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DYNAMICS OF THE EXPLOITED INDIAN MACKEREL *RASTRELLIGER KANAGURTA* STOCK ALONG THE SOUTHWEST COAST OF INDIA*

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ABSTRACT

The dynamics of the fishery for the Indian mackerel *Rastrelliger kanagurta* (Cuvier) along the southwest coast of India has been studied from the data for the annual catch, effort and length composition for five decades from 1934 to 1984. The mean lengths (total) at $\frac{1}{2}$ year, 1 year and $1\frac{1}{2}$ year were found to be 18.42 cm (weight : 56.9 g), 22.6 cm (weight : 113.8 g) and 23.43 cm (weight : 133.5 g) respectively. The length growth parameters in the von Bertalanffy growth function (VBGF) were estimated to be L_∞ = 23.83 cm, annual k = 2.84, t_0 = 0.0003 year and the weight growth parameters to be W_∞ = 143.0 g, annual k = 2.66, t_0 = 0.0009 year. The mean annual total mortality (Z) was 3.68, the mean annual natural mortality (M) 1.24 and the mean fishing mortality (F) 2.44. The length at recruitment (l_r) was 9.8 cm (0.2 year) and the length at first capture (l_c) 18.4 cm (0.5 year). The yearclass is comprised of one major brood originating in the premonsoon season (February to May) and an occasional secondary brood originating in November. For the Kerala-Karnataka stretch within the southwest coast, the mean annual catch during 1934-1975 comprised 105 × 10^6 0 + (1 to 5 months), 523.6 × 10^6 $\frac{1}{2}$ + (6 to 11 months), 92.7 x 10^6 1 + (12 to 17 months) and 25.3 x 10^6 $1\frac{1}{2}$ + (18 to 23 months) old fish. The mean annual size of the population for this period included 17,242 × 10^6 0+, 1,338 × 10^6 $^1/_2$+, 170 × 10^6 1+ and 35 × 10^6 $1\frac{1}{2}$ + old fish. The average annual stock was estimated to be 109,299 tonnes (393.89 × 10^6 fish), the MSY 70,788 t and the recruits at t_c, 2,135 × 10^6 fish. The average annual exploitation ratio (0.68) was only marginally less than the value of 0.72 required for harvesting the MSY. The progeny was estimated to attain the maximum number (5,258 × 10^6) when the number of spawners was 140 × 10^6. The recruits attain maximum size (3,375 × 10^6) at a stock size of 525 × 10^6 fish. The MSY of 73,490 t (Schaefer model) and 76,197 t (Fox model) agrees very well with that based on the analytical model (70,788 t) and is only marginally higher than the average annual yield of 62,198 t for 1956-1984. The Schaefer model fitted to the limited data indicates the biologically optimum number of purse seiners operating for about 200 days a year to be about 1,000 which seems quite unrealistic as the fleet has stabilized at 500 vessels owing to diminishing returns.

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INTRODUCTION

THE INDIAN MACKEREL *Rastrelliger kanagurta* (Cuvier) is one of the most important commercial fisheries along the Indian southwest coast comprising the States of Kerala, Karnataka, Goa and southern Maharashtra, particularly between the latitudes off Quilon (09° N) in Kerala and Ratnagiri (17° N) in Maharashtra, a distance of 864 km (Fig. 1).

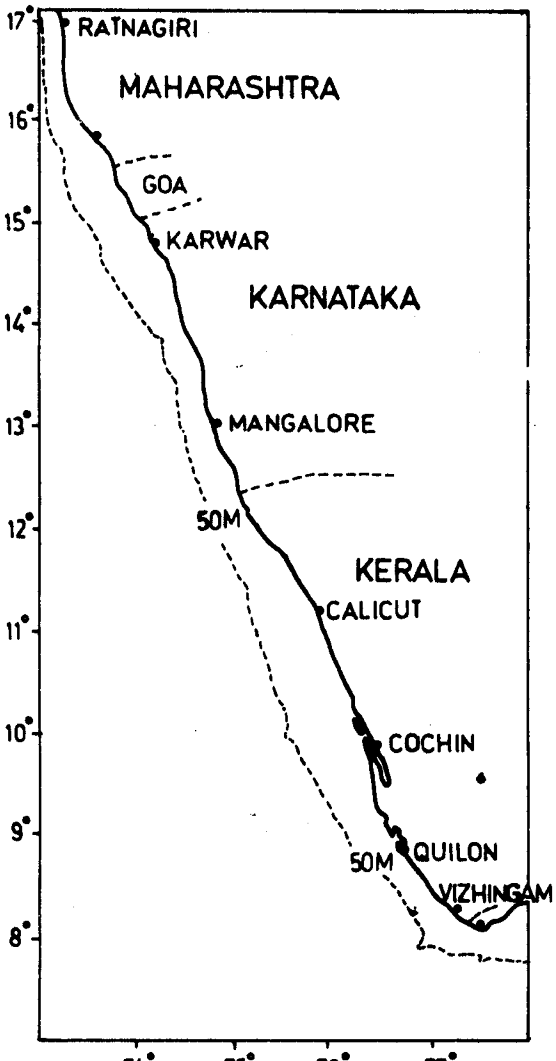

FIG. 1. The southwest coast of India indicating the study area.

This fishery has been widely studied for its biology which includes some preliminary stock estimates also. A review of the most important contributions to the knowledge of the Indian mackerel fishery is found in Bal and Rao (1984). Studies on the estimation of the Indian mackerel stock include those by Banerji (1973), Sekharan (1976), the UNDP/FAO (1973, 1974, 1975), George *et al.* (1977), Yohannan (1983) and Biradar (1985). The present account which uses the length frequency, catch and effort data for the 1934-1973 period, deals with the dynamics of the Indian mackerel stock along the southwest coast of India on the basis of the analytical model of Beverton and Holt (1957), cohort analysis of Pope (1972), stock-recruitment relation of Ricker (1954, 1958, 1975) and the surplus production models of Schaefer (1954) and Fox (1970). The study also discusses the possible impacts of the purse seiner fleet on the fishery and stock since its advent in 1975-1976, and suggests appropriate management measures.

TABLE 1. *Sources of length frequency data*

Area & Locality	Period	Source
Karwar	1949-52	Pradhan, 1956.
	1954-56	Radhakrishnan, 1958
Mangalore	1957-61	Rao, Sekharan and Pradhan, 1965.
	1959-73	Yohanan, 1977; 1979.
South Kanara District (Mangalore and nearby centres)	1934-41	Sekharan, 1958
Southwest Coast (from Cape Comorin to Ratnagiri - Pelagic)	1972-73	UNDP/FAO, 1974; 1976 a; 1976 b.
Malpe (Karnataka State) and Calicut and Mannassery (Kerala State)	1973-75	UNDP/FAO, 1976;
Cochin	1960-63	George and Banerji, 1968.
	1964	Silas, 1975.
Vizhinjam	1960-63	Bennet, 1967.

Materials and Methods

The sources of length frequency data used in the study are listed in Table 1. The catch and effort data, where available, have been taken from the various publications of the Central Marine Fisheries Research Institute (CMFRI), Cochin such as its Bulletins, Marine Fisheries Information Service Technical and Extension Series and Annual Reports.

The parameters of Beverton and Holt (1957) model were estimated from the age-length key and the age composition data. Age was estimated by the scatter diagram method of length mode analysis (Devaraj, 1977, 1981, 1983) which also resolves the time of origin of each brood and the number of broods comprising each year class. Where necessary, data gaps in the scatter diagram of modal lengths against time in successive months were bridged by transposing modes from a certain month of a year to the same month of another year, for the same locality or in some rare cases even for a different, but contiguous locality. The transposed values are invariably shown to be so in the scatter diagrams by means of distinctly different symbols (*e.g.* Fig. 5). The length and weight growth parameters were determined according to the von Bertalanffy growth model for length in mm (l) - at - age in months (t) and weight

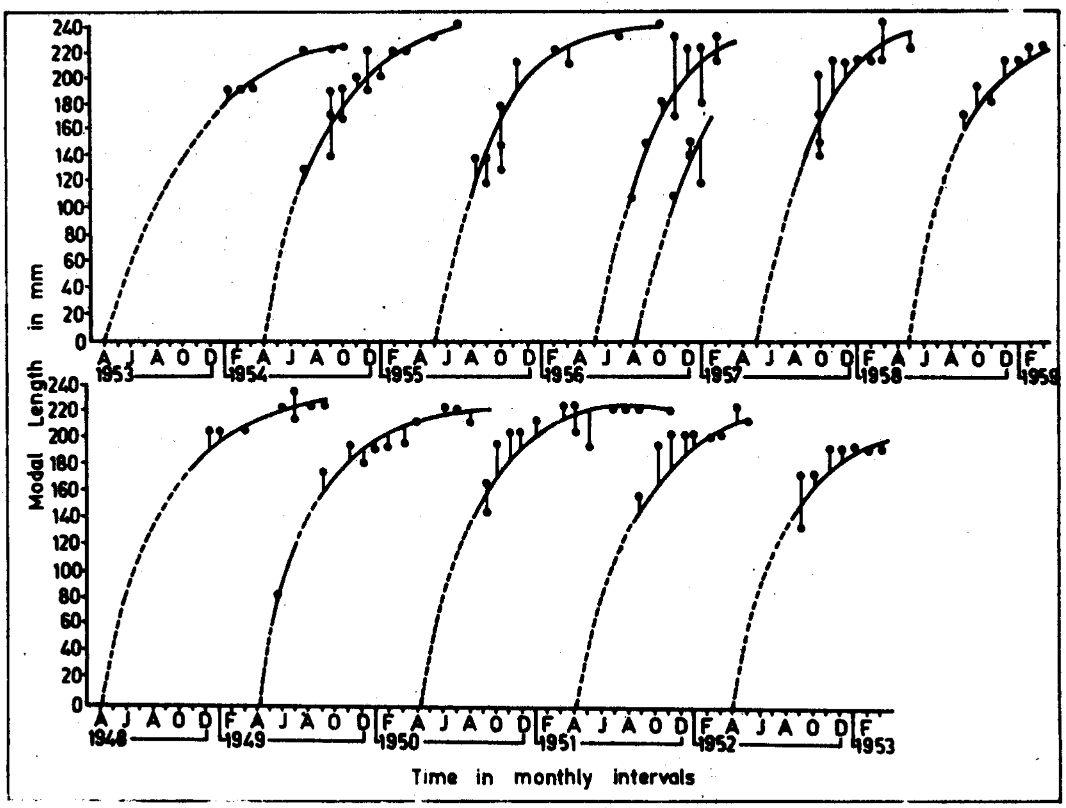

Fig. 2. Scatter diagram of length frequency modes against time in months for Karwar tracing the growth of broods during 1948 to 1959.

in g (w) - at - age in months (t) data, but the k and t_0 values were converted to annual basis. The length in cm (L) - weight in g (W) relation was used for the conversion of length-at-age to weight-at-age.

the catch per effort for the ascending phase of the fishery in the second half of a year $(c/f)_1$ and that for the descending phase of the fishery in the first half of the following year $(c/f)_2$, according to Paloheimo (1961)

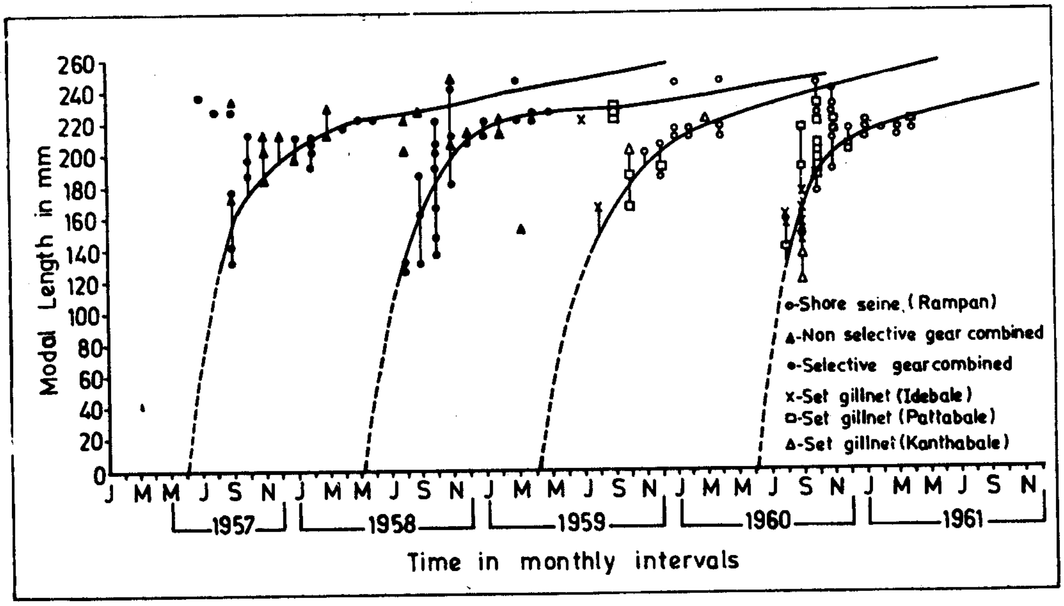

FIG. 3. Scatter diagram of length frequency modes against time in months for Mangalore tracing the growth of broods during 1957 to 1961.

The annual recruitment pattern was constructed by working back the length frequency distributions for the successive months of the year to zero age (Pauly, 1982). The length at recruitment (l_r) and the length at first capture (l_c) were determined arbitrarily from the annual length composition data owing to the problems of gear selectivity studies arising from : (1) the highly multigear and multimesh nature of the fishery and (2) the seasonal and annual changes in the composition of the gear operated.

Owing to the very short life span of the fish, the total annual mortality coefficient (Z) was calculated from the age composition data in half year groups, as per Jackson's (1939) method and then converted to annual basis. Z was also determined from either the catch or

$$Z = -\log_e (c/f)_2 \;/\; (c/f)_1 \quad \text{.........} \quad (1)$$

The effort data is either incomplete or not available for most years. Moreover, the fishery deploys a variety of gear rendering standardization of effort extremely difficult and complicated. Therefore, the fishing mortality (F) and the natural mortality (M) constituents of Z were estimated independently rather than by the regression of Z on annual effort (f). F was also estimated from tag-recovery data for the 1967-1968 Calicut fishery (Prabhu and Venkataraman, 1970), using the equation (Beverton and Holt, 1957; Devaraj, 1983).

$$F = \frac{\text{Progressive number of tagged fish recovered}}{\text{Total number of fish tagged}} \times \frac{\text{Days between release and recovery}}{365 \text{ days}} \quad \text{.........} \quad (2)$$

F was also estimated from the ratio of annual yield (Y) to the direct estimates of stock (P) given by the UNDP/FAO (1974, 1976 a, 1976 b) according to the equation,

$$F = Y/P \quad \ldots\ldots (3)$$

Independent estimates of M were made according to Cushing (1968),

The annual yield (Y) and Z data for the mackerel did not conform to the parabola (Caddy and Csirke, 1983),

$$Y = a + b_1 Z + b_2 Z^2 \quad \ldots\ldots (6)$$

and therefore, M could not be estimated by the relation

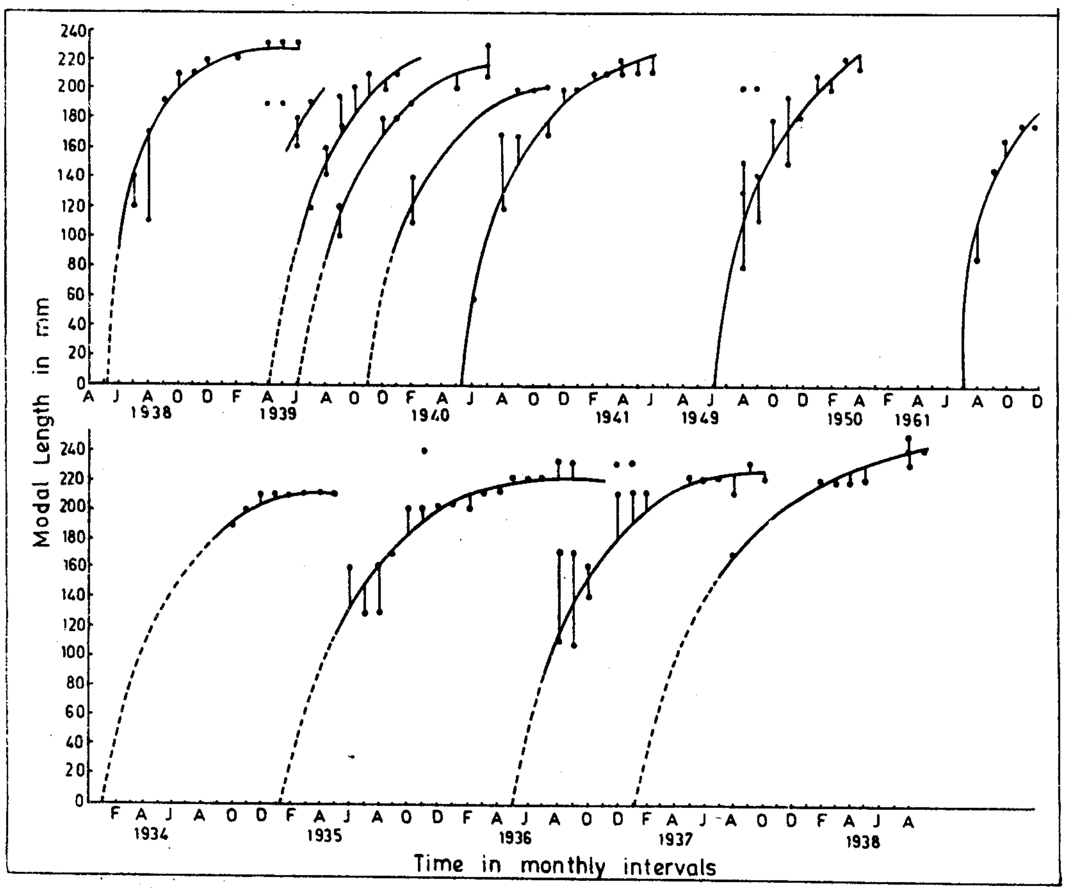

FIG. 4. Scatter diagram of length frequency modes against time in months for Mangalore tracing the growth of broods during 1934 to 1941, 1949, 1950 and 1961.

$$Z = M = \frac{1}{T_{max^{-1}}} \times l_n \frac{N_t}{N_{T_{max}}} \quad \ldots\ldots (4)$$

and according to Pauly (1980),

$$\log M = 0.1228\text{-}0.1912 \log L_\infty \text{ (in cm)} + 0.7485 \log k \text{ (annual)} + 0.2391 \log T \text{ (in °C)} \quad \ldots\ldots (5)$$

$$M = \frac{-b_1 + \sqrt{b_1^2 - 4ab_2}}{2b_2} \quad \ldots\ldots (7)$$

The wide scatterance of the values in the plot of Y against Z strongly suggested the possibility that M was not a constant, but varied quite considerably and therefore, it was thought

TABLE 2. *Peak months of brood origin in the different year classes, according to localities along the southwest coast (K = Karwar; M = Mangalore; Ct = Calicut; Cn = Cochin; V = Vizhinjam; CR = Cape Comorin to Ratnagiri)*

Year	Intermonsoon			Pre-SW Monsoon		SW Monsoon			Post SW Monsoon		Northeast Monsoon		Intermonsoon	Premonsoon	SW monsoon	Post monsoon	NE monsoon
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.					
1934	Ct	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—
1935	Ct	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—
1936	—	—	—	—	Ct	—	—	—	—	—	—	—	—	1	—	—	—
1937	Ct	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—
1938	—	—	—	—	Ct	—	—	—	—	—	—	—	—	1	—	—	—
1939	—	—	—	Ct	—	Ct	—	—	—	—	Ct	—	—	1	1	—	1
1940	—	—	—	—	Ct	—	—	—	—	—	—	—	—	1	—	—	—
1948	—	—	—	K	—	—	—	—	—	—	—	—	—	1	—	—	—
1949	—	—	—	K	—	Ct	—	—	—	—	—	—	—	1	1	—	—
1950	—	—	—	K	—	—	—	—	—	—	—	—	—	1	—	—	—
1951	—	—	—	K	—	—	—	—	—	—	—	—	—	1	—	—	—
1952	—	—	—	K	—	—	—	—	—	—	—	—	—	1	—	—	—
1953	—	—	—	K	—	—	—	—	—	—	—	—	—	1	—	—	—
1954	—	—	—	K	—	—	—	—	—	—	—	—	—	1	—	—	—
1955	—	—	—	—	K	—	—	—	—	—	—	—	—	1	—	—	—
1956	—	—	—	—	K	—	—	K	—	—	—	—	—	1	1	—	—
1957	—	—	—	—	K	M	—	—	—	—	—	—	—	1	1	—	—
1958	—	—	—	—	K, M	—	—	—	—	—	—	—	—	1	—	—	—
1959	—	—	—	M	—	—	—	—	—	—	—	—	—	1	—	—	—
1960	—	—	—	V	Cn	M	—	—	V	—	—	—	—	2	1	1	—
1961	—	—	—	V	Cn	—	Ct	—	—	V	—	—	—	2	1	1	—
1962	—	—	—	V	Cn	—	—	—	—	V		—	—	2	—	—	—
1963	—	—	—	V	Cn	—	—	—	—	—	—	—	—	2	—	—	—
1965	—	—	—	—	Cn	—	—	—	—	—	—	—	—	1	—	—	—
1966	Cn	—	Cn	—	Cn	—	—	—	—	—	—	—	2	1	—	—	—
1967	—	Cn	—	—	Cn	—	—	—	—	—	—	—	1	1	—	—	
1969	—	—	M	—	—	—	—	—	—	—	—	—	1	—	—	—	—
1970	—	—	—	M	—	—	—	—	—	—	—	—	—	1	—	—	—
1971	—	—	—	M	—	—	—	—	—	—	—	—	—	1	—	—	—
1972	—	—	—	—	M	—	—	—	—	—	—	—	—	1	—	—	—
1973	—	—	CR	—	—	—	—	—	—	—	—	—	1	—	—	—	—
1974	—	—	CR	—	—	—	—	—	—	—	—	—	1	—	—	—	—
Total	4	1	4	15	15	4	1	1	1	2	1	—	—	—	—	—	—
%	8.16	2.04	8.16	30.61	30.61	8.16	2.04	2.04	2.04	4.08	2.04	—	9	30	6	3	1

that there was little justification to base the dynamics of this stock on a constant value of M, as normally assumed in the Beverton and Holt (1957) model. Therefore, M and F for individual years were estimated from the mean weight $(\overline{w})$ *and the weight at first capture* (w_c) statistics. This method first gives the estimate of F according to the relation in equation (8) for the exploitation rate (U) (Allen, 1953),

$$U = w_c / \overline{w} = F/Z\,(1 - e^{-Z}) \qquad \ldots\ldots (8)$$

and the value of M is found by subtracting F from Z.

The biomass in weight per recruit (P_w/R), biomass in number per recruit (P_n/R), yield in weight per recruit (Y_w/R), yield in number per recruit (Y_n/R) and the mean weight of fish in the population $(\overline{w})$ were estimated for each year from 1934 to 1973 according to Beverton and Holt (1957) for the respective values of M, F, t_r and t_c and for constant values of k, W_∞ and t_0 as growth differences between years

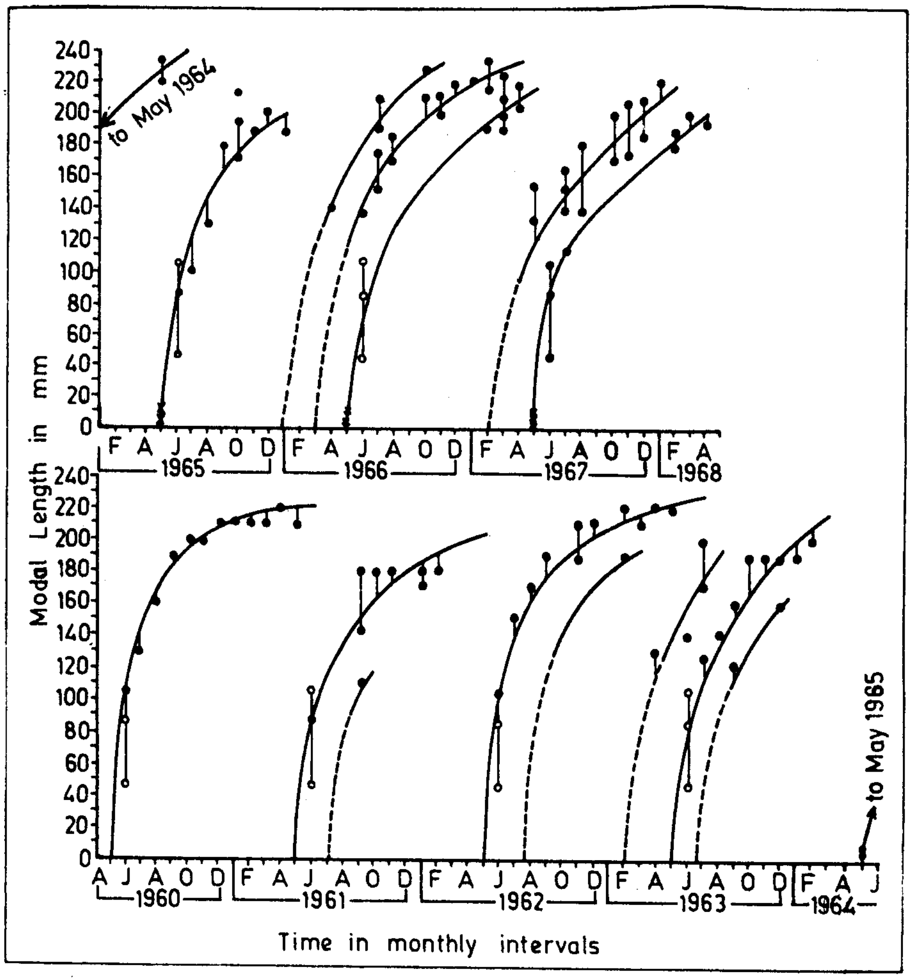

FIG. 5. Scatter diagram of length frequency modes against time in months for Cochin tracing the growth of broods during 1960 to 1963 and 1965 — 1968 (o & x = transposed values).

and between localities were found to be insignificant. The optimum age of exploitation (t_y) and the corresponding potenttial yield per recruit (Y_w/R) at the meeting point of the eumetric yield curve with the maximum sustainable yield (MSY) curve at F_∞ on the yield isopleth were estimated according to Krishnankutty and Qasim (1968).

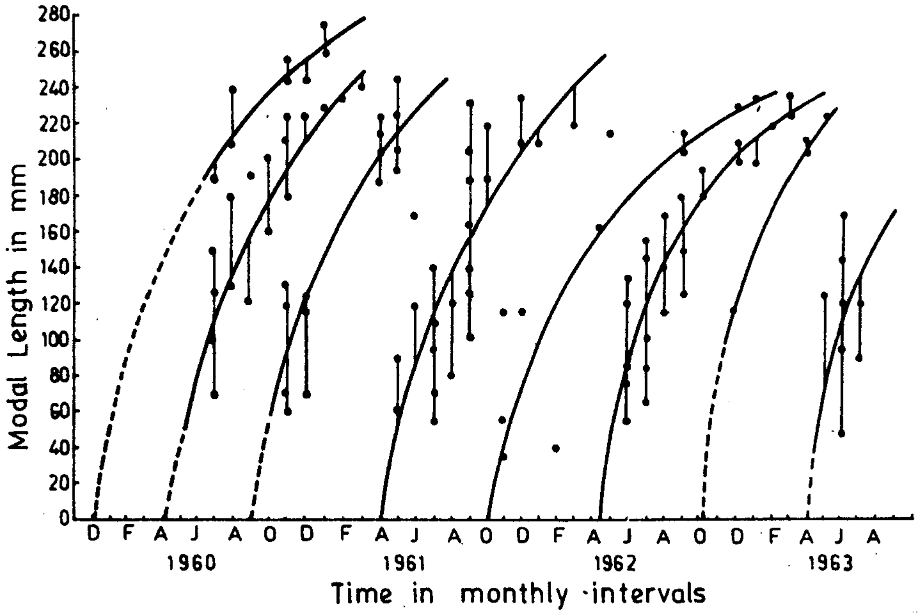

FIG. 6. Scatter diagram of length frequency modes against time in months for Vizhinjam tracing the growth of broods during 1960 to 1963.

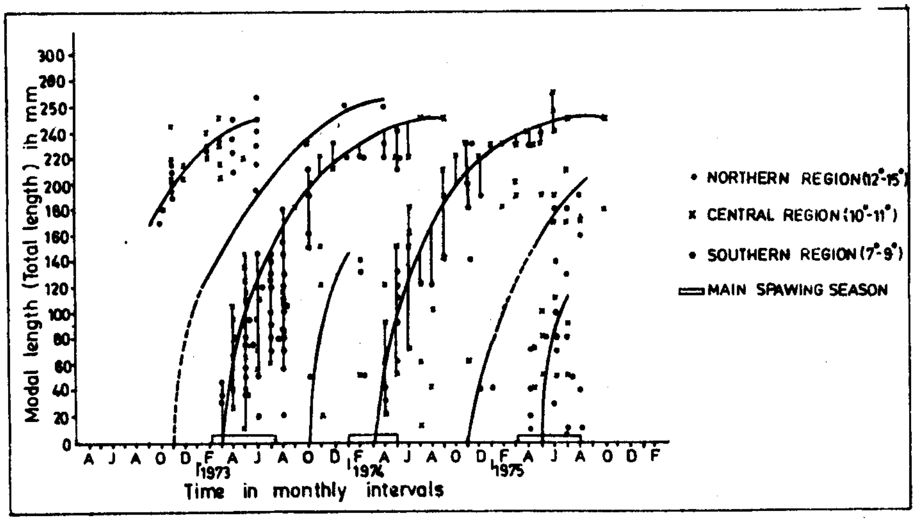

FIG. 7. Scatter diagram of length frequency modes against time in months for the three regions of the southwest coast of India tracing the growth of broods during 1972 to 1974.

TABLE 3. *Distribution of broods between different seasons for various localities*

	Intermonsoon		Pre-monsoon		Monsoon		Postmonsoon		Northeast monsoon	
	No.	%	No.	%	No.	%	No.	%	No.	%
Karwar (1949—1958)	—	—	11	92	1	8	—	—	—	—
Mangalore (1957-1960; 1970-72)	1	13	5	62	2	25	—	—	—	—
Calicut (1934-1949; 1961)	3	27	4	36	3	27	—	—	1	10
Cochin (1960–1967)	3	30	7	70	—	—	—	—	—	—
Vizhinjam (1960-1963)	—	—	4	57	—	—	3	43	—	—
Ratnagiri to Cape Comorin (1973-1974)	2	100	—	—	—	—	—	—	—	—

Estimates of standing stock ($\bar{P}_w$), total stock (P_w), number of recruits at t_c (R_c), population number (P_N) and yield in number (Y_N) were made for individual years from 1934 to 1973 for the Kerala–Karnataka Coast and from 1956 to 1973 for the entire southwest coast.

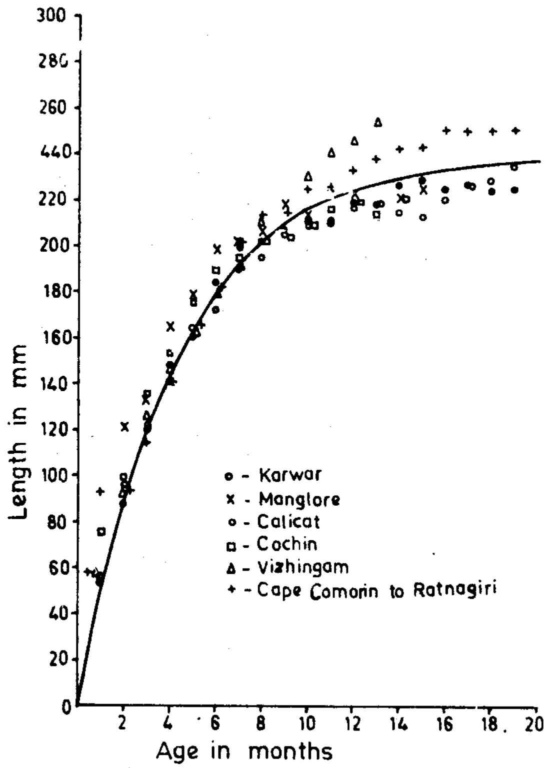

FIG. 8. The fitted growth curve for the entire southwest coast of India together with observed values for the individual centres.

Pope's (1972) cohort analysis was carried out by following the stepwise treatment (Sparre, 1985) of the catch in number (C_t) according to half year groups. The estimated number of fish in each age group in the stock obtained from cohort analysis was summed up separately into the progeny, *R* (0+ and $\frac{1}{2}$ + old fish, *i.e.*, 1 to 11 months old fish) and the spawner stock *P* (1 + and 1$\frac{1}{2}$ + old fish, *i.e.* > 12 months

TABLE 4. *Mean length in mm at age in months for different localities together with estimates of length growth and weight growth parameter for the southwest coast*

Age in months	Karwar 1948-59	Mangalore 1957-73	Calicut 1934-61	Cochin 1960-65	Vizhinjam 1960-63	Cape Comorin to Ratnagiri 1972-74	Means 1934-74	Weight (g)
1	52	54	56	75	57	57	58.5	1.3
2	88	120	96	99	92	92	97.6	7.0
3	120	133	121	136	125	114	124.8	16.7
4	141	164	148	154	147	140	149.0	30.5
5	161	178	164	175	161	164	167.2	42.7
6	184	198	172	191	180	180	184.2	56.9
7	199	202	190	194	195	201	196.8	72.9
8	202	206	195	201	210	212	204.3	76.6
9	207	218	205	204	218	213	210.8	91.7
10	211	213	209	208	230	225	216.0	100.7
11	210	222	211	216	240	225	220.7	105.5
12	219	222	217	219	246	233	226.0	113.8
13	218	231	219	214	254	239	229.2	118.9
14	227	220	215	220	—	242	224.8	122.5
15	229	224	213	—	—	243	227.25	126.0
16	225	—	220	—	—	250	231.7	127.9
17	227	—	225	—	—	250	234.0	133.5
18	224	—	229	—	—	250	234.3	133.5
19	225	—	235	—	—	250	236.7	139.2
L_∞	230	228	242	227	285	259	238.3	W_∞ = 143.0
Annual k	2.96	3.80	2.24	2.96	1.95	2.25	2.84	2:665
t_0 in year	-0.04	0.012	-0.05	-0.05	0.02	-0.04	+0.003	+0.009

old fish) and Ricker's (1954, 1958, 1975) spawner (*P*) - progeny (*R*) relation fitted on the generally dome-shaped distribution of *R* on *P*. The MSY and the corresponding exploitation rate were estimated from this relation. For the purpose of fitting Ricker's (1954, 1958, 1975) stock (*P*) - recruit (*R*) relation, R_c in number was estimated by dividing the annual yield in weight (*Y*) by the yield in weight per recruit (Y_W/R) while *P* in number was estimated by multiplying R_c by the population number per recruit (P_N/R).

The maximum sustainable yield (MSY) and the optimum fishing effort (f_{msy}) for MSY were estimated for Kerala, Karnataka, Goa and Maharashtra using the surplus production models according to Schaefer (1954) and Fox (1970).

RESULTS AND DISCUSSION

Age and growth

Out of 32 year-classes analysed for the period 1934 to 1973, as many as 23 (72%) were single brood year-classes, of which 17 had their broods originating in April or May in the pre-southwest monsoon season (April - May) while 6 had their broods originating in January (3) or March (3) in the inter-monsoon season (January to March). Evidently, the origin of all the year classes with single broods is limited to the period from January to May comprising the inter-monsoon and the pre-southwest monsoon seasons. Of the 6 year-classes constituted by two broods each, all had their major brood originating in the pre-monsoon season and the minor one either in the southwest monsoon season from June to August or in the post-monsoon in September-October.

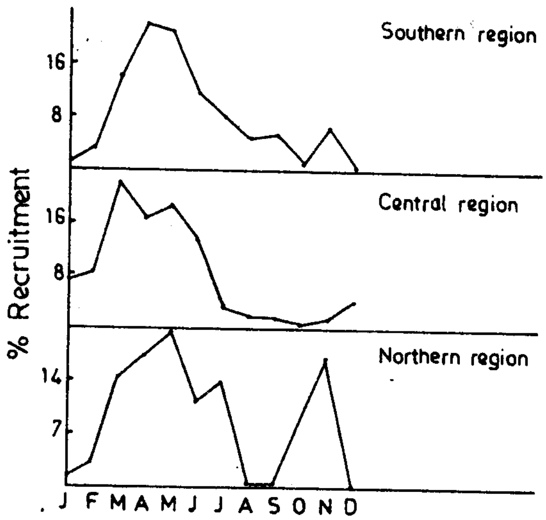

FIG. 9. Recruitment pattern in the three regions of the southwest coast of India.

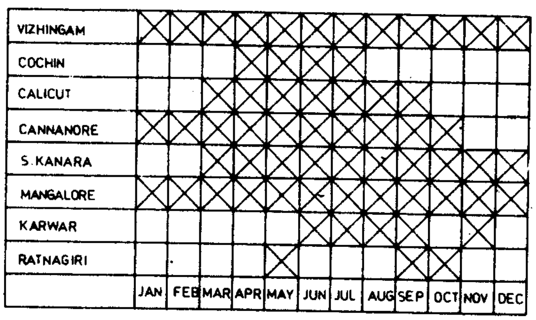

FIG. 10. Occurrence of maturing and mature fish by months and localities (indicated by crossed squares).

The growth in length-at-age in months and the growth characteristics (L_∞, k and t) for various centres and the periods studied are very similar to each other.

A comparison of the growth of the Indian mackerel estimated in this study (Table 4) with that of others (Table 5) shows close agreement with the results given by George and Banerji (1968) and Yohannan (1979), because the technique used in these studies is essentially based on the sequential progression of modes through time in the length frequency data for successive months. While George and Banerji (1968) traced the modes by regression of l_t on l_{t+1}, in the present study the modes were traced by means of the scatter diagram method (Devaraj, 1983) (Figs. 2 to 8). The values given by Sekharan (1958) are apparently

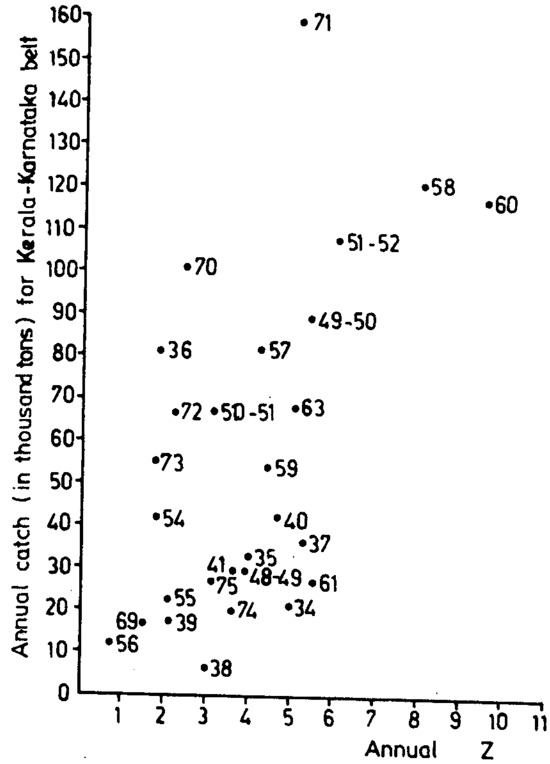

FIG. 11. Distribution of annual catch against annual total mortality coefficient (Z).

underestimates owing to the fact that the progression was traced through unequal panels used for the length frequency polygons for the

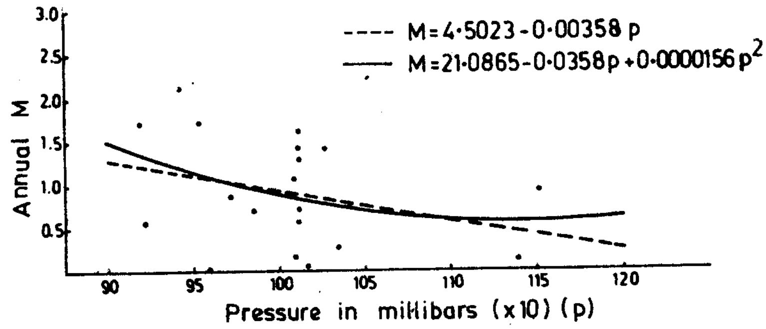

FIG. 12. Regression of annual natural mortality coefficient (*M*) on sea surface pressure (*p*) at Cochin.

successive months. Since the periodicity of ring formation has not been established by Seshappa (1972), the length-at-age in year given by him cannot be considered valid.

Recruitment pattern

The percentage mean recruitment per month to the mean annual recruitment during 1947 to 1975 was the highest from March to June (14.42% to 18.56% per month) and poor in all other months (0.87% in October to 6.45% in February) (Fig. 9). The peak spawning from March to June, evident from the recruitment pattern, is also obvious from the scatter diagram tracing the modal progression in the length frequency data. In contrast, maturity stages studied in the past suggest protracted spawning well round the year (Fig. 10). Occurrence of advanced maturing and ripe mackerel has been observed throughout the year in Vizhinjam (Balakrishnan, 1957; Rao, 1965; Bennet, 1967), April to July in Cochin (Anon., 1961, 1964, 1965), March to September in Calicut (Devanesan and John, 1940; Chidambaram and Venkateswaran, 1946; Devanesan and Chidambaram, 1948; Chidambaram *et al.*, 1952; Bimachar and George, 1952; Anon., 1966), January to October in Cannanore (Anon., 1961, 1965), March to December in South Kanara (Sekharan, 1958), throughout the year in Mangalore (George *et al.*, 1959; Rao *et al.*, 1965), June to September and November in Karwar (Pradhan, 1956; Radhakrishnan, 1965) and May and September to October in Ratnagiri (Sekharan, 1958). Recruitment pattern (Fig. 9)

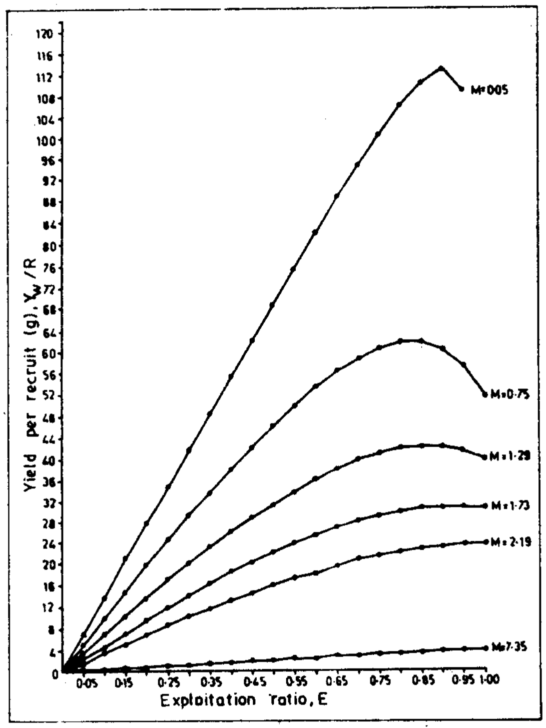

FIG. 13. Y/R curves for different values of *M*.

however, suggests maximum survival of larval and postlarval stages only during March-June, evidently owing to calm sea surface conditions enabling highly patchy distribution of plankton, which is crucial to larval survival (Horwood and Cushing, 1977).

TABLE 5. *Results of growth studies by various authors*

Authors	Method used	Length at age in years (cm)				Growth parameters	
		1	2	3	4	L_∞ (cm)	k (Annual)
Pradhan (1956)	Length frequency	10	18	—	—	—	—
Sekharan (1958)	"	12-15	21-23	—	—	—	—
Rao *et al.* (1962)	"	15	22.5	26.6	28.9	31.6	0.6
George and Banerji (1964)	"	22	24	—	—	22.84	3.6
Seshappa (1969)	Scales	11-15	21-24	25-27	28-29	—	—
Yohannan (1977)	Length frequency	14-16	20-22	—	—	—	—
Yohannan (1979)	"	22	—	—	—	—	—
Biradar (1985)	"	24-24.9	—	—	—	24.5-26.5	2.6-3.8
Present study	"	22.6	—	—	—	23.8	2.84

TABLE 6. *Common types of gear employed in the mackerel fishery along the southwest coast of India (sm = stretched mesh)*

Locality	Basic gear types				
	Nonselective			Selective	
	Boat seine	Beach seine	Cast net	Set gill net	Drift gillnet
Karwar	—	Rampani, Yendi	—	—	—
Mangalore	Kollibale Paithubale	Rampani (12 mm sm at at the centre) Kairampani	—	Kanthabale (25 to 55 mm sm) Pattabale Idabale	—
Calicut Cochin and Vizhinjam	Ayilakolli (15 to 25 mm sm) Paithuvala, Avakolli, Odamvala, Nethalvala Mathikolli	Karavala	Veechuvala	Ayilachalavala (25 to 50 mm sm) Mathichalavala	Ozhukuvala

Mortality estimates

Total mortality (Z) from age composition : The gears employed in the mackerel fishery belong to both selective and non-selective types (Table 6). The age composition of mackerel for *Z* estimates is given in successive half year groups according to gears for the various localities (Tables 7 to 13) to bring out the influence, if any, of gear selectivity.

TABLE 7. *Percentage age composition of beach seine (nonselective) catches and Z estimates for Karwar*

Year	0 +	$\frac{1}{2}$+	1 +	$1\frac{1}{2}$+	Z	
					$\frac{1}{2}$ Year	Annual
1948-49	—	86.80	7.20	6.00	1.96	3.92
1949-50	6.60	87.40	3.00	3.00	2.71	5.42
1950-51	2.09	78.86	12.17	6.88	1.56	3.12
1951-52	1.31	89.18	4.34	5.17	3.02	6.04
1952	2.40	59.00	38.70	—	0.42	0.84
1954	3.28	61.87	23.48	11.37	0.90	1.80
1954-55	—	85.10	15.00	—	1.74	3.48
1955	25.70	34.40	12.05	27.85	1.05	2.10
1955-56	8.90	51.40	39.90	—	0.25	0.50
1956	34.80	31.00	38.10	6.10	0.36	0.72
1957	2.50	95.30	2.40	—	3.68	7.36
1958	5.00	83.50	11.50	—	1.98	3.96
1959	35.80	50.30	13.90	—	1.29	2.58
Mean	9.88	68.77	16.28	5.11	—	3.11

TABLE 8. *Percentage age composition of selective gear catches and Z estimated for Mangalore and nearby centres*

Year	Gear	0 +	$\frac{1}{2}$ +	1 +	Z	
					$\frac{1}{2}$ Year	Annual
1957-58	Combined	28.3	68.6	3.1	3.10	6.20
1958-59	Combined	17.1	60.7	22.3	1.00	2.00
	Kanthabale at Ullal	—	95.1	4.9	2.97	5.94
	Kanthabale at other localities	—	88.9	11.1	2.08	4.16
1959-60	Pattabale at Ullal	—	80.3	19.7	1.41	2.82
	Pattabale at other localities	—	98.3	1.7	4.06	8.12
	Idabale	33.3	66.7	—	—	—
1960-61	Kanthabale	8.8	65.4	25.8	0.93	1.86
	Idabale at Ullal	100.0	—	—	—	—
	Idabale at other localities	100.0	—	—	—	—
	Pattabale at Ullal	19.4	37.8	42.8	—	—
	Pattabale at other localities	43.7	40.2	16.0	0.40	0.80
Mean		29.2	58.5	12.3	—	3.99

Karwar : In the non–selective beach seine catches for the period 1948 to 1959 the 0+, $\frac{1}{2}$ +, 1 +, $1\frac{1}{2}$ + fish formed 9.88%, 68.77%, 16.28% and 5.11% respectively. The fully recruited $\frac{1}{2}$ + old fish ranged from 31% in 1956 to 95.3% in 1957 with the mean annual contribution to the catch at 68.77%. Annual Z ranged from 0.5 in 1955-1956 to 7.36 in 1957, with the mean at 3.11 (Table 7).

Mangalore : In the case of selective gears, the 0+, $\frac{1}{2}$ + and 1+ fish contributed 29.2%, 58.5% and 12.3% respectively to the mean annual catch for 1957-1961. The $\frac{1}{2}$ + fully recruited group ranged from 37.8% in 1960-1961 to 98.3% in 1959-1960 with the mean at 58.5%. Annual Z ranged from 0.8 in 1960-1961 to 8.12 in 1959-1960 with the mean at 3.99 (Table 8).

TABLE 9. *Percentage age composition of nonselective gear catches and Z estimates for Mangalore and nearby centres*

Year	Gear	0 +	$\frac{1}{2}$+	1 +	Z	
					$\frac{1}{2}$ Year	Annual
1957-58	Combined	29.6	59.7	10.6	1.73	3.46
1958-59	Combined	16.2	73.8	10.1	1.99	3.98
1959-60	Kollibale	13.3	86.7	—	—	—
	Rampani	—	98.0	1.9	3.94	7.88
	Kairampani	—	100.0	—	—	—
1960-61	Kollibale	100.0	—	—	—	—
	Paithubale	100.0	—	—	—	—
	Cast-net	100.0	—	—	—	—
	Kairampani	100.0	—	—	—	—
	Rampani	63.6	27.0	9.4	0.92	1.84
1969	Kollibale	45.0	55.0	—	—	—
	Cast-net	100.0	—	—	—	—
	Kairampani	100.0	—	—	—	—
	Rampani	72.5	27.5	—	0.97	1.94
1970	Kollibale	5.1	48.1	46.8	0.03	0.06
	Cast-net	26.8	73.2	—	—	—
	Kairampani	—	100.0	—	—	—
	Rampani	32.7	46.6	20.7	0.81	1.62
1971	Kollibale	—	77.7	23.3	1.20	2.40
	Rampani	—	74.8	25.2	1.09	2.18
1972	Kollibale	—	87.4	12.6	1.94	3.98
	Trawl	—	60.0	40.0	0.41	0.82
	Kairampani	5.0	86.0	9.0	2.26	4.52
	Rampani	—	100.0	—	—	—
1973	Rampani	—	92.30	7.7	2.48	4.96
Mean		36.4	55.0	8.7	—	3.05
Selective and nonselective combined for 1957-73		32.8	56.7	10.5	—	3.52

In the case of non-selective gears, the 0+, $\frac{1}{2}$ + and 1+ fish formed 32.8%, 56.8% and 10.5% in the mean annual catch for 1957-1975, indicating thereby no significant difference with that for the selective gears. The mean annual Z (3.95) also agreed closely with that for the selectivity gears (3.99). For the gears combined, the mean Z was found to be 3.52 (Table 9).

Calicut : For gears combined, the mean annual catch for 1934-1941 was comprised by 10.9% 0+ fish, 63.9% $\frac{1}{2}$+ fish, 23.2% 1+ fish and 2.1% $1\frac{1}{2}$+ fish. The annual Z ranged from 1.82 in 1936 to 5.32 in 1937, with the mean at 3.71 (Table 10).

Cochin : The 0+, $\frac{1}{2}$ + and 1+ fish formed 29.1%, 69.2% and 1.7% respectively of the

TABLE 10. *Percentage age composition of combined catches of selective and nonselective gears and Z* estimates for Calicut (the main gear is the nonselective Ayilakolli)

Year	0 +	$\frac{1}{2}$+	1 +	$1\frac{1}{2}$+	Z	
					$\frac{1}{2}$ Year	Annual
1934	—	92.4	7.6	—	2.50	5.00
1935	25.6	65.0	6.2	3.2	2.02	4.04
1936	3.6	58.4	35.6	2.4	0.91	1.82
1937	1.0	17.8	76.0	5.3	2.66	5.32
1938	20.9	62.2	14.9	1.9	1.52	3.04
1939	17.6	55.5	23.6	3.4	1.08	2.16
1940	18.7	73.5	7.5	0.3	2.34	4.68
1941	—	86.1	13.9	—	1.82	3.64
Mean	10.6	63.9	23.2	2.1	—	3.71

TABLE 11. *Percentage age composition of combined catches of selective and nonselective gears and Z estimates for Cochin (the main gear is the nonselective Ayilakolli)*

Year	0 +	$\frac{1}{2}$+	1 +	Z	
				$\frac{1}{2}$ Year	Annual
1957	63.4	36.6	—	0.55	1.10
1958	11.1	88.7	0.2	6.09	12.18
1959	27.3	69.7	3.0	3.15	6.30
1960	16.6	82.6	0.7	4.77	9.54
1961	20.6	74.7	4.7	2.77	5.54
1962	33.3	66.7	—	—	—
1963	32.6	62.4	5.0	2.52	5.04
1964	36.7	63.3	—	—	—
Mean	29.1	69.2	1.7	—	6.49

mean annual catch by all gears during 1957-1964. Annual Z showed extremely high variation, ranging from 1.1 in 1957 to 12.18 in 1958, with the mean at 6.49 which is very high compared to the values for Karwar, Mangalore, Calicut and Vizhinjam (Table 11).

Vizhinjam : The 0 year (0 to 11 months old), 1 year (12 to 23 months old) and 2 year (24 months old) old fish formed 71.5%, 26.5% and 2.0% respectively of the mean annual number of fish caught during 1960-1962. Annual Z ranged from 2.54 in 1960-1961 to 3.30 in 1961-1962, with the mean at 2.92 (Table 12).

TABLE 12. *Percentage age composition of combined catches of selective and nonselective gears and Z estimates for Vizhinjam (the main gear is the nonselective Karavala)*

Year	0	1	2	Z (annual)
1960-61	46.6	49.4	3.9	2.54
1961-62	96.3	3.6	0.1	3.30
Mean	71.5	26.5	2.0	2.92

Entire southwest coast : Pelagic trawl (non-selective) catches for 1972-1975 for the entire southwest coast were comprised by 45.2% 0+, 45.0% $\frac{1}{2}$+, 9.2% 1+ and 0.5% $1\frac{1}{2}$+ fish. Variations between the southern, central and northern sections along this coast were not very

TABLE 13. *Percentage age composition of pelagic trawl (nonselective) exploratory catches and Z estimates for different sections along the southwest coast*

Section	Year	O +	$\frac{1}{2}$+	1+	$1\frac{1}{2}$+	Z	
						$\frac{1}{2}$ Year	Annual
Northern	1972	—	91.7	8.3	—	2.40	4.80
11° N to 15° N	1973	78.9	6.1	15.0	—	2.56	5.12
	1974	22.9	66.7	6.3	4.2	1.94	3.88
	1975	83.1	10.2	6.8	—	1.70	3.40
	Mean	46.2	43.7	9.1	1.1	—	4.30
Central	1972	—	69.5	30.5	—	0.82	1.64
09° N to 11° N	1973	65.6	26.7	7.7	—	0.99	1.98
	1974	69.3	28.9	1.6	0.1	1.18	2.36
	1975	65.9	25.7	8.1	0.2	1.71	3.42
	Mean	50.2	37.7	12.0	0.1	—	2.35
Southern	1972	—	100.0	—	—	—	—
07° N to 09° N	1973	47.3	31.0	20.0	1.7	0.62	1.24
	1974	38.2	56.0	5.8	—	2.27	4.54
	1975	71.8	27.6	0.6	—	1.26	2.52
	Mean	39.3	53.7	6.6	0.4	—	2.77
	Overall mean	45.2	45.0	9.2	0.5	—	3.14

TABLE 14. *Estimation of Z for various centres and M from 1934 to 1975*

Year	Catch	Karwar	Mangalore	Calicut	Cochin	Vizhingam	Cape Comorin to Ratnagiri	Z	M
1934	21,689	—	—	5.00	—	—	—	5.00	1.71
1935	33,058	—	—	4.04	—	—	—	4.04	1.44
1936	81,111	—	—	1.82	—	—	—	1.82	0.57
1937	36,540	—	—	5.32	—	—	—	5.32	0.18
1938	7,644	—	—	3.04	—	—	—	3.04	1.08
1939	17,732	—	—	2.16	—	—	—	2.16	0.74
1940	42,107	—	—	4.68	—	—	—	4.68	1.62
1941	29,896	—	—	3.64	—	—	—	3.64	1.27
1948-49	29,509	3.92	—	—	—	—	—	3.92	1.39
1949-50	89,163	5.42	—	—	—	—	—	5.42	1.86
1950-51	67,033	3.12	—	—	—	—	—	3.12	1.12
1951-52	107,999	6.04	—	—	—	—	—	6.04	2.26
1952	—	0.84	—	—	—	—	—	0.84	0.57
1954	41,962	1.80	—	—	—	—	—	1.80	0.57
1954-55	—	3.48	—	—	—	—	—	3.48	—
1955	22,631	2.10	—	—	—	—	—	2.10	0.86
1955-56	—	0.50	—	—	—	—	—	0.50	—
1956	14,018	0.12	—	—	—	—	—	0.72	0.10
1957	86,522	7.36	—	—	1.10	—	—	4.23	1.41
1957-58	—	—	4.83	—	—	—	—	4.83	—
1958	122,559	3.96	—	—	12.18	—	—	8.07	2.12
1958-59	—	—	2.99	—	—	—	—	2.99	—
1959	60,170	2.58	—	—	6.30	—	—	4.44	0.70
1959-60	—	—	5.78	—	—	—	—	5.78	—
1960	129,581	—	—	—	9.54	—	—	9.54	7.35
1960-61	—	—	1.50	—	—	2.54	—	2.02	—
1961	21,680	—	—	—	5.54	—	—	5.54	0.88
1961-62	—	—	—	—	—	3.30	—	3.30	—
1963	72,702	—	—	—	5.04	—	—	5.04	1.72
1969	87,791	—	1.51	—	—	—	—	1.51	0.93
1970	132,779	—	2.41	—	—	—	—	2.41	0.05
1971	199,119	—	5.08	—	—	—	—	5.08	0.73
1972	92,271	—	1.21	—	—	—	3.22	2.22	0.27
1973	65,232	—	0.78	—	—	—	2.78	1.78	0.03
1974	30,523	—	—	—	—	—	3.60	3.60	—
1975	36,038	—	—	—	—	—	3.12	3.12	—
Mean	63,771	3.11	2.90	3.71	6.49	2.92	3.18	3.68	1.24

significant. The mean annual Z ranged from 2.35 for the central section to 4.30 for the northern section, with the mean for the entire coast at 3.14 (Table 13).

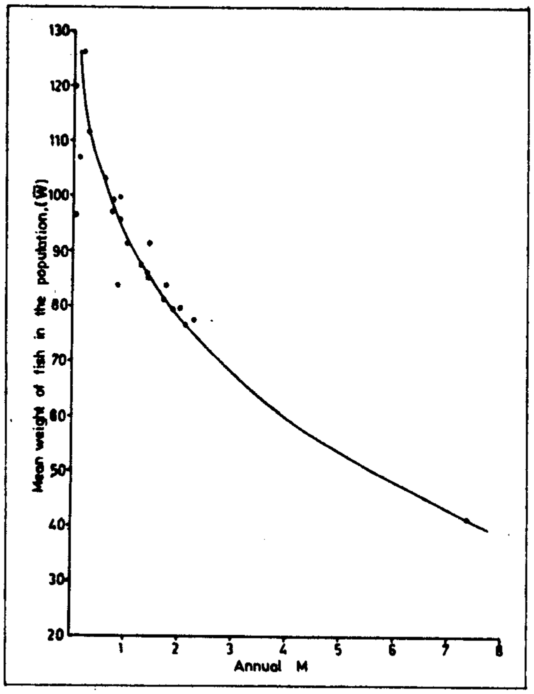

FIG. 14. Relation between mean weight of fish in the population and annual M.

Comparison of Z between various localities : Mean annual Z values for the various centres ranged narrowly from 2.92 for Vizhinjam to 3.71 for Calicut except for Cochin which recorded a high value of 6.49 (Table 14).

Total mortality (Z) from the Paloheimo (1961) method : Calicut mackerel fishery CPUE data for 1959-1968 indicated the mean annual Z to be 1.01, although in certain years as in 1967-1968, the value was as high as 3.22. When the total catch for Calicut for the two phases was fitted for the same period, mean Z was found to be 1.65. The total catch for the two phases for the various periods for the different centres along the southwest coast fitted to Eq. (1) did not indicate any great difference from the result based on the 1959-1968 Calicut CPUE data as shown in Table 15 (Devaraj, 1983).

TABLE 15. *Z estimate from phasewise mackerel catch data fitted to* $Z = -\log_e (c/f)_2/(c/f)_1$

Centre/State	Z	Period
Vizhinjam (Kerala)	0.67	1960-1963
Calicut (Kerala)	1.65	1956-1958
Mangalore (Karnataka)	1.43	1958-1961
Karwar (Karnataka)	1.10	1956-1959
Mean	1.21	
Kerala	0.82	1956-1958
Karnataka	1.57	1956-1956
Maharashtra	0.78	1956-1958
Mean	1.06	
Kerala	0.26	1962-1974
Karnataka	0.70	1962-1974
Maharashtra	1.89	1962-1974
Mean	0.95	

TABLE 16. *F estimates for the 1967-1968 Calicut mackerel fishery based on tagging*

Duration from release to recovery		Progressive number of tagged fish recovered	*F*
in days	in years		
2	0.0055	2	0.7905
3	0.0082	5	1.3255
7	0.0192	6	0.6793
15	0.0411	7	0.3703
25	0.0684	8	0.2542
30	0.0822	9	0.2380
35	0.1370	10	0.1597
		Mean (excluding the last value)	0.6096

Independent estimates of fishing mortality (F) : Based on tag-recovery data, mean F for the 1967-1968 Calicut fishery was estimated to be 0.61 (Table 16; Devaraj, 1983). Z from Eq. (1) for the same period for Calicut was found to be 3.22 and therefore, M was 2.61 (= 3.22 - 0.61).

The 1973-1975 stock and yield data for the entire southwest coast, solved by Eq. (3), showed mean F to be 0.23 and the CPUE data fitted to Eq. (1), gave Z = 2.44 which indicated M to be 2.21.

Independent estimates of natural mortality (M) : For the observed T_{max} of 19 months, M estimated according to Eq. (4) was found to be 3.072. Using T_∞ = 23.2 months instead of T_{max}, M was estimated to be 2.5 according to the same equation. For the mean annual growth parameters of L_∞ = 23.83 cm, annual k = 2.84 and t_0 = 0.003 year and mean ambient temperature 28.5°C, Eq. (5) gave a value 3.52 for M. The estimates of M for the Indian mackerel along the southwest coast of India by Banerji (1973), Sekharan (1976), Yohannan (1979) and Biradar (1985) are 0.65, 0.90, 1.50 and 3.6 respectively. The plot of annual yield (Y) against annual Z (Fig. 11) does not lend itself to the solution for M suggested by Caddy and Csirke (1983) (Eq. 6 and 7).

The wide scatter of Y for Z suggests that M is not necessarily a constant, but is widely variable. Therefore, values of M were estimated by means of Eq. (8) for each year from 1934 to 1973. They ranged from 0.03 in 1973 to 7.3 in 1960 with the mean at 1.31 (Table 7; Fig. 12).

The temporal and spatial distribution of the mackerel stock along this coast is directly governed by the ecological conditions in the premonsoon (April to May), monsoon (June to August) and post-monsoon (September to October) seasons. In the premonsoon season, the layer of discontinuity (thermocline) is deep at about 140 m and the oxygen regime in the entire isothermal layer (upto a depth of 140 m) is quite congenial for the mackerel stock to spread over a wide area. With the onset of the monsoon, the oxygen minimum layer at the 140 m depth progressively upslopes towards the coast and the sea surface. As a result the stock including the new brood released in the premonsoon season and the surviving spent adults concentrate towards the coast and the sea surface over a narrow area where the oxygen regime is favourable. The survival of the stock during the monsoon season seems to be crucially dependent on the intensity of the upsloping, of the oxygen layer. Since sea surface

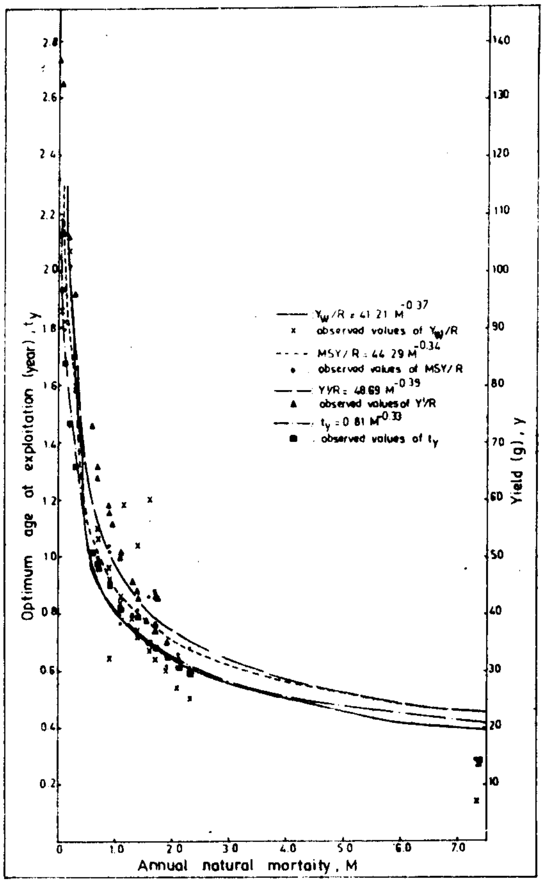

FIG. 15. t/y, Y/R, MSY/R and Y'/R as functions of M.

pressure is an indicator of the intensity of upwelling, values of M were plotted against the mean daily sea surface pressure (p) at Cochin for July and August for the period 1935 to 1973 (Table 18; Fig. 12). The regression of M on p (the extraordinarily high value of M = 7.35 for 1960 at p = 1005.00 millibars was excluded from the regression) was found to be,

M = 4.5023 - 0.00358 p (11.25% of M variation is explained by p)

TABLE 17. *Estimation of natural mortality from mean weight statistics and weight at first capture*

	t_c (years)	w_c (g)	$\overline{W}$ (g)	$U = \frac{W_c}{\overline{W}} = \frac{FA}{Z}$	F (estimated from U)	Z	M
1934	0.5	56.9	87.4	0.65	3.29	5.00	1.71
1935	0.5	56.9	90.8	0.64	2.62	4.06	1.44
1936	0.5	56.9	100.0	0.57	1.23	1.80	0.57
1937	1.0	113.8	125.0	0.91	3.14	3.32	0.18
1938	0.5	56.9	93.0	0.61	1.96	3.04	1.08
1939	0.5	56.9	98.0	0.58	1.42	2.16	0.74
1940	0.5	56.9	88.0	0.65	3.06	4.68	1.62
1941	0.5	56.9	90.0	0.64	2.37	3.64	1.27
1948-49	0.5	56.9	90.0	0.63	2.53	3.92	1.39
1949-50	0.5	56.9	87.0	0.65	3.56	5.42	1.86
1950-51	0.5	56.9	93.0	0.61	2.00	3.12	1.12
1951-52	0.5	56.9	89.0	0.64	3.80	6.06	2.26
1954	0.5	56.9	100.0	0.57	1.23	1.80	0.57
1955	0.5	56.9	110.0	0.52	1.24	2.10	0.86
1956	0.25	16.7	38.0	0.44	0.62	0.72	0.10
1957	0.50	56.9	89.0	0.64	2.61	4.02	1.41
1958	0.50	56.9	86.0	0.66	4.24	6.36	2.12
1959	0.50	56.9	96.0	0.60	1.62	2.50	0.70
1960	0.25	16.7	75.0	0.22	2.09	9.44	7.35
1961	0.50	56.9	95.0	0.60	1.62	2.50	0.88
1963	0.50	56.9	87.0	0.65	3.32	5.04	1.72
1969	0.25	16.7	55.0	0.30	0.59	1.52	0.93
1970	0.50	56.9	64.0	0.89	2.37	2.42	0.05
1971	0.50	56.9	87.0	0.66	3.35	5.08	1.73
1972	0.50	56.9	104.0	0.55	0.95	1.22	0.27
1973	0.50	56.9	108.0	0.52	0.75	0.78	0.03

TABLE 18. *Values of M for the mackeral stock along the southwest coast and mean daily sea surface pressure (p) at Cochin for July and August*

Year	*P* (M. bars)	*M*
1935	1010.84	1.44
1936	1010.84	0.57
1937	1009.82	0.18
1938	1009.14	1.08
1939	1010.84	0.74
1940	1011.18	1.62
1941	1010.50	1.27
1954	921.00	0.57
1955	1006.00	0.86
1956	1138.00	0.10
1957	1027.00	1.41
1958	942.00	2.12
1959	985.00	0.70
1960	1005.00	7.35
1961	972.00	0.88
1963	953.00	1.72
1969	1152.00	0.93
1970	1016.00	0.05
1971	919.00	1.73
1972	1034.00	0.27
1973	959.00	0.03

$M = 21.0865 - 0.0358\,p + 0.0000156\,p^2$ (12.70% of M variation is explained by p).

These equations reveal that M which is high at low pressure (indicating upwelling) keeps decreasing with increasing p. The observed variations in M, therefore, seem to be caused by the variations in the intensity of monsoon and upwelling.

Cohort analysis

Since continuous catch data for Goa and Maharashtra is available only from 1956 onwards, cohort analysis for the period 1934-1973 was carried out separately for the Kerala-Karnataka section and for the entire southwest coast for 1956-1973.

Kerala-Karnataka Coast : The annual catch for Kerala-Karnataka for 1934-1973 ranged from 111.4 × 10^6 fish in 1938 to 188.6 × 10^6 in 1971 with the mean annual catch at 746.6 × 10^6 fish comprising 14.06% 0+, 70.13% $\frac{1}{2}$+, 12.42% 1+ and 3.39% $1\frac{1}{2}$+ old fish. The 0+ and 1+ old fish rarely formed the fully recruited group, the former in 1956, 1960 and 1969 and the latter in 1957 while the $\frac{1}{2}$+ which was the mainstay of the fishery formed the fully recruited group in all the other years. The 0+ old fish in the catch ranged from virtually zero in 1934, 1941, 1948-1949, 1971, 1972 and 1973 to 497.2 × 10^6 in 1969 with the mean at 105.0 × 10^6; the $\frac{1}{2}$+ old fish ranged from 52.9 × 10^6 in 1956 to 1,748 × 10^6 in 1971 with the mean at 523.6 × 10^6; the 1+ old fish ranged from 11.1 × 10^6 in 1960 to 310.9 × 10^6 in 1936, with the mean at 92.7 × 10^6; and the $1\frac{1}{2}$+ old fish ranged from 0.4 × 10^6 in 1961 to 108.3 × 10^6 in 1972 with the mean at 25.3 ×10^6.

In the total number of fish in the population in the sea (N_t), the 0+ old fish ranged from 268 × 10^6 (1938 and 1956) to 391,372 × 10^6 (1960) with the mean at 17,242 × 10^6 (91.79%), the $\frac{1}{2}$+ old fish ranged from 138 × 10^6 (1938) to 9,896 × 10^6 (1960) with the mean at 1,338 × 10^6 (7.122%) the 1+ old fish ranged from 17 × 10^6 (1969) to 417 × 10^6 (1951-1952) with the mean at 170 × 10^6 (0.905%) and the

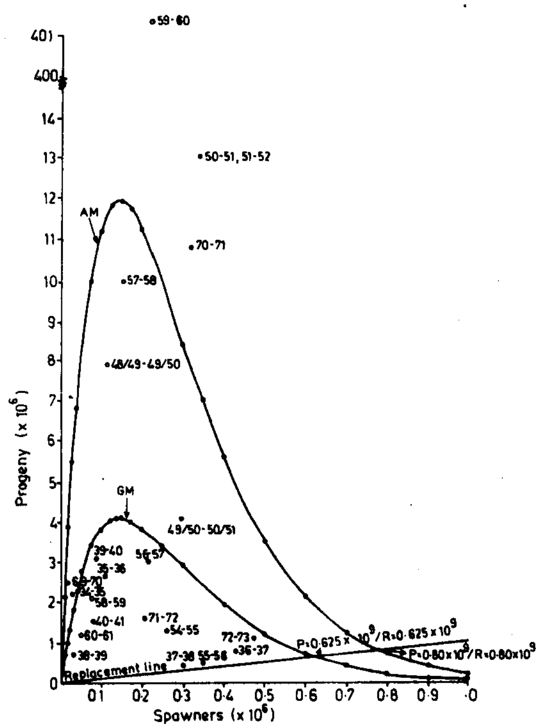

FIG. 16. Spawner - progeny relationship for the Kerala - Karnataka Coast.

$1\frac{1}{2}$+ old fish ranged from 1 × 10^6 (1961) to 140 × 10^6 (1972) with the mean at 35 × 10^6 (0.1863%). In the mean number of fish in the sea ($\overline{N}_t$), the 0+ old fish ranged from 104 × 10^6 (1939) to 103,662 × 10^6 (1960) with the mean at 1,988 × 10^6, the $\frac{1}{2}$+ old fish ranged from 69 × 10^6 (1938) to 1,861 × 10^6 (1960) with the mean at 631 × 10^6 and the 1+ old fish ranged from 12 × 10^6 (1938) to 226 × 10^6 (1951-1952) with the mean at 69 × 10^6 (Table 19).

Southwest coast : The annual catch fo the entire southwest coast includin

Kerala-Karnataka, Goa and southern Maharashtra for 1956 to 1973 ranged from 198.57 × 10^6 fish (1956) to 2,348.74 × 10^6 fish (1971) with the mean at 1,217.44 × 10^6 fish comprising 18.99% 0+, 66.41% $\frac{1}{2}$+, 11.04% 1+ and 3.55% $1\frac{1}{2}$+ old fish. The $\frac{1}{2}$+ formed the fully recruited group (except in 1959). The 0+ old fish ranged from 0 (1971, 1972 and 1973) to 1,009.6 × 10^6 (1969) with the mean at 234.26 × 10^6, the $\frac{1}{2}$+ old fish ranged from 61.36 × 10^6, (1956) to 2,176.15 × 10^6 (1971) with the mean at 819.146 × 10^6, the 1+ old fish ranged from 12.25 × 10^6 (1969) to 339.72 × 10^6 (1970) with the mean at 136.14 × 10^6 and the $1\frac{1}{2}$+ old fish ranged from 0.41 × 10^6 (1961) to 149.67 × 10^6 (1972) with the mean at 43.84 × 10^6.

In the total number of fish in the population in the sea (N_t), the 0+ old fish ranged from 217.08 × 10^6 (1956) to 432,037.54 × 10^6 (1960) with the mean at 41,930.10 × 10^6 (94.41%), the $\frac{1}{2}$+ old fish ranged from 138.72 × 10^6 (1956) to 10,923.62 × 10^6 (1960) with the mean at 2,226.65 × 10^6 (5.01%), the 1+ old fish ranged from 33.72 × 10^6 (1969) to 464.7 × 10^6 (1972) with the mean at 201.35 × 10^6 (0.45%) and the $1\frac{1}{2}$+ old fish ranged from 0.624 × 10^6 (1961) to 193.11 × 10^6 (1972) with the mean at 54.04 × 10^6 (0.12%). In the mean number of fish in the sea ($\overline{N_t}$), the 0+ old fish ranged from 175.0 × 10^6 (1956) to 114,507.81 × 10^6 (1960) with the mean at 12,249.26 × 10^6, the $\frac{1}{2}$+ old fish ranged from 101.76 × 10^6 (1956) to 2,055.87 × 10^6 (1960) with the mean at 711.80 × 10^6 and the 1+ old fish ranged from 20.8 × 10^6 (1961) to 309.29 × 10^6 (1972) with the mean at 75.67 × 10^6 (Table 20).

Analytical model

Since M varied from year to year, yield per recruit was estimated individually for all the years from 1934 to 1973 (Table 21). While M ranged from 0.03 in 1973 to 7.35 in 1960 (mean = 1.31), the exploitation ratio (E) ranged from 0.22 in 1960 to 0.97 in 1973 (mean = 0.68) revealing thereby an inverse relation between M and E; however, the range in F from 0.59 in 1969 to 4.24 in 1958, did not show such a direct relation with M. The exploitation ratio at the maximum sustainable yield per recruit (E_{msy}) ranged from 0.55 in 1936, 1939, 1954, 1955, 1959, 1961 and 1969 to 0.95 in 1937 (mean = 0.72). A comparison of mean E = 0.68 with the mean E_{msy} = 0.72 suggests that the stock was only marginally underexploited, *i.e.* by 4.38%. The yield in weight per recruit (Yw/R) ranged from 6 g in 1960 for M = 7.35, F = 2.09, E = 0.22 and t_c = 0.25 year to 115.27 g in 1973 for M = 0.03, F = 0.75, E = 0.97 and t_c = 0.5 year, indicating high yields per recruit for low M (Fig. 13). The years of minimum and maximum values of *MSY/R* (14.53 g in 1960 to 116.57 g in 1973) were found to be the same as that for the Yw/R values (6 g in 1960 to 115.27 g in 1973) owing to minimum M in 1973 and maximum M in 1960. The mean Yw/R (50.16 g) was only marginally less than the mean *MSY/R* (52.71 g) indicating that the stock has in generally been exploited at a level very close to the MSY. The mean weight of the fish in the catch ($\overline{W}$), which ranged from 26 g in 1950-1951 (for M = 1.12, F = 2.0, E = 0.64 and t_c = 0.5) year to 126 g in 1937 (for M = 0.18, F = 3.14, E = 0.95 and t_c = 1 year), decreased almost progressively with increasing M (Fig. 14). The mean weight of the fish for the 1934-1973 period was 89 g.

For the Kerala-Karnataka section, the annual yield during 1934-1973 ranged from 7,644 t in 1938 (83.71 × 10^6 fish in 1938) to 120,841 t in 1958 (2,824.41 × 10^6 fish in 1960) with the average annual yield at 59,048 t comprising 793 × 10^6 fish. The standing stock (P_W) was minimum in 1938 (4,116.76 t) and maximum in 1939 (73,803.35 t), while the total annual stock (P_W) was minimum in 1938 (12,778.33 t) and maximum in 1960 (529,481.28 t).

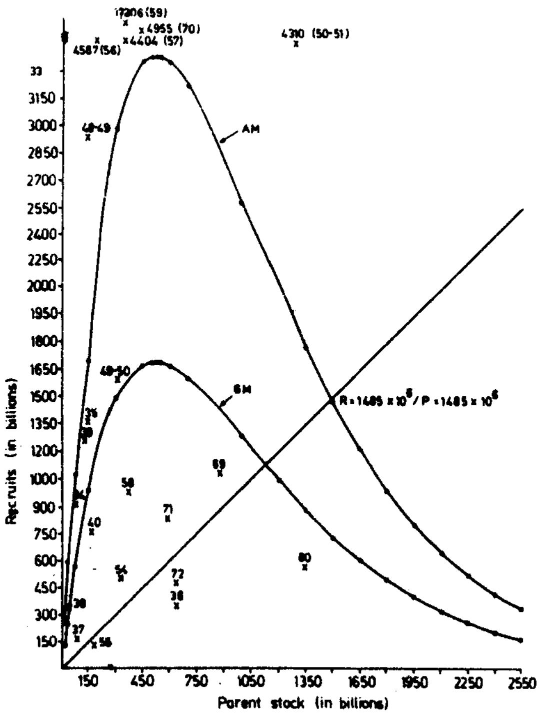

FIG. 17. Stock - recruitment relationship for the Kerala - Karnataka Coast.

The mean $\bar{Pw}$ and Pw were 30,966 t and 109,299 t respectively. The MSY ranged from 6,813.10 t in 1938 to 251,462.28 t in 1960 with the mean at 70,788 t. Thus, the average annual yield represents 54.02% of the total stock and 83.42% of the MSY. The number of recruits (R_c) ranged from 178.40 × 10^6 in 1938 to 17,306.42 × 10^6 in 1960 with the mean at 2,135 × 10^6 (Table 22). The number of fish in the stock (P_N) ranged from 42.78 × 10^6 in 1938 to 1,349.90 × 10^6 in 1960 with the mean at 393.89 × 10^6 (Table 22). The total annual stock (P_W) of mackerel for the southwest coast for 1960-1971 was estimated to be 130,000 t (Sekharan, 1976) while the standing stock (Pw) was estimated to be 57,000 t for 1960-1971 (Sekharan, 1976), 470,000 t for 1973, 100,000 t for 1974 and 30,000 t for 1975 (UNDP/FAO, 1973; 1974; 1975) and 416,625 for 1965-1976 (Kulkarni, 1978). The MSY was estimated to be 90,600 t for 1958-1967 (Banerji, 1973) and 80,000 t for 1972-1976 (George *et al.*, 1977).

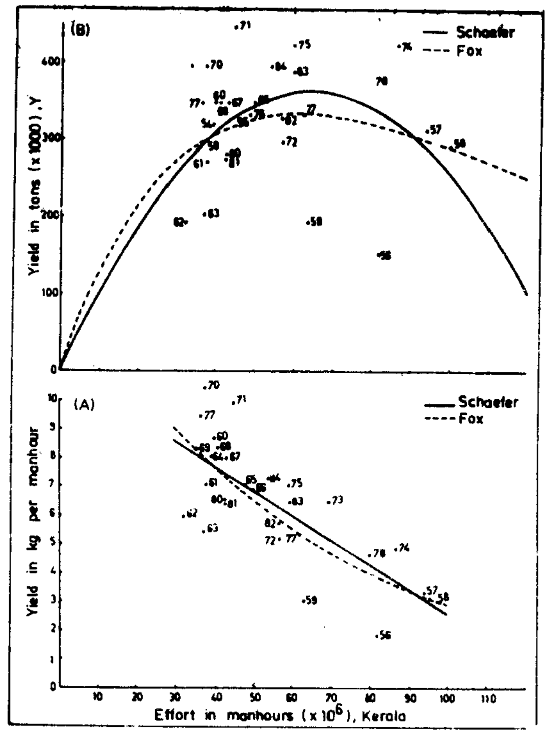

FIG. 18. Catch per unit effort (A) and catch (B) as functions of effort in respect of inshore fisheries in Kerala.

Spawner-progeny relation

Kerala-Karnataka : Considering the 1+ and $1\frac{1}{2}$+ in the population in a certain year as spawners (since the mean size at first maturity

TABLE 19. *Cohort analysis for the Kerala-Karnataka section of the mackeral stock along the southwest coast for 1934 to 1973*

Year	Total catch in tonnes and in numbers X 10^6	Age (t)	No. Caught $\times 10^6$ (C_t)	No. in population (N_t) $\times 10^6$	Z ($\frac{1}{2}$ year basis)	F ($\frac{1}{2}$ year)	Average Numbers in the sea (N_t) $\times 10^6$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1934	21,689	0+	0	1034	0.85	0	695
	(260.4)	$^1/_2$+	240.6	440	2.68	1.83	153
	$^1/_2$ M=0.8548	1+	19.8	30	2.50	1.65	—
1935	33,058	0+	127.7	1531	0.84	0.13	1033
	(499.0)	$^1/_2$+	324.6	658	1.94	1.23	290
	$^1/_2$ M=0.7173	1+	30.9	94	1.35	0.63	52
		$1^1/_2$+	15.8	24	2.03	1.31	—
1936	81,111	0+	31.0	1528	0.31	0.02	1314
	(872.5)	$^1/_2$+	509.9	1120	1.03	0.75	699
	$^1/_2$ M=0.2868	1+	310.9	399	2.58	2.29	143
		$1^1/_2$+	20.7	30	0.90	0.61	—
1937	36,540	0+	3.2	411	0.10	0.01	391
	(332.2)	$^1/_2$+	59.1	373	0.27	0.18	327
	$^1/_2$ M=0.0897	1+	252.3	284	2.73	2.64	97
		$1^1/_2$+	17.6	19	1.66	1.57	—
1938	7,644	0+	23.3	268	0.66	0.12	196
	(111.4)	$^1/_2$+	69.3	138	1.61	1.07	69
	$^1/_2$ M=0.5416	1+	16.6	28	2.03	1.55	12
		$1^1/_2$	2.2	3	1.52	0.98	—
1939	17,732	0+	40.3	441	1.62	1.26	104
	(229.7)	$^1/_2$+	127.7	272	1.20	0.83	158
	$^1/_2$ M=0.3682	1+	54.0	82	1.95	1.58	36
		$1^1/_2$+	7.7	12	1.08	0.71	—
1940	42,107	0+	120.4	2183	0.90	0.09	1441
	(644.9)	$^1/_2$+	474.3	890	2.42	1.61	335
	$^1/_2$ M=0.8109	1+	48.1	79	3.21	2.40	24
		$1^1/_2$+	2.1	3	2.34	1.53	—
1941	29,896	0+	0	1005	0.63	0	745
	(337.4)	$^1/_2$+	290.5	534	2.01	1.37	230
		$^1/_2$M=0.6326	1+	46.9	72	1.82	1.19
1948-49	29,509	0+	0	1157	0.70	0	833
	(318.5)	$^1/_2$+	276.3	577	1.83	1.14	264
	$^1/_2$ m=0.6964	1+	23.0	92	1.13	0.44	55
		$1^1/_2$+	19.2	30	1.96	1.26	—

TABLE 19 *(Contd.)*

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1949-50	89,163	0+	81.2	5703	0.95	0.02	3679
	(1223.7)	$^{1}/_{2}+$	1069.7	2203	2.41	1.48	832
	$^{1}/_{2}$ M=0.9284	1+	36.4	198	1.27	0.35	112
		$1^{1}/_{2}+$	36.4	55	2.71	1.78	—
1950-51	67,033	0+	15.6	2162	0.57	0.01	1650
	(743.0)	$^{1}/_{2}+$	585.9	1226	1.56	1.00	621
	$^{1}/_{2}$ M=0.5579	1+	90.4	258	1.18	0.62	152
		$1^{1}/_{2}+$	51.1	80	1.56	1.00	—
	107,999	0+	16.4	10141	1.13	0.0029	6089
1951-52	(1252.5)	$^{1}/_{2}+$	1117.0	3260	2.06	0.93	1380
	$^{1}/_{2}$ M=1.1321	1+	54.3	417	1.39	0.26	266
		$1^{1}/_{2}+$	64.8	103	3.03	1.90	—
1954	41,962	0+	14.5	731	0.31	0.02	6.26
	(415.9)	$^{1}/_{2}+$	247.0	537	1.04	0.76	335
	$^{1}/_{2}$ M=0.2856	1+	104.0	189	0.94	0.66	122
		$1^{1}/_{2}+$	50.4	74	0.90	0.61	—
1955	22,637	0+	66.8	794	0.54	0.11	606
	(259.7)	$^{1}/_{2}+$	89.3	467	0.71	0.27	337
	$^{1}/_{2}$ M=0.4318	1+	31.3	228	0.62	0.19	169
		$1^{1}/_{2}+$	72.3	123	1.05	0.62	—
1956	12,163	0+	59.3	268	0.31	0.26	229
	(170.7)	$^{1}/_{2}+$	52.9	197	0.37	0.32	165
	$^{1}/_{2}$ M=0.0508	1+	48.0	136	1.38	1.33	39
		$1^{1}/_{2}+$	10.5	82	0.36	0.31	—
1957	81,941	0+	350.0	2070	0.83	0.26	1402
	(1237.8)	$^{1}/_{2}+$	769.7	906	1.74	1.18	430
	$^{1}/_{2}$ M=0.5715	1+	117.0	158	4.64	4.06	34
		$1^{1}/_{2}+$	1.1	2	2.01	1.44	—
1958	120,841	0+	115.8	7657	1.09	0.03	4722
	(1504.9)	$^{1}/_{2}+$	1333.5	2510	3.40	2.34	714
	$^{1}/_{2}$ M=1.0623	1+	55.6	83	3.18	2.12	—
1959	54,021	0+	90.3	1271	0.44	0.09	1030
	(699.0)	$^{1}/_{2}+$	434.2	818	1.35	1.00	450
	$^{1}/_{2}$ M=0.3520	1+	170.7	211	3.69	3.33	56
		$1^{1}/_{2}+$	3.8	5	1.25	0.90	—

TABLE 19 *(Contd.)*

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1960	117,386	0+	254.2	391372	3.68	0.0041	103662
	(1577.8)	$^1/_2$+	1262.5	9896	5.29	1.61	1861
	$^1/_2$ M=3.6735	1+	11.1	50	4.72	1.05	—
1961	27,320	0+	92.9	776	0.60	0.16	583
	(387.9)	$^1/_2$+	210.4	426	1.39	0.95	230
	$^1/_2$ M=0.4385	1+	84.2	106	5.15	4.71	20
		$1^1/_2$+	0.4	1	1.25	0.81	—
1963	68,049	0+	321.8	3149	1.03	0.17	1967
	(986.1)	$^1/_2$+	615.0	1123	2.71	1.85	387
	$^1/_2$ M=0.8604	1+	49.3	75	2.52	1.66	—
1969	43,234	0+	497.2	2143	1.17	0.71	1266
	(932.1)	$^1/_2$+	428.5	662	3.69	3.22	175
	$^1/_2$ M=0.4671	1+	6.4	17	0.76	029	—
1970	100,996	0+	407.4	1461	0.36	033	1225
	(1405.4)	$^1/_2$+	709.3	1020	1.25	1.22	589
	$^1/_2$ M=0.8657	1+	258.4	284	2.25	2.22	112
		$1^1/_2$+	30.3	31	1.21	1.18	—
1971	159,211	0+	0	7587	0.87	0	5052
	(1886)	$^1/_2$+	1748.0	3192	2.72	1.86	1097
	$^1/_2$ M=0.8657	1+	138.0	209	2.54	1.67	—
1972	66,765	0+	0	853	0.14	0	786
	(606.6)	$^1/_2$+	334.0	743	0.79	0.66	515
	$^1/_2$ M=0.1372	1+	164.3	336	0.88	0.74	223
		$1^1/_2$+	108.3	140	0.67	0.47	—
1973	55,248	0+	0	592	0.07	0	586
	(485.9)	$^1/_2$+	213.8	551	0.59	0.52	415
	$^1/_2$ M=0.0726	1+	187.9	306	1.08	1.01	188
		$1^1/_2$+	84.2	103	0.39	0.32	—
Mean	59,048	0+	105.0	17242.0	0.80	0.15	19880
for	(746.6)	$^1/_2$+	523.6	1338.0	1.85	1.20	631
1934-73	$^1/_2$ M=0.6505	1+	92.7	170.0	1.95	1.56	69
		$1^1/_2$+	25.3	35.0	1.20	0.74	—
Total			746.6	18785	1.45	0.91	20580

is about 220 mm when the fish is 12 months old) and 0+ and the $\frac{1}{2}$+ fish in the population in the following year as the progeny (since February to May is the peak spawning season) the spawner-progeny relation (Fig. 16) for 1934-1973 was fitted by the equation,

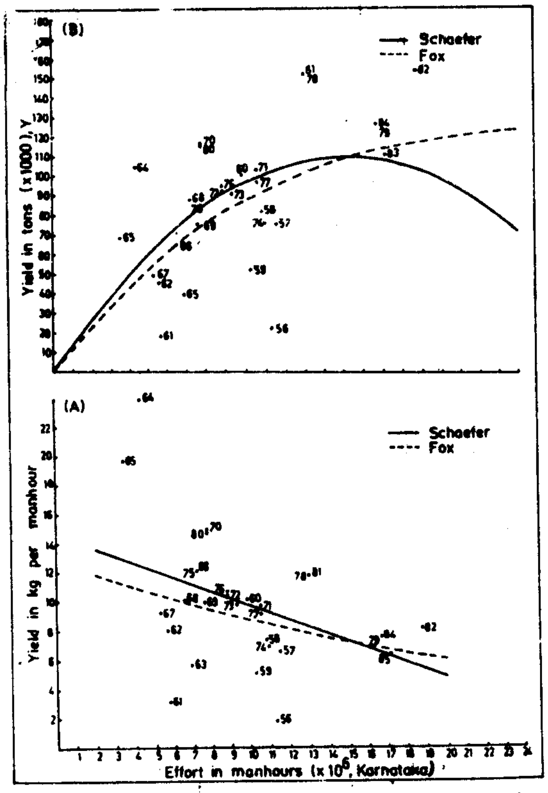

FIG. 19. Catch per unit effort (A) and catch (B) as functions of effort in respect of inshore fisheries in Karnataka.

$$R = Pe^{4.3412\,(1 - P/625.3529)} \times 2.9277$$

The replacement point at which the number of progeny is the same as the spawners is found to be 0.79 × 10^9. The progeny attains its maximum (11.9 × 10^9 fish) at a spawner strength of 0.15 × 10^9 fish. The MSY of 11.769 × 10^9 progeny (out of a total of 11.9 × 10^9 progeny) could be harvested at an exploitation ratio of 98.8% at which only just the number of spawners (139 × 10^6) required to maximize the progeny would be left. However, the average E_{msy} = 0.72 according to the analytical model (Table 21) seems more realistic than the E_{msy} = 0.99 indicated by the Ricker model of spawner-progeny relationship.

Entire southwest coast : The spawner-progeny relation for the entire southwest coast for 1956-73 (Fig. 17) was fitted by the equation,

$$R = Pe^{3.7130\,(1 - P/12{,}459.035)} \times 4.1631$$

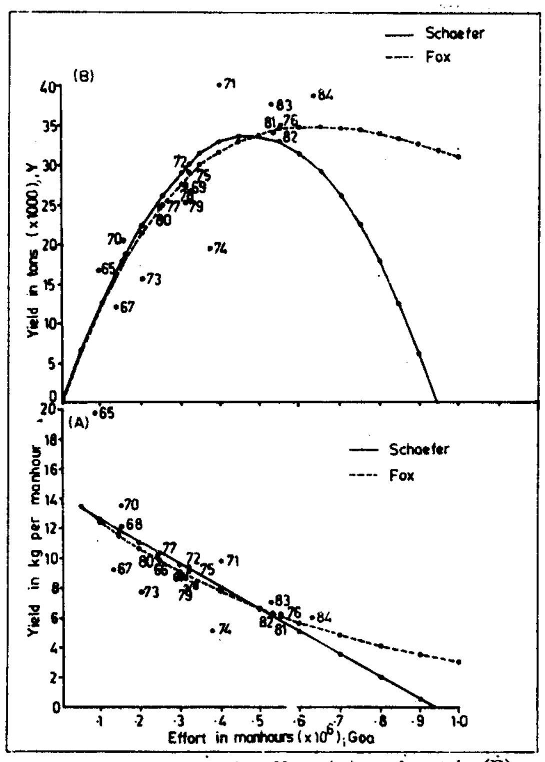

FIG. 20. Catch per unit effort (A) and catch (B) as functions of effort in respect of inshore fisheries in Goa.

The replacement point at which the number of progeny is the same as the spawners is found to be 16 × 10^9. The progeny attains its maximum (215 × 10^9 fish) at a spawner strength of 3.25 × 10^9 fish. The MSY of 207 × 10^9 progeny (out of 215 × 10^9 progeny) could be harvested at an exploitation rate of 98.50% at which only just the number of spawners (3.146 × 10^9) required to maximize the progeny would be left.

TABLE 20. *Cohort analysis for the Kerala-Karnataka section of the mackeral stock along the southwest coast for 1934 to 1973*

Year	Total catch in tonnes and in numbers (× 10^6)	Age (t)	No. Caught × 10^6 (C^t)	No. in population (N^t) (× 10^6)	Z (1/2 basis)	F (1/2 year)	Average numbers in the sea ($\bar{N}$) × 10^6
1956	14,018	0+	69	217	0.45	0.40	175
	(198.57)	1/2+	61	139	0.66	0.60	102
	1/2 M=0.0508	1+	56	72	1.63	1.57	36
		1 1/2+	12	14	0.36	0.31	—
1957	86,522	0+	370	2932	0.76	0.18	2058
	(1307.00)	1/2+	813	1378	2.11	1.54	574
	1/2 M=0.5715	1+	124	167	4.64	4.06	36
		1 1/2+	1.2	2	2.01	1.44	—
1958	122,559	0+	118	7564	1.09	0.03	4608
	(1526.30)	1/2+	1352	2545	3.40	2.34	723
	1/2 M=1.0623	1+	56	85	3.18	2.12	—
1959	60,1710	0+	101	1415	0.38	0.02	1179
	(788.56)	1/2+	484	971	1.42	1.07	519
	1/2 M=0.3520	1+	190	235	3.69	3.33	62
		1 1/2+	4	6	1.25	0.90	—
1960	129,581	0+	281	432038	3.68	0.01	114508
	(1686.52)	1/2+	1394	10924	5.29	1.61	2056
	1/2 M=3.6735	1+	12	55	4.72	1.05	—
1961	27,680	0+	94	786	0.60	0.16	591
	(393.01)	1/2+	213	432	1.39	0.95	233
	1/2 M=0.4385	1+	85	107	5.14	4.71	21
		1 1/2+	0.4	0.6	1.25	0.81	—
1969	87,791	0+	101	3114	0.99	0.53	1974
	(1892.72)	1/2+	870	1153	3.53	3.06	317
	1/2 M=0.4671	1+	13	34	0.76	0.29	—
1970	132,779	0+	536	1920	0.36	0.33	1613
	(1847.28)	1/2+	932	1341	1.25	1.22	767
	1/2 M=0.0266	1+	340	386	2.25	2.22	154
		1 1/2+	40	41	1.21	1.18	—
1971	199,119	0+	0	9452	0.87	0	6325
	(2348.74)	1/2+	2176	3977	2.72	1.85	1366
	1/2 M=0.8657	1+	173	262	2.54	1.67	—
1972	92,271	0+	0	1180	0.14	0	1102
	(839.44)	1/2+	463	1029	0.79	0.66	710
	1/2 M=0.1372	1+	227	465	0.88	0.74	309
		1 1/2+	150	193	0.61	0.47	—
1973	65,232	0+	0	613	0.01	0	609
	(573.71)	1/2+	252	605	0.56	0.54	464
	1/2 M=0.0126	1+	222	347	1.04	1.03	215
		1 1/2+	99	122	0.39	0.32	—
Mean	1,217.44	0+	234	41930	0.85	0.21	12249
	(1233)	1/2+	819	2227	2.10	1.40	712
	1/2 M=0.6962	1+	136	201	2.77	2.07	76
		1 1/2 +	44	54	0.32	0.85	—
Total			1233	44412	6.04	4.53	13037

Considering that the Kerala-Karnataka Coast and the Goa-southern Maharashtra Coast contributed 79.33% and 20.67% respectively to very few observations, all limited to a narrow section on the ascending limb of the fitted curve for the entire southwest coast. Therefore,

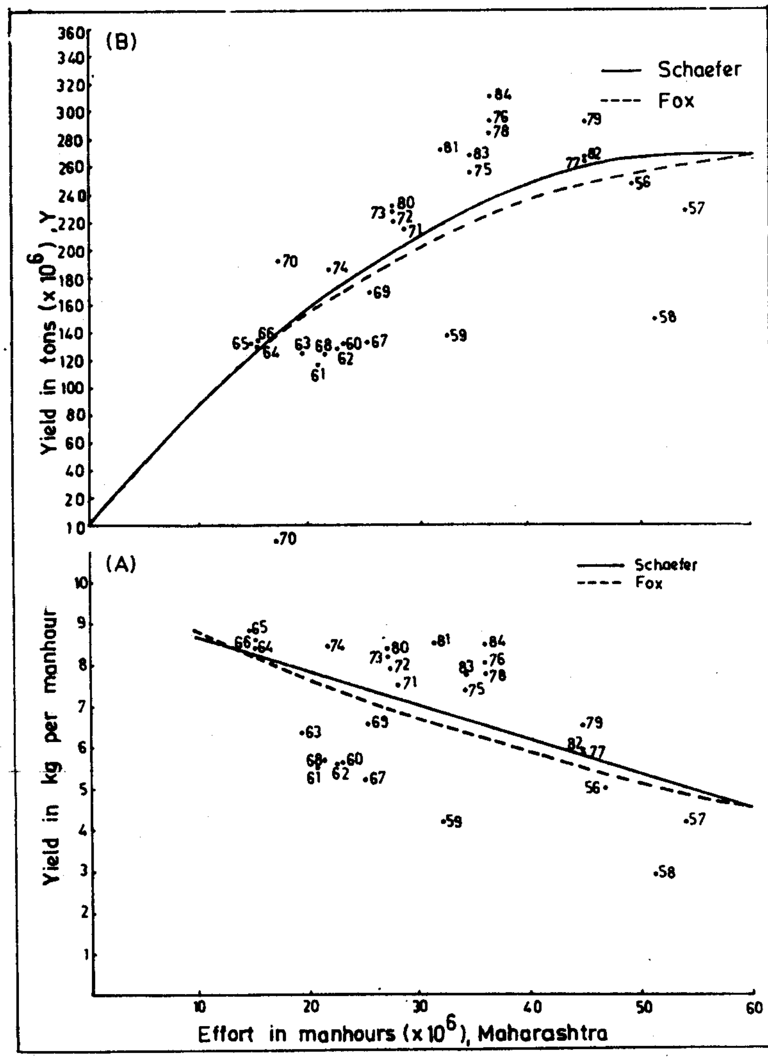

FIG. 21. Catch per unit effort (A) and catch (B) as functions of effort in respect of inshore fisheries in Maharashtra.

the average annual catch of 62,198 t during 1956-1984, the maximum of 215 × 10^9 progeny for 3.25 × 10^9 spawners for the entire southwest coast seems to be a gross overestimate compared to the maximum of 11.9 × 10^9 progeny for 0.15 × 10^9 spawners for the Kerala-Karnataka Coast. This anomoly is evidently due to the the likely number of maximum progeny and spawners required for maximizing progeny was estimated by raising the estimates for Kerala-Karnataka to that for the entire southwest coast on the basis of the percentage of average annual catch that Kerala-Karnataka contributes (79.33%) to that for the southwest coast. Thus,

TABLE 21. *Estimates of yield per recruit for 1934 to 1973 for Kerala-Karnataka belt*

Year	F	M	t^c (y_r)	E	E_{msy}	Status of exploi-tation	%	P_w/R (g)	Y_w/R (g)	MSY/R (g)	P_N/R	Y_N/R	W (g)	t_y (yr)	Y' (g)
1934	3.29	1.71	0.5	0.66	0.70	UE	4	9.84	32.4	43.4	0.12	0.40	81.0	0.68	37.70
1935	2.62	1.44	0.5	0.65	0.70	UE	5	13.80	36.2	41.1	0.16	0.43	85.1	0.7	42.63
1936	1.23	0.57	0.5	0.68	0.55	OE	13	48.49	59.5	48.2	0.47	0.58	103.2	1.1	72.85
1937	3.14	0.18	1.0	0.95	0.95	—	—	32.96	103.5	101.2	0.26	0.82	126.1	1.5	106.25
1938	1.96	1.08	0.5	0.64	0.70	UE	6	21.90	42.9	38.2	0.24	0.47	91.3	0.8	51.58
1939	1.42	0.74	0.5	0.66	0.55	OE	11	36.97	52.6	49.8	0.37	0.53	99.0	1.0	64.11
1940	3.06	1.62	0.5	0.65	0.70	UE	5	10.95	33.5	42.6	0.13	0.41	82.2	0.7	39.20
1941	2.37	1.27	0.5	0.65	0.70	UE	5	16.55	39.3	39.6	0.19	0.45	87.1	0.8	46.45
1948	2.53	1.39	0.5	0.64	0.70	UE	6	14.59	36.9	41.7	0.17	0.43	85.9	0.8	43.69
1949	3.56	1.86	0.5	0.66	0.85	UE	19	8.53	30.4	31.4	0.11	0.38	79.5	0.7	35.40
1950	2.00	1.12	0.5	0.64	0.70	UE	6	21.01	42.1	38.4	0.81	1.62	26.1	0.8	50.41
1951	3.80	2.26	0.5	0.63	0.85	UE	22	6.60	25.1	34.1	0.09	0.32	77.5	0.6	30.50
1954	1.23	0.57	0.5	0.68	0.55	OE	13	48.52	59.6	48.2	0.47	0.58	102.2	1.1	72.85
1955	1.24	0.86	0.5	0.59	0.55	OE	4	36.90	45.6	51.1	0.37	0.46	99.7	0.9	59.07
1956	0.62	0.10	0.25	0.85	0.80	OE	5	147.90	91.5	89.8	1.38	0.86	106.9	1.7	118.04
1957	2.61	1.41	0.5	0.65	0.70	UE	5	20.06	52.3	40.9	0.22	0.57	91.5	0.7	43.26
1958	4.24	2.12	0.5	0.67	0.85	UE	18	6.48	27.4	33.2	0.08	0.36	76.6	0.6	32.05
1959	1.62	0.70	0.5	0.70	0.55	OE	15	33.98	55.1	49.5	0.35	0.57	97.1	1.0	65.98
1960	2.09	7.35	0.25	0.22	0.90	UE	68	3.25	6.8	14.5	0.08	0.16	41.6	0.3	13.83
1961	1.62	0.88	0.5	0.65	0.55	OE	10	29.64	48.1	51.3	0.31	0.50	95.7	0.9	58.31
1963	3.32	1.72	0.5	0.66	0.70	UE	4	9.71	32.2	43.5	0.12	0.40	80.9	0.7	37.52
1969	0.59	0.93	0.25	0.39	0.55	UE	16	52.94	31.0	51.9	0.63	0.37	83.6	0.9	56.47
1970	2.37	0.05	0.5	0.98	0.90	OE	8	39.24	92.9	108.8	0.41	0.96	96.5	1.9	21.55
1971	3.35	1.73	0.5	0.66	0.70	UE	4	9.96	32.1	43.6	0.12	0.40	83.8	0.7	37.36
1972	0.95	0.27	0.5	0.78	0.85	UE	7	84.90	79.8	78.7	0.76	0.72	111.5	1.3	95.91
1973	0.75	0.03	0.5	0.97	0.90	OE	7	152.69	115.3	116.6	1.27	0.96	120.0	2.1	132.17
Mean	2.21	1.31	0.49	0.68	0.72	UE	4.38	35.32	50.16	52.71	0.37	0.57	89.0	0.95	60.43

considering the maximum progeny of 11.9 × 10^9 for the optimum of 0.15 × 10^9 spawners for Kerala-Karnataka to be 79.33% of that for the southwest coast, the maximum progeny for the latter is estimated to be 15.00 × 10^9 for 0.19 × 10^9 spawners.

$$R = Pe^{2.1797\,(1\,-\,P/1129.8082)} \times 2.0098$$

The replacement point at which the number of recruits is equal to the number in the stock is found to be 1.485 × 10^9. The recruits attain their maximum strength (3.273 × 10^9) at a stock strength of 0.393 × 10^9 fish. The MSY

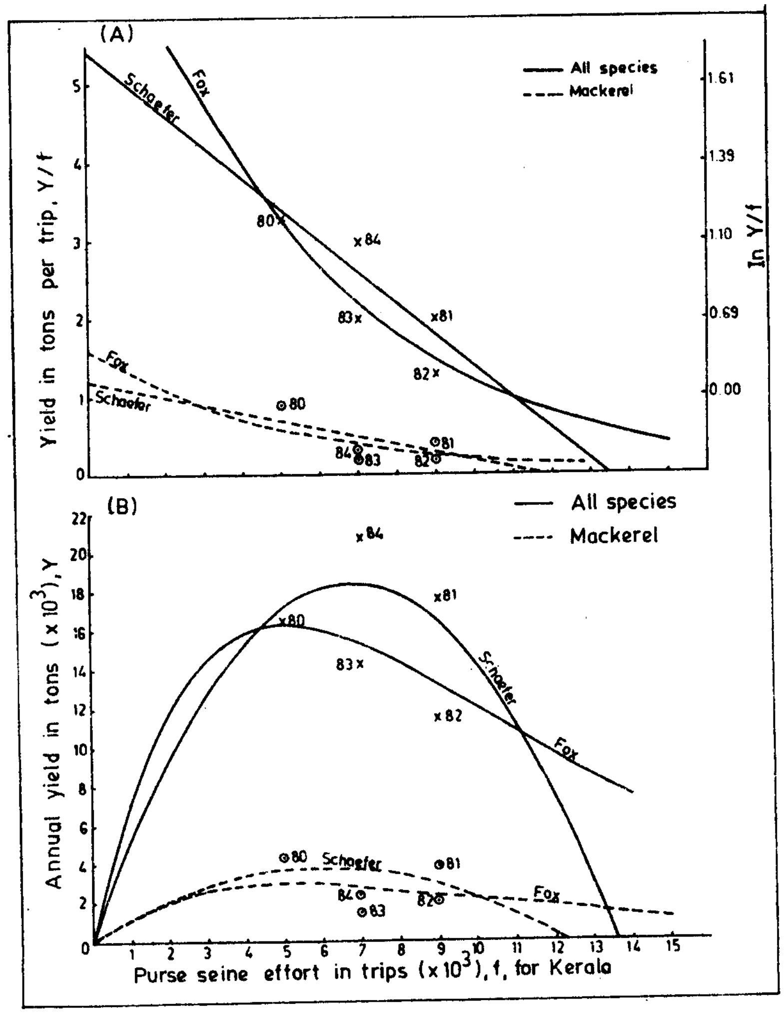

FIG. 22. Catch per trip (A) and catch (B) as functions of purse-seine effort in trips in respect of all species and mackerel for Kerala.

Stock-recruitment relationship

Kerala-Karnataka : The stock and recruits were calculated according to the analytical model (Table 22) and the stock-recruitment relationship (Fig. 17) fitted by

of 2.880 × 10^9 recruits (out of a total of 3.273 × 10^9 recruits) could be harvested at an exploitation ratio of 88% at which only 0.393 × 10^9 fish in the stock will be left to maximize the recruits.

Considering the maximum recruits of 3.273 × 10^9 at a stock of 0.393 × 10^9 fish to be 79.33% of that for the entire southwest coast, the maximum recruits at t_c = 0.5 year for the t_c = 0.5 year) is 1 : 0.28. The mean annual size of the population for the period 1934-1973 (18.785 × 10^9 fish) comprised 17.242 × 10^9 0+, 1.338 × 10^9 $\frac{1}{2}$+, 0.17 × 10^9 1+ and 0.035

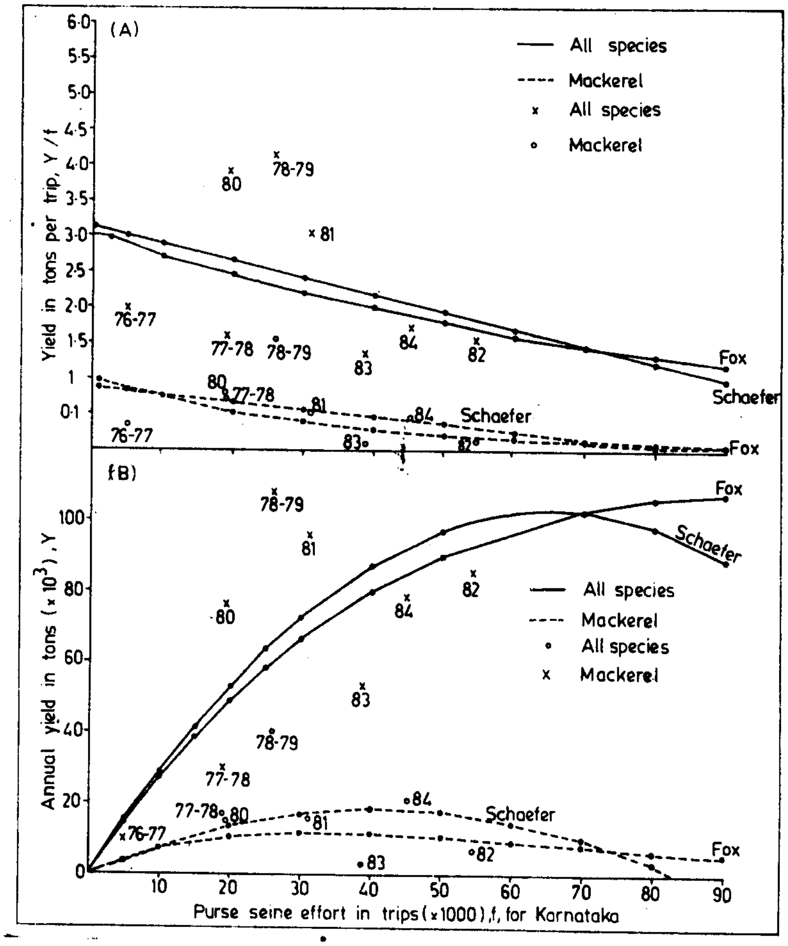

FIG. 23. Catch per trip (A) and catch (B) as functions of purse seine effort in trips in respect of all species and mackerel for Karnataka.

latter is estimated to be 4.126 × 10^9 at a stock strength of 0.495 × 10^9 fish, while the maximum progeny comprising the 0+ and $\frac{1}{2}$+ old fish has already been estimated to be 15 × 10^6 fish for 0.19 × 10^9 spawners.

Thus, the ratio of maximum progeny of 15.19 × 10^9 fish (1 to 11 months only) to the maximum recruits of 4.13 × 10^9 fish (at × 10^9 1$\frac{1}{2}$+ fish. The estimated maximum progeny of 15 × 10^9 fish matches well with the mean annual size of 18.6 × 10^9 0+ and $\frac{1}{2}$+ estimated from cohort analysis (Table 19). This significant agreement between the maximum progeny estimated from the Ricker model and the average progeny estimated by cohort analysis is quite compatible with the significant agreement

TABLE 22. *Estimates of stock, yield and recruits for 1934 to 1973 for Kerala-Karnataka belt*

Year	Y_W in tonnes	P_W in tonnes (Y/F)	P_W in tonnes (Y/E)	MSY in tonnes R_Cx (MSY/R)	R_c (10^6 Nos.) (Y % Y_W/R)	P_N (10^6 Nos.) (R_C x P_N/R)	Y_N (10^6 Nos.) R_c x Y_N/R)
1934	21,689	6,591.40	33,178.83	30,392.26	699.96	85.05	279.84
1935	33,058	12,595.44	52,035.26	37,473.72	912.88	147.98	388.25
1936	81,111	66,137.48	142,625.29	65,733.09	1364.04	641.10	786.23
1937	36,540	11,634.35	40,074.58	35,715.03	353.02	92.24	289.76
1938	7,644	4,116.76	12,778.33	6,813.10	178.40	42.78	83.71
1939	17,732	12,454.87	30,409.88	16,789.72	336.94	125.78	179.08
1940	42,107	13,768.56	65,040.16	53,605.93	1256.88	167.42	511.80
1941	29,896	12,588.85	47,058.08	30,154.54	760.71	144.46	343.08
1948-49	29,509	11,676.56	52,237.56	32,571.53	800.48	136.00	343.73
1949-50	89,163	25,023.29	136,230.71	92,119.12	2933.73	314.79	1122.15
1950-51	67,033	33,446.26	109,174.27	61,207.79	1591.88	1282.74	2570.89
1951-52	107,999	28,452.24	172,810.05	147,126.33	4309.50	367.17	1394.55
1954	41,962	34,146.76	73,643.38	33,902.05	703.80	331.00	406.73
1955	22,637	18,307.32	43,810.72	25,371.07	496.11	183.66	227.07
1956	12,163	19,665.32	27,586.75	11,933.16	132.96	183.88	113.73
1957	81,941	31,429.94	128,655.99	64,022.72	4566.88	343.62	895.63
1958	120,841	28,530.52	181,770.46	146,128.04	4404.10	372.59	1577.99
1959	54,821	33,307.23	85,856.64	48,514.95	980.10	343.13	556.50
1960	117,386	56,085.04	529,481.28	251,462.28	17,306.42	1349.90	2824.41
1961	27,320	16,833.02	45,846.62	29,127.08	567.89	175.88	285.40
1963	68,049	20,507.80	104,018.65	91,896.62	2111.11	253.54	841.49
1969	43,234	73,803.35	143,586.85	72,383.96	1394.95	882.72	517.11
1970	100,996	42,670.16	113,226.35	116,223.14	1086.41	441.95	1046.21
1971	159,211	47,544.12	243,033.12	216,127.50	4954.78	588.63	1971.51
1972	66,765	70,598.50	122,213.07	65,817.39	836.52	632.99	598.61
1973	55,248	73,185.85	105,394.89	55,872.00	479.30	610.01	460.51
Mean	59,048	30,965.50	109,299.15	70,787.85	2135.38	393.89	792.93

noticed between the average E of 0.68 with the E_{msy} of 0.72, indicating thereby that, overall, during the span of 40 years from 1934 to 1973, the mackerel fishery remained generally at its optimum level.

maximum recruitment of 4.13 × 10^9 fish at t_c = 0.5 year indicated by the Ricker model for the period 1934-1973 matches well with the direct estimate of stock comprising essentially the recruits. However, during 1973

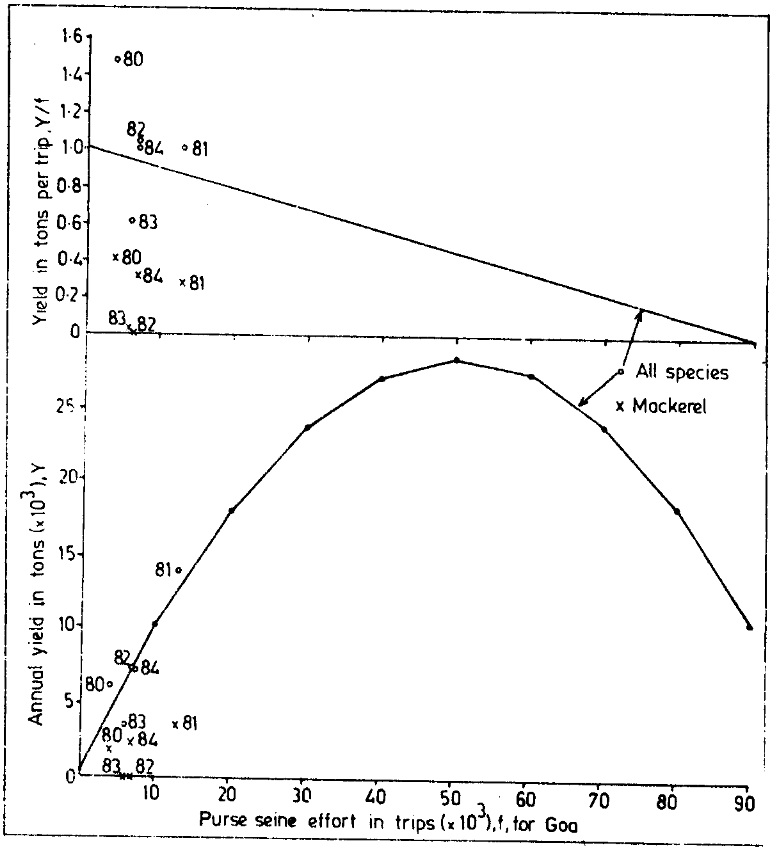

FIG. 24 Catch per trip (A) and catch (B) as functions of purse seine effort in trips in respect of all species and mackerel for Goa.

The direct estimate of the stock during the period 24th September to 1st October 1973 when mackerel schools concentrated in a narrow belt along the southwest coast was about 400,000 t comprising 5.5 × 10^9 fish (UNDP/FAO, 1974), the average weight being 81.8 g corresponding to 20.4 cm and 8 months which is slightly older than the age at first capture of 6 months. The estimate of 89 g as the mean weight of the fish in the population by the analytical model agrees very well with the observed value of 81.8 g for 1973. The the mean size of the population in the entire stock area was found to be 1.552 × 10^9 fish comprising 0.592 × 10^9 0+, 0.551 × 10^9 $\frac{1}{2}$+, 0.306 × 10^9 1+ and 0.103 × 10^9 $1\frac{1}{2}$.

Surplus production models

On the basis of the data for 1956-1984 the maximum sustainable yield (MSY) for the inshore fisheries along the southwest coast of India including the States of Kerala, Karnataka, Goa and Maharashtra is estimated

TABLE 23. *Yield equations for total landings and purse seine landings*

State		For total landings (tonnes) and total fishing effort (x 1000 manhours)	For purse seine landings (tonnes) and effort (trips)	
			All species	Mackerel
Kerala	Schaefer	: y/f = 11.14-0.00008584 f	y/f = 5.4336-0.0004 f	y/f = 1.2342-0.0001 f
	Fox	: y/f = exp (2.69-0.00001628 f)	y/f = exp (2.1787-0.0002 f)	y/f = exp (0.4908-0.00028 f)
Karnataka	Schaefer	: y/f = 14.5347-0.0004797 f	y/f = 3.1325-0.000024 f	y/f = 0.8734-0.0000104 f
	Fox	: y/f = exp (2.5469-0.00003753 f)	y/f = exp (1.1017 - 0.0000102 f)	y/f = exp (-0.0091-0.000031 f)
Goa	Schaefer	: y/f = 14.2292-0.0015 f	y/f = 1.1298 - 0.000011 f	—
	Fox	: y/f = exp (2.69-0.0001556 f)	y/f = exp (-0.0127-0.00000089 f)	—
Maharashtra	Schaefer	: y/f = 9.5002 - 0.00008318 f	—	—
	Fox	: y/f = exp (2.3213-0.00001365 f)	—	—

TABLE 24. *Estimates of MSY and f_{msy} for inshore marine fisheries in different States along the southwest of India, together with estimates of MSY for the Indian mackerel based on its proportion to total catch during 1956-1984*

State	Average annual yield (t)	Average annual effort in manhours (x 1000)	Schaefer model		Fox model		Mackerel in total catch		MSY of mackerel (t) within total MSY	
			MSY (t)	f_{msy} in (x 1000)	MSY (t)	f_{msy} in (x 1000)	(t)	(%)	Schaefer	Fox
Kerala	324,625	54,559	361,352	64,883	333,066	61,433	23,857	7.35	26,559	24,480
Karnataka	89,170	9,785	110,092	15,149	125,157	26,647	25,484	28.58	31,464	35,770
Goa	29,015	3,754	33,400	4,695	34,702	6,425	9,361	32.26	10,774	11,195
Maharashtra	202,488	30,550	271,256	57,105	274,681	73,282	3,496	1.73	4,693	4,752
Total	645,298	98,648	776,100	141,832	767,606	167,787	62,198	9.64	73,490 (74,816)	76,197 (73,997)

to be 776,100 t for an effort of 141.8 million manhours according to the Schaefer (1954) model and 767,606 t for 167.8 million manhours according to the Fox (1970) model (Tables 23 and 24; Figs. 18 to 21). Considering that the percentage of mackerel in the inshore fish catch is 9.6% for 1956-1984, the MSY of mackerel in the total MSY is found to be 73,490 t according to the Schaefer model and 76,197 t according to the Fox model (Table 24). These estimates of MSY for mackerel agree very well with the mean MSY estimated from the analytical model (70,788 t; Table 22). The average annual yield of 62,198 t during 1956-1984 indicates that there is only marginal scope for increasing the yield to the MSY of 73,490 t. The total MSY of 73,490 t for the southwest coast comprises 26,559, 31,464, 10,774 and 4,693 t for Kerala, Karnataka, Goa and Maharashtra respectively while the average annual yield of 62,198 t for the southwest coast includes 23,857 t, 25,484 t, 9,361 t and 3,496 t for the four States in the above order.

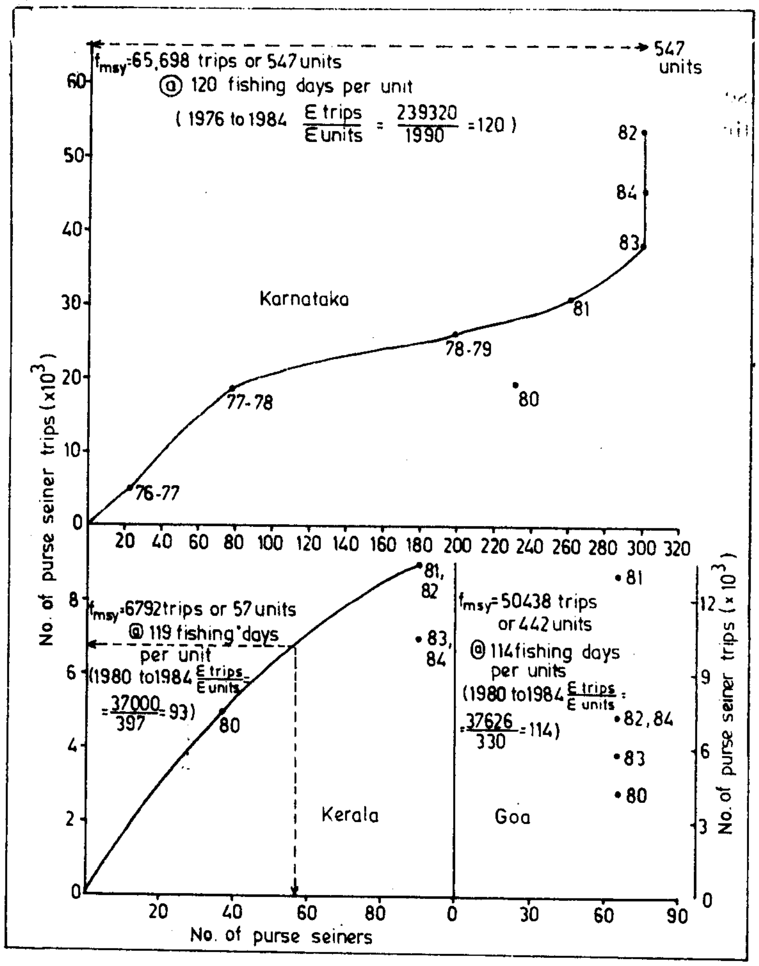

FIG. 25. Graphic estimation of optimum number of purse seiners for Kerala, Karnataka and Goa.

The application of the Schaefer model to the purse seine fishery along the southwest coast indicates that for Kerala the MSY. (all species) for this fishery is 18,453 t for an effort of 6,792 purse seiner days equivalent to 57 purse seiners operating at the rate of 119 fishing days per year; for Karnataka 102,900 t for an effort of 65,698 purse seiner days equivalent to 547 purse seiners at the rate of 120 fishing days per year; and for Goa, 28,441 t for an effort of 50,437 purse seinar days equivalent to 442 units operating at the rate of 114 fishing days per year (Figs. 22 to 25; Table 25). The above estimates of optimum effort based on limited observations appear very unrealistic as the effort has stabilized at the present level of about 500 purse seiners comprising 90 in Kerala, 300 in Karnataka, 66 in Goa and 40 in Southern Maharashtra owing to the poor returns on investment. Therefore, in the context of the artisanal and purse seiner fleets exploiting the common small pelagic resources in the same inshore grounds, the purse seine fishery has no prospect of expansion any further. According to Haywood (1982) the optimum number of purse seiners for Karnataka is 230 while according to Devaraj (1979) it is 275 in the absence of any major artisanal fishing, such as beach seining which has been almost totally replaced by purse seining.

Discussion

For the purpose of determination of age and growth, the modes in the length frequency data for different gears (selective and nonselective) were treated together in the same figures (with different symbols) of scatter diagram of length modes for successive months in order to bring out the differences in the position and alignment of length modes, if any, between the two gear types. In all such combined treatment, no discernible difference was noticed between the selective and nonselective gear types. Therefore, treatment of length modes for the two gear types together in the same figures seems necessary and important, particularly in situations of multigear; multilocational fisheries for the same species in its stock area, to take advantage of the available data. Selective gears like the gillnets employed in the Indian mackerel fishery along the southwest coast of India are effective over the entire commercial size groups (> 120 mm), and hence, the length modes for these commercial size groups together with those for the nonselective gears, rendered tracing the growth for the entire length range, much easier.

As the growth estimates of mackerel pertain to over five decades from 1934 to 1984 from material collected from and pooled on annual basis for as many as seven centres within the stock area, a certain degree of spatial and annual variations in growth was very likely, as observed in this study, evidently due to such variations in the biotic and abiotic factors. Despite these variations, the mackerel stock along the southwest coast of India is considered here as a unit stock, primarily because of the continuity in the distribution of the population within the stock area (between Ratnagiri in the north to Vizhinjam in the south). Therefore, it has been considered more appropriate to use the average values of age-length key to delineate the length frequency into age groups for the estimation of total mortality rates (Z) and the average values of growth parameters (L_∞ and k) for stock assessment and yield estimation than the maximum values.

Total mortality was estimated according to gear types, years and centres in order to bring out the magnitude of differences between gear types, between years and between centres. However, as in the case of growth parameters, Z for individual years for the enitre stock area was computed by averaging the values for the different centres. The lack of good fit between annual yield (Y) and Z, prompted independent estimation of M for individual years. Because of annual variations of M, cohort analysis, stock assessment and yield estimation were performed for individual years.

In multigear, multilocational, tropical, small pelagic fisheries like the Indian mackerel, large variations in fishing effort and ecological conditions occur and bring about considerable variations in population parameters. Although the present study is based on conventional models, some of the approaches followed here for the estimation of various parameters (*e.g. M*) emerged in the course of the analysis of the data and necessitated by the peculiarities of the fishery. For example, in the attempt to establish the relationship between *M* and *Y*, it became necessary to seek the possible oceanographic cause for the annual fluctuations in *M*. Inspite of the poor fit between *M* and sea surface pressure (*p*) there is a pointer suggesting *p* to be atleast partly responsible for the fluctuations in *M*. This relationship is presented here more with the purpose of initiating further studies for the establishment of the precise relationship between various oceanographic parameters and *M* to elucidate the most likely cause or causes for the variations in *M*.

TABLE 25. *Estimates of MSY (t) and f_{msy} (trips) for the purse seine fishery in Kerala, Karnataka, Goa and Maharashtra, for 1977-84*

State (Year)		Yield	Effort in trips	Schaefer model		Fox model	
				MSY	f_{msy}	MSY	f_{msy}
Kerala	All species	16,144	7,400	18,453	6,792	16,251	6,171
(1980-84)	Mackerel	2,878	do	3,808	6,171	3,005	5,000
Karnataka	All species	67,046	29,915	102,900	65,698	108,058	97,609
(1977-84)	Mackerel	14,509	do	18,337	41,990	11,823	32,433
Goa	All species	7,766	7,525	28,441	50,437	—	—
(1980-84)	Mackerel	1,542	do	—	—	—	—
Maharashtra	All species	295	132	—	—	—	—
(1983-84)	Mackerel	84	do	—	—	—	—

Variations in *M* need not necessarily render the production models invalid, although these models assume constant values of *M*. In the case of the analytical model this difficulty could be offset by estimation of stock or yield for the individual years as followed in this study. As the surplus production model fits the relation directly between yield and effort (equivalent of *F*), the influence of *M* on this model is indirect through its influence on the stock and hence the estimates of yield from the fitted model should be valid and realistic. In as much as the *F* component of *Z* varies as a function of fishing effort, it will be illogical to follow the path of constant value of *M* (assumed by the analytical model), which after all could vary in as much as the underlying causes might themselves vary.

It will be fundamentally wrong if the dynamics and problems of the mackerel fishery are perceived from a purely conservative, numerical point of view and to insist on the application of purely conventional principles underlying the production models for the solution to the problems such as those posed by the variations in the population parameters of critical importance to stock assessment and yield estimate. Therefore this study should be seen as a bold attempt to consolidate the excellent basic data on the Indian mackerel fishery built up over a period of five decades, to work on it to highlight the dynamics of the stock and the fishery, and to formulate a basis for the long term management and sustenance of the fishery.

TABLE 26. *Number of purse seiners (units), their effort in trips (boatdays) and catch per trips (all species) for Kerala, Karnataka and Goa*

Year	Kerala			Karnataka			Goa			Maharashtra		
	Units	Trips	Catch/trip	Units	Trips	Catch/trip	Units	Trips	Catch/trip	Units	Trips	Catch/trip
1977	—	—	—	23	5000	2.000	40	NA	NA	—	—	—
1978	—	—	—	79	19000	1.576	50	NA	NA	—	—	—
1979	—	—	—	198	26000	4.151	50	NA	NA	—	—	—
1980	37	5000	3.296	230	19540	3.896	66	4184	1.486	—	—	—
1981	90	9000	1.966	260	31120	3.068	66	12977	1.088	—	—	—
1982	90	9000	1.277	330	54580	1.565	66	7333	1.038	—	—	—
1983	90	7000	2.039	300	38760	1.369	66	582	0.613	1	78	0.640
1984	90	7000	2.971	300	45320	1.731	66	7311	1.002	2	186	2.900

TABLE 27. *Proportion of purse-seiner effort to total effort in Kerala, Karnataka, Goa and Maharashtra*

Year	Total effort in manhours (x10^3)				Purse seiner effort in manhours (x10^3) (1 trip = 90 manhours) (9 crew x 10 hours)				% of purse seiner effort to total effort			
	Kerala	Karnatak	Goa	Maharashtra	Kerala	Karnataka	Goa	Mahrashtra	Kerala	Karnataka	Goa	Maharashtra
1977	36573	10559	2440	44810	—	450	—	—	—	4.26	—	—
1978	80221	13002	3120	36351	—	1710	—	—	—	13.15	—	—
1979	62485	16704	3120	44810	—	2340	—	—	—	14.01	—	—
1980	42821	7824	2440	27451	450	1759	377	—	1.05	22.28	15.45	—
1981	42891	13002	5544	31761	810	2801	1168	—	1.89	21.54	21.07	—
1982	56921	18758	5349	44810	810	4912	660	—	1.42	26.19	12.34	—
1983	59893	17186	5305	34528	630	3488	524	7	1.05	20.30	9.88	0.02
1984	54124	16704	6306	36351	630	4079	657	17	1.16	24.42	10.42	0.05

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