Indian J. Fish., 70 (3): 22-30, 2023 doi:10.21077/ijf.2023.70.3.131136-03
Available online at: epubs.icar.org.in/index.php/IJF

An insight into the fishery, biology and population dynamics of *Auxis rochei* (Risso, 1810) along the south-west coast of India

S. Surya[1*], E. M. Abdussamad[2], R. Pratibha[3], J. M. Ponni, J. H. Kingsly[1], S. Jasmine[1], K. G. Mini[2], K. M. Rajesh[3], P. Abdul Azeez[4], C. Anulekshmi[5], H. M. Manas[6], J. K. Dona[1], D. Y. Dispin[1] and M. K. Anil[1]

[1]Vizhinjam Regional Centre of ICAR-Central Marine Fisheries Research Institute, Vizhinjam P.O., Thiruvananthapuram - 695 521, Kerala, India
[2]ICAR-Central Marine Fisheries Research Institute, Ernakulam North P. O., Kochi - 682 018, Kerala, India
[3]Mangalore Regional Centre of ICAR-Central Marine Fisheries Research Institute, Mangaluru - 575 001, Karnataka, India
[4]Veraval Regional Station of ICAR-Central Marine Fisheries Research Institute, Veraval - 362 269, Gujarat, India
[5]Mumbai Regional Station of ICAR-Central Marine Fisheries Research Institute, Mumbai - 400 061, Maharashtra, India
[6]Visakhapatnam Regional Centre of ICAR-Central Marine Fisheries Research Institute, Visakhapatnam - 530 003, Andhra Pradesh, India

Abstract

Auxis rochei is one of the coastal tunnies contributing substantially to the tuna landings in India, with an average (2014-2019) annual catch of 7210 t. Kerala stood first, with an annual average landing of 3176 t. The fishery comprised 14.5 - 39.6 cm fork length (FL) size groups with a mean length of 27.64 cm and a major mode of 26 cm FL. The Length-weight (L-W) relationship of pooled fishes was expressed as W= 0.000003 $L^{3.22}$ (r^2= 0.91). The size at first maturity was estimated at 25.8 cm FL when the fish was 1.5 years old. The number of eggs per spawning ranged from 84,562 to 1,33,698 and the ova diameter ranged between 0.1 and 0.6 mm, indicating asynchronous oocyte development with multiple spawning. Higher gonadosomatic index (GSI) was recorded during April, May and June and coincided with the minimum gastrosomatic index (GaSI). The recruitment pattern was bimodal, with varied intensity ranging from 0.79-17.89%. Growth was allometric and the von Bertalanffy growth equation derived was $L_t=43.5(1-e^{-0.8(t+0.0212)})$. The growth performance index (ϕ) was 3.18 and the longevity of the fish was estimated at 3.7 years. One-year-old plus fishes sustained the fishery (22 - 32 cm FL). Total mortality (Z), natural mortality (M) and fishing mortality (F) were estimated at 3.70, 1.40 and 2.30, respectively, with an exploitation rate (E) of 0.62 and the exploitation ratio (U) of 0.60. Beverton and Holt yield per recruit (Y/R) and Biomass per recruit analysis indicated that the E_{max} was at 0.87, much higher than the present level of exploitation, reflecting the sustainable fishery along the coast. Standing stock biomass (SSB) was estimated at 7215.7 t, and the spawning stock biomass formed 55.5% of the SSB. Thompson and Bell analysis indicated the MSY as 8125 t, at F-factor, 2.6. The biological reference points F_{CURR}/F_{MSY} (0.4) and B_{CURR}/B_{MSY} (1.5) were at safe levels, signifying the scope for fishery enhancement.

*Correspondence e-mail:
revandasurya@gmail.com

Keywords:
Biological reference point, Fecundity, Growth, GSI, L-W relationship, Mean length, Mortality, SSB

Received : 07.12.2022
Accepted : 17.03.2023

Introduction

Tuna forms the largest, highly specialised, commercially important group of fishes, distributed in temperate and tropical oceans of the world (Collette and Nauen, 1983). They are classified under the family Scombridae, consisting of 50 species and as a group ranks as the third largest product in the international seafood trade providing direct employment to about 200 million people (FAO, 2018). Moreover they contribute significantly to global nutrition accounting for 19% of the total human consumption of animal protein (Botsford *et al.,* 1997). Tunnies maintain a body temperature several degrees above the surrounding water temperature and have high metabolic rates and exhibit distinctive growth patterns that set them apart from other fish species (Pillai and Ganga, 1985). They are fast swimmers capable of travelling more than 48 km h^{-1} (Collette and Nauen, 1983), migratory, and they have relatively few natural predators in their habitat. In India, tuna fishing remains an artisanal activity except for a brief phase of chartered and joint venture tuna fishing by longliners during the 1990s. Various artisanal sectors involving traditional low technology and low capital fishery practices contribute to the tuna fishery. However, tuna catches substantially improved during the post-nineties compared to the early eighties, mainly due to the motorisation of traditional crafts and the mainland fishers' adoption of progressive and innovative fishing techniques. Fishery practices like coastal fishery, oceanic fishery, pole and line fishery, troll-line fishery and the gill net fishery have led to a targeted fishery of highly valued tunas (Ramachandran and Ramalingam, 2019). Tuna fisheries of India comprise four coastal tunas (*Euthynnus affinis, Auxis rochei, Auxis thazard* and *Sarda orientalis*), one energetic neritic tuna (*Thunnus tonggol*), three oceanic tunas (*Thunnus albacares, Thunnus obesus* and *Katsuwonus pelamis*) and one neritic/oceanic tuna (*Gymnosarda unicolor*). The coastal tuna fishery has played a prominent role in targeted fishing of the smaller tunas along the Indian mainland. *A. rochei,* also known as the bullet tuna, is the smallest of all the known tunas from Indian waters and is mainly distributed in tropical waters to depths of 50 m. The fishery of *A. rochei* has gained importance on a commercial level only in the south-west region of the Indian mainland (Jasmine *et al.,* 2013). The exploitation of *A. rochei* along the Indian coast till the late eighties was minimal, but with the popularisation of motorised crafts, *A. rochei* emerged as an important component of the commercial fishery (Gopakumar *et al.,*1994), especially along the south-west coast. The annual average landings of *A. rochei* (2010-2019), estimated at 4031.2 t, contributed about 4.46% to the annual average tuna landings along the Indian coast. The good domestic market preference for the fish among consumers in Kerala and Tamil Nadu has led to the targeted fishing of the species along the southern tip of Kerala and Tamil Nadu. Age determination, length at first maturity, gonado-somatic index and spawning period of bullet tuna were reported (Bok and Oray, 2001; Marcias *et al.,* 2006; Valeiras *et al.,* 2008; Kahraman *et al.,* 2010). Investigations on the biology and population dynamics of *A. rochei* were reported from the East Java Sea (Lelono and Bintoro, 2019); Indian EEZ (Jasmine *et al.,* 2013), Turkish Mediterranean waters (Kahraman *et al.,* 2011) and Pacific water off Kochi, Japan (Niiya, 2001). The fishery, distribution of spawners and the bionomics of the bullet tuna have been investigated by several researchers (Yoshida and Nakamura, 1965; Ishida, 1971; Yesaki and Arce, 1994; Sabates and Recasens, 2001; Oray and Karakulak, 2005; Oray *et al.,* 2005). Studies on the biology and stock assessment of *A. rochei* from India are limited and include those of Silas (1969), Muthiah (1985), Gopakumar and Sarma (1989), James *et al.* (1993) and Jasmine *et al.* (2013). The present investigation focused on the fishery, biology and population dynamics of *A. rochei* landed along the Indian Coast during 2014-2019.

Materials and methods

Length frequency data collected during 2014-2019 was used to estimate stock parameters. The database on the estimated landings and effort of bullet tuna was collected at fortnightly intervals from different landing centres of the Indian mainland following the stratified random sampling design (Srinath *et al.,* 2005).The landing centres of sample collection are shown in Fig. 1. Since the fishery of *A. rochei* was reported majorly from the south-west coast of India, the study was more concentrated on the specified area. *A. rochei* (n=685), of which males (n=364), females (n=260) and inditerminates (ID) (n= 61) with fork lengths 14.50 - 39.5 cm landed off south-west coast of India from March 2017 to February 2019 were used for the biological studies. Total length (TL), fork length (FL) and the total weight of the fish were recorded and examined to identify the sex and gonadal maturity. The gonadal maturity was assessed as per the ICES maturation scale by Wood (1930) and Nancy *et al.* (2011). The length-weight relationship was estimated using the formula suggested by Le Cren (1951). Length at first maturity (L_{m50}) was assessed using the logistic curve (King, 1996) and fish with the third stage of maturity onwards were included in the L_{m50} estimation. The ovaries were preserved in 5% neutral buffered formalin to estimate the fecundity. Small samples weighing 0.1-.5 g were taken from the anterior, posterior and middle portions of the preserved ovaries, to count the matured ova and the absolute fecundity and relative fecundity were estimated.

Growth parameters *viz,* asymptotic length (L_∞) and growth coefficient (K), were estimated using the ELEFAN I module of FiSAT software. The length frequency data for assessing growth and mortality parameters were taken from the hook and line fishing since, during the study period,

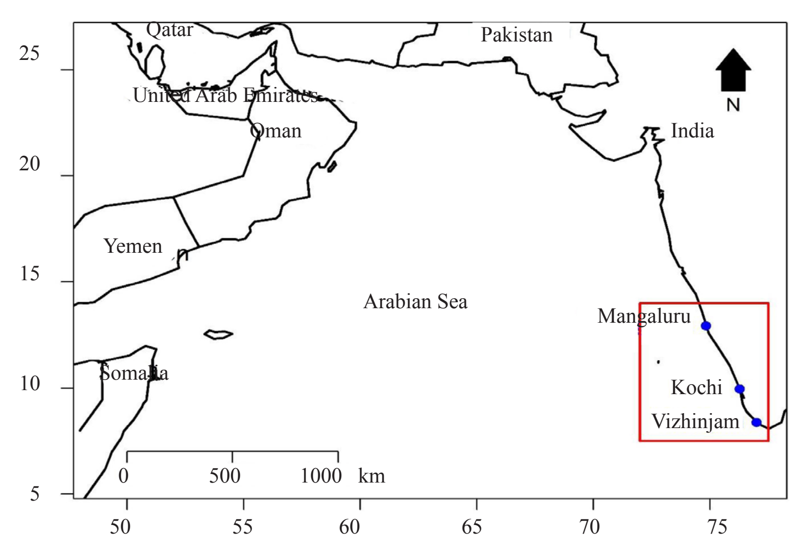

Fig. 1. Map showing the study locations

hook and line accounted for more than 50% of the total bullet tuna catch. The growth performance index φ was calculated from L_{∞} and K (Pauly and Munro, 1984). The probability of capture and size at first capture (Lc) were estimated as in Pauly (1984) and the age at zero length (t_0) from Pauly's empirical equation (Pauly, 1979). Natural mortality (M) was calculated by Pauly's empirical formula (Pauly, 1980) and total mortality (Z) from the length converted catch curve (Pauly, 1983b). Longevity (t_{max}) was estimated as t_{max} = 3/K + t0 (Pauly, 1983a). Length-structured virtual population analysis (VPA) was used to obtain fishing mortalities per length class. The exploitation ratio (U) was estimated as U= F/Z (1-e^{-Z}) and the exploitation rate (E) was calculated as E=F/Z. The relative yield per recruit (Y/R) and biomass per recruit (B/R) at different levels of F were estimated using the Beverton and Holt model (Beverton and Holt, 1957; Gayanilo *et al.*, 1996). Length-based Thompson and Bell model combined with length-based cohort analysis and Virtual Population Analysis (VPA) was used to predict catches and stock sizes under given assumptions on future exploitation levels (Pauly, 1984).

Results and discussion

The estimated annual average tuna landing in India during 2007- 2019 was 81146 t and peaked at 108712 t in 2019 (Fig. 2). The annual average estimated landings of *A. rochei* during 2007-19 was 5911 t, with a peak of 11304 t during 2017. The landings during 2012-2019 in different maritime states indicated that Kerala stood first (3176 t), followed by Goa (2262 t), Tamil Nadu (1005 t), Karnataka (646 t), Maharashtra (140 t) and Andhra Pradesh (3.5 t). The annual landings of *A. rochei* in India during 2012-20 are shown in Fig. 3 and the percentage contribution of maritime states to the annual average landing of *A. rochei* is shown in Fig. 4. Gear-wise landing of *A. rochei* (annual average) along the south-west coast of India is shown in Fig. 5. The exploitation was mainly by employing hooks and lines, gillnets and drift gillnet and occasionally from trawls and purse seines. Though *A. rochei,* a neritic tuna species is distributed all along the coast of India, distribution and landings were recorded mainly from the south-west coast of India (James and Pillai, 1993; James *et al.,* 1993; Gopakumar *et al.,* 1994; Pillai and Gopakumar, 2003; Pillai *et al.,* 2003; Gopakumar and Ajithkumar, 2005; Jasmine *et al.,* 2013). Bullet tuna fetches a fair price in the domestic market of southern Kerala and is one of the most preferred tuna species in this region. A targeted fishery for bullet tuna exists in southern Kerala for almost 8 months a year. Due to its high preference, bullet tuna landed in other regions were transported to southern Kerala. The comparatively low and affordable cost of bullet tuna compared to other tuna species was also responsible for the high demand in southern Kerala. There is a good local demand for this tuna species because some consumers attribute higher nutritional value to it. The crafts employed fishing exclusively for bullet tuna along the south-west coast are fibre boats with a length overall (LOA) ranging from 9.6-9.9 m and fitted with two engines of 9.9 and 25 HP. A few boats are fitted with two engines of 9.9 HP each. Generally, the crew consists of three to four fishers. The fishing is just for a day, with the trip lasting ,10-11 h and the fishing ground is approximately 24-25 nautical miles from the shore. Hooks and lines, fixed and drift gillnets, are the major gears used. Of these, the hooks and lines were the most common and popular gear used to capture bullet tuna along the south-west coast of

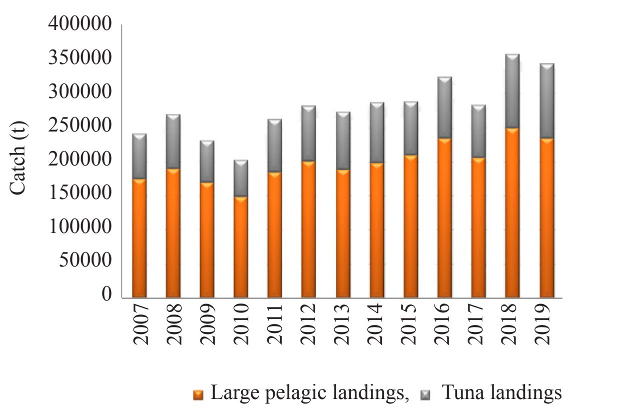

Fig. 2. Annual average landings of large pelagics and the contribution of tunas to the total large pelagic landings of India

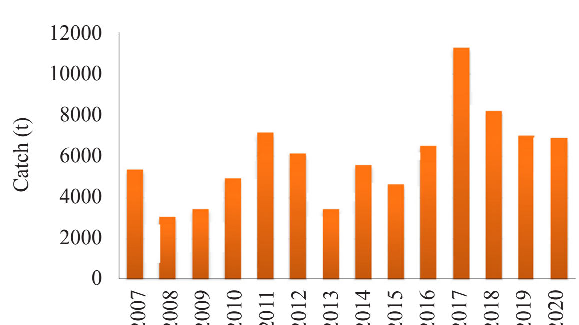

Fig. 3. Average annual landing of *A. rochei* during 2007-20 in India

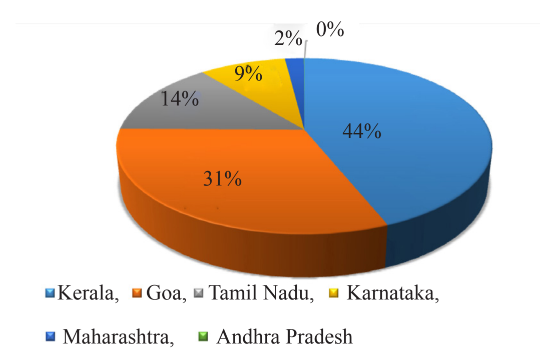

Fig. 4. Percentage contribution of different maritime states to the annual average landing of *A. rochei*

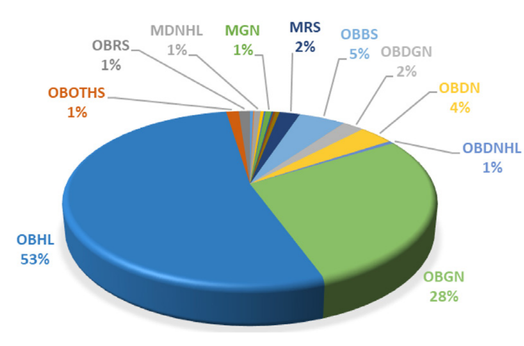

Fig. 5. Annual average gear-wise catch of *A. rochei* along the south-west coast of India

India. The main line (length-10 m) with 17-20 branch lines (length- 50 cm each) fitted with an iron rod at the end of the mainline is used for hooking. A craft with a crew of 3-4 fishers keeps a set of 7-8 hooks and line baskets. Hook number 13, covered with a glittering artificial substance, was used as jigs to attract the fish. The highly experienced fisher folk set one basket at a time and haul it as fast as possible. Around 10-12 fishes are hooked in a single basket operation and 35-40 baskets are operated per boat trip. Every basket holds 20 numbers of hooks. A detailed sketch of hook and line operation of *A. rochei* along the south-west coast is shown in Fig. 6.

During the study period, the fishery comprised fishes with FL ranging from 14.5 to 39.6 cm. The length frequency distribution of *A. rochei* is given in Fig. 7. Fishes in the length range 22-32 cm dominated the catch and contributed about 78% of the catch. The major mode was 26 cm, and the average annual mean length was 27.64 cm. The mean length estimated for *A. rochei* during the years of study was 24.6 (2014), 29.8 (2015), 26.4 (2016), 26.2 (2017), 28.1 (2018) and 27.9 cm FL (2019). The fishery of bullet tuna was sustained mainly by a length group of 22-32 cm (1-2-year-old fishes) (Jasmine *et al.,* 2013). The annual average mean length was estimated at 27.64 cm FL with a major mode at 26 cm. Jasmine *et al.* (2013) estimated a smaller mean length of 25.3 cm FL and the mode at 24 cm in conformity with the present study.

The relationship between FL (cm) and weight (g) for bullet tuna (unsexed) is shown in Fig. 8. The expressions for the L-W relationship for pooled fishes were: W = 0.000003 L3.22 (r^2 = 0.91). The estimated L-W relationship of bullet tuna given by different authors from different regions is shown in Table 1. The present study confirmed a positive allometric growth of fish, indicating that, with the increase in size, there is a disparity in weight gain. The authors eluded some specimens, with regard to their size during spawning, in the current analysis of LWR. The 'a' and 'b' values estimated in the present study agree with Rodriguez-Roda (1966); Bok and Oray (2001); De la Serna *et al.* (2005); Machias *et al.* (2005); Macías *et al.* (2006); Palandri *et al.* (2008); Jasmine *et al.* (2013); Noegroho *et al.* (2013); Kantun *et al.* (2019); Tampubolon *et al.* (2016) and Mariasingarayan *et al.* (2020) indicating a positive allometric growth for bullet tuna from different regions, while Kahraman *et al.* (2011); Asrial *et al.* (2021a) presented a negative allometric growth.

The size at first maturity was estimated at 25.8 cm FL when the fish was 1.5 years old (Fig. 9). The L_m estimated (FL) was below the annual mean size of capture (27.64 cm), thus providing the fish at least one chance to breed in its lifetime. L_{m50} of 23 cm FL has been reported by Jasmine *et al.* (2013) which conforms to the present results. Muthiah (1985) also estimated L_m at 23.8 cm for females and 24 cm for males,

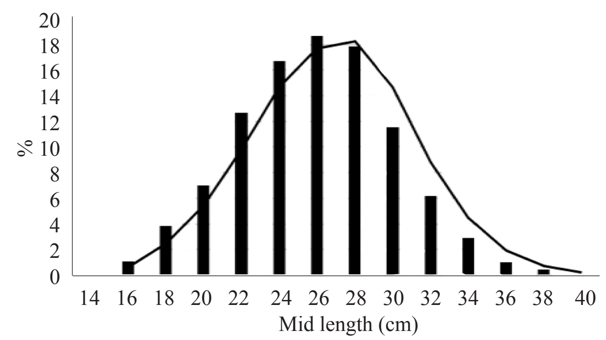

Fig. 7. Percentage contribution of different length classes to the total landings of *A. rochei* during the study period.

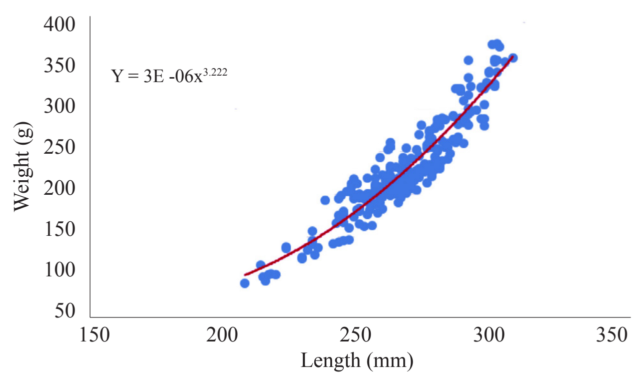

Fig. 8. Relationship between fork length (mm) and weight (g) for *A. rochei*

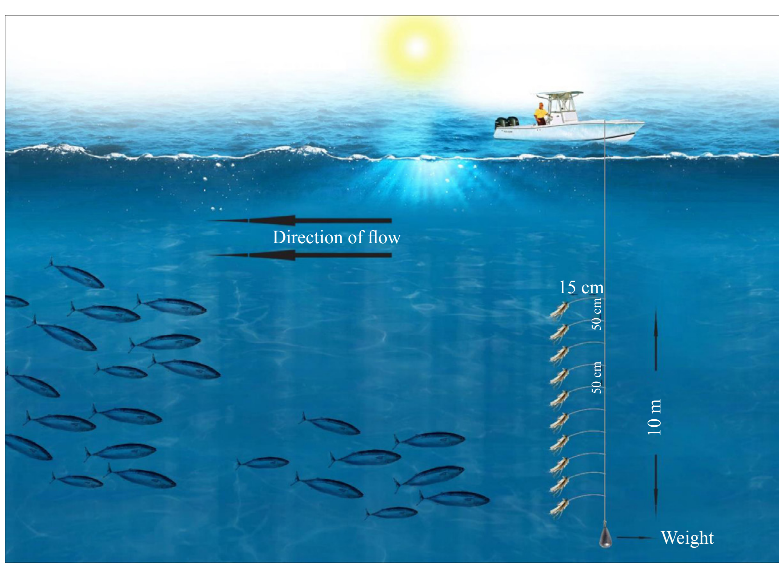

Fig. 6. Detailed sketch of hook and line operation along the south-west coast of India for the exploitation of bullet tuna

Table 1. Comparative L-W relationship of bullet tuna estimated by different authors

LWR of bullet tuna estimated from different regions			
'a' value	'b' value	Region	Reference
0.00001005	3.129	Gibraltar Strait	Rodriguez- Roda (1966)
0.0076	3.24	Turkish Medit. and the Aegean Sea	Bok and Oray (2001)
0.002182	3.561	Spanish Mediterranean	De la Serna *et al.* (2005)
1.61E-05	3.003	S.Western Spanish Mediterranean	Macias *et al.* (2005)
0.00559	3.29	Western Mediterranean	Macias *et al.* (2006)
0.0014	3.675	Ligurian Sea	Palandri *et al.* (2009)
0.0542	2.685	Turkish Mediterranean	Kahraman *et al.* (2011)
0.0076	3.243	Indian waters	Jasmine *et al.* (2013)
0.0031	3.4439	Tuticorin coast, Bay of Bengal	Mariasingarayan *et al.* (2020)
0.018	3,089	West Coasts Sumatera IFMA 572, Eastern Indian Ocean	Noegroho *et al.* (2013)
0.0059	3.246	Makassar Strait, West Sulawesi, Indonesia	Kantun *et al.* (2019)
$6.3x10^{-6}$	3.2567	West Coast Sumatera, Eastern Indian Ocean	Tampubolon *et al.* (2016)
0.000003	3.22	Present study	-

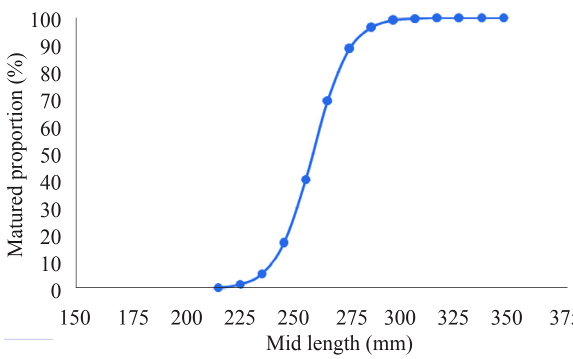

Fig. 9. Length at first maturity of *A. rochei* estimated during the study period

and Amri *et al.* (2019) estimated L_m at 23.6 cm FL. However, a higher L_m of 27.16 cm FL (Tampubolon, 2016), 35 cm (Rodriques-Roda 1966), 38 cm (Rodriguez-Roda, 1983), 35 cm FL (Macias *et al.*, 2005), 31.11 cm (Asrial *et al.*, 2021 a, b) have also been reported for the same. The fecundity of the fish ranged from 84,562 to 1,33,698 ova per spawning, and Silas (1969) has indicated the fecundity of *A. rochei* as 31,000 to 1,03,000 with an average of 52,000 ova per spawning. According to Macias *et al.* (2005), the average fecundity of *A. rochei* reported was 2 33,941 oocytes and the relative fecundity was 242 oocytes per g body mass. They concluded that bullet tuna have an indeterminate fecundity pattern. Relative fecundity of around 52 oocytes per g body mass has also been reported by Niiya (2001) and fecundity of 52,570 - 1 62,777 eggs has also been recorded by Muthiah (1985).

The ova diameter studies of matured bullet tuna indicated that a cross-section of the matured gonadal tissue consists of oocytes with a size ranging between 0.1 and 0.6 mm (Fig. 10a). The percentage occurrences of immature, maturing and matured oocytes in the spawning capable gonads were also shown in Fig. 10b. Tampubolon *et al.* (2016) have indicated that the spawning frequency of these species can be estimated from the egg diameter. Analysis of the distribution of egg size indicated that *Auxis* sp. was a partial spawner and generally had large fecundity. The results of the current investigation also showed that *A. rochei* is a multiple spawner with asynchronous oocyte development, as indicated by Megalofonou *et al.* (2000), Niiya (2001) and Macías *et al.* (2005). Since variations in modal values in yolked oocytes were noted, these species can be suggested to have indeterminate fecundity, as indicated by Macías *et al.* (2005). Calicdan-Villarao *et al.* (2017) recorded insignificant (p>0.05) differences in the GSI values between males (2.8 yr^{-1}) and females (3.23 yr^{-1}) and for both the sexes mean GSI reached its peak during March. In their study, Kahraman *et al.* (2010) indicated a similar value for GSI for females (2.18) with a high value between May and September, indicating spawning from the Mediterranean waters. In the present investigation the maximum GSI was recorded

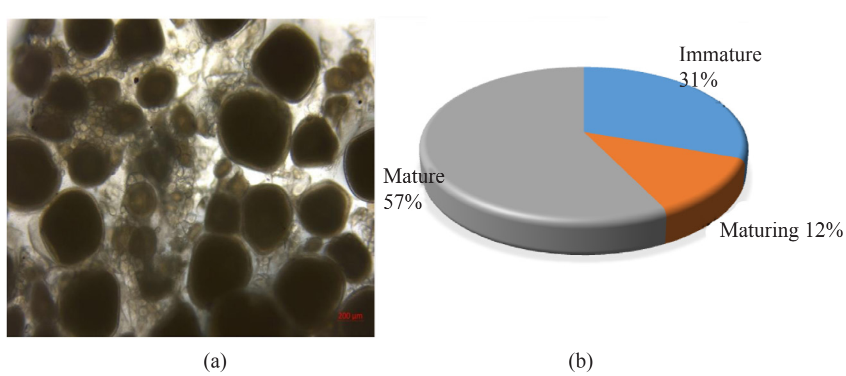

Fig. 10. (a) Photomicrograph of a matured ovary showing immature, maturing and mature oocyte stages and (b) Percentage contribution of different stages in the mature ovary of bullet tuna

during April, May and June and spawning during June, July and August (Fig. 11). The unimodal recruitment pattern recorded for bullet tuna in the study (Fig. 12) depicted continuous spawning with varied intensity in recruitment (0.56-17.73%) and the peak recruitment from April (8.13%) to September (17.73%), implying that one cohort is produced in the year.

The growth in bullet tuna was allometric and the von Bertalanffy growth equation was derived as $L_t=43.5(1-e^{-0.8(t+0.0212)})$. Length at maximum possible yield (L_{opt}) was estimated at 27.1 cm. The length attained by the fish at different ages (von Bertalanffy Growth Function Plot) is given in Fig. 13. The growth performance index was estimated at 3.18, and the longevity at 3.7 years. The fishery was sustained mainly by the one-year-old plus fishes (22 - 32 cm FL). The present study indicated a fast growth rate, attaining the L_∞ (43.5 cm FL) and T_{max} at 4 years. The values estimated were comparable to other studies (Grudstev, 1992; Bok and Oray, 2001; De la Serna *et al.,* 2005; Valeiras *et al.,* 2008; Jasmine *et al.,* 2013; Kahraman *et al.,* 2013).

The total mortality (Z), natural mortality (M) and fishing mortality (F) were estimated at 3.70, 1.40 and 2.30, respectively (Fig. 14). The exploitation rate (E) was 0.62 and the exploitation ratio (U) at 0.60. The Beverton and Holt yield per recruit (Y/R) and Biomass per recruit analysis showed that the E_{max} was around 0.87, which is much higher than the level of exploitation estimated during the present study, reflecting that the fishery along the coast is sustainable (Fig. 15). The highest fishing mortality of 2.2 was observed in the length group of 30-32 cm (Fig. 16) and mortality among the smaller length groups was mainly due to natural reasons. The largest number of fish caught (14883818) was from the length group of 26-28 cm when the fishing mortality was 1.44. The F steadily increased for fish measuring 19 cm and above and peaked when fishes attained an FL of 31 cm. After that, the F decreased and the mean F for the fully recruited groups (26-41 cm FL) was 1.55.

The annual average catch of *A. rochei* (2014-2019) along the south-west was 7210 t. The total yield and standing stock biomass (SSB) were estimated at 7392 and 7215.7 t, respectively. The spawning stock biomass formed 55.5% of the SSB. The Gulland equation estimated the MSY as 8297 t, and the Thompson and Bell analysis provided the MSY as 8125 t, at F-factor, 2.6 (Fig. 17). The F_{MSY} was estimated as 5.98. The biological reference points of *A. rochei* are given in Table 2. A higher estimated MSY against the average yield and a spawning stock biomass of more than 50% indicated that the fishery for *A. rochei* along the south-west coast was healthy and a 2.6 times increase in the fishing effort from the present fishing rate would result in F_{MSY} as in case of hooks and line operation. The maximum economic yield (MEY) obtained at an F-factor of 2 also shows that the current fishing efforts

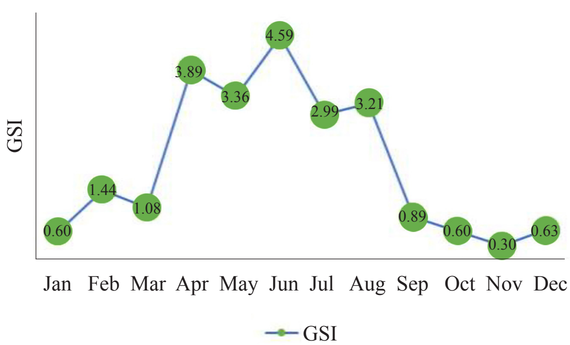

Fig. 11. Monthly variation in gonadosomatic Index (GSI)

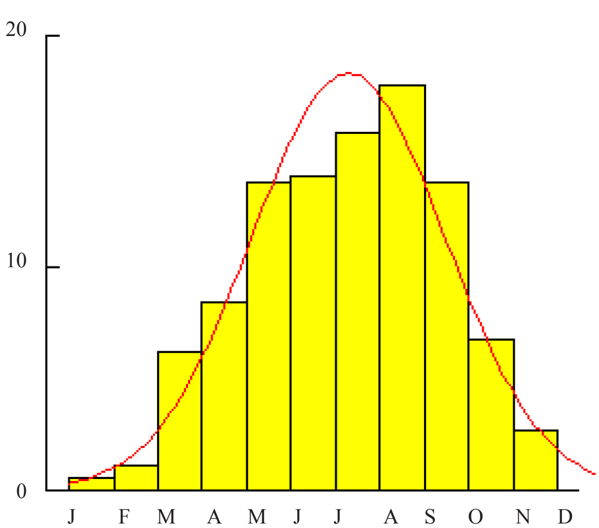

Fig. 12. Annual recruitment pattern observed in *A. rochei*

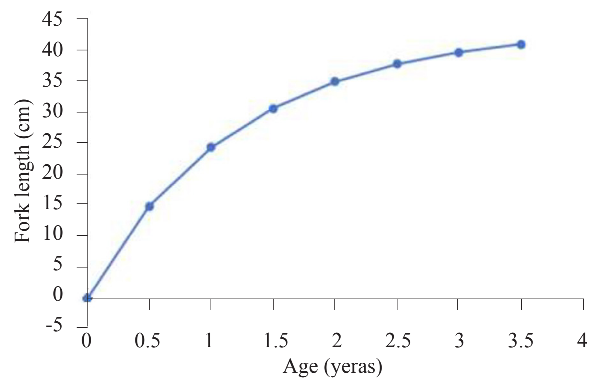

Fig. 13. Length attained by bullet tuna at different ages (in years) (VBGF plot)

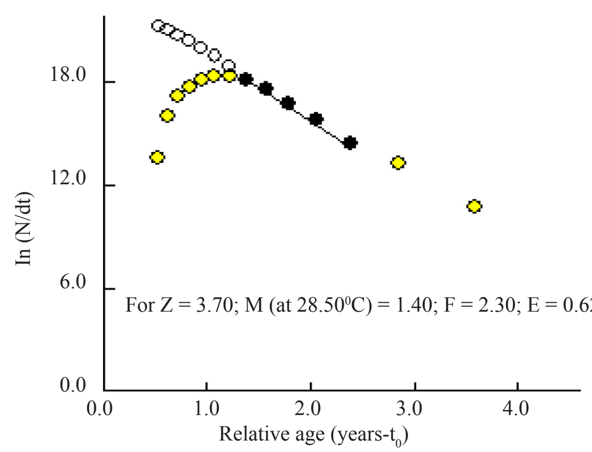

Fig. 14. Length converted catch curves applied to length frequencies data of *A. rochei*. Black dots allow the estimation of total mortality (Z). White and grey dots indicate expected and observed numbers of fish specimens, respectively.

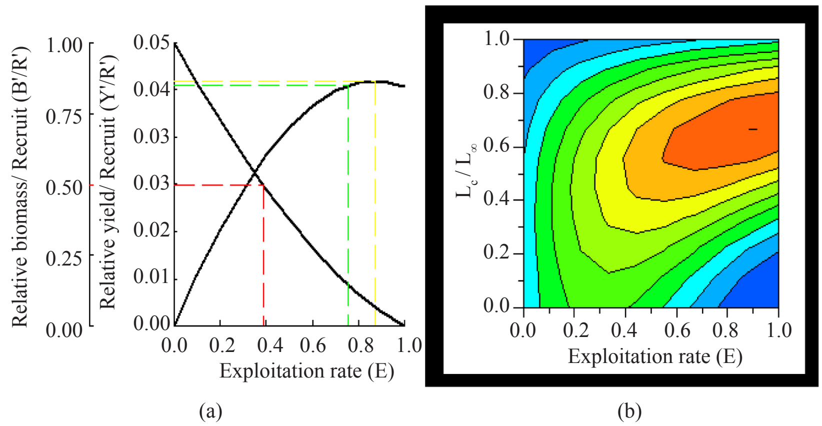

Fig. 15. Beverton and Holt's relative yield per recruit and average biomass per recruit models for *A. rochei*. (a) E10 - green line; E_{50} (optimum sustainable yield) - redline and the E_{max}. (maximum sustainable yield) - Yellow line (b) Yield per recruit plot with exploitation rate variability across the critical length ratio, L_c/L_∞.

Table 2. Biological reference points of *A. rochei*

Biological Reference point	*Auxis rochei*
Total Yield	7392 t
MSY	8125 t
Spawning stock Biomass (SSB %):	55%
B_{curr}	8303 t
B_{msy}	5518 t
F_{curr}	2.3
F_{msy}	5.98
B_{curr}/B_{msy}	1.5
F_{curr}/F_{msy}	0.4

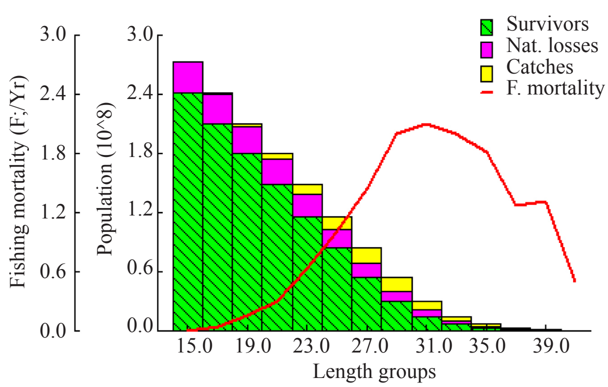

Fig. 16. Length-structured virtual population analysis (VPA) of *A. rochei*

for exploiting bullet tuna along the south-west coast does not create any chaos in the fishery of bullet tuna. The fishing rates (F_{CURR}/F_{MSY}) and biomass (B_{CURR}/B_{MSY}) were also within safe levels, signifying the fishery's enhancement scope.

Abdussamad *et al.* (2012) have also reported that *A. rochei* is mainly harvested by the artisanal sector along the south-west coast of India. However, the E_{max} observed in the present study (E_{max}=0.897) is higher than that of the current, E (0.62), depicting the resource is exploited at sustainable levels. Sustainable fishing practice for this species is practised in the Labangka region (Asrial, 2020) and TanjungLuar Fishing Port, Indonesia (Asrial, 2021a). In India, the demand and supply of bullet tuna depend on the quantum of availability. When a vast quantity of fish is landed, especially during the monsoon season, about 70-80% of the tuna is sold to wholesalers and 20-30% is directly sold to consumers. The average price of bullet tuna ranged between ₹150 and 200 per kg and at times, it fetched up to ₹ 250-300 per kg.

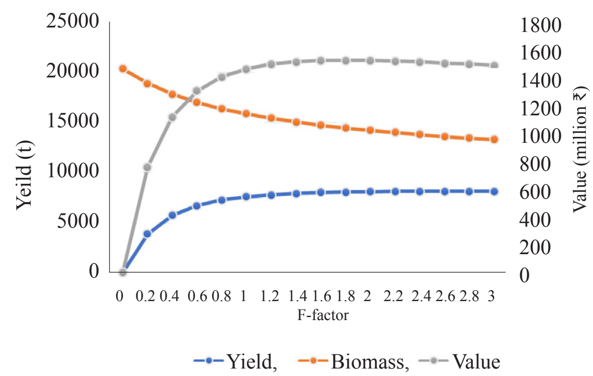

Fig. 17. Thompson and Bell predicted model for *A .rochei*

A. rochei is an epipelagic fish that shows interannual fluctuations in landing along the south-west coast of India. In India, the targeted fishery for *A. rochei* was limited to Southern Kerala and the fishing practices employed for the exploitation of bullet tuna are sustainable and were designed and fabricated exclusively for the bullet tunas along the coast. The mean length estimated during the study period was much above the $L_{m50,}$ allowing the fish to sustain themselves. The biological reference points evaluated during the present study also reflected the sustainable nature of the exploitation of *A. rochei* along the south-west coast of India.

Acknowledgments

The authors acknowledge the Director, ICAR-CMFRI, Kochi for the constant support and funding. The authors are grateful to the Scientists-In-Charge, scientific, technical and supporting staff of different Regional and Research stations of ICAR-CMFRI for their kind support.

References

Abdussamad, E. M., Rao, G. S., Koya, K. P. S., Rohit, P., Joshi, K. K., Sivadas, M., Kuriakose, S., Ghosh, S., Jasmine, S., Chellappan, A. and Koya, M. 2012. Indian tuna fishery - Production trend during yesteryears and scope for the future. *Indian J. Fish.,* 59(3): 1-13.

Amri, K., Novalina, A. and Setyadji Bram 2019. Some biological stock indicators of bullet tuna (*Auxis rochei,* Risso 1810) from the Banda Sea and its adjacent waters. *Indonesia Fish. Res. J.,* 25: 103-112. https://doi.org/10.15578/ifrj.25.2.2019.

Asrial, E. 2020. Utilisation, growth and population of bullet tuna (*Auxis rochei* Risso 1810) in Indian Ocean Southern Sumbawa. *Indonesia J. Aquacult. Fish.,* 2(1): 19-28.

Asrial, E., Arapat, Y., Hadi, U., Kalih, L., Liliyanti, M., Rosadi, E., Khasanah, R. and Rathnayake, I. 2021a. The length-weight relationship and condition factors of bullet tuna landed at the TanjungLuar Fishing Port, Indonesia. *J. Ilm. Perik. Kelaut.,* 13(1): 1-10. https://doi.org/10.20473/jipk.v13i1.22585.

Asrial, E., Khasanah, R., Fathrurriadi, F., Arapat, Y., Hadi, U., Kalih, L., Rizal, L., Liliyanti, M., Rosadi, E., Setyohadi, D., Junaidi, M. and Rathnayake, I. 2021b. Population dynamics of bullet tuna (*Auxis rochei* Risso 1881) from the Indian Ocean, West Nusa Tenggara, Indonesia. *J. Ilm. Perik. Kelaut.,* 13(144). https://doi.org/10.20473/jipk.v13i2.26017.

Beverton, R. J. H. and Holt, S. J. 1957. On the dynamics of exploited fish populations. *Fishery Invest.,* 19(2): 1-533.

Bok, T. and Oray I. K. 2001. Age and growth of bullet tuna *Auxis rochei* (Risso, 1010) in Turkish waters. *ICCAT, Col. Vol. Sci. Pap.,* 52: 708-718.

Botsford, L. W., Castilla, J. C. and Peterson, C. H. 1997. The management of fisheries and marine ecosystems. *Science,* 277: 509-515. https://doi.org/10.1126/science.277.5325.509.

Calicdan-Villarao, M. A., Encarnacion, A. B., Ame, E. C. and Morales, M. C. 2017. Biology and population dynamics of bullet tuna (*Auxis rochei*) and frigate tuna (*Auxis thazard*) in Babuyan Channel, Philippines. *Kuroshio Science,* 11(1): 63-72.

Collette, B. B. and Nauen, C. E. 1983. FAO Species Catalogue. Scombrids of the world. An annotated and illustrated catalogue of tunas, mackerels, bonitos and related species known to date. *FAO Fish. Synop.,* 125(2). Food and Agriculture Organisation of the United Nations, Rome, Italy, 137 p.

De la Serna, J. M., Ortiz de Urbina, J. M., Alot, E., Garcia, S. and Rioja, P. 2005. Biological parameters of bullet tuna (*Auxis rochei*) observed in the Spanish Mediterranean fisheries. *ICCAT, Col. Vol. Sci. Pap.,* 58(2): 517-526.

FAO 2018. Review of the state of world marine fishery resources. *FAO Fish. Tech. Pap., Marine Resource Service.* Food and Agriculture Organisation of the United Nations, Rome, Italy, 335 p.

Gayanilo, F. C. Jr., Sparre, P. and Pauly, D. 1996. The FAO ICLARM Stock Assessment Tools (FiSAT) User's Guide. *FAO computerized information series (Fisheries) No.8,* Food and Agriculture Organisation of the United Nations, Rome, Italy, 126 p.

Gopakumar, G. and AjithKumar, T. T. 2005. Troll line fishery for yellowfin tuna at Colachel, Kanyakumari District. *Proc. Tuna Meet.,* p. 177-180.

Gopakumar, G. and Sarma, P. S. S. 1989. The present status of coastal tuna fishery at Vizhinjam, Trivandrum coast. *Mar. Fish. Infor., Serv., T&E Ser.,* 97: 1-7.

Gopakumar, G., Sarma, P. S. S. and Velayudhan, A. K. 1994. Motorization of traditional craft and its effect on the exploitation of tuna and whitebait anchovy resources. *Indian J. Fish.,* 41(2): 92-99.

Grudtsev, M. E. 1992. Peculiarities of distribution and biological characteristic of Melva *Auxis rochei* (Risso) in the Waters of the Sahara. *ICCAT, Col. Vol. Sci. Pap.,* 39(1): 284-288.

Ishida, Y. 1971. Investigation on frigate mackerel (*Auxis rochei*) (1968) season. *Rep. Kochi Pre. Fish. Expo. Stn.,* 66 and 67: 119-140.

James, P. S. B. R. and Pillai, P. P. 1993. Tuna fisheries and fishery in the Indian EEZ- An update. *Proceedings on the National Conference on Tunas,* 21-22 April 1989, ICAR-Central Marine Fisheries Research Institute, Kochi, India.

James, P. S. B. R., Pillai, P. P., Jayaprakash, A. A., Pillai, N. G. K., Gopakumar, G., Kasim, H. M., Sivadas, M. and Koya, K. P. S. 1993. *Fishery, biology and stock assessment of small tunas. Tuna Research in India,* Fishery Survey of India, Mumbai, India, pp. 123-148.

Jasmine, S., Rohit, P., Abdussamad, E. M., Koya, K. P. S., Joshi, K. K., Kemparaju, S., Prakasan, D., Elayathu, M. N. K. and Sebastine, M. 2013. Biology and fishery of the bullet tuna, *Auxis rochei* (Risso, 1810) in Indian waters. *Indian J. Fish.,* 60: 13-20.

Kahraman, A. E., Gokturk, D., Bozkurt, E. R., Akaylı, T. and Karakulak, F. S. 2010. Some reproductive aspects of female bullet tuna, *Auxis rochei.* (Risso), from the Turkish Mediterranean coasts. *Afr. J. Biotechnol.,* 9(40): 6813-6818. https://doi.org/10.5897/AJB10.709.

Kahraman, E. A., Gokturk, D. and Karakulak, F. S. 2011. Age and growth of bullet tuna, *Auxis rochei* (Risso), from Turkish Mediterranean coasts. *Afr. J. Biotechnol.,* 10(15): 3009-3013. https://doi.org/10.5897/AJB10.2021.

Kantun, W., Cahyono, I. and Arsana, W. 2019. Biological aspect of bullet tuna *Auxis rochei* (Risso, 1810) in the Makassar Strait, West Sulawesi, Indonesia. *Ribarstvo.,* 77: 119-126. https://doi.org/10.2478/cjf-2019-0013.

King, M. 1996. *Fishery biology, assessment and management.* Blackwell Publishers, USA, 382 p.

Le Cren, E. D. 1951. The length-weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). *J. Anim. Ecol*., 20: 201-219. https://doi.org/10.2307/1540.

Lelono, T. D. and Bintoro, G. 2019. Population dynamics and feeding habits of *Euthynnus affinis, Auxis thazard* and *Auxis rochei* in South Coast of East Java waters. *IOP Conference Series: Earth and Environmental Science,* 370: 012054. https://doi.org/10.1088/1755-1315/370/1/012054.

Macias, D., Gomez-Vives, M. J. and de la Serna, J. M. 2005. Some reproductive aspects of bullet tuna (*Auxis rochei*) from the south-western Spanish Mediterranean. *ICCAT, Col. Vol. Sci. Pap.,* 58(2): 484-495.

Macias, D., Lema, L., Gomez-Vives M. J. and de la Serna, J. M. 2006. A preliminary approach to the bullet tuna (*Auxis rochei*) fecundity in the Spanish Mediterranean. *ICCAT Col. Vol. Sci. Pap.,* 59(2): 571-578.

Mariasingarayan, Y., Danaraj, J., Vajravelu, M., Mayakrishnan, M. and Ayyappan, S. 2020. Allometry coefficient variations of length-weight relationship of Scombridae family caught along the Tuticorin coast, Bay of Bengal. *Indian J. Geo-Mar. Sci.,* 49(3): 496-500.

Megalofonou, P., Damalas, D., Yannopoulus, C., De Metrio, G., Deflorio, M., Santamaría, N., De La Serna, J. M. and De Urbina, J. M. O. 2000. Incidence of the cupleoid purse seines on small tunas and tunas. by-catch quantification in the Mediterranean, biology and dynamics of their early life. *Final Report of the Project 96/093 DG XIV/C1.*

Muthiah C. 1985. Maturation and spawning of *Euthynnus affinis, Auxis thazard* and *A. rochei* in the Mangalore inshore area during 1979 to 1982. Tuna fisheries of the exclusive economic zone of India: Biology and stock assessment. *Bull. Cent. Mar. Fish. Res. Inst.,* (36): 71-85.

Nancy, J. B., David, M. W., Fran, S., Beverly, J. M. and Susan, K. L. 2011. A standardized terminology for describing reproductive development in

Fishes. *Mar. Coast. Fish.,* 3(1): 52-70. https://doi.org/10.1080/19425120.2011.555724.

Niiya, Yoshio. 2001. Age, growth, maturation and life of bullet tuna *Auxis rochei* in the Pacific waters off Kochi Prefecture. *Nippon Suisan Gakkaishi,* 67: 429-437. https://doi.org/10.2331/suisan.67.429.

Noegroho, T., Hidayat, T. and Amri, K. 2013. Some biological aspects of frigate tuna (*Auxis thazard*), bullet tuna (*Auxis rochei*) and kawakawa (*Euthynnus affinis*) in West Coasts Sumatera IFMA 572, Eastern Indian Ocean. *Third Working Party on Neritic Tunas, Bali, Indonesia. IOTC–2013–WPNT03–19.* Indian Ocean Tuna Commission, Victoria, Seychelles, pp. 1-13.

Oray, I. K. and Karakulak, F. S. 2005. Further evidence of spawning of bluefin tuna (*Thunnus thynnus thynnus* L, 1978) and the tuna species (*Auxis rochei., 1*810, *Euthynnus alletteratus,* 1810) in the eastern Mediterranean Sea: Preliminary results of TUNALEV larval survey in 2004. *J. Appl. Ichthyol.,* 21: 236-240.

Oray, I. K., Karakulak, F. S., Alich, Z., Ate, C. and Kahraman, A. 2005. First evidence of spawning in the eastern Mediterranean Sea: Preliminary results of TUNALEV larva survey in 2004. I*CCAT, Coll. Vol. Sci. Pap.,* 58: 1341-1347.

Plandri, G., Lanteri, L., Garibaldi, F. and Relini, L.O. 2009. Biological parameters of bullet tuna in the Ligurian Sea. *Collect. Vol. Sci. Pap. ICCAT,* 64(7), pp. 2272-2279.

Pauly, D. 1979. Theory and management of tropical multi-species stocks: A review with emphasis on the South-east Asian demersal fisheries. *ICLARM Stud. Rev., 1.* International Centre for Living Aquatic Resources Management, Manila, Philippines, 35 p.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. *L. Cons. Ciem.,* 39(2): 175-192.

Pauly, D. 1983a. Some simple methods for the assessment of tropical fish stocks. *FAO Fish. Tech. Pap., 243.* Food and Agriculture Organisation of the United Nations, Rome, Italy, 52 p.

Pauly, D. 1983b. Length converted catch curves. A powerful tool for fisheries research in tropics (Part-I). *ICLARM Fishbyte,* 2: 9-13.

Pauly, D. 1984. Length converted catch curves. A powerful tool for fisheries research in tropics (Part-II). *ICLARM Fishbyte,* 2(1): 13-14.

Pauly, D. and Munro, J. L. 1984. Once more, on the composition of growth in fish and invertebrates. *Fishbyte*, 2(1): 21

Pillai, N. G. K. and Ganga, U. 1985. Fishery and biology of tunas in the Indian seas. In: *Harvest and post-harvest technology of fish.* ICAR-Central Institute of Fisheries Technology, Kochi, India, pp. 10-35.

Pillai, N. G. K., Ganga, U., Gopakumar, G., Muthaih, C. and Kuriakose, S. 2003. Stock assessment of coastal tunas along the west coast. *Proceedings of Tuna Meet-2003,* Fishery Survey of India, Mumbai, India, pp. 54-57.

Pillai, P. P. and Gopakumar, G. 2003. *Status of exploited marine fishery resources of India.* ICAR-Central Marine Fisheries Research Institute, Kochi, India, pp. 51-59.

Ramachandran, S. and Ramalingam, L. 2019. *Distribution, abundance and some biological aspects of billfish species under the family Xiphiidae* (Xiphias gladius) *and Istiophoridae* (*Istiophorus platypterus, Istiompax indica, Makaira nigricans*) *in Indian EEZ. IOTC-2019- WPB17-26.* Indian Ocean Tuna Commission, Victoria, Seychelles.

Rodriguez-Roda, J. 1966. Study of the little tunny, *Euthynnus alletteratus* (Raf.), bonito, *Sarda sarda* (Bloch) and melva, *Auxis thazard* (Lac), caught by the Spanish traps. *Inves. Pesq.,* 30: 247-292.

Rodriguez-Roda, J. 1983. Age and growth of the *Auxis rochei* (Risso), from Southern Spain. *Inves. Pesq.,* 43(3): 591-599.

Sabates, A. and Recasens, L. 2001. Seasonal distribution and spawning of small tunas, *Auxis rochei* (Risso) and *Sarda sarda* (Bloch) in the northwestern Mediterranean. *Sci. Mar.,* 65(2): 95-100.

Silas, E. G. 1969. *Exploratory fishing by R. V. Varuna. Technical Report,* ICAR-Central Marine Fisheries Research Institute, Kochi, India.

Srinath, M., Kuriakose, S. and Mini, K. G. 2005. Methodology for estimation of marine fish landings in India. *CMFRI Spl. Publ., 86,* ICAR-Central Marine Fisheries Research Institute, Kochi, India.

Tampubolon, P. A. R. P., Novianto, D., Hartaty, H., Kurniawan, R., Setyadji, B. and Nugraha, B. 2016. *Size distribution and reproductive aspects of Auxis* spp. *from west coast Sumatera, eastern Indian Ocean. IOTC-2016-WPNT06-19.* Central Marine Fisheries Research Institute.

Valeiras, J., Macías, D., Gomez Vives, M. J., Lema, L., Godoy, D. and Urbina, J. 2008. Age and growth of Atlantic little tuna (*Euthynnus alliterates*) in the western Mediterranean Sea. *ICCAT, Coll. Vol. Sci. Pap.,* 62.

Wood, H. 1930. Scottish herring shoals. Pre-spawning and spawning movements. *Scotland Fish. Bd. Sci. Invest.,* 1: 1-71.

Yesaki, M. and Arce, F. 1994. A review of the *Auxis* fisheries of the Philippines and some aspects of the biology of frigate (*A. thazard*) and bullet (*A. rochei*) tunas in the Indo-pacific Region. *Interactions of Pacific Tuna Fisheries. FAO Fish. Tech. Pap.,* 336(2). Food and Agriculture Organisation of the United Nations, Rome, Italy, pp. 409-439.

Yoshida, H. O. and Nakamura. E. L. 1965. Notes on schooling behaviour, spawning and morphology of Hawaiian frigate mackerels *Auxis thazard* and *Auxis rochei. Copeia,* 1: 111-114.