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Fishery and stock dynamics of ribbonfish *Trichiurus lepturus* (Linnaeus, 1758) in the Indian Exclusive Economic Zone

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Abstract

The fishery and stock dynamics of *Trichiurus lepturus* (Linnaeus, 1758) were studied in the Indian Exclusive Economic Zone (EEZ) for the period 2014-2019. The average annual landing was 2,09,285 t and varied from 1,77,259 to 2,39,355 t. Trawl nets were the major gear, contributing more than 85% with an average annual catch rate of 4.56 kg h^{-1}. The annual catch rate decreased over the years from 5.40 to 3.85 kg h^{-1}. Landings (23,155-40,354 t) and catch rates (4.24-8.67 kg h^{-1}) were highest during the post-monsoon months (September-December). Around 63% of the landings (1,32,072 t) were from the north-west coast, with Gujarat alone contributing three-fourth (98,296 t) of it, followed by the south-west coast (17%, 36,017 t), the south-east coast (12%, 25,322 t) and the north-east coast (8%, 15,875 t). The von Bertalanffy's growth equation was $L_t = 143.8\ [1-e^{-0.48\ (t + 0.03285)}]$. Natural mortality, Exploitation ratio and Maximum Sustainable Yield (MSY) were 0.76; 0.65 and 1,59,504 t respectively. Recruitment was substantial throughout the year with a single modal peak during June-October. With lower lengths at first capture and recruitment and with exploitation above the maximum permissible level and landings higher than MSY; the species appears to be overexploited along the Indian coasts. The present study is the first holistic report on the population parameters and stock status of *T. lepturus* from the Indian EEZ.

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Introduction

Ribbonfishes are cosmopolitan in distribution, inhabiting the coastal pelagic and warm temperate shelf waters of the world (Nakamura and Parin, 1993). Also known as large head hair-tail or cutlass fishes, ribbonfishes form one of the major marine fishery resources in the Indian EEZ. Belonging to the family Trichiuridae, ribbonfishes are represented by eight species *viz*., *Trichiurus lepturus*, *T. auriga*, *T. pantului*, *T. haumela*, *Lepturacanthus savala*, *L. gangeticus*, *Eupleurogrammus muticus* and *E. intermedius* (James *et al*., 1986) in the marine waters of India; of which only *T. lepturus* supports a commercial fishery by virtue of being the most abundant and the dominant species landed all along the Indian coast. Prior to the 1990s, the ribbonfish fishery was confined to the depth zone shallower than 50 m and the resource was exploited by traditional, motorised and small mechanised sectors (Lazarus *et al*., 1992). During 1991-2000, the fishery extended further offshore to depths of around 70 m (Nair *et al*., 1996; Nair and Prakasan, 2003). Post 2000, with improvements in fishing technology and exploitation efficiencies, the operational depths increased to more than 120 m as a result of the vertical and horizontal extension in the fishing grounds of mechanised crafts. Similarly, there has been a steady increase in the landings of the resource over the decades. During 1956-1970, the average landings in the Indian EEZ was 0.3 lakh t, which doubled during 1971-1990 and this further doubled to 1.2 lakh t on an average during 1991-2000 (Nair and Prakasan, 2003). The landings subsequently increased to an average of 1.78 lakh t during 2007-2012 (Rajesh *et al*., 2015). In the last decade, the landings have been hovering around 2.0 lakh t, with no significant increase. Presently, the resource is exploited by a multitude of gears, but more than three-fourths of the contribution comes from multiday trawls and the bulk of the remaining is by gillnets. Ribbonfishes are targeted all along the Indian EEZ owing to its consistent export demand in frozen form, especially from China and other South-East Asian countries (Ghosh *et al*., 2014).

Fish stock assessment fundamentally aims to provide fishery managers advisories on the optimum level of exploitation and on effectively managing the resources using the information on population characteristics gained from estimating age and growth (Sparre and Venema, 1998). Although the landings of ribbonfishes from the Indian EEZ have stagnated over the last few years, no comprehensive studies on the stock status of the resource are available on a national scale. Studies conducted to date are all region-specific along the Saurashtra coast (Ghosh *et al*., 2009; Avinash *et al*., 2014; Ghosh *et al*., 2014), Mumbai coast (Chakraborty, 1990; Khan, 2006), Mangalore coast (Rajesh *et al*., 2015), Kakinada coast (Narasimham, 1976; 1983; 1994; Abdussamad *et al*., 2006) and Visakhapatnam coast (Reuben *et al*., 1997; Ghosh *et al*., 2014). In the above context, the present study was performed to decipher the population dynamics and to elucidate the status of stocks of *T*. *lepturus* fished along the Indian coast.

The National Policy for Marine Fisheries (NPMF, 2017) emphasises the need for a national management strategy for fishery resources in the Indian EEZ. Presently, due to the nature of resource distribution and abundance coupled with overcapacity and enhanced fishing efficiency, fishing vessels often land catches taken from one maritime state at landing centres of another maritime state. Population and stock parameters for the resource, estimated using such state-wise catch and effort data for individual maritime states are therefore, often misleading and not precise. With no holistic survey data available for the species in estimating the biomass or abundance (Udupa *et al*., 2022), it is assumed that the landing information is a proxy for the available biomass and abundance in Indian EEZ. The knowledge gained from the study would be used for evolving pan-India measures for sustainably exploiting and managing the species.

Materials and methods

Considering the classification of marine ecoregions by Spalding *et al*. (2007), the oceanographic realms and unique biodiversity of the resources, the Indian EEZ for the present study was divided into four zones; north-west coast, south-west coast, south-east coast and the north-east coast. Data on month-wise and gear-wise landings from each maritime state during 2014-2019 for *T. lepturus* was obtained from the Fishery Resource Assessment Division of the ICAR-Central Marine Fisheries Research Institute, Kochi. The catch and effort data for adjacent maritime states were pooled and expressed zone-wise for the zones: north-west coast (Gujarat, Maharashtra and Daman and Diu); south-west coast (Kerala, Karnataka and Goa); south-east coast (Tamil Nadu, Andhra Pradesh, and Puducherry) and north-east coast (Odisha and West Bengal).

Random samples of *T. lepturus*, predominantly (>99%) from the trawl landings were collected at weekly intervals from Veraval, Mangrol and New Ferry Wharf fish landing centres for the north-west coast; Mangalore, Malpe and Vizhinjam fish landing centres for the south-west coast and Kasimedu, Mandapam, Pamban Therkuvadi, Rameshwaram, Kakinada and Visakhapatnam fish landing centres for the south-east coast between January 2014 to December 2019 and Paradeep and Digha fish landing centres for the north-east coast between January 2014 to December 2016. Total length (TL) in all individuals sampled was measured to the nearest millimeter. The length ranges of the samples across the different zones were as follows: north-west - 22-118 cm; south-west - 6-136 cm; south-east - 14-110 cm and north-east - 44-82 cm. The corresponding sample sizes were: north-west -3963; south-west - 4317; south-east - 5425 and north-east - 1495. No samples were obtained in July along the entire west coast and May along the south-east and April-May along the north-east coasts, as a ban on mechanised fishing during June-July and April-June exists along the west coast and the east coast respectively. Length (TL) frequency from the four zones were pooled, as the stocks were neither geographically isolated nor genetically different and was grouped into 2.0 cm class intervals and raised for the day and the month, following the methodology of Sekharan (1962).

Monthly raised length frequencies were analysed using the ELEFAN I module of FiSAT software (Gayanilo *et al*., 1996) for estimating the von Bertalanffy growth parameters *viz,* asymptotic length (L_∞) and growth coefficient (K). Length-based growth performance index (Ø) was calculated from the final estimates of L_∞ and K (Pauly and Munro, 1984). The length at first capture (L_c) was estimated as in Pauly (1984) and the age at zero length (t_0) from Pauly's (1979) empirical equation, Log ($-t_0$) = - 0.3922 - 0.2752 LogL_∞ - 1.038 K. The growth and age were estimated using the von Bertalanffy growth equation, $Lt = L\infty (1-e^{-k(t-to)})$. Optimal fishing length (L_{opt}), the length at which the unfished cohort provides the maximum biomass, was estimated using the equation proposed by Froese and Binohlan (2000). The mid-point of the smallest length group in the catch was taken as length at recruitment (L_r). The recruitment pattern was studied from the recruitment curve using final estimated values of L_∞, K and t_0. Lifespan (t_{max}) was estimated at $3/K + t_0$ (Pauly, 1983a). Natural mortality (M) was estimated as in Pauly (1980), by taking the mean sea surface temperature as 28^{0}C and total mortality (Z) from the length converted catch curve (Pauly, 1983b) 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. Exploitation rate (E) was estimated from the equation, E = F/Z and exploitation ratio (U) from $U = F/Z (1-e^{-z})$.

Total biomass and spawning biomass were obtained using the algorithm of Srinath (1998). Maximum sustainable yield (MSY) was estimated following Cadima for exploited fish stocks as MSY = Z*0.5*B, where B is the annual average exploited biomass (Sparre and Venema, 1998). Relative yield per recruit (Y/R) and biomass per recruit (B/R) at different levels of F were ascertained from Beverton and Holt Yield per Recruit model using Microsoft Excel.

Results

Fishery

The average annual landings of *T. lepturus* from the Indian EEZ during 2014-2019 was 2,09,285 t. Landings fluctuated in individual years, from a minimum of 1,77,259 t in 2015 to a maximum of 2,39,355 t in 2017. During 2014, 2016, 2018 and 2019; the average monthly landings were 2,09,441 t, 2,17,100 t, 1,93,822 t and 2,18,736 t, respectively. Seasonal abundance in catches revealed the landing to be highest in September (40,354 t), followed by October (33,766 t), November (26,311 t) and December (23,155 t). Landings were the lowest during June-July (2,028-2,908 t), in tune with the existing trawl ban along the Indian coast. During January-May, the landings varied from 6,664 t to 17,369 t and in August, the landing was 15,932 t. The annual and seasonal landings of *T. lepturus* for each maritime state are presented in Table 1.

Landings in trawl nets and gillnets, both annually and seasonally, are depicted in Tables 2 and 3. More than 85% of the landings are from trawl nets (Fig. 1). The catch rate in trawl nets has decreased over the years from 5.40 kg h^{-1} in 2014 to 3.85 kg h^{-1} in 2018. On a seasonal note, catch rates were high during September (8.67 kg h^{-1}) and October (6.75 kg h^{-1}) and low during June (1.32 kg h^{-1}) and July (1.14 kg h^{-1}). For gillnets, on the contrary, the catch rates have exhibited an increasing trend, from a minimum of 2.85 kg $unit^{-1}$ in 2014 to a maximum of 7.55 kg $unit^{-1}$ in 2017. For gillnets, the catch rate was highest in November (13.52 kg $unit^{-1}$) and lowest in April (1.93 kg $unit^{-1}$).

North-west coast

Around 63% of the landings from the Indian EEZ were contributed by the north-west coast. Of this, approximately 75% of the landings were from Gujarat alone, 15% from Daman and Diu and 10% from Maharashtra. Landings in various years fluctuated from a minimum of 1,15,613 t to a maximum of 1,51,590 t. Average annual landings during 2014-2019 were 1,32,072 t. Landings were highest in September (25,303 t), followed by October (20,161 t), November (15,414 t) and December (15,597 t). Landings were trivial during June-July and from January-May and August and varied from 5,068 to 12,796 t. Trawl net was the major gear in the region, with 85.2, 98.2 and 82.8% contribution to the landings in Gujarat, Daman and Diu and Maharashtra (Fig. 2). For Gujarat, *T. lepturus* formed 20.57% of the total trawl net landings and 0.92% of the total gillnet landings, while for Maharashtra, the share of the resource in total trawl net and gillnet landings was 7.08 and 1.21%. The catch rate in trawl nets for individual years in the region varied from 5.74 to 6.98 kg h^{-1} with an annual average of 6.14 kg h^{-1}. Seasonally, catch rates were highest during August (12.51 kg h^{-1}) and September (11.09 kg h^{-1}). In gillnets, annual catch rates ranged from 2.83 to 4.79 kg $unit^{-1}$ with an average of 3.59 kg $unit^{-1}$. Similar to trawl nets, the highest catch rates were observed in August (6.95 kg $unit^{-1}$) and September (4.38 kg $unit^{-1}$) (Table 4).

South-west coast

Around 17% of the country's *T. lepturus* landings were from the south-west coast. Karnataka contributed half of the catches, followed by Kerala (48.5%), with a negligible contribution from Goa. During 2014-2019, the annual average landing was 36,017 t with catches varying in respective years from 23,695 to 45,116 t. Average monthly landings were higher during August-December

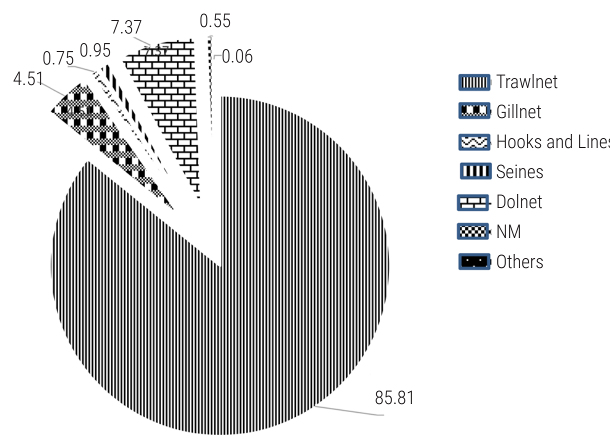

Fig. 1. Contribution of various gears (%) to the landings of *T. lepturus* from the Indian EEZ during 2014-2019

Table 1. Annual and average monthly landings (t) of *T. lepturus* in the maritime states along the Indian EEZ during 2014-2019

Years/Months	West Bengal	Odisha	Andhra Pradesh	Puducherry	Tamil Nadu	Kerala	Karnataka	Goa	Maharashtra	Gujarat	Daman and Diu
2014	1677	12065	20269	863	5978	25828	17910	208	13421	101521	9701
2015	3073	9439	8808	1547	8477	12253	17866	183	12214	88734	14665
2016	4887	12588	14993	1615	17103	12688	16808	144	18190	95561	22522
2017	12671	10502	15476	927	7075	20729	24055	332	18583	113904	15101
2018	7658	5929	8189	1042	10877	27499	14672	1231	15006	87186	14533
2019	11135	3624	13490	1306	13894	5935	16973	787	8123	102872	40595
Jan	922	677	1105	110	692	329	713	40	1154	10067	1575
Feb	492	328	1107	57	686	120	871	127	790	7059	1153
Mar	212	356	747	89	685	115	1640	24	1606	8194	1755
Apr	55	109	294	79	262	162	1412	35	1552	6977	2037
May	3	4	45	5	45	139	1339	29	1237	3259	572
June	142	126	543	179	707	149	42	0	41	131	3
July	543	306	784	93	866	279	2	8	26	10	
Aug	608	640	1672	137	1225	3081	1743	125	1276	5082	769
Sep	572	798	1820	56	1755	6766	3265	21	1907	18312	5084
Oct	860	1588	1860	152	1855	3725	3490	90	1753	16837	1571
Nov	1108	2717	2183	63	938	1706	2122	61	1649	10669	3095
Dec	1333	1397	1377	201	852	917	1424	82	1265	11701	2631

Table 2. Annual *T. lepturus* landings (t) in trawl nets and gillnets for each maritime state of Indian EEZ

Years/Gears	West Bengal	Odisha	Andhra Pradesh	Puducherry	Tamil Nadu	Kerala	Karnataka	Goa	Maharashtra	Gujarat	Daman & Diu
Trawl net											
2014	483	11558	16352	836	5301	20502	17828	108	10512	90608	9498
2015	695	8992	5813	1538	7570	11296	17806	132	11137	77600	13959
2016	1981	10816	13422	1435	16263	10380	16686	73	15681	81424	21865
2017	7180	5964	12055	853	5684	17243	23595	80	15713	91945	14835
2018	4466	1980	6080	1015	9688	17539	13863	308	11888	68551	14388
2019	8228	2700	10921	430	11051	3247	16653	207	5841	85280	40520
Gillnet											
2014	338	455	1504	27	586	557	21	0	186	1946	183
2015	1562	296	1632	9	877	26	39	11	385	2125	675
2016	2084	1179	519	178	831	517	6	10	199	3164	630
2017	3589	4470	1495	65	1104	1351	3	5	101	1979	210
2018	511	3840	1597	21	1014	1517	12	0	347	2408	93
2019	702	746	1913	9	560	109	0	0	546	1944	54

Table 3. Seasonal landings (t) of *T. lepturus* in trawl nets and gillnets for each maritime state of India during 2014-2019

Years/ Gears	West Bengal	Odisha	Andhra Pradesh	Tamil Nadu	Kerala	Karnataka	Maharashtra	Gujarat
Trawl net								
Jan	368	710	900	570	226	622	1044	9328
Feb	268	336	943	526	109	740	707	6757
Mar	96	370	644	585	105	1757	1539	6934
Apr	4	111	286	202	151	1406	1526	5149
May	0	0	0	0	143	1219	1110	2186
June	43	40	466	605	65	39	39	80
July	380	235	577	659	0	0	0	0
Aug	439	547	1570	1206	3263	1693	1180	3951
Sep	278	850	1506	1799	6820	3514	1920	15454
Oct	292	1608	1285	1319	2863	3921	1570	14094
Nov	328	1698	1449	737	1198	1925	1328	8788
Dec	464	1366	1117	694	450	1127	1022	9306
Gillnet								
Jan	307	81	164	44	2	1	7	293
Feb	87	35	67	24	5	2	37	158
Mar	96	15	35	30	2	5	35	223
Apr	25	10	9	32	0	3	27	163
May	0	3	10	41	0	0	18	182
June	20	18	22	62	51	2	0	18
July	75	59	36	46	178	0	0	8
Aug	58	158	76	79	75	2	7	270
Sep	163	29	131	118	296	1	11	313
Oct	154	132	311	194	107	0	39	278
Nov	389	1329	360	151	72	1	42	190
Dec	244	182	129	61	6	1	22	230

(ranging between 2,395 and 10,052 t) and lower during January-May (ranging between 1,068 and 1,779 t), with a negligible amount in June-July. In Karnataka, 98.4% of the landings were by trawl nets, whereas in Kerala, trawl nets contributed 82.2 and gillnets 5.3% of the landings (Fig. 2). Around 5.7% of all trawl landings in Karnataka were composed of *T. lepturus* and for Kerala, the resource contributed 6.6 and 1.8% to the total trawl net and gillnet landings. Trawl catch rate in the region registered a decline from 9.06 kg h^{-1} in 2014 to 4.40 kg h^{-1} in 2018, with an annual average of 6.22 kg h^{-1}. High catch rates were observed from August-October (13.83 to 21.02 kg h^{-1}). Gillnet catch rates, however, exhibited an increasing trend with a minimum of 0.32 kg $unit^{-1}$ and a maximum of 4.29 kg $unit^{-1}$. The average catch rate was 2.35 kg $unit^{-1}$, with July (11.91 kg $unit^{-1}$) and September (11.98 kg $unit^{-1}$) being the dominant landing months (Table 4).

South-east coast

The region contributed around 12% to the total landings of *T. lepturus* in India. More than half (53.5%) of the catches were from Andhra Pradesh, followed by 41.7% from Tamil Nadu and 4.8% from Puducherry. The annual average landing during 2014-2019 was 25,322 t, with inter-annual variations from 18,832 to 33,711 t. Landings were higher during August-December (2,431 to 3,867 t) and low during January-March (1,521 to 1,906 t) and June-July (1,429 to 1,742 t), with minor landings in April and May. For Andhra Pradesh, Tamil Nadu and Puducherry; 80.62, 91.09 and 95.50% of the landings were by trawl nets and 10.66, 7.98 and 4.23% of the landings were by gillnets (Fig. 2). *T. lepturus* constituted 11.43 and 2.01% of the total trawl landings in Andhra Pradesh and Tamil Nadu. The contribution to the total gillnet landings of Andhra Pradesh and Tamil Nadu was 3.5 and 6.05% respectively. Trawl catch rate in the region varied from 1.34 to 2.74 kg h^{-1}, with a decreasing pattern and the annual average was 1.97 kg h^{-1}. Catch rates were the maximum during August-November (2.33 to 3.10 kg h^{-1}). For gillnets, catch rates registered an increasing pattern and ranged from 2.91 to 7.31 kg $unit^{-1}$. The annual average was 4.78 kg $unit^{-1}$, with the highest values observed during October (13.07 kg $unit^{-1}$) and November (11.42 kg $unit^{-1}$) (Table 4).

North-east coast

Close to 8% of the national landings of *T. lepturus* were from the north-east coast. Odisha was the major contributor with 56.85% and the rest (43.15%) was landed from West Bengal. Landings varied annually from a minimum of 12,512 to a maximum of 23,173 t, with an average of 15,875 t during 2014-2019. Catches were more during August-January (1,248 to 3,825 t). Trawl nets contributed 77.58 and 56.05% of the landings in Odisha and West Bengal, whereas the share of gillnets was 20.29 and 21.38% respectively (Fig. 2). The species contributed 9.50 and 5.58% to the total trawl net landings and 5.96 and 1.59% of the total gillnet landings in Odisha and West Bengal respectively. The average catch rate in the region for trawl nets and gillnets was 2.68 kg h^{-1} and 13.10 kg $unit^{-1}$ respectively. Catch rates in trawl nets decreased annually and varied from 1.47 to 5.59 kg h^{-1}, whereas for gillnets, the trend in catch rate was the reverse and it increased from 3.34 to 25.17 kg $unit^{-1}$. Catch rates in trawl nets were the highest during October-December (3.63 to 4.66 kg h^{-1}) and for gillnets, it was maximum during October-January (11.40 to 55.28 kg $unit^{-1}$) (Table 4).

Population and Stock

Mid-length in the overall population for *T. lepturus* ranged from 6.95 to 136.95 cm. Modal mid-lengths were 66.95, 64.95 and 62.95 cm. The fishery was dominated by 1+ year class (56.21-89.60 cm) with around 79.3% contribution by number to the landings, followed by 0+ year class (up to 56.20 cm) with a contribution of 13.4% and 2+ year class (89.61-110.26 cm) with a contribution of 6.8%. Individual length compositions for the four zones are depicted in Fig. 3. The von Bertalanffy's growth equation was $L_t = 143.8 [1-e^{-0.48 (t + 0.03285)}]$. Population parameters and stock estimates from the Indian EEZ are illustrated in Table 5. Size at age is shown in Fig. 4. Recruitment was substantial throughout the year with a single modal peak during June-October. The peak pulse produced 63.68% of the recruits. Mortality during the 1st year of life was mostly due to natural causes, thereafter; fishing mortality increased and eventually exceeded natural mortality by the end of 1st year. Maximum fishing mortality was recorded during the early part of 3rd year. E_{max} estimated was 0.50, lower than the present exploitation. Landings are higher than MSY, warranting an immediate decrease in fishing effort to the tune of 60%. Yield and biomass, yield per recruit, and biomass per recruit for different multiples of fishing efforts are presented in Table 6 and the corresponding yield percentage is shown in Fig. 5. Stocks along the Indian EEZ are exploited above optimum, thus a reduction in fishing effort by 60% was felt necessary. At the reduced effort, the increase in yield would be 59.26%.

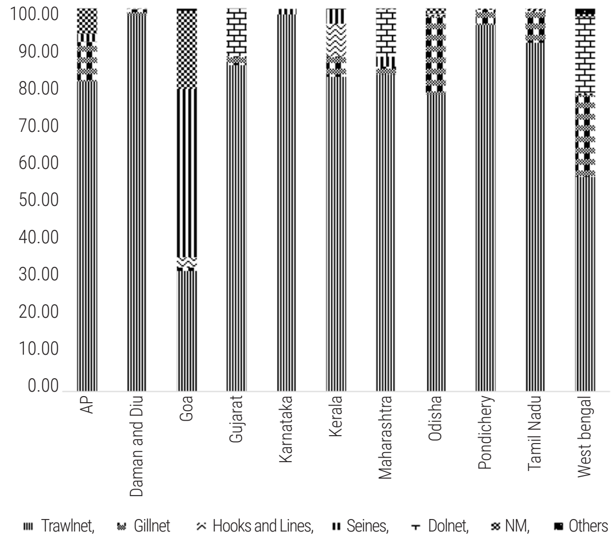

Fig. 2. Contribution of various gears (%) to the landings of *T. lepturus* in different maritime states during 2014-2019

Table 4. Annual and seasonal catch rates of *T. lepturus* in trawl nets and gillnets for each zone of Indian EEZ during 2014-2018

Years/	Trawlnet (kg h^{-1})				Gillnet (kg $unit^{-1}$)			
Months	NE	NW	SE	SW	NE	NW	SE	SW
2014	5.59	6.42	2.19	9.06	3.34	2.83	3.43	1.61
2015	3.64	5.77	1.34	6.47	7.17	2.90	5.52	0.32
2016	3.48	5.74	2.74	8.20	10.19	4.79	2.91	4.29
2017	1.79	6.98	1.84	5.34	25.17	3.32	7.31	2.40
2018	1.47	5.81	1.66	4.40	16.63	4.42	5.77	3.23
Jan	2.56	5.59	1.56	1.51	15.06	3.80	3.85	0.06
Feb	1.92	4.82	1.81	1.46	5.85	2.77	2.00	0.20
Mar	2.71	4.46	1.42	3.09	4.32	3.59	1.60	0.16
Apr	2.69	4.29	1.18	2.50	2.74	2.75	1.65	0.09
May	-	3.62	-	2.37	0.61	3.48	3.92	0.00
June	0.70	2.24	1.34	1.29	1.83	0.88	2.58	4.04
July	1.54	-	1.03	-	4.55	1.91	1.81	11.91
Aug	1.60	12.51	2.33	14.15	6.67	6.95	3.38	3.23
Sep	1.93	11.09	3.10	21.02	6.76	4.38	6.94	11.98
Oct	3.63	7.41	3.01	13.83	11.40	3.55	13.07	4.09
Nov	4.66	5.58	2.73	6.37	55.28	3.13	11.42	1.96
Dec	4.26	5.95	1.83	3.10	17.71	3.80	4.07	0.24

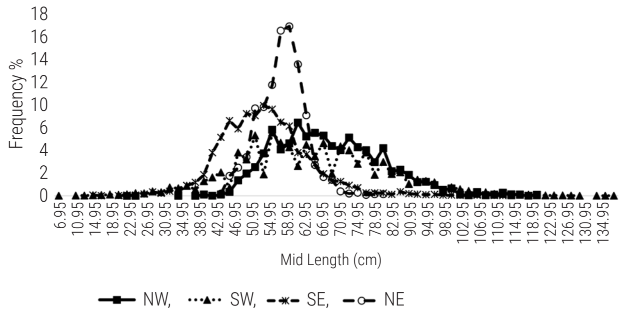

Fig. 3. Length composition of *T. lepturus* from different regions of the Indian EEZ (NW = north-west, SW = south-west, SE = south-east and NE = north-east)

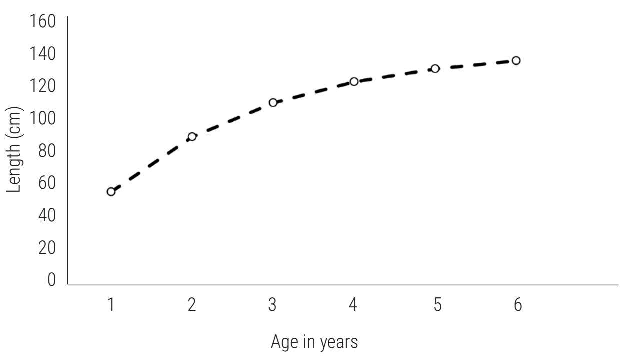

Fig. 4. Length-at-age for *T. lepturus* from the Indian EEZ

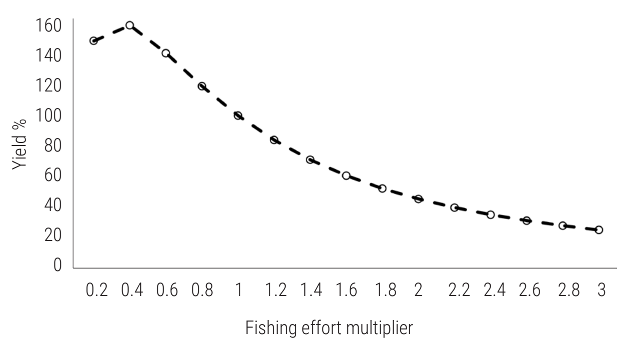

Fig. 5. Relative yield % at different multiples of fishing effort for *T. lepturus* from the Indian EEZ

Table 5. Population parameters and stock estimates of *T. lepturus* from Indian EEZ

Parameter	Value
Asymptotic length (L_{∞}) (cm)	143.8
Asymptotic weight (W_{∞}) (g)	2443.56
Growth co-efficient (K) (yr^{-1})	0.48
Growth performance index (Ø)	4.0
Length at first capture (L_c) (cm)	7.54
Age at first capture (t_c) (years)	0.08
Age at zero length (t_0) (years)	-0.03285
Length at recruitment (L_r) (cm)	6.95
Age at recruitment (t_r) (years)	0.07
Lifespan (t_{max}) (years)	6.22
Optimal fishing length (L_{opt}) (cm)	93.5
Optimal fishing age (t_{opt}) (years)	2.16
Natural mortality (M) (yr^{-1})	0.76
Fishing mortality (F) (yr^{-1})	1.44
Total mortality (Z) (yr^{-1})	2.20
Exploitation rate (E)	0.65
Exploitation ratio (U)	0.58
Maximum Sustainable Yield (t)	1,59,504
Total Biomass (t)	3,58,759
Spawning Biomass (t)	1,45,003
Annual Recruitment (millions)	4772.44

Table 6. Yield (Y), Biomass (B), Yield per recruit (Y/R) and Biomass per recruit (B/R) for different multiples of fishing effort (F) in trawls for *T. lepturus* from Indian EEZ

F (×) multiplier	Y/R (g)	Y (t)	B/R (g)	B (t)
0.2	65.20	311179.70	226.40	1080485.08
0.4	69.68	332539.55	120.97	577325.62
0.6	61.70	294471.63	71.41	340823.64
0.8	52.21	249146.68	45.32	216273.16
1	43.75	208805.00	30.38	145003.47
1.2	36.77	175462.27	21.28	101540.67
1.4	31.12	148498.79	15.43	73660.12
1.6	26.56	126770.34	11.53	55021.85
1.8	22.88	109192.11	8.83	42126.58
2	19.88	94871.46	6.90	32941.48
2.2	17.41	83108.54	5.50	26233.76
2.4	15.37	73363.88	4.45	21227.97
2.6	13.67	65223.14	3.65	17420.71
2.8	12.23	58367.29	3.03	14476.02
3.0	11.01	52549.26	2.55	12164.18

Discussion

Over the decades, the ribbonfish landings from the Indian EEZ have steadily increased. During 1976-1985, the annual average landing of ribbonfish was 58,450 t, contributing 4% to the country's landings; with Kerala contributing the most and closely followed by Tamil Nadu, Maharashtra, Gujarat and Andhra Pradesh (James and Pillai, 1994). The annual average landings increased to 1,53,466 t during 1999-2000, with Gujarat dominating the landings (39%), followed by Maharashtra (27%), Kerala (11%) and Andhra Pradesh (8%) (Nair and Prakasan, 2003). The same authors (Nair and Prakasan, 2003) reported trawl nets to contribute around three-fourths of the ribbonfish landings for the same period. In the present study, during 2014-2019, the average annual landing was 2,09,285 t. Targeted fishing coupled with improvement in the operating efficiency of trawl nets has resulted in higher landings. In fact, 85% of the ribbonfishes caught are by trawl nets. Multi-day trawlers conduct voyage fishing lasting for 4-12 days at depths of 30-75 m throughout the Indian coastline and ribbonfish constituted an important and major resource. The resource is abundantly available in waters at depths between 25 and 75 m (James *et al*., 1986). Seasonal fluctuations in landings are an inherent feature of tropical fisheries and are due to several biotic and abiotic factors *viz.*, environmental parameters, fishing intensity, fishing techniques, changes in the fishing pattern, fishing ground, food availability and spawning success. Seasonal abundance revealed the landings to peak in post-monsoon. Similar observations, on peak catch and catch rates upon resumption of fishery in the months from September-December, had earlier been reported by Lazarus *et al*. (1992), Khan (2006), Ghosh *et al.* (2009), Avinash *et al.* (2014) and Rajesh *et al*. (2015). *T. lepturus* is known to undertake short-duration migrations for breeding and feeding purposes (Rao *et al*., 1977). During monsoon, the species moves to the inshore areas of the continental shelf for feeding, and in post-monsoon, remains close to the shore in areas less than 60 m depth to maximally utilise the available food, thus contributing abundantly to the fishery. In the latter half of the winter months, the resource moved away from the coastal areas to deeper regions for spawning.

The north-west coast contributed close to two-thirds of the country's ribbonfish landings, with Gujarat alone landing close to half. With the south-west coast contributing 17%, the west coast landed four-fifths of the country's ribbonfish. During 1984-1988, the average annual production from the west coast was 56,883 t (Lazarus *et al*., 1992), which has presently increased to 1,68,089 t. A tremendous surge in ribbonfish landings was observed in the past few decades, particularly from Gujarat. The probable reason could be the wider continental shelf, which is thrice larger on the west coast as compared to the east coast (Panikkar and Jayaraman, 1966). Along the north-west coast, the continental shelf is wider and the gradient is low which increases the fishing ground area. On the contrary, along the east coast, the continental shelf is narrow and the gradient is steep, thus the stock becomes unavailable to the fishery in certain months when breeding migration is performed to deeper waters.

With the resource in good abundance, even beyond 60 m depth along the north-west coast, specially designed nets that can target ribbonfishes in the column waters have been implemented by the local fishermen owning multi-day trawlers. These nets possess cod end mesh sizes of 4-6 cm and large mesh of 45-60 cm in the wing sections of the trawl herd the *T. lepturus* shoals into the trawls with minimum drag resistance (Ghosh *et al*., 2009). This targeted fishing explains the increased landings along the north-west coast. Along the southern Saurashtra coast of Gujarat, juveniles of *T. lepturus* were abundant at depths above 30 m in summer and 50 m during post-monsoon and winter. The southern Saurashtra coast being close to the mouth of the Gulf of Khambhat, a known highly productive zone and influenced by large amounts of nutrients brought in by many perennial and seasonal rivers and high tidal ranges, feeding assemblages were present therein, especially for the preferred prey, *Acetes* (Deshmukh, 2002). Subadults and adults, with higher abundances, were known to be targeted and caught by the trawl fishery along this coast (Azeez *et al*., 2016). Along the east coast, the resource is rarely targeted, and is caught in trawl nets with 2-2.5 cm cod end mesh and 25-40 cm mesh sizes in the wings. As a result, landings have stagnated over the decades. From 20,539 t landed annually during 1976-1985 along the south-east coast (Lazarus *et al*., 1992), present landings, after three and a half decades, registered a marginal increase of 25,322 t. Also, unlike the east coast, the west coast is blessed with large-scale seasonal coastal upwelling resulting in an abundance of food ensuring successful spawning and recruitment (Bakun *et al*., 1998).

Catch rates in trawl nets for all regions exhibited a decreasing trend. On the contrary, for gillnets, for most regions apart from the north-west, the catch rates have increased over the years. Most of the earlier studies on the fishery for the species (Chakraborty, 1990; Lazarus *et al*., 1992; Khan, 2006) had computed catch rates in terms of fishing units, for gears apart from trawls; hence, no comparisons were possible. From some studies along the coast of Gujarat (Ghosh *et al*., 2009; Avinash *et al*., 2014), it is evident that the catch rate in trawl net for the species has drastically declined over the past two decades. During 2003-2006, from Gujarat waters, the catch rate of *T. lepturus* in trawl nets gradually enhanced from 4.31 kg h^{-1} in 2003 to 24.1 kg h^{-1} in 2006, with an annual average of 10.77 kg h^{-1} (Ghosh *et al*., 2009). Similarly, during 2008-2009 for the same area, the average catch rate in trawls was more than 10.0 kg h^{-1} (Avinash *et al*., 2014). Though catch rates in trawl nets were highest for the north-east coast, it was still much less (6.14 kg h^{-1}) than previously reported. Seasonal abundance in catch rates has, however, remained similar. During 2003-2006 and 2008-2009, catch rates were high in September (18.95 kg h^{-1}) and August (29.13 kg h^{-1}, respectively and low during February-May (Ghosh, 2009; Avinash *et al*., 2014), akin to that reported presently, albeit with much lower values. Other researchers, from a variety of gears, had earlier reported the post-monsoon from September to December to be the most productive in terms of catch rates (Chakraborty, 1990; Lazarus *et al*., 1992; Khan, 2006). With catch rates globally agreed to be a proxy for the stock abundance, a consistent decline in catch rates for the trawl fishery is indicative of reducing abundance for the species (Froese *et al*., 2012). Though landings have increased in comparison to the past, courtesy of intensive exploitation with enhanced fishing effort, during the present study period (2014-2019) landings were stagnating and further increase may not be possible with an increase in effort.

Fish stock assessment uses information on population parameters for efficiently managing the resource and predicting stock responses to current and future management measures. With markings on scales, vertebrae and other hard parts for direct determination of age found not reliable for tropical resources, length frequency was examined in the present study to arrive at age and growth. Growth parameters such as asymptotic length and growth coefficient, estimated earlier for *T. lepturus* from the Indian seas ranged from 106.83 to 145.2 cm and 0.13 to 0.72 (Narasimham 1976; 1983; 1994; Somvanshi and Joseph, 1989; Chakraborty, 1990; Thiagarajan *et al*., 1992; Reuben *et al*., 1997; Abdussamad *et al*., 2006; Ghosh *et al*., 2009; Avinash *et al*., 2014; Ghosh *et al*., 2014; Rajesh *et al*., 2015). The present results (143.8 cm and 0.48) are in tune to the earlier findings and represent a moderate growth rate for the species. The growth performance index is consistent for a particular species, therefore L_{∞} and K compensate each other to arrive at the index value (Sparre and Venema, 1998). For *T. lepturus* along the Indian EEZ, the value was 4.0. Substantial differences in growth are observed at the individual, population and cohort levels; which are usually genetic but are also highly dependent on physical (temperature, salinity, levels of dissolved oxygen, photoperiod), biotic (food availability and quality, competition and age and maturity) and general environmental conditions (Sparre and Venema, 1998). Maximum growth rate in length was observed during the 1st year of life, after which the annual increment decreased with increasing age. Fishery was dominated by 1+ year age group. No temporal changes were observed, as decades back, both along north-west (Ghosh *et al*., 2009) and south-east (Reuben *et al*., 1997) coasts, fishes of 1-3 year old classes mostly contributed to the landings. Though the species is known to live up to fifteen years (Nakamura and Parin, 1993), the lifespan recorded presently was 6.22 years. Various workers, in accordance, have reported longevity ranging from 4.4 - 10.29 years (Narasimham, 1983; Reuben *et al*., 1997; Ghosh *et al*., 2009; Rajesh *et al*., 2015). Length at sexual maturity for *T. lepturus* in the Indian waters varies between 52.9 - 61.2 cm (Ghosh *et al*., 2014; Rajesh *et al*., 2015). Present estimate for length at first capture (7.54 cm) was much lower than the length at sexual maturity, indicating that majority of the individuals were caught before they could mature and spawn at least once in their life. This indicated stress on spawning stock and corrective measures would be needed to increase the sizes and ages at exploitation, which warrant an increase in mesh size of gears to avoid capture of young fishes. Similarly, smaller size of capture was reported earlier from the north-west (Ghosh *et al*., 2009) and north-east coasts (Narasimham, 1983).

Beverton and Holt (1956) stated that the natural mortality coefficient of a fish is directly related to the growth coefficient and inversely related to the asymptotic length and the life span. The same was observed for *T. lepturus*, with a natural mortality value of 0.76. The natural mortality coefficient varies with the age of the species and also with predator abundance in the respective environment (Pauly, 1980). The ratio M/K explains the relationship between natural mortality and physiological factors. For *T. lepturus*, the ratio was 1.58, well within the normal range of 1-2.5 (Beverton and Holt, 1959). The ratio Z/K (Barry and Jegner, 1989) is used to determine the predominance of growth on mortality, with a ratio equal to 1 implying the population to be in a steady state and with a ratio much higher than 2 implying the stocks to be overexploited. The current Z/K ratio was higher than 4, indicating the population to be mortality dominated. Natural mortality in the present study is in accordance with earlier estimates of 0.7-1.05 (Narasimham, 1983; Ingles and Pauly, 1984; Somvanshi and Joseph, 1989; Chakraborty, 1990; Thiagarajan *et al*., 1992; Reuben *et al*., 1997; Mohite and Biradar, 2001; Abdussamad *et al*., 2006). The exploitation rate is used to assess the status of stocks, either using E_{opt} equal to 0.5 or using estimated E_{max} (Gulland, 1969; 1971). For the Indian EEZ, present exploitation was higher than the maximum permissible, signifying the stocks to be overexploited. Similar higher exploitation rates had earlier also been reported from various parts of the Indian EEZ (Thiagarajan *et al*.,1992; Reuben *et al*.,1997; Khan, 2006; Abdussamad *et al*., 2006; Ghosh *et al*., 2009; Rajesh *et al*., 2015).

However, in a recent study conducted nation-wide, incorporating several biological attributes to length-based analytical models, the results on stock status are more encouraging (Rajan *et al*., 2024). The ratio of the fishing pressure to that which gave the maximum sustainable yield <1, indicating the sustainable status of the stocks. Similarly, the ratio of the biomass to that which gave the maximum sustainable yield >1. Therefore, in spite of the fact that the stocks appear overexploited in the present study using length-based micro-analytical models, combining the current results with biological information on spawning stock biomass based on length at first maturity and juvenile abundances is expected to improve their status.

A combination of trophic enrichment and concentration and retention processes during June-October provides a favourable reproductive regime for the spawning and recruitment of pelagic fishes. Monsoon and upwelling with consequent replenishment of nutrients induce plankton blooms, giving better chance for the larvae to survive as food is plenty. Moreover, growth becomes faster and the larvae pass quickly through the critical stages, resulting in higher recruitment during these months. Present yield per recruit of 43.75 g is in conformity to earlier recorded values ranging from 23 - 74.69 g (Narasimham, 1983; Abdussamad *et al*., 2006; Ghosh *et al*., 2009; Avinash *et al*., 2014). For the Indian EEZ, to achieve maximum yield for the species, a reduction of fishing effort is essential. Earlier studies similarly recommended a decrease in fishing effort ranging from 30-60% for the north-west coast (Khan, 2006; Ghosh *et al*., 2009) and 20% for the south-west coast (Rajesh *et al*., 2015). It is evident, that the exploitation status of the resource has not changed much during the last couple of decades.

With the introduction of voyage fishing from the nineties and fishing extending to deeper waters, coupled with increased biological productivity of the Indian seas owing to increased nutrient discharge and eutrophication, landings of *T. lepturus* have increased annually to around 2.1 lakh t in the last half a decade. However, the catch rates in the major gear, the trawl net, have decreased steeply in comparison to the earlier decade. The present landings are higher than the estimated MSY, and exploitation is higher than E_{opt} and E_{max}. Hence, the species appears overexploited, as was the case in the last few decades, albeit with no regulatory measures on fishing efforts. Substantial amounts of total biomass and spawning biomass with high and continuous recruitment (Rajan *et al*., 2024) have prevented the stocks from collapsing, in spite of the higher prevalent exploitation. The population of *T. lepturus* in the Indian EEZ is, however stressed, and a precautionary approach with effort reduction, mesh size regulation and spatio-temporal restrictions on fishing in identified spawning and nursery grounds would minimise both growth and recruitment overfishing of the species in Indian waters.

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