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Research Article

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Effect of tidal variation on the growth of *Anadara senilis* L. (1758) in the marine protected area of Bamboug (Senegal)

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Abstract
An in-situ study was conducted in the Sine Saloum Delta with the objective of studying the growth rate of Anadara senilis according to size and tide variation. The study revealed a minor allometry with values of 2.60 and 2.53 in the consistently submerged area and intermittently submerged area, respectively. The Von Bertalanffy linear growth parameters estimated from the ELEFAN in R Software are $L\infty$ = 58.1 mm; K = 0.20, t_0 = -0.70 and Φ' = 2.83 in the intermittently submerged area and $L\infty$ = 53.2 mm; K = 0.31; t_0 = - 0.46 and Φ'= 2.94 in the consistently submerged area. The growth rate is inversely proportional to the size of the individual. The results of this study should help to develop strategies for the sustainable management of A. senilis in Sine Saloum Delta.

Keywords: Sine Saloum, allometry, Von Bertalanffy

Introduction
The clam *Andara senilis* is a common bivalve of estuaries and West African coastal lagoons [1]. Taxonomically, it is a lamellibranch mollusk and lives in the lagoon or estuarine biotopes of the West African coast, from Western Sahara to Angola [2]. This euryhaline species can live both in hypersaline zones such as Arguin Bank in Mauritania and in brackish conditions such as the Benya Lagoon in Ghana [3, 4]. This mollusk is known for its ability to withstand the exodusation, namely the hypersaline and low levels of dissolved oxygen [5].

In Senegal, the artisanal fishing sector is responsible for the exploitation of molluscs which are harvested in the deltaic areas of the country's major rivers, the Senegal, Saloum and Casamance rivers [6]. In the Sine Saloum Delta, *A. senilis* is one of the most common molluscs and has been harvested for centuries [7, 8]. The exploitation of this species is of great socio-economic and cultural importance in the delta, constituting the primary source of income for many households. The exploitation of *A. senilis* has grown considerably due to demographic pressures and because of the rapid transition of communities in the Sine Saloum Delta from subsistence to a market economy. These changes have resulted in a decrease in the abundance and size of *A. senilis*, jeopardizing its contributions to local economies and food security.

Work on *A. senilis* in West Africa has been conducted on its biogeography and preferred habitats and environmental conditions and bioaccumulation of heavy metals [1, 3, 3, 4, 7, 9-13]. The objective of this work is to study the effect of tidal variation on the growth of *A. senilis*.

Materials and methods
Study Area
The study was carried out in the Bamboung marine protected area (MPA) (13 ° 50 N-16 ° 33 W) located in the Sine Saloum Delta (130 km southeast of Dakar, Senegal). Within the Bamboung MPA is located the Bamboung bolon, a complex and diffuse system of canals and mangrove swamps characteristic of intertropical brackish wetlands, in this case a tributary of Diomboss river. Three stations were selected in the Bamboung MPA and arranged from upstream to downstream in the bolon, the first at the entrance, the second in the middle and the third at the end (Fig. 1). At each station two experimental devices were placed, one of which was constantly submerged and the second submerged intermittently depending upon the tide.

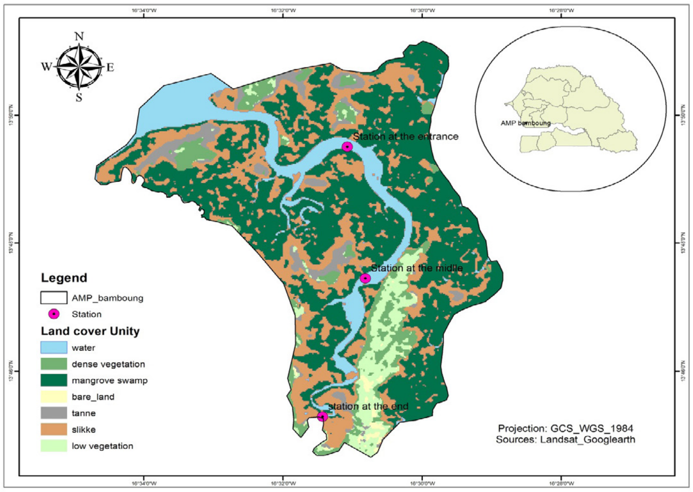

Figure 1: Study area

Experimental Protocol

Monitoring was conducted twice per month from December 2013 through December 2014. At the beginning of the experiment, individuals were divided into 6 size classes (0-5; 5-10; 10-15; 15-20; 20-25; 25-30 and >30 mm). In order to facilitate subsequent identification and to prevent possible loss by migration, the individuals were placed in a device made of stakes surrounded by a fence with an area of approximately 12 m². Each device is divided into 12 parcels of one m^2. Subsequently, every two months the bivalves were recaptured and measured and weighed using a Vernier caliper and a balance with a precision of 0.01 g. For each individual, the following morphometric parameters were measured: length (L in mm), height (H in mm) and weight (W in g). Thirty individuals of each size class are measured and weighed.

Study of Growth Parameters

Length-Weight Relationship

The height-weight relationship is given by the expression:

$$W=a\times L^b$$

Where W is the total weight in grams, L is the length of the shell in millimeters, a is an exponent describing the rate of change of weight with length, and b is the slope of the regression line (also referred to as the allometric coefficient). The an and b values were obtained from a linear regression of the length and weight of *A. senilis*:

$$Ln\ (W) = b\times Ln\ (L)+Ln\ (a)$$

Linear Growth

The mathematical model of individual growth developed by Von Bertalanffy considers body size as a function of age which is represented by the equation: $L(t) = L\infty[1-l^{-k(t-t_0)}]$

Where L(t) is the length of *A* [14]. *senilis* at time t; K is the growth coefficient; t_0; time (theoretical age of the species) where the length is assumed to be zero; L∞ is the asymptotic length when t tends to infinity. From the parameters L∞ and K the values of t_0 and (Φ') are determined from the following formula:

$$Log \rightleftarrows(-t_0) = -0.3922-0.2752\times Log(L\infty)-1.038\times Log(K)$$

$$(\varphi') = \text{“}Log\text{”}(K)+2\times\text{”}Log\text{”}(L\infty)$$

Where (Φ') is the growth performance index and is used to compare the growth of the same species in a stock or different stocks [15, 16].

Statistical Analyses

Statistical processing and graphics were performed with Microsoft Office Excel 2010 software, R and ELEFAN in R. For all statistical tests p<0.05 was considered a significant difference.

Results

Length-Weight Relationship

Impact of Tides

The length-weight relationship of *A. senilis* in consistently submerged and intermittently submerged areas is shown in Fig. 2. The allometric equations between the two variables (Weight and Length) show a minor allometry in both the consistently submerged area (b = 2.58) and in the intermittently submerged area (b = 2.53). The Student's test showed that there are no significant differences in the allometric rate between the two zones (p>0.05). However, the value of the allometric rate is slightly higher for individuals in the submerged zone (Table 1).

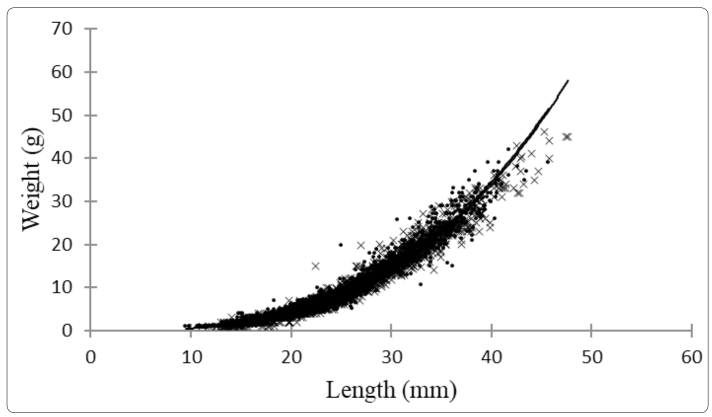

Figure 2: Length-weight relationship for *Anadara senilis* in consistently submerged area (•) and intermittently submerged area (×)

Table 1: Parameters of the length-weight relationship

Parameters					
Areas	**a**	**b**	**R²**	**N**	**Equation**
Consistently submerged	4×10^{-4}	2.60	0.950	2176	$W=0.0004\times L^{2.58}$
Intermittently submerged	5×10^{-4}	2.53	0.956	1714	$W=0.0005\times L^{2.53}$

Relationship Between Allometry and Size

The length-weight relationship parameters by size class of *A. senilis* showed a minor allometry in the submerged area and in the open area at low tide. The value changes with increasing size (age). However, for each size class, the value of the allometric rate of individuals in the submerged zone is slightly higher than that of individuals in the open zone at low tide (Table 2 and Table 3).

Table 2: Parameters of length-weight relationship according the size class in consistently submerged area.

Size class (mm)	Parameters			
	a	b	R^2	Equation
5-10	6×10-4	2.87	0.887	$W=0.0006\times L^{2.87}$
10-15	11×10-4	2.76	0.822	$W=0.0011\times L^{2.76}$
15-20	3×10^{-4}	2.65	0.855	$W=0.0003\times L^{2.65}$
20-25	16×10^{-4}	2.57	0.678	$W=0.0016\times L^{2.57}$
25-30	24×10^{-4}	2.41	0.846	$W=0.0024\times L^{2.41}$
> 30	174×10^{-4}	2.02	0.686	$W=0.1740\times L^{2.02}$

Table 3: Parameters of length-weight relationship according the size class in intermittently submerged area

Size class (mm)	Parameters			
	a	b	R^2	Equation
5-10	5×10^{-4}	2.83	0.885	$W = 5.10\text{-}4\times L^{2.83}$
10-15	10^{-4}	2.74	0.844	$W= 0.0010\times L^{2.74}$
15-20	17×10^{-4}	2.60	0.887	$W=0.0017\times L^{2.60}$
20-25	22×10^{-4}	2.55	0.744	$W=0.0022\times L^{2.55}$
25-30	58×10^{-4}	2.33	0.712	$W=0.0058\times L^{2.33}$
> 30	194×10^{-4}	1.96	0.666	$W=0.0194\times L^{1.96}$

Linear Growth

Relationship Between Linear Growth Rate and Size

From the size frequencies the parameters of the linear growth of *A. senilis* are established according to the size classes in the consistently submerged area (Table 4) and in the intermittently submerged area (Table 5). The change in growth rate (K) is similar between the zones submerged permanently and intermittently. A gradual increase in the growth rate from the size class 05-10 mm to the 15-20 mm size class. From the class 15-20 mm the growth rate decreases progressively in the last three classes (20-25; 25-30 and > 30 mm). For each size class, the growth rate is slightly higher in the submerged zone.

Table 4: Growth parameters in consistently submerged area according the size class

Size class (mm)	Parameters			
	$L\infty$	K ($Year^{-1}$)	t_o	(Φ’)
05-10	23.7	2.5	0.10	2.98
10-15	31.4	2.3	0.07	3.36
15-20	26.3	1.7	0.05	3.37
20-25	32.8	1.4	0.11	3.18
25-30	34.4	1.2	0.13	3.15
>30	49.2	0.43	0.33	3.02

Table 5: Growth parameters in intermittently submerged area according the size class

Size class (mm)	Parameters			
	$L\infty$	K ($Year^{-1}$)	t_0	(Φ’)
05-10	21.5	2.2	0.11	2.87
10-15	27.7	2	0.08	3.19
15-20	30.6	1.6	0.07	3.31
20-25	33.3	1.2	0.13	3.12
25-30	31.4	1.2	0.13	3.07
>30	48.5	0.38	0.38	2.95

Relationship Between Linear Growth Rate and Tide

The parameters $L\infty$, K, t_0, and Φ’ of the Von Bertalanffy equation were estimated in the submerged zone and in the discovery at low tide (Table 6). The analysis of the growth coefficients (K) and the linear growth performance indices (Φ’) shows that the linear growth of *A. senilis* is slightly faster in the submerged area. However, the difference between the growth performance indices of the two zones is not significant ($p>0.05$).

Table 6: Growth parameters for *Anadara senilis*

Area	L_∞	K (an^{-1})	t_0	(Φ’)	Equation
Consistently submerged	53.2	0.31	-0.46	2.94	$L(t) = 53.2\times [1- e^{(-0.31\times(t+0.46)}]$
intermittently submerged	58.1	0.20	-0.70	2.83	$L(t) = 58.1\times [1- e^{(-0.20\times(t+0.70)}]$
Global	55.65	0.29	-0.49	2.95	$L(t) = 55.65\times [1- e^{(-0.29\times(t+0.49)}]$

The linear growth of *A. senilis* is faster in the submerged area (Figure 3). However, beyond 45 mm growth rate begins to slow in the consistently submerged area and becomes slower and slower. In general, we find that the species shows relatively rapid growth during these first two years of life. The average length at 6 months is 13.5 mm and becomes 18.7 mm at 12 months in the consistently submerged area. While in intermittently submerged this average length increases from 14 mm to 20.9 mm between 6 months and 12 months.

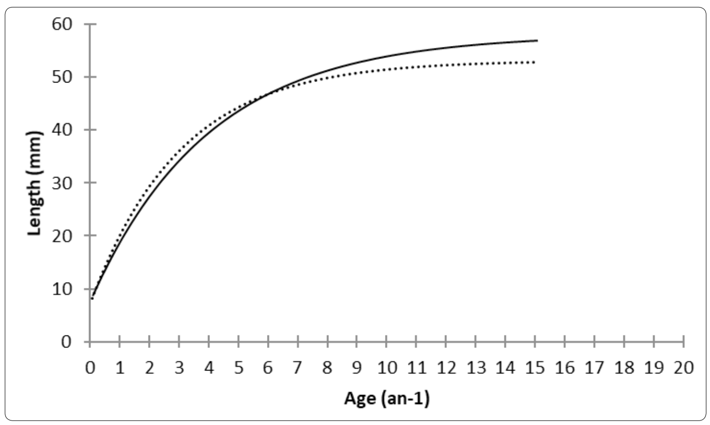

Figure 3: Linear growth for *Anadara senilis* in consistently submerged area (…) and intermittently submerged area (-)

Discussion

The length-weight relationships for *A. senilis* from different localities are given in Table 7. It has been reported that the coefficients of the genus *Anadara* varied between 2.286 and 3.295 and the values determined in this study are within this range [17].

Table 7: Parameters of length-weight relationship for *Anadara senilis* compared to literature

Country	Area	a	b	R^2	Author
Senegal	(consistently submerged area)	0.0004	2.58	0.950	Present study
	(intermittently submerged area)	0.0005	2.53	0.956	
Ghana	Benya Lagon	0.0018	2.55	0.940	[18]
Nigeria		0.0005	2.942	0.997	[19]
Mauritania	West Africa	0.239×10^{-4}	2.686		[3]

The conventional Von Bertalanffy growth model provides a good description of molluscan growth, which is confirmed in the current study for *A. senilis.* The parameters of the linear growth in submerged (L∞ = 53.2 mm, K = 0.31 yr-1) and in the open zone at low tide (L∞ = 58.1 mm, K = 0.20 yr^{-1}) revealed indices of growth performance (Φ') equal to 2.94 and 2.83, respectively. This indicates that the linear growth is slightly faster in the submerged area. This difference in growth is likely due to differences in the environmental conditions between the two areas. The individuals in open areas at low tide are more exposed to a range of environmental factors than individuals in submerged areas where, salinity, temperature, and turbidity are higher [19-21] showed that a combination of high temperature and high salinity affect the growth of *A. senilis.*

The parameters of linear growth, L∞ and K, (55.65 mm and 0.29 $year^{-1}$, respectively) provided a growth performance index (Φ') of 2.93, within the range of values 2.7 to 3.7 previously reported for this species (Table 8). The growth performance index found in this study is lower than those found in Sierra Leone and Nigeria and higher than that found in Mauritania [3, 10, 22]. These results may reflect climatic differences along the tropical Atlantic coastline of Africa including levels of rainfall. There are arid coastal regions (rainfall is upper 200 mm per year) (Mauritania, Angola), relatively dry coastal areas (rainfall is between 200 mm and 1600mm) (Senegambia, Ghana-Togo-Benin), coastal areas fed by rivers (rainfall is 700 mm and 2200 mm) (Ivory Coast, Congo), and coastal regions where rainfall is more than 1600 mm / year (Guinea-Bissau, Guinea Conakry, Sierra Leone, Liberia, Nigeria, Cameroon, Gabon) [23]. Thus, growth of *A. senilis* is faster in the wetter coastal regions (Sierra Leone, Nigeria) followed by relatively dry coastal areas (Senegal) and slower in arid coastal regions (Mauritania). This is explained by the fact that in the driest climates, benthic organisms are subject to severe environmental constraints [23]. These results are confirmed by the work of who showed good agreement between the results from Nigeria and Sierra Leone on the growth of this species [11].

Table 8: Some linear growth parameters for *Anadara senilis*

Country	L∞ (mm)	K (an^{-1})	(Φ')	Author
Mauritania	77	0.09	2.727	[3]
Senegal	55.65	0.29	2.93	Present study
Sierra Leone	145	0.22	3.665	[10]
Nigeria	49.16	0.46	3.05	[22]

This study characterized the growth of *A. senilis* in the Saloum delta estuary shows and a negative allometry in the length-weight relationship in consistently submerged area and in intermittently submerged area. The linear growth indicated that the species shows relatively rapid growth during these first two years of life. The results of this study should help to develop strategies for the sustainable management of *A. senilis* in Sine Saloum Delta [24].

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