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Stock assessment of oil sardine, *Sardinella longiceps* Val., off west coast of India

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ABSTRACT

The oil sardine contributes nearly 15% of the total annual marine fish landings of the country and forms the most important pelagic fishery resource. A brief account of the fishery, biology and stock position of the oil sardine based on the data collected from several centres along the west coast of India during 1984–88 is given. The growth parameters were estimated by employing the ELEFAN-I method and the values obtained for L_∞ and K were 221 mm and 0.75 respectively. The instantaneous total mortality rate (Z) was estimated as 2.23 and the instantaneous natural mortality rate (M) as 1.30. The maximum sustainable yield (MSY) was estimated as 150 000 tonnes against a mean biomass of 107 000 tonnes.

The oil sardine, *Sardinella longiceps* Val., is a major neretic pelagic fishery resource of the country. It has a wide distribution along the coasts of Seychelles, Somalia, Africa, Pakistan, India, Indonesia and Philippines. Along the Indian peninsula, the resource has been predominant along the southwest coast between 8° N and 16° N latitudes covering Kerala, Karnataka, Goa and southern part of Maharashtra. Of late, its emergence as a new fishery along the east coast has been reported by Luther (1988). The oil sardine fishery is known for its highly erratic and fluctuating nature and exhibits both short-term and long-term annual fluctuations. Detailed studies on the fishery, biology and probable reasons for the fluctuations in the fishery, have been carried out by Nair (1952), Sekharan (1965), Radhakrishnan (1965), Murty and Edelman (1966), Sekharan and Dhulkhed (1968), Bensam (1968), Antony Raja (1972, 73), Balan (1971, 1984), Banerji (1973), Annigeri (1987), James (1981) and James *et al.* (1987). Longhurst and Wooster (1990) have made a detailed study on the short-term and long-term abundance of oil sardine in relation to the oceanographic and meteorological conditions and the upwelling on the southwest coast of India.

Stock assessment studies are, no doubt,

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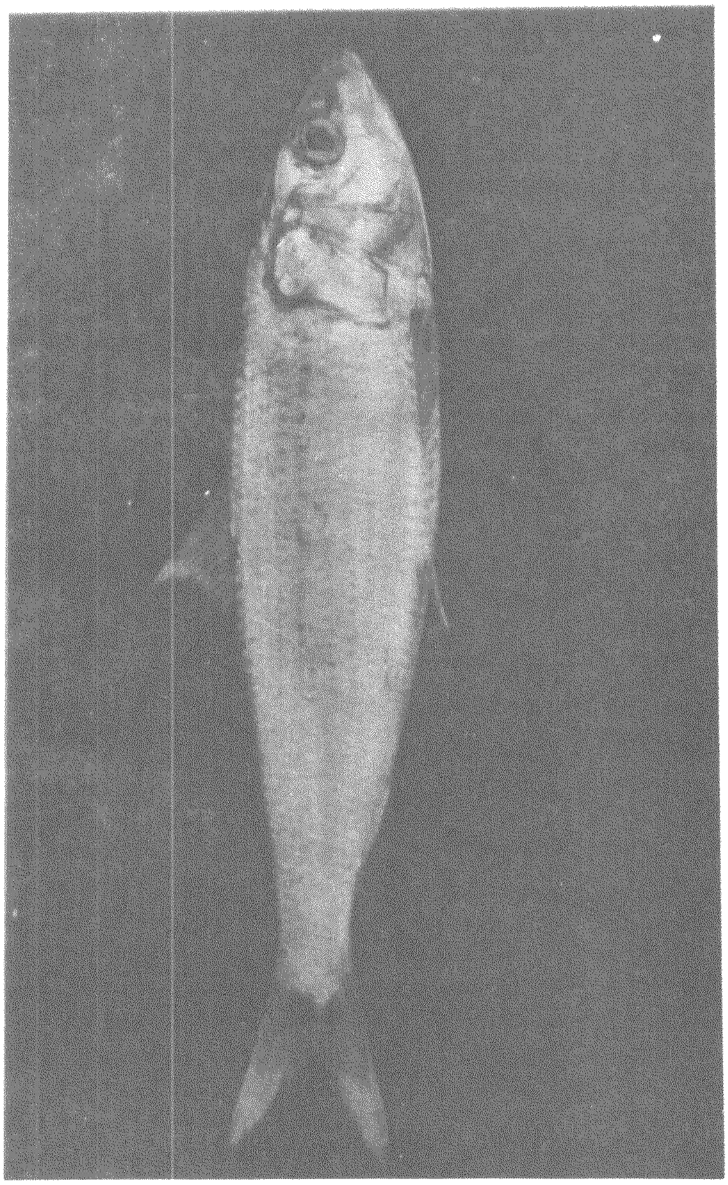

Sardinella longiceps

the essential means for deciding guidelines for rational exploitation and management. Assessment of oil sardine stock was made earlier by many workers (Banerji 1973, Sekharan 1974, Balan *et al.* 1979, Kurup *et al.* 1987). The present study is appropriate in the context of recent changes in the method of fishing introduced and becoming popular in this part of the country.

MATERIALS AND METHODS

Weekly data on catch and effort were collected from important landing centres on the west coast viz., Panaji, Karwar, Mangalore, Calicut, Cochin and Vizhinjam, covering the region between 8° N and 16° N latitudes. Random samples of oil sardine were brought to the laboratory and its total length, wet weight, sex ratio, maturity, fecundity, etc., were studied. The length frequencies were arranged at the interval of 5 mm in total length, raised to the day's landings, then raised to the month and summed up for the year. The estimates of landings of oil sardine for the west coast were made available by NMLRDC, CMFRI. During this period, purse seine was most prominent gear in Cochin, Mangalore, Karwar and Goa whereas boat seine was prominent in Calicut and Vizhinjam for oil sardine fishery. A few other gears of minor importance contributed low catch. The data on length frequencies were raised to the total catch by the purse seine and boat seines at purse seine and boat seine centres respectively.

From the length composition data, the estimates of growth parameters, mortality rates and other stock parameters were derived. Along the east coast, the resource is only now emerging as a fishery. In this study, emphasis has been laid on the observations made along the west coast during 1984–88.

Measurements on length and weight were taken on 499 specimens representing the possible range of length distribution. Total length was measured to the nearest mm and weight to the nearest g.

Growth was described by von Bertalanffy growth function where the parameters L_∞ and K were estimated by ELEFAN I programme (Pauly and David 1981).

The instantaneous natural mortality coefficient M was estimated using the empirical relationship (Pauly 1980) given by $\log_{10}M = 0.0066 - 0.279 \log_{10}L_\infty + 0.6543 \log_{10}K + 0.4634 \log_{10}T$, where L_∞ and K are parameters of von Bertalanffy growth function and T is the annual mean temperature. The estimate so obtained is adjusted for shoaling behaviour of the fish (Pauly 1980).

Fishing mortality coefficient F and stock size were estimated by length converted cohort analysis (Jones 1984, Sparre 1985).

Yield (catch in weight) and biomass were predicted for varying levels of fishing effort following length converted Thompson and Bell analysis (Sparre 1985, 1987). The outputs of length converted cohort analysis, namely, the recruitment and fishing mortalities at length groups, formed inputs for Thompson and Bell (1934) long-term forecast. Using surplus production model (Schaefer 1954), maximum sustainable yield and corresponding effort level were also estimated.

RESULTS

Fishery

An examination of the oil sardine fishery during the 10 years (1979–88) showed that the landings ranged from about 78 700 tonnes (1986) to 221 000 tonnes (1981) and at an average annual landings of 145 000 tonnes it contributed to about 10% of the total marine fish catch of India (Fig. 1). The average catch of oil sardine for the first five-year period (1979–83) was about 176 000 tonnes and for

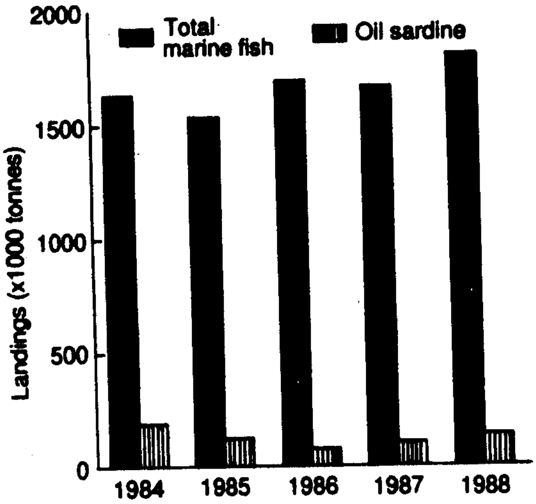

Fig. 1. Oil sardine production and total marine fish landings in India during 1984-88.

Table 1. Average catch of oil sardine in southwest coast (Goa, Karnataka and Kerala) during 1984-1988

States/gears	Catch (tonnes)
Goa	
Purse seine	32 441
Karnataka	
Purse seine	176 753
Kerala	
Purse seine	27 909
Boat seine (outboard engine)	122 939
Boat seine (non-mechanised)	23 165
Ring seine	46 312

In Goa and Karnataka traditional gears have become ineffective.

the second five-year period (1984–88) 124 000 tonnes. For the present study on population dynamics, data collected during the second five-year period were used.

In the west coast of India, Goa, Karnataka and Kerala recorded the maximum catch (96.5%) of oil sardine (Fig. 2). Tamil Nadu and Andhra Pradesh along the east coast contributed to the remaining (3.5%) catch. The purse seine was the dominant gear used for sardine fishery off Goa and Karnataka whereas in Kerala, boat seine, purse seine and ring seine were used. Oil sardine in Maharashtra forms insignificant catch and is available in small percentage along the southern part of Maharashtra covering the latitude between 15° and 16°. Along the east coast the oil sardine is an emerging resource. The main gear used in Tamil Nadu was *edavala* (boat seine). In Andhra Pradesh, boat seine, shore seine and gill net were used for catching sardine shoals. Table 1 gives the average statewise landings by major gears for 1984–88.

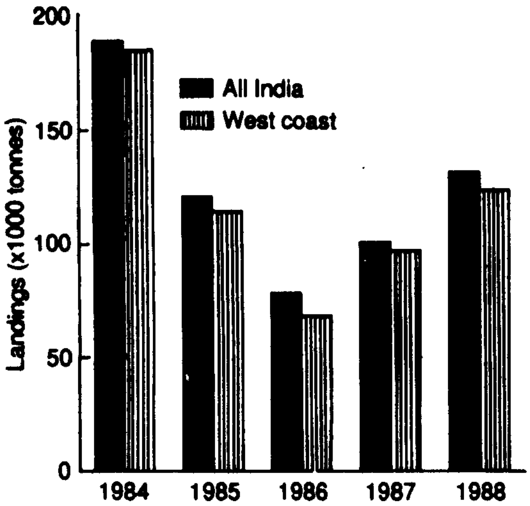

Fig. 2. Oil sardine production in the west coast against all-India oil sardine landings during 1984-88.

Biology

The biology of oil sardine has been studied in detail. The commercial fishery is mainly sustained by the 0 and 1 + year classes. The oil sardine attains maturity at a total length of 150 mm (Hornell and Nayadu 1924, Chidambaram and Venkataraman 1946) and the average fecundity values range from 37 000 to 80 000 (Balan 1984). For sex ratio studies,

Table 2. Sex-ratio of oil sardine during 1984-88

State	Sex ratio (M:F)
Goa	1:1.13
Karnataka	1:1.08
Kerala	1:1.07
Tamil Nadu	1:1.03
Andhra Pradesh	1:1.60
Southwest coast	1:1.08
East coast	1:1.45
All-India	1:1.11

a total of 13 927 specimens, 12 659 from the west coast and 1 268 from the east coast, were examined. The females, in general, were dominant in numbers in the landings of all the states, more prominently along the east coast (Table 2).

The statewise percentage contribution of different stages of gonad maturity is given in Table 3. The results are based on the study conducted on 12 183 mature fishes. Resting stage (II b) fishes contributed 38% and were the most dominant group on all-India basis. This feature was same on both east and west coasts. The groups next in dominance were developing stage (26.35%), partially spent stage (21.45%), gravids (9.14%) and fully spent stage (5%), considering the all-India data.

Stock assessment

Length-weight relation is described by the function:

$$W = 0.00000347194 \times L^{3.163582} \text{ (g, mm)}$$

The parameters L_∞ and K in von Bertalanffy growth function were estimated as L_∞ = 221 mm and K = 0.75 per year

The above estimates of growth parameters were obtained from length frequency analysis using ELEFAN I programme and the growth curve so obtained is shown in Fig. 3. Attempts were made to estimate the parameters by other methods as well, for example, by modal progression analysis resolving the multimodal length frequency distribution to unimodal components (Bhattacharya 1967) and as per Wetherall *et al.* (1987). The Bhattacharya (1967) method led to high values of L_∞ (231 mm) and K (1.52) whereas Wetherall *et al.*(1987) method gave lower values (L_∞ = 225 mm and K = 0.73).

The estimates of length-at-age as obtained by various authors are given in Table 4 for comparison.

M, the instantaneous rate of natural mortality, was estimated by using Pauly's empirical relationship as M = 1.30. It was also

Table 3. Percentage distribution of different maturity stages of oil sardine in different states and east and west coasts of India (1984-88)

State	Stage					
	IIb (Resting)	III-IV (Developing)	V-VI (Gravid)	VII a (Partially spent)	VII b (Fully spent)	Total number
Goa	65.07	18.96	6.28	5.05	4.64	733
Karnataka	29.73	32.56	8.17	26.11	3.43	7 502
Kerala	47.60	14.97	9.00	19.13	9.30	2 645
Tamil Nadu	43.54	43.54	8.12	—	4.80	209
Andhra Pradesh	52.74	12.89	18.28	10.24	5.85	1 094
Southwest coast	36.45	27.37	8.24	23.00	4.94	10 880
East coast	51.27	17.80	16.65	8.60	5.68	1 303
Total	38.04	26.35	9.14	21.45	5.02	12 183

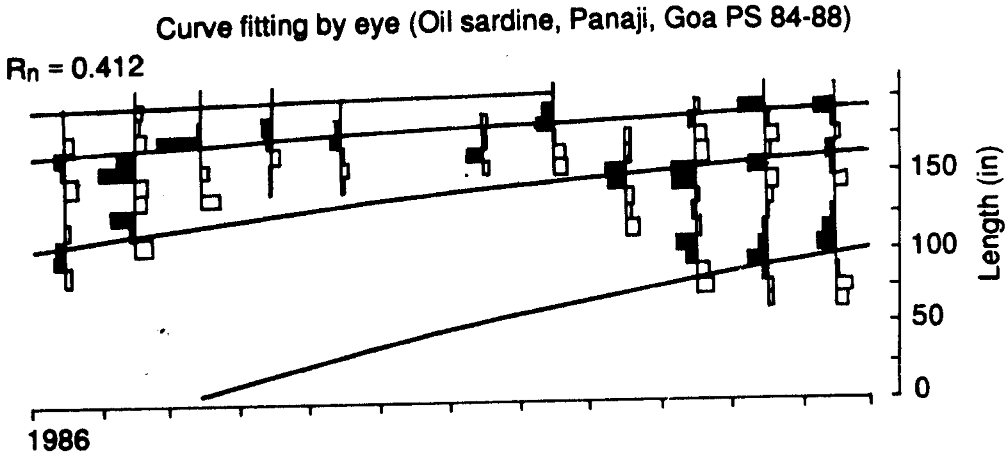

Fig. 3. Growth curve of oil sardine *Sardinella longiceps* using ELEFAN I method at Goa during 1984-88.

found to coincide with estimate of M, obtained following Rikhter and Efanov (1976) for a size at maturity of 140 mm.

F, the instantaneous rate of fishing mortality, was estimated from length cohort analysis (Table 5) against a size at capture of 140 mm which is the size at which fish seems to be fully vulnerable for exploitation and thus F = 0.93. Instantaneous rate of total mortality Z was obtained as

$$Z = M + F = 1.30 + 0.93 = 2.23.$$

This value agreed fully with the one estimated by Beverton and Holt (1957) method. Taking Z as 2.2 and F as 0.9 the current exploitation rate (E = F/Z) was 0.41.

The length cohort analysis also showed that differential mortality was taking place at higher size levels. Table 5 shows that fishing mortality is maximum in the size 150–160 mm and then in 190–200 mm indicating thereby a greater vulnerability of these sizes to the fishery, probably associated with the breeding dynamics of this species.

The length converted cohort analysis gave an estimate of 2.596 × 10^7 numbers for the recruitment to fishery assuming the size at recruitment as 65 mm. Long-term forecast by Thompson and Bell model estimated the

Table 4. Estimates of length-at-age of *Sardinella longiceps* obtained by various authors

Length (cm) at age				Authors	Remarks
1yr	2yr	3yr	4yr		
15.0	16.0	—	—	Hornel & Nayudu (1924)	Estimated 12.5-14.0 cm growth in 6 months and suggested T_{max} of 2.5 years
10.0	14.5	18.3	20.5	Chidambaram (1950)	T_{max} 4 years
10.0	15.0	19.0	—	Nair (1949, 1952)	
13.0	16.0	17.5	—	Balan (1968)	Based on length frequency data
15.0	17.8	—	—	Antony Raja (1969)	18.5 cm in 2.5 years
12.5	17.1	18.8	19.4	Kurup *et al.* (1987)	L_∞ = 197.2 cm, K = 1.006 (annual)
11.7	17.2	19.8	21.0	Present study	L_∞ = 221 cm, K = 0.75 (annual), t_0 = 0

? more than two meters!

Table 5. Catch, stock size, exploitation rate (F/Z) and fishing mortality (F) of *Sardinella longiceps* during 1984-88 along the west coast

Size interval (mm)	C	N	F/Z	F
20.00-30.00	0.00	38 142 918.55	0.0000	0.0000
30 00-40.00	0.000	34 913 918.27	0.0000	0.0000
40.00-50.00	0.000	31 806 578.29	0.0000	0.0000
50.00-60.00	10.184	28 822 656.93	0.0000	0.0000
60.00-70.00	51 681.289	25 964 030.53	0.0186	0.0246
70.00-80.00	175 104.500	23 183 863.36	0.0634	0.0880
80.00-90.00	108 596.102	20 422 583.59	0.0426	0.0579
90.00-100.00	248 337.797	17 875 825.24	0.0981	0.1415
100.00-110.00	364 197.813	15 345 417.26	0.1475	0.2249
110.00-120.00	346 633.813	12 876 328.12	0.1532	0.2351
120.00-130.00	337 862.094	10 613 177.11	0.1637	0.2545
130.00-140.00	592 951.688	8 549 824.00	0.2826	0.5121
140.00-150.00	839 410.688	6 451 522.50	0.4063	0.8895
150.00-160.00	822 872.625	4 385 338.50	0.4740	1.1715
160.00-170.00	381 190.813	2 649 322.75	0.3689	0.7600
170.00-180.00	238 411.500	1 616 057.00	0.3375	0.6623
180.00-190.00	223 845.394	909 709.13	0.4263	0.9661
190.00-200.00	135 214.406	384 644.25	0.4739	1.1712
200.00-210.00	38 542.898	99 350.91	0.4332	0.9937
210.00 plus	4 679.856	10 392.59	0.4507	1.0668

C, Catch in thousand numbers; N, stock size in thousand numbers.

Table 6. Thompson and Bell long-term forecast on yield and biomass for *Sardinella longiceps* during 1984-88

X	Yield	Mean biomass
0.0000	0.00	365 536.90
0.2000	43 316.53	313 451.53
0.4000	72 305.21	275 410.31
0.6000	92 454.97	246 496.56
0.8000	106 872.29	223 820.50
1.0000	117419.36	205 582.12
1.2000	125 265.43	190 605.76
1.4000	131 173.93	178 093.59
1.6000	135 660.00	167 486.03
1.8000	139 081.06	158 379.40
2.0000	141 691.31	150 475.48

MSY, 148 007.8; X, 4.015625; Biomass MSY, 105 176.9

maximum sustainable yield (MSY) of 148 007 tonnes against a mean biomass of 107 000 tonnes at a fishing mortality equivalent to 4 times the current one (Table 6). The MSY estimated by the Schaefer (1954) model was 134 000 tonnes.

Table 7 gives catch per unit effort in three states and total catch and CPUE of purse seine units. A weighted average of these was worked out weighing these rates by the corresponding effective effort (proportional to the landings of oil sardine) in terms of number of purse seine operations.

Table 7. Catch (tonnes), effort (No. of operations) and CPUE (tonnes) of oil sardine during 1984-88

	Kerala		Karnataka		Goa		Total		CPUE
Year	Effort	CPUE	Effort	CPUE	Effort	CPUE	Effort	Catch	(weighted)
1984	7 127	2.3000	45 320	0.7756	7 311	0.1397	59 758	63 905	1.0694
1985	4 707	2.3374	40 015	0.7561	9 721	0.4185	54 443	55 744	1.0239
1986	2 553	0.1273	41 451	0.6245	8 622	0.0616	52 626	30 139	0.5727
1987	2 313	0.0471	41 897	0.9968	28 305	0.3363	72 515	53 168	0.7332
1988	571	0.1419	53 362	0.7970	24 548	0.6782	78 481	59 967	0.7641

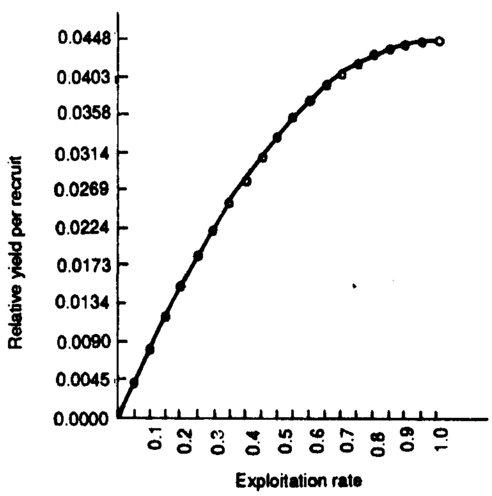

Fig. 4. Yield per recruit of oil sardine (optima - E_{max} = 1.000, E at 0.1 = 0.917, E at 0.5 = 0.404 for L_c/L_∞ = 0.63, M/K = 1.73).

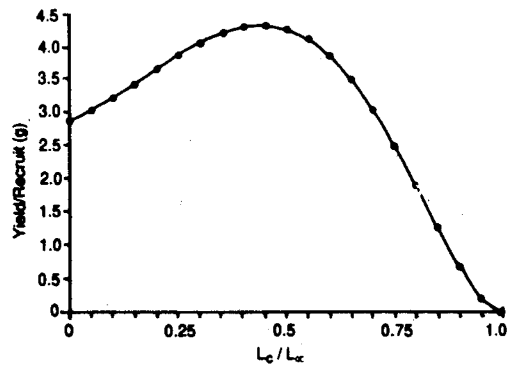

Fig. 5. Yield per recruit of oil sardine at 1984-88 exploitation level along the west coast.

The relative yield per recruit was maximum when the exploitation rate (F/Z) was 1 (Fig. 4). This indicates that F should be very high compared to M so that the ratio F/Z tends to be 1. Fig. 5 shows that the yield per recruit is maximum when L_c/L_∞ = 0.45 which would suggest that length at first capture should be around 100 mm.

DISCUSSION

Oil sardine fishery on the west coast shows wide fluctuations over the years but continues to be commercially an important resource. Fishery generally starts in June–July and continues till March–April.

The stock assessment of typical tropical pelagic resource like oil sardine is beset with problems of accurate determination of growth parameters. The growth curve as obtained by ELEFAN I programme is shown in Fig. 3. Sekharan (1965) and Prabhu and Dhulkhed (1967) were of the opinion that oil sardine measuring 10 cm is one year old and that between 10 cm and 15 cm is of the second year. Antony Raja (1972) stated that fish attains 6–9.5 cm, 9.5–11 cm, 11–12.5 cm and 12.5–14 cm at the end of one, two, three and four months respectively. According to him, the mean length of 18.5 cm is attained on completion of two and half years. Thus, there is no definite conclusion on the age structure of this species.

Antony Raja (1972) and Banerji (1973) estimated the growth parameters as follows:

	L_∞ (mm)	K (annual)	t_0 (annual)
Antony Raja (1972)	209.8	0.60	1.12
Banerji (1973)	207.0	0.53	1.33

Kurup *et al.* (1987) estimated the parameters L_∞ and K (annual) as 197 mm and 1.006. In the present study, three estimates of L_∞ were obtained. Modal progression method, modes being identified following Bhattacharya (1967), gave an estimate of 231 mm. Following Wetherall *et al.* (1987), L_∞ was estimated as 225 mm. ELEFAN I programme yielded an estimate of 221 mm. Since fundamental assumption on the growth pattern being the same, these methods should have resulted in identical estimates but for the subjectivity and the sampling error. Thus we have estimates ranging between 197 mm and 231 mm and in all the cases the size ranges used to differ very much. Hence comparing all the estimates available the one provided by ELEFAN I programme looks reasonably an acceptable estimate.

Often the lack of reliable estimate of M, the instantaneous rate of natural mortality, is a serious handicap in stock assessment studies of tropical fish species. Pauly's empirical relation between growth parameters and ambient temperature is observed to be popularly attempted in recent times to estimate M.

In the present study the estimates of M obtained by Rikhter and Efanov method (1.33) and Beverton and Holt method (1.30) also almost coincided with the one obtained by Pauly's empirical relation (1.30).

Comparing the estimates of M obtained as above, a value of 1.3 was chosen for further analysis.

The estimates of Z were also obtained by other methods as cumulative catch curve method (Jones and van Zalinge 1981), Beverton and Holt (1957) method and length converted catch curve method. The estimates from these methods were, 2.22, 2.23 and 2.21 respectively. These estimates differed insignificantly among themselves and hence the choice of 2.23 as estimate of Z was justifiable. This, inter alia justified also the choice of M as 1.3.

The present yield and MSY showed that there is scope for increasing the production by 26% against a four-fold increase in terms of fishing effort without affecting the sustainability of the stock but this reduces the catch per unit operation by 49% and possibly making it uneconomical. But if the effort is nearly doubled, then the increase expected in the landings is 21% against a reduction in CPUE by 27%. Hence it is evident that increasing the fishing effort to the MSY level is not desirable in the present fishery. However, this wide difference in the effort required to raise the production to MSY level and the current effort warrants further investigation. It may be that the model is deficient in absorbing the characteristics of the fishery. From the above account it would appear that an increase in fishing pressure on the stock could result in increased landings to the maximum sustainable level. Increasing the total number of fishing units from the current level to achieve this objective does not, however, seem to be a viable proposition since such a step would decrease considerably the returns per boat to an uneconomic level. Redeployment of the existing fishing units more effectively to exploit the oil sardine resource during its peak fishing season would seem to be more viable proposition to achieve the desired objective of increased production at the maximum sustainable level from the present level of the oil sardine stock.

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