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Research Article

Population Parameters and Exploitation Rate of the Heavy African Ark *Senilia senilis* in the Gandoul Marine Protected Area (MPA) (Sine-Saloum, Senegal) and Its Surroundings

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Abstract

The Heavy African ark *Senilia senilis* is amongst the most harvested shellfish by local populations in the Gandoul MPA, located in the Sine-Saloum estuary, Senegal. It is accessible, and its harvesting does not require many financial means. This harvesting pressure, combined with the deterioration in environmental conditions in the MPA, is believed to be the cause of the decline in *S. senilis* stocks, with a reduction in the size of individuals and lower yields. The goal of this study was to estimate the population parameters and exploitation rate of *Senilia senilis* in the Gandoul MPA and its periphery to inform better resource management. The population parameters were estimated using the FiSAT II software. A total of 7.123 individuals were sampled, with a mean weight of 14.4 ± 7.4 g and a mean length of 29.1 ± 6 mm. The asymptotic length ($L\infty$) is 53.55 mm and the theoretical age t_0 is estimated to be 0.08 yr^{-1}. The growth coefficient (K) and growth performance index (Φ') are 1.70 yr^{-1} and 3.69, respectively. Total mortality (Z) is estimated at 6.51 yr^{-1}. Natural mortality (M) and fishing mortality (F) are 2.19 yr^{-1} and 4.30 yr^{-1}, respectively. Recruitment is continuous, with a first peak in March-April (21.80%) and another in September-October (15.09%). The exploitation rate (E) is 0.66 while the sustainable exploitation rate (E0.1) is 0.28, the optimum exploitation rate (E0.5) is 0.36 and the maximum exploitation rate (Emax) is 0.42. The results of the study show that *Senilia senilis* is overexploited in the Gandoul MPA and its periphery. Therefore, concrete management measures must be implemented to address this situation.

Keywords

Senilia senilis, Population Dynamics, Growth Parameters, Exploitation Rate, Gandoul Marine Protected Area, Sine-Saloum, Senegal

1. Introduction

Senegal's fisheries resources are facing a serious crisis that is jeopardizing biodiversity and the living conditions of the people who depend on them. Local fishing practices are said to have led to overexploitation of fishery resources, resulting in a considerable drop in catches. To address this situation, the Senegalese government has initiated, since 2004, the creation of several Marine Protected Areas (MPA) in coastal ecosystems, creating a network of high marine biodiversity. The goal of this network is to preserve the biological and cultural diversity of the coastal zone, replenish or maintain fish and other

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marine life stocks, and promote improved livelihoods for coastal populations [1].

The Gandoul MPA was created on March 31st, 2014, by Presidential Decree N° 2014-416. The aim of creating the MPA is to conserve marine and coastal biodiversity with a view to the socio-economic development of local communities [1]. Shellfish harvesting is an important socio-economic activity for local people in the Sine-Saloum, particularly women [2]. Thousands of women are involved in this activity in the villages of the Saloum islands [3]. Shellfish harvest represents a significant contribution to the supplemental income in local population [4].

The Heavy african ark *Senilia senilis* is one of the most harvested species in the Sine-Saloum estuary. The presence of numerous shellfish heaps along the shores is proof of the history and cultural significance of this activity in the delta [5, 6]. Formerly harvested as a food source for sustenance, farming of the species has become a major commercial activity in the region, resulting in strong anthropogenic pressure on the species. This harvesting pressure, combined with the deterioration in local environmental conditions, is believed to be the cause of the decline in *S. senilis* stocks, with a reduction in the size of individuals and lower yields.

Despite the decline in *S. senilis* stocks in the area, there is little scientific knowledge about the growth parameters of the species in the Sine-Saloum Delta. Scientific studies carried out to date have focused mainly on the production potential and farming systems of this species in the Sine-Saloum Delta [7-13]. The aim of this study is to determine the growth parameters and the current exploitation level of *S. senilis* in the Gandoul MPA and its periphery to inform better resource management.

2. Material and Method

2.1. Study Area

The Gandoul MPA (Figure 1) covers an area of 28 121 ha, and forms an integral part of the Saloum Delta Biosphere Reserve (SDBR) in the Sine-Saloum estuary. The climate of the area is Sudanian, with two clearly defined seasons: a dry season (cool from November to March and hot from April to June) and a rainy season (hot and humid) which lasts from July to October. Rainfall is usually concentrated between July and September, with August being the wettest month [14]. The Sine-Saloum estuary is oversalted, and its salinity gradient increases from downstream to upstream, thus creating a reverse estuary [15]. Indeed, the rainfall deficit of recent decades has greatly reduced the continental freshwater input in favor of the sea.

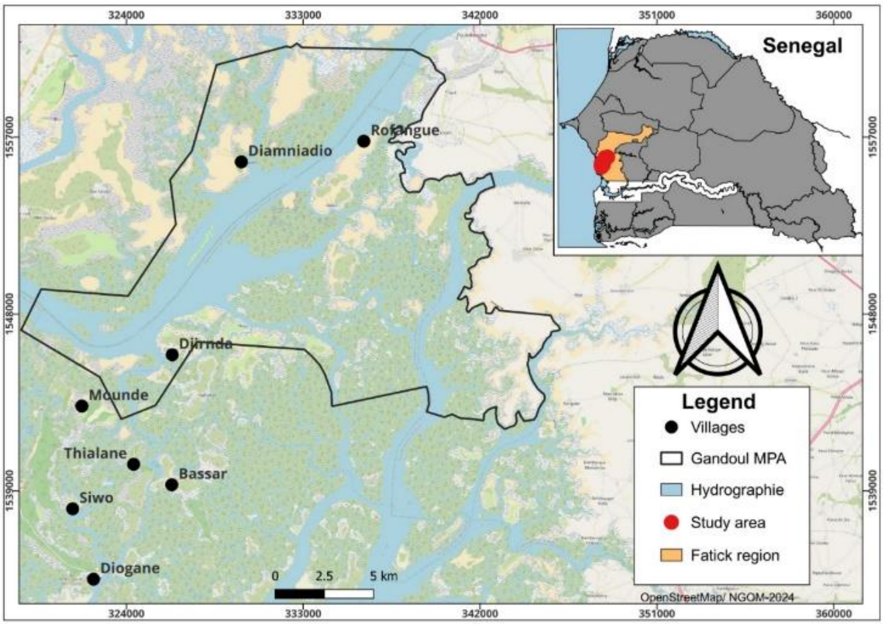

Figure 1. Map showing the location of the Gandoul MPA and its surrounding area.

2.2. Sampling Protocol

Sampling was carried out every two months between June 2022 and April 2023. *S. senilis* individuals were collected by hand at low tide from 38 stations inside and outside the Gandoul MPA. Each individual collected was measured (total shell length, mm) and weighed (total weight, g).

2.3. Growth Parameters

These parameters were calculated from size frequency and weight data for 8124 individuals, organized into 5 cm size classes. The theoretical asymptotic length (L∞) and the growth coefficient (K) of the Von Bertalanffy Growth Function (VBGF) were estimated with the ELEFAN I program, using the FiSAT II software (version 1.2.2) [16]. The Von Bertalanffy equation is written as follows:

$$Lt = L\infty \; [1 - e^{-K(t-t_0)}] \quad (1)$$

Where Lt = length of the individual at time t; L∞ = theoretical asymptotic length if the individual grows indefinitely; K = growth coefficient or growth rate and t_0 = theoretical age at which the length would be zero.

t_0 was calculated from the empirical equation (3) [17]:

$$Log(-t_0) = -0,392 - 0,275 * Log(L\infty) - 1,038 * Log(K) \quad (2)$$

The values of K and L∞ were then used to evaluate the growth performance index (Φ') using the following formula [18]:

$$\Phi' = 2Log(\infty) + Log(K) \quad (3)$$

2.4. Length-weight Relationship

The relationship between total shell length and total weight of the individuals is a power function. Using a power function to describe this relation is practical, since it makes it possible to compare the biological cycles of a species in different regions [19]. For this study, it was calculated for combined sexes using the following formula [20]:

$$W = aL^b \quad (4)$$

Where W = total weight of individuals in g, L = total shell length in mm, a is a constant and b is the allometry coefficient.

2.5. Mortality Parameters

Total mortality (Z) was estimated using the catch-to-length curve method, also known as the Pauly method [21]. The natural mortality rate (M) was estimated from the empirical equation below [22]:

$$Log(M) = -0,0066 - 0,279 * Log(L\infty) + 0,6543 * Log(K) + 0,4634 * Log(T) \quad (5)$$

Where M = natural mortality, i.e. any death due to a cause other than fishing (old age, predation, pathology, etc.), L∞ = theoretical asymptotic length, K = VBGF's growth coefficient and T = average water temperature (°C) =29°C in the Sine-Saloum estuary [23].

Fishing mortality (F) was obtained by resolving the following equivalence [24]:

$$F = Z - M \quad (6)$$

Where Z = total mortality and M = natural mortality.

The exploitation rate (E) was obtained using the following relationship [25]:

$$E = \frac{F}{(F+M)} = F/Z \quad (7)$$

2.6. Recruitment Model

The recruitment model describes how new individuals are added to the population. It was determined by back-projecting all the available length-frequency data onto the length axis. This makes it possible to determine the number of recruitment peaks and the relative strength of each peak [26].

2.7. Virtual Population Analysis (VPA)

Virtual population analysis is a method of reconstructing populations from total catch data by age or size. It is used to model the progression of a cohort over time [25]. A length-structured VPA was performed on the 8124 Heavy african arks harvested in this study using relevant information and cohort analyses in the FiSAT II stock valuation software [27]. The following growth parameters were used for the VPA: Theoretical asymptotic length (L∞), growth coefficient (K), fishing mortality (F) and natural mortality (M). The length-weight constants (a and b) were also used as input for the species' VPA [28].

2.8. 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 using FiSAT II and are based on the model of Beverton, R. J. H. and Holt, S. [29]. This model was updated and is defined according to the following formula [30].

$$Y'/R = EU^{M/K} \; [1 - ((3U/1) + m) + ((3U^2/1) + 2m) - ((U^3/1) + 3m)] \quad (8)$$

Where Y'/R is the relative yield per recruit, M is the natural mortality, K is the growth coefficient, and m= (1 - E) / (M/K) = K/Z;

U = 1 – (Lc/L∞) (Lc = the length of the smallest fish in the sample);

E = F/Z (exploitation rate).

The assessment of the relative biomass yield per recruit (B'/R) was estimated by the following relationship:

$$B'/R = (Y'/R)/F \quad (9)$$

Where Y'/R is the relative yield per recruit, and F is the fishing mortality.

This model was then used to determine the maximum exploitation rate (E_{max}), where the entire population would be harvested, the sustainable exploitation rate ($E_{0.1}$), where E does not exceed 10% of the total stock, and finally the optimum exploitation rate (E0.5 or E_{opt}), where E represents no more than half of the total population. The current exploitation rate (E) in any given population can thus be evaluated against these three biological target reference points [31].

3. Results

3.1. Growth Parameters

Results from the VBGF indicated that the estimated theoretical asymptotic length ($L\infty$) of *S. senilis* in this population is 53.55 mm, and its growth coefficient (K) is 1.70 yr^{-1} (Figure 2). The length frequency distribution and the growth curves from these parameters are shown in Figure 3. The growth performance index (Φ') and theoretical age (t_0) of *S. senilis* were estimated at 3.69 and 0.08 yr^{-1}, respectively.

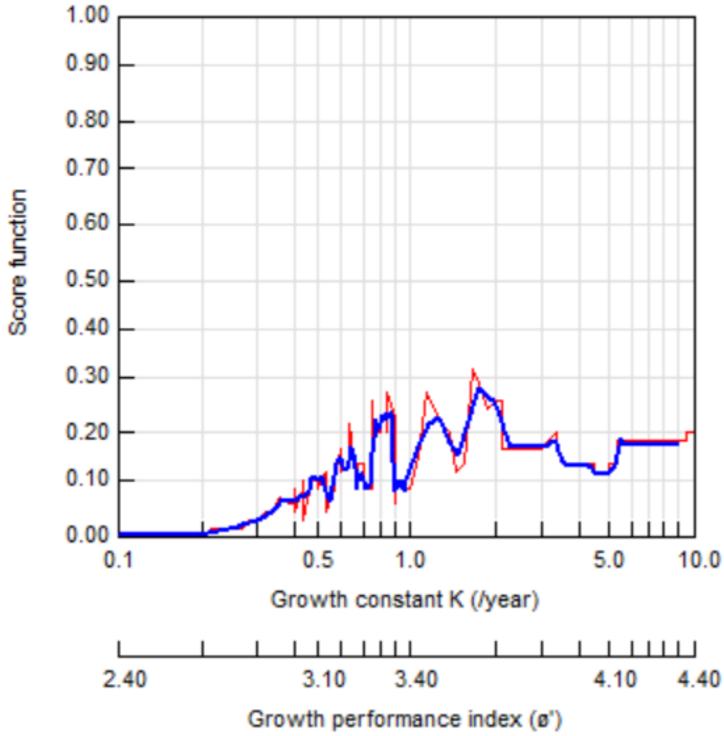

Figure 2. *Growth performance index of S. senilis in the Gandoul MPA and its periphery.*

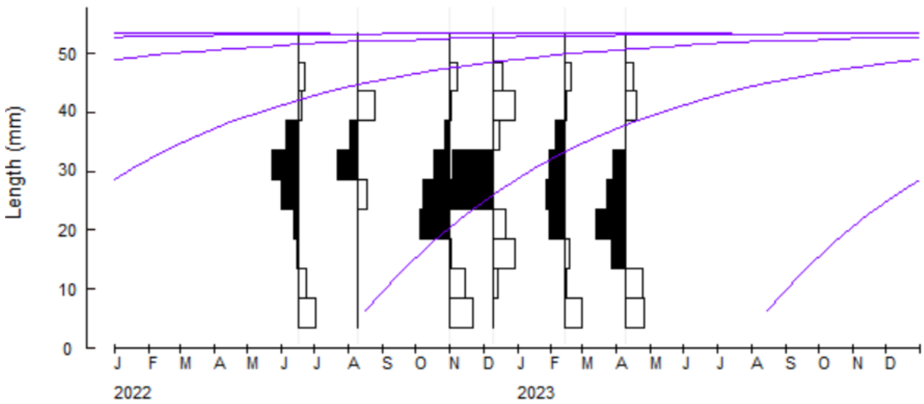

Figure 3. *Restructured length frequency distribution with superimposed growth curves for S. senilis in the Gandoul MPA and its periphery (dark bars=actual frequency bars, white bars=reconstructed bars).*

3.2. Length-weight Relationship

Analysis of Figure 4 shows an allometry coefficient of 2.65 (95% CI: [2.636; 2.668]), indicating a significant negative allometry ($b < 3$ and $p < 0.001$) for this population. *S. senilis* grows faster in length than in weight in the Gandoul MPA, with a high correlation ($r^2 = 0.93$) between the two variables.

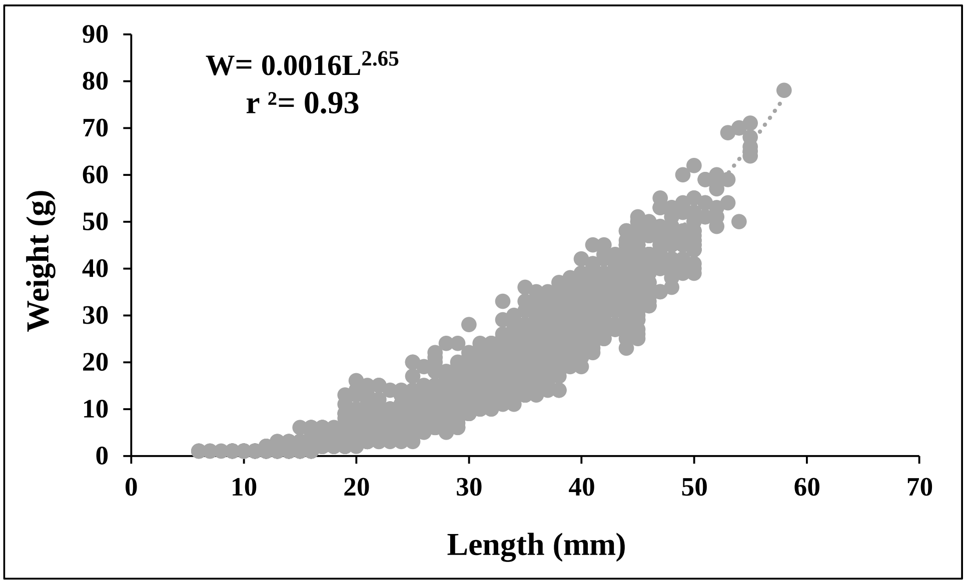

Figure 4. *Length-weight relationship of S. senilis in the Gandoul MPA and its periphery.*

3.3. Mortality and Exploitation

Mortality and exploitation rates for *S. senilis* in the Gandoul MPA are shown in Figure 5. Total mortality (Z), natural mortality (M), and fishing mortality (F) are estimated at 6.50 yr^{-1}, 2.19 yr-1 and 4.33 yr^{-1} respectively. The current exploitation rate (E) of the species in that area is estimated at 0.66.

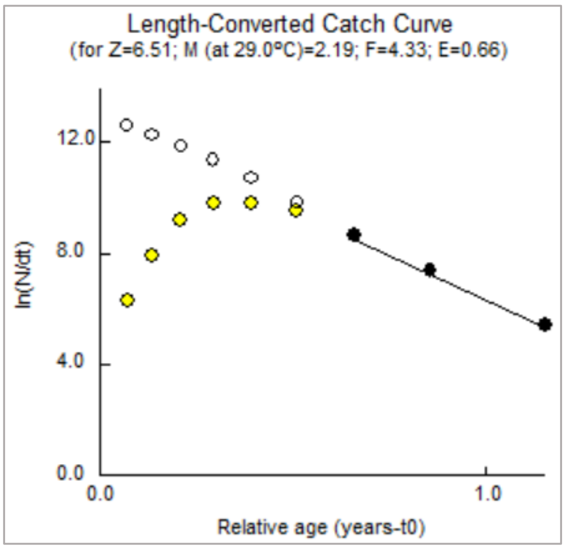

Figure 5. *Length-converted catch curve of S. senilis in the Gandoul MPA and its periphery (yellow dots are dots used in calculation and white dots are dot not used in calculations).*

3.4. Recruitment Model

The recruitment pattern shows two peaks of varying intensity throughout the year (Figure 6), indicating a biannual reproduction strategy for the species. The first spawning event is observed in March-April, with 21.80% of recruitment, while the second event is observed in September-October, with 15.09% of recruitment.

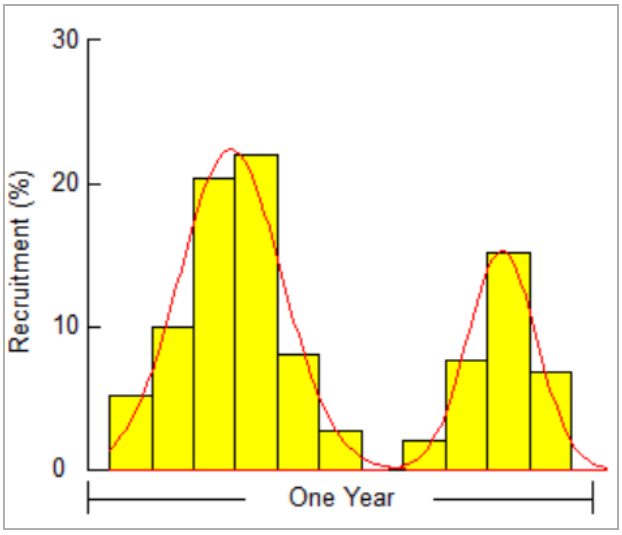

Figure 6. *S. senilis biannual recruitment model in the Gandoul MPA and its periphery.*

3.5. Virtual Population Analysis (VPA)

S. senilis population modeling in the study area shows a higher natural mortality rate among juveniles (Figure 7) but remains marginal in terms of mortality (approx. 14% of the population). Natural mortality decreases as the individuals grow, in favor of the fishing mortality that increases as they get bigger, starting at around 16 mm. Fishing mortality is higher among mature individuals between 26 and 36 mm.

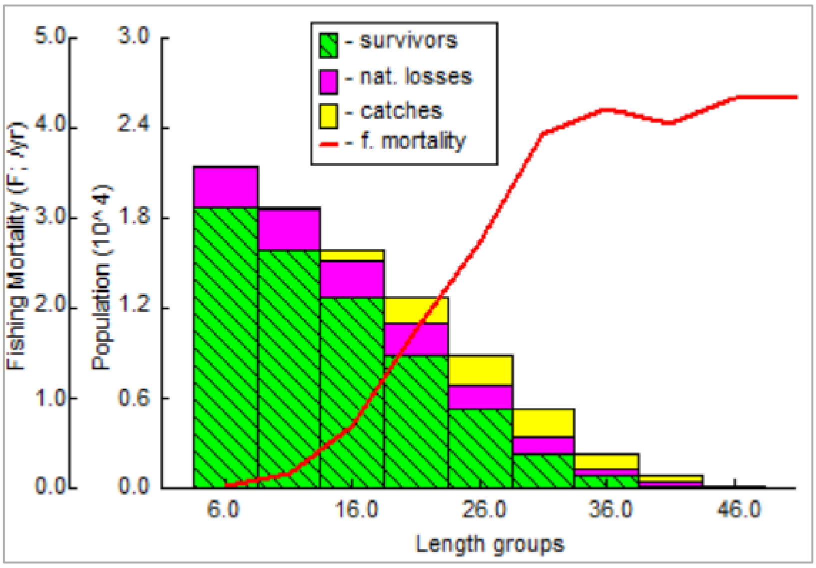

Figure 7. *Virtual population analysis of S. senilis in the Gandoul MPA and its surrounding area.*

3.6. Relative Yield per Recruit (Y'/R) and Relative Biomass per Recruit (B'/R)

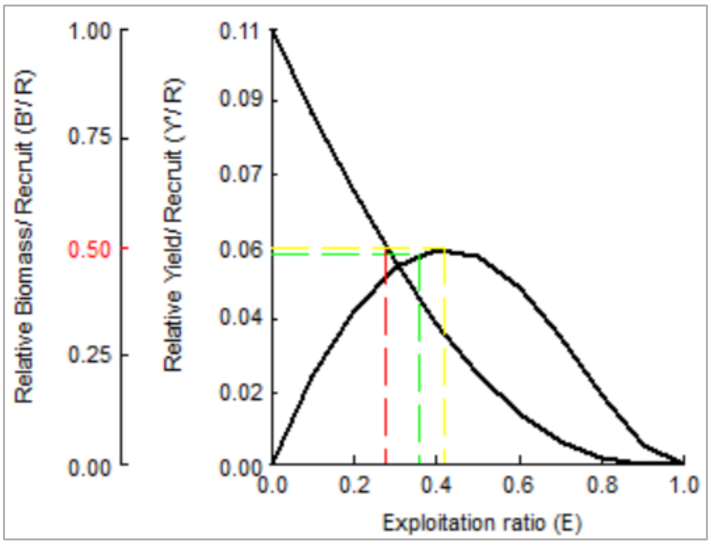

Figure 8. *Relative yield per recruit, relative biomass per recruit and exploitation rates of S. senilis in the Gandoul MPA and its periphery (red dashes=E0.1, green dashes=E0.5 and yellow dashes=Emax).*

Y'R and B'R estimates are shown in Figure 8. For *S. senilis* in the Gandoul MPA, the sustainable exploitation rate (E0.1), the optimum exploitation rate (E0.5) and the maximum exploitation rate (E_{max}) were established at 0.28, 0.36 and 0.42, respectively.

4. Discussion

In the Gandoul MPA, results indicate that *S. senilis* had an asymptotic length of 53.55 mm, a growth coefficient of 1.7 yr-

^{1}, and a performance index of 3.69. These values show that this species is growing relatively faster in the Gandoul MPA and its periphery, when compared with those obtained for *S. senilis* in other regions of Africa (Table 1). Interestingly, *S. senilis* grow faster in the Gandoul MPA than in the Bamboung MPA, located in the same estuary. The growth performance index obtained in this study is also higher than those found in Mauritania and Nigeria for the same species, although the asymptotic length seems to be significantly higher in Mauritania [32, 33]. These differences in growth could be due to local environmental and biological factors. According to several authors, these factors can influence the growth of bivalves, not only within the same population but also within the same species [32, 34, 35]. It should also be noted that the study sites are characterized by relatively low densities, thereby reducing competition for food resources and potentially promoting rapid growth of *S. senilis*.

Table 1. *Comparison of S. senilis growth parameters in different studies.*

Locations	L∞ (mm)	K (yr^{-1})	Φ'	Source
Gandoul MPA, Senegal	53.55	1.70	3.69	This study
Bamboung MPA, Senegal	55.65	0.29	2.93	[13]
Niger Delta, Nigeria	49.16	0.46	3.05	[33]
Banc d'Arguin, Mauritania	77.00	0.09	2.73	[32]

The length-weight relationship analysis of *S. senilis* in the Gandoul MPA (Figure 4) showed a negative allometry (b = 2.65) and a strong correlation between them (r^2 = 0.93), also reflected by other studies of shellfish in West Africa [13, 32]. Results from this study are compared to others in different African regions in Table 2 below. *S. senilis* show faster growth in length than in weight in most studies. In the Bamboung MPA, a negative allometry and a strong correlation were noted in both intermittently submerged mudflats and in those constantly submerged [13]. These similarities in allometry observed in several parts of the Sine-Saloum estuary suggest that this growth model is linked to the conditions prevailing in the area. This pattern was also highlighted in the Benya and Muni lagoons (Ghana), two areas subject to the same environmental conditions [36]. These results are also similar to those of [32] on the Banc d'Arguin in Mauritania. However, it is shown isometric growth (b ≈ 3) in *S. senilis* on the mudflats of Andoni Island in the Niger Delta (Nigeria) [37].

Table 2. *Comparison of length-weight relationships of S. senilis from different studies.*

Locations	a	b	r^2	Source
Gandoul MPA, Senegal	0.00160	2.65	0.93	This study
Bamboung MPA, Senegal	0.00040	2.58	0.95	[13]
Saloum Delta, Senegal	1.20300	2.53	0.68	[38]
Muni lagoon, Ghana	0.00260	2.47	0.95	[36]
Benya lagoon, Ghana	0.00180	2.55	0.94	[36]
Niger Delta, Nigeria	0.00050	2.94	1.00	[37]
Banc d'Arguin, Mauritania	0.00002	2.69	-	[32]

Mortality rates of *S. senilis* recorded in the Gandoul MPA and its periphery are very high compared with those obtained in Nigeria for the same species, but also in Costa Rica for *Anadara tuberculosa* (Table 3), a parent species. In these areas, total mortality (Z) was less than 1 yr^{-1}, whereas it was estimated at 6.51 yrs^{-1} in this study. These results show that natural mortality and fishing mortality are higher in the Sine-Saloum Delta. Natural mortality could be linked to predation or perhaps changes in habitat quality. *Cymbium cymbium*, was encountered on the mudflats during sampling for this study and it is a sea snail that is a known predator of *S. senilis* [39]. In the Sine-Saloum Delta, shorebirds are observed feeding on *S. senilis* by perforating the shell with continuous pecking [8]. In addition, black crabs (*Pugilina morio)* are also considered to be predators of bivalves [10]. However, predation pressure is normally greater in young individuals [40]. The same observations have been made by several authors, notably in Gambia [39, 41]. Additionally, ark clams are very sensitive to temperature and salinity changes and a sharp variation (like seasonal salinity changes, for instance) in these parameters could lead to the death of young individuals [34].

Fishing mortality is higher for larger individuals (Figure 6). Indeed, low abundances of *S. senilis* were observed in several mudflats sampled during this study. This is reflected in the current exploitation rate (E) of 0.66 found in this study. It is well established that a stock is at its optimum level if F=M and E=0.5 [25]. Additionally, E is greater than E_{max}, which is 0.42. All in all, it seems that *S. senilis* is overexploited in the Gandoul MPA. Highly prized for its quality as an animal protein, *S. senilis* has also been overexploited in the Andoni plain (Niger Delta), with an exploitation rate rising from 0.38 in 1999 to 0.63 in 2000 [33]. It has been shown that heavy exploitation can lead to the disappearance of the species in formerly rich areas [42, 43]. Indeed, there is every reason to believe that arcids are not resistant to over-exploitation [44, 45]. In Costa Rica, the stock of *Anadara tuberculosa* declined because of overexploitation 15 to 20 years prior [46]. Similarly, in Colombia, strong pressure on this species has led to it becoming endangered [46, 47]. The same situation was observed in Bahia Magdala, Mexico [48]. In this area, densities, which varied between 1 and 18 individuals/m² in 1980, fell to 0.5-0.8 individuals/m² in 2002.

S. senilis recruitment is continuous throughout the year, with a first peak in March-April (21.80%) and a second in September-October (15.09%). Two new cohorts are thus added to the population yearly. Studies have shown that arch recruitment is greatest in the rainy season (July to September) in the Sine-Saloum Delta and Somone lagoon, both in Senegal [49, 50]. In Sierra Leone, on the other hand, recruitment peaks in January-February, after the larvae have settled on the bottom in November-December. On the Banc d'Arguin, reproduction and recruitment depend on rainfall [46]. In the Sine-Saloum estuary, it has been shown that *S. senilis* is more abundant in mudflats during the period when reproduction is most important [38]. This theory is further supported by previous studies reporting higher densities in the Sine-Saloum Delta during the rainy season [8]. In Lower Casamance, densities were also higher in October [51].

However, several limitations should be acknowledged. The sampling period was limited, which does not allow for a full assessment of the species' dynamics. Furthermore, environmental parameters (salinity, temperature, pH, etc.) were not measured, despite their well-established influence on the biology and ecology of aquatic species.

Table 3. *Comparison of mortality and exploitation parameters for S. senilis and Anadara tuberculosa in different studies.*

Species	Locations	Z (yr-1)	M (yr-1)	F (yr-1)	E	Source
Senilia senilis	Gandoul MPA, Senegal	6.51	2.19	4.33	0.66	This study
Senilia senilis	Niger Delta, Nigeria	0.94	0.50	0.46	0.51	[33]
Anadara tuberculosa	Chomes, Costa Rica	0.48	0.14	0.34	0.71	[46]
Anadara tuberculosa	Rincón, Costa Rica	0.37	0.14	0.23	0.62	[46]
Anadara tuberculosa	Purruja, Costa Rica	0.59	0.14	0.45	0.76	[46]

5. Conclusion

This study of the growth dynamics of *Senilia senilis* in the Gandoul MPA and its surrounding area has provided a better understanding of the growth pattern of this species and the state of the available stock. It has shown that in this part of the Sine-Saloum Delta, *S. senilis* grows faster in length than in weight, and that recruitment is greatest in March-April and September-October. Despite its rapid growth, this species is subject to high mortality. In juveniles, this mortality is mainly due to natural causes, whereas in mature individuals, it seems linked to anthropogenic factors (capture). Analysis of the exploitation parameters revealed that this stock is overexploited (E = 0.66 > Emax = 0.42), hence the need to take urgent measures to manage this resource. Restocking measures could be implemented, involving the introduction of juvenile of *S. senilis* into low-density mudflats from other areas characterized by overabundance. Fallowing, which would consist of temporarily closing the lowest-density mudflats for several months, could also be a way of restoring this stock. Managers could also extend the duration of biological rest to accommodate both recruitment periods.

The short sampling duration and the lack of environmental parameters are the limitations of this study. However, the results may constitute an essential reference baseline for future research.

Abbreviations

MPA	Marine Protected Area
SDBR	Saloum Delta Biosphere Reserve
VBGF	Von Bertalanffy Growth Function
VPA	Virtual Population Analysis

Author Contributions

Coumba Sambe Marie Madeleine Ngom: Conceptualization, Data curation, Formal Analysis, Resources

Alassane Sarr: Conceptualization, Investigation, Validation, Writing – review & editing

Patrick Diedhiou: Data curation, Methodology, Software

Alioune Badara Dia: Formal Analysis, Resources

Mbaye Dieng Diouf: Formal Analysis, Resources

Oumar Sow: Formal Analysis, Resources

Conflicts of Interest

There is no conflicts of interest.

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