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Fishery, biology and stock structure of skipjack tuna, *Katsuwonus pelamis* (Linnaeus, 1758) exploited from Indian waters

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ABSTRACT

Fishery and population dynamics of skipjack tuna, *Katsuwonus pelamis* (Linnaeus), was studied during the period 2006-2010. Length frequency data from gillnet as well as pole and line catches were used for estimation of the growth parameters using FiSAT software. Total landing showed substantial increase from 5,882 t in 1985-'89 to 20,924 t in 2006-'10. However, since 2007, the landings exhibited a continuous decline. Replica pattern reported by some of the adjacent tuna fishing nations call for a cautious approach. Exploited size of the species ranged from 12 to 88 cm fork length (FL). On an average, 31.7% landings of skipjack was contributed by Island systems, 31.4% by south-east coast, 23.2% by north-west coast, 12.3% by south-west coast and 1.3% by north-east coast. Among the maritime states and island territories, the major contributors were Lakshadweep (29.9%), Andhra Pradesh (18.3%), Gujarat (13.2%), Tamil Nadu (12.8%), Kerala (10.2%), Karnataka (2.08%) and the rest by Orissa, West Bengal, Puducherry and Andaman and Nicobar Islands. The species mature and spawn round the year with peak during December- March. Fecundity estimated was 3, 00,718 per kg body weight. Recruitment to the fishery takes place during most part of the year with peak during May-November. Length-weight relationship was $W=0.0109 L^{3.147}$. The von Bertalanffy growth factors (VBGF) were $L_\infty = 92.0$ cm, $K=0.50$ yr^{-1} and $t_o = -0.0012$. Estimate of total mortality (Z) was 1.41, natural mortality (M) 0.557, fishing mortality (F) 0.853 and exploitation rate (E) 0.605. This indicates moderate fishing pressure on the stock in the present fishing grounds. Presently fishing is centered at selected grounds and stocks at many areas like shelf break areas, reefs, banks, seamounts and Andaman waters remain largely under low fishing pressure. Scope for increasing the production from the present grounds is limited and hence the scope for enhancing production from the hitherto under-exploited grounds may be explored. There is an urgent need for international co-operation among Indian Ocean tuna fishing nations for optimum exploitation and sustainable management of the stock.

Keywords: Fishery, Growth, *Katsuwonus pelamis*, Population dynamics, Spawning

Introduction

Global catches of skipjack tuna have been steadily increasing since 1951, reaching a peak in 2009 at 25, 99,681 t (Fig.1). Most of the catches were reported from the fishing areas 71, 51, 61 and 34 (FA0, 2011). Globally skipjack tuna is caught at the surface, mostly with purse seines and pole and lines and to a small extent by gillnets, troll lines and longlines. Gears like purse-seine and very long gillnets enabled few nations to augment their production, whereas traditional pole and line nations suffered heavily. Recent Indian Ocean Tuna Commission (IOTC) tagging and tag recovery studies indicate a trans-national or trans-oceanic migration pattern. On account of interaction between adjacent fisheries, significant implications/impacts are possible on the stock and in the adjacent fishery because of the gears employed and the size of the fish caught by each nation. The importance of artificial fish aggregating devices has increased greatly in recent years. Furthermore, aerial spotting find increasing application in skipjack fisheries and utilisation of remote sensing is also being tried in recent years. In the pole and line/live bait fishery,

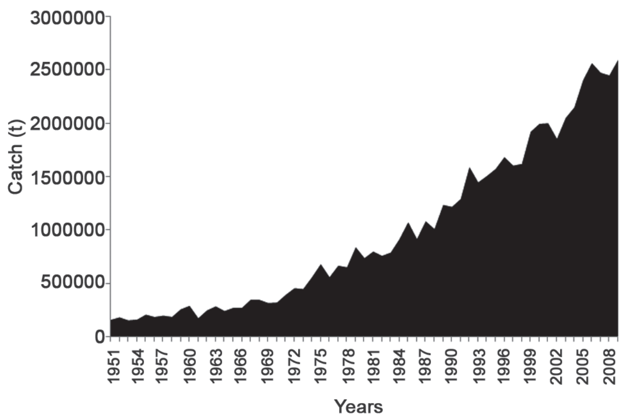

Fig. 1. World capture production of skipjack tuna (FAO) (1951 - 2008)

availability of suitable bait-fish is one of the major constraint as large scale bait fish farming to the extent of requirement is hardly feasible.

Earlier studies on the fishery of skipjack tuna gathered information of the resources from selected centers mainly Lakshadweep areas (Jones and Kumaran, 1959; Appukuttan *et al.,* 1977; Pillai and Silas, 1979; Silas and Pillai, 1982; Madan *et al.,* 1985; Livingston, 1987; James *et al.,* 1992; James and Pillai, 1993; Yohannan *et al.,* 1993; Sivadas *et al.,* 2003; Ganga and Pillai, 2006; Kasim and Mohan, 2009). Various aspects on the biology have been given by Jones and Kumaran (1959), Raju (1964), Appukuttan *et al.* (1977), Madan and Kunhi Koya (1985), Silas *et al.* (1985), James *et al*. (1993) and Yohannan *et al*. (1993). However, the present study is the first holistic attempt during the last two decades, to study the biology and stock structure of *K. pelamis* on a national level incorporating data generated from almost all the maritime states and Island territories.

Materials and methods

Fishery of skipjack tuna by gillnets and pole and lines along the mainland and Lakshadweep were monitored along with biology during 2006-'10. Samples were obtained at weekly intervals from unsorted commercial landings. Data on fork length (FL), weight, sex and stages of maturity were recorded. A total of 482 female specimens in length range of 28-88 cm were analysed for determining the spawning season, length at maturity and fecundity.

Growth parameters, L_∞ and K were estimated from the monthly length frequency data using ELEFAN-1 programme in FiSAT software (Gayanilo *et al.,* 1988; Sparre and Venema, 1991). A total of 28,493 fishes in the length range of 12-82 cm FL were measured for the estimation. The rate of total instantaneous mortality (Z) and exploitation ratio (E) was estimated using length converted catch curve method proposed by Pauly (1983) using the total annual length frequency distribution of catch. The natural mortality rate (M) was estimated using the equation of Pauly (1980) and for this purpose, the temperature in the fishing grounds was taken as 27 ^{0}C following Suseelan and Rajan (1989). The fishing mortality (F) was calculated as F = Z-M.

Estimation of Yield and biomass at different levels of F and t_c was made using Beverton and Holt's (1957) Yield per Recruit analysis. The smallest length in the catch over the two-year period was taken as length at recruitment (L_r). Estimation of yield at different values of F and length at first capture was calculated and presented in the form of a graph.

Results and discussion

Fishery

The total landing showed an increase from 5,882 t in 1985-'89 to 20,924 t in 2006-'10. The skipjack tuna landings in India have shown a steady increase from a meagre few hundred tons in seventies to a peak of 27,127 t in 2007. Thereafter, landings exhibited a continuous decline to 14,761 t in 2010. Seasonal variations of landings for India are given in Fig. 2. On an average, major share of the catch (31.7%) was contributed by island territories, 31.4 % by south-east coast, 23.2% by north-west, 12.3% by south-west and the rest by north-east coast. The major contributors to skipjack fishery were Lakshadweep (29.9%), Andhra Pradesh (18.3%), Gujarat (13.2%), Tamil Nadu (12.8%) and Kerala (10.2%) (Fig. 3). Several gears contributed to the skipjack fishery, with major share by gillnets (44.8%), pole and lines (27.1%) and hooks and line (24.9%). They formed target fishery only along the Lakshadweep mainly by pole and lines, to a smaller extent by troll lines and gillnets.

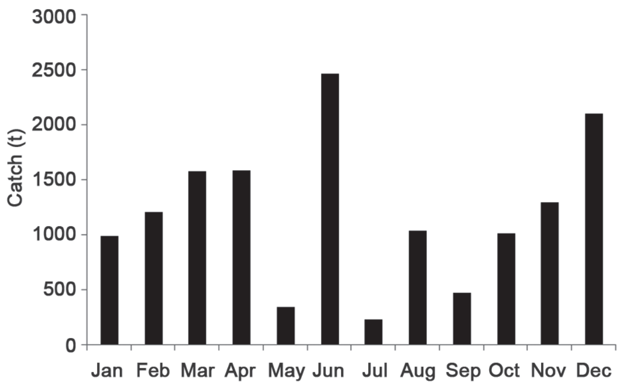

Fig. 2. Monthly variation in catch of skipjack tuna along the Indian coast

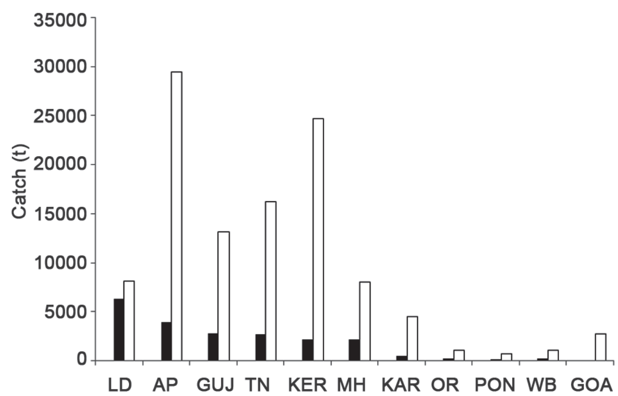

Fig. 3. Distribtuion of catch of skipjack tuna in different states of India

The average skipjack landing of 20,924 t in 2006-'10, accounts only 24.6% of their estimated potential from Indian EEZ. Detailed analysis showed that fishery at present is centred in Lakshadweep, south-east and north-west coasts. Production from the less exploited regions, including shelf edge, reefs, banks, oceanic ridges, seamounts and Andaman waters needs to be explored for expanding the fishery.

Length distribution

The exploited size ranged from 12 to 82 cm FL. Length distribution from different regions showed marked difference (Fig. 4). The difference may be due to the change in distribution pattern of fishes in different areas, gears employed and other environmental parameters. The length-weight relationship was $W=0.0109\,L^{3.147}$, where W is weight in g and L is length in cm.

Growth parameters

The estimated growth parameters, length at infinity (L_∞) and growth coefficient (K) indicated difference between areas (Fig. 5-8, Table 1). The parameters of growth estimated by earlier workers globally shows that the L_∞ values range from 61.3 to 142.5 cm and K from 0.25 to 1.25 yr^{-1} (Appukuttan *et al.*, 1977; Tandog *et al.,* 1987; James *et al*., 1992; Yohannan *et al*., 1993; Chu Tien Vinh, 2000; Kasim and Mohan, 2009). The parameter values obtained in the present study are well within the ranges known in this species from Indian waters (Table 2).

The value of W_∞ was estimated as 17.18 kg from the length-weight relationship, f and t_r as 0.444 taking 18 cm as the smallest length at recruitment (L_r) and t_c=1.47 when L_c=48 cm.

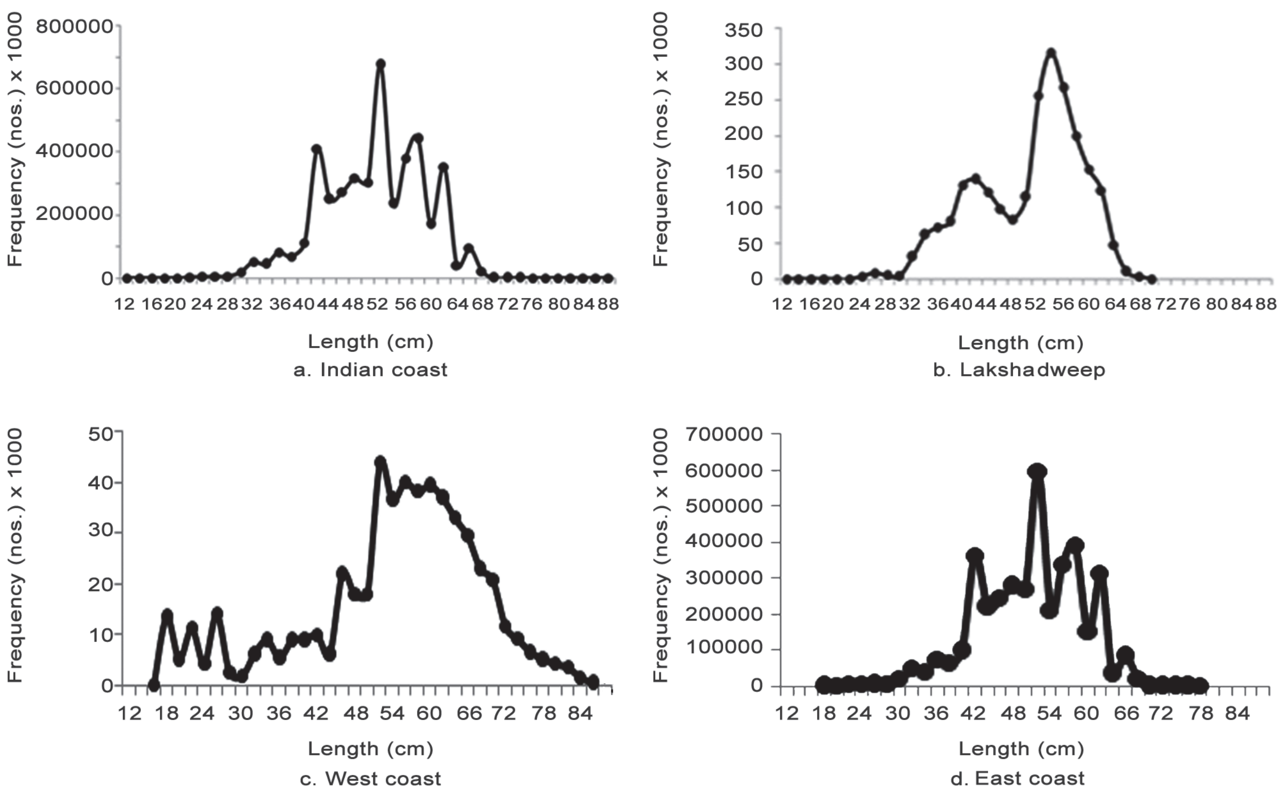

Fig. 4. Length frequency distribution of skipjack tuna landed along the Indian mainland and Lakshadweep coast

Table 1. Population parameters of *K. pelamis* exploited from different regions during 2006-2010

Parameter/area	South-west coast	South-east coast	Lakshadweep	All India
L_c (cm)	52	38	52	48
T_c (yr)	1.90	1.09	1.90	1.47
L_r (cm)	19	18	22	18
T_{ry} (yr)	0.478	0.44	0.57	0.44
K	0.50	0.50	0.50	0.50
L_∞ (cm)	84.60	90.3	89.0	92.0
W_∞ (kg)	13.39	16.03	15.48	17.85

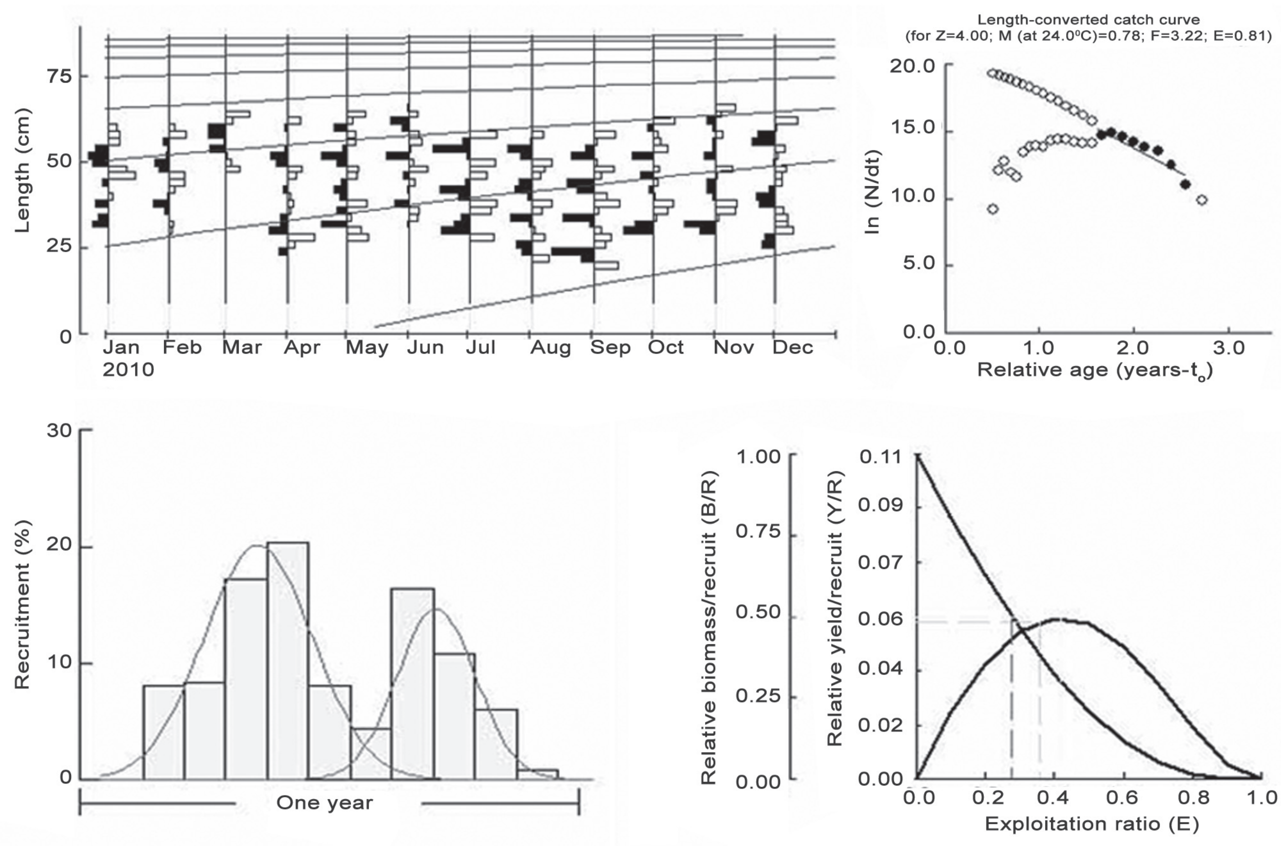

Fig. 5. Population parameters of skipjack tuna of Lakshadweep coast of India

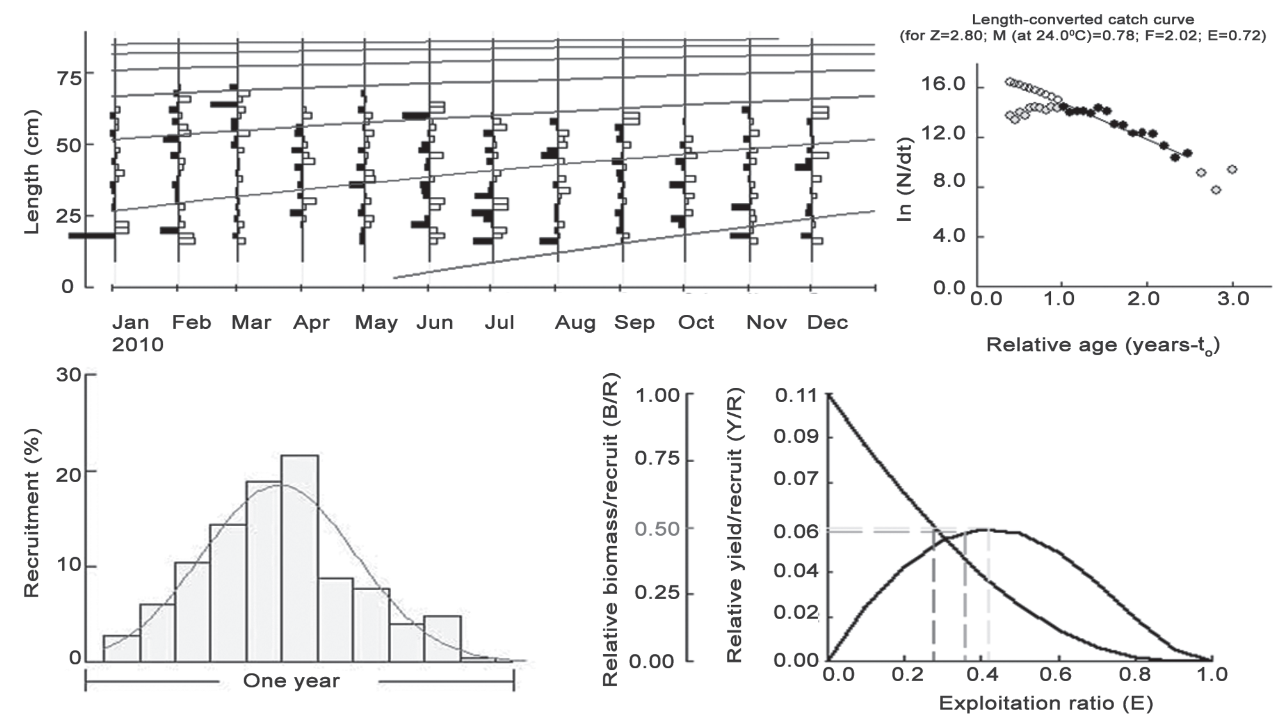

Fig. 6. Population parameters of skipjack tuna of south-east coast of Inida

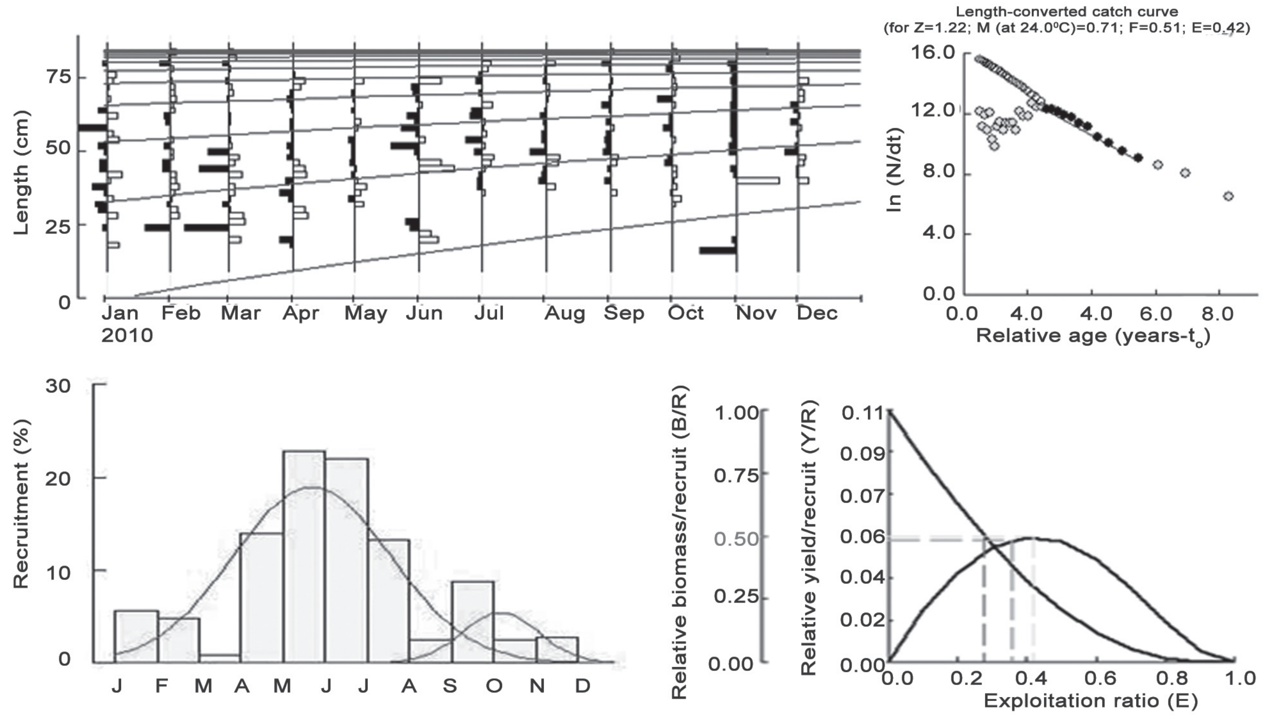

Fig. 7. Population parameters of skipjack tuna of south-west coast of India

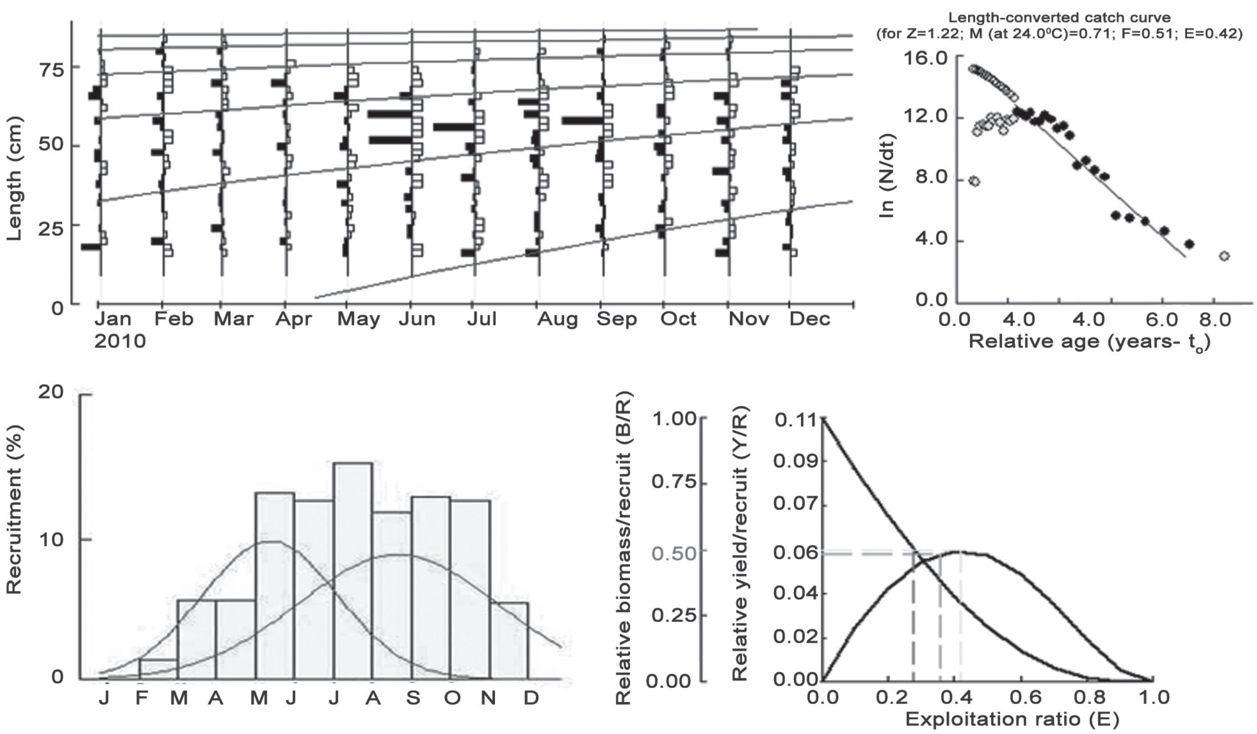

Fig. 8. Population parameters of skipjack tuna exploited along the Indian coast

Age and growth

The species is found to grow relatively fast in Indian waters (Table 2). The age and growth estimates in the present study are comparable with earlier estimates for the species from Indian waters (Appukuttan *et al.,* 1977; Madan and Kuhnikoya, 1985; Yohannan *et al.,* 1993; Sivadas *et al.,* 2003). Chu Tien Vinh (2000) estimated growth of skipjack as 28 cm in the 1st year, 42 cm in the 2nd year and 50 cm in the 3rd year in China Sea. Growth estimate for the one year old fish reported from different areas are 27 cm (Aikawa and Kato, 1938), 52.3 cm (Brock, 1954); 37 cm (Yokota *et al.,* 1961); 30.4 cm (Schaefer, 1961; Rothschild, 1966; Joseph and Calkins, 1969) and 40.6 cm (Batts, 1972). The difference in growth rate can be attributed to several reasons including prevailing eco-biological conditions of the habitat during time to time.

Table 2. Comparison of estimates of age and growth of *K. pelamis* from Indian coast

Year/length (cm)					Author
I	II	III	IV	L_∞	
40.6	49.3	56.2	60.4	84.2	Appukuttan *et al.* (1977)
36.7	57.3	69.7	77.7	90.9	Madan and Kuhnikoya (1985)
44.0	58.7	63.6	65.2	66.0	Yohannan *et al.* (1993)
57.8	79.6	87.7	90.8	92.6	Sivadas *et.al.* (2003)
36.3	58.0	71.5	79.6	92	Present study

Maturity and spawning

Skipjack tunas mature and spawn round the year in Indian waters with a peak from December to March and a minor one during June-August (Fig. 9). Jones and Silas (1963) stated that no definite range of spawning activity for skipjack has been established in any areas in the Indian Ocean except that from the Lakshadweep Sea. Based on the skipjack larvae collections (Jones, 1959) and the examination of gonads (Raju, 1964), it can be presumed that the spawning of skipjack in the Minicoy waters takes place for an extended period from January to April and from June to September with peaks in January and June respectively. According to James and Pillai (1988), this species spawns during March. But Madan and Kuhnikoya (1985) observed mature females throughout the pole and line fishing season (August to May) in Minicoy and occurrence of young fishes of 30 cm during January to May and September to December indicating spawning throughout the year. James *et al.* (1992) also reported occurrence of mature fishes almost throughout the year with two spawning peaks during January-April and September-December. Amaraisiri and Joseph (1986) observed ripe and oozing ovaries in all months of the year except in November and December. These observations confirmed that this species spawn almost round the year with one major peak during late winter and a minor peak during the south-west monsoon.

Size at maturity of the species was estimated at 41 cm (Fig. 10). Raju (1964) estimated size at first maturity at around 40-45 cm in TL and according to James *et al.* (1992), it was 44-45 cm TL. Amaraisiri and Joseph (1986) observed maturity for males at 42.0 cm and for females at 43.3 cm. In the present study, fecundity was estimated as 3,00,718 per kg body weight. The fecundity was reported to vary between 1,51,200 and 19,77,900 (Raju, 1964) while Amaraisiri and Joseph (1986) observed fecundity between 2,11,410 and 29,52,253. But the size of the fish was not clearly indicated by these authors.

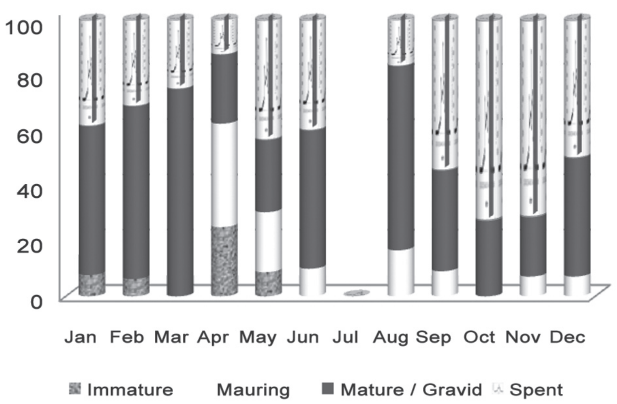

Fig. 9. Percentage distribution of different maturation stages of female skipjack tuna

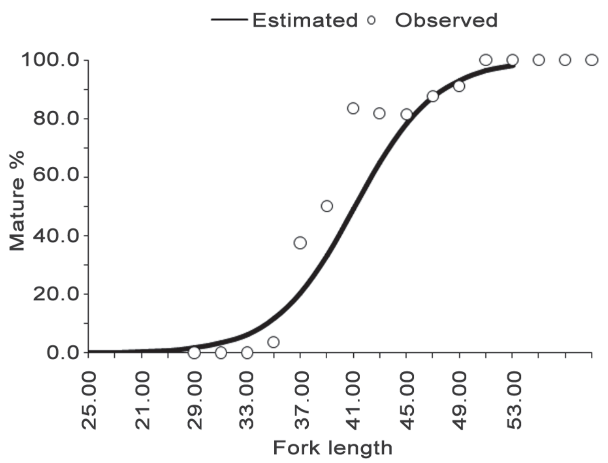

Fig. 10. Percentage frequency of mature individuals in different groups of skipjack tuna

In general, males dominated the landings . In immature and maturing population, sex ratio was found to be normal. However, in the gravid and spent population, males predominate. It may be due to the segregation of spent females from the population which remain in deeper waters for more time, making themselves non-accessible to the traditional gears, as opined by fishers. Low feeding intensity, particularly in females, during spawning time could be another reason for the phenomenon. Raju (1964) also reported similar disparity in sex ratio in spent population from Minicoy waters with the male predominating during most months and the occurrence of slightly higher percentage of females among smaller size groups.

Recruitment pattern showed that young recruits enter the fishing grounds during most part of the year with peak during May - November.

Mortality and exploitation

The estimates of mortality and exploitation rates for the period 2006-’10 showed considerable variation between different regions (Table 3). Fishing mortality at Lakshadweep is very high; more than three times of natural mortality and is very close to 3 for south-east coast. For all other regions, it is well within the desirable range. Exploitation rate is more than E_{max} for south-east coast, Lakshadweep and at national level and less for other regions. Since the major gears exploiting skipjack at these regions are gillnet and pole and lines, which target mainly surface tunas, the catch comprised of relatively smaller ones. So large values for fishing mortality and exploitation rates observed during the study for these two regions could be due to large proportion of small fishes in the catch (Fig. 4) and not related to the actual stock in the region. Silas *et. al.* (1985) obtained similar high values of fishing mortality and exploitation rates, when length frequency data of yellowfin tuna landed by pole and lines, which comprised mainly of small length groups was analysed.

Stock assessment

The estimated values of biomass, yield and stock of *K. pelamis* are furnished in Table 3. The yield per recruit as a function of fishing mortality rate (under the current t_c) shows that the present fishing mortality rate is much below the level at which maximum yield per recruit is obtained in *K. pelamis.* Thus, the present fishing pressure is lower than the level at which greater yield per recruit could be obtained. The yield per recruit as a function of age at first capture (under the current F) shows that the present age at first capture in *K. pelamis* is far less than the level at which maximum Y_w/R could be obtained. The maximum equilibrium yield of around 24000 t could be harvested at around 47% level of the present fishing mortality (Fig. 11).

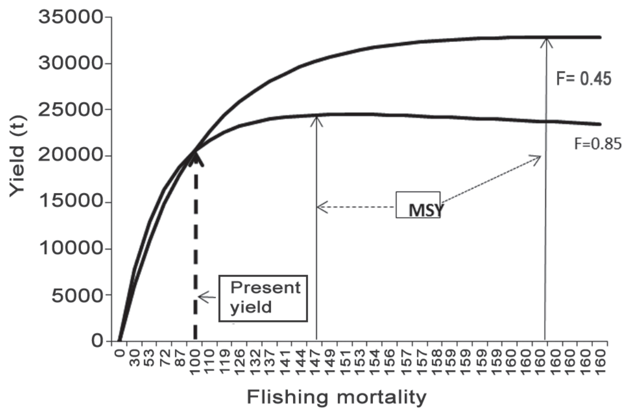

Fig. 11. Estimated yield of *K. pelamis* as percentage of fishing mortality

According to Yohannan *et al*. (1993), skipjack was exploited from a narrow area around the Lakshadweep islands and the fishing success depends on shoal migration in response to the prevailing eco-biological conditions of the region. The then Y/R values suggested considerable scope for further augmentation of yield. Similar studies from other regions are lacking. However, detailed analysis of fishery scenario and data interpretation indicate that present fishing grounds are almost well exploited and has only limited scope for augmenting production. Scope for further augmentation of production lies with the expansion of fishery to the less exploited areas like the oceanic islands, shelf break areas, seamounts and knolls/submerged banks, sea ridges and reef areas, where considerable concentration

Table 3. Estimated values of biomass, yield and stock of *K. pelamis* along Indian coast (2006-’10)

Area	Total mortality	Fishing mortality	Exploitation rate (E)	Exploitation ratio (U)	Yield (t)	Biomass (t)	Stock (t)
	(Z)	(F)	E=F/Z	U=F/Z x (1-e^{-z})	(Y)	B=Y/U	S=Y/F
NE	1.12	0.32	0.2857	0.19249	280	1455	875
SE	2.8	2.02	0.7214	0.67756	6562	9685	3249
SW	1.23	0.44	0.3577	0.25316	2576	10175	5855
NW	1.12	0.34	0.3036	0.20452	4865	23787	14309
LD	4	3.22	0.8050	0.79026	6261	7923	1944
India	1.410	0.853	0.605	0.4574	20544	44915	24078

of the species are noticed from personal observation and gathered information (ITK's). Occasional aggregation along the convergent paths, thermal fronts and floating objects are also observed. Spatial and seasonal distribution and abundance of the species, especially sub-surface in the open waters need to be explored.

Recent reports on fishery and migratory pattern of the species indicate that they are generally moving along the submerged plateau, ridges and oceanic islands. By tracking the migration, they are being exploited. Yohannan *et al.* (1993) raised certain issues like whether we are fishing the same stock on which Maldives, Spain, France and Srilanka are also fishing. Ganga and Pillai (2006) described some of the constraints faced by Lakshadweep fishermen, such as live bait scarcity, smaller sizes obtained in the FAD fishing as compared to the larger size in the natural schools and non-availability of adequate quantity of ice and fuel. Kasim and Mohan (2009) stated that tunas and related groups have very distinct behavioural patterns and they congregate in areas where favourable conditions prevail. Information on their ecology and influence of several oceanographic parameters on the resource is essential to predict abundance and to locate the productive fishing grounds and season. Detailed studies on the pelagic food supply, surface and subsurface temperature, illumination and current pattern of tuna fishing grounds needs to be undertaken.

James *et al*. (1992) opined from the stock assessment study (1984-88) that exploitation of tunas from the traditional grounds has reached the optimum level or near to it. Increase in the effort may not fetch enhanced returns in terms of direct operational coast (DOC) and cost benefit ratio (C:B). They reported heavy recruitment to the stock during south-west monsoon (June/July) and also during January/February. However, according to Sivasubramanian (1972), recruitment of skipjack may be occurring irregularly throughout the year with peak during July/August. In Lakshadweep, the exploitation of the skipjack tuna (*K. pelamis*) by pole and line is carried out in the vicinity of the islands. The present catch is 20,544 t. Increasing the effort by 4.7 times will yield an additional catch of 4000 t from the present grounds. But future expansion of the pole and line fishery beyond the traditional grounds is possible by maximum utilisation of the live baits, their large scale confinement/culture and supply, and proper conservation of their natural fishing grounds. In the pole-and-line/bait boat fishery, availability of suitable bait-fish presently represents one of the major constraints and hence, efforts to culture bait-fishes are receiving more attention. It appears, however, that bait rearing is hardly feasible on a large-scale to support a major fishery.

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