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Biometric Relationships and Evaluation of the Density of *Tagelus angulatus* Gray, 1847 (Mollusca, Solecurtidae) on the West African Coasts in Three Villages of the Community Protected Area of Urok, Guinea-Bissau

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Authors' contributions

This work was carried out in collaboration between all authors. Author MD designed the study, wrote the protocol, collected the data and managed the literature searches. Author AF performed the statistical analysis and wrote the first draft of the manuscript. Author AR anchored the field study. Authors NC and CK managed the project and funded the study. Author EMF made the sampling map. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This study aimed to examin the biometric relationships, size frequencies and density of *Tagelus angulatus* in the Community Marine Protected Area of the Bijagós Islands of Guinea Bissau.

Methodology: Sampling was carried out in three villages (Formosa, Nago and TChediã) of the Community Marine Protected Area. A total of 1596 individuals were collected. On each mudflat, four

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random transects 30 m apart and oriented from the shore to the sea were established. On each transect, individuals of *Tagelus angulatus* were collected on 6 plots of 1m² that were separated by 10 m.

Results: The length of the individuals sampled ranged from 12 mm to 69 mm in all three of the villages studied with an average length of 48.65 ± 9.53 mm and a main mode equal to 53 mm. The results showed a positive allometry. The length and width of the species are also strongly correlated. The mean density for all three villages was 16.63 individuals.

Conclusion: Management of the shellfish industry generally requires the knowledge and use of biometric relationships to translate data collected in the field into indicators that can be used for the development of management plans. This study provided knowledges on biometric relationships and density of *Tagelus angulatus*.

Keywords: Bijagós Islands; allometry; marine bivalves; conservation plans; community sustainability.

1. INTRODUCTION

The family Solecurtidae Orbigny, 1846 comprises two genera: *Solecurtis and Tagelus*. This taxon has about 40 species distributed throughout the world but is more abundant in tropical regions [1]. *Tagelus angulatus* is the only species reported in West Africa and ranges from Mauritania to Angola [2-8]. It is considered a euryhaline species, tolerating large variations in salinity and living in substrates that are sandy and muddy [2], near river mouths and in the intertidal zones of oceanic islands. It builds galleries, which allow it to move through the sediment and thus protect itself against predators. *Tagelus angulatus* feeds by filtering particles suspended in the water column through its inhaling siphon [9].

The bivalve shell of *Tagelus angulatus* is in the form of a knife, white in color, almost rectangular, and with two halves that are equivalent in size and shape. The shell is thin and fragile with a surface that is smooth with concentric lines. It can reach a maximum length of 70 mm [2]. The ecology and the knowledge of the length frequencies distribution of a species is a fundamental prerequisite for effective and successful management of fisheries resources and for the implementation of recovering programs in collapsed fisheries areas [10].

The density of individuals (i.e., the number of individuals/m^2) provides information on the health and renewal capacities of shellfish populations.

The management of fisheries often requires the use of biometric relationships to translate data collected in the field into indicators that can be used for this management. One of the most common relations is that which links the length of the individual to his weight. The use of the length-weight relationship achieves two objectives: the theoretical conversion of weight in term of size and vice-versa the conversion of a theoretical weight-size relationship and vice versa and the shift from linear growth to weight growth. The relation of allometry linking the length and the weight of an individual can be described by the formula [11]:

$$Wt = a \times Lb. \tag{1}$$

(Where Wt is the total weight in gram (g), L is the length in millimeters, «a» is a constant of the relation and «b» is the allometric coefficient). When the body growth is isometric, i.e. when growth is at the same rate in the three dimensions of space, the body volume (and more or less the body weight) is expected, of course, to vary as the cube of the linear size. Thus, when growth is isometric (which often is approximately the case), the coefficient b equal 3 or is close to 3. When it is different from 3, the body growth is allometric [11].

There are many unknowns about the biology of many bivalve species in West Africa, while they constitute an important key source of animal protein in the diet of coastal ethnic groups or communities such as in Bijagós islands [12]. Certain bivalve species are crucial to the Bijagós, including *Tagelus angulatus* (lingron) which is used in initiation ceremonies, are exploited as food source, and still plays in women's animist rituals. The species is also valued by elderly women because of the low weight of its shell, in contrast to the mollusc, *Anadara senilis*, an important consideration to the Bijagós. The scarcity and even disappearance of *Tagelus angulatus* in some areas has been cause for concern for this strongly hierarchical and animistic society.

The aim of this study is to determine some biometric relationships (length-weight relationship and length-width relationship), to establish the length frequencies distribution, and to evaluate variations in the density of *Tagelus angulatus* in three localities of the Community Marine Protected Area of the Bijagós Islands of Urok of the coast of Guinea-Bissau for sustainable management of its operations. Recognized officially in 2005 by the state of Guinea-Bissau, the Community Marine Protected Area aims to ensure the protection of the natural and cultural heritage of the Bijagós Islands.

2. MATERIALS AND METHODS

2.1 Sampling Sites

The Bijagós archipelago, which is composed of more than eighty islands and islets, extends over a deltaic area of 10,270 km^2 between 10° 36' East of the mainland of Guinea-Bissau, and 11° 37' North latitude and 15° 36' and 16° 29' West longitude (Fig. 1). Its deltaic origin [13] has resulted in the division of the archipelago into channels and four main subsets of islands which follow one another in "strips" according to a main orientation North East-South West, (Within each subset the islands are separated from one another by secondary channels. (Two groups appear to be very compact: the Orango group and the Formosa group). The Urok island complex is located in the northern part of the Bijagós archipelago. It includes a group of islands and islets, the main one being Formosa which includes the villages of Nago and TChediã.

2.2 Data Collection

Sampling was carried out in the Community Marine Protected Area on mudflats in the East (Aquina/Formosa Bank), in the West (Ancanacubi/Nago Eticopua Bank) and in the North (Etighapua Bank/TChediã). The samples were collected in March 2016 as part of the project "Management of Marine and Coastal Biodiversity in West Africa through the Strengthening of Conservation and Monitoring

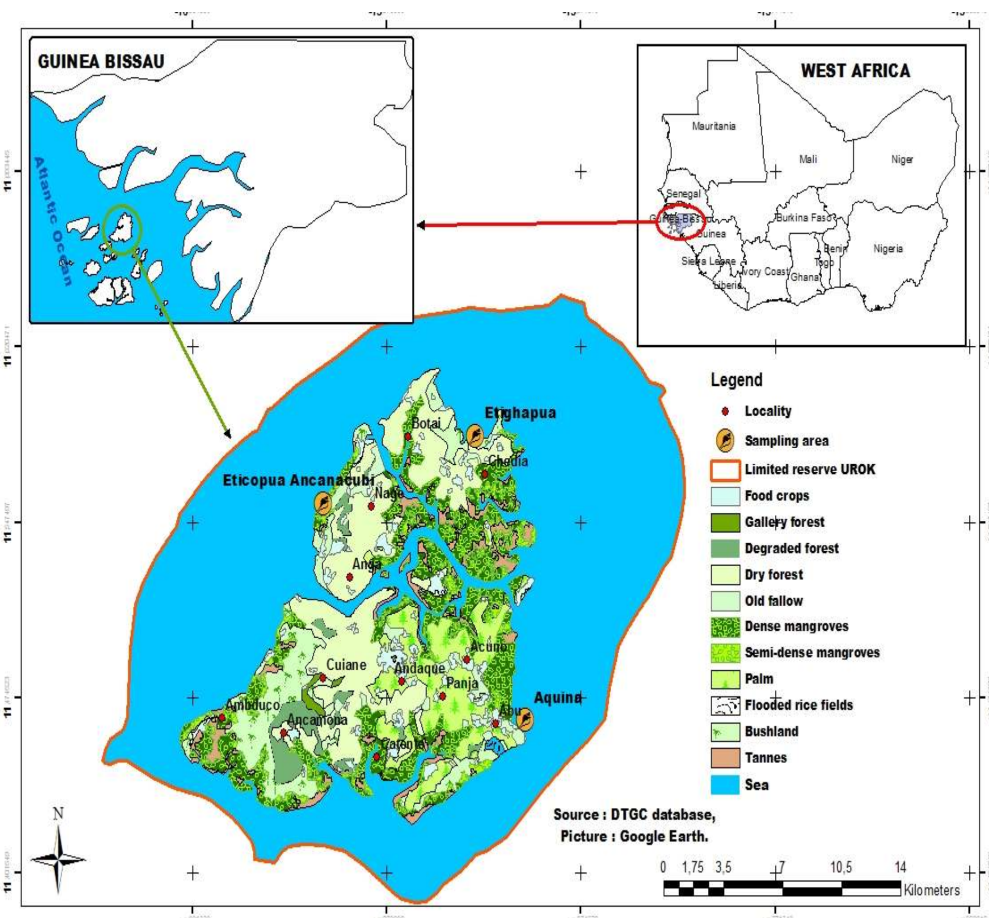

Fig. 1. Sampling sites

Initiatives in Marine Protected Areas-BioCos Project". The project is sponsored by the French Fund for the Environment (FFEM), the MAVA Foundation for the Management of Marine and Coastal Biodiversity in West Africa through the Conservation and Monitoring Initiatives in Marine Protected Areas. A total of 1596 individuals were collected, including 543 in Formosa, 662 in Nago and 391 in TChediã. On each mudflat, four random transects 30 m apart and oriented from the shore to the sea were established. On each transect, individuals of *Tagelus angulatus* are collected on 6 plots of 1m² that were separated by 10 m.

For each individual collected, width (ω), and length (L) were measured to the nearest millimeter using an electronic caliper. The total weight (Wt) was determined using an electronic precision balance that is accurate to ± 0.01 g.

2.3 Relationship between Length and Width

The relationship between the length and width of *Tagelus angulatus* is described by the formula:

$$L = A \times \omega + B. \quad (2)$$

Where L is the length in millimeters, ω is the width in millimeters, A and B are slope, intercept respectively.

2.4 Density

Density is defined as the number of individuals per square meter.

2.5 Statistical Analysis

Graphics were performed with Excel and R software's. The R software program was used for statistical analysis. The analysis of variances (ANOVA) followed by the Tukey test was used to compare the lengths of the individuals from the three localities and the densities. The student test was used to compare the allometric coefficient of the length-weight relationship to the value 3. Statistical significance was determined at $P < 0.05$. Data are presented as mean ± SD.

3. RESULTS

3.1 Length Frequencies Distribution

The length spectra of the individuals sampled in the entire studied area ranged from 12 mm to 69 mm with an average size of 48.65±9.53 mm and a main mode around 53 mm (Fig. 2). The smallest and highest values of the length were found in Nago with the range of 12 mm to 69 mm followed by Formosa and TChediã. The length frequencies distribution obtained showed average sizes of 50.11±11.04 mm 48.11±7.76 mm and 48.46±6.88 mm respectively at Nago, Formosa and TChediã. All distributions are multi-modal. However, the most frequent size classes in the Nago, Formosa and TChediã samples are 57 mm, 51 mm and 53 mm, respectively. Analysis of these results shows that the smallest and largest sizes are found in Nago and that the mean size of the individuals collected there is significantly (P <0.05) higher than those of Formosa and TChediã.

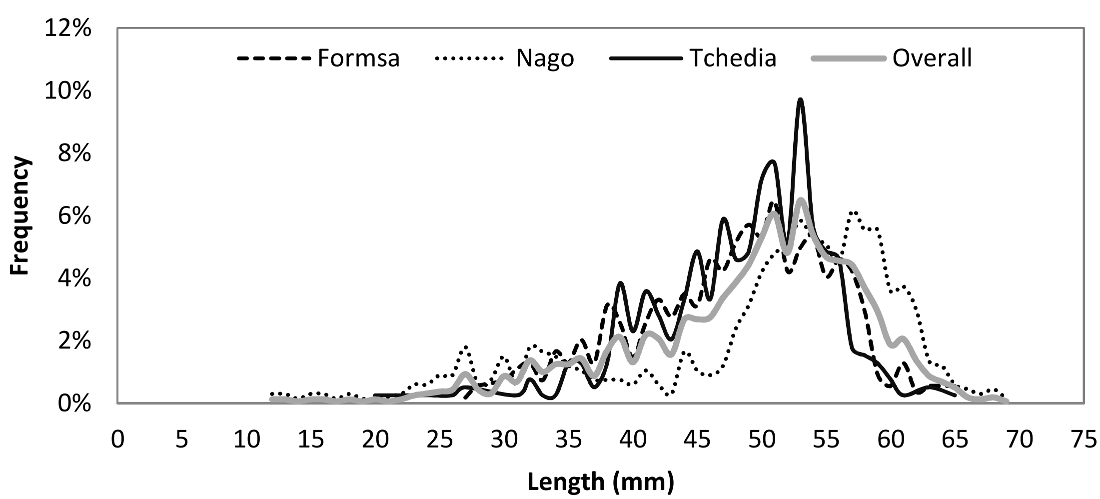

Fig. 2. Length frequencies distribution of *Tagelus angulatus*

3.2 Length-weight Relationship

The length-weight relationships of *Tagelus angulatus* were established separately for each of the three localities (Fig. 3). Comparison to the value of 3 indicates that the allometric coefficients of individuals collected at TChediã and Formosa are significantly greater than 3 ($P < 0.05$). On the other hand, the allometric coefficient of the specimens sampled at Nago is not significantly different from 3 ($P > 0.05$). These results demonstrate a positive allometry (b>3) for individuals collected from TChediã and Formosa, while those from Nago show an isometry (b~3). For the Community Marine Protected Area (three localities combined), the allometry coefficient is significantly greater than 3 (p <0.05). *Tagelus angulatus* presents globally a positive allometry (b> 3).

3.3 Length-width Relationships

Length-width relationships are established for all three localities (Fig. 4). The establishment of these length-width relationships has involved 1596 individuals. The parameters of these relationships are shown in Table 1. The analysis of these relationships shows a strong correlation between length and width. Moreover this correlation is practically proportionality between length and width, since the intercept of the linear regression is very close to zero.

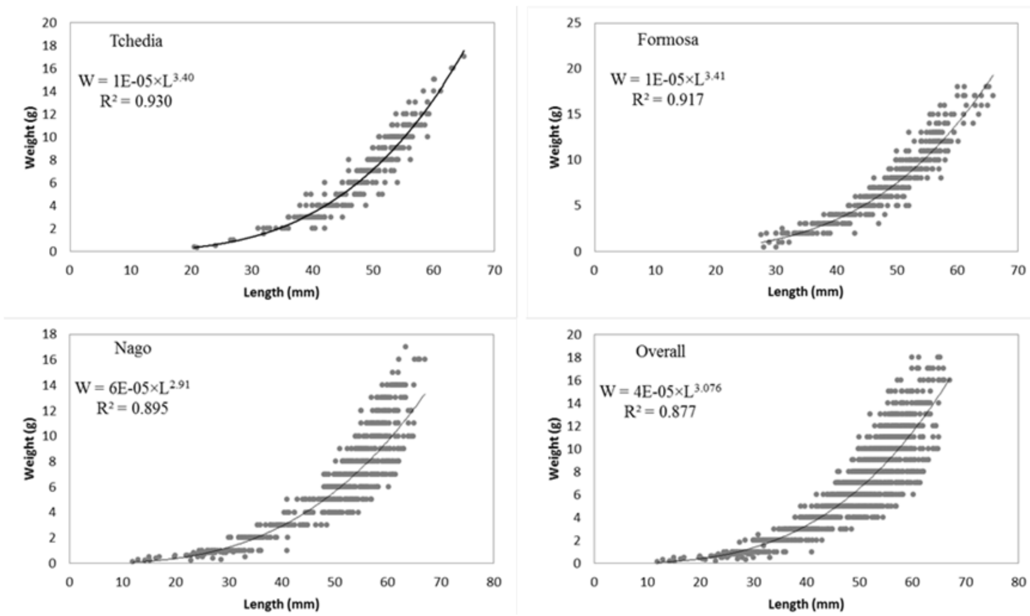

Fig. 3. Length-weight relationships for *Tagelus angulatus*

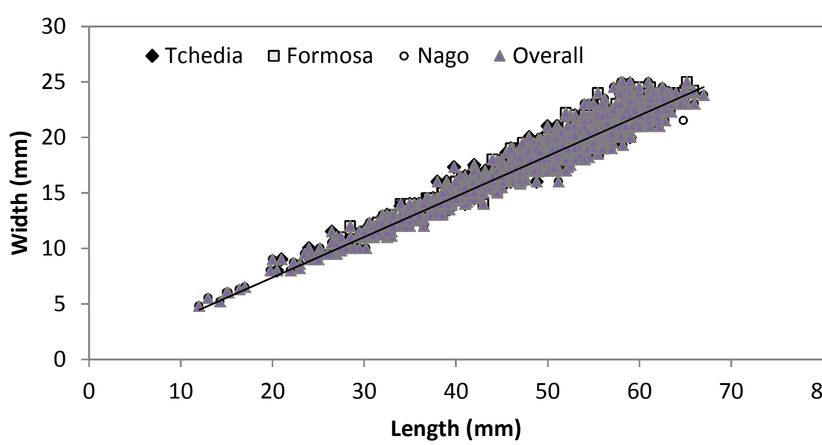

Fig. 4. Length-width relationship of *Tagelus angulatus*

Table 1. Parameters of length-width relationship for *Tagelus angulatus*

Localities	Length-width relationship parameters				Equations
	A	B	R^2	n	
TChediã	0.361	0.742	0.913	391	L = 0.361×w + 0.742
Formosa	0.379	0.193	0.934	543	L = 0.379×w + 0.193
Nago	0.364	0.090	0.953	662	L = 0.364×w + 0.090
Overall	0.365	0.299	0.939	1596	L = 0.365×w + 0.299

(A and B are respectively the slope and intercept of the linear regression between the length and the width)

3.4 Density

The average densities of *Tagelus angulatus* for each locality are shown in Fig. 5. The density is higher at Nago (36.78 ± 3.62 ind./m²) followed by TChediã (16.29±13.36 ind./m²) and Formosa (10.06±10.39 Ind./m²). For all three localities, the average density is 16.63 ind./m². Analysis of variances (ANOVA) indicates a significant difference (P <0.05) in the density between the three localities.

4. DISCUSSION

4.1 Size Frequency

The overall length spectrum follows a plurimodal distribution with a main mode equal to 53 mm and an average length of 48.65±9.53 mm. Specimens smaller than 10 mm were not found in the sample. This is due to the collection equipment used, which did not allow sampling of very small sizes. [14] found a larger average size for the same species. The average size of *Tagelus angulatus* found in this study is compared with the average sizes of *Tagelus plebeius* and *Tagelus dombeii* found in the literature (Table 2).

These differences in average sizes could be attributed to differences in environmental conditions in different study areas or harvest practices. The observed differences in size could be related to specific ecological characteristics of the *Tagelus* genus in each environment or to distinctive hydrological and sedimentological patterns between zones [15]. Community Marine Protected Area of Urok has become an archipelago of islands which is completely oceanic and characterized by strong tidal amplitudes. Compared to the results found by [14], in a closed estuarine complex (higher salinity) appears to be more favorable to the development of the species in West Africa. A comparative study of the density and reproduction variations of the species in two different ecosystems could be of great help in understanding the evolution of the life traits of this species.

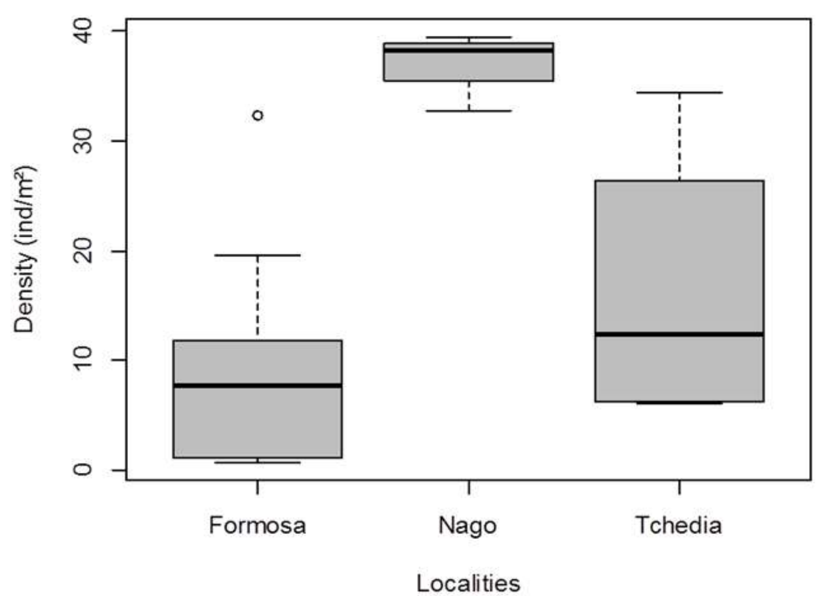

Fig. 5. Average densities of *Tagelus angulatus* in each site

Table 2. Minimum, maximum and mean size of *Tagelus* in different countries

Species	Area	Sex	Variable	Length range	Mean	Reference
T. angulatus	Guinea-Bissau	Both male and female	Length	12-69	48.65±9.53	Present study
T. angulatus	Gambia	Both male and female	Length	40-69	58.49±5.43	[14]
T. plebeius	Brazil	Male Female	Length	23-53.2 22-62.5	40.3±6.21 40.9±5.72	[16]
T. plebeius	Brazil	Both male and female	Length	36.5-68.3	53.2±6.66	[17]
T. dombeii	Peru	Both male and female	Length	41.7-90.4	73.8	[18]
T. plebeius	Argentina	Both male and female	Length	6.57-73.78	60.24	[19]

4.2 Length-weight Relationship

Length and weight measurements were used to establish the length-weight relationships of *Tagelus angulatus* globally but also in each of the three localities. The results obtained showed positive allometry for the individuals collected at TChediã and Formosa and an isometry for those of Nago. This means that *Tagelus angulatus* grows faster in weight than in size (length) at TChediã and Formosa, whereas individuals sampled at Nago grow faster in size than in weight. These observed differences could be related to sedimentological conditions [15], but other factors could influence these two parameters (length/weight). Being a filter-feeder living in depth, weight growth is strongly influenced by the amount_and quality of food available in the water column but also by the tidal swing. When conditions are satisfactory, *Tagelus angulatus* weight gain is consistent with growth in length. Indeed in bivalves, the growth in length and thickness of the shell is discontinuous and depends on the periodic secreting activities of the mantle. Composed of organic and inorganic substances, the shell is influenced by certain external factors such as pH, temperature and salinity during its growth. In fact, sites of a muddy nature of acidic pH (3 and 4) of TChediã and Formosa, which are more sheltered, are rich in organic matter and nutrients unlike the site of Nago, which are composed of fine sand with low amount of organic matter and more open to the ocean [15]. The difference in allometry confirms the decreased levels of nutrients. Its basic pH would be more favorable to the mobilization of the carbonate ions necessary in the constitution of the shell. This situation could be correlated with its geographical position and the configuration of the coast. Indeed Nago is characterized by a sandy cord that constitutes a barrier for the organic deposits originating from the mangrove which is in a lagoon unlike the other two sites.

The results for all the individuals of the three localities indicate a positive allometry. So globally, *Tagelus angulatus* grows (weight) faster than it grows (length) in the Community Marine Protected Area. A study on the same species [14] showed a negative allometry in the estuarine complex of the Saloum in its Gambian part. The work of [19,20] on another species of the same genus (*Tagelus plebeius*) also revealed negative allometry. According to [20] the negative allometry detected for *Tagelus* could reveal a morphological adaptation found in these depth burrowing animals, which have elongated shells.

4.3 Density

The densities of *Tagelus angulatus* calculated for Nago followed by TChediã and Formosa are respectively 36.78±3.62 ind./m², 16.29±13.36 ind./m² and 10.06±10.39 ind./m². The overall average density for the three localities is 16.63±14.22 ind./m². This result is close to that of [21] on *Tagelus divisus* in Brazil, which found an average of 19.1±16.1 ind./m2 in the median area of the estuarine complex of Paranaguá. However, the density values for *Tagelus divisus* found by [22] in Biscayne Bay, Florida are different from those found in this study. In the northern part of Biscayne Bay, the average density of *Tagelus divisus* is 35.2 ind./m², while in the southern part it is 1 ind./m². The results obtained show a random spatial distribution in the genus *Tagelus*. Differences in densities between the three localities could be related to differences in environmental conditions such as substrate nature, currentology, etc. or harvests by communities. Indeed, on sandy substrates, the spatial distribution seems to be more homogeneous (as in the case of Nago) and according to the geomorphology of the littoral the effects of currents of tidal swing seems to be uniform. On the other hand, in muddy substrates, the number of individuals per unit area is greater in the area around the mangrove. The proximity to channels may also be a factor as they are the site of the return and the arrival of the waters but are also the paths taken by the exploiting populations. With similar environmental conditions, the differences between densities on Formosa and TChediã could be explained by the size of the sites. Indeed, the Formosa site is about 5 times larger than that of TChediã.

5. CONCLUSION

In this study we characterized the biometric relationships (length-weight relationship and length-width relationship) and the density of *Tagelus angulatus* in Guinea Bissau. These results will be useful for communities and conservationists to suggest for sustainable management and conservation for *Tagelus angulatus* in this region.

Our result could provide the basis for biological studies of this species in West Africa and comparative studies in Senegal, The Gambia, Guinea-Bissau and the Republic of Guinea would be of great value in understanding the life-history of this species for its sustainable use.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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