

Stocks of *Mugil bananensis* (Pellegrin, 1927) in the Estuary of Senegal River by Determining Yields Per Recruit and Biomass Per Recruit

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Abstract: Mullet occupy an important place in artisanal fishing in the region of Saint-Louis. They provide substantial income to the various actors in the sector. Overfishing would adversely affect the recovery capacity of the Mugilidea stock in the Senegal River Estuary. A biological collapse is then to be feared. This risk is all the more so since fishermen from Saint-Louis go as far as Mauritania, Guinea Bissau and Sierra Leone to search for mules that have reached sexual maturity for their gonads. Works on the assessment of the stock status of *M. bananensis* have not been done in Senegal, although it has been carried out in other countries. The objective of the study is to contribute to the assessment of banana mullet stocks in the Senegal River estuary by determining yields per recruit and biomass per recruit. Data were collected on total length, total weight and the sex. FiSAT II and ViT4 softwares enabled analytical models based on virtual populations' analysis, yield per recruit (Y / R) and biomass per recruit (B / R). The results obtained showed overexploitation of *M. bananensis* in the estuary of the Senegal River. The stock of *M. bananensis* is overexploited in sea and the coefficients of fishing mortality and total mortality are remarkably high to the class mastses fish of III⁺ age, IV⁺ and V⁺. In sum, the study allowed us to know the dynamics of exploitation of mules in the estuary of the Senegal River and to propose a management plan and management of banana mullet for a sustainable management of this species.

Keywords: *Mugil*, *Bananensis*, Exploitation, Coefficients, Mortality, Senegal, River

1. Introduction

The use of increasingly performance gear and fishing techniques, including purse seine and sliding purse seines, surface gillnets and beach seines increased fishing effort through intensive exploitation of *M. bananensis*. Studies have been conducted on the biology and ecology of the species [1]. Works on the assessment of the stock status of *M. bananensis* have been carried out particularly in Asia [2, 3,

4], in the Mediterranean [5, 6].

However, there are no studies in Senegal on the determination of stocks of banana mullet. Our study aims to determine yields per recruit and biomass per recruit to better assess the status of *M. bananensis* stocks in the Senegal River estuary by models incorporated into a FiSATII software program.

2. Material and Methods

2.1. The Study Area

The Senegal River travels through 1700 km before flowing into the sea in the south of Saint Louis City by a sole mouth. The study area is localized between latitudes 15°45' and 16°30' north and longitudes 15°40' and 16°35' west (Figure 1). The coastal zone is largely influenced by upwellings coming from the central waters of the southern Atlantic Ocean [7].

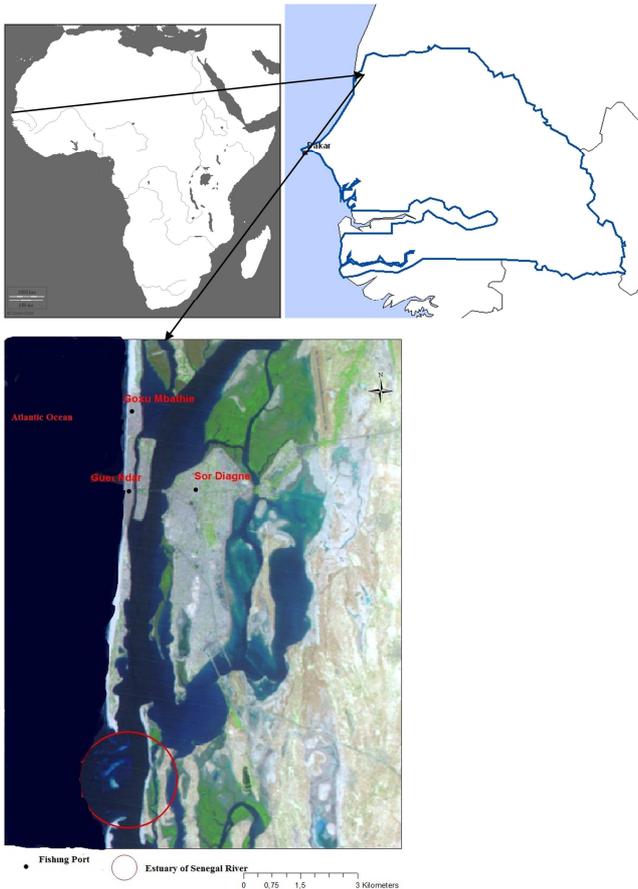


Figure 1. Map to locate the study area (Sarr, 2012).

2.2. Data Collection

Samples of *M. bananensis* were weekly collected between January 2011 and March 2012. The sampling is an aleatory type and includes 1.665 fish, of which 1243 juveniles are collected in the river and 422 individuals captured in sea including 245 females and 177 males. The data collected concerned total length (Lt), total weight (Pt) and the sex. The field interview [8] is used for the 96 field trips over a period of 2 years and 21 fishing units regularly monitored.

2.3. Biological Material

M. bananensis is a fish of great commercial value in Senegal and is a species of the Mugilidae. It is a species of catadromous fish and widely distributed in fresh waters, estuarine waters and brackish waters [1]. Its body is

cylindrical and robust with a large head, a well-developed adipose eyelid, covering most of the pupil (Figure 2). It has a thin upper lip, no papillae and two dorsal fins. The pectoral axillary scales are well developed. The back of *M. bananensis* is bluish-gray, the sides and belly are whitish silvery with sometimes golden reflections and often gray longitudinal lines. The ventral fins (mainly), anal fins and the lower lobe of the caudal fin (sometimes) are yellow.



Figure 2. Banana mullets captured in the Great coast Senegal (©Sarr, 2012).

2.4. Methodology

Data analysis: FiSAT II and ViT4 softwares are used to analyze the data.

Most routines for estimating mortality and related parameters incorporated in FiSATII require estimates of growth parameters. The initial and sufficient condition for using this software for a given species is to have a size frequency data file with a constant length class of at least 100 individuals. The sample is distributed over 10 to 20 classes of sizes. The ViT4 software is used to determine yield and biomass per recruit, virtual populations analysis and recruitment level.

Relative analysis of yields per recruit (Y/R) and biomass per recruit (B/R) using knife blade selection

The model expresses the relative yield per recruit (Y'/R) [9], making it possible to determine the ratio between the yield and the fishing effort for the different sizes of first captures. It belongs to the category of length-based models [10]. The expression of Y'/R is:

$$Y'/R = EU^{M/K} [1 - 3U/(1+m) + 3U^2/(1+2m) - U^3/(1+3m)]$$

With

$$U = 1 - L_c/L_\infty$$

$$m = (1 - E/M/K) = K/Z$$

$$E = F/Z$$

E = exploitation rate; K = growth coefficient; Z = total mortality; M = natural mortality and F = fishing mortality

L_C = average size of fish at first catch; Equivalent to L_{50} mean size of fish at first catch;

L_∞ = Asymptotic length, i.e. the (average) length, the fish for a given stock, should reach if its growth is infinite and m = mesh size

Relative biomass per recruit (B' / R) is estimated from the relationship:

$B' / R = (Y' / R) / F$, while E_{max} (exploitation rate yielding maximum yield)

E_{-10} (exploitation rate of 10% of its virgin stock) and E_{-50} (exploitation rate where the stock is reduced by half of its virgin biomass) are estimated using the first derivative of this function.

Relative analysis of per-recruit (Y/R) and biomass per recruit (B/R) yield using the selection warhead

The relative production per recruit model presented here is based on the model [9], modified by reference [11]. The relative per-recruit yield (Y'/R) is calculated from:

$$Y'/R = \sum Pi ((Y'/R)_i - G_{i-1})$$

or

$(Y'/R)_i$ refers to the relative per-recruit performance calculated from the lower class i limit using:

$$(Y'/R)_i = EUM/K [1 - 3U/(1+m) + 3U^2/(1+2m) - U^3/(1+3m)]$$

With

P_i is the probability of capture between L_i and $L_i + 1$, while G_i is defined by

$$G_i = \prod r_j \text{ with } r_j = (1-c_i)^{S_i} / (1-c_{i-1})^{S_i} \text{ et } S_i = (M/K)(E/(1-E))P_i.$$

S = variables used to estimate the probability of capture under the logistic model

Here, B'/R is estimated from

$$(B' / R)_i = (1-E) A / B$$

$$S_i = (M / K) (E / (1-E)) P_i.$$

Here, B' / R is estimated from:

$$(B' / R)_i = (1-E) A / B$$

$$A = \{1 - 3U/(1+m) + 3U^2/(1+2m) - U^3/(1+3m)\}$$

$$B = \{1 - 3U/(1+m) + 3U^2/(1+2m) - U^3/(1+3m)\}$$

Here, B' / R is estimated from

$$(B / R)_i = (1-E) (A / B) \text{ and where } m' = 1 / (M / K) = m / (1-E).$$

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

Predictive Model of Thompson and Bell and Stock Prediction

This model combines the elements of the Y'/R model [9] with those of VPA, which it reverses. In the FiSATII software is incorporated a prediction routine that runs the model and produces the graphical and numerical results. For the procedure, it is necessary to calculate:

The sum of the yields ($Y = \sum Y_i$) which is calculated from:

$$Y_i = C_i \cdot W_i$$

Where the average body weight is:

$$W = (1/L_{j+1}) \cdot (a/b+1) \cdot (L_{i+1}^{b+1} \cdot L_j^{b+1})$$

Where a and b are the coefficients of the size-weight relation and L_i and L_{i+1} are respectively the lower and upper limits of the size class, so we have

$$C_i = (N_i - N_{i+1} + 1) (F_i / (M + F_i)) \text{ with } C_i = \text{number cumulative catch for a given mesh size}$$

Where the predicted population (N_i) is indicated by:

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

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

Δt_i Time difference, for example, the time required for an average fish to grow from the lower limit to the upper limit in a class of length i

The biomass is calculated from:

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

And the value (V_i) is calculated by $V_i = Y_i \cdot v_i$ where v_i is the unit of value of class i .

Y_i is the yield at size i

3. Results

3.1. Assessment of Banana Mullet Stocks in the Senegal River Estuary

We have two models to analyze and predict the evolution of *M. bananensis* stocks in the Senegal River Estuary.

3.2. Model of Beverton and Holt (1966): Relative Analysis of Yield Per Recruit (Y/R) and Biomass Per Recruit (B/R)

The exploitation rates are recorded in Table 1. For the different sizes of first capture L_c and as a function of the rate of return, the relative yield per recruit Y' / R increases to a maximum and then decreases.

Table 1. Y / R recruit yield and biomass per recruit B / R .

Lc/L∞=0.240 Emax=0.476 E50=0.287 E10=0.42 M /K= 1.74 Y'/R= 0.03g B'/R=0.70g										
E	0.01	0.20	0.3	0.40	0.50	0.60	0.70	0.80	0.90	0.99
Y/R	0.011	0.019	0.025	0.028	0.029	0.027	0.024	0.019	0.013	0.009
B/R	0.808	0.634	0.481	0.348	0.237	0.149	0.083	0.038	0.012	0.001

The maximum exploitation rate allowed for $E_{max} = 0.476$ (Figure 3) is largely exceeded for adult banana mullets with an exploitation rate of 0.65 for females and 0.66 for males (Figure 4). The diagnosis of yield per recruit showed that *M. bananensis* is in a state of overexploitation in Senegal coast.

Biomass per recruit declined sharply as fishing effort increased.

The optimum level of relative performance per recruit is achieved. The species is overexploited in the locality.

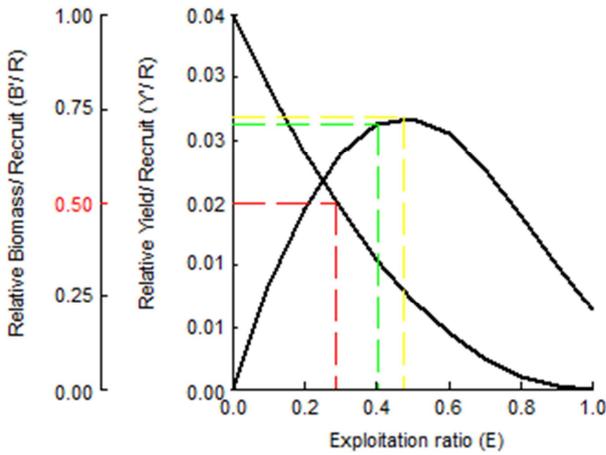


Figure 3. Yield per recruit (Y/R) and biomass per recruit (B/R).

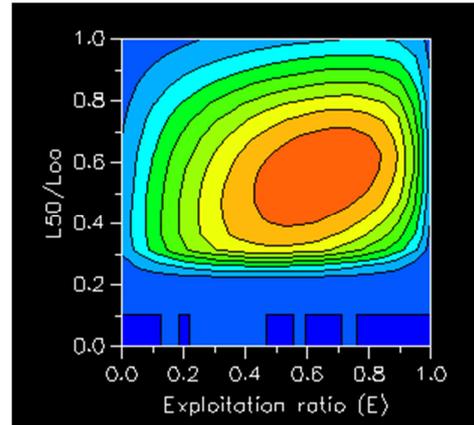


Figure 4. Exploitation rate of *Mugil bananensis* in the estuary of the Senegal river.

3.3. Predictive Model of Thompson and Bell (1934)

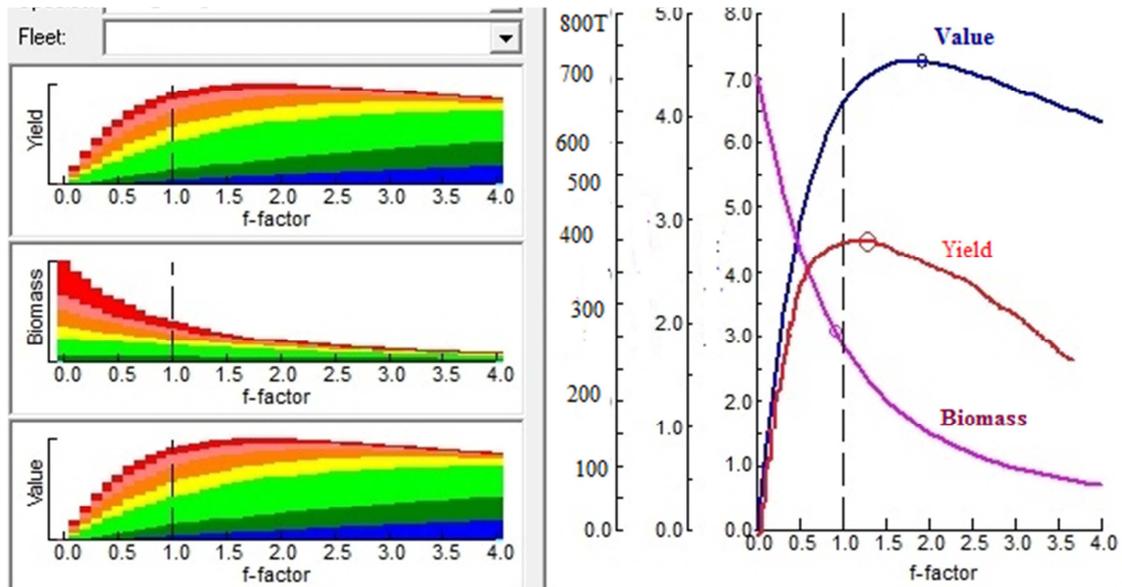


Figure 5. Prediction of *Mugil bananensis* stocks by Thompson and Bell method.

The model used shows maximum sustainable yield (MSY), maximum sustainable economic output (MSE), factor f and corresponding biomass (Figure 5). Concerning *M. bananensis*, the factor F is 1.8 therefore corresponds to the MSY whereas the MSE is obtained with a factor of F ($X = 2$). The value is on the upward part of the curve of the value (V) and on the plateau of the production curve (Y). The results show that the level of fishing effort is higher than that corresponding to the MSE.

Table 2 shows the evolution (in percentage) of yields (Y/R), biomass (B/R) and fertilized biomass per recruit (SSB/R) in relation to their virgin level according to an effort multiplier. These yields and biomass per recruit models show

a very strong impact of fishing on the current state of the stock.

The total abundance of the *M. bananensis* stock is now only 6.8% of what it would be in the virgin state. The fertilizer biomass is reduced to 2.56%, compared to the non-farming situation. Moreover, these values are not very sensitive to the VPA adjustment parameter (in the most favorable hypothesis, for $f = 0.6$, the relative fertility biomass is estimated at 5.304%). These values are below the generally accepted precautionary levels; this seems corresponding to a situation of overexploitation of recruitment where there is therefore a risk of collapse of recruitment by overfishing.

Table 2. Impact of effort multiplier on yields, biomass per recruit and per-recruit biomass per recruit (% of virgin biomass) of *M. bananensis*.

MF force multiplier	0	0.1	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2
Y/R (%)	0	0.24	0.45	0.84	1.08	1.29	1.46	1.58	1.69	1.77	1.83	1.88
B/R (%)	10.56	10.05	9.58	8.74	8.03	7.36	6.80	6.31	5.87	5.48	5.14	4.83
SSB/R(%)	5.37	4.96	4.61	3.95	3.42	2.95	2.56	2.23	1.94	1.69	1.48	1.30

For *M. bananensis*, the estimations of the main components of the stock using the VIT software are shown in Table 3. The global F values express the relationship between the annual captures and the annual mean numbers in the stock. They are calculated by weighting the arithmetic mean of the F / ages by the corresponding numbers of individuals. Critical ages and sizes are those for which a cohort reaches its maximum biomass. The biomass balance (D) is the amount of biomass renewed during the unit of time (year). This is the balanced balance between the weight gains due to recruitment and losses due to mortality (natural and fishing). The ratio Bmax / Bmoyen expresses the proportion of biomass produced by a cohort when it reaches its critical age. The D / B turnover ratio reflects the importance of annual biomass renewal.

Table 3. Summary results of the main components of the *Mugil bananensis* stock in the Senegal River estuary.

B / R: 54.72 SSB / R: 23.63 Y / R: 69.32 F = 1.80	
Average age (current stock)	2.076
Critical Age (current stock)	2.488
Critical age (virgin stock)	2.586
Average length (current stock)	33.296
Critical length (current stock)	40
Critical length (blank stock)	41
Number of recruits, R	269987.57
Average biomass (virgin stock)	147.723
Biomass fertility (current stock), SSB	637.89 tonnes
Biomass of the equilibrium situation (Balance, D)	113.71 tonnes
Natural Mortality / D	83.54
Maximum Biomass / Average Biomass	27.58
D / B "turnover" average	76.98

4. Discussion

The average total number of individuals was estimated at 211.770 10³ bananas mullets and the average total biomass at about 147.73 tons. This biomass consists mainly of individuals whose size classes vary from 17 cm to 64 cm and represent 76.98% of the total biomass of the exploited stock. The average critical length of the current stock is 40 cm and the current stock age is 2.48 years. The renewed biomass (113.711 tons) is lower than the biomass produced (147.751 tons). Stock renewal is slow in relation to the exploitation of *M. bananensis* in the Senegal River estuary [12].

The yields per recruit and the biomass per recruit (Y/R and B/R) of mullets in the estuary of the Senegal River are respectively 69.32 g and 54.72 g (Table 2). Figure 4 showed that the relative yield per recruit reached its maximum Y / R = 0.03 g with a biomass per recruit

B/R = 0.70 g for a maximum exploitation rate (E_{max} = 0.476). The best yields were obtained for E between 0.4 and 0.7 (Table 2).

The model of Thompson and Bell (Figure 5) used shows maximum balanced production (MSY), maximum sustainable economic output (MSE), factor f and corresponding biomass. The maximum production balanced is obtained with a factor of f (X = 1.8).

The factor (f = 1.8) therefore corresponds to the MSY

whereas the MSE is obtained with a factor of f (X=1). The current value of f is found on the rising part of the production curve (Y = 726.86) and the value (V = 726.86), with a biomass of 105.28 T. The yield analysis per recruit (Y / R) showed that the current level of exploitation far exceeds the level of maximum sustainable yield. The stock of *M. bananensis* in the Senegal River estuary is overexploited with a directed fishing effort towards mature fish [13, 14]. 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, for this purpose and with reference to the analysis of the cohorts, it will be wise to reduce the fishing effort and reduce the size of the captures. The method of Thompson and Bell [15] confirms the results of the exploitation rate obtained by the relative yield per recruit and the relative biomass by the model [9]. The situation of the stock of banana mullet in Senegal is particularly worrying for several reasons. The results show that the stock is in a state of overexploitation of very marked growth. The current effort is nearly three times the effort to maximize unshipments per recruit. Any increase in fishing pressure on juveniles may lead to an increase in catches in numbers, but the average weight of individuals is becoming increasingly low. The most worrying aspect of stock status is the significant decline in recruitment and the current low levels of fertile biomass. Indeed, the current fertile biomass corresponds to 17.86% of the biomass balanced. The current mode of exploitation thus tends to keep the fertility of *M. bananensis* stock at a low level because fish are unlikely to reach a size compatible with a good reproduction. In fact, as [16] (2012) has well demonstrated, a stock in overfishing will be made up of young individuals due to the decline in life expectancy and consequently low fertility. Overfishing would adversely affect the recovery capacity of the banana mullet stock in the Senegal River estuary. A biological collapse is then to be feared. This risk is real, especially as fishermen from Saint-Louis go to Mauritania, Guinea Bissau and Sierra Leone to find yellow mules that have reached sexual maturity for their gonads. The management measures necessary for the sustainable management of the banana mullet stock in the Grande Côte in Senegal are a reduction of the current fishing effort, especially during the breeding season and an increase in size at the first capture.

5. Conclusions

This study revealed the balanced state of the banana mullet population stock and estimated exploitation rates. The parameters, in particular the yield per recruit and the biomass per recruit, also reflect an overfishing situation for the *M. bananensis* species in the Senegalese coast. It is concluded from this study that the banana mullet fisheries in the maritime and river areas of Senegal are in a state of overexploitation, that a planning and better monitoring of captures are essential to safeguard the growth dynamics of the population of *M. bananensis* species.

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