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Population Dynamics of *Senilia senilis* (Linnaeus, 1758) from the Senegal River Delta, Senegal

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Abstract This study investigated the growth, mortality and exploitation parameters of *Senilia senilis* in the Senegal River delta, Senegal. Samples were collected monthly from July 2017 to Jun 2018. The parameters were estimated based on size-frequency data processed by FISAT II software. The measured length of 9939 specimens ranged from 5 to 65.48 mm. The growth parameter (K) was estimated as 1.30 yr^{-1} with asymptotic length ($L\infty$ = 68.25 mm). The growth performance index and the theoretical age at birth (t_0) were estimated as 3.78 and -0.097 yr^{-1} respectively. Total mortality, natural mortality and fishing mortality rates were estimated as 3.29 yr^{-1}, 1.64 yr^{-1} and 1.65 yr^{-1} respectively. The current exploitation rate (E) was calculated as 0.5 which showed an optimal exploitation of *Senilia senilis* in the Senegal River delta. However, urgent management actions should be taken for a sustainable exploitation of this species.

Keywords: *Senilia senilis, Senegal River, Gandiol, Population Dynamics, Growth*

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1. Introduction

Senilia senilis (also known as *Anadara senilis*) is a taxodont lamellibranch mollusc found in lagoon or estuarine biotopes along the West African coast, from Western Sahara to Angola [1]. It is a species well known to West African coastal populations, and is the most extensively studied of the bivalve molluscs [2].

In Senegal, *S. senilis* is one of the most widely exploited bivalve molluscs. The existence of shellfish beds where *S. senilis* is the dominant species, or even often the only species present, attests to the long history of exploitation of this species in Senegal. Recently, the opening of the Langue de Barbarie breach in Gandiol, to prevent flooding of the city of Saint-Louis, has disrupted a number of socio-economic activities, including fishing, tourism, flood recession farming and market gardening [3,4].

The ecological disruption caused by the development of the breach has had the positive effect of encouraging the appearance of certain species of bivalve mollusc, such as *S. senilis*. Exploitation of this mollusc has become an income-generating activity in Gandiolais [5]. However, the harvesting of this species in the Gandiolais area escapes government control and remains an informal activity [5].

This is the reason why the present study attempts to study the parameters of growth, mortality and exploitation of this species with a view to its sustainable management in the Senegal River delta.

2. Materials and Methods

2.1. Study Area

The study was carried out in Gandiol, which straddles the Niayes of Senegal’s northern coastline and the Senegal River delta [6]. The area lies downstream of the Diama dam, south of the city of Saint-Louis. Located at 16°15' north latitude and 16°25' west longitude, Gandiol borders the commune of Saint-Louis to the east, the commune of Fass Ngom, National Road 2 and the Toubé area, and to the south, the rural commune of Léona in the department of Louga (Figure 1). It lies between the Senegal River and the Atlantic Ocean to the west, covering an area of around 360 km^2 [5].

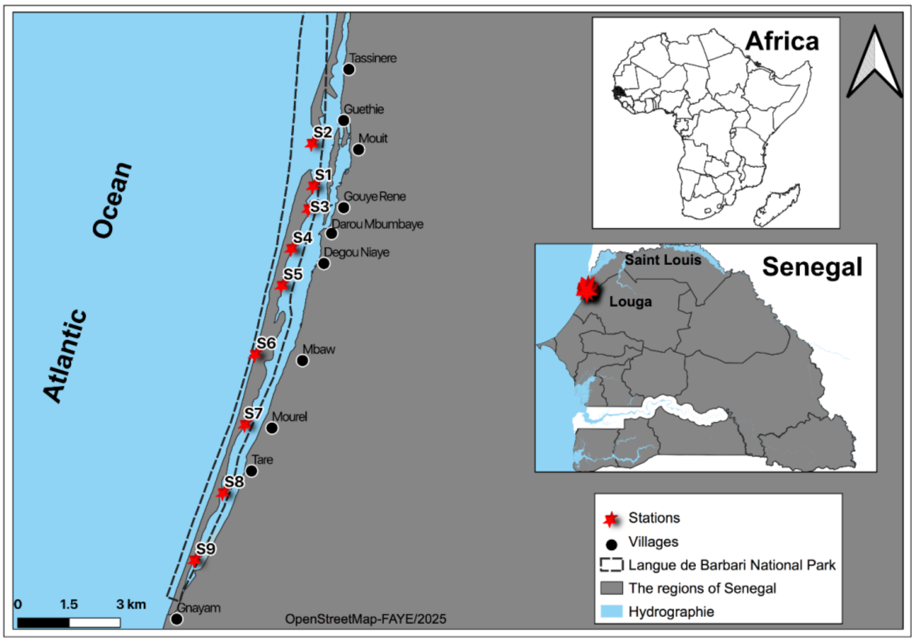

Figure 1. Map showing sampling stations

2.2. Sampling Protocol

Sampling was carried out monthly from July 2017 to June 2018. A total of 09 collection stations were chosen (Figure 1). Data were collected using two sampling techniques: the quadrat technique along a transect and the dredge technique. For the first technique, quadrats of 25 cm on each side, spaced 5 m apart, were laid out perpendicular to the bank to a depth of around 70 cm. The number of quadrats varied between 2 and 5, depending on the width of the bank. For the second technique, a cylindrical-conical dredger was used in the deep areas (middle of the bed). This dredge, with an opening diameter of 50 cm and equipped with a metal bar, is wrapped in a net with a mesh size of 1 cm. Once at the bottom, the dredge was pulled by a strong rope attached to a pirogue to collect the fauna and accumulate it at the bottom of the net. The dredge was raised every 5 minutes to recover the *S. senilis* individuals collected. The individuals from each surface unit explored by both the dredge and the quadrats are collected and placed in numbered bags. In the laboratory, *S. senilis* individuals were measured and weighed using a caliper and a 0.01 g precision electronic balance, respectively. For each individual, length, height and bulge were measured and the animal weight with shell was weighed.

2.3. Growth Parameters

The FAO-ICLARM Stock Assessment Tool (FiSAT II, version 1.2.2) software was used to analyze the monthly length frequency data [7,8]. The parameters of the von Bertalanffy Growth function (VBGF), asymptotic length ($L\infty$) and growth coefficient (K) were estimated using the ELEFAN-1 method [9]. 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. [10]'s empirical equation for the theoretical age at length zero (t_0) was used to obtain this parameter as: $\text{Log}(-t_0) = -0.392 - 0.275 \times \text{Log}\,L\infty - 1.038 \times \text{Log}K$. The growth performance index (Φ') was computed from the equation [11]: $(\Phi') = 2 \times \log L\infty + \text{Log}K$ and the longevity (t_{max}) was estimated as [12]: $t_{max} = 3/K + t_0$

2.4. Mortality Parameters

Total annual instantaneous mortality rate (Z) was estimated using the Length converted catch curve [13]. The natural mortality (M) was estimated by Pauly's empirical equation [14], 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 [15]: $F = Z - M$, where F = fishing mortality, Z = total mortality and M = natural mortality. The exploitation rate (E) was given by FiSAT from 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 [11].

2.5. Recruitment Patterns

The recruitment pattern was determined by backward projection on the length axis of the set of available length-frequency data [16]. Length at first recruitment (Lr) was taken as the mid-length of the smallest length interval [17] while age at first recruitment followed [18].

2.6. Virtual Population Analysis (VPA)

VPA (Length structured) was undertaken by applying the values of growth and mortality parameters as well as growth pattern from the length-weight relationship. The length-weight relationship was done using the expression [19]: $W = a \times L^b$, where W = body weight and L = length.

2.7. 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, 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 Knife-edge option.

3. Results

3.1. Growth Parameters

A total of 9929 specimens of *S. senilis* were collected for the study. Results of length-weight measurements gave the following ranges, length 5 - 65.48 mm. The mean length of samples was 20.98±9.46 mm. The observed and the predicted extreme length (L_{max}) were found to be 65 and 67.90 mm respectively (Figure 2). The range at 95% confidence interval for extreme length was calculated as 64.73 - 71.07 mm.

The best value of VGBF growth constant (K) was estimated to be 1.30 yr^{-1} by ELEFAN-I with an asymptotic length ($L\infty$) of 68.25 mm and a growth performance index (Φ') calculated as 3.78 (Figure 3).

The restructured length frequency distribution diagram and growth curves produced by ELEFAN I method and displayed in Figure 4. The theoretical age t_0 and longevity (t_{max}) of *S. senilis* values were calculated as -0.097 yr and 2.21 respectively.

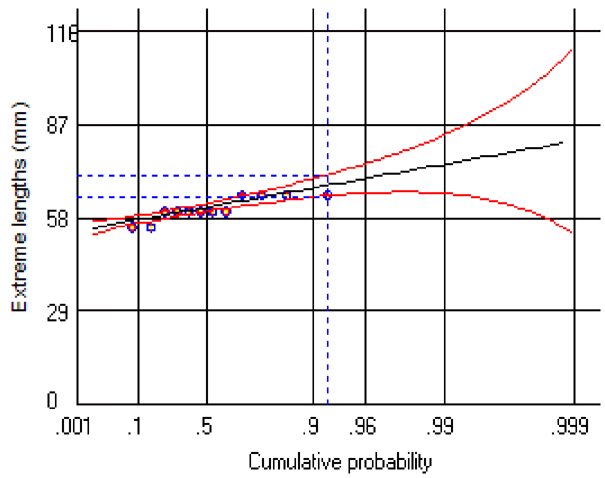

Figure 2. Predicted maximum length for *S. senilis* based on extreme value theory. The predicted maximum length value and the 95% confidence interval are obtained from the intersection of overall maximum length with the line y and x, z respectively

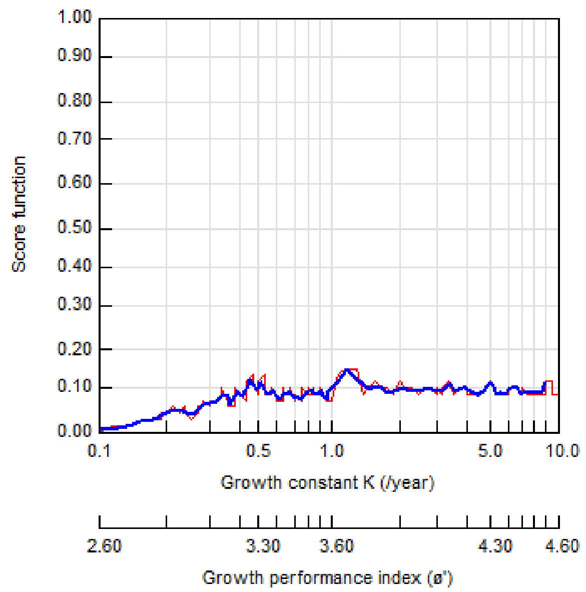

Figure 3. Growth performance of *S. senilis*

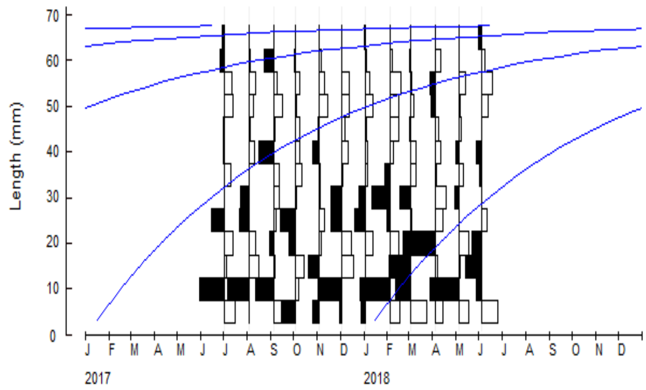

Figure 4. Restructured Length frequency distribution output from FiSAT II with superimposed growth curves (Dark bars=actual frequency bars and White bars=reconstructed bars)

3.2. Mortality and Exploitation Rates

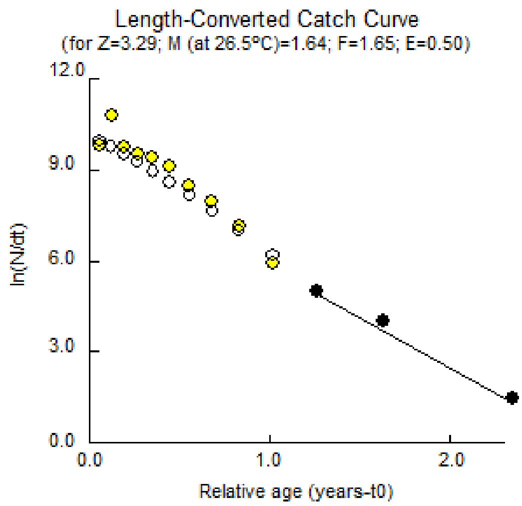

Figure 5. FISAT II output of linearized length-converted catch curve for *S. senilis* (Yellow dots are dots used in calculation and White dots are dot not used in calculations)

The mortality rates for *S. senilis* were showed in Figure 5. The total mortality rate (Z) was calculated as 3.29 year^{-1}. The natural (M) and fishing (F) mortality rates were estimated to be 1.64 year^{-1} and 1.65 year^{-1}, respectively. The current exploitation rate (E) was found to be 0.50.

3.3. Recruitment Patterns

The recruitment pattern of *S. senilis* was continuous throughout the year with two peaks (January-February and August-September) indicating two distinct spawning events (Figure 6). The major peak recorded 28.53% recruitment while the minor peak recorded 19.34 %.

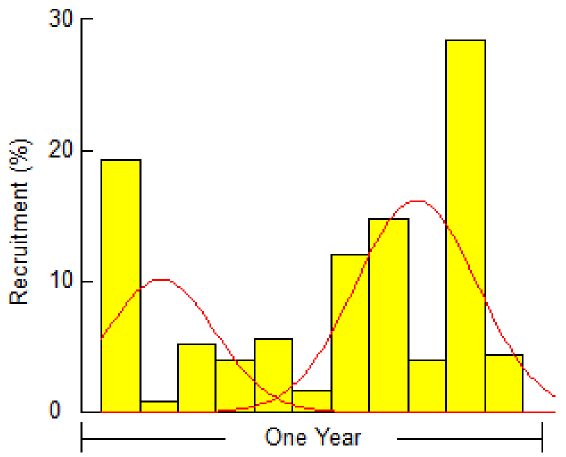

Figure 6. Recruitment pattern of *S. senilis* from FiSAT Output

The virtual population analysis of *S. senilia* was shown in Figure 6. Individuals within the range of 10 - 15 mm experienced the highest level of exploitation. *S. senilia* observed natural loss due to natural mortality at 5 mm to 10 mm. The minimum and maximum fishing mortality rates were recorded as 1.19 yr^{-1} and 4.16 yr^{-1}, respectively. The fishing mortality (F) reached a maximum of 4.16 yr^{-1} at 10 mm. Surviving individuals in the stock exhibited a declining trend with increased rate of fishing pressure (Figure 7).

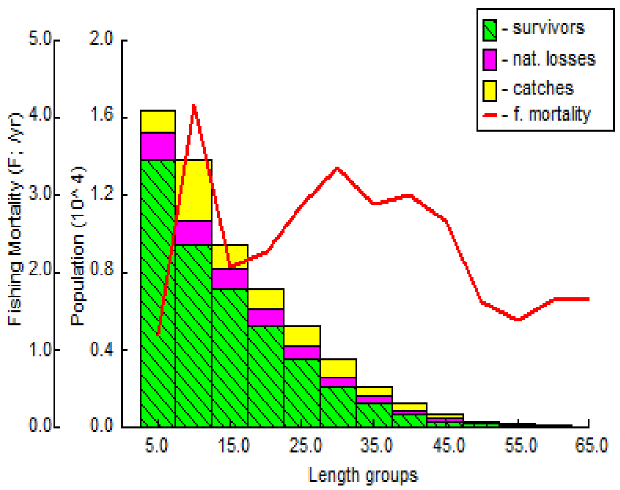

Figure 7. Length structured virtual population analysis of *S. senilis* in Senegal River

3.4. Relative Yield Per Recruit (Y'/R)

As fishing exploitation increased relative yield per recruit (Y'/R) decreased (Figure 8). The Beverton and Holt relative yield per recruit model showed that the optimum sustainable yield ($E_{0.5}$), the maximum sustainable yield (E_{max}) and the economic yield target ($E_{0.1}$) indices were 0.26; 0.40 and 0.32, respectively.

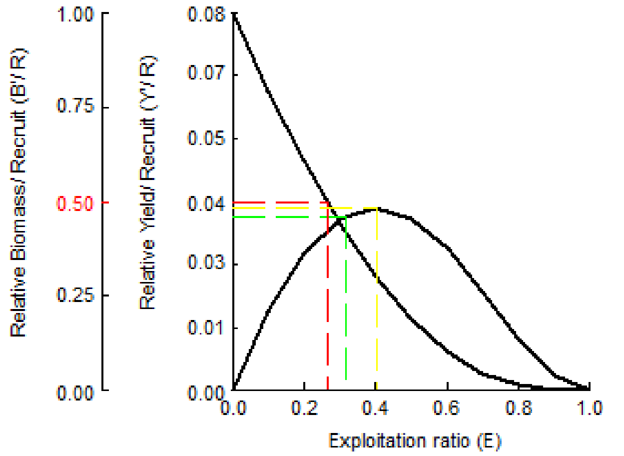

Figure 8. Beverton and Holt's relative yield per recruit and average biomass per recruit models, showing levels of yield indices for *S. senilis* in south Coastal Senegalese waters (Red dashes=$E_{0.1}$, Green dashes=$E_{0.5}$ and Yellow dashes=E_{max})

4. Discussion

The conventional von Bertalanffy growth model has been found to be a good description of molluscan growth [20,21]. In addition, reliable estimates of growth parameters in bivalves are likely to be associated with similar (Φ') values as long as the species in the comparison group have a similar shape [21]. Thus, the values of (Φ') were used in the present study to evaluate the reliability of the growth parameters obtained for *S. senilis* by comparing the values of (Φ') with those calculated for other species of the Senilia genus (Table 1) [22]. The growth performance index, (Φ') = 3.78, of this study was higher than the estimated values for other Senilia species (Table 1). These disparities may be attributed environmental peculiarities at the different locations. Indeed, growth performance of bivalves could be as a result of influences of environmental factors, and thus, bivalves found at different geographical locations may have different growth performance indices which could be as a result of the prevailing environmental conditions [23]. Indeed, [24] and [25] suggested that linear growth may vary from one water body to another, because environmental factors such as the productivity of the areas, the availability of food may vary. Growth in bivalves is influenced by many factors, including temperature, food intake, current action, salinity, food availability, water flow, and reproductive state [26].

The coefficients of total mortality, natural mortality and fishing mortality estimated during the present study were Z = 3.29 yr^{-1}, M = 1.64 yr^{-1} and F = 1.65 yr^{-1}, respectively (Table 2). It appears that natural mortality was roughly equal to fishing mortality. However, fishing mortality is slightly higher, which suggested that mortality based on exploitation was relatively higher than that based on natural causes. The causes of natural mortality can be environmental or biological in origin [34]. Because, bivalves serve as food for a wide range of other organisms from groups such as fish, birds, mammals, crustaceans, echinoderms, flatworms, and even other molluscs [23].

Table 1. Growth parameter comparisons for Senilia species.

Species	Country	L_∞ (mm)	K (y^{-1})	(Φ')	Author
Senilia senilis	Senegal	68.25 ShH	1.30	3.78	Present study
Senilia senilis	Sierra Leone	47 ShL	0.550	1.08	[21]
Senilia senilis	Nigeria	49 ShL	0.460	3.05	[27]
Senilia senilis	Mauritania	77 ShL	0.09	2.73	[28]
A. tuberculosa	Costa Rica	63.15	0.141	2.75	[22]
Anadara tuberculosa	Costa Rica	75	0.09	2.70	[29]
Anadara tuberculosa	Costa Rica	59.9	0.15	2.73	[30]
Anadara ovalis	USA	57.5	0.45	3.17	[31]
Anadara corena	Turkey	75.2	0.37	3.32	[32]
Anadara granosa	Phillippines	36.9	1.84	3.40	[21]
Anadara granosa	Malaysia	44.4	1.01	3.30	[33]

Table 2. Comparison of mortality rates for the Genus *Senilia* from different regions of the world

Species	Country	Z (yr^{-1})	M (yr^{-1})	F (yr^{-1})	E	Author
Senilia senilis	Senegal	3.29	1.64	1.65	0.50	Present study
Senilia senilis	Nigeria	0.944	0.46	0.503	0.51	[27]
Anadara tuberculosa	Costa Rica	0.48	0.14	0.34	0.71	[22]
Anadara antiquata	Indonesia	9.01	2.27	6.74	0.75	[35]

The continuous recruitment pattern found for *S. senilis* with two major peaks (January-February and August-September) was the result of the spawning events that took place in December and July. The presence of recruits during January-February and August-September might indicate that the larval phase lasted at least 1 month [36]. These results were relatively similar to those of [37] who suggested that the major spawning period of *S. senilis* was in October-November.

Length-based VPA provides a medium for estimating fishing pressure on various length groups [38]. In the present study, Virtual analysis populations of *S. senilis* indicates that natural mortality was higher at small sizes (5-10 mm) and decreased gradually. This phenomenon could be explained by the fact that young individuals are more vulnerable to natural predation [39].

From the results of Beverton & Holt's relative yield per recruit, the exploitation rate 0.5 yr^{-1} was close to the maximum sustainable yield (0.40), but it was higher than the optimum sustainable yield (0.26) and economic yield (0.32) indices. Then, this showed an optimal exploitation of *S. senilis* in the Senegal River delta. The estimated exploitation rate in the present study for *S. senilis* was smaller than those obtained by [27] for *A. senilis* (E = 0.51), by [22] for *A. tuberculosa* (E = 0.71) and by [35] for *A. antiquate* (E = 0.75). The low exploitation rate estimated in the present study could be due to the fact that the exploitation of *S. senilis* in the Senegal River delta does not date back long. Indeed, the exploitation began after the installation of the breach in 2003, the ecological disturbances of which caused the appearance of certain species such as the bivalve molluscs *S. senilis* and *Carasostrea gasar*.

5. Conclusion

This study was a first attempt to assess the growth and exploitation parameters of *S. senilis* in the Senegal River delta in North of Senegal. The current exploitation rates (E) of *S. senilis* was estimated as 0.5. This might be supported that the species had not over exploitation but they reached the optimal fishing level in this study area. To ensure the availability and sustainability of *S. senilis*, it is in the stakeholders' interest not to increase fishing effort since this could lead to a situation of overexploitation of this species. Especially since, there are still no official planning and management measures for the sustainable exploitation of this resource. In this sense, the present study provides important information that would help in developing efficient management and conservation strategies.

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Statement of Competing Interests

The authors have no conflict of interest.

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