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Fishery, population dynamics and stock structure of frigate tuna *Auxis thazard* (Lacepede, 1800) exploited from Indian waters

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ABSTRACT

The fishery, population characteristics and stock estimates of frigate tuna *Auxis thazard* (Lacepede, 1800) from Indian waters was studied during 2006 – 2010. The average annual catch was 11,157 t, which contributed to 13.2% of the total tuna catches. The length–weight relationship showed that growth was allometric for the species. Length at first maturity estimated was 29.7 cm and fecundity 8,07,986. The von Bertalanffy growth equation derived was: $Lt = 57.95\ [1 - e^{-1.2\ (t + 0.0075)}]$. Growth performance index was 3.605 and the length at first capture 32.83 cm. The natural mortality, fishing mortality and total mortality were 1.65, 3.24 and 4.89 respectively and with an exploitation ratio 0.66. E_{max} estimated was 0.778, which is higher than the present exploitation, indicating scope for further exploitation. Maximum sustainable yield estimated was 13,100 t and the yield per recruit 332.3 g. Maximum yield and yield/recruit was obtained by doubling the present fishing effort, but at the increased fishing effort, the increase in yield is only 2.93%which indicates that the present level of fishing can be continued.

Keywords: *Auxis thazard*, Fishery, Indian waters, Population dynamics, Stock assessment

Introduction

Auxis thazard, commonly known as frigate tuna represents an important group of coastal tuna species occurring in the Indian waters. The species is landed all along the Indian coastline and the major landing is along the south-west coast with Kerala contributing the most. The species is exploited by a variety of gears *viz*., drift gill nets, shore seines, ring seines and hooks and lines. Though there is recent information on the fishery and the exploitation status of *Auxis thazard* from Tuticorin (Kasim, 2002; Abdussamad *et al*., 2005) and Veraval (Ghosh *et al*., 2010), studies on the catch, population characteristics and stock estimates covering the entire coasts of India are lacking after the work of Silas *et al*. (1985) and James *et al*. (1993). These studies date back to two decades, after which there has been a change in the fishing pattern of coastal tunas throughout the country. Therefore, the present study was undertaken to provide an insight into the fishery, population dynamics and stock structure of *A. thazard* exploited from Indian waters.

Materials and methods

The data on catch and effort expended at different centres along the west and east coasts for *A. thazard* for the period 2006 – 2010 was obtained from Fishery Resource Assessment Division, Central Marine Fisheries Research Institute, Kochi. The length frequency was collected from major gears operated in each region. The length frequency data was raised to the annual average catches for the respective regions. The length-weight relationship was calculated as in Le Cren (1951). The size at first maturity (L_{50}) was determined by plotting the percentage of mature specimens (stage III and above) against their fork length. Proportions of gravid and ripe females (stage V and VI) over time were taken to determine the spawning season. Fecundity was worked out by raising the number of ova in all subsamples of the mature and ripe ovary (V and VI) to the total ovary weight. The ovary subsamples were obtained from the anterior, middle and the posterior regions of the ovary. The feeding intensity was assessed based on the distension of their stomach and the volume of food contained in it.

Growth parameters *viz*., asymptotic length (L_∞) and growth co-efficient (K) were estimated using the ELEFAN I module of FiSAT software and the Powell – Wetherall plot (Gayanilo *et al*., 1996). The length based growth performance index Ø was calculated from L_∞ and K as in 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 (1979) empirical equation. Longevity was estimated from $t_{max} = 3/K + t_0$ (Pauly, 1983a).

Natural mortality (M) was calculated using Pauly's empirical formula (Pauly, 1980) and total mortality (Z) from length converted catch curve (Pauly, 1983b). Length structured virtual population analysis (VPA) was used to obtain fishing mortalities per length class. Exploitation ratio was estimated from the equation, E = F/Z and exploitation rate from $U = F/Z*(1-e^{-z})$; where, F is the fishing mortality rate.

Total stock (P) and biomass (B) were estimated from the ratios Y/U and Y/F respectively; where Y is the annual average yield in tonnes. Maximum sustainable yield was calculated as in Gulland (1979) for exploited fish stocks. The relative yield per recruit (Y/R) and biomass per recruit (B/R) at different levels of F was estimated from Beverton and Holt Yield per Recruit model using Excel worksheet (Sparre, 1987).

Results

Fishery

The annual average catches of *A. thazard* for the five year period was 11,157 t forming 10.32% of the total tuna catches. The catch was highest in 2006 wherein 14,162 t were landed contributing 13.2% to the total tuna catches. The catches decreased henceforth and stagnated at around 10,500 t (Fig. 1). Kerala with an annual average catch of 3,567 t recorded the maximum landings, followed by Goa (2,501 t) and Andhra Pradesh (2,025 t) (Fig. 2). In Goa, 92.5% of the tunas landed were *A. thazard* alone and the catch remained steady over the years. The contribution of *A. thazard* in other states to the total tuna catch fluctuated between a maximum of 14.7% in Kerala and a minimum of 4.8% in Gujarat. There was a bumper catch of 8,578 t of frigate tuna in Kerala during 2006 after which it decreased gradually in successive years. However in Andhra Pradesh, the catch increased tremendously from a meager 41 t and 28 t in 2006 and 2007 respectively to 5,393 t in 2009.

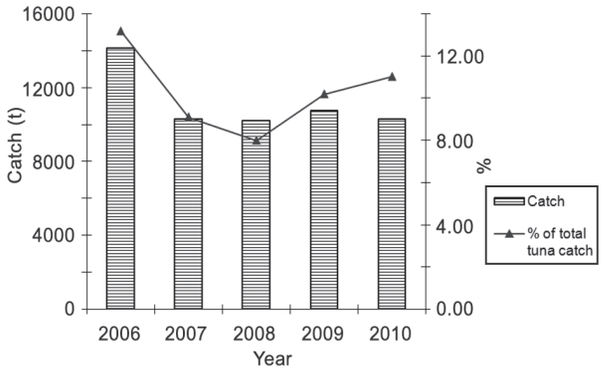

Fig. 1. Trend in annual production of frigate tuna in the Indian waters

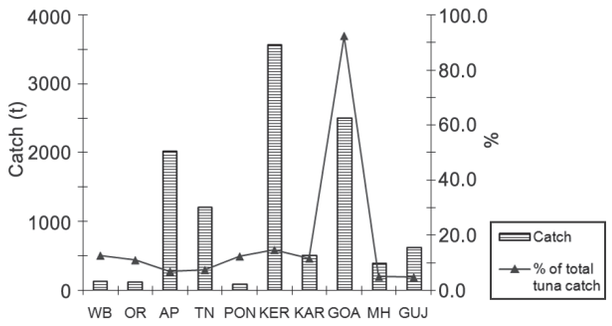

Fig. 2. Average percentage statewise landing of frigate tuna during 2006 - 2010

Seasonal abundance

Frigate tunas were exploited round the year. Majority of the fish were landed during April - May and September-December period. The annual average monthly catch of *A. thazard* was highest in May (2,832 t) followed by September (1,686 t) and October (1,361 t) (Fig 3). In Andhra Pradesh, on an average, 99% (2,013 t) of the annual (2,025 t) frigate tuna catch was landed in May. Along the west coast, frigate tuna catch dominated during the post-monsoon months of September and October.

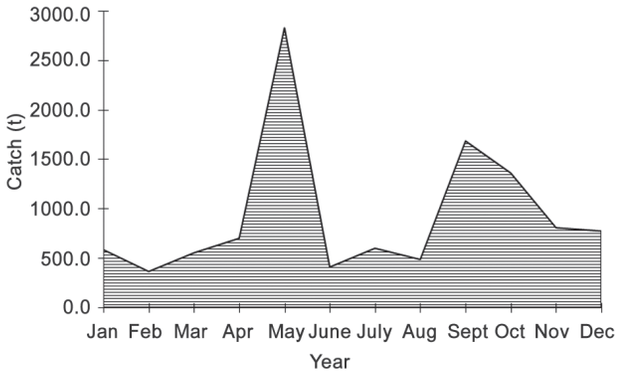

Fig. 3. Seasonal abundance of frigate tuna

Length composition

The length range varied from a minimum of 18 - 19.9 cm to a maximum of 54 - 55.9 cm. The maximum variations in length were recorded in the state of Tamil Nadu and the minimum variations recorded in the states of Karnataka and Gujarat (Fig. 4). The length ranges recorded were generally higher in the east coast than that of the west coast (Fig. 4). An analysis on the occurrence of different size groups in the national catch revealed that the length group 34 – 35.9 cm dominated the catches (11.82%), followed by the length group 32 – 33.9 cm (10.91%) (Fig. 5). The estimated length-weight relationship for *A. thazard* is:

$\log W = -2.082723 + 3.171805 \log L$ (n = 884, $r^2 = 0.92$) (95% C. I.)

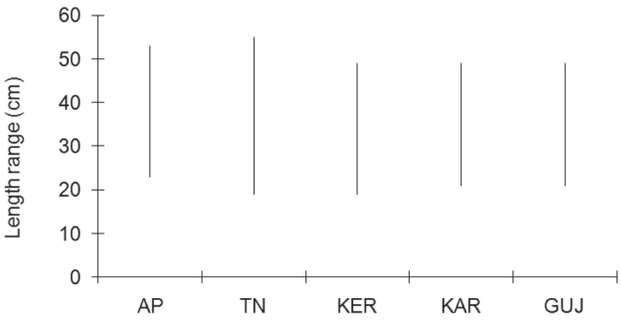

Fig. 4. Length ranges of *A. thazard* landed in different states for the years 2006 - 2010

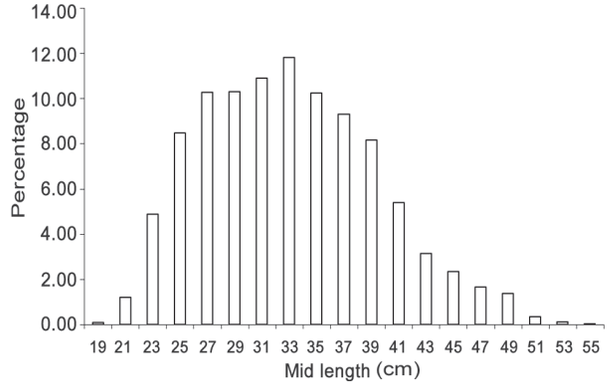

Fig. 5. Percentage occurrence of different size groups in the catch of *A. thazard*

Reproductive biology

Auxis thazard attained sexual maturity at a size of 29.7 cm fork length (Fig. 6). Gravid and ripe females were recorded in all the months except December with peak occurrence observed during February and again during July-October (Fig. 7). This suggested a prolonged spawning season for *A. thazard*. Mature females accounted for 37.2% of the population, followed by spent ones (23.7%), mature ones (21%) and immature ones (18.1%). The number of eggs released generally increased with the weight and size of the fish. The total fecundity ranged between 6,97,531 and 11,63,438 with an average of 8,07,986.

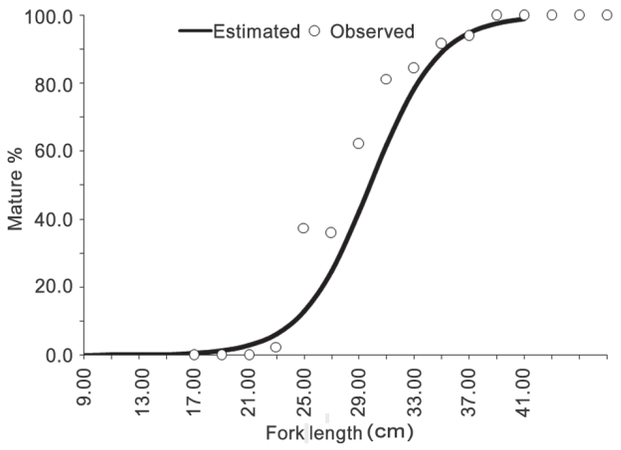

Fig. 6. Estimated size at first maturity of *A. thazard*

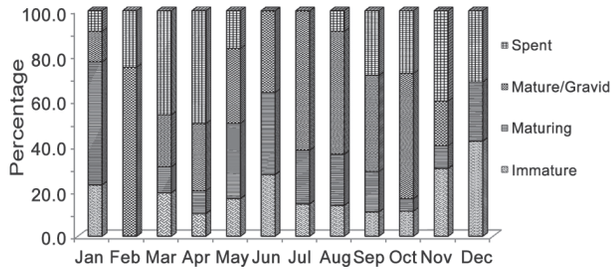

Fig. 7. Percentage occurrence of different maturity stages in the catch of *A. thazard*

Trophodynamics

Fishes possessing empty stomachs were encountered frequently in all the months for all the years. The average contribution of fishes with empty stomach was 74%. The feeding intensity was more in the months of March, April, June and December. An annual variation in feeding with high feeding intensity in alternate years was observed for *A. thazard*. The food items in the diet of *A. thazard* were classified broadly into three major groups: crustaceans, cephalopods and finfishes. Crustaceans comprised mainly non-penaeid prawn, *Acetes* spp. and crabs. The squid, *Loligo duvaucelli* dominated among cephalopods. Sardines, anchovies, mackerels, scads and tuna juveniles were dominant among finfishes.

Growth

The growth parameters, L_∞ and K estimated using the ELEFAN I programme were 57.95 cm and 1.2 year^{-1}, respectively which was close to the value (L_∞ = 56.97 cm) obtained from the Powell – Wetherall plot. The results of growth parameters obtained by ELEFAN were selected for further estimation. The asymptotic weight was 3205 g and size at first capture (Lc) was 32.83 cm at an age (t_c) of 0.69 year. The growth performance index was 3.605 and t_0 at - 0.0075 years. The von Bertalanffy growth equation derived was: $L_t = 57.95\ [1 - e^{-1.2\ (t + 0.0075)}]$.

The longevity of *A. thazard* was 2.49 years and the length attained by the fish at the end of 1st and 2nd year was 40.65 cm and 52.74 cm, respectively. The fishery was constituted primarily by 0+ year fishes.

Mortality, exploitation and Virtual Population Analysis (VPA)

The mortality rates M, F and Z computed were 1.65, 3.24 and 4.89 respectively. The exploitation rate was 0.658 and exploitation ratio 0.66. E_{max} obtained is 0.778, which is higher than the present exploitation, indicating further scope for exploitation of this species.

VPA indicated that main loss in the stock upto 20.9 cm size was due to natural causes (Fig. 8). Fishes became more vulnerable to the gear after this size and mortality due to fishing increased and eventually outnumbered the natural losses from 30.9 cm onwards. The maximum fishing mortality of 5.36 was recorded at size of 48.9 cm (Fig. 8).

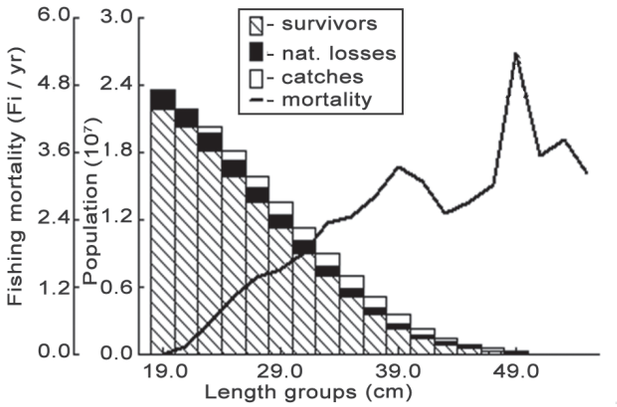

Fig. 8. Length structured VPA for *A. thazard* for the years 2006 - 2010

Stock and Maximum Sustainable Yield (MSY)

The annual total stock, biomass and MSY of *A. thazard* were estimated at 16,966 t, 3,444 t and 13,100 t, respectively.

Recruitment pattern

A bimodal recruitment pattern was observed for *A. thazard* with young ones being recruited into the fishery for most months of the year. The major peak in recruitment was from February - April and this pulse produced 53.3% of the recruits. The minor peak was in June and this pulse produced 11.15% of the recruits. The smallest length of recruitment was 18.95 cm.

Yield / Recruit

The yield and biomass curves showed that the maximum yield and yield/recruit could be obtained by increasing the present level of fishing by 100% (Fig. 9). The maximum yield and yield per recruit obtained by doubling the present fishing effort is 11,484.4 t and 342.05 g, whereas at the present level of fishing, it is 11,157 t and 332.3 g (Fig. 9). The increase in relative yield at the increased effort would be 2.93%.

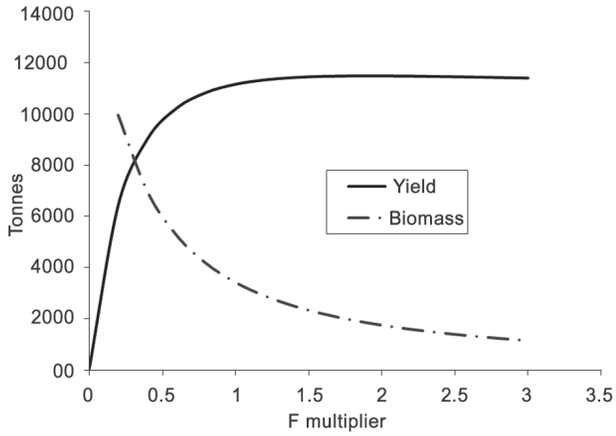

Fig. 9. Yield and biomass of *A. thazard* for different multiples of F

Discussion

The catch of frigate tuna was highest in 2006 after which it has decreased in successive years. The average contribution of *A. thazard* to the tuna fishery in the present study was 10.32% which is lower than 15.9% recorded during 1985 – 2000 by Pillai and Gopakumar (2003). The expansion of tuna fishing grounds coupled with enhanced exploitation of oceanic tunas from deeper waters is the causative factor for the decreased representation of this species in the total tuna landing. The length ranges recorded in the present study fully agree with 16 – 52 cm reported during 1985 – 2000 by Pillai and Gopakumar (2003). Frigate tunas of 32 - 44 cm and 30 – 40 cm formed the major share of the catch at Tuticorin (Abdussamad *et al*., 2005) and Andaman and Nicobar Islands (Madhu *et al*., 2002), respectively which are in full conformity to the present study. The length-weight relationship showed that *A. thazard* exhibited isometric growth. Similar exponent values for frigate tuna were recorded from Mangalore by Muthiah (1985) and from Tuticorin by Kasim (2002).

The L_∞ recorded in this study (57.95 cm) is higher than 46.6 cm recorded by Ghosh *et al*. (2009) from Veraval, 52.9 cm reported from Tuticorin by Abdussamad *et al*. (2005) and 56 cm recorded by James *et al*. (1993) from the Indian seas. In contrary, Silas *et al*. (1985) recorded much higher value of L_∞ (63 cm) from the Indian EEZ. These differences in the L_∞ values are mainly because of the differences in the length variation in the length frequency data owing to variation in the type of fishing gears used and methodology adopted in the study of growth parameters. The growth coefficient of 1.2 per year recorded was also higher than 0.93, 0.82, 0.77 and 0.49 reported by Ghosh *et al*. (2009), Abdussamad *et al*. (2005), James *et al*. (1993) and Silas *et al*. (1985) respectively, but is similar to 1.3 as reported by Kasim (2002) from Tuticorin. Likewise, the growth rate in length recorded at the end of

each year for *A. thazard* is higher than that reported by Ghosh *et al*. (2009), Abdussamad *et al*. (2005) and Silas *et al*. (1985) but is similar to that reported by Kasim (2002). 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 length at first capture of 32.83 cm was similar to 33 cm reported by Abdussamad *et al*. (2005) from Tuticorin and 30 cm reported by Silas *et al*. (1985) from the Indian EEZ. The length at first capture was higher than the size at first maturity of 30 cm reported by Pillai and Gopakumar (2003) indicating that majority of them might mature and spawn atleast once before being caught. The continuous recruitment of *A. thazard* throughout the year with a peak during February – April was in full conformity to earlier published reports by several authors (Pillai and Gopakumar, 2003; Abdussamad *et al*., 2005).

Beverton and Holt (1956) pointed out that the natural mortality coefficient of a fish is directly related to the growth coefficient (K) and inversely related to the asymptotic length (L_∞) and the life span. Accordingly, *A. thazard* which had higher growth coefficient of 1.2 per year and shorter lifespan of 2.49 years was found to have relatively higher natural mortality coefficient of 1.65 per year. Similar values of natural mortality ranging from 1.4 to 1.85 were reported by Ghosh *et al*. (2009), Abdussamad *et al*. (2005) and Kasim (2002). The M/K ratio obtained in the present study was well within the normal range of 1 – 2.5, as suggested by Beverton and Holt (1959). As a rule, the Z/K ratio of 1.0 is considered as growth dominated and if it is more than 2, then it is mortality dominated. In the present study it was more than 3, which showed that the fishery of *A. thazard* was mortality dominated. The exploitation ratio of 0.66 obtained in the present study is similar to 0.63 reported by Abdussamad *et al*. (2005) and 0.62 – 0.66 reported by Kasim (2002). It is evident from the results that since the value of E is lower than that of E_{max} and MSY higher than the annual catch, the stock is under less fishing pressure than the sustainable level.

The yield per recruit of 332.3 g obtained in the present study for *A. thazard* was far lower than the potential yield per recruit of 429 g reported by Kasim (2002). The yield and biomass/recruit and yield and biomass curves depicted that the maximum yield and yield/recruit could be obtained by doubling the present fishing effort. However at the increased fishing effort, the increase in yield is only 2.93%. Therefore it is suggested that the present level of fishing be maintained to keep the stock at near optimum fishing pressure. However, the stock estimates made on frigate tuna have several limitations. There is very less targeted fishery for frigate tuna in the seas along the Indian coast. The gears in which they are caught are not operated exclusively for frigate tunas. The migratory and straddling nature of frigate tuna and the occurrence of multispecies fisheries which are seasonal and very short at different localities make it difficult to arrive at realistic conclusions on their stock positions.

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