliths examined per month for the four years 1968-1971 is shown in Table 3 as well as the percentage of otoliths with opaque and hyaline edges.

Otoliths showed a seasonal variation in the formation of hyaline and opaque edges in all the years examined. Table 3 shows that hyaline zones were mainly formed in the months

TABLE 3

Percentage occurrence per month of otoliths with hyaline or opaque edges, 1968–1971

	1968			*1969*			*1970*			*1971*		
Months	*%O**	*%H**	*n**	*%O*	*%H*	*n*	*%O*	*%H*	*n*	*%O*	*%H*	*n*
January	78	22	100	68	32	115	—	—	0	—	—	0
February	69	31	13	81	19	58	—	—	0	69	31	36
March	34	66	33	58	42	12	—	—	0	56	44	89
April	46	54	39	—	—	0	—	—	0	52	48	46
May	24	76	21	45	55	31	—	—	0	—	—	0
June	30	70	54	38	62	24	21	79	47	49	51	61
July	35	65	91	42	58	73	25	75	160	35	65	66
August	—	—	0	36	64	66	—	—	0	34	66	38
September	—	—	0	—	—	0	—	—	0	41	59	37
October	—	—	0	—	—	0	—	—	0	—	—	0
November	—	—	0	—	—	0	—	—	0	—	—	0
December	—	—	0	—	—	0	—	—	0	—	—	0

*%*O* = Percentage of otoliths with opaque edges
%*H* = percentage of otoliths with hyaline edges
n = number of otoliths examined

March to September. Figure 1 illustrates that when the data of all four years from Table 3 were pooled, the highest frequency of hyaline edges occurred from April to September. Opaque zones were dominantly formed during January and February, but most probably also during the summer months of the preceding year. Opaque and hyaline edges were noted in all months of the year but the general pattern indicates that one opaque and one hyaline zone are deposited each year (Figure 1). It would also appear that hyaline zones are mainly formed during winter and opaque ones during summer.

In all the otoliths examined, the central area or nucleus was always of an opaque nature which is typical of summer growth. The first, large opaque zone can therefore be correlated with the period immediately following spawning, which takes place during late winter, spring and early summer (Figure 3), and the subsequent growth period until the first hyaline zone is formed during the following autumn and winter. Further development is represented by the second opaque zone which indicates the beginning of the second year's growth.

Only the hyaline zones were counted and recorded for each individual fish. Otolith readings were repeated three times with a time lapse between readings to reduce bias and nullify the interference of one reading with another. If agreement could be obtained in two

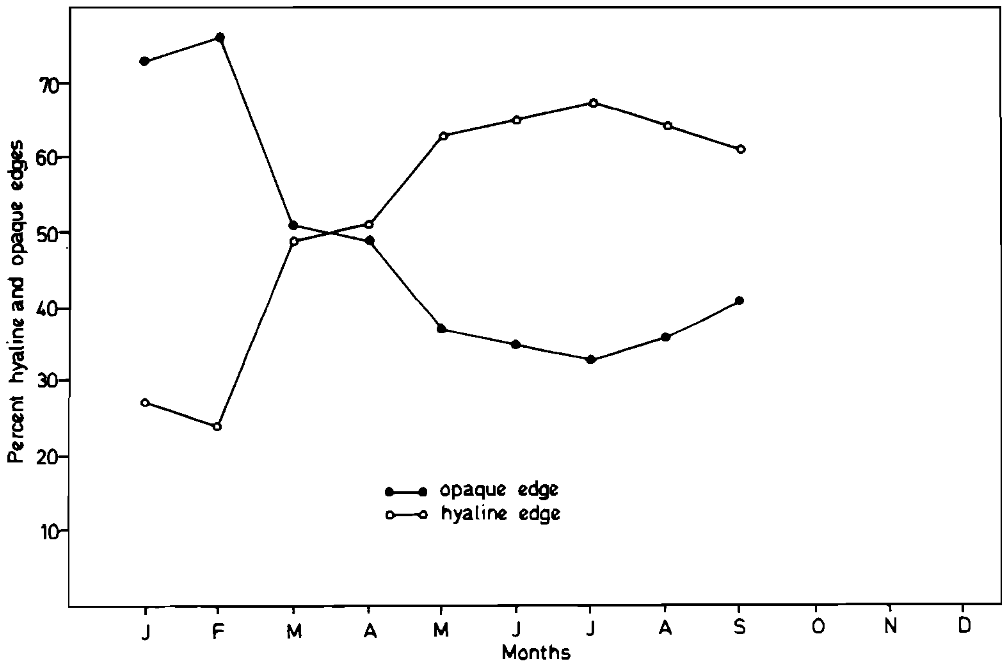

FIGURE 1

Mean monthly percentages of otoliths with opaque and hyaline edges, 1968 - 1971.

of the three readings of an individual otolith, the readings were accepted and the otolith considered as readable. If all three readings were different the otolith was classified as unreadable. A number of otoliths did not show any recognizable growth zones. These were also considered as unreadable.

The following measurements were recorded from each otolith (Figure 2) by inserting a measuring disc in the right eyepiece of the microscope:

(a) The total otolith length (OL): the distance from the sharp anterior end, the rostrum, to the posterior edge.
(b) The otolith radius (OR): the distance from the nucleus or centre to the posterior edge.
(c) The distance to the outer posterior edge of each hyaline zone from the otolith nucleus (R).

Growth in length

Having established the fact that zone formation appears to be regular and can therefore be used to determine age, the relationship between otolith length and fish length was estab-

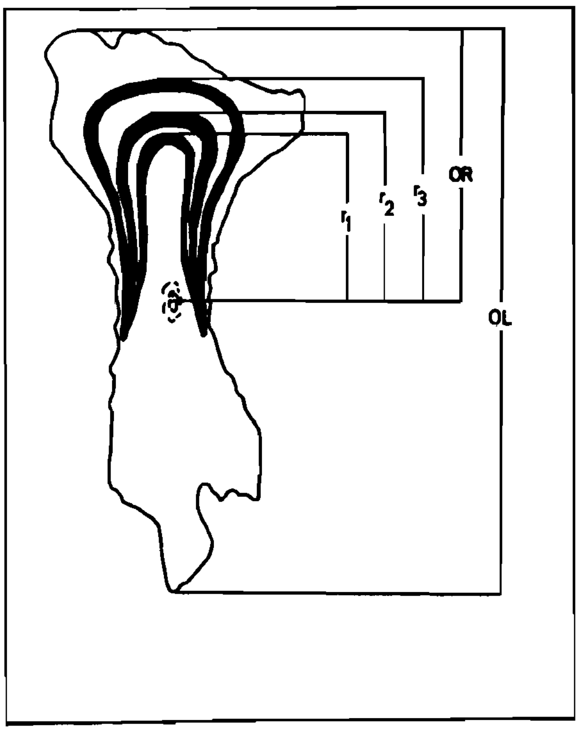

FIGURE 2

Schematic drawing of mackerel otolith showing measurements.

lished by linear regression. The equation calculated for these data by the method of least squares was found to be

$$OL = 0{,}1045Lc + 1{,}6250$$
$$(r = 0{,}9367;\ n = 420)$$

where OL is otolith length at fish length Lc.

Proof of a linear relationship between otolith radius and fish length was also obtained when measurements of the otolith radius were plotted against fish length. The resulting equation was

$$OR = 0{,}0457Lc + 0{,}8215 \ldots\ldots (1)$$
$$(r = 0{,}9514;\ n = 491)$$

where OR is otolith radius at fish length Lc.

Because of the positive correlation between fish length and otolith length, and between fish length and otolith radius, it was judged valid enough to permit the use of otolith radius measurements (Figure 2) to calculate fish length at annulus formation.

Mean distances of the outer annulus from the otolith nucleus for males and females are shown in Table 4. The annuli measurements for males and for females (Table 4, columns a and b) were substituted in (1) to obtain the length at a particular age. To determine length at age for both sexes combined, the mean annuli distances, r_1, r_2, ∴ r_n of each age class I +, II +, etc. (Table 4, column c) were also substituted in (1).

The back-calculated standard body length at age for males, females and for males and females combined, obtained by substituting r_n measurements of the different age classes in (1), is presented in Table 5.

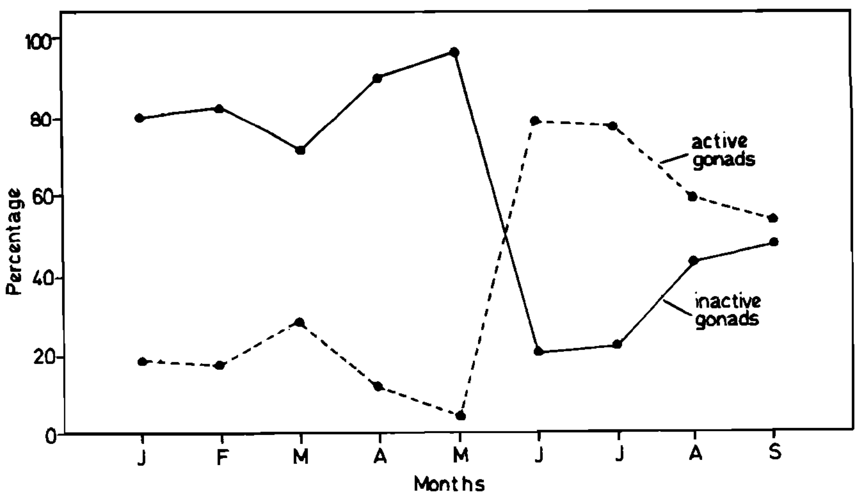

FIGURE 3
Seasonal maturity cycle of the mackerel, *Scomber japonicus*.

TABLE 4

Mean annulus distance from otolith nucleus for males (column a) and for females (column b) and for sexes combined (column c)

Age Class	*Males (column a)*			*Females (column b)*			*Males & Females (column c)*		
	r_n (mm)	Standard deviation	n	r_n (mm)	Standard deviation	n	r_n (mm)	Standard deviation	n
I+	r_1=1,88	0,092	115	r_1=1,88	0,106	128	r_1=1,88	0,110	243
II+	r_2=2,26	0,113	195	r_2=2,28	0,139	148	r_2=2,26	0,131	343
III+	r_3=2,57	0,141	71	r_3=2,56	0,160	48	r_3=2,57	0,150	119
IV+	r_4=2,84	0,153	72	r_4=2,80	0,146	49	r_4=2,82	0,148	121
V+	r_5=3,08	0,167	25	r_5=3,04	0,216	30	r_5=3,06	0,193	55
VI+	r_6=3,16	0,129	8	r_6=3,22	0,208	12	r_6=3,20	0,161	20
VII+	r_7=3,41	0,182	5	r_7= —	—	0	r_7=3,41	0,178	5
VIII+	r_8=3,73	—	1	r_8=3,43	0,134	2	r_8=3,53	0,251	3

TABLE 5

Back-calculated mean standard body length at age for males, females and males and females combined.

Age (years)	*Females*			*Males*			*Males and Females*		
	(cm)	SD	n	(cm)	SD	n	(cm)	SD	n
I	23,16	2,32	128	23,16	2,02	115	23,16	2,32	243
II	31,91	3,04	148	31,47	2,48	195	31,48	2,82	343
III	38,04	3,50	48	38,25	3,10	71	38,26	3,33	119
IV	43,29	3,20	49	44,16	3,36	72	43,73	3,26	121
V	48,54	4,73	30	49,41	3,66	25	48,98	4,16	55
VI	52,48	4,56	12	51,16	2,33	8	52,05	3,56	20
VII	—	—	0	56,63	4,00	5	56,63	4,00	5
VIII	54,67	2,93	2	63,64	—	1	59,27	5,65	3

The following useful relationships have been calculated. Standard length values can be converted to

(a) total length (Lt) by means of the equation

$$Lt = 0,8807 + 1,1925Lc \ (N = 565)$$

(b) fork length (Lcf) by means of the formula

$$Lcf = 0,2113 + 1,0650Lc \ (N = 621)$$

No significant difference ($P>0,05$) was found between the mean length at age values for males and females. (Age eight was excluded from the t-test as the number of samples was too small). A single growth curve for the mackerel representing both males and females was therefore calculated and expressed by means of the von Bertalanffy growth equation. The parameters calculated were

$Lc_{\infty} = 68,01$ cm standard body length

$K = 0,2070$ and

$t_0 = -0,9845$

and the equation thus becomes

$$Lc_t = 68,01\,(1 - e^{-0,2070\,(t\,+\,0,9845)})$$

Values calculated by this equation (fitted curve) agree well with the observed points (Figure 4).

Growth in mass

In order to express growth in terms of mass, the length/mass relationship for mackerel was calculated. Total mass and body length values were used. Males and females were initially considered separately but as no difference ($P>0,05$) was observed all data were pooled and the following relationship was obtained:

$$W = 0,0049Lc^{3,3112} \qquad (2)$$

where

W = total mass and

Lc = standard body length.

The mass at age of the mackerel can be obtained by substituting the observed length at each age for both sexes combined from Table 5, in (2). W_{∞} may also be calculated by substituting L_{∞} in (2) so that the von Bertalanffy equation describing the growth of the mackerel in terms of mass becomes

$$W_t = 5730,7\,(1 - e^{-0,2070\,(t\,+\,0,9845)})^{3,3112}$$

This function is graphically illustrated in Figure 5.

REPRODUCTION

Seasonal maturity and spawning

The seasonal development of the mackerel gonad was determined from data collected during the years 1969 to 1973. Owing to the fact that catches of mackerel were not made during all the months of the fishing season in any of these years, the data were pooled. In this way, all the months of the fishing season (January to September) were well represented.

To establish the length at which mackerel attain sexual maturity, only the data of fish larger than 35 cm were considered to exclude the possible masking effect which smaller fish could have had. The numbers of fish examined per month, males and females combined, are indicated in Table 6. The criteria for differentiating between reproductively active and inactive or immature gonads was based on the macroscopic method of maturity determination. The ratio of mature and immature gonads for the months January to September is plotted in Figure 3.

It is clear that reproductive activity was at its lowest during the months January to May. Sexually inactive fish predominated in the catches while mackerel with active gonads were present in low percentages during these months. The number of fish with active gonads

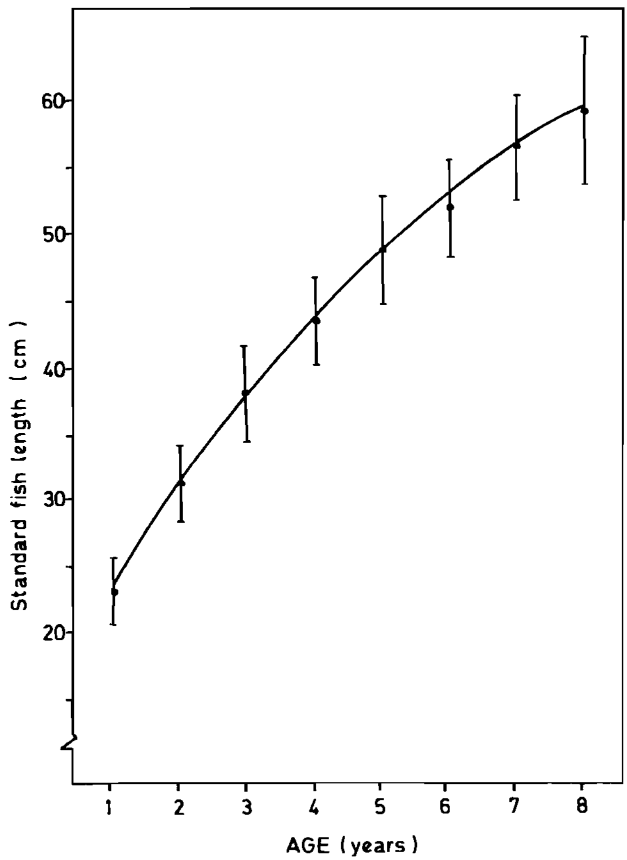

FIGURE 4
Growth in length of the mackerel, *S. japonicus*.

TABLE 6

Numbers of fish examined for length at maturity and for seasonal development of the gonads, 1969–1973

	Years					
Months	*1969*	*1970*	*1971*	*1972*	*1973*	*Total*
Jan	408	0	103	1 042	0	1 553
Feb	151	0	0	826	215	1 192
March	0	1	281	1 245	1 932	3 459
April	0	0	124	636	0	760
May	24	0	48	0	0	72
June	150	109	50	0	0	309
July	500	551	145	324	0	1 520
Aug	200	0	115	0	1 132	1 447
Sept	0	0	75	0	0	75

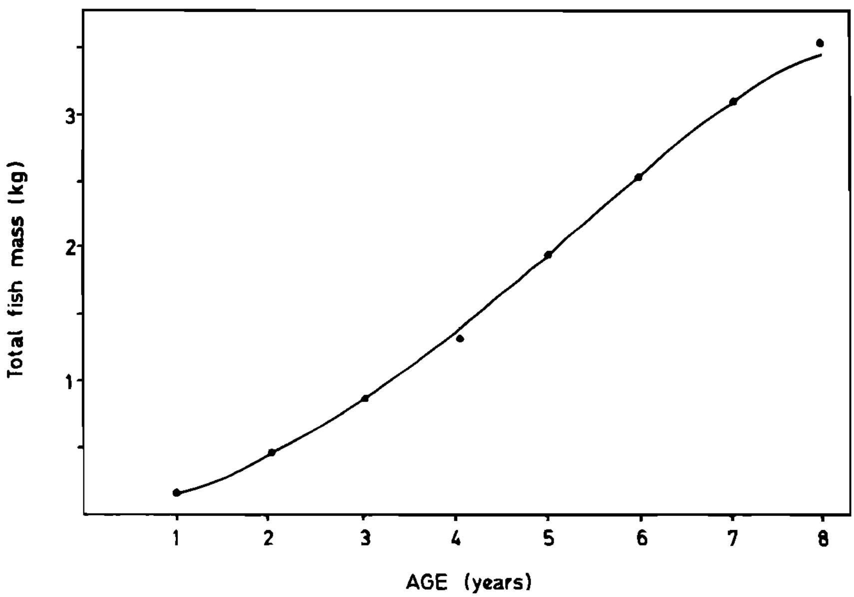

FIGURE 5
Growth in mass of the mackerel, *S. japonicus*.

increased during June and the percentage of reproductively active mackerel in the catches reached a peak during the period June to mid-August.

Length and age at maturity

Length at reproductive maturity was established by macroscopic examination of gonads.

Data on the gonad activity of mackerel were collected during the period 1969-1973. The classification of gonads into the different maturity stages was done during the routine analysis of a commercial fish sample.

Only data from the period of maximum gonad activity during each of the years 1969 to 1973 were used to establish length at reproductive maturity. This was done in order to eliminate the possible influence of the retarded gonad condition of late spawners or the recovered gonads of early spawners.

The criterion used to differentiate between immature and mature fish was based on the classification of gonads into the following maturity stages:

Stage I:	(immature, virgin individuals). Testes and ovaries thin and thread-like, translucent and nearly colourless, sexes usually indistinguishable.
Stage II:	(maturing virgins or recovering spent). Ovaries more rounded and beginning to enlarge, colour translucent pinkish, eggs not visible to naked eye: Testes thin and straplike, beginning to thicken with slight white coloration.
Stage III:	Gonads developing and filling half body cavity. Ovaries pale yellow, eggs small but visible to naked eye. Testes greyish white with smooth texture.
Stage IV:	Gonads maturing and filling approximately two thirds of body cavity. Ovaries yellow, ova discrete. Testes opaque white and smooth.
Stage V:	Mature gonads, filling most of body cavity. Ovaries dark yellow, ova large. Testes opaque white, smooth texture.
Stage VI:	Ripe. Gonads at maximum size and filling body cavity. Ovaries dark yellow, pressure on belly causing extrusion of translucent pale-golden eggs. Testes opaque white, crumbly in texture, milt extruded by pressure on abdominal wall. Roe and milt running (spawning).
Stage VII:	Spent. Ovaries slack, thin, bloodshot. Testes thin, flaccid, bloodshot.

From Stage VII the maturation cycle begins anew at Stage II in the surviving spawners. Although the maturity assessments made in the routine analysis of mackerel samples were fairly consistent and quite adequately give an overall picture of the maturity range in a given sample, the macroscopic criteria for distinguishing between spent or recovering spent fish (Stages VII, II) and virgin gonads maturing for the first time (Stages I, II) were unsatisfactory. Stage II covers a whole range of gonad states and it was difficult to subdivide them on macroscopic grounds alone. However, the time factor in the examination of large numbers of fish excluded the use of more detailed techniques. All gonads of males and females which were classified as Stage I or II at the peak of the reproductive season were regarded as immature. At these stages ovaries were thin and translucent with no visible eggs and the testes thin with slight white coloration. Mackerel having ovaries containing visible eggs were considered to be mature and capable of spawning. An opaque to greyish white colour of the testes was considered to indicate sexual maturity. Those mackerel with gonads at Stages III to VI were therefore regarded as having attained sexual maturity. The number of mackerel examined in this way during the months (June to September) when the gonad activity is at its peak is shown in Table 6 for the years 1969 to 1973. The fish ranged in size from 26 to 54 cm. The numbers of mature and immature fish per size class have been illustrated in Figure 6 and show that:

(a) all mackerel smaller than 33 cm were immature;
(b) the onset of sexual maturity occurs at a length of 33 cm. Mackerel are then in their third year of life (II+);
(c) fifty per cent of mackerel were mature at length group 39,0 to 39,9 cm;
(d) all mackerel were mature at a length of 42 cm, that is when they are in their fourth year of life (III+)

TABLE 7

Growth rate of *S. japonicus* in other parts of the world and of *S. scombrus* in the North Sea.

	South Africa			*Argentine**	*Pacific (USA)**	*Japan**		*S.scombrus* (North Sea)*
Age (Years)	*body length (cm)*	*fork length (cm)*	*total length (cm)*	*total length (cm)*	*fork length (cm)*	*body length (cm)*	*fork length (cm)*	*body length (cm)*
1	23,2	24,5	26,7	28,9	26,8	22,8	20,0	18,5
2	31,5	33,3	36,7	31,7	30,4	29,7	27,0	26,4
3	38,3	40,5	44,7	33,8	34,0	36,1	32,0	29,7
4	43,7	46,4	51,3	35,5	35,3	43,3	35,0	35,2
5	49,0	53,0	57,5	38,0	37,2	49,7	37,5	35,8
6	52,1	55,2	61,2	39,7	38,0		39,5	36,4
7	56,6	60,1	66,7	41,3	38,8		41,0	38,1
8	59,3	62,9	69,8	42.6	39,3			

* Sources: Argentine: Gagliardi & Cousseau (1970)
Pacific, West Coast, U.S.A.: Fitch (1951)
Japan: Aikawa (1937) body length; Iizuka (1967) fork length
North Sea: Castello & Hamre (1969)

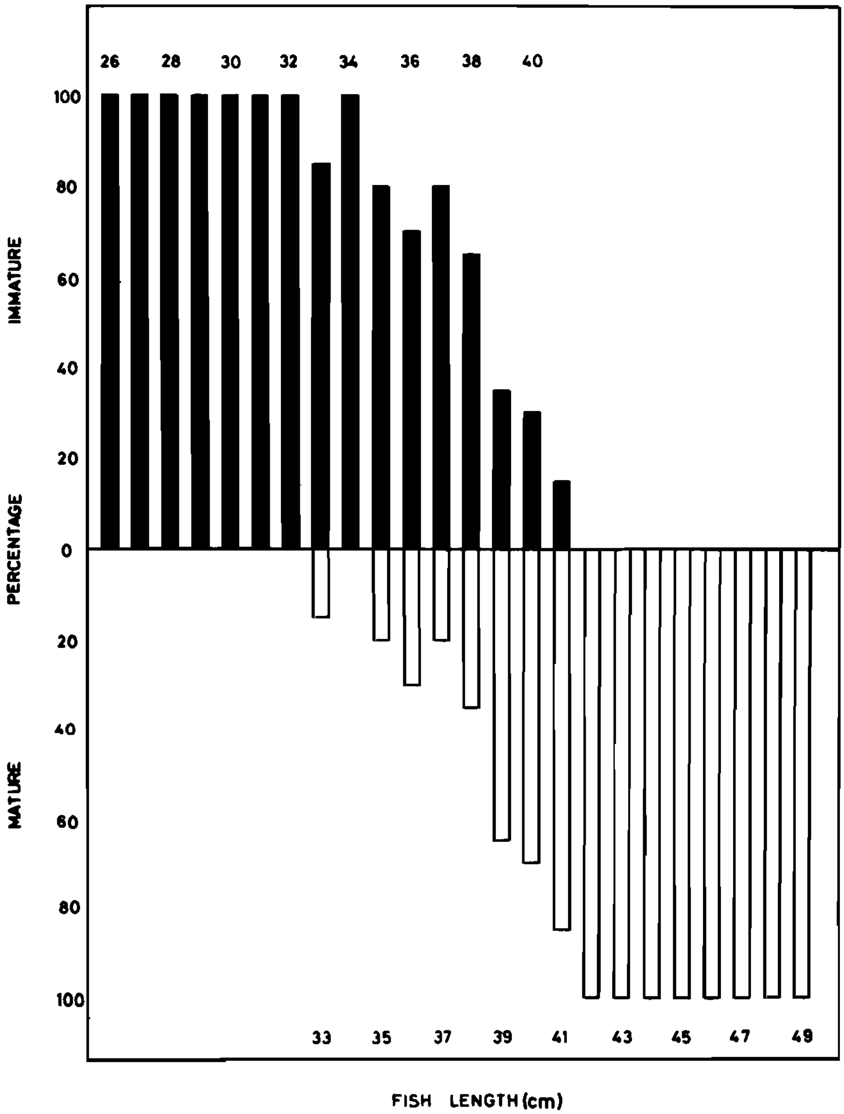

FIGURE 6
Length at maturity of the mackerel, *S. japonicus*.

DISCUSSION

The growth rates of *S. japonicus* occurring in the western Atlantic off Argentine, in the Pacific off the west coast of the Unites States, in the Sea of Japan, and for *Scomber scombrus* in the North Sea are compared to that of the South African mackerel in Table 7.

Length at age values show that the growth is more or less uniform for *S. japonicus* in the various seas during the first two years of life. Significant differences, however, in the growth rate of subsequent years are noticeable and it is clear that the South African form outstrips the others with the exception of the Japanese mackerel. However, Iizuka (1967) has reported a slower growth rate for the latter. The growth rates of *S. japonicus* from Argentine and from the Pacific (U.S.A.) appear to be quite similar. No explanation can be offered for these obvious differences in the growth rate of the same species in different parts of the world, but environmental conditions and the abundance of food undoubtedly have some influence.

The length and age at which the mackerel attains sexual maturity have been determined from macroscopic examination of gonads. Although the data presented do not distinguish between males and females, results have shown that both sexes attain sexual maturity when they are in their third or fourth year of life. The spawning season of the mackerel may be defined as the months of June, July, August and September. The data suggest a gradual decrease in reproductive activity from August onwards but the possibility of spawning during the remaining months of the year cannot be excluded. No data, however, are available for those months due to the closed fishing season.

The low percentage of mackerel with active gonads in January would suggest that the decrease of active and the increase of inactive fish, noticed the data of August and September, would continue. The density distribution of mackerel eggs in the spawning ground, which will be discussed in a later paper, also suggest a decrease in egg production towards September.

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