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STOCK ASSESSMENT OF MIGRATORY FISH SPECIES BASED ON LOCALIZED DATA - OCEANIC SKIPJACK TUNA POLE AND LINE FISHERY AT MINICOY AS A CASE STUDY

by

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ABSTRACT

The highly migratory nature of the skipjack tuna (Katsuwonus pelamis) coupled with inadequacy of data which is likely to cover only a fringe of its entire geographical distribution range poses problems in the estimation of population parameters and stock size of this species. The present study is an attempt to evaluate estimates of these parameters based on pole and line fishery data collected during 1985 and 1986 at Minicoy, Lakshadweep only. Problems encountered in the estimation of migratory stocks as exemplified by skipjack tuna are presented and discussed.

1 INTRODUCTION

In recent years, the fishery on the oceanic skipjack tuna (Katsuwonus pelamis) in the Indian Ocean changed significantly with the introduction of purse seiners. This resulted in a production increase from about 61,000 t in 1983 to 136,000 t in 1985. In the latter year about 47 percent of the total catch was taken by foreign fishing fleets (purse seiners) and the rest mainly by the artisanal fisheries of the Maldives, Sri Lanka, India (Lakshadweep) and Indonesia (IPTP, 1987).

Skipjack tuna in the Indian Ocean is exploited as far south as 40°-45° S in the western Indian Ocean, and south of Australia by a variety of gears such as pole and line, drift gillnets, troll lines, longlines and purse seines.

As stated earlier, the spurt in the production of this species in 1985 was due to the introduction of large purse seiners in the tropical area of the Indian Ocean by countries such as Côte d'Ivoire, France, Spain, Panama and UK, which amounted to 35 vessels in 1986.

In India, tuna fishing in an organized manner exists only in the Lakshadweep Islands at present. There are 10 inhabited islands and 17 uninhabited islets with a land area of 28.5 km² lying between 8° and 12°30' N, and 71° and 74° E. Of these, Minicoy and Agatti islands are the important ones in terms of production of tunas by the artisanal sector. The small scale pole and line fishery for surface tunas in these islands needs attention in view of the resource potential in the EEZ and contiguous high seas. If properly exploited this resource could make an important contribution to the national economy. Any development programme for improvement of the surface fishery for tuna within the EEZ of India has likely to be oriented towards strengthening and expanding the Lakshadweep live-bait pole and line fishery and purse seining. Minicoy is the most important centre among these islands, since a traditional pole and line fishery with live-bait has been in vogue for a long time.

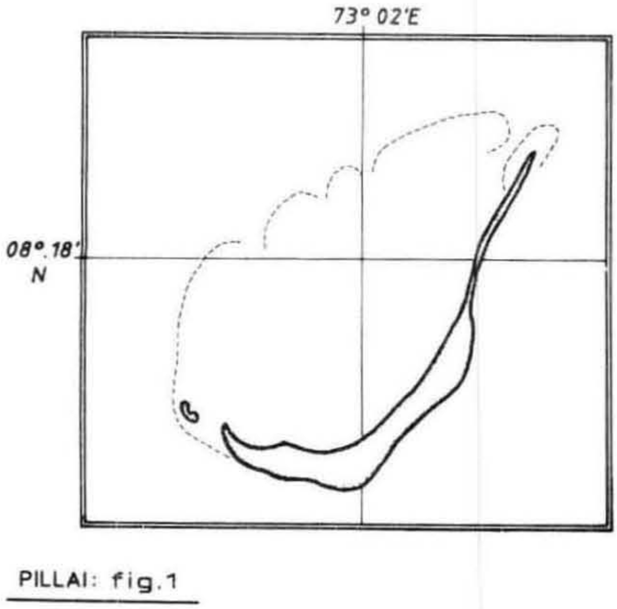


Fig. 1 Topography of Minicoy island

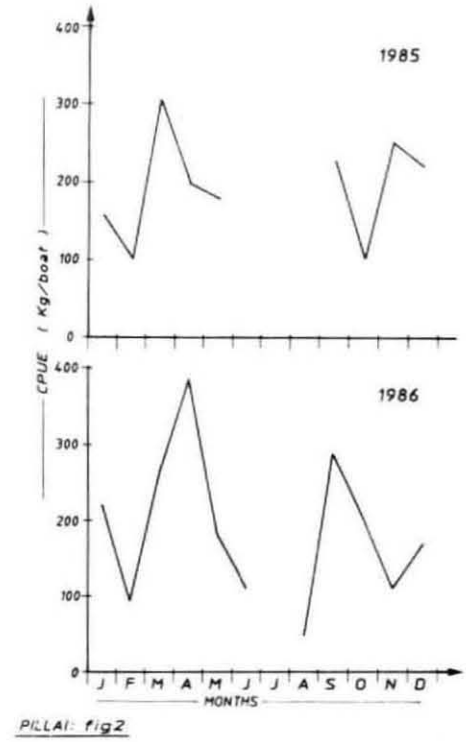


Fig. 2 CPUE (kg/boat) of skipjack at Minicoy, 1985 and 1986

Table 1 Catch (kg), effort (no. of boats) and CPUE (kg/boat) of skipjack tuna in the pole and line fishery at Minicoy (Jan. 1985 - Dec. 1986)

Month	catch kg	effort boats	CPUE kg/boat
Jan. 1985	59,492	374	159
Feb.	22,154	215	103
March	118,226	372	318
April	66,384	336	198
May	37,091	211	176
June	no fishing		
July	no fishing		
August	no fishing		
Sept.	32,818	142	231
Oct.	20,456	202	101
Nov.	84,191	333	253
Dec.	79,334	359	221
Jan. 1986	45,253	210	216
Feb.	14,462	171	85
March	129,676	489	265
April	149,265	386	387
May	54,250	309	176
June	6,435	58	111
July	no fishing		
Aug.	996	22	45
Sept	64,408	225	286
Oct.	72,121	359	201
Nov.	24,815	212	117
Dec.	49,674	289	172

Our knowledge on the fishery, biology, stock structure and availability of skipjack tuna in the tropical Indian Ocean and in the Lakshadweep area in particular is mainly due to the recent works by Cort (1986), Hallier (1986), Silas *et al*. (1986), Pillai *et al*. (1986), Silas and Pillai (1986), Silas *et al*. (1986), Mohan, Livingston and Kunhikoya (1986), Mohan and Kunhikoya (1986), Amarasiri and Joseph (1986, 1987), Hafiz (1986, 1987), Michard and Hallier (1987), BOBP (1987, 1987 a), Merta (1987), Sivasubramaniam (1987), Gafa (1987), Joseph and Moiyadeen (1987), Anderson and Hafiz (1987), James and Pillai (1987) and James, Srinath and Jayaprakash (1987). These studies indicate the availability of skipjack tuna in space and time and provide information on the population parameters and discuss possibilities for the expansion of the fishery and the implication of management measures.

The migratory behaviour of skipjack tuna in combination with non-availability of data covering its entire geographical distribution range often makes it difficult to estimate the growth parameters, let alone stock sizes of this species. The present study is an attempt to estimate growth parameters and availability of skipjack tuna to the local fishery based on the pole and line (live-bait) fishery data collected during 1985 and 1986 at Minicoy. The problems faced in the estimation of the above parameters are presented and discussed.

2 FISHERY OF SKIPJACK TUNA AT MINICOY

2.1 Fishing area

The operational area of the pole and line fishery is confined to a 20 km wide zone around Minicoy Island, with a seasonal shift in the area of operation *viz*. from north-west to south-east of the island. Major bait-fishing grounds are located in the southern and middle parts of the Minicoy lagoon, but bait is also collected from the reef edge at the central and northern parts. (Fig. 1).

2.2 Crafts and gear

Details of crafts and gear and fishing operation were described earlier (Silas and Pillai, 1982; Mohan, Livingston and Kunhikoya, 1986). Mechanised boats of two size classes (LOA 7.9 m and 9.1 m) are being employed for bait fishing and pole and line tuna fishing. An engine of 10-40 HP is fitted in the middle of the boat and is protected with wooden planks on the top and sides. A bait tank, size 1.6 x 0.8 x 0.8 m is fitted in front of the engine. It is divided into two parts by a removable wooden partition. Seawater circulation is maintained in the bait tank by an ingenuous water circulating device connected to the bottom of the boat. A fishing platform, about 1 m wide is located at the stern.

The gear consists of a bamboo pole of 3-4 m, with diameter of 35 mm and 45 mm at top and bottom respectively, straight, strong and flexible. A line of nylon twine or polyethelene is attached to the tip of the pole. Barbless, leadcoated hooks of 1.5 cm - 3.7 cm diameter are used.

Encircling nets of mosquito net webbing are employed to collect sprats, *Spratelloides delicatulus* and *S. gracilis*, while stick-held lift nets of 6 mm mesh size are employed in the fishery for other live-bait such as apogonids, caesionids, pomacentrids and atherinids dwelling in the deeper parts of the lagoon.

Table 2 **Total estimated monthly length frequency distribution of skipjack tuna caught at Minicoy from January 1985 to December 1986 (Raising factor = (weight of total catch)/(weight of sample)**

Fork-length	1985 Jan	1985 Feb	1985 Mar	1985 Apr	1985 May	1985 Sep	1985 Oct	1985 Nov	1985 Dec	1986 Jan	1986 Feb	1986 Mar	1986 Apr	1986 May	1986 Jun	1986 Aug	1986 Sep	1986 Oct	1986 Nov	1986 Dec	Total 1985/86
20-										117											117
22-										234											234
24-										817											817
26-										1109											1109
28-										234											234
30-				56						117							107				280
32-		60		0						0							374				434
34-		60		0					167	58							855	82			1222
36-		178	70	112			79		0	0							1180	82			1701
38-		119	0	0	67		19		335	58				124			1283	161			2166
40-		358	70	0	67		19	37	167	350		290		0		83	1658	324		240	3663
42-		60	353	0	67	83	58	0	0	0		724		124		21	1764	1291		1682	6227
44-	52	298	1269	322	202	42	353	221	501	467	36	4194	235	742		144	2459	2986		1682	16205
46-	52	357	1974	725	539	208	470	478	1252	1518	0	9112	941	2350	197	0	1978	6054	435	2163	30803
48-	104	1607	4299	1728	2559	83	705	405	1255	1284	394	13451	4939	4328	132	114	3689	7587	1956	3123	53742
50-	311	774	3454	1784	2357	167	549	921	918	876	251	16778	9642	3833	855	124	2727	5973	5433	1441	59168
52-	206	834	3806	2285	3839	208	176	995	583	175	644	9691	8936	4823	921	52	1658	2340	1956	1201	45329
54-	933	237	4863	1395	1549	84	196	773	1669	350	429	2182	5409	2967	395	73	1551	1130	0	721	26906
56-	622	655	4933	1561	1145	374	255	1730	834	526	108	867	4233	1113	132	113	1390	968	0	481	22040
58-	1658	357	3243	947	674	1039	490	1951	1001	992	35	579	4233	618	132	41	1069	565	0	1441	21065
60-	3108	357	3806	1840	135	1538	1019	3277	1168	1226	144	579	2587	124	66	73	1497	1291	217	1201	25253
62-	4714	535	2467	3624	67	1787	765	3424	2172	700	143	0	470				695	323		961	22847
64-	2850	595	846	2731		997	255	2687	3256	817	179	0	1411				159	0		480	17263
66-	206	178	564	1282		498		1988	4258	1576	896	0	2117				53	81			13697
68-	52		141	335		83		699	1670	1109	609	0	2587								7285
70-								111	251	350	250	289	940								2191
Total	14868	7619	36158	20727	13267	7191	5408	19697	21457	15060	4118	58736	48680	21146	2830	838	26146	31238	9997	16817	381998
Raising factor	51.8	59.9	70.48	55.7	67.4	41.6	19.6	36.8	83.5	58.4	35.8	144.6	235.1	123.7	65.8	10.3	53.5	80.7	217.3	240.2	

2.3 Fishing operations

Baitfishes are collected from Minicoy lagoon either in the morning at the start of a fishing trip or in the evening of the previous day. Normally, fishermen leave for tuna fishing by 09.00 and return by 16.00 h.
Common ways of locating tuna shoals are: (1) Noting the presence of bird flocks, (2) operating a trial handline (3) noting breezing shoals or (4) jumping shoals or (5) tunas associated with floating objects. When a tuna shoal is located, the fishing boat is steered towards it. Tunas are chummed near the fishing platform of the boat. Water is splashed over the bait fishes broadcasted, and with the special skill developed by the local fishermen tunas are clipped on board the vessel.

2.4 General production trend

The tuna fishery by pole and line is suspended during the south-west monsoon at Minicoy. The month-wise catch of skipjack (in kg) and effort expended (units) are presented in Table 1, while catch per unit effort (CPUE) is presented in Fig. 2. The results of these and other observations suggest that most skipjack is produced during March-April and September-November, the inter monsoon periods.

The availability of live-bait is an important factor in the pole and line fishery. Effort is linearly related to the quantity of live-bait utilized. Thus the catch of tuna per kg of live-bait follows essentially the same pattern as is shown in Fig. 2 for the CPUE.

3 BIOLOGY

3.1 Sex-ratio

The overall sex-ratio in the period of observation Sept. 1985 to June 1986 was male: 1, female: 1.07. Males were dominant during most of the months, and females dominated in the landings during October, December and May. A similar trend in the distribution of the sex-ratio was observed for skipjack at Minicoy by Mohan and Kunhikoya (1986) during 1981 & 1982.

3.2 Spawning

Data on female specimens were divided into three groups viz., immature (stage I and II), maturing (stage III) and mature (stage IV and above). Analysis of the data on the maturity of skipjack during 1985-86 revealed that mature males and females occur in the artisanal fishery throughout the year and that a peak in the numbers of mature females (stage IV and above) occurred during March-May.

Data on the maturity and spawning of skipjack at Minicoy indicate that this species spawns throughout the year in this area. Similar observations were made by Mohan and Kunhikoya (1986) from Minicoy waters. In the Maldives mature and ripe females of skipjack occured in the fishery during July to December in 1985. According to Pillai and Silas (1979) spawning activity was high in the Central Indian Ocean during the period September through April. This is an agreement with the findings of Marcille and Suzuki (1974) from the same area. Data available on the larval abundance indicated spawning activity in this area during October-December (Nishikawa et al., 1985).

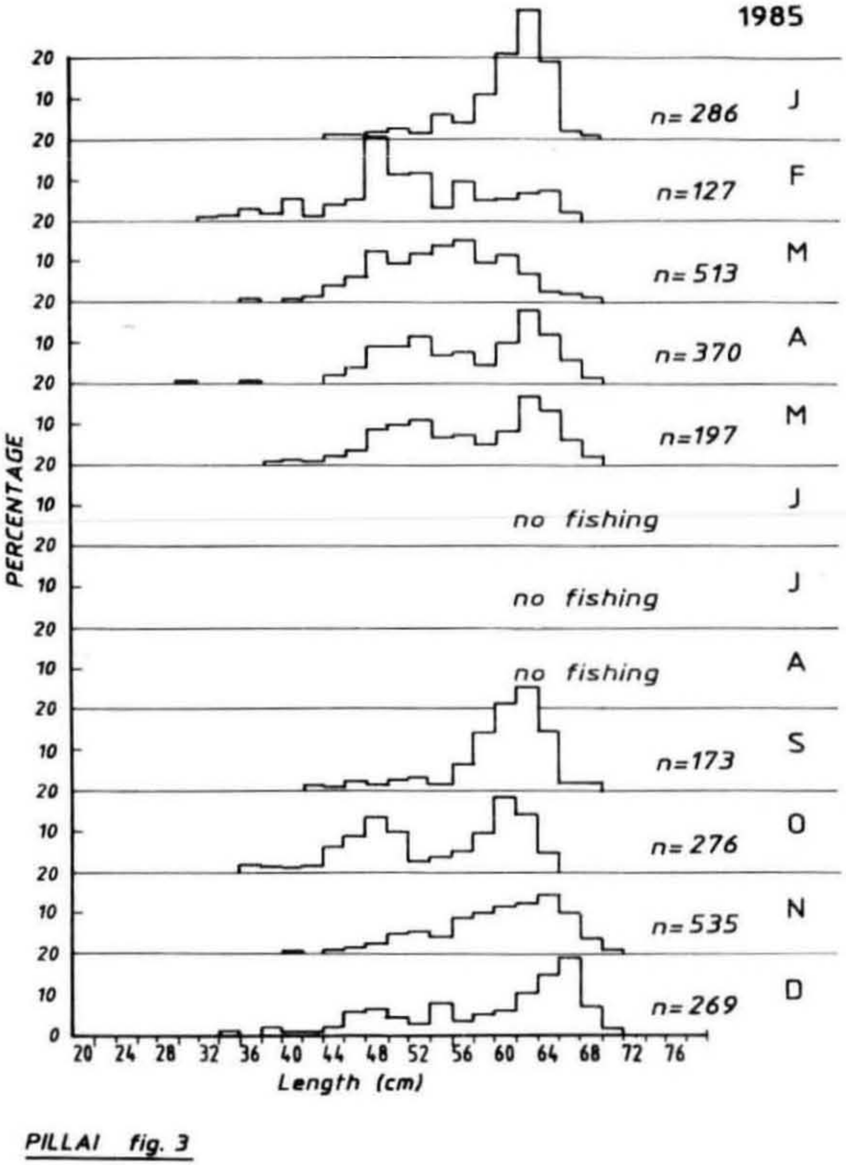


Fig. 3 Monthly size distribution of skipjack at Minicoy, 1985

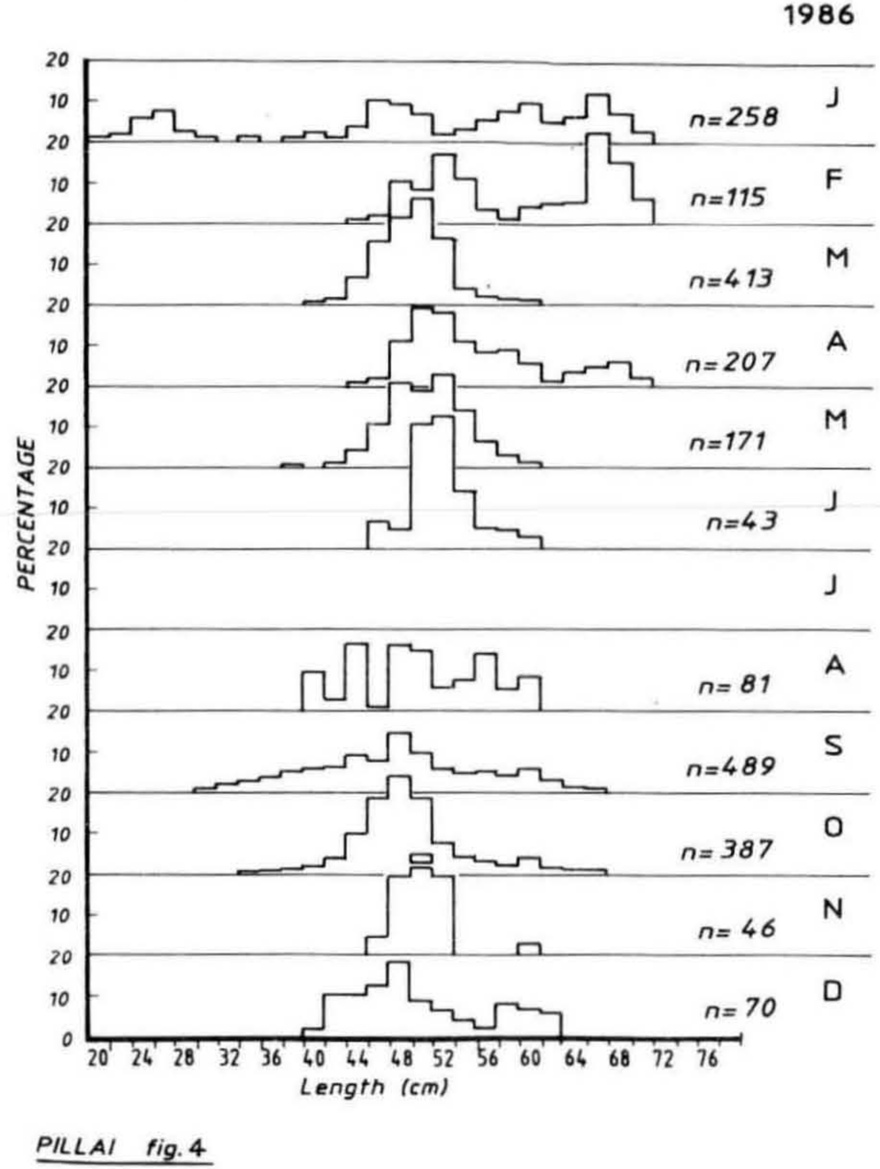


Fig. 4 Monthly size distribution of skipjack at Minicoy, 1986

4 MATERIAL AND METHODS

The length frequency data of the catches of skipjack collected from the pole and line fishery from January, 1985 to December, 1986 form the data base for the present study. Data were collected on trips to ten fish landing villages on all the fishing days. The skipjack catch, both in number and weight, the number of pole and line boats that were operating and the quantity of live-bait caught and utilized were recorded and compiled to get the monthly estimates. Biological data were collected when the tunas were landed in fresh condition.

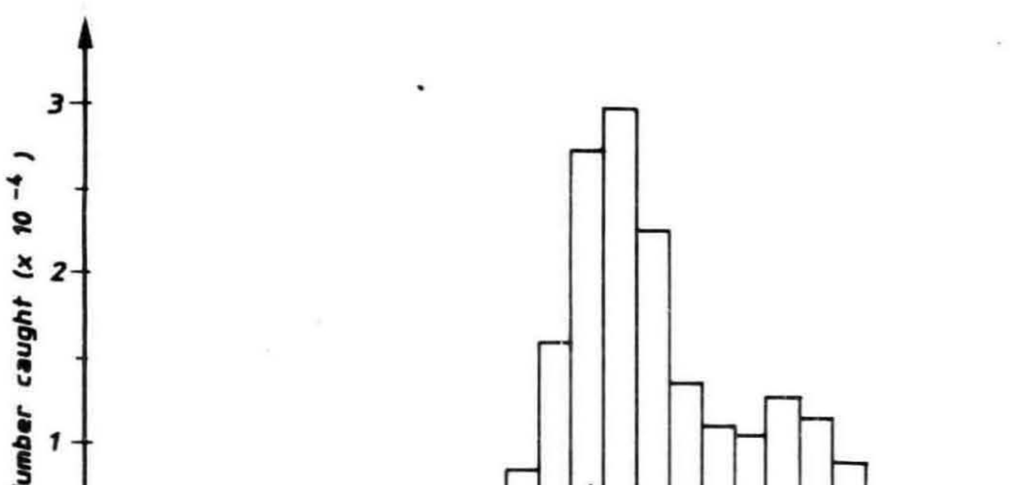
Two alternative methods for the estimation of the growth parameters were tried:

1) The Bhattacharya method of resolving length frequencies into normally distributed cohort components, followed by a modal progression analysis using the LFSA package of microcomputer programs (Sparre, 1987).

2) ELEFAN I, using an advanced release of the "COMPLEAT ELEFAN" package of micro computer programs (Gayanilo, Soriano and Pauly, 1988).

The use of both methods assumes that the samples taken by the pole and line fishery in Minicoy waters are representative of the entire stock in its entire distribution area (this assumption will be discussed later in this paper).

The length frequency samples (Figs. 3 and 4) were raised to the total catch (cf. Table 2) and summed over the two year period. The summed frequencies for the total catch are shown in Fig. 5. These data were used as input to the length converted catch curve analysis whereby the total mortality, Z, was estimated. This method assumes Z to remain constant for a range of length groups, and it provides an estimate of Z for these lengths only.



Pillai fig 5

Fig. 5 Summed skipjack size distribution of 1985 and 1986. (Input data for length converted catch curve analysis and cohort analysis)

The same data were also used as input for Jones' length converted cohort analysis (Jones, 1984). The cohort analysis also requires an estimate of M as input, which was obtained from Pauly's empirical formula (Pauly, 1980).

The output from the cohort analysis are estimates of stock numbers and fishing mortalities by length group. This method assumes M to remain constant for all length groups, whereas F may vary.

5 RESULTS

5.1 Length-weight relationship

The relationship between the fork length and the weight of the individual skipjack was obtained from a sample of 681 specimens of fresh fish. The data were fitted to the relationship $W = a\ L^b$ (where W = weight in kg and L = fork length in cm). The fitted equation is as follows:

$$W = 0.0000432\ L^{2.77}\ (r = 0.82)$$

5.2 Growth

Based on the mean length estimated by the Bhattacharya method and using a Gulland and Holt plot the estimated parametric values of growth were:

$L_\infty = 74.2$ cm; $K = 1.26$/year

The test version of the ELEFAN I program of the COMPLEAT ELEFAN package was also used and the estimated parametric values obtained were:

$L_\infty = 90.0$ cm; $K = 0.49$/year

As can be seen from Figs. 3 and 4, the time series of length frequencies are not easy to interpret in terms of modal progression. Furthermore, very few fish below 40 cm and above 70 cm are represented in the samples. Thus only about one third of the normal length range for skipjack is available for the analysis. Only for the period Oct.-Dec. 1985 there appears to be a visible modal progression. As will be discussed later, this picture is to be expected for a highly migratory species like skipjack tuna.

The estimate obtained from the Bhattacharya analysis and Gulland & Holt plot appears unrealistic compared to other estimates from the area (see Table 3), whereas the estimate from ELEFAN I is in line with other findings. However, to which degree these estimates (and those given in Table 3) are biased because of migration is unknown.

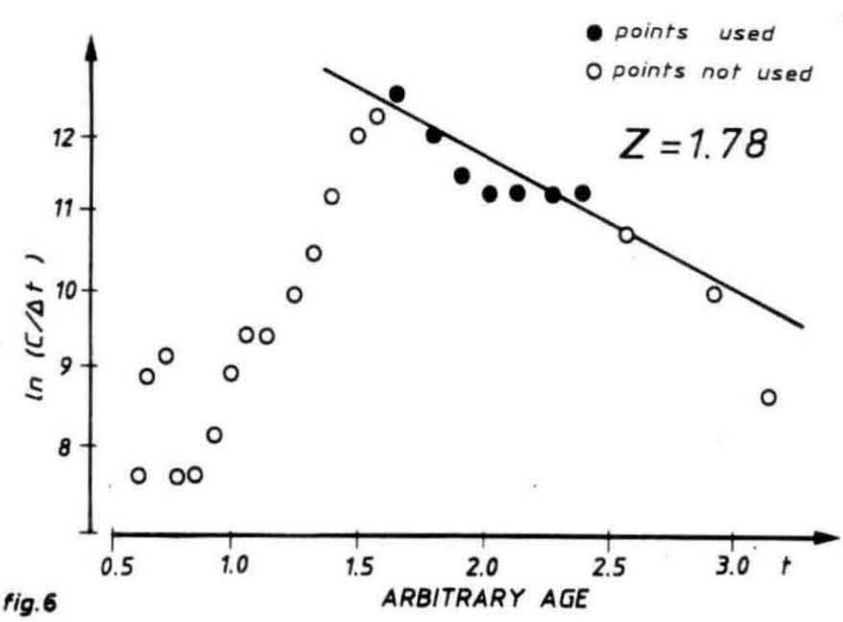
In the following the estimates of growth parameters obtained from ELEFAN I are used, as these (by coincidence?) appear to be the more realistic ones.

5.3 Mortality and stock numbers

Despite the reservations about the validity of the estimated growth parameters expressed above, attempts to estimate mortality rates and stock size were made. The growth parameters used as input were $L_\infty = 90$ cm and $K = 0.49$/year. The summed frequencies grouped into two cm intervals used as input are shown in Fig. 5.

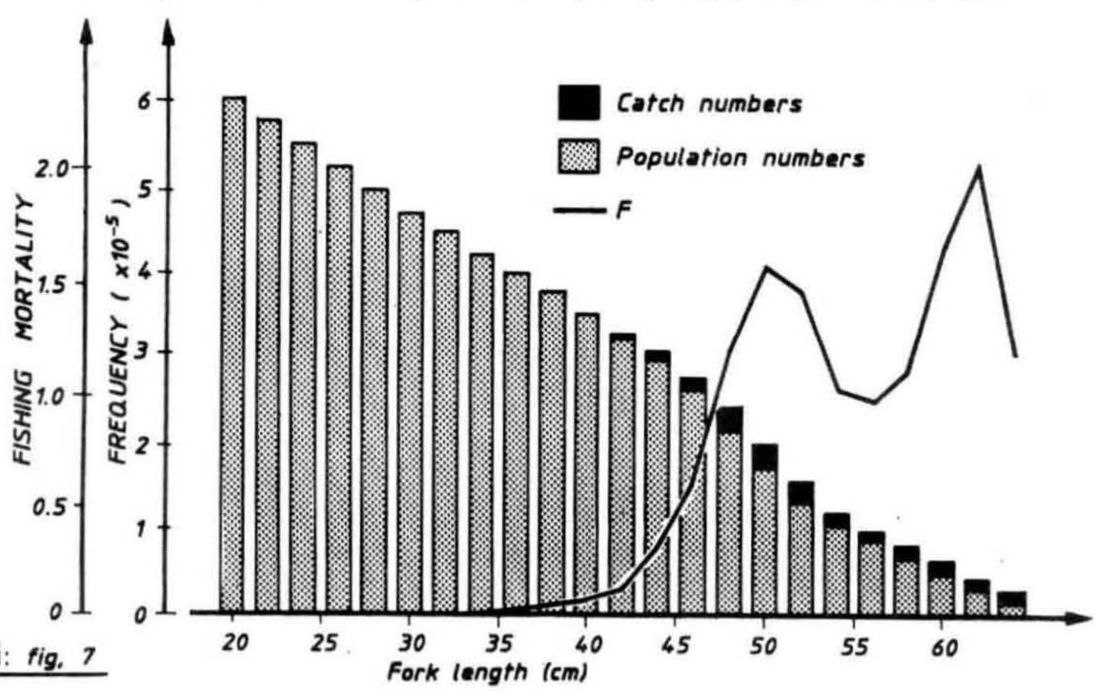
The total mortality Z was estimated by the length converted catch curve method to be 1.78/year for the seven length groups from 50 to 62 cm. As expected for a highly migratory species some length groups appear to be underrepresented. The frequency appears to be bimodal. No matter which explanation is given for the bimodal distribution it appears that the assumption of a constant Z in the catch curve analysis is violated (see Fig. 6). M was estimated to be 0.75/year (using 29.5°C for the surface temperature). This combined with the estimate of Z (1.78) from the catch curve analysis provides the estimate of F = 1.0/year for the length groups from 50 to 62 cm.

The results of the length converted cohort analysis are shown in Fig. 7. Below 40 cm skipjack appears not to be exploited. The fishing mortality increases between 45 and 50 cm from about 0.5/year to about 1.5/year, whereafter it reduces to about 1.0/year at length 55 cm.



Pillai fig.6

Fig. 6 Length-converted catch curve of skipjack at Minicoy, based on data presented in Fig. 5. (Length groups used: 50-62 cm)



Pillai: fig. 7

Fig. 7 Length converted cohort analysis of skipjack at Minicoy, based on data presented in Fig. 5

6 DISCUSSION

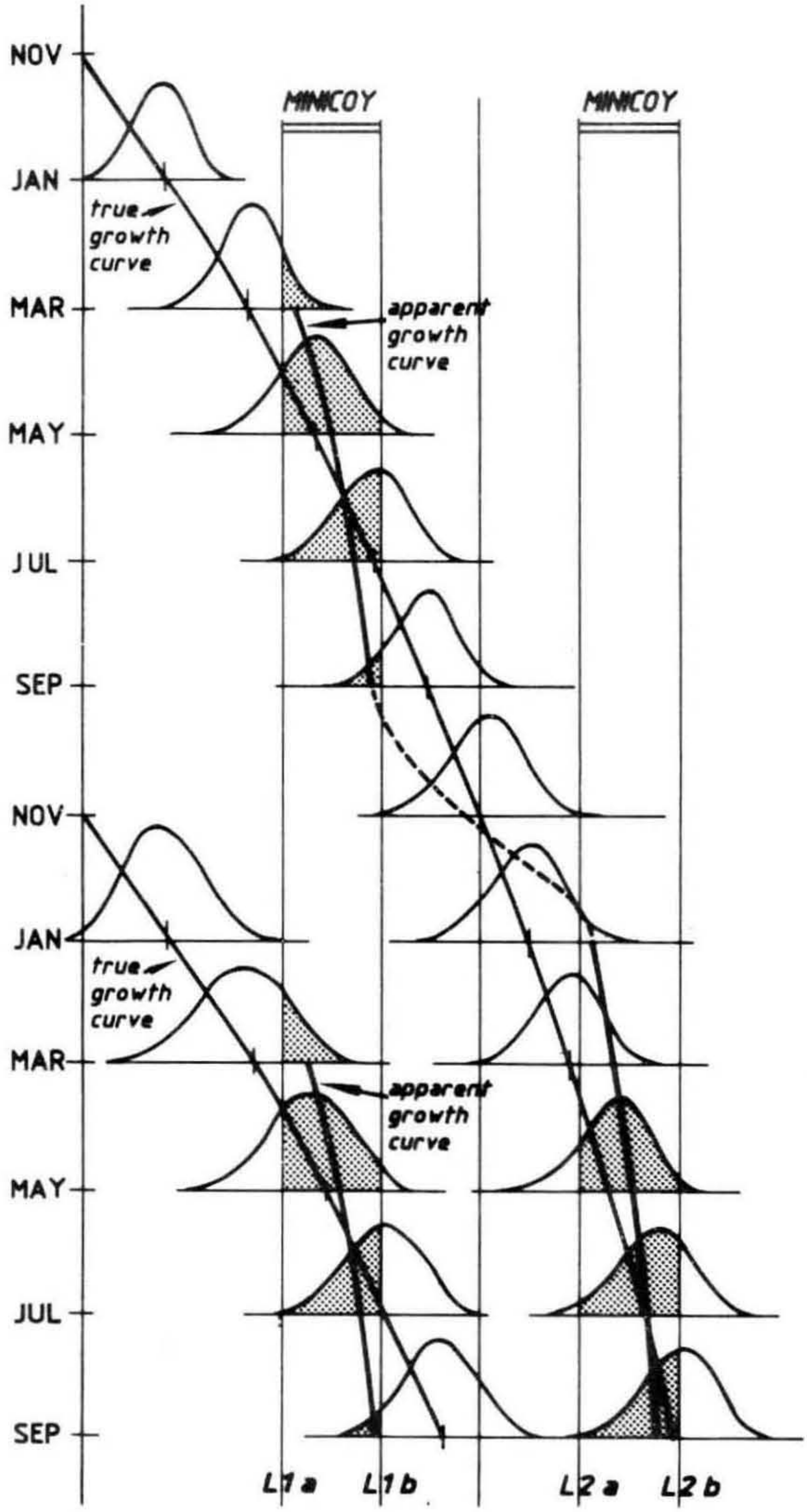
6.1 Seasonality and migration

A traditional length based fish stock assessment of the skipjack tuna fishery at Minicoy was carried out as if this stock was confined to Minicoy waters only. However, a number of difficulties were encountered. The underlying basic data appear not to conform to the assumptions behind the methods applied. These difficulties are believed to be a consequence of the migratory nature of skipjack tuna.

As discussed earlier, seasonality in the availability of skipjack tuna is evident in the waters around Minicoy, with a peak CPUE recorded during March-April and September-November (see Fig. 2), although no fishing occurred in the monsoon period. In the Maldives, Hafiz (1987) recorded that small sized skipjack occur on the west coast of the country during the SW monsoon (July to August) and on the east coast during the NE monsoon (October to December). Large sized skipjack tend to show better catch rates

Table 3 Estimates of the growth parameters of skipjack tuna in the tropical Indian Ocean and adjacent areas

Source	L_∞ (cm)	K/year	Area
Appukuttan *et al.*, 1977	84.3	0.22	Minicoy
Sivasubramaniam, 1985	77.0	0.52	Sri Lanka
Amarasiri and Joseph, 1986	85.0 85.0	0.62 0.64	Sri Lanka
Hafiz, 1986	78.0	0.62	Maldives
Silas *et al.*, 1986	90.0	0.49	Minicoy
Mohan and Kunhikoya, 1986	90.0	0.48	Minicoy
Dwiponggo *et al.*, 1986	80.0 79.0	0.95 1.10	Indonesia (W. Pacific sector)
BOBP, 1987	86.0	0.62	Andaman Sea
BOBP, 1987a	85.0 76.0 79.0	0.44 0.44 0.41	Maldives + Sri Lanka - " -
Hafiz, 1987	82.0	0.45	Maldives
Amarasiri and Joseph, 1987	79.7 76.0 76.0	0.41 0.44 0.44	Sri Lanka - " - - " -
Merta, 1987	86.0	0.62	W+N Sumatra
Present Study Bhattacharya + Gulland & Holt	74.2	1.26	Minicoy
- " - ELEFAN I	90.0	0.49	
Range	74.2 to 90.0	0.22 to 1.26	



PILLAI fig. 8

Fig. 8 Illustration of "apparent seasonality" in growth (hypothetical example). For further details see text

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during the NE monsoon both on the eastern and western coasts of the country. (BOBP, 1987a). In Sri Lanka it was reported that the peak catch rates for the gill net fishery on the west and south coasts occur during the SW monsoon (May-September) and that large size skipjack appear in the fishery during the rest of the year (BOBP, 1987). The peak season for the purse seine fishery around Seychelles has been reported to be during March/April in 1981/82, and October/November in 1983/84 and 1984/85 (Cort, 1986).

Hunter et al. (1986) stated that the movement of tunas and their resulting distribution was a key problem in the management of tuna fisheries, and that a single organization not covering the whole distribution area is insufficient to make rapid progress in solving it. Because it is believed that that part of the skipjack stock which is exploited in Minicoy waters represents only a tiny fraction of the stock, the length frequency samples collected here are not considered to be random samples representative for the entire stock. Because all the methods applied above assume the input data to be derived from random samples representing the entire stock, the results are not valid.

6.2 Migration induced bias in estimates of growth parameters

Length frequency samples of skipjack catches often tend to show a bimodal distribution with little or no progression of the modes (see e.g. Hafiz, 1987 and Mohan, Livingstone and Kunhikoya, 1986) and that was also the case in the present study. Apparent negative growth can also be observed. Thus, such data do not fit the ordinary von Bertalanffy growth model. One possible explanation of a stagnation in growth is that there is a seasonality in the growth rate. However, a bias in length frequency samples introduced by migration can have the same effect. To explain this idea a theoretical (oversimplified) example has been constructed (Fig. 8).

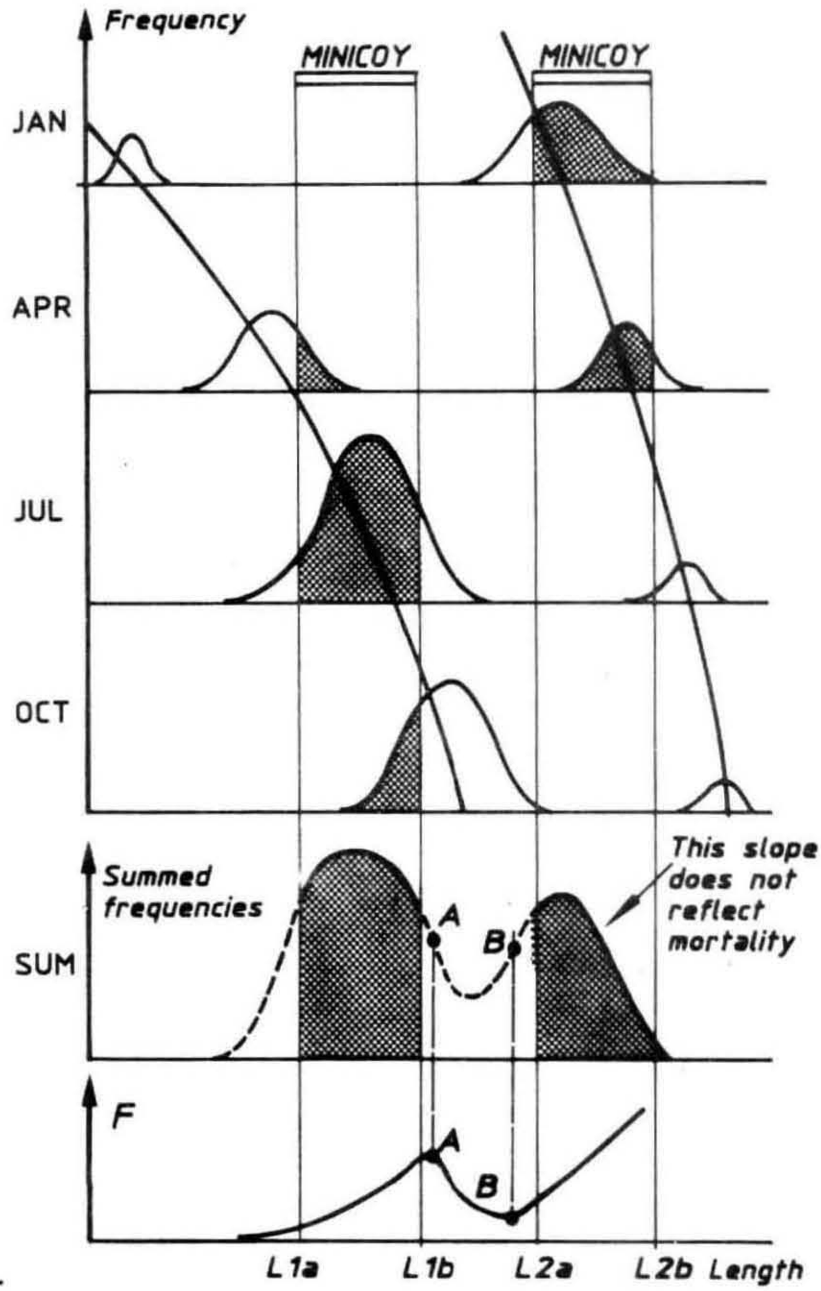
Suppose that skipjack cohorts undertake annual migrations and that at about the same time of the year the cohort returns to Minicoy waters where it stays for a while. Suppose also that different cohorts come to Minicoy at different times of the year and further that the arrival is size dependent, i.e. that the first group of skipjack arrives at Minicoy at length L1a (see Fig. 8) and leaves at length L1b.

Let the similar lengths for the next age group be L2a and L2b. If the skipjack follows the ordinary von Bertalanffy growth pattern the population may look like the bellshaped components shown in the time series in Fig. 8. What would be observed in Minicoy waters, however, would be only the hatched parts of those components. As indicated in Fig. 8 samples taken from the hatched part only lead to an apparent seasonality of the growth rate. (Note that Fig. 8 does not show any decay in the cohorts size as the fish grow older, since the mortality aspect has been ignored).

6.3 Migration induced bias in estimates of mortality rates

Fig. 9 aims at giving an explanation of apparent peculiar fishing patterns which may be observed for migratory fish stocks. The input data (summed frequencies) for the length converted catch curve analysis or the length cohort analysis are illustrated in the lower part of Fig. 9. In this (hypothetical) case the total catch summed over the year shows a bimodal distribution. One explanation of such a bimodal distribution might be variation in recruitment in the case of data of one year. However, if an average over several years is used as input for the analysis this explanation does not hold any more.

Fig. 9 is based on the same speculations on migration of skipjack tuna as Fig. 8, i.e. that the migration pattern on cohort level repeats itself each year so that the cohorts visit Minicoy at certain seasons determined



PILLAI: fig 9

Fig. 9 Illustration of "apparent mortality pattern" (hypothetical example). For further details see text

by their size. The fishing mortality shown in the lowest graph of Fig. 9 corresponds to the broken line in the summed frequencies graph. In case of a "knife edge" arrival to and departure from the fishing grounds the summed frequencies would be the shaded part of the graph. In the more realistic case where "knife edge" migration is not assumed, the summed frequencies would follow the broken line.

In a cohort analysis we would get high F-values around point A and low F-values around point B (see Fig. 9). Which part of the F-curve represents actual fishing mortality and which reflects migration cannot easily be determined. Thus a catch curve analysis cannot be applied, since the assumption of constant total mortality is obviously violated.

The slope at the right-hand descending part of the frequency distribution is primarily reflecting migration out of the Minicoy area rather than fishing mortality or natural mortality. If skipjack behaves along the lines hypothesized here, one should thus not try to extract information on mortality from data from Minicoy only.

6.4 Conclusion

The basic knowledge required for a meaningful assessment of the skipjack tuna stock exploited at Minicoy is not yet available. A major step forward would be to pool data from all areas of the Indian Ocean and to do the assessment on this data base. If all fisheries exploiting the stock are represented in the data base we can (more of less) ignore the migration induced bias, as this is believed only to be a problem for data covering a limited area.

A further step forward would be the acquisition of data on migration routes and stock identification, e.g. from tagging experiments. If migration routes are known we are in a position to "match" length frequency samples so that time series of length frequencies pertain to the same cohorts. This technique is believed to give much more reliable estimates of growth parameters.

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