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Original Research Paper

Recruitment, mortality and exploitation rates estimate and stock assessment of *Mugil cephalus* (Linnaeus, 1758 Mugilidea) in the estuary of the Senegal River

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The overfishing is the central problem of the *Mugil cephalus* fisheries in the estuary of the Senegal River. This species lives in the sea during its adult stage but returns in the Senegal River to reproduce and to spend its larval and juvenile stages. This study is aimed to pinpoint the state of exploitation dynamic and to assess the *M. cephalus* stock. The FISAT II software was used to perform the estimate of recruitment, mortality and exploitation rates. Meanwhile, a virtual population analysis using VIT4 software estimated yield per recruit (Y/R). The analysis yielded exploitation rates E of 0.44 and 0.23 respectively for adult fish and juveniles; therefore the adult stock is overfished during the *M. cephalus* life stage in sea. In addition, natural mortality (M=1.20 year^{-1}) and total mortality (Z=1.5 year^{-1}) are remarkably high for fish mature age groups III, IV and V. However, in the river the maximum sustainable exploitation (0.50) is not exceeded for juveniles age groups 0^{+}, I and II. In conclusion, management policies should be introduced to safeguard the *M. cephalus* fishery in the estuary of the Senegal River.

Key words: *Mugil cephalus*, mortality, exploitation, recruitment, stock assessment, Senegal River.

INTRODUCTION

The yellow mullet, *Mugil cephalus,* is a coastal pelagic and gregarious species that can go up the brackish water ecosystems such as estuaries and rivers. The central problem of the dynamics of *M. cephalus* fishery management in the estuary of the Senegal River is a declining stock. The use of fishing gear and fishing techniques of increasing catch performance (purse seines and sliding, surface drift nets and beach seines) increased fishing effort by intensive catch of the species (Sarr et al., 2012). Few studies have been conducted on the biology and ecology of the species (Lawson and Abayomi, 2010; Okumus and Başçnar, 1997). The literature indicate that others studies have focused on the exploitation parameters and the stock assessment of *M. cephalus* particularly in Asia (Zhang, 2006), Europe (Rathacharen et al., 1999, Katselis et al., 2010), America (Ibanez-Aguirre and Garlado-Cabello, 1996), the Mediterranean (Djabali et al., 1993) and West Africa (Uneke et al. 2010). However, none of those studies, especially the population dynamics and the state of exploiation of the yellow exploitation of the yellow mullet fishery in Senegal have ever been conducted and that is the topic of the present study: a sustainable resource management plan based on recruitment, mortality, exploitation rate and stock assessment.

MATERIALS AND METHODS

Location of the study area

The Senegal River is 1.700km long before connecting into the sea south of the city of Saint Louis (Senegal) by a single mouth. The study area is located between latitudes 15°45' and 16°30' North and longitudes 15°40' and 16°35' West (Figure 1). This area is largely influenced by upwelling coming from the central waters of the Southern Atlantic Ocean.

Figure 1. Map of Senegal River showing the sampling site

Data collection

Weekly random samplings were conducted to collect data on *M. cephalus* between January 2011 and March 2012, producing 1665 fish of which 1243 juveniles collected in the river and 422 specimens caught at sea (245 females and 177 males, all measured (TL, m), weighed (g) and sexed. The creel survey on site consisted of 36 interviews over 3 months on 12 groups of fishermen, recording their catches.

Statistical analysis of data

The software used for data processing was FiSAT II (Gayanilo et al., 2005) and it enabled the estimation of the exploitation parameters of *M. cephalus* related to total mortality (Z), natural mortality (M), fishing mortality (F), exploitation rate (E) and recruitment rate; while virtual population analysis (VPA) was used for stock assessment. In addition to these computation, the routines embedded in FiSAT II and VIT4 (FAO, 1997) required the estimation of von Bertalanffy growth parameters (Sarr et al., 2012).

Total mortality Z

Total mortality (Z) was estimated by the method called "length-based catch curves". The speed at which the

$$dN / dt = - Zt$$

The number of fish surviving at a given time, Nt, is:

$$N_t = N_0 e^{-Zt}$$

$$\ln(N) = a + b \cdot t'$$

N is the number of fish in (pseudo) cohorts "sliced" by successive growth curves which is the relative age of the fish in this pseudo cohort, while b, with the sign changed, provides an estimate of Z.

Natural mortality (M) and exploitation rate

The empirical method of Pauly (1980; 1984) has been used for the evaluation of the natural mortality of pelagic fish, since it fits better than the other input methods (Djabali et al., 1993).

$$\log_{10}(M) = -0.0066 - 0.279 \log_{10}(L_\infty) + 0.6543 \log_{10}(K) + 0.4634 \log_{10}(T°)$$

L_∞ = asymptotic length, K = growth coefficient and T = average temperature of habitat (°C).

Once Z and M were obtained, the fishing mortality (F) was estimated using the equation:

$$F = Z – M$$

Finally the exploitation rate (E) was obtained from:

$$E = F/Z = F/(F + M).$$

Recruitment

Recruitment was obtained using the length frequency data using software FiSATII. The routine reconstructs the rhythms of recruitment from a time series of length frequency data. The recruitment model is obtained by projecting the length frequency data back on the time axis using the growth parameters (Moreau and Cuende, 1991).

Virtual Population Analysis

The Virtual Population Analysis (VPA), also called sequential analysis and cohort analysis, is one of the most widely used methods of the structural approach (Gascuel et al, 2007). VPA is a method that allows the reconstruction of the population from the total catch data by age or size.

Stock assessment

Analysis of the relative performance recruits (Y/R) and biomass recruits (B/R)

Beverton and Holt (1966) express the relative yield per recruit (Y'/R), to determine the relationship between yield and fishing effort for different sizes of first capture. It belongs to the class of models based on length. Expression of Y'/R is:

$Y'/R=EU^{M/K}[1- 3U/(1+m) + 3U^2/(1+2m)-U^3(1+m)]$
Where: $U=1-(L_C/L\infty)$; $m= (1-E)/(M /K) = (K /Z)$; $E=F/Z$

L_C= average fish size at first capture, equivalent to L_{50} average fish size at first capture; m = mesh size

Biomass per recruit relative (B'/R) is estimated from the relationship:

$B'/R = (Y'/R)/F$

While E_{max}, E_{10} and E_{50} are estimated using the first derivative of this function

E_{10}= level of exploitation at which the marginal increase in yield per recruit reaches 1/10 of the marginal increase computed at a very low value of E; E_{50}= exploitation level which will result in a reduction of the unexploited biomass by 50%; E_{max}= exploitation level which maximizes Y/R or Y'/R.

Predictive model of Thompson and Bell (1934)

The model of Thompson and Bell (1934) is used to predict the effects of changes in fishing effort on future production and biomass from the historical data of fishery. The latter is based on the analysis of pseudo-cohorts to assess the impact of a change in fishing effort after determining mortality coefficients and therefore responsible for providing fisheries information actual stock status.

In the software FiSAT II, this model combines elements of the model Y'/R of Beverton and Holt with those of VPA; it reverses. The sum of the yields is:

$Y =\Sigma Yi$ and $Y_i=C_i.W'_i$

The average weight of the body is given as:

$W_i'= (1/L_{i+1}-L_i)(a/b+1)(L_{i+1}^{b+1};L_i^{b+1})$

Where a and b are the coefficients of the length-weight relationship; L_i and L_{i+1} are respectively the lower and upper limits of the size class.

$C_i = (N_i-N_{i+1})(F_i/(M+F_i))$

The predicted population (N_i) is given by:

$N_{i+1} = N_i \cdot EXP\ (-(M+F_i) \cdot \Delta t_i)$ and

$\Delta t_i = (1/K)\ \ln ((L\infty-L_i)/(L\infty-L_{i+1}))$

Biomass is calculated from:

$B_i=((N_i-N_{1+1})/(M+F_i)).\Delta t_i.W_i'$.

RESULTS

Parameters of mortality and exploitation rates

Different mortality parameters are given by the length-converted catch curve for males and females captured at sea and juveniles caught in the river.

For males: Z = 2.06yr^{-1}, M = 1.24 yr^{-1}, F = 0.82 yr^{-1} and E = 0.40 (Figures 2 and 3). To determine the natural mortality (M), the empirical equation of Pauly (1980) was employed considering an annual average temperature of 22.5°C thus:

$\log (M) =-0.0066 - 0.279 \log(L\infty) + 0.6543 \log(K) + 0.4634 \log(T)$.

Mortalities by age and sex are shown in Table 1. The total mortality Z, natural mortality M, fishing mortality F and exploitation rates E are presented in Table 2. Fishing mortality is higher in adults than in juveniles. The juveniles group natural mortality is very high compared to mature fish. In Table 3, the mortality rates resulting from this study may be compared to those of former studies.

Recruitment

The estimated rate of recruitment is shown in Figure 4 and

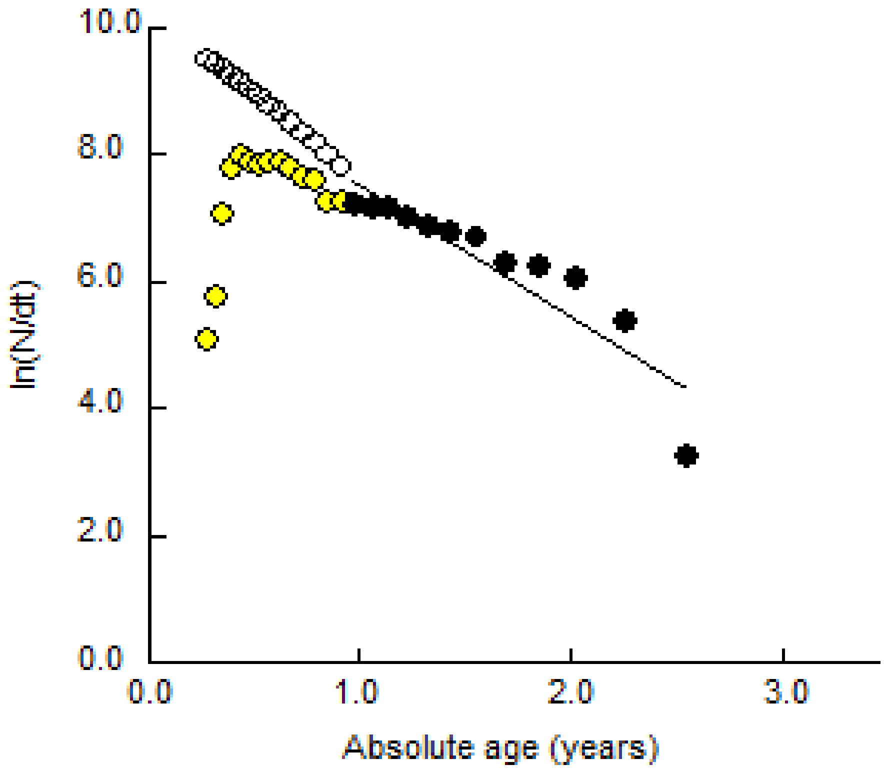

Figure 2. Length-converted catch curve for (males of *Mugil cephalus* in the Senegal River. Z=2.06; M (at 22.0°C)=1.24; F=0.82;E=0.40) (Z = total mortality, M = natural mortality, F= fishing mortality, E= exploitation rate).

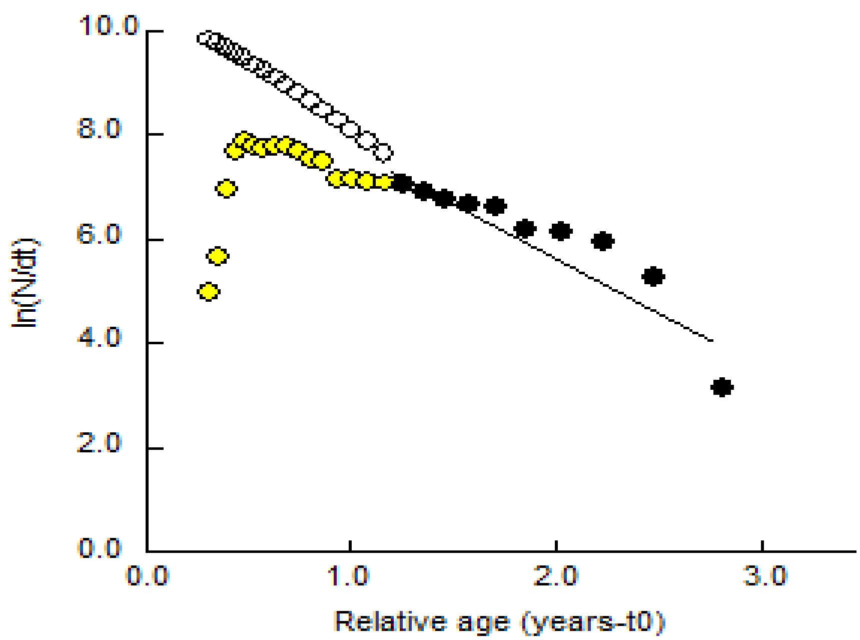

Figure 3. Length-converted catch curve for females of Mugil cephalus in the Senegal River. Z=2.09; M (at 22.5°C)=1.17; F=0.92; E=0.44) (Z =total mortality, M = natural mortality, F= fishing mortality, E= exploitation rate).

Table 1. Natural mortality of *Mugil cephalus* for each age group in the Senegal River (T=22.5°C).

Age (year)	TL (cm)	L∞ (cm)	K ($year^{-1}$)	M ($year^{-1}$)
0^+	23.81	67.6	0.43	1.20
I	33.05	68.78	0.42	1.20
II	38.21	68.78	0.42	1.24
III	50.35	73.09	0.32	1.20
IV	60.29	73.44	0.31	1.18
V^+	61.17	73.44	0.31	1.17

Table 2. *Mugil cephalus* exploitation rates by sex in the Senegal River.

Sex	Z($year^{-1}$)	M($year^{-1}$)	F = Z – M($year^{-1}$)	E=F/Z	Z/K	M/K
Females	2.09	1.17	0.92	0.44	6.52	3.65
Males	2.06	1.24	0.82	0.40	6.46	3.87
Juveniles	1.55	1.20	0.35	0.23	3.69	2.85

Table 3. Parameters of mortality computed for *Mugil cephalus* by various authors.

Author	Zone	Z ($year^{-1}$)	M($year^{-1}$)	F($year^{-1}$)	E($year^{-1}$)
Zhang (2006)	Korea		0.516		
Ibáñez-Aguirre and Garlando-Cabello (1996)	Tropical Lagoon, México	0.27	0.114	0.126	0.466
Katselis et al. (2010)	Greece	1.59	0.34	1.25	0.78
Rathacharen et al. (1999)	Coastal areas of Mauritius	1.65	0.53	1.12	0.67
Uneke et al. (2010)	Nigeria	4.03	2.77	1.26	0.31
Djabali et al. (1993)	Mediterranean Sea		0.17		

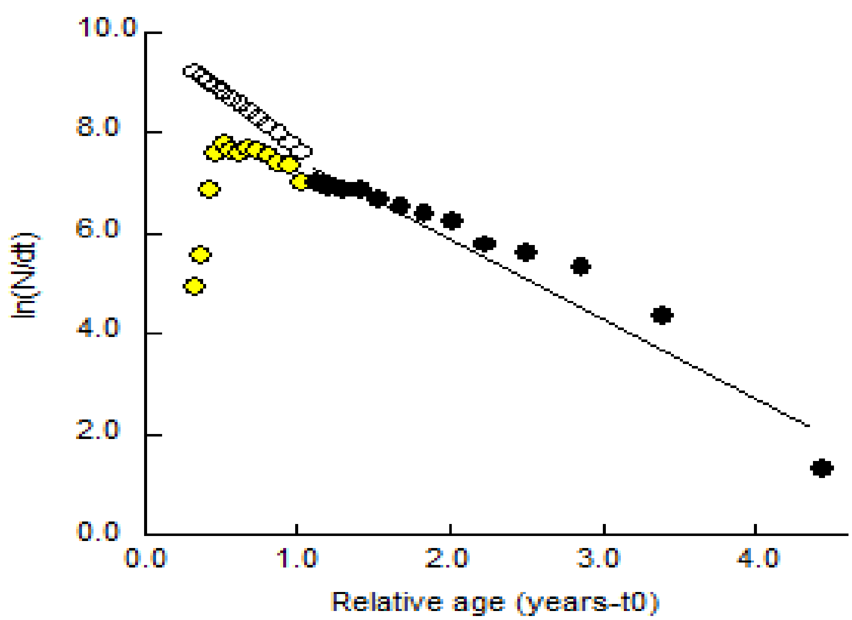

Figure 4. Length-converted catch curve for juveniles of *Mugil cephalus* in the Senegal River Z=1.55; M(at 22.5°C)=1.20; F=0.35;E=0.23) (Z = total mortality, M=natural mortality, F= fishing mortality,E=exploitation rate).

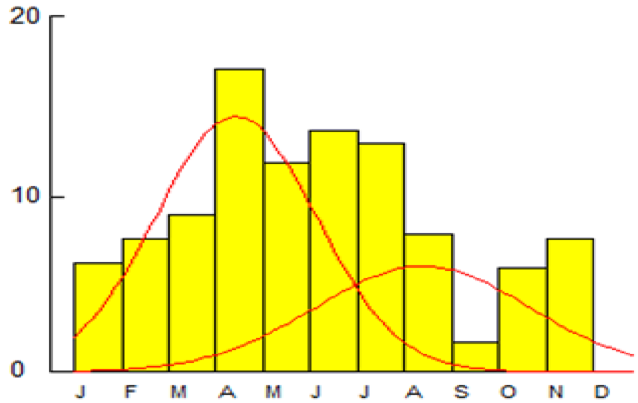

Figure 5. Recruitment curve for *Mugil cephalus* in the fisheries along the Senegal River.

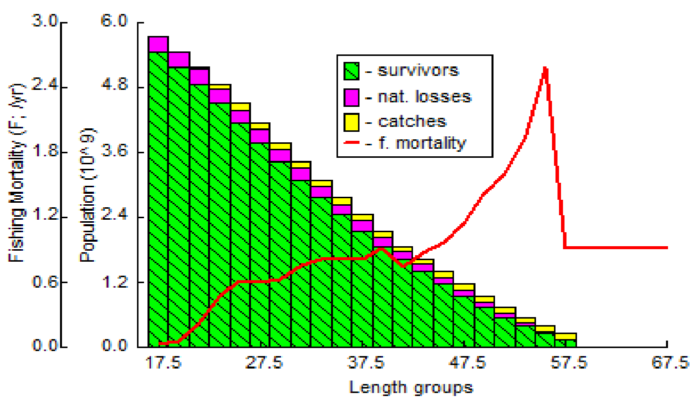

Figure 6. Histogram of the virtual population of *Mugil cephalus* in the Senegal River.

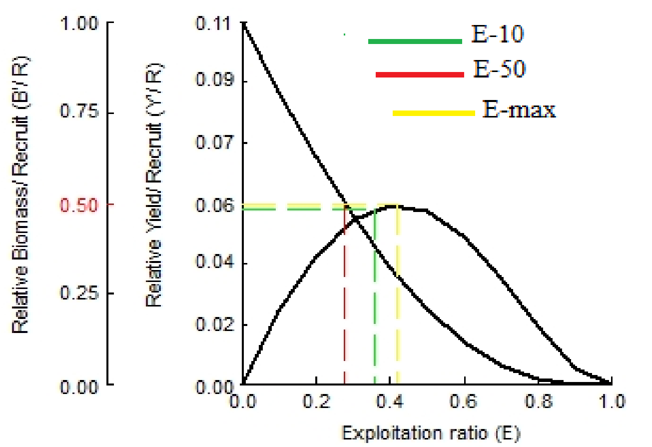

Figure 7. Curve of yield and relative biomass by recruit (knife–edge selection) for *Mugil cephalus* in the Senegal River. The values of Y'/R and B'/R are respectively 30 and 700g.

5. The annual recruitment model revealed one phase. It lasts all the year (January to December) over the three consecutive months of great recruitment, the office plurality of percentage varied.

STOCK ASSESSMENT

Analysis of relative performance recruits (Y'/R) and biomass recruits (B'/R) following Beverton and Holt (1966)

In Figure 6 and 7, the model of Beverton and Holt (1966) as modified by Pauly and Soriano (1986) was used to predict the relative yield per recruit (Y'/R) of *M. cephalus*. Plots (Y'/R) and (B'/R) as a function of exploitation rate E were used to estimate E-max (exploitation rate producing the maximum yield), E-10=0.355 (rate operation during which the marginal increase (Y'/R) is 10% of the virgin stock) and E-50=0.278 (the rate of exploitation under which the stock is reduced to half of its virgin biomass). These exploitation rates were calculated by the derivative function of the expression of yield per recruit (Y/R) and are reported in Table 4.

For different sizes of first capture Lc and the rate of operation E, the relative performance per recruit Y'/ R increases to a maximum and then decreases. The maximum allowable exploitation rates E-max = 0.42 of 0.44 for females and 0.40 for males. The optimum level of relative performance by rookie is reached. The species is overfished in the locality.

Predictive model of Thompson and Bell (1936)

The model shows the maximum sustainable yield (MSY), maximum sustainable economic production (MSE), the f-factor and the corresponding biomass (Figure 8).

For *M. cephalus*, the f-factor value of 1.8 corresponds to the MSY while the MSE is obtained with an f-factor of 2.0. The results show that the level of fishing effort is higher than that corresponding to the MSE.

DISCUSSIONS

Fishing mortality (F) and natural mortality (M) contribute to the total mortality (Z). In addition, growth and mortality are antagonistic. According to Barry and Tegner (1989), the predominance of growth on mortality can be perceived by the ratio Z/K being less than 1; a ratio greater than 1 means that the stock is collapsing; if the ratio is equal to 1, the population is in a steady state; finally, if this proportion is much higher than 2, the stock is overexploited. The total mortalities are respectively 2.06 and 2.09 year^{-1} for males and females caught at sea, while they are lower in juveniles

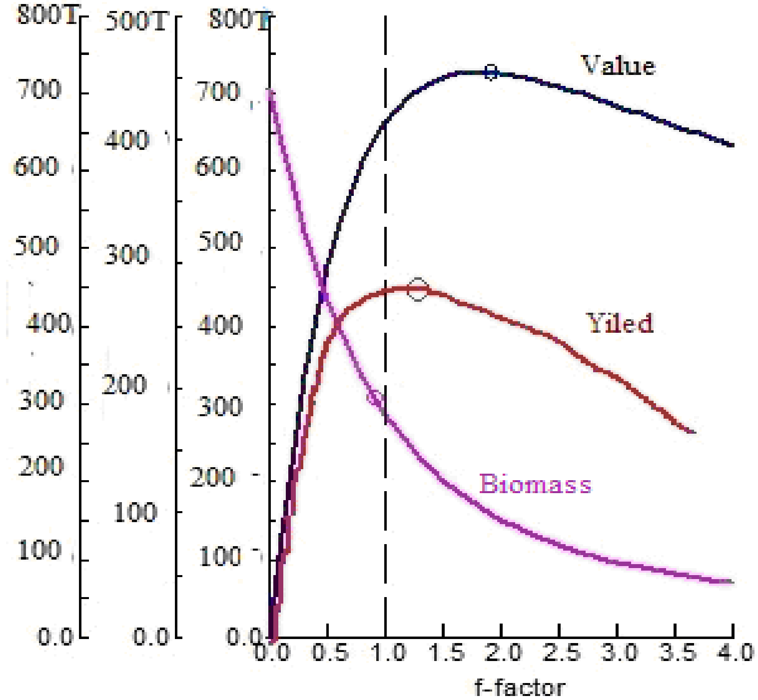

Figure 8. Thompson and Bell yield stock prediction of *Mugil cephalus* in estuary of the Senegal River.

juveniles (Z = 1.55 $year^{-1}$) from the river. The ratio Z/K is 6.52 for females, 6.46 for males and 3.65 for juveniles it shows overuse of *M. cephalus* in the sea and in the estuary of the Senegal River. Big fish as well as juveniles are under pressure and this can lead to long stocks a fuck.

According to Beverton and Holt (1959), the ratio M / K determines the level of fish mortality. If this ratio is between 1.5 and 2.5, the threshold is not exceeded permitted. The values of M/K for *M. cephalus* in the estuary of the Senegal River are between 2.85 and 3.87 (Table 2). Natural mortality is higher for age groups 0^+ and I, II (M = 1.20 $year^{-1}$). These natural mortalities decrease with age groups III, IV, V and are about 1.18 $year^{-1}$. These results could be explained by a high predation or other natural causes affecting fry and juveniles. Mortality parameters depend on both physiological factors (disease, old age, etc.), environmental factors (temperature, currents ...). According to Christensen and Pauly (1997) for juveniles, predation mortality is sometimes much higher than fishing mortality. The results of this paper were compared with those obtained by several other studies (Table 3). The comparison shows that the mortality estimates differ from author to author and from one region to another, the temperature of the environment and the parameters of the equation of von Bertalanffy are the main sources of variation values of natural mortality (Pauly, 1985).

The comparison between the fishing mortality (0.92 $year^{-1}$ for females and 0.82 $year^{-1}$ for males) and natural mortality (1.17$year^{-1}$ for females and 1.24 $year^{-1}$ for males) indicates a strong pressure while fishing at sea for yellow mullets. Our results on total and natural mortalities of *M. cephalus*, compared with those of Rathacharen and al.(1999) in Mauritius (Table 3) and of did not show significant differences because χ^2 calculated = 0.745 < χ^2 theoretical = 3.81; p = 0,05. By against the values of Z and M (Table 3) found in Nigeria Uneke et al. (2010) are very high compared to our results. This difference can be explained by a very high fishing effort and a high natural mortality.

The results of this study show different levels of exploitation. For the case of females (E = 0.44) and males (E = 0.4 caught at sea, the critical threshold (0.50) is not exceeded for *M. cephalus* in Senegal River , thus suggesting overexploitation of *M. cephalus* of ages between 3 and 5 years. By contrast optimum performance is not achieved for juveniles (E = 0.23) caught in the river. This situation is described by Froese (2004) as recruitment overfishing; other fish are caught before they can realize their full potential. . The effort of fishing is more intense on the sea level. The gravidic females are targeted by the fishermen for the gonades which will be transformed and sented in Europe. Increase in the biomass by recruit entrain a reduction in the reproductive biomass (Table 4). The curve of recruitment (Figure 5) is smoothed by two normal curves at end to allow a better visualization of the peak. Broadly the period of recruitment is between May and April. And the office plurality of the percentage of recruitment is 43.87%.

The peak is observed during the dry season, during which

Table 4. Values of yield, biomass and reproductive biomass by recruit of *Mugil cephalus* in the Senegal River.

Y'/R= 30 g E-10=0.42	E-50=0.287	E_{max}=0.476 B'/R=700 g	M/K= 1.74
Factor	**Y/R**	**B/R**	**SSB**
0	0	10.559	5.37
0.01	0.026	10.506	5.329
0.02	0.051	10.454	5.287
0.03	0.076	10.403	5.246
0.04	0.1	10.351	5.206
0.05	0.124	10.3	5.165
0.06	0.148	10.25	5.125
0.07	0.172	10.199	5.086
0.08	0.195	10.149	5.046
0.09	0.218	10.1	5.008
0.1	0.241	10.051	4.969
0.2	0.453	9.58	4.601
0.3	0.64	9.142	4.265
0.4	0.804	8.735	3.956
0.5	0.949	8.356	3.672
0.6	1.078	8.003	3.412
0.7	1.191	7.672	3.172
0.8	1.291	7.364	2.951
0.9	1.379	7.075	2.748
1	1.457	6.804	2.56
1.1	1.526	6.55	2.387
1.2	1.588	6.311	2.227
1.3	1.642	6.086	2.079
1.4	1.69	5.874	1.942
1.5	1.732	5.675	1.816
1.6	1.77	5.486	1.698
1.7	1.803	5.308	1.589
1.8	1.833	5.14	1.488
1.9	1.859	4.98	1.394
2	1.881	4.829	1.306

the water is brackish. Yellow mullets would develop strategies to match the period of larval emergence at a time when environmental factors could offer a better chance of survival. The length-based virtual population analysis (Figure 6) showed that the fishing mortality gradually increased with size, contrary to the natural mortality, i.e. the probability of capture increases with age, and the more mature are the fishes, the more they are caught. Recruitment and growth have contributed to gains respectively 11.46% and 88.54%. The average total number of individuals was estimated at 2117700 individuals and the total biomass specimens average about 300.731$10^3$ kg. This biomass is mainly composed of individuals whose size classes vary 17 cm to 64 cm and represents 76.98% of the total stock biomass exploited. The average length of the critical current stock is 40 cm and the mean age of the current stock is 2.48 years. Biomass renewed (298.711 10^3 kg) is less than the biomass produced (457.751$10^3$ kg).

The renewal of the stock is slow compared to the catch intensity of *M. cephalus* in the estuary of the Senegal River. Yield and biomass per recruit (Y/R and B/R) mules in the Senegal River Estuary are 69.32 g respectively and 54.72 g (Table 4). Figure 7 shows that the relative yield per recruit has reached its maximum Y'/R = 30 g biomass per recruit with B'/R = 700 g for maximum exploitation rate (E-max = 0.476). The best yields were obtained for E between 0.4 and 0.7.

For the relative yield per recruit and the relative biomass per recruit, our results are different from those obtained by Katselis et al(2010) in Greece for *M. cephalus*. The latter found Y'/R = 25g and B'/R = 275g for E-max=0.38. The analysis of yield per recruit (Y/R) showed that the current level of exploitation far exceeds the level of maximum sustainable yield. The stock of *M. cephalus* in the Senegal River Estuary is overfished with fishing effort mainly directed towards the mature fish. The results show that the level of fishing effort is higher than that corresponding to the MSE. This indicates that the exploitation of this stock exceeds its optimum level, and for that reference to the cohort analysis, it may be appropriate to reduce fishing effort and to found a biological rest each year. The Thompson and Bell (1936) model confirms the results obtained by the exploitation rate relative yield per recruit and relative biomass by the Beverton and Holt (1966) method.

CONCLUSION

In the Grande Côte in Senegal, yellow mullet are mainly exploited by artisanal fishing which takes large specimens (E= 0.44) at sea and juveniles in the river (E=0.23). For this type of operation almost any age of the exploit table phase is unaffected. The stock of *M. cephalus* in the Senegal River Estuary is overfished with fishing effort directed towards the mature fish. The renewed biomass (278.71 10^3 kg) is lower than the produced biomass (457.75 10^3 kg), showing the state of overexploitation of the fish stock, with the level of fishing effort higher than that corresponding to the MSE. It is concluded from this study that the yellow mullet fisheries in maritime and river Senegal are overexploited. The decrease in fishing effort for the species *M. cephalus* will help maintain the state of stocks.

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