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Original Article

Growth, mortality, exploitation rate and recruitment patterns of *Gerres nigri* Günther, 1859 from Saloum estuary, Senegal

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Abstract: The population parameters of *Gerres nigri* Günther, 1859 from the Saloum estuary in Senegal were studied from September 2017 to January 2018. A total of 591 individuals were collected monthly by experimental beach seine. The monthly length-frequency data (total length in cm) were obtained and analysed using the FiSAT II software and its sub-program ELEFAN for the evaluation of population parameters. Asymptotic length ($L\infty$) and growth coefficient (K) were estimated at 22.1 cm and 1.5 yr^{-1}, respectively. The growth performance index (Φ'), longevity (t_{max}), and the theoretical age at birth (t_0) were calculated as 2.86; 2.827 yr, and -0.11 yr^{-1}, respectively. Total mortality (Z), natural mortality (M), and fishing mortality (F) were calculated at 3.57 yr^{-1}, 2.48 $yr^{-1,}$ and 1.09 yr^{-1}, respectively. The probability of capture was calculated as L_{25} = 13.45, Lc = 14.34 and L_{75} = 15.08 cm. The recruitment pattern is a continuous two-peak model, with the minor peak occurring in May and the major peak occurring in August. The current exploitation rate ($E_{current}$) and maximum exploitation rate (E_{max}) were calculated as 0.31 and 0.421, respectively. Further, the current rate of exploitation of *G. nigri* was slightly lower than the maximum exploitation rate. The results showed that the *G. nigri* stock was not overexploited.

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Introduction

Fish of the Gerreidae family, known as mojarras or silver biddies, lived in shallow coastal waters of tropical and sub-temperate regions, preferentially in areas with sandy and muddy bottoms, and often showed a sympatric distribution (De La Cruz-Agüero et al., 2011). The Gerreids consisted mainly of medium to small estuarine coastal fish found on sandy or muddy bottoms (Gilmore and Greenfield, 2002; Delpiani, 2013; Faye, 2023). This family included about 44 species (Nelson, 2006), including *G. nigri* Gnther, 1859, which was distributed from the coasts of Equatorial Guinea to those of the Congo (Roux, 1981).

Gerres nigri was not a target species for the Senegalese artisanal marine fisheries. It was often caught accidentally by artisanal fishermen. In the Saloum Estuary, however, it was second only to the Clupeidae in abundance (Simier et al., 2004). Despite the importance of this species in terms of abundance in the Sine-Saloum estuarine waters of Senegal, studies on the biology of this species were insufficient. Thus, this study would be the first comprehensive study on growth parameters, mortality, and recruitment patterns of *G. nigri* in Saloum Estuary, Senegal.

Materials and Methods

Study Area: The Gandoul Marine Protected Area (MPA) is located in the municipality of Djirnda at latitude 13°58'6 N and longitude 16°36'0 W in the region of Fatick. It is bounded by the communes of Dionewar, Fimela, and Bassoul. The MPA was established on March 31, 2014, on an area of 15732 hectares stretching from Diamniadio Bolong, Fambine Pass, Sangue Island, Bird Island, and the adjacent

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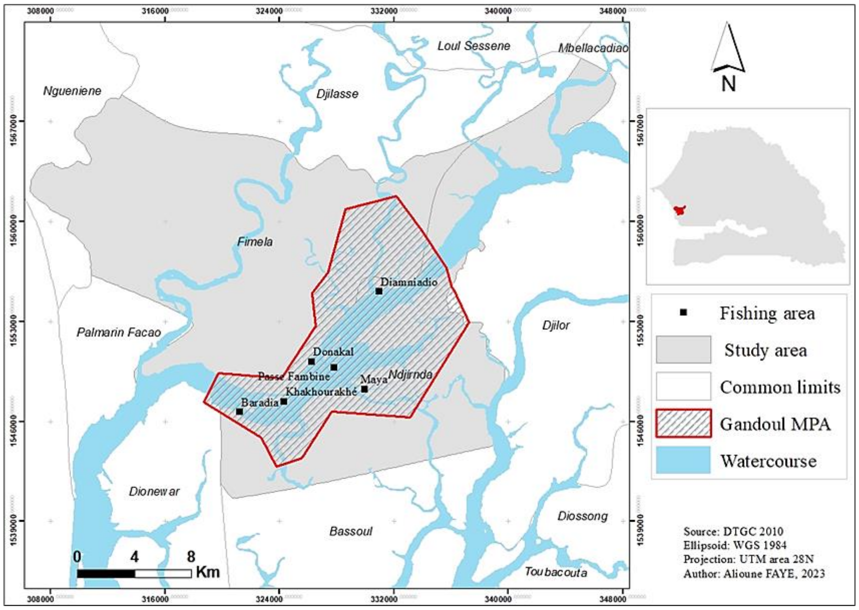

Figure 1. Sampling stations.

mangrove forests. It includes the belongs of Simale, Ndimsiro, Donakale up to the belong of Ndiougane-Ndakhne including Diad Island, the three islands, the baobab forests, and the mangrove forests bordering the waters. The fishery operations were carried out in 6 fishing stations which were distributed in the different parts of the Gandoul MPA (Fig. 1).

Sampling procedure: A total of 6 experimental fishing campaigns were carried out monthly from September 2017 to January 2018. The fishing operations were performed using a 250 m long, 20 m height and with a 14 mm mesh size experimental beach seine. A total of 591 individuals of *G. nigri* were sampled. For each individual, the total length was measured with a 1 mm precision ichthyometer.

Growth Parameters: The FAO-ICLARM Stock Assessment Tool (FiSAT II, version 1.2.2) software was used to analyze the monthly length-frequency data (Gayanilo and Pauly, 1997; Gayanilo et al., 2005). The parameters of the von Bertalanffy Growth function (VBGF), asymptotic length ($L\infty$), and growth coefficient (K) were estimated using the ELEFAN-1 method (Pauly and David, 1981). According to VBGF as expressed below, individual fishes grew on average towards the asymptotic length at an instantaneous growth rate (K) with length at time (t) following the expression: $Lt = L\infty\ [1 - e^{-k\ (t\ -\ t_0)}]$, where Lt = the length at age t, $L\infty$ = the asymptotic length that was the mean length of fish would reach if they were to grow indefinitely, K = the growth coefficient and t_0 was the age of the fish at zero length. Pauly's (1979) empirical equation for the theoretical age at length zero (t_0) was used to obtain this parameter as: $\text{Log}\ (-t_0) = -0.392 - 0.275 \text{Log}\ L\infty - 1.038 \text{Log} K$. The growth performance index (Φ') was computed from the equation (Pauly and Munro, 1984): $(\Phi') = 2 \times \log L\infty + \text{Log} K$, and the longevity ($t_{max}$) was estimated as (Pauly, 1983): $t_{max} = 3/K + to$

Mortality Parameters: The total annual instantaneous mortality rate (Z) was estimated using the length-converted catch curve (Sparre and Venema, 1998). The natural mortality (M) was estimated by Pauly's empirical equation (Pauly, 1980), where the mean habitat temperature was 26.6°C. $\text{Log} M = -0.0066 - 0.279 \times \log L\infty + 0.6543 \times \log K + 0.4634 \times \log T$, where M = natural mortality, $L\infty$ = asymptotic length, K = growth curvature of VBGF, T = mean surface temperature °C. The fishing mortality expresses the quantity of fish taken by the fishing activity in a year. After having calculated the coefficients Z and M, the determination of the fishing mortality (F) was made from the following relation (Bousseba et al., 2021): F = Z-M, where F = fishing mortality, Z = total mortality, and M = natural

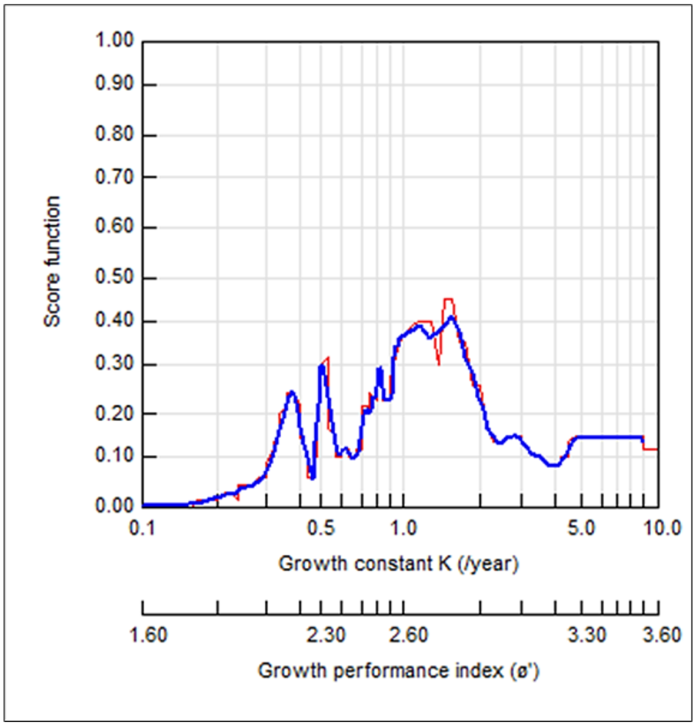

Figure 2. Growth performance of *Gerres nigri*.

mortality. The exploitation rate (E) was given by FiSAT from the linearized length-converted catch curve of each species: E = F/Z, where E = exploitation rate, F = fishing mortality and Z = total mortality. The exploitation rate (E) was compared to the optimum criterion of 0.5 (Pauly and Munro, 1984).

Probability Length at first capture: The probability of capture was estimated following Gayanilo et al. (2005). Length at first capture (Lc) corresponded to cumulative probability at 50%, whereas lengths at 25 and 75% paralleled to 25 and 75%, respectively.

Length at first maturity (Lm): To estimate the length at first maturity (Lm) for the assessed species, the procedure by Hoggarth et al. (2006) was used. The input parameters for the model included asymptotic length only (L∞): Lm = L∞ × 2/3, where Lm = length at first maturity and L∞ = asymptotic length.

Recruitment patterns: The recruitment pattern was determined by backward projection on the length axis of the set of available length-frequency data (Nurul et al., 2009). Length at first recruitment (Lr) was taken as the mid-length of the smallest length interval (Gheshlaghi et al., 2012) while age at first recruitment followed Beverton and Holt (1957).

Virtual Population Analysis (VPA): VPA (Length structured) was undertaken by applying the values of growth and mortality parameters as well as growth patterns from the length-weight relationship. The length-weight relationship was done using the expression (Pauly, 1984): $W = a \times L^b$, where W = body weight and L = length.

Relative yield per recruit (Y/R) and relative biomass per recruit (B/R): Relative yield per recruit (Y/R) and relative biomass per recruit (B/R) were calculated as a function of exploitation. Further to this, the exploitation rate at the maximum (E_{max}), exploitation rate at 0.1 of the virgin biomass ($E_{0.1}$), and $E_{0.5}$ tallying to the exploitation rate at 0.5 of the virgin biomass were worked out through the application of the Knife-edge option.

Results

Growth parameters: A total of 591 specimens of *G. nigri* were sampled for the study. The results of length-weight measurements gave the following ranges, length 8.7-21.7 cm. The mean length of samples was 16.2±1.65 cm. The best value of the VGBF growth constant (K) was estimated as 1.5 yr^{-1} by ELEFAN-I (Fig. 2) with an asymptotic length (L∞) of 22.1 cm. The restructured length frequency distribution diagram and growth curves were produced by the ELEFAN I method (Fig. 3). The calculated values for the growth performance index (Φ'), the theoretical age t_0, and longevity (t_{max}) of *G. nigri* were calculated as 2.86; -0.11 and 2.827, respectively.

Mortality Parameters: The mortality parameters of *G. nigri* in south Coastal Senegalese Waters are shown in Figure 4. The instantaneous total mortality coefficient (Z) was estimated as 3.57 $year^{-1}$. The natural mortality (M) and fishing mortality (F) were estimated to be 2.48 $year^{-1}$ and 1.09 $year^{-1}$, respectively. The current exploitation rate was estimated as E = 0.31 (Fig. 4).

Probabilities of capture: The probability of capture routine gave an estimate of Lc at 14.34 cm. Further, the sizes at which 25 and 75% of individuals were

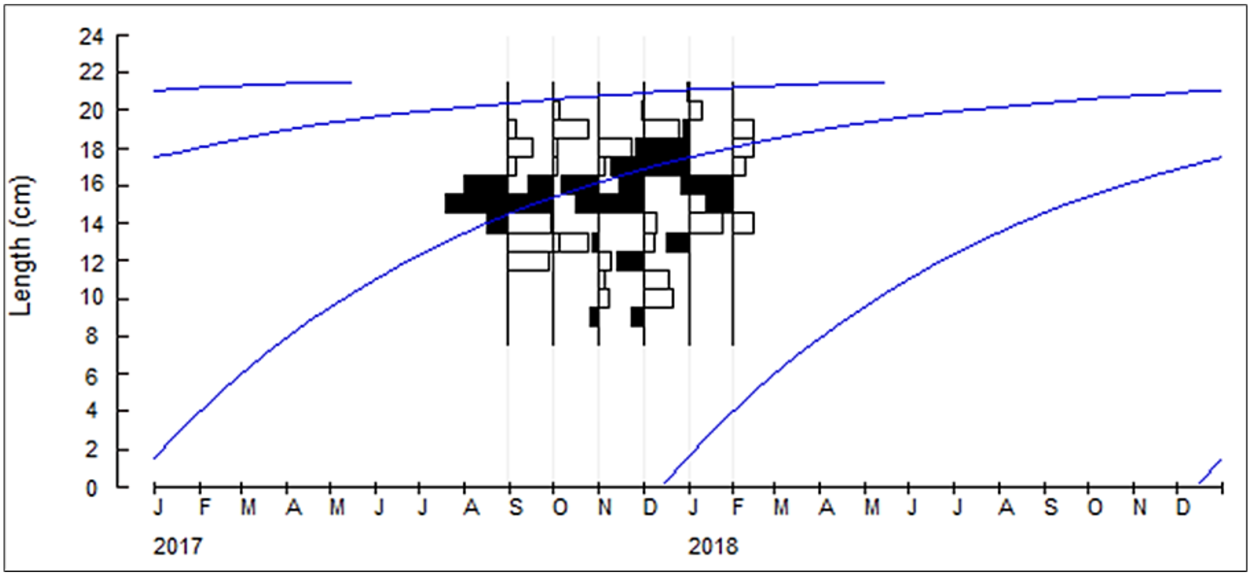

Figure 3. Restructured Length frequency distribution output from FiSAT II with superimposed growth curves (Dark bars=actual frequency bars and White bars=reconstructed bars).

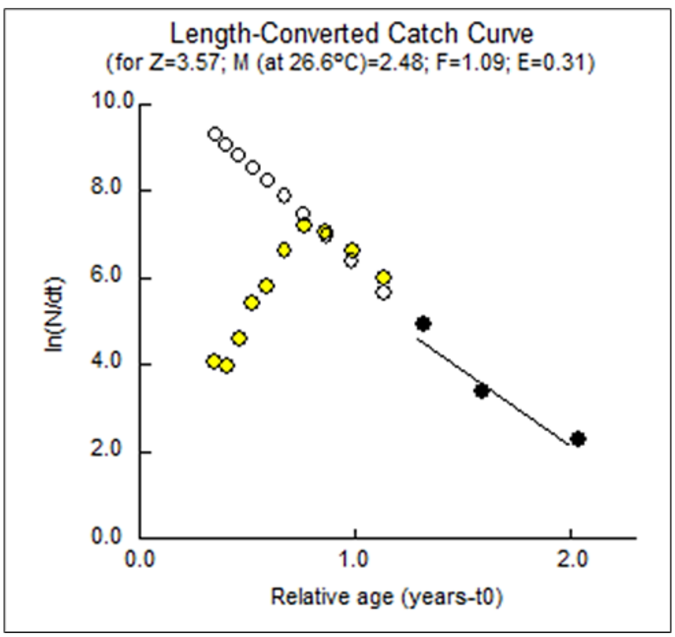

Figure 4. FISAT II output of linearized length-converted catch curve for *Gerres nigri* (Yellow dots are dots used in calculation and White dots are dot not used in calculations).

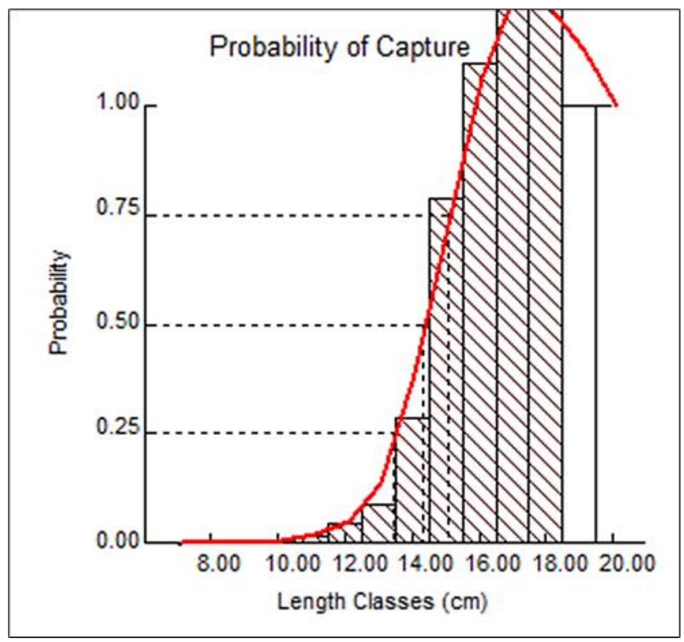

Figure 5. Probability of capture estimation from FiSAT Output.

captured are respectively 13.45 and 15.08 cm. The calculated length at first maturity for *G. nigri* was 17.73 cm (Fig. 5).

Recruitment patterns: According to the recruitment pattern analyses, the species had two peaks of recruitment over the year. The minor occurred peak in May and the major peak in August. The major peak recorded 18.41% recruitment while the minor peak recorded 12.07 % (Fig. 6).

Virtual Population Analysis (VPA): The virtual population analysis of *G. nigri* is shown in Figure 4. *Gerres nigri* observed natural loss due to natural mortality at 8 to 18 cm, with the highest loss due to natural mortality observed at 13 to 15 cm. The vulnerability of *G. nigri* to fishing gears began from size 14 cm, with the greatest catch occurring at 15 and 16 cm (Fig. 7).

Relative yield per recruit (Y'/R): The Beverton and

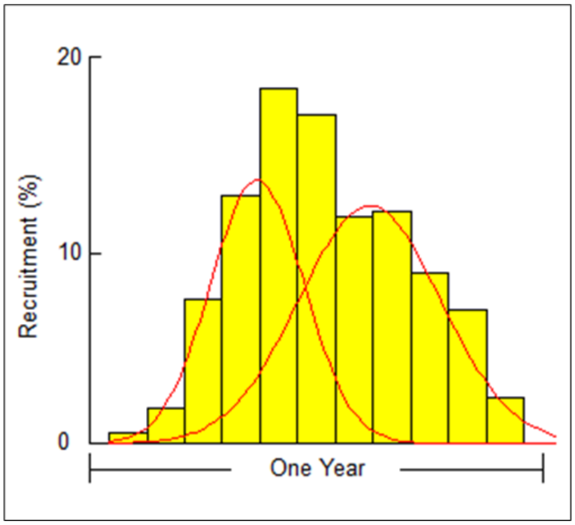

Figure 6. Recruitment pattern of *Gerres nigri* from FiSAT Output.

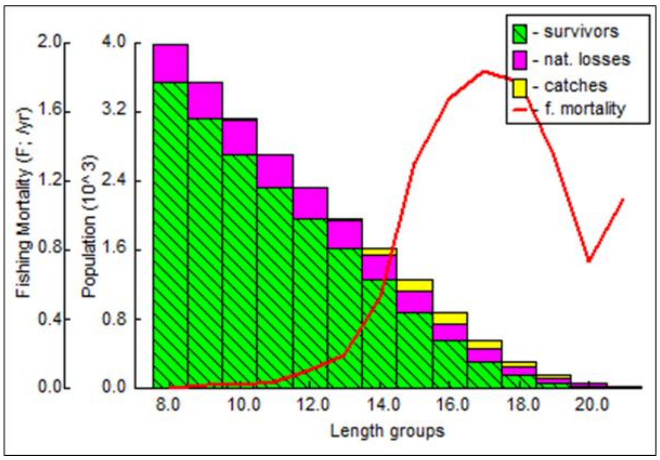

Figure 7. Length-structured virtual population analysis of *Gerres nigri.*

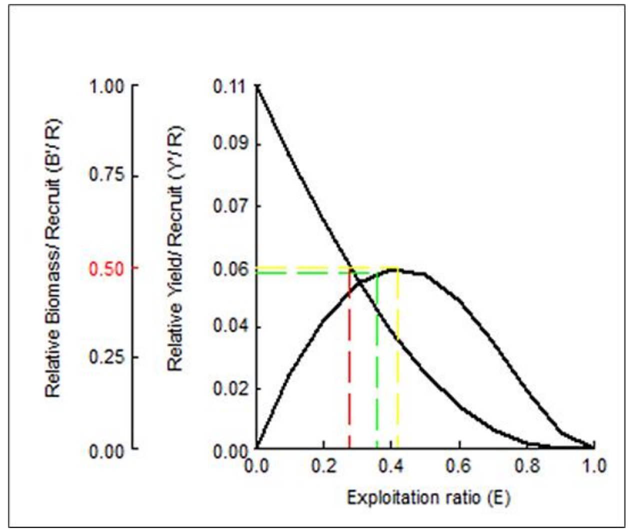

Figure 8. Beverton and Holt's relative yield per recruit and average biomass per recruit models, showing levels of yield indices for *Gerres nigri* in south Coastal Senegalese waters (Red dashes=$E_{0.1}$, green dashes=$E_{0.5}$ and yellow dashes=E_{max}).

Holt relative yield per recruit model in Figure 8 showed that the indices for sustainable yield were 0.278 for optimum sustainable yield ($E_{0.5}$), 0.421 for the maximum sustainable yield (E_{max}) and 0.355 for economic yield target ($E_{0.1}$) (Fig. 8).

Discussions

Estimation of growth and exploitation parameters is a vital component for understanding the ecology and life history of any fish species (Thomas et al., 2006). Age and growth parameters of *G. nigri* were not reported in Senegal. The present study was the first to estimate these parameters. However, few studies have been done on *G. nigri* congeners in different countries of the world. The $L\infty$, K, and t_0 values estimated for some species of the genus *Gerres* from different geographical regions are given in Table 1. Some examples of similar studies were *G. filamentosus* from Hurghada Red Sea in Egypt (Abu El-Nasr, 2017), the coastal waters of Quang Binh Province in Vietnam (Thiep et al., 2014), Azhikode Estuary in India (Aziz et al., 2013), Parangipettai Waters at Southeast Coast of India (Sivashanthini, 2009). There were also other similar studies other *Gerres* genus such as *G. cinerens* on the Pacific Coast of Mexico (Espino-Bar et al., 2014) and on the South coast of Quintana Roo in Mexico (Alvarez-Hernandez, 1999), *G. oblongus* from Jaffna lagoon in Sri Lanka (Shutharshan and Sivashanthini, 2011), *G. setifer* (Sivashanthini and Khan, 2004) and *G. abbreviatus* from the Parangipettai waters on Southeast coast of India (Sivashanthini, 2006), *G. equulus* from western Kyushu in Japan (Iqbal et al., 2006).

In the evaluation of linear growth, when different sets of parameters were available, it was not recommended to compare them individually (Sparre and Venema, 1996). For this reason, some authors recommended comparing linear growth performance indices (Φ') by combining several parameters of the Von vonBertalanffy equation (Pauly and Munro, 1984; Chauvet, 1988; Chakroun-Marzouk and Ktari, 2003; Faye et al., 2023). The growth performance index (Φ'), which showed very similar values within neighboring taxa, proved to be the best overall growth

Table 1. Growth parameters estimated for Gerres genus from different regions of the world (TL = Total length, SL = Standard length, BL: Body length, some Φ' values were calculated by us).

Species	Country	Sex	L_∞ (cm)	K (y^{-1})	($-t_0$)	(Φ')	
G. nigri	Senegal	Unsexed	22.1 TL	1.50	0.11	2.86	Present study
G. filamentosus	Egypt	Unsexed	42.2 TL	0.29	0.0283	2.7179	Abu El-Nasr (2017)
G. filamentosus	Vietnam	Unsexed	23.4 BL	0.35	0.996	2.284	Thiep et al. (2014)
G. filamentosus	India	Unsexed	29.9 TL	1.00	0.58	2.95	Aziz (2013)
G. filamentosus	India	Male	26.9 TL	1.45	0.1109	3.02	Sivashanthini (2009)
		Female	27.1 TL	1.50	0.1073	3.04	
G. oblongus	Sri Lanka	Unsexed	29.4 TL	1	0.151	2.94	Shutharshan and Sivashanthini (2011)
G. cinerens	Mexico	Unsexed	51.2 TL	0.270	0.534	2.849	Espino-Bar et al., 2014
G. cinerens	Mexico	Unsexed	36.0 TL	0.341	1.03	2.645	Alvarez-Hernandez (1999)
G. setifer	India	Male	17.4 TL	1.19	0.0817	2.56	Sivashanthini and Khan (2004)
		Female	17.1 TL	1.26	0.0775	2.56	
G. abbreviatus	India	Male	27.8 TL	1.30	0.1236	3.002	Sivashanthini (2006)
		Female	28.2 TL	1.36	0.1175	3.034	
G. equulus	Japan	Male	20.6 SL	0.42	0.038	2.25	Iqbal et al. (2006)
		Female	21.3 SL	0.45	0.001	2.31	

Table 2. Comparison of mortality coefficients for gerreids from different regions of the world.

Species	Country	Sex	Z (yr^{-1})	M (yr^{-1})	F (yr^{-1})	Author
G. nigri	Senegal	Unsexed	3.57	2.48	1.09	Present study
G. abbreviatus	India	Male	3.06	2.24	0.82	Sivashanthini (2006)
		Female	2.99	2.29	0.70	
G. filamentosus	India	Male	3.14	2.41	0.73	Sivashanthini (2009)
		Female	3.27	2.47	0.80	
G. setifer	India	Male	2.53	1.26	1.26	Sivashanthini and Khan (2004)
		Female	2.80	1.32	1.48	
G. filamentosus	India	Male	1.49	1.08	0.41	Narasimhaiah et al. (2021)
		Female	1.43	0.98	0.45	

performance index in terms of minimal variance (Chakroun-Marzouk and Ktari, 2003; Faye et al., 2023). The estimated growth performance index (Φ') in the present study for *G. nigri* was comparable with the (Φ') values reported by Aziz et al. (2013) for *G. filamentosus*, Espino-Bar et al. (2014) and Alvarez-Hernandez (1999) for *G. cinerens* and Shutharshan and Sivashanthini (2011) for *G. oblongus* (Table 1). However, it was smaller than those obtained by Sivashanthini (2009) for *G. filamentosus* and Sivashanthini (2006) for *G. abbreviates* and bigger than those calculated by Abu El-Nasr (2017) and Thiep et al. (2014) for *G. filamentosus*, Alvarez-Hernandez (1999) for *G. cinerens*, Sivashanthini and Khan (2004) for *G. setifer* and Iqbal et al. (2006) for *G. equulus*. The slight differences between growth performance indices (Φ') could be related to factors such as temperature, food availability, metabolic activity, and reproductive activity (Faye et al., 2023).

The coefficients of total mortality, natural mortality, and fishing mortality estimated during the present study were Z = 3.57 yr^{-1}, M = 2.48 yr^{-1}, and F = 1.09 yr^{-1}, respectively. It appears that natural mortality (M) was higher than fishing mortality (F). This could be explained by the fact that *G. nigri* was not a target species for Senegalese artisanal fishery. Similar results were reported by several authors for Gerreids where natural mortality was higher than fishing mortality (Table 2). This higher natural mortality for *G. nigri* could be attributed to factors such as disease, age, predation, or the variability of environmental factors (Narasimhaiah et al., 2021). However, the total mortality rate in this study was considered high compared to other species of gerreids such as *G. setifer*, *G. abbreviates*, *G. filamentosus* studied respectively by Sivashanthini and Khan (2004), Sivashanthini (2006) and Sivashanthini (2009) in the Parangipettai waters on Southeast coast of India and *G. filamentosus* from Coast of South West India (Narasimhaiah et al., 2021). The different results in mortality rates could be attributed to a different environment where the fish lives. Thus, it was subjected to a different level of predation, competition, food resources, and disease (Sparre and Venema, 1998).

The interaction of the fish with gear indicated that current Lc = 14.34 cm was higher than those obtained by Sivashanthini (2006) for *G. abbreviates* and Sivashanthini (2006) for *G. filamentosus.* However, the length at first capture was lower than the length at first maturation (Lc = 14.34 cm < Lm = 14.73 cm. This denoted that *G. nigri* was accidentally caught before they could reach maturity, suggesting that most of the stocks harvested were juveniles.

Recruitment patterns obtained in the present study showed two overlapping peak recruitment seasons, suggesting that *G. nigri* was a continuous breeder with two peak breeding seasons. The two recruitment peaks observed in the study were consistent with Pauly's (1980) assumption that tropical fish species had two recruitment peaks. Similar results were reported for *G. setifer* in the Parangipettai waters on the Southeast coast of India (Sivashanthini, 2004). The exhibited peaks of recruitment could be due to favorable environmental conditions, food availability, and the presence of a higher percentage of adult *G. nigri* individuals (Tsikliras and Anthonopoulou, 2006; Madkour, 2011; Amponsah et al., 2017b). The presence of continuous recruitment may be related to the presence of more females than males, as well as to geographic locations (Deekae and Abowei, 2010).

Knowledge of the population size of fish species becomes incomplete without insights into Virtual Population Analysis (VPA). Length-based VPA provided a medium for estimating fishing pressure on various length groups using fish landings from fishing operations (Neethiselvan and Venkataramani, 2002). The virtual analysis of the populations in the present study showed that the natural mortality rate progressively decreased as the size of the fish increased. The high fishing mortality of a large-sized individual was experienced by individuals within the interval of 15-16 cm. This could be explained by the fact that juveniles were more vulnerable to natural predation (Koné, 2000).

The exploitation rate ($E_{current}$ = 0.31) from the present study was lower than 0.5, depicting that the *G. nigri* stock was currently underexploited. Further, the current rate of exploitation ($E_{current}$ = 0.31) of *G. nigri* was slightly lower than the maximum exploitation rate (E_{max} = 0.421). This result showed that *G. nigri* was underexploited in Senegalese waters. Thus, the fishing pressure on *G. nigri* stock was not excessive. This was probably because this species had no commercial or nutritional value in this country. It was only accidentally caught by the Senegalese artisanal fisheries. Thus, higher yields could be achieved by reducing the size at first capture meaningfully, without leading to an overfishing situation. However, according to Sivashanthini (2006, 2009) reducing the stretched mesh size according to the minimum Lc was not a good recommendation to increase the yield.

This study constituted a first attempt to evaluate the growth and exploitation parameters of *G. nigri* in Senegal. The results of the present study were useful and fundamental indicators for the population dynamics studies of G. *nigir*. They provided some insights into the stock assessment relevant information to *G. nigri* fishery management. The results indicated that the stock of *G. nigri* was not in a situation of overexploitation most of the stocks harvested were juveniles.

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