



Population Age Structure and Stock Assessment of Reeve's Croaker *Chrysochir aurea* (Richardson, 1846) Along West Bengal Coast of India

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Abstract

The age structure, growth, mortality, and exploitation status of the *Chrysochir aurea* stock in West Bengal coast, India, were assessed. A sample of 618 specimens with total lengths ranging from 124 to 417 mm were collected from commercial trawlers between September 2021 and September 2022. The length-frequency distribution was analysed using the FISAT II tool. The growth parameters asymptotic length (L_{∞}), catabolic coefficient (K), and initial condition factor (t_0) were determined to be 435.23 mm, 0.26 yr^{-1} , and -0.309 years, respectively. The total (Z), natural (M), and fishing (F) mortality rates were estimated at 1.09, 0.35, and 0.74 yr^{-1} , respectively. A consistent recruitment trend was seen throughout the year, with two peaks, one from February to May and the other from July to November, with a length at first capture (L_C) of 177.95 mm. The current exploitation level (E_{now}) and maximum exploitation level (E_{max}) were calculated at 0.68 and 0.60 indicating overexploitation of the stock along the coast. The yield was projected to be 160.826 t at the current fishing level ($f = 1.0$) and 164.866 t at the maximum fishing level ($f = 0.9$). To create a sustainable fishery in the future, a reduction in fishing effort is suggested.

Keywords *Chrysochir aurea* · Population parameters · Stock assessment · West Bengal coast

Introduction

The Indian, Pacific, and Atlantic Oceans are home to a diverse population of sciaenids, also commonly referred to as drummers or croakers belonging to the family Sciaenidae. They are one of India's most valuable demersal fisheries resources, accounting for around 3.3% of all marine fish landings in the entire country. Their share of the West Bengal state's total marine fish and demersal fish landings, which has 158 km of coastline, is around 7.21% and 23.44%, respectively (CMFRI 2022).

The optimal strategy for exploiting and maintaining aquatic living resources can be determined with the use of population age structure (Sparre and Venema 1998). It makes quantitative forecasts on how alternative management strategies will affect fish populations using a variety

of statistical and mathematical models. The computation of growth, mortality, and recruitment patterns is imperative to comprehend population dynamics rates and is made possible by research on population dynamics in fishes (Chung and Woo 1999; Bhakta et al. 2020). Age at first maturity, spawning frequency, individual and stock reactions to environmental changes, recruiting success, stock structure, etc. are just a few of the issues that these factors can help us better understand (Johnson et al. 2020; Bhakta et al. 2022). The length-frequency distribution is an essential biometric statistic for assessing the dynamic rates of recruitment, growth, mortality, yields, and stock biomass in a particular ecosystem (Sabbir et al. 2021). One of the main objectives of fish stock assessments is to offer knowledge on the most effective uses of resource management. Several models must be used to assess how diverse environmental changes affect the biological and physical traits of a fish species, family, or group (Sarkar et al. 2018).

Reeve's croaker, *Chrysochir aurea* (Richardson 1846), is one of the most commercially significant species that is widely distributed in the Indo-West Pacific; it is primarily found in Sri Lanka, through the Bay of Bengal, to southern China (including Taiwan), the southern part of Indonesia, and Malaysia (Sasaki 2001; Jalal et al. 2012). It lives mostly

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in brackish and marine coastal areas. Effective fishery management and the development of sustainable fisheries require an assessment of population structure, including age and growth, as well as an assessment of a fish stock (Hilborn and Walters 1992; Campana 2001; Bhuyan et al. 2012). In general, and especially off the coast of West Bengal, India where the resource significantly contributes to trawl landings, information about the population parameters and stock assessment of *C. aurea* is noticeably lacking. As a result, the present research was undertaken to estimate population parameters and evaluate the stock status of *C. aurea* along the said coast.

Materials and Methods

Study Area

The coastline of West Bengal with a continental shelf area of 17,049 sq. km spread in two districts namely South 24-Parganas and Purba Medinipur. Purba Medinipur has an open coast on the south-eastern part of West Bengal. The study area was selected purposively in the inshore areas of the Bay of Bengal along the coast of Digha (Latitude 21.6800° N and Longitude 87.5500° E), Purba Medinipur

Sampling and Data Collection

Length frequency data were collected monthly at the Digha fish landing center from September 2021 to September 2022. The specimens were caught using a trawl net with a mesh size of between 18 and 35 mm at a depth of between 10 and 69 m and brought to the laboratory for further study in an insulated box that was kept frozen. Using a standard measuring board, the total length (TL) of the fish specimens was measured from the tip of the anterior-most region of the body to the tip of the caudal fin to the nearest mm accuracy. Total weight was measured to the nearest mg using digital electronic balance. The collected length frequency data were grouped into 10 mm class intervals, and monthly length frequency data were fed into FAO-ICLARM Stock Assessment Tool (FiSAT II) software version 1.2.2 (Gayanilo et al. 2005) to estimate various population parameters and yields and to assess stock.

Estimation of Population Parameters

The length-weight relationship was computed statistically by expressing the parabolic equation $W = aL^b$. This equation was expressed logarithmically as $\text{Log } W = \log a + b \log L$ (Le Cren 1951). Where W = weight of fish in g and L = length of fish in mm, 'a' and 'b' are intercept and regression coefficients, respectively.

Growth parameters like asymptotic length (L_∞) and growth coefficient (K) were estimated using the Electronic Length Frequency Analysis (ELEFAN I) module in FiSAT II, and the initial condition factor or age at zero-length (t_0) was calculated from Pauly's (1979) empirical equation as

$$\log_{10}(-t_0) = -0.3922 - 0.275 \log_{10} L_\infty - 1.038 \log_{10} K$$

where L_∞ is the asymptotic length, K is the growth coefficient, and t_0 is the initial condition factor or age at zero length.

The growth and age were estimated by employing the Von Bertalanffy (1938) growth equation

$$L_t = L_\infty \left(1 - e^{-K(t-t_0)} \right)$$

where L_t is the length of the fish at age t , e is exponential, L_∞ is the asymptotic length, K is the growth coefficient, and t_0 is the age at zero length. The growth performance index (ϕ') for *C. aurea* was estimated as per Pauly and Munro (1984)

$$\phi' = \text{Log}K + 2\text{Log}L_\infty$$

where L_∞ is the asymptotic length, K is the growth coefficient

The total mortality (Z) was calculated from the length-converted catch curve method (Pauly 1983a, 1984a) by using FiSAT II and the natural mortality (M) was estimated by Pauly's (1980) empirical formula

$$\ln(M) = -0.0152 - 0.279 \ln(L_\infty) + 0.6543 \ln(K) + 0.463 \ln(T)$$

where 'T' is the mean annual water temperature, which was taken as 27°C (India Meteorological Department, Kolkata). Fishing mortality (F) was estimated by subtracting natural mortality (M) from total mortality (Z), i.e., $F = Z - M$.

The exploitation level (E) was estimated by using the following equation

$$E = F/Z$$

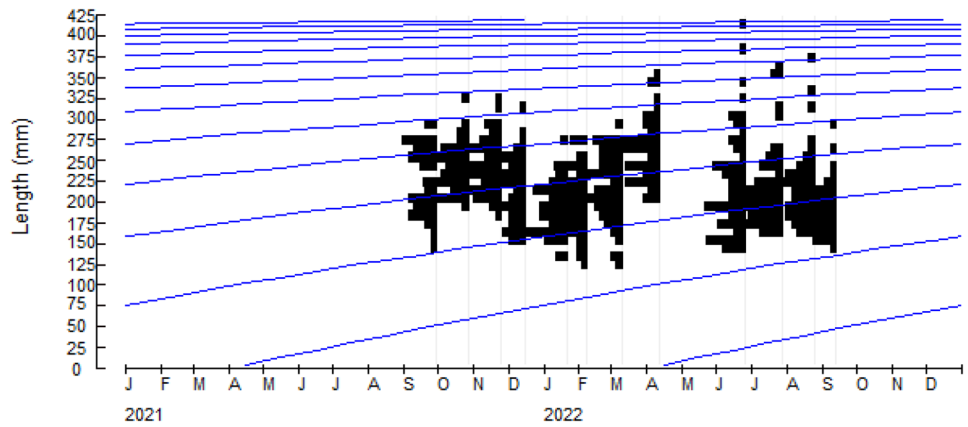
Stock Assessment

For stock assessment studies, the probability of capture was obtained from length-converted catch curves by backward extrapolation of the catch curve. Long-structured virtual population analysis was done by Pauly (1984b). The relative yield per recruit (Y'/R) and biomass per recruit (B'/R) at different levels of F were estimated from Beverton and Holt's (1966) relative yield per recruit model. The status of the stock was evaluated based on Y'/R . The longevity (t_{\max}) of the species was estimated by the equation given by Pauly (1983b) as:

$$t_{\max} = 3/K + t_0$$

where ' t_{\max} ' is the longevity of the species.

Fig. 1 Length-frequency distribution and seasonal occurrence of *C. aurea* from the West Bengal coast during the study period



Results

Length-Frequency Distribution

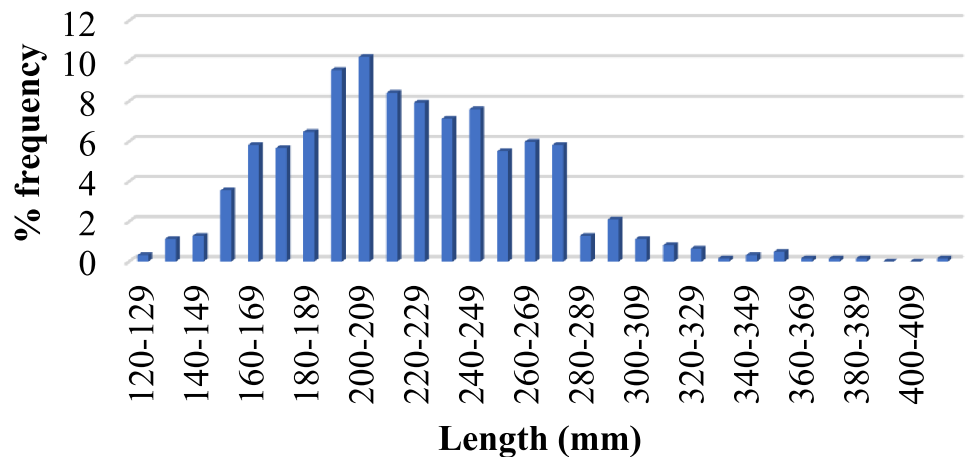
Analysis of catch composition data for *C. aurea* from the West Bengal coast revealed that the species is existing during the year along the coast. Month-wise length-frequency data are presented in Fig. 1. The size of *C. aurea* ranged from 124 to 417 mm with an average length of 221.07 ± 44.56 mm in total length. According to the percentage length frequency data, the length groups of 200–209 mm (10.19%), followed by 190–199 mm (9.55%) represented the majority of the species' commercial catches (Fig. 2).

Population Parameters

Age and Growth

The estimated growth parameters L_{∞} , K and t_0 were determined as 435.23 mm, 0.26 yr^{-1} , and -0.309 years, respectively. Von Bertalanffy's growth equation was subsequently obtained as: $L_t = 435.23[1 - e^{-0.26(t+0.309)}]$. Accordingly, lengths attained by *C. aurea* were estimated as 125, 198, 251, 293 and 325 mm at the end of 1, 2, 3, 4, and 5 years, respectively, by employing the growth equation (Fig. 3). The smallest length recorded was 124 mm, corresponding to an age of 0.98 years. Growth performance index (ϕ') and the maximum life

Fig. 2 The length-frequency distribution of *C. aurea*, which was trawled off the coast of West Bengal during the period of the study



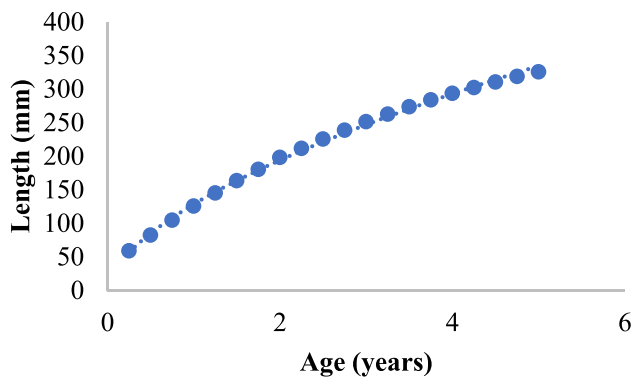


Fig. 3 Average length attained by *C. aurea* at different ages

span (t_{\max}) of *C. aurea* were estimated as 4.69 and 11.23 years, respectively. The pooled linear relationship between length and weight of *C. aurea* was obtained as $\text{Log } W = -5.6407 + 3.2756 \text{ Log } L$ with R^2 value of 0.9855.

Mortality Parameters

The estimated total mortality (Z) was 1.09 yr^{-1} (Fig. 4), and the values of natural mortality (M) and fishing mortality (F) were 0.35 yr^{-1} at 27°C annual mean temperature and 0.74 yr^{-1} , respectively. The current exploitation level (E_{now}) was estimated at 0.68.

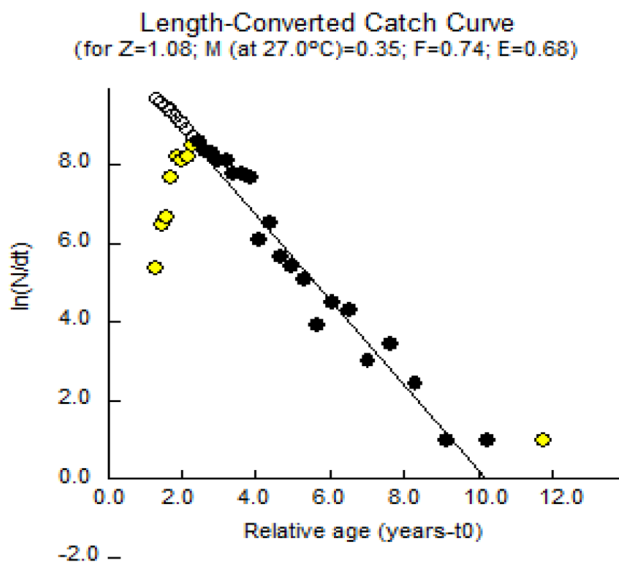


Fig. 4 Length converted catch curve for estimation of total mortality (Z) for *C. aurea* from the West Bengal coast during the study period

Stock Assessment

Recruitment Pattern

Using the estimated values of growth parameters, the recruitment pattern was analysed from recruitment curves. The length frequency data of *C. aurea* indicated a persistent recruitment pattern during the year (Fig. 5), with two peaks, one during the months of February to May and another during July to November. The midpoint, 124.5 mm of the smallest length group (120–129 mm) in the catch was taken as length at recruitment (L_r) for *C. aurea*.

Probability of Capture (L_C)

The monthly length-frequency data was pooled together, and the frequency, cumulative frequency, and cumulative percentage were calculated by applying the length-converted catch curve method. The value of L_C or $L_{50\%}$ (the length at which 50% of fish become vulnerable to the gear) was estimated at 177.95 mm from the graph (Fig. 6), and the corresponding age was 1.71 years.

The input parameters used for virtual population analysis (VPA) were L_∞ of 435.23 mm, K of 0.26 yr^{-1} , M of 0.35 yr^{-1} , 'a' of 0.0000023 and 'b' of 3.2756 from the length-weight relationship. The results obtained from length structured VPA depicted that *C. aurea* along the West Bengal coast is overexploited.

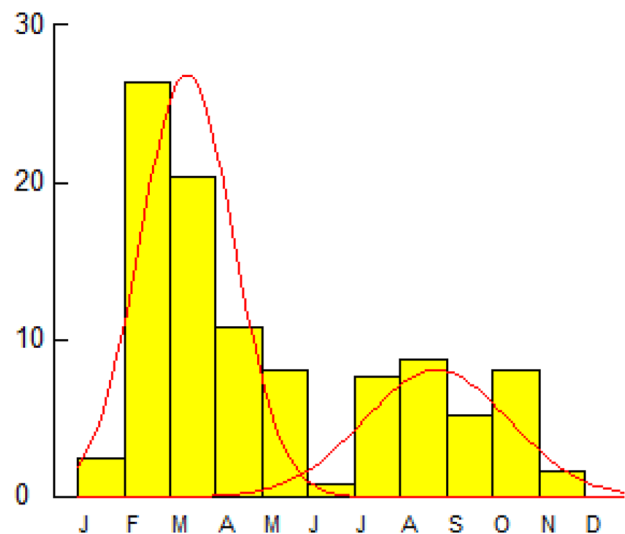
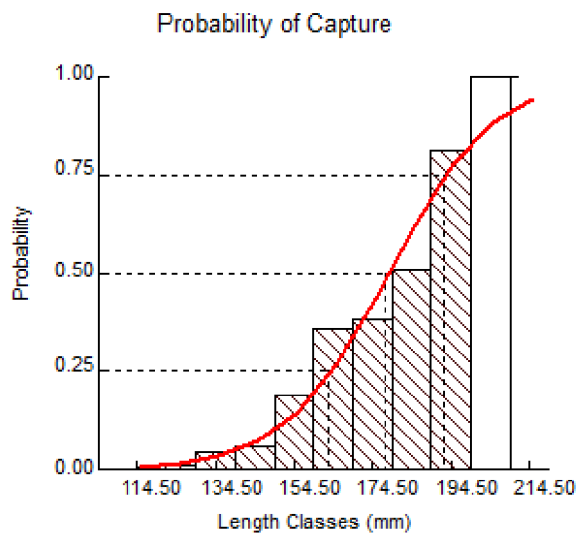


Fig. 5 Depicted recruitment pattern of *C. aurea* from the West Bengal coast. ($L_{25\%} = 163.32 \text{ mm}$, $L_{50\%} = 177.95 \text{ mm}$, $L_{75\%} = 192.58 \text{ mm}$)



($L_{25\%} = 163.32$ mm $L_{50\%} = 177.95$ mm $L_{75\%} = 192.58$ mm)

Fig. 6 Trawl net selection curve to determine length at first capture of *C. aurea* from West Bengal coast

The exploitation ratio was estimated at 0.68 (Fig. 7). The fishing mortality was found to be outweighed by the length groups of 200–209 mm (Fig. 7), reaching the highest value of 1.4783 yr^{-1} at the 270–279 mm length group, followed by 1.0919 yr^{-1} at the 260–269 mm length group. The shorter group showed relatively low fishing mortalities. The length groups of 120–129 mm to 140–149 mm were subjected to mortality mainly. The highest number of fish populations (2285288) be noticed in the 120–129 mm

length group, with a biomass of 46.5 tonnes and a respective fishing mortality of 0.0132 yr^{-1} . The largest length group of 410–419 mm showed the least number of fish population (2338) with fishing mortality of 0.74 yr^{-1} and a respective biomass of 18.5 t. The biomass increased from 46.5 metric tonnes to the highest of 163.46 tonnes from the length class of 120–129 mm to 220–229 mm and then gradually decreased to its lowest level of 18.5 tonnes at the 410–419 mm length class.

Fig. 7 Length structured VPA indicating survivors, natural losses, catches and fishing mortality of *C. aurea* along the West Bengal coast. ($E_{\text{max}} = 0.604$, $E_{0.01} = 0.521$, $E_{0.05} = 0.337$, $L_{\infty} = 435.23$ mm, $M/K = 1.35$)

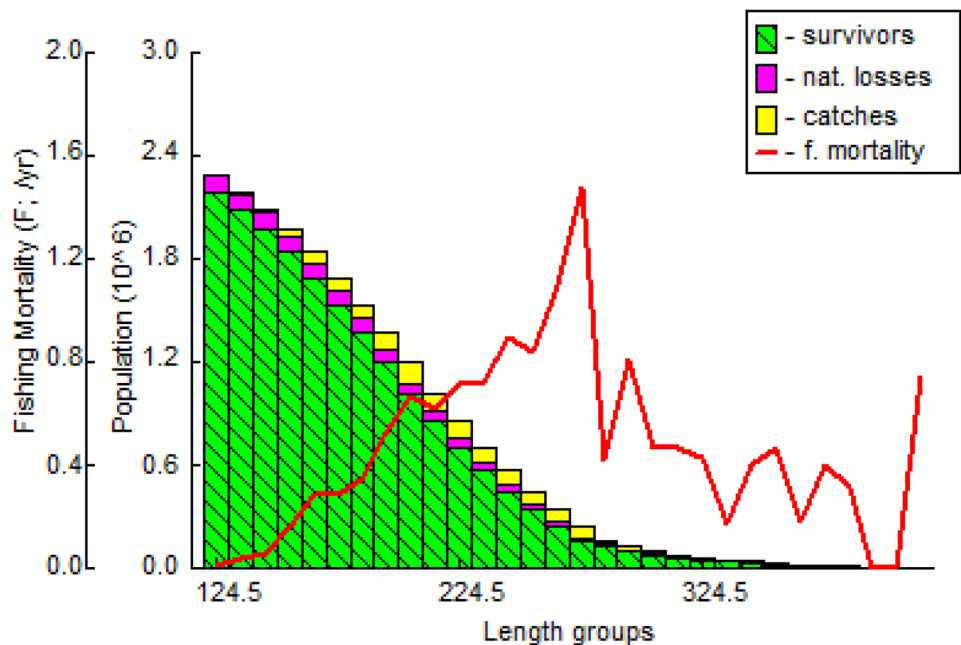
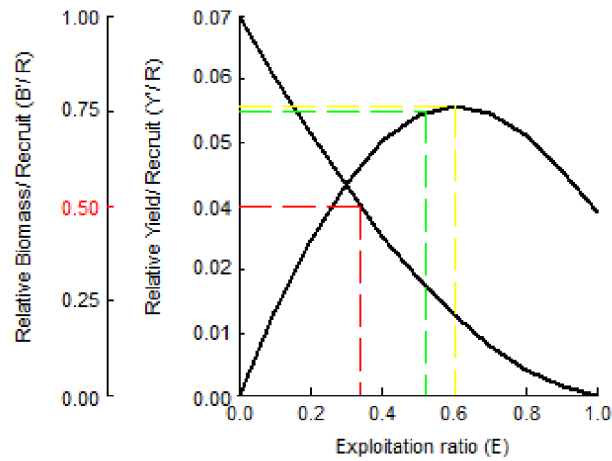


Fig. 8 Relative yield per recruit and relative biomass per recruit model using knife-edge selection curve for *C. aurea*



$$(E_{\text{-max}} = 0.604, E_{-0.01} = 0.521, E_{-0.05} = 0.337, L_{\infty} = 435.23 \text{ mm}, M/K = 1.35)$$

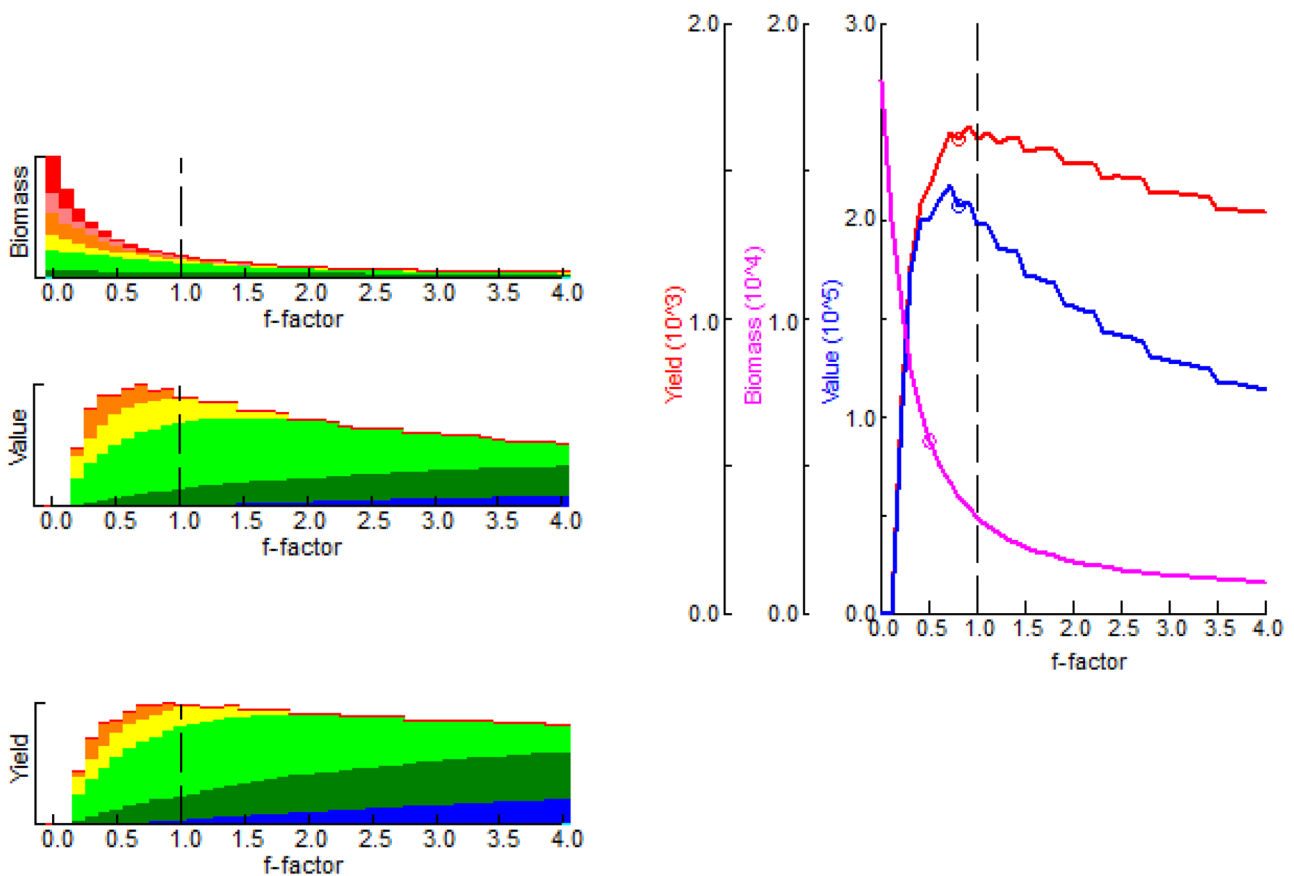


Fig. 9 Graphical representation of the Thompson and Bell prediction model for *C. aurea*

Yield and Yield Per Recruit

The Beverton and Holt relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) were estimated from the knife-edge selection of the size at first capture, which was 177.95 mm. The input data were L_C/L_∞ (0.41) and M/K (1.35). The E_{\max} , $E_{0.1}$ and $E_{0.5}$ values were obtained as 0.60, 0.521, and 0.337, respectively, from the knife-edge selection method (Fig. 8).

Thompson and Bell Prediction Model

The length based VPA file was stored and further used as input along with the price assigned according to each length group for the analysis of Thompson and Bell's (1934) prediction model (Fig. 9). The output shows an array of 'f-factors with corresponding yield, biomass, and values. The 'f-factor' of 1.0 indicates the present level of fishing. The result of the Thompson and Bell prediction model indicated that yield increased from 73.76 tonnes at an f-factor of 0.2 to a maximum sustainable

yield (MSY) of 164.866 t at an f-factor of 0.9. Beyond the fishing pressure ('f-factor' = 0.9), yield has declined. The maximum value of the catch was obtained at the 'f-factor' of 0.7.

Discussion

Age and Growth

Understanding the composition of the fish population, the impact of a particular brood or age group on catch fluctuations, and the length or age at capture and maturity are all highly important aspects of fishery management. The east coast of India has fewer studies on sciaenid growth parameters and stock evaluation than the west coast. Since work on *C. aurea* population parameters and stock assessment has not yet been done, earlier findings on other closely related sciaenid species have been used to compare the findings of the present study (Table 1).

Table 1 A comparative analysis of population parameters of some sciaenid species along the east coast of India

Species	Author	Study area	L_∞ (mm)	K (yr ⁻¹)	ϕ'	Z (yr ⁻¹)	M (yr ⁻¹)	F (yr ⁻¹)	E
<i>Otolithes ruber</i>	Chakraborty et al. (2000)	Tamil Nadu (SE)	469	0.47	3.01	3.53	1	2.53	0.72
			315	0.65	2.80	5.05	1.33	3.72	0.74
	Bhuyan et al. (2012)	Odisha (NE)	511	0.67	3.24	-	-	-	-
	Santhoshkumar et al. (2017)	Tamil Nadu (SE)	372.8	0.27	2.57	2.45	0.71	1.74	0.71
<i>Johnius carutta</i>	Vivekanandan (1985)	Tamil Nadu (SE)	259	0.726	-	-	-	-	-
	Murty (1985)	Andhra Pradesh (SE)	281	0.557	2.64	-	-	-	-
	Murty (1986)	Andhra Pradesh (SE)	333.3	0.44	2.68	5.07	1.00	4.07	0.80
	Rao et al. (1992)	Tamil Nadu (SE)	293	0.51	2.64	-	-	-	-
		Andhra Pradesh (SE)	281	0.557	-	-	-	-	-
	Chakraborty et al. (2000)	Andhra Pradesh (SE)	281	0.56	2.64	3.7	1.11	2.59	0.70
Rajkumar et al. (2004)	Andhra Pradesh (SE)	305	0.84	2.90	3.02	2.05	0.97	0.68	
Bhuyan et al. (2012)	Odisha (NE)	308	0.89	2.90	-	-	-	-	
<i>Johnius gangeticus</i>	Mandal and Nagesh (2007)	West Bengal (NE)	480	1.00	3.36	4.512	1.53	2.98	0.66 (U)
<i>Pennahia macrophthalmus (=aneus)</i>	Jayasankar 1995	Tamil Nadu (SE)	233	1.26	2.84	2.7	-	-	-
	Chakraborty et al. 2000	Tamil Nadu (SE)	260	0.98	2.82	4.9	1.9	3	0.61
		Odisha (NE)	303	0.86	2.90	-	-	-	-
<i>Pennahia anea (=aneus)</i>	Muktha et al. 2015	Andhra Pradesh (SE)	-	-	-	4.15	1.38	2.77	0.67
<i>Nibea maculata</i>	Chakraborty et al. 2000	Tamil Nadu (SE)	284	0.85	-	6.18	1.66	1.67	0.73
		Tamil Nadu (NE)	314	0.72	-	4.3	1.4	2.9	0.67
		Andhra Pradesh (SE)	315	0.61	-	2.93	1.26	1.67	0.57
	Santhoshkumar et al. 2011	Tamil Nadu (SE)	-	-	-	2.73	1.67	1.06	0.39
<i>Otolithoides pama</i>	Bhakta et al. 2020	West Bengal (NE)	418	0.58	3.01	4.16	1.14	3.02	0.73
<i>Chrysochir aurea</i>	Present study	Digha coast, West Bengal	435.23	0.26	4.69	1.08	0.35	0.74	0.68

Chakraborty et al. (2000) and Santhoshkumar et al. (2017) reported L_{∞} as 469 mm and 372.8 mm, K as 0.47 yr^{-1} and 0.27 yr^{-1} , ϕ' as 3.01 and 2.57, respectively, of *Otolithes ruber* from Tamil Nadu, southeast coast of India where values differed for the species from the same study area. *Otolithoides pama* from the Hooghly-Matlah estuary in West Bengal, northeast coast of India reported values for L_{∞} and K as 418 mm and 0.58 yr^{-1} (Bhakta et al. 2020). *O. ruber* has been studied all over the world since it appears to have a more widespread distribution. According to various sources (Morgan 1984; Ingles and Pauly 1984; Gislason 1985; Schultz 1992; Almatar 1993; Chakraborty et al. 2000; Brash and Fennessy 2005; Bhuyan et al. 2012), the L_{∞} of this species varied between 295 and 696 mm, and its K value ranged between 0.14 and 0.67 yr^{-1} . For the several sciaenids from the Indian seas, the value of K ranged between 0.21 to 2.0 (Table 1).

In the present investigation, the asymptotic length of *C. aurea* is slightly on the higher side, and the K value (0.26 yr^{-1}), appears low compared to other sciaenids reported by previous authors. Such low K values in the range of 0.14 – 0.26 yr^{-1} for *O. biauritus* from Mumbai (Jayaprakash 1976; Manojkumar et al. 1992) and 0.28 yr^{-1} for *Pseudotolithus elongatus* from Nigeria (Nawa 1987) have been recorded. It is evident that there is an inverse relationship between L_{∞} and K (Chakraborty 1987, 2006). The largest fish of 417 mm recorded in the present study and low K value justifies a higher L_{∞} value (435.23 mm) for this species.

The overall growth performance of the fish population as measured by growth in length is represented by the growth performance index (ϕ') (Pauly and Munro 1984). The range of ϕ' for sciaenid species found on the east coast varied between 2.57 and 3.36 (Table 1). Though the ϕ' value in the present study (4.69) slightly deviated from the earlier observations, which ranged from 6.13 to 6.87. For sciaenid species found in Bombay waters (northwest coast), such as *Johnius macrorhynchus*, *Johnius vogleri*, *Johnius sina*, *Johnius dussumieri*, *Otolithes cuvieri* and *Pennahia macrophthalmus*, these values were comparatively higher (Chakraborty 1997, 2001). The main causes of these fluctuations include changes in K values, environmental factors and varying fishing intensities. Growth factors vary from stock to stock and sex to sex within the same species, also due to differential growth rates of successive cohorts owing to environmental conditions (Chakraborty 1996; Sparre and Venema 1998).

Mortality Parameters

No reports of mortality parameters for *C. aurea* are available from India or elsewhere. The Z and F of sciaenids recorded by the earlier investigators from the east coast of India ranged between 2.45 yr^{-1} and 6.18 yr^{-1} and, 0.97 yr^{-1} and

4.07 yr^{-1} , respectively (Table 1). The present study indicated that the F is almost double the M which clearly implies the excess fishing pressure on *C. aurea* along the West Bengal coast. The earlier studies (Table 1) on different sciaenid species from Indian waters also reported higher fishing mortality than natural mortality (Murty 1986; Chakraborty 1987; Manojkumar et al. 1992; Chakraborty et al. 2000; Chakraborty 2006; Mandal and Nagesh 2007; Bhakta et al. 2020). According to Chakraborty (1994), fast-growing fish with a high K value would have a high M and *vice versa*, and fish with a high L_{∞} would have a low M . In the current study, *C. aurea* had relatively higher L_{∞} , K and lower M values, which are justified.

The mortality rate of *C. aurea* in the present study associated with fishing mortality is on the higher side, and around 60% of the catch (Figure 2) was below the length at first maturity (L_m) reported by Jana (2023) (218 mm for males and 222 mm for females) and Ni (2018) (263 for males and 210 mm for females) which may be due to the use of small cod-end mesh sizes of 18 to 35 mm. Hence, there is a great need for mesh size regulations to avoid overfishing. The age of the species and the predator abundance present in the surroundings, among other environmental factors, have a significant impact on the natural mortality coefficient in fish. (Pauly 1980, 1983a; Jones 1984).

Ratio of Mortality and Growth Coefficient

The M/K value shows how the natural mortality coefficient and physiological variables interact. The growth coefficient, K is related to fish longevity, and the M/K values ranging from 1.5 to 2.5 or lower appear to be most common (Beverton and Holt 1959; Prince et al. 2015). Sparre and Venema (1998) suggested that natural mortality could be associated with environmental temperature because higher temperatures result in a high metabolic rate. If $M/K < 0.5$, growth is high relative to mortality; if $M/K > 2.0$, natural mortality exceeds growth, indicating that many fish will die before reaching their optimum level of growth. According to Chakraborty (2001), six species of Indian sciaenids had M/K values that ranged from 1.81 to 2.18. The M/K value in the current investigation was assessed to be 1.35, although slightly lower than the values specified by Chakraborty (2001), the M estimated in the current study is found to be realistic.

The ratio of Z/K is typically believed to be dominated by growth when it is less than 1, dominated by mortality when it is equal to 1 and indicates a high level of exploitation when equal to or more than 2 (Chakraborty 2006). The Z/K value was estimated to be 4.15 in the present study on *C. aurea*, indicating a very high level of

exploitation. Chakraborty (2006) also found a high level of exploitation ($Z/K = 3.48$) for *O. biauritus* from the northwest coast of India.

Exploitation Level

The degree of exploitation (E_{now}) indicates whether a stock is overfished, underfished, or being fished to its maximum potential. The current study's exploitation level was calculated to be 0.68, which is significantly higher than the ideal level of 0.5 suggested by Gulland (1983). The West Bengal coast's *C. aurea* stock is overexploited as evidenced by the maximum exploitation level (E_{max}) of 0.60, which is lower than the current level of exploitation ($E_{\text{now}} = 0.68$). Additionally, studies reported by several experts revealed E values of greater than 0.5 for many sciaenid species near the Indian coast (Table 1). To avoid stock depletion and promote sustainable sciaenid fisheries throughout the Indian coast, all these authors, including the present one, recommended reducing fishing effort in addition to the monsoon fishing ban and mesh size regulations which are already in vogue.

Stock Assessment

Recruitment Pattern

The recruitment pattern of *C. aurea* in the current study showed a continuous recruitment pattern with two peaks, one during the months of February–May and another during the months of July–November. The availability of juveniles throughout the year also lends credence to it. Several researchers have noted a continuous recruitment trend throughout the year in Indian seas with changing peaks in several sciaenid species (Chakraborty et al. 2000; Manojkumar 2007; Santhoshkumar et al. 2017; Sabbir et al. 2021). The current study's findings of a prolonged spawning season suggest mixing of subpopulations that spawn at varying times depending on the various fishing locations (Muktha et al. 2015). The study on reproductive biology from Southwestern Taiwan found that *C. aurea* is a multiple spawner and primarily spawns from July to December, which lends confirmation to the current finding (Ni 2018).

Probability of Capture

In the current study, the length at first capture (L_C) was assessed to be 177.95 mm, which is less than the length at maturity of the species reported by Ni (2018) and Jana (2023) indicating that they were caught before they reached maturity and began to reproduce, sign of growth overfishing. This may be prevented by increasing the size of the fish when they are harvested through regulation of mesh size.

Length Structured Virtual Population Analysis

The virtual population analysis of the *C. aurea* population from the West Bengal coast demonstrated that the highest fishing mortality of 1.4783 at the length group of 270–279 mm, followed by 1.0919 at 260–269 mm, which was consistent with the observation of Rao et al. (1992). A similar finding was achieved in *O. cuvieri* from northwest coast of India by Telvekar (2006), who found higher fishing mortality rates in medium-length groups owing to the underrepresentation of the smaller and larger-length fish groups in commercial catches.

Yield on Prediction Model

Thompson and Bell's prediction model indicated that the yield at the present fishing level ('f-factor = 1) was 160.826 t (Fig. 9). The maximum yield of 164.866 t could be obtained at a fishing level of 0.9. The present study indicated that the yield of *C. aurea* from the West Bengal coast is already in a declining stage at the present fishing effort ('f-factor = 1). So, a further increase in fishing effort will decrease the yield and drastically reduce the biomass. Therefore, a reduction of fishing effort to 0.9 is suggested for the sustainable fishery of *C. aurea* along the coast. The estimated exploitation value (0.68) obtained from the present study is higher than that of the E_{max} value (0.60) indicated the species is already experiencing high fishing pressure, which is in accordance with the results reported for several species of sciaenids in Indian waters (Chakraborty et al. 2000; Rahangdale et al. 2022; Abinaya and Sajeevan 2023).

Conclusion

The present study suggested a combination of reduction of fishing efforts and mesh size regulation to ensure sustainable benefits from sciaenid resources along the coast of West Bengal.

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Data Availability No datasets were generated or analysed during the current study.

The data that support the findings of this study are not openly available due to reasons of sensitivity and are available from the corresponding author upon reasonable request.

Declarations

Competing Interests The authors declare no competing interests.

Ethical Approval All the research meets the ethical guidelines including adherence to the legal requirements of India

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