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Fishery, biology and population characteristics of frigate tuna *Auxis thazard* (Lacepede, 1800) from Indian waters

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Abstract

The frigate tuna, *Auxis thazard* forms a coastal fishery in India throughout the year. During the period 2015-2020, with an annual average catch of 6,387 t, the resource formed 7.14% of the total tuna catch of the country. Andhra Pradesh (1,131 t) recorded the maximum landings followed by Karnataka (968 t) and Tamil Nadu (701 t). In West Bengal and Odisha, *A. thazard* formed more than 60% of the total tunas landed. Mature fishes dominated in January-March. Size at first maturity was 31.9 cm TL. Size (fork length) was in the range 22.8-68 cm and the estimated length-weight relationship was log W = 0.000049 + 3.1740 log L (n = 832, r^2= 0.93) (95% CI). The von Bertalanffy growth equation derived was: Lt = 72.6 [1 - $e^{-0.73 (t + 0.063)}$]. The growth performance index was 3.585 and the length at first capture was estimated at 33.35 cm. The estimated natural mortality, fishing mortality and total mortality were 1.17, 1.21 and 2.38 respectively; the exploitation rate was 0.508. E_{max} estimated was 0.735, which is higher than the present levels, indicating scope for further exploitation. The prediction analysis for MSY, F/F_{msy} and B/B_{msy} showed the current exploitation is sustainable, indicating scope for increasing catch with increased effort.

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Introduction

Tuna constitute the largest group among the large pelagics in Indian waters and accounts for almost 43% of total large pelagics fish landings (CMFRI, 2019). Tuna fishery is constituted of five species *i.e.,* kawakawa, yellowfin, skipjack, long tail and frigate tuna. The frigate tuna (*Auxis thazard*) is an important coastal tuna occurring throughout Indian waters (Ghosh *et al.*, 2012; Abdussamad *et al.*, 2021). The major landing was along the south-west coast with Kerala contributing the maximum. The species is exploited from coastal waters by drift gill nets, purse seine, ring seines, trawl nets and hooks and lines as incidental catch (Abdussamad *et al.*, 2021). The genetic stock structure of frigate tuna along the coastal waters of India suggests that there are two stocks *i.e.,* one around the Andaman Sea and a second around the rest of the Indian coast (Girish *et al.,* 2012). Therefore, national-level periodic estimation of the biology and population characteristics of the fishery is important for understanding the changing trends in marine fish production and evaluating the exploitation level.

Previous studies on the fishery biology and population characteristics of frigate tuna were predominately based on length-frequency at regional as well as national levels and include reports from Tuticorin (Kasim, 2002, Abdussamad *et al.,* 2005), the east coast of India (Kasim and Abdussamad, 2003), north-west coast

of India (Ghosh *et al.*, 2010; Mudumala *et al.,* 2018a) from the Indian waters (Silas *et al.*, 1985, James *et al.*, 1992; 1993, Pillai *et al.,* 2002; Ghosh *et al.,* 2012). However, recently there has been a change in the fishing pattern, availability and species composition of coastal tunas landed throughout the country. Further, a comprehensive report on the fishery and biological characteristics of the frigate tunas has been lacking for the past decade. Therefore, the present study aims to provide insight into the fishery, population dynamics and stock structure of frigate tuna exploited in Indian waters.

Materials and methods

The monthly length-frequency data for frigate tuna landed by major gears operated at different landing centres along the west and east coasts were collected for the period 2015-2020. The data was raised to the annual average catches. The data on fishery, catch and effort was obtained from the Fishery Resources Assessment Division of ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI), Kochi. India. Maturity stages were studied following the standard classification of the stages of maturity (Rao, 1967), fecundity was estimated by gravimetric method and the relative fecundity was derived by dividing the absolute fecundity by body weight. The size at first maturity (L_{mat} or L_{50}) was estimated as described by Haig *et al.* (2016). Individual fishes were categorised as mature (1) or immature (0) based on the gonad developmental stage, where gonads in stages 3-7 were characterised as mature and gonads in developmental stages 1 and 2 were categorised as immature. The logistic regression model is built in R version 3.6.1 software (R Core Team, 2019). Confidence intervals were determined by bootstrapping the model for 10,000 runs. The length-weight relationship was calculated as in Le Cren (1951).

Stock assessment of *A. thazard* was carried out following conventional methods using length-frequency data from 2015 to 2020. The von Bertalanffy growth parameters (asymptotic length (L_{∞}) and growth coefficient (K) were estimated using monthly raised length-frequency data in the ELEFAN I module of FiSAT II software. The instantaneous total mortality rate (Z) was estimated from the length converted catch curve (Pauly, 1983) and the natural mortality rate (M) was calculated using Pauly's empirical formula (Pauly, 1980) [ln(M) = -0.0152-0.279 ln(L_{∞}) +0.6543 ln(K)+ 0.463 ln(T)], where 'T' is the average sea surface temperature assumed as 27.5°C during the study period. The fishing mortality rate (F) was estimated as F = Z-M, the current exploitation rate (E) was estimated as E= F/Z and the exploitation ratio (U) was estimated as U= F/Z*(1-e^{-z}). Length-structured virtual population analysis (VPA) was used to obtain fishing mortalities per length class. The relative yield per recruit (Y/R) and biomass per recruit (B/R) at different levels of F were estimated from the Beverton and Holt Yield per Recruit model (Beverton and Holt, 1957). The equilibrium yield, standing stock biomass (B) and spawning stock biomass (SSB) at different fishing levels were predicted using the length-based Thompson and Bell bio-economic model (Thompson and Bell, 1934).

Results

Fishery

The annual average landings of *A. thazard* during the 2015-2020 period was 6,387 t comprising 7.14% of the total tuna landings. The highest landing was observed in 2006 when 14,162 t were landed. The landing trend during the last decade registered an increase since 2012 and reached a peak (7,826 t) in 2018 (Fig. 1). Andhra Pradesh with an annual average landing of 1,131 t recorded the maximum, followed by Karnataka (968 t) and Tamil Nadu (701 t) (Fig. 2). In West Bengal and Odisha, this species formed more than 60% of the total tunas landed. The contribution of *A. thazard* to the total tuna catch in other states fluctuated between a minimum of 3.55% in Kerala to a maximum of 13.17% in Karnataka.

Seasonal abundance

Frigate tunas were exploited round the year and the majority of landings were recorded during March - April and September-October periods. The annual average monthly catch of *A. thazard* was highest in April (1,409.37 t) followed by October (1,356.87 t) and September (814.60 t) (Fig 3). In Andhra Pradesh, 93% (1,051 t) of the annual (1,131 t) frigate tuna was landed in April. Along the west coast, in Karnataka and Kerala, frigate tuna catch dominated during the post-monsoon months (September and October).

Length composition

The fork length of sampled *A. thazard* ranged from a minimum of 22.8 cm to a maximum of 68 cm recorded from Karnataka. An analysis of the sex-wise distribution in different size groups at a

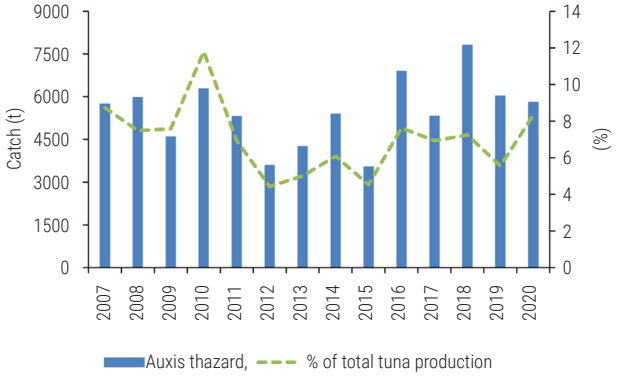

Fig. 1. The trend in annual production of frigate tuna in the Indian waters during 2007-2020

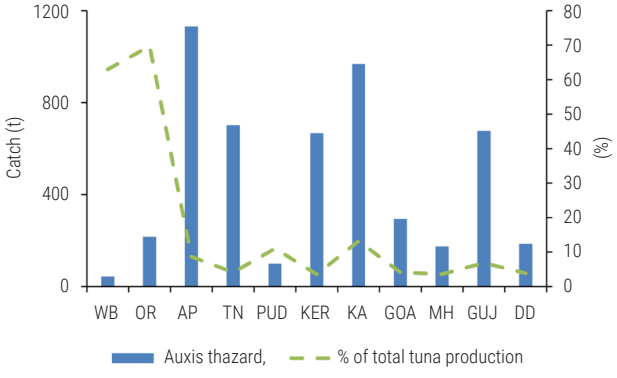

Fig. 2. Average percentage state-wise landing of frigate tuna during 2016-2020

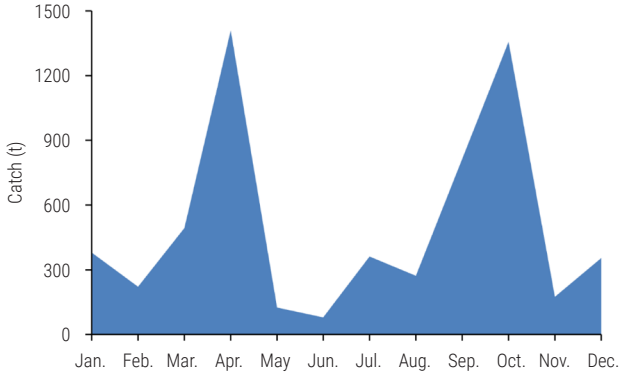

Fig. 3. Monthly average landing of frigate tuna from Indian waters during 2016-2020

national level revealed that the males dominated in the length group of 37-40 cm, followed by 34-37 cm and 31-34 cm, whereas in the 37-40 cm, female group dominated followed by length group of 40-43 and 43-46 cm (Fig. 4). The estimated combined length-weight relationship for *A. thazard* is:

log W = 0.000049 + 3.1740 log L (n = 832, r^2= 0.93) (95% C. I.)

Reproductive biology

The estimated length at which 50% of fishes attained sexual maturity was 31.9±0.52 cm total length, whereas 95% of the fish attained sexual maturity at 43.16±0.83 cm (Fig. 5). Gravid and ripe females were recorded in all the months with peak occurrence during January-March followed by May. This suggested that the first quarter of the year is the peak spawning time for *A. thazard* (Fig. 6). Spent females accounted for 32% of the population, followed by immature ones (26.22%), maturing ones (25.86%) and mature ones (15.91%). The number of eggs released generally increased with the weight and size of the fish. The total fecundity ranged between 2,26,538 and 5,68,333 with an average of 4,21,433 numbers.

Growth

The growth parameters, L_{∞} and K estimated using the ELEFAN I programme were 72.60 cm and 0.73 $year^{-1}$ respectively. The size

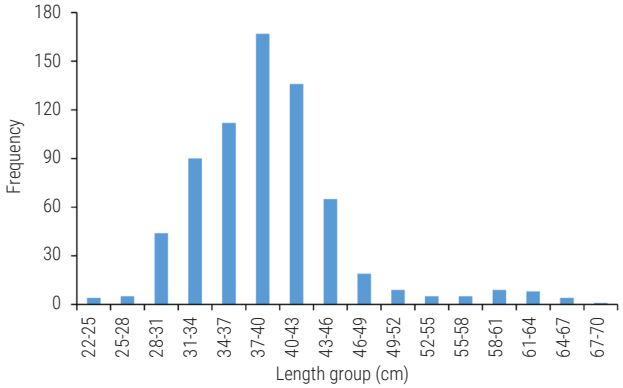

Fig. 4. Length frequency of *A. thazard* from Indian EEZ during 2016-2020

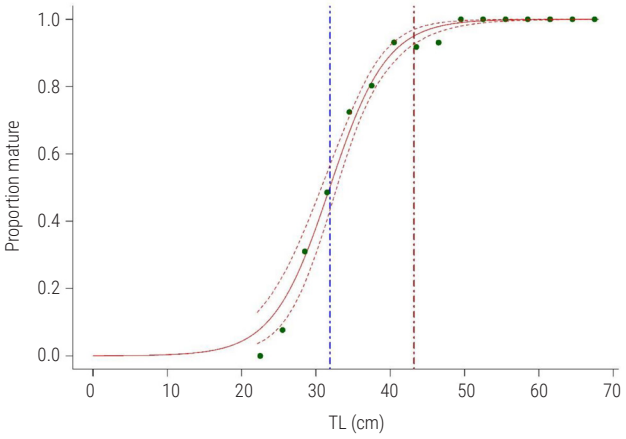

Fig. 5. Estimated size at first maturity of *A. thazard* from Indian waters. The red dash line denotes a 95% confidence interval at various length groups, the blue vertical dash line denotes $L_{50\%}$ maturity and the brown vertical dash line denotes $L_{95\%}$ maturity

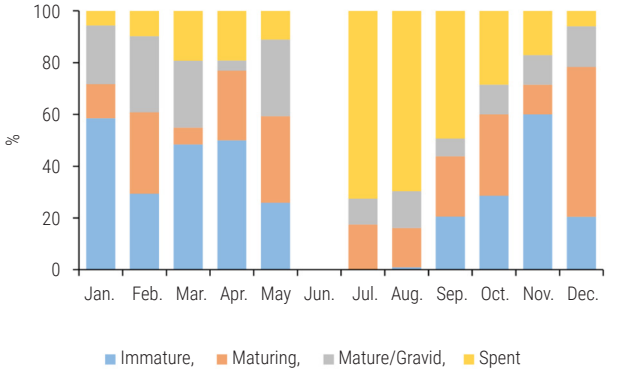

Fig. 6. Percentage occurrence of different maturity stages in the catch of *A. thazard*. Specimens were not found during June due to the monsoon fishing ban

at first capture (L_c) was 33.35 cm at an age (t_c) of 0.72 years. The growth performance index was 3.585 and t_0 -0.063 years. The von Bertalanffy growth equation derived was: $Lt = 72.6 [1 - e^{-0.73 (t + 0.063)}]$. The longevity of *A. thazard* was 3.6 years and the length attained by the fish at the end of 1st, 2nd and 3rd years were 37.33, 51.64 and 63.47 cm, respectively. The fishery was constituted primarily by 1+ year fishes.

Mortality, exploitation and virtual population analysis (VPA)

The estimated mortality rates M, F and Z were 1.17, 1.21 and 2.38 respectively. The exploitation rate was 0.508 and the exploitation ratio was 0.46. E_{max} obtained was 0.735, which is higher than the $E_{current}$, indicating further scope for exploitation of this species. VPA indicated that the main loss in the stock up to 23 cm size was due to natural causes (Fig. 7). Fishes became more vulnerable to the gear after this size and mortality due to fishing increased and

eventually outnumbered the natural losses from 33 cm onwards. The maximum fishing mortality of 2.56 was recorded at a size of 39 cm (Fig. 7).

Recruitment pattern

A bimodal recruitment pattern was observed for *A. thazard* with young ones being recruited into the fishery during most months of the year. The major peak in recruitment was in February-May and this pulse produced 76.14% of the recruits. The minor peak was in August-September and this pulse produced 11.22% of the recruits. The smallest length of recruitment was 19.5 cm.

Biological reference points (Thompson and Bell)

Table 1 shows the key biological reference points from frigate tuna stock in the Indian EEZ which includes the fishing rate, yield and biomass at the current fishing level at MSY. The fishing rates and biomass were at safe levels for *A. thazard* in the Indian EEZ (Fig. 8). Hence, there is considerable scope for enhancing their fishery.

Table 1. Key biological reference of *A. thazard* during 2015-2020 from Indian EEZ

Biological reference	Estimate
MSY	5,972
F_{curr}	5.69
F_{msy}	6.83
B_{curr}	3086
B_{msy}	2750
B_{curr}/B_{msy}	1.12
F_{curr}/F_{msy}	0.83
Spawning stock biomass (t)	1,592
Standing stock biomass (t)	2,371
Total yield (t)	5,648
Recruitment (Nos.)	24,503

Discussion

The estimated catch trend of frigate tuna in Indian waters revealed an increasing tendency till 2018, after which it decreased. A reduction in the number of fishing days due to the frequent bad

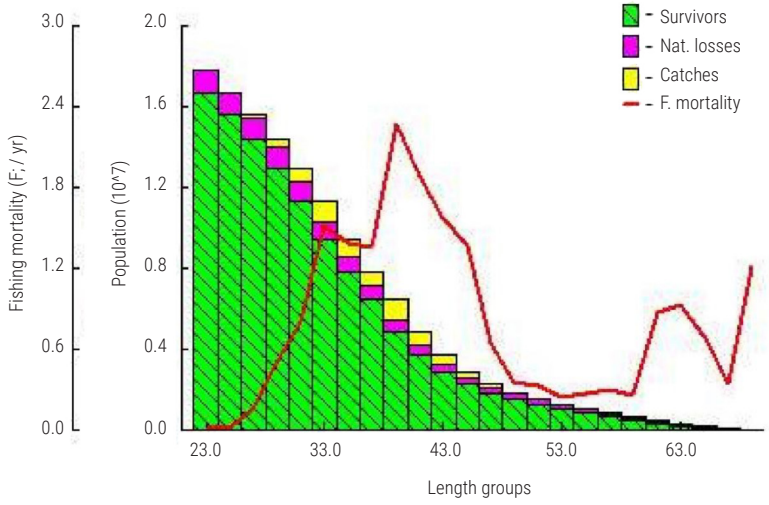

Fig. 7. Length structured VPA for *A. thazard* during 2015-2020

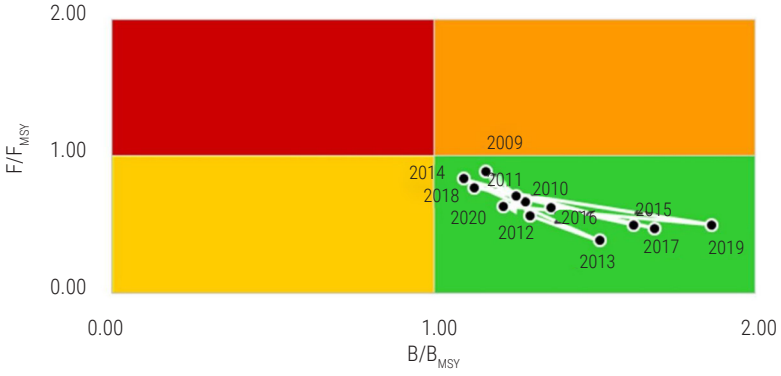

Fig. 8. Comparison of F/F_{MSY} and B/B_{MSY} for *A. thazard* from Indian waters

weather alerts and the COVID-19 pandemic lockdown in 2019 and 2020 also contributed to the decrease in catch. The average contribution of *A. thazard* to the tuna fishery (7.14%) during the present study further decreased by 15.9% as compared to the previous reports during 1985-2000 (Pillai and Gopakumar, 2003) and by10.32% during 2006-2010 (Ghosh *et al.*, 2012). The reasons for the same could be due to the expansion of fishing grounds and targeted exploitation of oceanic tunas from deeper waters. The maximum fork length recorded in the present study (68 cm) is comparable to the length reported by Pillai and Ganga (2008). However, frigate tunas measuring 32-44 and 25-40 cm formed the major share of the catch at Tuticorin (Abdussamad *et al.*, 2005) and Indian EEZ (Pillai and Ganga, 2008), respectively and in full conformity to the observations in the present study. The length-weight relationship showed that *A. thazard* exhibited isometric growth. Similar exponent values for frigate tuna were recorded from Indian waters by Ghosh *et al.* (2012)

Maturity studies clearly showed that the spawning is continuous with a peak during January-March and the present finding agreed with the observations of Ghosh *et al.* (2012) from the Indian EEZ. In contrast to this, the peak spawning of *A. thazard* was observed during September along the north-west coast of India. Similarly, L_{mat} observed in the present study is similar to the report by Ghosh *et al.* (2012). In the present study, the L_{mat} estimated for males and females combined was 31.9 cm. However, the estimated value in the present study is much smaller compared to the earlier studies by Mudumala *et al.* (2018b) from the north-west coast of India (37.5 cm) and by Pillai and Ganga (2008) from the Indian EEZ (38 cm).

The present L_{∞} (72.60 cm) is higher than the value previously reported along the Indian coast (Table 2). However, the growth coefficient (0.73) observed in the present study is close to that reported by James *et al.* (1992) and Pillai and Ganga (2008). The growth coefficient of more than 1.00 per year has been reported by Ghosh *et al.* (2012) and Mudumala *et al.* (2018a) from the Indian EEZ. The differences in the length in the length-frequency data owing to variations in the type of fishing gears as suggested by Ghosh *et al.* (2012) could be the reason for these observed changes. All studies however indicated *A. thazard* to be a fast-growing species, attaining a length of 37.33 cm in the first year. The present study revealed that for *A. thazard*, the maximum growth rate in length was observed during the 1st year of life after which the annual increment decreased with increasing age. The fish attained a fork length of 37.33 cm at the end of the first year when 50% of the stock was matured *i.e.,* L_{mat} 31.9 cm. The estimated length at first capture of 33.35 cm which is higher than the L_{mat} indicates that the majority of them might mature and spawn at least once before being caught and therefore the stocks do not experience growth overfishing. Length at first capture (33 cm) in the present study is similar to that reported by Abdussamad *et al*. (2005) from Tuticorin, 32.83 cm and 30 cm reported by Ghosh *et al.* (2012) and Silas *et al*. (1985), respectively from the Indian EEZ. Similarly, the continuous recruitment of *A. thazard* throughout the year with a peak during February-May is in full conformity with previous studies (Pillai and Gopakumar, 2003; Abdussamad *et al.,* 2005; Ghosh *et al.,* 2012).

The mortality and exploitation rate of *A. thazard* from previous studies is presented in Table 2. The exploitation rate reported by James *et al.* (1992) is lower *i.e.,* 0.48 and the remaining were higher (>0.6) than the present study. However, values calculated for Indian EEZ in the present study showed that the present rate of exploitation is well within the limits of a healthy stock condition. Moreover, a higher estimated MSY as compared to the present yield and the estimates of F/F_{msy} and B/B_{msy} indicate that the fishery is sustainable. Hence, there is scope for increasing the yield by increasing the effort to exploit the resource. The fluctuation noticed in the *A. thazard* landing in the last decade along the Indian coast necessitates the study of fishery-dependent environmental factors along with the fishery and biology for a better understanding of the resource dynamics.

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Table 2. Comparative estimates of growth parameters, mortality rates and exploitation rate of *A. thazard* from Indian EEZ

L_{∞} (cm)	K	t_0	M	Z	F	E	References
63.00	0.48	-0.27	-	-	-	-	Silas *et al*. (1985)
56.00	0.77	-	1.02	1.98	0.96	0.48	James *et al.* (1992)
49.00 (M)	1.30	0.002	1.85	5.55	3.70	0.67	Kasim (2002)
51.20 (F)	1.30	0.004	1.82	4.85	3.03	0.62	-
54.00	0.87	-	1.20	4.40	3.20	0.73	Pillai *et al.* (2002)
52.90	0.09	0.288	1.40	3.30	2.40	0.73	Abdussamad *et al.* (2005)
53.75-58.00 (Range)	0.72-1.02	-0.023--0.011	1.22-1.53	1.58-8.83	0.11-7.30	0.07-0.83	Pillai and Ganga, (2008)
46.60	0.93	-0.0153	1.48	5.97	4.49	0.75	Ghosh *et al*. (2010)
57.95	1.20	-0.0075	1.65	4.89	3.24	0.66	Ghosh *et al.* (2012)
47.03	1.30	-0.23	1.00	4.43	3.43	0.77	Mudumala *et al*. (2018a)
72.60	0.73	-0.063	1.17	2.38	1.21	0.51	Present study

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