Indian Journal of Geo-Marine Sciences
Vol. 42(6), October 2013, pp. 758-769

Reproductive biology and population characteristics of *Sardinella gibbosa* and *Sardinella fimbriata* from north west Bay of Bengal

S Ghosh[1], M V Hanumantha Rao, S Sumithrudu, P Rohit[2] & G Maheswarudu

Visakhapatnam Regional Centre of CMFRI, Visakhapatnam – 530003, India
[2]Mangalore Research Centre of CMFRI, Mangalore – 575001, India
[1][E-mail: subhadeep_1977@yahoo.com]

Received 9 July 2012; revised 12 September 2012

Reproductive biology and population characteristics of *Sardinella gibbosa* and *Sardinella fimbriata* landed by gill netters from north west Bay of Bengal was studied during 2005 – 2010. Average annual catch was 21080 t, in which the contribution of *S. gibbosa* was 12790 t and the contribution of *S. fimbriata* was 8290 t. SST, rainfall and chlorophyll a were found to affect the annual catch of lesser sardines. Length weight relation showed differential growth between adults and indeterminates for both the species. Overall sex ratio varied between 1:1.28 to 1:1.33 for *S. gibbosa* and between 1:1.02 to 1:1.025 for *S. fimbriata* with length at first maturity of 13.03 cm for *S. gibbosa* and 13.27 cm for *S. fimbriata*. Peak spawning season was February – April for *S. gibbosa* and May - July for *S. fimbriata*. Total fecundity ranged between 12786 ova to 68377 ova for *S. gibbosa* and between 11066 ova to 60981 ova for *S. fimbriata*. Mature ovaries in lesser sardines contained both immature and mature ova. Von Bertalanffy growth equation was $L_t = 20.7\ [1 - e^{-0.96\ (t + 0.018)}]$ for *S. gibbosa* and $L_t = 20.7\ [1 - e^{-0.85\ (t + 0.023)}]$ for *S. fimbriata*. Natural mortality, fishing mortality, total mortality and exploitation rate were 1.90, 3.56, 5.46 and 0.65 for *S. gibbosa* and 1.75, 2.57, 4.32 and 0.59 for *S. fimbriata*, respectively. A higher value of E than $E_{0.5}$ for both *Sardinella gibbosa* and *Sardinella fimbriata* and a lower value of Maximum Sustainable Yield than annual average catch indicate intensive fishing of lesser sardines along north west Bay of Bengal.

[Keywords: Lesser sardines, Population dynamics, Spawning, Gill netters, Bay of Bengal]

Introduction

Bay of Bengal Large Marine Ecosystem (BOBLME) is considered a Class 1, highly productive ecosystem with primary production >300 g cm^{-2} yr^{-1} and chlorophyll a >0.5 mg m^{-3} [1]. Large nutrient input from river run-off supports high primary production in the coastal waters but the central parts of the bay are less productive because of the absence of large scale mixing or upwelling[1]. Zooplankton biomass is low near the shore but increases towards the EEZ boundary[2]. Fisheries of the BOBLME target a wide range of species, including sardine, anchovy, shad, mackerel, ribbonfish, tuna, snapper, grouper, eel, shark, shrimps and bivalves. Number of collapsed and overexploited stocks in the BOBLME is low but on the rise, with over 80% of the landings from fully exploited stocks. Intensive fishing in recent years is the primary force driving biomass changes in the BOBLME which in turn is threatening their long term sustainability[3].

Lesser sardines along with oil sardine and rainbow sardine form one of the largest fishery resources of the coastal waters of north west Bay of Bengal in terms of biomass. By virtue of occupying the lowest position in the food web, they play a vital role in the marine ecosystem. They occupy a position just above the primary producers and graze on them for their energy needs and support a variety of predatory resource by offering themselves as forage[4]. Any variation in their abundance will have a direct impact on the marine ecosystem. Two species of lesser sardines viz., *Sardinella gibbosa* Bleeker 1849 and *Sardinella fimbriata* Valenciennes 1847 has emerged as an important resource along north west Bay of Bengal. Indigenous, non-motorised and motorised crafts are employed to catch lesser sardines in substantial quantities. Catamarans are used in the inshore waters whereas gill netters are employed for exploiting the resource in the near shore areas upto depth of 40-60 m. Gill nets with mesh sizes of 20 mm, 23 mm, 25 mm, 28 mm, 30 mm and 38 mm account for about 75% of their landings and are now the chief

[1]Correspondence address:

gear for exploiting the lesser sardine fishery resources. Although *Sardinella gibbosa* and *Sardinella fimbriata* occur in the same locality, their schools always remain discrete and the occurrence of mixed species samples is very rare. The seasonal distribution and abundance of lesser sardines in the inshore waters of the north west Bay of Bengal appears to be influenced by the pattern of the sea surface circulation of the water masses in the Bay of Bengal[5]. The entry and abundance of lesser sardines in the coastal waters of north west Bay of Bengal during September-February coincides with the period of maximum biomass production of zooplankton, which forms food of the lesser sardines[2].

There is published information on the fishery and biology of lesser sardines from the Visakhapatnam – Kakinada region of north west Bay of Bengal[6-9] dating back to three decades. However, recent information from this region on the population characteristics and reproductive biology of lesser sardines are scanty. Information on the fishery and reproductive biology of lesser sardines from the Paradeep region of the north west Bay of Bengal are few. Present study is an attempt to provide a holistic insight into the reproductive biology and population characteristics of two species of lesser sardines viz., *Sardinella gibbosa* and *Sardinella fimbriata* from the entire north west Bay of Bengal.

Materials and Methods

Data on catch of *S. gibbosa* and *S. fimbriata* in north west Bay of Bengal viz., Andhra Pradesh, Odisha and West Bengal were collected weekly from commercial gill netters for six years from January 2005 to December 2010. Monthly and annual estimates of catches were made following the procedure adopted by the Fishery Resource Assessment Division of Central Marine Fisheries Research Institute, India[10]. Mean values of sea surface temperature (SST), rainfall and chlorophyll a for the region from January 2005 to December 2010 was obtained from International Comprehensive Ocean Atmospheric Data Sets (ICOADS), Indian Meteorological Department (IMD) and Sea Viewing Wide Field View of Sensor (SeaWifs), respectively.

A total of 6128 specimens of *S. gibbosa* in the size range of 3 to 19.9 cm and 7199 specimens of *S. fimbriata* in the size range of 2.5 to 19.9 cm were collected from Paradeep, Visakhapatnam and Kakinada and total length (cm) and body weight (grams to 0.01 g precision) were measured. Length-weight relationship from northern (Paradeep) and southern (Visakhapatnam – Kakinada) regions for *S. gibbosa* and *S. fimbriata* was calculated as $W = aL^{b}$ [11] separately for both sexes and indeterminates and significant differences in the slopes of the regression lines for males, females and indeterminates were ascertained by ANACOVA[12]. Monthwise sex ratio was determined from 2542 specimens from the southern region and 398 specimens from the northern region for *S. gibbosa* and 2654 specimens from southern region and 480 specimens from northern region for *S. fimbriata* and Chi-square test was performed to test the homogeneity of male and female distribution. Size at first maturity (L_{50}) was determined from 502 female specimens of *S. gibbosa* (433 specimens from southern region and 69 specimens from northern region) and 536 female specimens of *S. fimbriata* (461 specimens from southern region and 75 specimens from northern region) logistically by fitting the fraction of mature fish (stage III and above) against length interval using the nonlinear least square regression method of King[13]. Proportions of gravid and ripe females (V and VI) over time were taken to determine the spawning season of *S. gibbosa* and *S. fimbriata*. Gonadosomatic index (GSI) for females of *S. gibbosa* and *S. fimbriata* from each region was calculated by the formulae: $GSI = (Weight\ of\ gonad \times 100) / Weight\ of\ fish$. Fecundity for *S. gibbosa* and *S. fimbriata* was worked out by raising the number of ova in all subsamples of the mature and ripe ovary (V and VI) to the total ovary weight. Ovary subsamples were obtained from the anterior, middle and the posterior regions of the ovary. Ova diameter distribution in each subsample of the ovary was studied under a microscope using calibrated ocular micrometer.

For estimating Von Bertalanffy growth parameters, $L\infty$ and K of *S. gibbosa* and *S. fimbriata*, the monthwise length composition data of six years for the entire region were pooled and grouped with 0.5 cm class interval and analyzed using the ELEFAN (Electronic Length Frequency Analysis) I module of FiSAT (FAO ICLARM Stock Assessment Tools) software version 1.2.0[14]. Growth performance index (φ) was calculated from the final estimates of $L\infty$ and K[15]. The probability of capture and size at first capture (L_c) were estimated as in Pauly[16] and the age at zero length (t_0) from Pauly's[17] empirical equation. The growth and age for *S. gibbosa* and *S. fimbriata*

were determined using the von Bertalanffy growth equation, $Lt = L\infty\ (1 - \exp^{-k\ (t-\ t_0)})$. Longevity was estimated from $t_{max} = 3/K + t_0$[18]. Midpoint of the smallest length group in the catch was taken as length at recruitment (L_r). Natural mortality (M) was calculated by Pauly's empirical formula[19], taking the mean sea surface temperature as 28°C and total mortality (Z) calculated from length converted catch curve[20] using FiSAT software. Fishing mortality (F) was estimated by $F = Z - M$. Length structured virtual population analysis (VPA) of FiSAT was used to obtain fishing mortalities per length class of *S. gibbosa* and *S. fimbriata*. Exploitation rate was estimated from the equation, $E = F/Z$ and exploitation ratio from $U = F/Z(1\text{-}\exp^{-z})$ where, F is the fishing mortality rate. The yield per recruit (Y/R), spawning stock biomass per recruit (SSB/R), fishable biomass per recruit (Fish B/R), total biomass per recruit (Total B/R), total biomass (Total B), spawning stock biomass (SSB) and fishable biomass (Fish B) for *S. gibbosa* and *S. fimbriata* was estimated from Beverton and Holt Yield per Recruit Model using Yield software ver 1.0, MRAG Ltd, London, UK. Maximum sustainable yield (MSY) was calculated by the equation[21] for exploited fish stocks.

Results

Fishery

Average annual catch of lesser sardines by gill netters along north west Bay of Bengal for the period 2005 – 2010 was 21080 t, in which the contribution of *S. gibbosa* was 12790 t and the contribution of *S. fimbriata* was 8290 t. Annual catch of lesser sardines exhibited a steady increase from 19942 t in 2005 to 24214 t in 2008 after which it decreased to 22079 t in 2010. During 2005 – 2008, the lesser sardine catch in north west Bay of Bengal was dominated by *S. gibbosa* forming on an average 78.5% of the catches. However in 2009 – 2010 there was a distinct change in species composition of lesser sardines with *S. fimbriata* emerging as the dominant species contributing on an average 77.5% to the catches. Highest catch of 23245 t for *S. gibbosa* in 2008 coincided with the lowest catch of 969 t for *S. fimbriata*. Similarly in 2009, the maximum catch of 18110 t for *S. fimbriata* coincided with the minimum catch of 1791 t for *S. gibbosa*. The average catch of lesser sardines by gill netters in Andhra Pradesh was 13021 t, Odisha was 5424.3 t and West Bengal was 2634.7 t (Fig. 1).

Average SST, rainfall and chlorophyll a for north west Bay of Bengal during 2005 – 2010 were 28.5 ± 1.6°C, 17.5±15.63 cm month^{-1} and 1.94 ± 0.95 mg m^{-3} (Table 1). Maximum SST of 28.85 ± 1.3°C was recorded in 2010 and minimum SST of 28.11 ± 1.7°C was recorded in 2007. Highest rainfall of 24.7±23.8 cm month^{-1} was observed in 2006 and lowest rainfall of 14.4±16.9 cm month^{-1} was observed in 2007. Chlorophyll a values peaked in 2007 with 2.14 ± 0.55 mg m^{-3} and was lowest in 2008 with 1.58±0.79 mg m^{-3}. Strong linear association (One year lag Pearson Correlation Coefficient: 0.95; P = 0.007) was observed between chlorophyll a for the region and the annual catch of *S. gibbosa*. SST, rainfall and chlorophyll a in combination were found to effect significantly (P=0.008) the annual catch of lesser sardines with a one year lag ($F_{cal} = 9.05$; Multiple Regression Coefficient = 1).

Length composition

The length frequency distribution of *S. gibbosa* and *S. fimbriata* from the north west Bay of Bengal for the six year period indicated exploitation of juveniles in large numbers during October of 2008 for *S. gibbosa* (size range 30- 54 mm) and during October and April-May of 2005 - 2007 for *S. fimbriata* (size range 25-69 mm). The mean length of *S. gibbosa* and *S. fimbriata* in different months along north west Bay of Bengal is depicted in Fig. 2.

Mean length of *S. gibbosa* has decreased in this region from 132.3 ± 11.9 mm in 2005 to 128.1 ± 12.3 mm in 2010. This decrease in mean length was more pronounced (P > 0.05) in the southern region than that of the northern region. However the decreasing trend in mean length of *S. gibbosa* is compensated by the

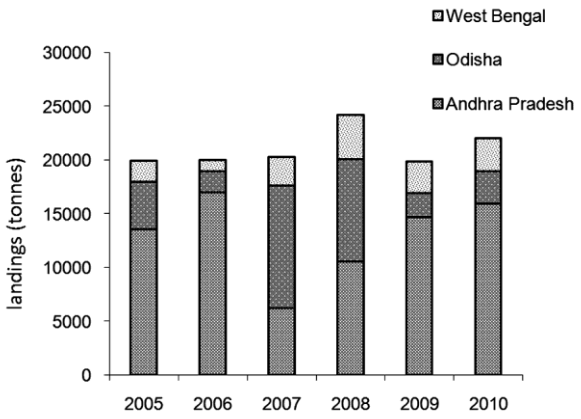

Fig. 1 — Annual landing trends of lesser sardines by gill netters along north west Bay of Bengal

Table 1 — Monthly environmental parameters (Mean±SD) during 2005-2010 along north west Bay of Bengal

Months	Temperature (°C)		Rainfall (cm)		Chlorophyll a (mg m^{-3})	
	Southern Region	Northern Region	Southern Region	Northern Region	Southern Region	Northern Region
January	26.20±0.60	26.26±1.14	13.9±4.0	5.5±2.5	0.35±0.07	2.18±1.47
February	27.1±0.92	26.29±0.49	7.8±9.7	1.5±1.1	0.32±0.07	2.24±1.54
March	27.91±1.03	27.66±1.81	3.7±5.2	1.7±1.7	0.28±0.03	2.25±1.66
April	29.79±1.32	29.36±1.38	0.8±0.9	12.6±10.9	0.65±.77	2.86±2.04
May	30.35±0.66	29.68±0.64	1.4±1.0	10.5±9.2	0.27±0.09	1.90±1.55
June	29.35±0.80	30.04±1.03	1.8±1.8	33.8±21.3	0.29±0.15	1.30±1.41
July	29.18±0.54	29.33±1.00	4.1±4.6	36.4±24.6	0.41±0.18	2.19±1.64
August	28.47±1.85	28.78±0.99	8.8±6.5	54.7±49.2	0.88±0.36	2.80±1.75
September	29.66±0.42	29.97±0.97	15.0±12.0	37.8±17.0	0.82±0.28	2.90±1.33
October	29.35±1.72	29.03±0.70	14.3±8.9	23.4±17.7	0.56±0.08	2.76±1.59
November	28.33±1.00	28.65±1.05	21.5±5.4	6.3±3.1	0.46±0.10	2.69±1.47
December	26.92±0.56	25.73±1.52	20.8±3.8	3.1±3.4	0.62±0.35	2.79±1.82

*Southern Region refers to Andhra Pradesh
* Northern Region refers to Odisha and West Bengal

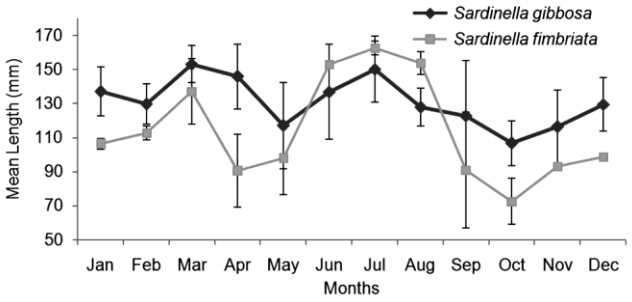

Fig. 2 — Mean lengths (Mean±SD) of *S. gibbosa* and *S. fimbriata* landed by gill netters in different months along north west Bay of Bengal during 2005-2010

increasing trend in mean length observed for *S. fimbriata*. Mean length of *S. fimbriata* increased in north west Bay of Bengal from 112.8 ± 12.1 mm in 2005 to 118.3 ± 10.4 mm in 2010. This overall increase in mean length was contributed entirely by the southern region ($P < 0.05$) wherein the mean length increased from 104.2 ± 10.9 mm in 2005 to 118.0 ± 8.6 mm in 2010. Mean length was more or less the same over the years in the northern region. Highest means length of 159.5 ± 6.6 mm and 165.4 ± 8.2 mm was recorded during July and lowest mean length of 62.9 ± 10.5 mm and 82.2 ± 13.6 mm was recorded during October in the southern and northern regions, respectively.

For both *S. gibbosa* and *S. fimbriata* (Table 2), the slope of the regression lines of length weight relation for indeterminates was significantly different ($P < 0.05$) from males ($F_{cal} = 9.6$ and 7.2) and females ($F_{cal} = 15.3$ and 20.0). However between males and females, there was no significant difference ($P > 0.05$) in the slope of the regression lines. Therefore a combined length – weight relationship was estimated which was log $W = -2.2514 + 3.1415$ log L ($r = 0.92$) for *S. gibbosa* and log $W = -1.8204 + 2.8513$ log L ($r = 0.95$) for *S. fimbriata*. Slope (b) of the combined regression relation for *S. gibbosa* and *S. fimbriata* ($t_{cal} = 2.8$ and 3.8; $t_{crit\ 0.05} = 1.96$) and of the regression relation for indeterminates ($t_{cal} = 9.2$ and 8.7; $t_{crit\ 0.05} = 1.96$) were significantly different from the isometric value of 3 indicating allometric growth.

Sex ratio and size at first maturity

Females dominated the commercial catches of *S. gibbosa* in most months (Table 3) with an overall sex ratio of 1:1.28 for the southern region and 1:1.33 for the northern region. Chi-square values indicated significant ($P<0.05$) dominance by females along the north west Bay of Bengal during January, February and April which happens to be the peak breeding season for this species. Sex ratio varied between 1:1.21 to 1:1.34 in the southern region and 1:1.29 to 1:1.38 in the northern region during 2005 – 2010 with significant dominance ($P < 0.05$) by females in most years.

There was more or less equal contribution by males and females in *S. fimbriata* (Table 4) with overall sex ratio of 1:1.03 for southern region and 1:1.025 for northern region. Significant ($P < 0.05$) dominance by females along the southern region of north west Bay of Bengal were observed during July-August and December and by males during April-May. Preponderance of females ($P > 0.05$) in the catch were observed in most years along north west Bay of Bengal.

Table 2 — Length weight relation of lesser sardines from north west Bay of Bengal

Sardinella gibbosa	Southern Region	Northern Region	P	Entire Region
Males	Log W = –2.2119 + 3.1055 log L (r^2 = 0.82)	Log W = –2.2872 + 3.1751 log L (r^2 = 0.80)	>0.05	log W = –2.2462 + 3.1375 log L (r = 0.90)
Females	Log W = –2.3156 + 3.1923 log L (r^2 = 0.88)	Log W = –2.2026 + 3.1032 log L (r^2 = 0.84)	>0.05	log W = –2.2601 + 3.1486 log L (r = 0.93)
Indeterminates	Log W = –1.7124 + 2.6906 log L (r^2 = 0.94)	Log W = –1.7634 + 2.7404 log L (r^2 = 0.96)	>0.05	log W = –1.7386 + 2.7162 log L (r = 0.97)
Sardinella fimbriata				
Males	Log W = –1.9202 + 2.9218 log L (r^2 = 0.88)	Log W = –1.8301 + 2.8432 log L (r^2 = 0.90)	>0.05	log W = –1.8812 + 2.8875 log L (r = 0.94)
Females	Log W = –1.9290 + 2.9555 log L (r^2 = 0.93)	Log W = –1.8431 + 2.8802 log L (r^2 = 0.94)	>0.05	log W = –1.8865 + 2.9184 log L (r = 0.98)
Indeterminates	Log W = –1.4914 + 2.4573 log L (r^2 = 0.81)	Log W = –1.5110 + 2.4715 log L (r^2 = 0.82)	>0.05	log W = –1.5006 + 2.4638 log L (r = 0.90)

*Southern Region refers to fish sampled from Visakhapatnam and Kakinada
* Northern Region refers to fish sampled from Paradeep

Table 3 — Monthly sex ratio of *Sardinella gibbosa* during 2005 – 2010 along north west Bay of Bengal

Months	Southern Region		Northern Region	
	Sex ratio (Female / Male)	Chi square value	Sex ratio (Female/Male)	Chi square value
January	0.46	25.79	1.44	2.40
February	2.01	60.45	1.73	5.08
March	1.12	1.01	1.35	1.15
April	1.96	33.80	1.50	1.60
May	1.13	0.48	0.84	0.11
June	0.73	2.18	0.81	0.16
July	1.00	0	1.00	0
August	1.00	0	1.06	0.01
September	1.17	0.46	1.13	0.05
October	0.94	0.18	0.94	0.03
November	1.33	8.57	1.33	0.95
December	1.37	4.36	1.37	0.69

* $P_{0.05}$ = 3.86
*Southern Region refers to fish sampled from Visakhapatnam and Kakinada
* Northern Region refers to fish sampled from Paradeep

S. gibbosa and *S. fimbriata* along north west Bay of Bengal attained sexual maturity at total lengths of 13.03 cm and 13.27 cm respectively (Figs 3 & 4). However, gonadal development and sexual maturity in both *S. gibbosa* and *S. fimbriata* was observed to commence from 10.75 cm onwards. Length at first maturity for both the lesser sardine species were marginally higher in the northern region as compared to the southern region (Table 5).

Spawning season

Gravid and ripe females of *S. gibbosa* and *S. fimbriata* were recorded in most months with their peak occurrence observed during February-March in

Table 4— Monthly sex ratio of *Sardinella fimbriata* during 2005- 2010 along north west Bay of Bengal

Months	Southern Region		Northern Region	
	Sex ratio (Female / Male)	Chi square value	Sex ratio (Female / Male)	Chi square value
January	0.87	0.86	0.75	0.86
February	1.20	2.18	0.91	0.10
March	0.94	0.18	0.92	0.05
April	0.46	32.93	0.70	1.69
May	0.67	9.60	1.00	0
June	1.04	0.12	1.47	2.41
July	1.64	20.28	1.52	2.15
August	1.50	6.00	1.26	0.69
September	1.10	0.29	1.27	0.26
October	1.20	1.09	0.76	0.56
November	1.00	0	0.89	0.08
December	1.30	5.55	0.95	0.02

* $P_{0.05} = 3.86$
*Southern Region refers to fish sampled from Visakhapatnam and Kakinada
* Northern Region refers to fish sampled from Paradeep

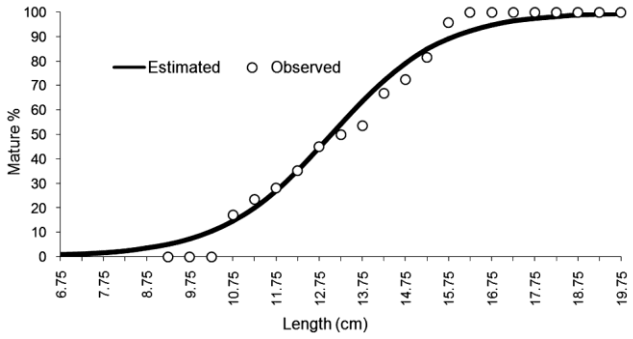

Fig. 3 — Size at first maturity of females of *S. gibbosa*

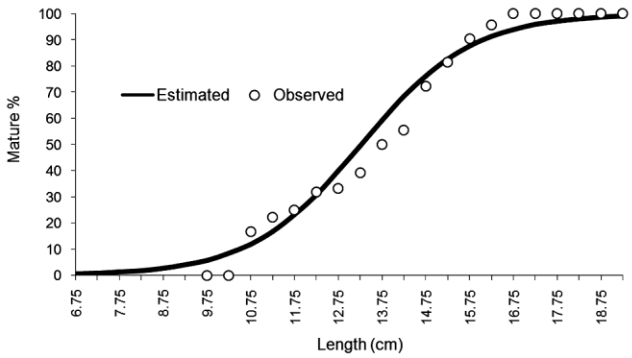

Fig. 4 — Size at first maturity of females of *S. fimbriata*

the southern region and March-April in the northern region for *S. gibbosa* and May-July throughout the north west Bay of Bengal for *S. fimbriata* (Table 5 and Fig. 5). Along north west Bay of Bengal for *S. fimbriata*, the percentage of mature spawners were marginally higher during 2009-2010 ($P > 0.05$) but for *S. gibbosa*, the percentage of mature spawners were more or less the same throughout the study period. The gonadosomatic index for females of *S. gibbosa* and *S. fimbriata* varied in different months with peaks of 8.0 ± 1.4 in February and 7.7 ± 2.7 in March in the southern region and 8.5±2.3 in March and 7.9 ± 1.4 in April in the northern region for *S. gibbosa* and 7.7 ± 1.4 and 8.5 ± 1.4 in May, 8.1 ± 0.8 and 8.0 ± 0.8 in June and 7.6 ± 0.7 and 6.9 ± 1.6 in July for *S. fimbriata* along the southern and northern regions, respectively after which it decreased in subsequent months (Fig. 6) for both the species of lesser sardines. This is in general agreement with the peak spawning season observed for both the species.

Mature ovaries of females of *S. gibbosa* and *S. fimbriata* from the north west Bay of Bengal contained both immature and mature ova. A single batch of mature or large maturing ova was observed which was sharply separated from the general stock of small eggs. Mature ova of *S. gibbosa* measured from 0.50 to 0.79 mm in diameter and of *S. fimbriata* measured from 0.60 to 0.79 mm in diameter (Fig. 7). Presence of largest sizes of yolked ova in mature ovary during February-April for *S. gibbosa* and May-July for *S. fimbriata* further confirms this to be the peak breeding season of *S. gibbosa* and *S. fimbriata*.

3.5 Fecundity

The number of eggs released by *S. gibbosa* and *S. fimbriata* generally increased with the weight and size of the fish. The number of ova per gram body weight in *S. gibbosa* ranged from 847.7 to 1365.1 with a mean of 1103 along the southern region and

Table 5 — Comparison on the reproductive biology of lesser sardines from north west Bay of Bengal

	Sardinella gibbosa		*Sardinella fimbriata*	
	Southern Region	Northern Region	Southern Region	Northern Region
Length at first maturity	12.98 cm	13.10 cm	13.23 cm	13.32 cm
Peak Spawning Season	February- March	March - April	May - July	May - July
Percentage of mature females during peak spawning (Mean ± SD)	57.87 ± 11.38	57.99 ± 9.81	55.70 ± 6.56	52.84 ± 7.51
Percentage of mature females throughout the year (Mean ± SD)	25.36 ± 23.47	26.97 ± 23.14	29.30 ± 23.55	25.07 ± 21.83
Gonadosomatic index during peak spawning (Mean ± SD)	7.88 ± 2.10	8.23 ± 1.80	7.83 ± 1.27	7.81 ± 0.97
Gonadosomatic index throughout the year (Mean±SD)	4.54 ± 2.20	4.33 ± 2.20	4.56 ± 2.47	4.62 ± 2.33
Fecundity – Length Relation	log F = 1.1578 + 2.8415 log L (r = 0.99)	log F = 1.2294 + 2.7958 log L (r = 0.99)	log F = 0.5727 + 3.2353 log L (r = 0.99)	log F = 0.6929 + 3.1493 log L (r = 0.99)
Fecundity – Weight Relation	log F = 3.3154 + 0.8277 log W (r = 0.99)	log F = 3.3230 + 0.8313 log W (r = 0.98)	log F = 2.7345 + 1.1019 log W (r = 0.99)	log F = 2.7638 + 1.0927 log W (r = 0.99)

*Southern Region refers to fish sampled from Visakhapatnam and Kakinada
* Northern Region refers to fish sampled from Paradeep

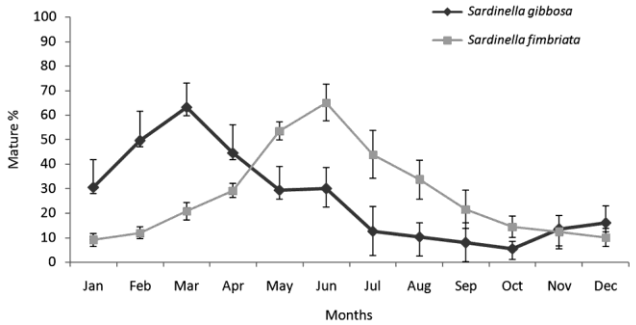

Fig. 5 — Month-wise occurrence (Mean±SD) of mature females of *S. gibbosa* and *S. fimbriata* during 2005 – 2010

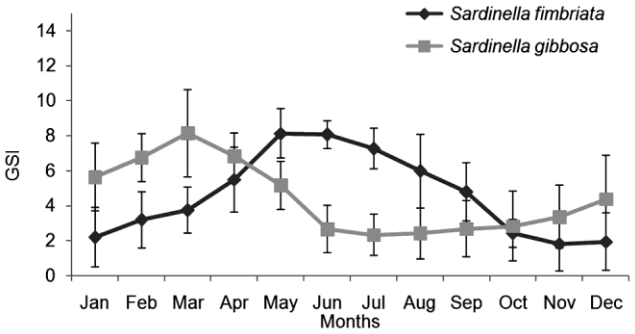

Fig. 6 — Gonadosomatic index (Mean±SD) of females of *S. gibbosa* and *S. fimbriata* during different months

from 894 to 1398.7 with a mean of 1138.9 along the northern region. In *S. fimbriata*, it ranged from 621.3 to 955.6 with a mean of 793.1 along the southern region and from 648.4 to 982.2 with a mean of 818.7 along the northern region. Total fecundity for *S. gibbosa* ranged between 12786 ova to 66113 ova in the southern region and between 13594 ova to 68377 ova in the northern region. For *S. fimbriata*, total fecundity ranged between 11066 ova to 59133 ova in the southern region and between 11430 ova to 60981 ova in the northern region. In *S. gibbosa* and *S. fimbriata*, there were no significant differences in the slopes of the regression lines for body length and fecundity (F = 1.1 and 2.0) and for body weight and fecundity (F = 0.03 and 0.3) between the two regions along the north west Bay of Bengal and hence a common relation was arrived at which was log F = 1.1936 + 2.8186 log L (r = 0.99) and log F = 3.3192 + 0.8295 log W (r = 0.98) for *S. gibbosa* and log F = 0.6328 + 3.1923 log L (r = 0.99) and log F = 2.7492 + 1.0973 log W (r = 0.99) for *S. fimbriata*.

Population characteristics

Growth parameters, L∞ and K (annual) estimated using the ELEFAN I programme for *S. gibbosa* were 20.7 cm and 0.96 and for *S. fimbriata* were 20.7 cm and 0.85. Age at zero length (t_0) was -0.018 years for *S. gibbosa* and -0.023 years for *S. fimbriata*. The von Bertalanffy growth equation was:

$L_t = 20.7\ [1 - e^{-0.96\ (t + 0.018)}]$ for *S. gibbosa* and $L_t = 20.7\ [1 - e^{-0.85\ (t + 0.023)}]$ for *S. fimbriata*.

Accordingly, *S. gibbosa* attained sizes of 12.90 cm, 17.71 cm and 19.55 cm by the end of 1, 2 and 3 years. *S. fimbriata* reached lengths of 12.02 cm, 16.98 cm and 19.11 cm after 1, 2 and 3 years. The fishery was dominated by fishes of 1 year old class for *S. gibbosa* and by fishes of 0 year old class for *S. fimbriata*. The

Table 6—Population characteristics of lesser sardines from north west Bay of Bengal

Parameter	*Sardinella gibbosa*	*Sardinella fimbriata*
Growth performance index (φ)	2.61	2.56
Lifespan (t_{max})	3.11 years	3.51 years
Length at first capture (L_c)	14.9 cm	15.5 cm
Age at first capture (t_c)	1.31 year	1.59 year
Annual Recruitment Numbers	5246698873	4379264723
Length at recruitment (L_r)	3.2 cm	2.7 cm
Natural Mortality (M)	1.90	1.75
Fishing Mortality (F)	3.56	2.57
Total Mortality (Z)	5.46	4.32
Exploitation Rate (E)	0.65	0.59
Exploitation Ratio (U)	0.65	0.59
Maximum Sustainable Yield	9976 t	6858 t
Total Biomass	14173.3 t	16695.6 t
Fishable Biomass	2552.8 t	2602.8 t
Spawning Stock Biomass	6816.8 t	7294.1 t
Yield per Recruit	1.73 g	1.53 g
Total Biomass per Recruit	2.70 g	3.81 g
Fishable Biomass per Recruit	0.49 g	0.59 g
Spawning Stock Biomass per Recruit	1.3 g	1.67 g

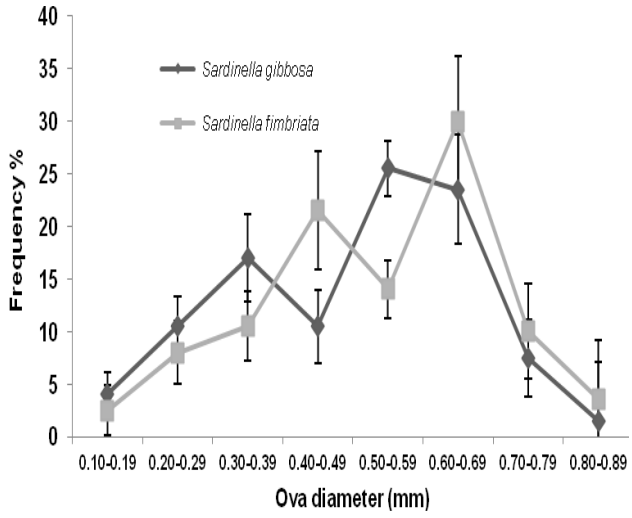

Fig. 7—Ova diameter distribution percentage in mature and ripe ovaries of *S. gibbosa* and *S. fimbriata*

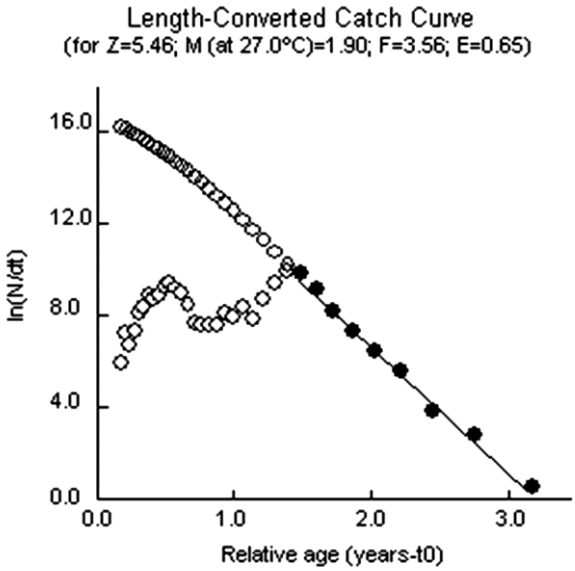

Fig. 8—Length converted catch curve of *S. gibbosa* landed by gill netters along north west Bay of Bengal where N is the number of fish in each length class, dt is the time needed for the fish to grow through each length class and t_0 is the age at zero length

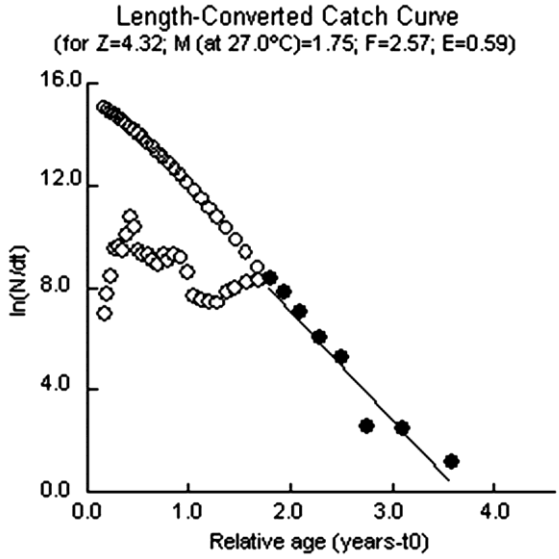

Fig. 9—Length converted catch curve of *S. fimbriata* landed by gill netters along north west Bay of Bengal where N is the number of fish in each length class, dt is the time needed for the fish to grow through each length class and t_0 is the age at zero length

other growth parameters, mortality and exploitation rates, yield and biomass and yield per recruit and biomass per recruit is depicted in Table 6. The length converted catch curve utilized in the estimation of Z for *S. gibbosa* is represented in Fig. 8 and for *S. fimbriata* is represented in Fig. 9. VPA indicated that main loss in the stock up to 14.2 cm size for *S. fimbriata* and *S. gibbosa* was due to natural causes. Fishes became more vulnerable to the gear after this size and mortality due to fishing increased. Maximum fishing mortality of 3.57 for *S. fimbriata* was recorded at size of 18.2 cm and 4.78 for *S. gibbosa* was recorded at size of 16.2 cm. Unimodal recruitment

pattern with recruitment occurring in most months was observed for *S. gibbosa*. Peak in recruitment was recorded during April-July contributing 66.5% of the recruits. Bimodal recruitment pattern with primary peak in recruitment during March-April and secondary peak in recruitment during September-October was observed for *S. fimbriata*. Primary peak pulse produced 46.75% of the recruits and secondary peak pulse produced 24.64% of the recruits. Annual average yields for *S. gibbosa* and *S. fimbriata* is above MSY and exploitation rates are above optimum ($E_{0.5}$) suggesting the fact that both the species of lesser sardines are overexploited along the northwest Bay of Bengal.

Discussion

A gradual shift in the fishing grounds from nearshore waters to offshore waters coupled with favourable environmental conditions has resulted in catching more of lesser sardines in recent years. Rise in temperature and an increase in chlorophyll a content in sea water over the years would have increased the plankton production and the subsequent abundance of lesser sardines, as lesser sardines are known to feed exclusively on plankton. Similar observations were recorded by Ganapati and Rao[6] where in peak catch of lesser sardines coincided with peak in phytoplankton production. Environmental parameters like temperature, rainfall intensity, thermocline, upwelling, solar periodicity, wind etc. are known to greatly influence the spawning, recruitment and yield of pelagic stocks like lesser sardines[22-24]. Domination of *S. gibbosa* during 2005-2008 and of *S. fimbriata* during 2009-2010 could be attributed to the cyclic pattern generally observed in the catches of sardines[25].

Gill nets with mesh sizes of 20, 23, 25, 28, 30 and 38 mm are operated in various degrees during the lesser sardine fishery season. The exploitation of juveniles in large numbers during October of 2008 for *S. gibbosa* and during October and April – May of 2005-2007 for *S. fimbriata* is because of extensive use of gill nets with 20 mm mesh sizes during this period. Similar observations were made in earlier studies from north Andhra coast wherein large number of juveniles of *S. gibbosa* and *S. fimbriata* measuring 5-10 cm were encountered in gill net catches during September-October[5,26,27]. Operation of gill nets with smaller meshes gradually changes to those with larger meshes as the fishing season advances from September to July. Certain size groups of *S. gibbosa* and *S. fimbriata* suddenly disappeared from the fishing grounds during some months and certain other size groups showed up in the catches indicating that the schools of lesser sardines are constantly on the move and that different broods entered the population[6, 9,27,28]. The decrease in mean length of *S. gibbosa* recorded over the years is probably because of growth overfishing. The high fishing mortality and exploitation rate observed for *S. gibbosa* in the present study further substantiate the present finding. There was differential growth between juveniles and adults of *S. gibbosa* and *S. fimbriata*. This difference is possibly because of factors related to biological phenomena like maturity stages, feeding behaviour and competition for food.

Females outnumbered males in the commercial catches of *S. gibbosa* for most months, while there was more or less equal contribution by males and females in the catches of *S. fimbriata*. Peak breeding season for both the lesser sardine species coincided with an abundance of females in the catch. This could be attributed to the changes in the pattern of migration of sexes to and from the fishing grounds during spawning season. Similar results were reported by Dutt[26], wherein males dominated the catches of *S. gibbosa* at the commencement of the fishing season but as the fishing season progressed females outnumbered males. Size at first maturity ranging from 13.3 cm-13.6 cm for *S. gibbosa* was reported in earlier studies from Gulf of Mannar[29] and Visakhapatnam[30] which are in conformity to the present study. However in *S. fimbriata*, the present length at first maturity was lower than 14.6 cm observed earlier from Indian waters[30]. This decrease in length at first maturity is because of the changes in the biotic and the abiotic components of the ecosystem over the years. Length at first maturity for both the species of lesser sardines were marginally lower in the present study in the southern latitudes. Prevalent high temperature accelerating gonadal development coupled with lower mean length observed explains the decreased length at first maturity in the southern latitudes. Peak spawning of *S. gibbosa* in February-April corroborates well with the findings of earlier workers[6,7,31] from Visakhapatnam. In *S. fimbriata*, there appears to be a shift in the peak spawning season over the decades from July-August during 1984-1988[30] to the present May-July. This change can be attributed to the early

onset of monsoon in recent years which is beneficial for the spawning of *S. fimbriata*. Rainfall intensity during monsoon has been found to positively impact the spawning and recruitment of sardines along the Indian coast[23,25]. About 50-55% of females encountered in the catch during May-July were mature which contradicts the reports of earlier workers[9 and 26], who stated that the occurrence of mature females of *S. fimbriata* is rare during their spawning season along north west Bay of Bengal. This can be either because of change in the spawning ground of *S. fimbriata* from offshore waters to nearshore waters or because of extension in fishing operations to farshore areas in recent times. Proportion of mature females and gonadosomatic index were found to vary marginally between regions along north west Bay of Bengal. Variation in plankton availability causes a change in the content of body lipid and its conversion into gonadal tissue resulting in differences in gonadal maturation, spawning and recruitment in sardines[23]. Observations on the spawning season of *S. gibbosa* and *S. fimbriata* are further supported by the size progression of yolked ova during different months. Ripe ovaries of *S. gibbosa* and *S. fimbriata* contained one batch of mature ova sharply separated from the general stock of immature eggs. Therefore it is reasonable to assume that lesser sardines probably spawn only once in a year[31]. Fecundity of *S. gibbosa* and *S. fimbriata* recorded were higher than those reported by earlier workers[9,32]. Higher fecundity recorded in the present study is because fishes were sampled from Paradeep in addition to Visakhapatnam and Kakinada and fishes in general tend to produce large batches of eggs in waters with marked variations in annual temperature[33]. Relationship between fecundity and body length and between fecundity and body weight indicated that the increase in fecundity in relation to the weight of fish is much lower than that of the length of fish. This exponential increase in rate of egg production with length and weight of fish is highly significant in the context of protection and conservation of spawners of marine fishes.

Lesser sardines exhibit all characteristics of small pelagic tropical fishes like fast growth, short life span and high natural mortality. *S. gibbosa* and *S. fimbriata* attain 65-70% of their maximum length in the first year itself. $L\infty$ recorded for *S. gibbosa* was higher while that for *S. fimbriata* was lower than those reported earlier from Indian waters[29,30,34,35]. Growth coefficient for both the species of lesser sardines was lower than that reported earlier from various places[29,30,34,35]. Fishery along the north west of Bay of Bengal for lesser sardines was dominated by fishes of 0 and 1 year old classes, as also observed from Visakhapatnam by various earlier workers. Life span of lesser sardines recorded in the present study is also similar to that reported earlier from Indian waters[30,34]. Length at first capture was high for lesser sardines when compared to the length at first maturity indicating that majority of them were caught after they had matured and spawned at least once in their life. Peak in recruitment of *S. gibbosa* and *S. fimbriata* conforms to the peak breeding season of this two species. Beverton and Holt[38] pointed out that the natural mortality coefficient of a fish is directly related to the growth coefficient (K) and inversely related to the asymptotic length ($L\infty$) and the life span. Same appeared to be true for *S. gibbosa* and *S. fimbriata* which had higher growth coefficient of 0.96 per year and 0.85 per year and lower lifespan of 3.1 and 3.5 years were found to have relatively higher natural mortality coefficient of 1.90 per year and 1.75 per year. Various authors have reported natural mortality ranging from 2.16 to 3.2 per year for lesser sardines[29,34]. The M/K ratio of 1.98 and 2.06 obtained in the present study for *S. gibbosa* and *S. fimbriata* was well within the normal range of 1-2.5, as suggested by Beverton and Holt[39]. High exploitation rate of 0.65 for *S. gibbosa* and 0.59 for *S. fimbriata* observed was an indication of intensive fishing of this species. It is evident from the results that since the value of E for both the species of lesser sardines are higher than $E_{0.5}$ and the value of MSY are lower than their annual average catch, the stocks are under higher fishing pressure than the sustainable level. A possible management measure would be to ban the use of gill nets with mesh sizes ranging from 20 mm to 25 mm which are used extensively in the early part of the lesser sardine fishery season (September-October) catching very young juveniles. This ban on the use of small meshed gill nets would enable partial relief to young juveniles from fishing mortality allowing them to feed abundantly on the available zooplankton and grow rapidly before they become vulnerable to capture by gill nets of mesh sizes 28 mm to 38 mm. However, the relatively high values of E_{max} close to '1' for both the species of lesser sardines indicate the capacity of these resources to sustain heavy fishing pressure.

Conclusion

The landings of lesser sardines along north west Bay of Bengal witnessed an increasing trend because of intensive fishing and favourable environment. Exploitation status and MSY reveals both the species of lesser sardines to be overexploited. Ban on the use of gill nets with mesh sizes below 28 mm would allow all the juveniles to grow and replenish the depleted stock. Peak spawning season for both the species coincided with the domination of females in the catch. The mean length and reproductive biology varied insignificantly between regions and years and this minor deviation is possibly induced by the climatic differences.

Acknowledgements

Authors are thankful to Dr. G. Syda Rao, Director, CMFRI for the financial support, encouragement and facilities provided.

References

1 Dwivedi S N, Long-tem variability in the food chains, biomass yield and oceanography of the Bay of Bengal Ecosystem, in: *Large Marine Ecosystems: Stress, Mitigation and Sustainability*, edited by K. Sherman, L. M. Alexander and B. D. Gold, (AAAS Press, Washington DC) 1993, pp. 43-52.

2 Desai B N & Bhargava, R M S, Biologic production and fishery potential of the Exclusive Economic Zone of India, in: *Large Marine Ecosystems of the Indian Ocean: Assessment, Sustainability and Management*, edited by K. Sherman, E. Okemwa and M. Ntiba, (Blackwell Science, Cambridge, US) 1998, pp. 327-333.

3 Preston G L, *Review of the status of Shared/Common Marine Living Resource Stocks and of Stock Assessment Capability in the BOBLME region*, Bay of Bengal Large Marine Ecosystem (BOBLME) Theme Report, FAO-BOBLME Programme, Rome, 2004.

4 Chacko P I, On the bionomics of the Indian sprat *Sardinella gibbosa* (Cuv & Val), *J. Bombay Nat. Hist. Soc*, 46 (1946) 407-408.

5 Luther G, Management of lesser sardine fishery resources along North Andhra coast, *Souvenir*, (Visakhapatnam Regional Centre of CMFRI, India) 2001, pp. 5 – 9.

6 Ganapati P N & Rao K S, On the bionomics of *Sardinella gibbosa* (Blkr) off Waltair coast, *J. Zool. Soc. India* 9 (1957) 162-182.

7 Dharmamba M, Studies on the maturation and spawning habits of some common clupeoids of Lawson's Bay, Waltair, *Indian J. Fish*., 6 (1959) 374-388.

8 Rao K V S, Rao V R, Mojumder P, Appa Rao T, Reuben S, Dan S S & Rao B N, Pelagic fishery resources of Lawson's Bay, Waltair, *Indian J. Fish*., 27 (1980) 35-53.

9 Appa Rao T, On some aspects of the fishery and biology of sardines of the Waltair area, *Indian J. Fish*., 28 (1981) 96-103.

10 Srinath M, Kuriakose S & Mini K G, Methodology for estimation fish landings in India, CMFRI Special Publication 86 (2005), 57 pp.

11 Le Cren E D, The length weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*), *Journal of Animal Ecology* 20 (1951) 201-219.

12 Snedecor G W & Cochran W C, *Statistical Methods*, (Oxford and IBH Publishing Co., Calcutta, India), 1967, 593 pp.

13 King M, Fisheries biology, assessment and management, (Oxford University Press, Oxford, UK) 1995, 342 pp.

14 Gayanilo Jr. F C, Sparre P & Pauly D, The FAO-ICLARM stock assessment tools (FiSAT) user's guide, FAO computerised information series: Fisheries, (FAO, Rome, Italy) 1997.

15 Pauly D & Munro J L, Once more, on the composition of growth in fish and invertebrates, *Fishbyte* 2 (1984) 21.

16 Pauly D, Length converted catch curves. A powerful tool for fisheries research in tropics (Part-II), ICLARM *Fishbyte*, 2 (1984) 13-14.

17 Pauly D, Theory and management of tropical multi-species stocks. A review with emphasis on the south-east Asian demersal fisheries, ICLARM studies and reviews 1, 1979, 35 pp.

18 Pauly D, Some simple methods for the assessment of tropical fish stocks, FAO Fisheries Technical Paper 243, 1983a, 52 pp.

19 Pauly D, On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks*, Journal Cons. CIEM*, 39 (1980) 175-192.

20 Pauly D, Length converted catch curves. A powerful tool for fisheries research in tropics (Part-1), *ICLARM Fishbyte*, 1(1983b) 9-13.

21 Gulland J A, Report of the FAO/UNDP workshop on the fishery resources of the Western Indian Ocean – South Equator, 10FC/DEV/79/45, (FAO, Rome) 1979, pp. 1-37.

22 Kawasaki M, Long-term variability in the pelagic fish populations, in: *Long-term variability of pelagic fish populations and their environment*, edited by Tsuyoshi Kawasaki Pergamon, Proceedings of the International Symposium, (Sendai, Japan) 1989, p. 47-60.

23 Jayaprakash A A, Long term trends in rainfall, sea level and solar periodicity: A case study for forecast of Malabar sole and oil sardine fishery, *J. Mar. Biol. Ass. India*, 44 (2002) 163-175.

24 Borges M F, Santos A M P, Crato N, Mendes H & Mota B, Sardine regime shifts off Portugal: a time series analysis of catches and wind conditions, *Sci. Mar*., 67 (2003) 235-244.

25 Srinath M, Exploratory analysis on the predictability of oil sardine landings in Kerala, *Indian J. Fish*., 45 (1998) 363-374.

26 Dutt S, Biometric studies on *Sardinella* spp. off Waltair coast 1. *Sardinella fimbriata* Val, *Proc 1st All India Congr. Zool*., (1959) 287-298.

27 Dutt S, Biometric studies on *Sardinella* spp off Waltair Coast 2 *Sardinella gibbosa* Blkr, *Zool. Soc. India*, XIII (1961) 78-89.

28 Luther G, Status of sardine fishery at Visakhapatnam, *Marine Fisheries Information Service*, *Technical and Extension Series*, 133 (1994) 1-10.

29 Abdussamad E M, Pillai N G K, Habeeb Mohammed O M M J & Jayabalan K, Sardines of the Gulf of Mannar ecosystem – fishery and resource characteristic of major species, *Indian J. Fish*., 57 (2010) 7-11.

30 Bennet P S, Radhakrishnan Nair P N, Luther G, Annigeri G

G, Srinivasarangan S & Kurup K N, Resource characteristics and the stock assessment of lesser sardines in the Indian waters, *Indian J. Fish*., 39 (1992) 136-157.

31 Sekharan K V, Muthu M S, Rao G S & Rao B N, Spawning concentrations of the sardine, *Sardinella gibbosa* (Bleeker), off the north Andhra Coast in March - April 1969, *Indian J. Fish*., 16 (1969) 156-160.

32 Bennet P S, Some observations on the fishery and biology of *Sardinella fimbriata* (Val.) at Vizhinjam, *Indian J. Fish*., 14 (1967) 145-158.

33 Martins A S & Haimovici M, Reproduction of the cutlassfish *Trichiurus lepturus* in the southern Brazil subtropical convergence ecosystem, *Scientia Marina*, 64 (2000) 97-105.

34 Devaraj M, Kurup K N, Pillai N G K, Balan K, Vivekanandan E & Sathiadhas R, Status, prospects and management of small pelagic fisheries in India, in: *Small Pelagic fisheries in the Asia Pacific region*, Proceedings of the APFIC Working Party on Marine Fisheries, (APFC FAO RAP, Thailand) 1997, pp. 91-198.

35 Annigeri G G, On the age, growth and mortality of *Sardinella gibbosa* (Bleeker) of Karwar waters (west coast of India), *Indian J. Fish*., 36 (1989) 199-203.

36 Beverton R J H & Holt S J, A review of method for estimating mortality rates in exploited fish population, with special reference to source of bias in catch sampling, *Rapports et Proces – Verbaux des Reunions CIEM*, 140 (1956) 67-83.

37 Beverton R. J H & Holt S J, A review of the lifespans and mortality rates of fish in nature and their relation to growth and other physiological characteristics, in: *Ciba Foundation Colloquia on ageing*, edited by G. E. W. Wolsenholmy and M. O'Connor, 5, 1959, pp. 142-180.