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Biometric Characteristics and Condition Index of the Mangrove Oyster *Crassostrea tulipa* Lamarck, 1819 in the Interface Ecosystems of the Saloum Delta in Senegal: Case of the Commune of Dionewar

Ibrahima Thiao

Faculté des Sciences et Techniques (FST), Institut Universitaire de Pêche et Aquaculture (IUPA), Université Cheikh Anta Diop de Dakar (UCAD), BP 5005 Dakar-Fann

Jean Fall

Institut Universitaire de Pêche et Aquaculture (IUPA), Cheikh Anta Diop de Dakar (UCAD), BP 5005 Dakar-Fann, II bâtiment pédagogique/Rez de chaussée BP 5005 Dakar-Fann, Sénégal

Eric Tamigneaux

Département Aquaculture, Ecole des Pêches et l'Aquaculture du Québec, Cégep de la Gaspésie et des Iles

Jeanne Elisabeth Diouf

Faculté des Sciences et Techniques (FST), Université Cheikh Anta Diop de Dakar (UCAD), BP 5005 Dakar-Fann

Abdou Karim Houménou

Faculté des Sciences et Techniques, Département de Biologie Animale, Université Cheikh Anta Diop de Dakar (UCAD), BP 5005 Dakar-Fann

Malick Diouf (Corresponding author)

Faculté des Sciences et Techniques, Département de Biologie Animale, Université Cheikh Anta Diop de Dakar (UCAD), BP 5005 Dakar-Fann

E-mail: malicknem@gmail.com; malick.diouf@ucad.edu.sn; mdiouf@cegepgim.ca

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Abstract

The mangrove oyster *Crassostrea tulipa* (syn. *Crassostrea gasar*) has been subjected to strong anthropic pressure. As in several West African countries, Senegal in particular in the Saloum delta, the oyster resource was severely strained. This situation had led to disturbances in the renewal of stocks and their productivity. The objective of this study was to determine the size frequency distribution, the size-weight relationship and the condition index in order to provide scientific arguments for sustainable management of *C. tulipa*. Monthly sampling from January 2021 to January 2022 at the Akat, Baobab Rasta, Falia 1, Falia 2 and Fandiongue stations revealed that the individual sizes of the oysters collected ranged from 0.63 mm to 93.19 mm, with an average height of 34.63 ± 16.12 mm. The size frequency distribution is unimodal with a modal class of 30 - 40 mm and the allometry coefficient is minorizing (2.57). The correlation coefficient is 0.86. However, from one site to another the differences are not significant. The monthly monitoring of the oyster condition index showed several variations in values throughout the year, with an overall average of 11.47±2.89% for the 5 stations. The maximum value (12.97±2.60) was observed in March while the minimum value (9.85±2.22) was recorded in November. This study suggests that *C. tulipa* is overexploited in the commune of Dionewar and that the best time to collect the oyster is around March.

Keywords: *Crassostrea tulipa*, size, weight, condition index, Saloum delta

1. Introduction

Oysters are bivalve molluscs that have been exploited for millennia throughout the world for their socio-economic value. They are an important source of income and animal protein for coastal, island and inner-city populations (Dias *et al*., 2022; Mahu *et al*., 2022). The mangrove oyster *Crassostrea tulipa* (syn. *C. gasar*) is the species described on both shores of the Atlantic Ocean, in tropical areas (Adite *et al*., 2013; Lapègue *et al.*, 2002; de Morais, 2011). In West Africa, this species is under increasing anthropogenic pressure due to growing market demand (Dias *et al*., 2022; Hayford *et al*., 2021; Asare *et al*., 2019; Yapi *et al*., 2016; Thiam *et al*., 2011; Diouf *et al.*, 2010). However, intense and uncontrolled harvesting of the resource leads to disturbances in stock renewal and productivity (Mahu *et al.*, 2022; Christensen and Pauly, 1997). In spite of these disturbances, which are added to the effects of climate change, it is important to set up a management system that will allow for the sustainability of the exploitation of this resource.

In Senegal, local management policies for the mangrove oyster exist. This is mainly a biological rest period lasting six months. In the commune of Dionewar, the oyster exploitation period extends from January to June. Unfortunately these management measures are not based on scientific knowledge. Moreover, in West Africa, there are very few studies on bio-indicators (size frequency distribution, size-weight relationship and condition index). It is mainly in the Guinean zone (Ghana and Nigeria) but also in South America (Brazil) that such work has been carried out on *C. tulipa* (Akinjogunla and Soyinka, 2022; Hayford *et al*., 2021, Osei *et al.*, 2021; Asare *et al.*, 2019; Yankson *et al*., 1996; Oliveira *et al*., 2018; Gomes *et al*., 2014; Lopes *et al.*, 2013; Rebelo *et al*., 2005). To our knowledge, there are no studies on the size frequency distribution and/or size-weight relationship of this oyster in the

Sahelian zone of the West African sub-region. The only publication containing information on the Condition Index of *C. tulipa* was conducted in Casamance (southern Senegal) almost 30 years ago (Diadhiou, 1995). As these different bioindicators are likely to change according to environmental conditions (Mahu *et al*., 2022), periodic monitoring of management bioindicators is necessary to increase the resilience of populations whose livelihoods depend in part on this resource.

The objective of the present study was to provide scientific arguments to support management initiatives and policies for the rational exploitation of *C. tulipa* in the Saloum Delta (central Senegal).

2. Material and Methods

2.1 Study Area

The study took place in the commune of Dionewar, located in the interface zone of the Saloum delta, between the two tributaries, the Saloum and the Diombos (Figure 1). This area is marked by a network of bolongs bordered by mangrove forests whose stilt roots are the main supports for the oyster *C. tulipa*.

In the framework of this study, five sampling stations were chosen, three in the village of Niodior (Akat, Baobab Rasta and Fandiongue) and two in the village of Falia (Falia 1 and Falia 2) (Figure 1).

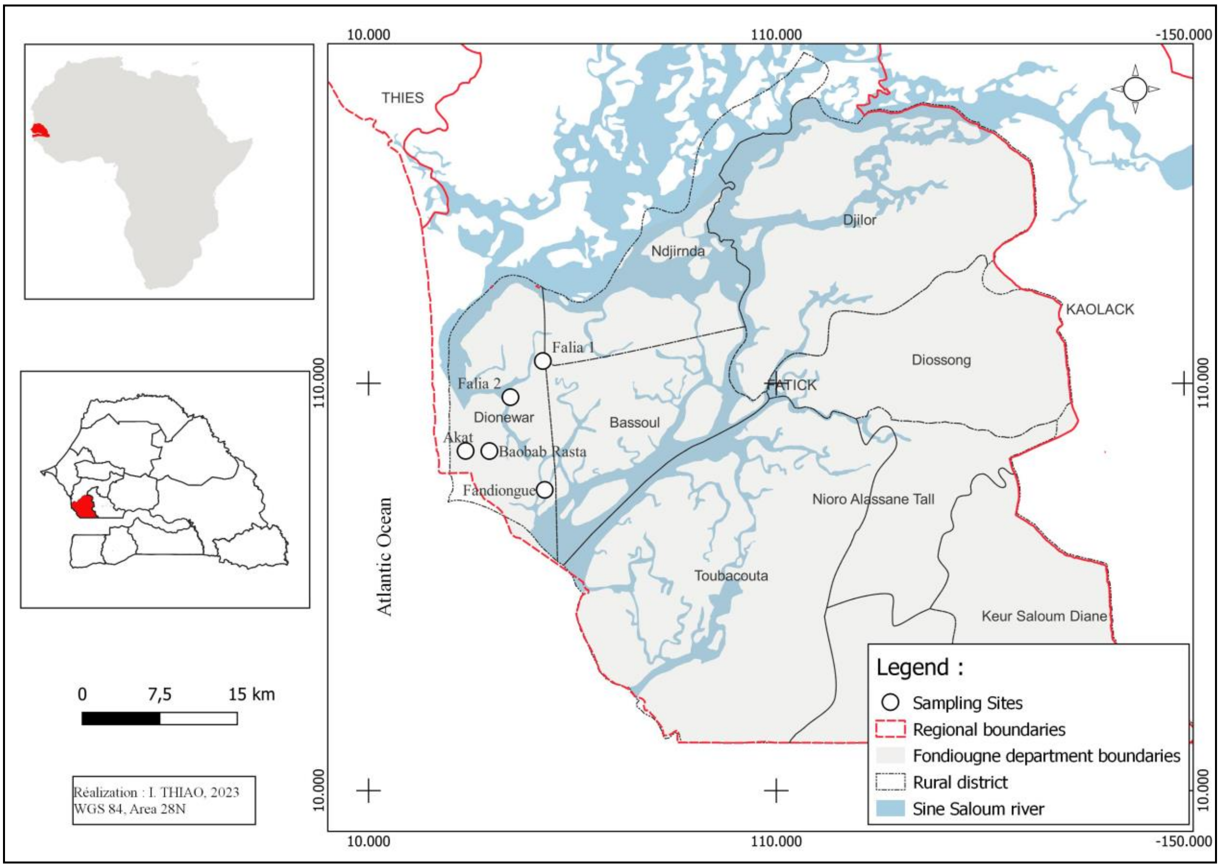

Figure 1. Location of sampling stations in the Saloum Delta (Senegal, West Africa)

The sampling stations have contrasting characteristics in terms of proximity to the ocean, agitation by currents and/or navigation as perceived by the operators, accessibility to the operators during low tide and non-exploitation (fallow) in 2020 (Table 1).

Table 1. GPS coordinates and major distinguishing features of the sampling stations

Stations	GPS coordinates		Proximity to ocean	Agitation perceived	Accessibility to operators	Fallow in 2020
	Latitudes	Longitudes				
Akat	13°51.125'	016°44.209'	very close	strong	very accessible	No
Baobab Rasta	13°51.792'	016°43.003'	close	weak	not very accessible	No
Falia 1	13°56.253'	016°40.867'	very distant	strong	very accessible	Yes
Falia 2	13°54.043'	016°41.819'	far	medium	Accessible	Yes
Fandiongue	13°49.701'	016°40.230'	far	medium	Accessible	No

very close: < 2 km; close: between 2 and 5 km; far: between 5 and 10 km; very far: > 10 km (Figure 1)

2.2 Sampling Protocol

Monthly sampling was carried out between January 2021 and January 2022. The protocol described below is inspired by the Guide de suivi participatif des coquillages exploités en Afrique de l'Ouest (Diouf *et al.*, 2010) with some modifications. Over a linear meter of mangrove, three types of stilt roots not fixed to the substrate were selected: the most heavily loaded, the moderately loaded and the least loaded with oysters. All individuals attached to these roots were removed, cleaned and placed in a referenced container. At each station, this sampling strategy of one linear meter was repeated three times over a distance of approximately 50 to 100 m.

In the laboratory, a separation was carried out gently with a knife in cases oysters were stuck together and/or overlapped. Each individual was weighed with an electronic scale (XY5002C) with a precision of 0.01g and the longest length of each shell was measured with a digital and automatic vernier scale (Mitutoyo; CD-20PMX) with a precision of 0.01mm.

2.3 Size Frequency Distribution

To determine the size frequencies of the shells, the measurements were divided into size classes of 10 mm intervals. The following formula was used to calculate the size frequencies of *C. tulipa:*

$$Fi = ni * 100 / N$$

Where ***Fi*** is the frequency (%), ***ni*** is the number of individuals in a given class and ***N*** is the total number of individuals.

2.4 Size-Weight Relationship

The size-weight relationship is very often used in biology and fisheries management. It is used to compare mono-specific populations living in environments with different conditions. It is established according to the following equation (Le Cren, 1951)

$$P = a*H^b$$

Where ***P*** is the total wet weight (g) of the individual live oyster before opening, ***H*** is the shell height (mm), ***a*** is a constant corresponding to the intercept and ***b*** is the allometry coefficient. Depending on whether ***b*** is less than, greater than or equal to 3, there are three possible scenarios for assessing shell length growth in relation to weight growth. If ***b*** is equal to 3, there is growth isometry. If ***b*** is different from 3, the growth is said to be allometric. The allometry is said to be minorating if ***b*** is less than 3. If ***b*** is greater than 3, the allometry is majoring.

2.5 Condition Index

For the determination of the condition index, thirty (30) individuals between 35 and 90 mm in size were subsampled per collection point. For each individual, the total weight of the live oyster, the weight of the empty shell and the fresh weight of the meat were determined. The oyster condition index was calculated using the formula recommended by Rainer and Mann (1992) :

$$CI = FCW * 100 / ITW$$

Where ***CI*** = condition index (%), ***FCW*** = fresh meat weight (g) and ***ITW*** = total individual weight (g).

1.6. Statistical analysis

Data processing and graphics were performed with Microsoft Office Excel 2010 and R studio version 4.0.2. Pearson's correlation coefficient was used to assess the degree of relationship between individual weights and heights. For the CIs, the Kruskal-Wallis test (checking for significant differences) and Dunn's method (the multiple comparison test) were used ($p < 0.05$).

3. Results

3.1 Size Frequency Distribution

The shell sizes of the individuals collected at the five (05) sampling stations ranged from 0.63 mm to 93.19 mm, with an average height of 34.63 ± 16.12 mm (Table 2). The minimum and maximum heights of the individuals collected at Akat were respectively equal to 0.63 mm and 88.53 mm, with a mean value of 34.38 ± 16.14 mm. At Baobab Rasta, the minimum height was 2.03 mm and the maximum height 87.66 mm (Table 2). At this station the mean height was 34.63 ± 16.12 mm (Table 2). Individuals collected at the Falia 1 station had a minimum and maximum height of 1.37 mm and 91.12 mm, respectively (Table 2), and the average height was 34.28 ± 16.13 mm. For the oysters sampled at Falia 2, the minimum, maximum, and mean heights were 1.64 mm, 93.19 mm, and 34.14 ± 16.03 mm respectively (Table 2). At the Fandiongue station, the minimum and maximum heights of the individuals collected were 1.52 mm and 90.03 mm respectively, with an average of 34.52 ± 16.16 mm (Table 2).

For all stations combined, the size class distribution was unimodal, with a modal class of 30-40 mm (Figure 2). For the Akat and Fandiongue stations, the modal class was 20-30 mm, while for the Baobab Rasta, Falia 1 and Falia 2 stations, this class was 30-40 mm (Figure 2).

Table I. Mean (mean ± standard deviation), minimum, maximum and number of individuals of *C. tulipa* sampled in the Saloum Delta

Station	**Number of individuals**	**Average height (mm)**	**Minimum height (mm)**	**Maximum height (mm)**	**Modal class (mm)**
Akat	3910	34.38 ± 16.14	0.63	88.53	20 – 30
Baobab Rasta	3701	34.63 ± 16.12	2.03	87.66	30 – 40
Falia 1	2 488	34.28 ± 16.13	1.37	91.12	30 – 40
Falia 2	2904	34.14 ± 16.03	1.64	93.19	30 – 40
Fandiongue	3094	34.52 ± 16.16	1.52	90.03	20 – 30
Overall	16097	34.63 ± 16.12	0.63	93.19	30 – 40

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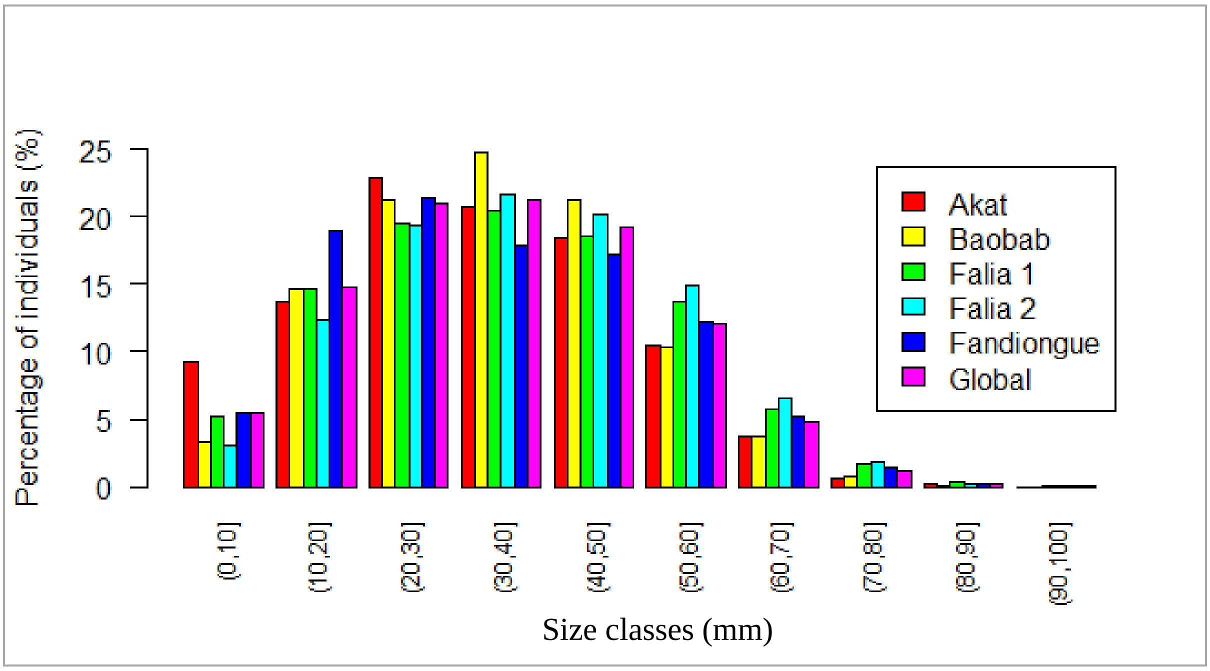
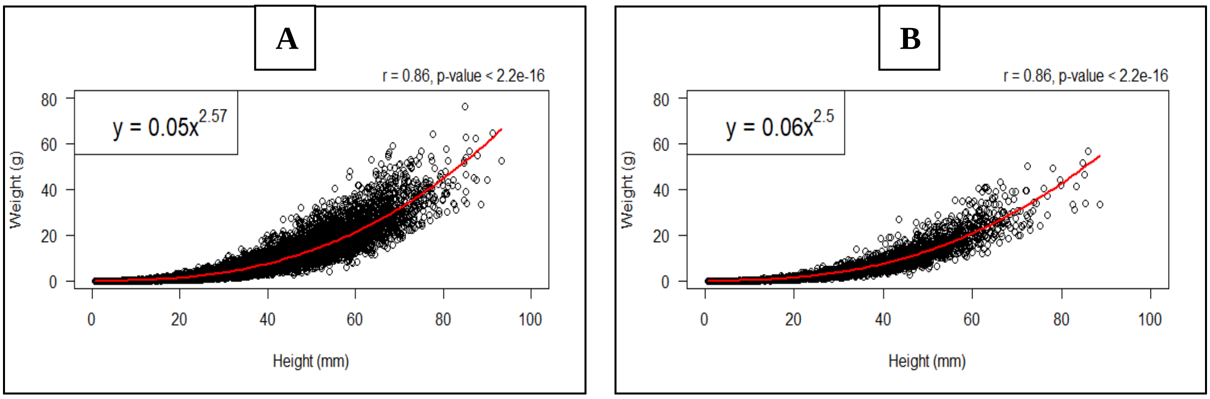


Figure 2. Size classes distribution of *C. tulipa* per station and overall in Dionewar commune

1.2 Size-weight relationship

The results of the size-weight relationship show that, overall, the allometry of *C. tulipa* is minorizing (b = 2.57). This was also true for all stations (Figure 3), with non-significant inter-station differences ($p<0.05$). For all stations combined, the correlation coefficient r is 0.86 (Figure 3 A). From station to station, r values vary between 0.85 and 0.88 (Figure 3 B, C, D, E and F).



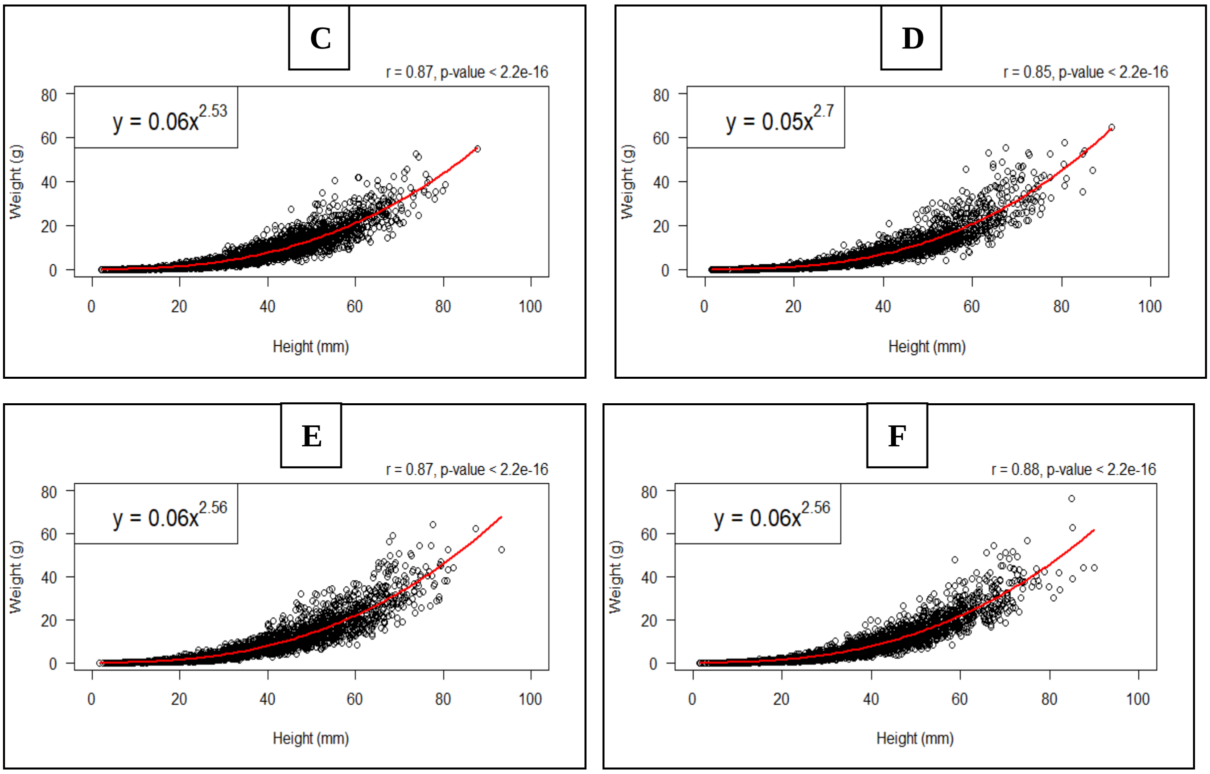


Figure 3. Size-weight relationship of *C. tulipa*. A. all stations combined, B. Akat, C. Baobab Rasta, D. Falia 1, E. Falia 2 and F. Fandiongue.

3.2 Condition Index

The results showed that during the 12 months of monitoring, the condition index of *C. tulipa* experienced several periods of successive increase and decrease at each station (Table 3). For all stations combined, the mean annual value of the condition index was 11.47±2.89%. The maximum observed was 15.14% (Falia 1, July) and the minimum was 7.63% (Baobab Rasta, July). The CI evolved in a similar way at the Akat, Falia 1, Falia 2 and Fandiongue stations: the value increased between January 2021 and March and then there was a decrease with a first dip in April or May. A further increase was observed between June and August, followed by a decrease with a second dip in November and an increase in December and January 2022. The Baobab Rasta station stood out from the other stations, with an increase in the index between January and March 2021, a first decrease between April and June followed by a second dip in July (7.63±1.24%), an increase between August and October and a third dip in November followed by an increase in December and January 2022. It was also at Baobab Rasta that the condition index was always lower than at the other stations.

Table II. Monthly variability of condition index for all stations combined (overall) and for each station specifically

Dates	CI (%)					
	Global	**Akat**	**Baobab Rasta**	**Falia 1**	**Falia 2**	**Fandiongue**
January 21	11.57±2.88	11.29±2.68	9.48±2.66	12.43±2.70	11.79±2.63	12.51±2.04
February 21	11.20±2.85	10.81±2.07	9.36±2.07	12.55±2.49	12.14±3.01	10.17±2.63
March 21	12.97±2.60	14.73±2.25	12.22±1.84	14.88±2.58	13.29±2.00	12.71±2.17
April 21	12.40±2.68	12.87±2.63	10.25±1.59	13.15±1.92	12.21±2.49	11.28±1.79
May 21	12.16±2.58	12.33±2.18	10.05±1.55	13.52±3.05	10.09±2.04	12.41±2.18
June 21	12.30±3.29	14.21±3.09	9.74±1.72	14.51±3.91	11.50±2.53	11.90±3.25
July 21	12.92±2.73	13.37±1.99	7.63±1.24	15.14±1.35	12.99±2.24	13.28±2.05
August 21	12.62±3.02	13.46±2.36	8.48±1.51	13.37±3.36	13.50±2.60	12.42±2.17
September 21	11.65±2.79	12.09±2.11	8.39±1.99	12.88±2.12	12.95±2.54	12.61±2.70
October 21	11.63±2.68	12.37±2.64	10.22±1.88	11.80±2.06	10.43±2.07	12.65±3.55
November 21	9.85±2.22	10.18±2.33	7.76±1.45	9.70±1.93	9.80±2.17	11.11±1.74
December 21	10.71±2.07	10.36±1.91	7.85±1.62	10.22±1.77	10.67±2.33	11.81±1.90
January 22	10.81±2.83	10.55±2.02	8.10±1.75	12.79±2.89	9.71±2.04	12.56±2.33

4. Discussion

The management of fisheries resources (fish, crustaceans and molluscs) is at the heart/center of the sustainable development objectives. These resources have considerable nutritional and economic value worldwide. However, with repeated anthropic actions and the effects of climate change, the sustainability of these resources is threatened. In Senegal, apart from cephalopods, molluscs are one of the least studied resources. In the mangrove ecosystems of the Senegalese coast, shellfish exploitation (oysters and clam) remains the main income-generating activity for the inhabitants of the islands and coastal areas (Diouf *et al*., 2010). Facing climate change and anthropogenic actions, *C. tulipa* remains the most affected species (Wélé *et al*., 2021). Knowledge of its bio-ecology (population size frequency distribution, size-weight relationship and temporal evolution of the condition index) is therefore necessary to improve the management of this resource.

The results of the present study on the size frequency distribution showed that the distribution is unimodal and that the 30-40 mm modal class represents 21.25% of the population for all stations. These results are similar to those of (Akinjogunla and Soyinka, 2022; Asare *et al*., 2019) in Nigeria and Ghana, which also reported a unimodal size frequency distribution of *C. tulipa*. However, in both countries, sizes associated with the mode are larger than 40 mm and can even exceed 60 mm (Table 4). In the present study, individuals of commercial sizes (≥ 60 mm) represent only 6.24% of the population. Compared to the values found by other authors on the same species (Akinjogunla and Soyinka, 2022; Cohen *et al*., 2020; Yapi *et al*., 2017; Legat *et al*., 2017; Lopes et *al*., 2013; Thiam et *al*., 2011), *C. tulipa* oysters from the Saloum Delta interface area are smaller in size (Table 4).

Table 4. Comparison of the total number of individuals measured (N), minimum (Min), maximum (Max) and mean (Mean.) shell height, nature of shell size distribution (dist.) and modal classes (MC) in *C. tulipa* populations from different West African countries

Authors (year)	**Country**	**N**	**Min (mm)**	**Max (mm)**	**Mean (mm)**	**Dist.**	**MC (mm)**
Present study	Senegal	16 097	0.63	93.19	34.64±16.12	unimodal	30-40
Thiam *et al.* (2011)	Senegal	-	33	53	45±4	-	-
Akinjogunla and Soyinka (2022)	Nigeria	1260	15	184	-	unimodal	55-64
Asare *et al.* (2019)	Ghana	335	25	114	59.5±0.07	unimodal	55-69
Osei *et al.* (2021)	Ghana	802	20	146	-	unimodal	40-49

In the present study, samples were taken in the outer part of the mangrove, at the edge of the bolongs, thus the area most accessible for harvesting. The smaller size of the Saloum Delta oysters compared to those measured in Nigeria and Ghana could be the result of early and intense exploitation of *C. tulipa* in the Saloum Delta interface area. Moreover, compared to the value found by Thiam *et al*. in 2011 (45±4 mm), it appears that the average size of *C. tulipa* individuals in the Saloum delta interface zone has dropped by about 10 mm in 10 years (34.64±16.12 mm in 2022). Several studies on the growth of *C. tulipa* (Adite *et al.*, 2013; Lopes et *al.*, 2013) have shown that more than half of the individuals in a 12-month-old cohort are 60 mm or smaller. In the present study, this proportion is 93.76%, which means that there are very few individuals > 60 mm. So it happens that the management policy implemented by the Dionewar commune imposes a biological rest period of six (6) months, between July and December. It would therefore appear that the recruits of the *C. tulipa* oyster are collected even before they are a year old.

Another possible explanation for these discrepancies in results could be attributed to differences in sampling effort. Indeed, the above-mentioned authors did not collect very small individuals, whereas in the present study, spat (sizes ≤30 mm) represented 6,645 individuals (Table 2), which may have reduced the relative contribution of the larger size classes in the distribution.’

For all stations studied, weight was strongly correlated with size ($r \geq 0.85$) (Figure 3). For *C. tulipa*, different values of r have been reported in the literature by authors such as Asare *et al.* (2019) and Akinjogunla and Soyinka (2022) (Table 5). However, it is important to note that the individuals sampled by these authors were larger in size (Table 4). The size-weight relationship shows a minorizing allometry with $b < 3$, which translates into a greater growth in height of the individuals than in weight. These results are similar to those obtained for the same species by Asare *et al*. (2019) and Akinjogunla and Soyinka (2022) (Table 5). These results also corroborate those of Lopes *et al*. (2013) who stated that in *C. tulipa*, height growth is faster in young individuals than in adults. Conversely, for a temperate species, in the USA, Grizzle *et al*. (2017) showed that allometric growth in oysters (*Crassostrea virginica*) was dominant (Table 5).

Table 5. Summary of size-weight relationship results on different species of the genus Crassostrea

Authors (year)	**Species**	**Country**	**b**	**r**
Present study	*C. tulipa*	Senegal	2.56	0.88
Akinjogunla and Soyinka (2022)	*C. tulipa*	Nigeria	Log b = 0.2864	0.5826
Asare *et al.* (2019)	*C. tulipa*	Ghana	1.36	0.53
Grizzle *et al.* (2017)	*C. virginica*	*USA*	3.375	0.920

The continuity of reproduction in the *C. tulipa* species, with successive spawning throughout the year, could be at the origin of this difference, which seems to be specific and/or geographical (Cohen *et al*., 2020). Indeed, according to Wellesley-Cole and Kamara (1978), stored glycogen is used to form gonads in tropical oysters, unlike in oysters from temperate countries, which have only one spawning period per year.

Monthly monitoring of the condition index of Dionewar oysters in Saloum showed several variations in values during the year, with an overall average of 11.47±2.89% for the 5 stations. For the same species, in Ghana, Asare *et al.* (2019) obtained a CI of approximately 8%. In Nigeria, Akinjogunla and Soyinka (2022) found CIs ranging from 6.5 to 10.5%. Based on the CI value, these authors concluded that the oysters were healthy which would indicate that this is also the case for Dionewar oysters. The results of the present study are similar to those of Rebelo *et al.* (2005) who reported temporal variations in CI for *C. tulipa*. The increases in condition index observed between November and March are probably related to food availability. Indeed, Senegal is covered by the Canary Current Large Marine Ecosystem (CCLME) where coastal upwelling stimulates phytoplankton growth and abundance in this period (Ottaviani, 2020; Mahu *et al*., 2022).

On the other hand, the periods during which small decreases in the condition index were observed would probably correspond to partial reproduction events. Indeed, it is well known that in mangrove oysters, the release of gametes is accompanied by a decrease in meat weight (Wellesley-Cole and Kamara, 1978). Moreover, reproduction is closely linked to environmental factors including salinity and temperature (Gomes *et al*., 2014). These authors have shown that decreasing salinity causes egg laying in *C. tulipa*. It could also be the case in the Saloum, which receives large freshwater inflows during the rainy season (August-September).

For seawater temperature, Gomes *et al*. (2014) claimed that it was positively associated with oyster CI. Their study showed that the highest CI values were observed during the months when seawater temperature gradually increased.

5. Conclusion

Finally, this study shows that, compared to other West African countries, *C. tulipa* sizes are generally small in Dionewar and that the resource may be over-exploited. For the preservation of the resource and also in the economic interest of the harvesters, the species should be allowed to reach commercial sizes > 60 mm before harvesting. From a commercial point of view, the best time to harvest the *C. tulipa* oyster would be around March, when condition index values are highest. More scientific knowledge on reproduction of *C. tulipa* could also help to better understand the basis of its farming in the park and ensure the sustainability of its exploitation at the scale of the Saloum Delta. In that, it would be important to support studies on condition index with investigation of larval abundance in the water column, spat settlement, reproductive stages (histological sections of gonads) combined with temperature and salinity monitoring.

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