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Spatial and Seasonal Variations in the Size-Weight Relationship and Condition Index of the Mangrove Oyster *Crassostrea tulipa* (Lamarck, 1819) in the Saloum Delta, Senegal

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Abstract

In the Saloum delta in Senegal, the mangrove oyster *Crassostrea tulipa* is under increasing human pressure, leading to a decline in wild stocks, a decrease in the quality of the marketed oysters and the degradation of mangrove tree roots. Previous studies have pinpointed some of these disturbances and yet, there is little information available on the structure of the population and the condition index of the species. The aim of this study was to document these aspects in order to support a sustainable management of the resource. From January 2021 to December 2022, monthly sampling was carried out at five stations to study the size-weight relationship and the condition index (CI) of oysters. A total of 26,790 individuals ranging in size from 0.23 to 93.19 mm with an average of 33.86±16.38 mm shell height were collected. The species was found to have a minority allometry (b = 2.54 <3), with a strong correlation between individual weight and oyster shell height (r = 0.88). CI showed seasonal and inter-site variations over the two years, with an overall mean value of 11.17±2.72%. The highest CI values were observed during the hot season and the lowest during the hot-cold transition period.

Keywords: mangrove oyster, *Crassostrea tulipa*, size-weight relationship, condition index

1. Introduction

In Senegal, as in several other West African countries, oysters have been exploited for food and commercial purposes for centuries (Drago *et al.* 2023; Mahu *et al.*, 2022). These bivalve mollusks are an important source of animal protein for coastal, island and urban populations (Dias *et al.*, 2022; Mahu *et al.*, 2022; Wélé *et al.*, 2021). Their production is mainly based on harvesting. According to a recent FAO study, annual oyster production in Senegal is 16,000 tones (t), of which 15,600 t come from harvesting wild oysters and 400 t from oyster farming (Drago *et al.*, 2023). This national oyster production comes mainly from the Casamance region in the south of the country and the Saloum delta (Drago *et al.*, 2023).

The Saloum delta combines the characteristics of marine and estuarine zones (Dia, 2003). The climate is characterized by a cold season (January-May) and a hot season (July-October) separated by transition periods (cold-hot in June; hot-cold between November and December) (Diouf *et al.*, 2021). Hydrologically, it is characterized by a long dry season running from October to May-June and a shorter rainy season generally running from June-July to October (Sarr, 2009). The socio-economic life of certain communities in the Saloum delta, particularly women, is closely linked to the collection of shellfish, including oysters, which have the highest market value (Wélé *et al.*, 2021; De Morais, 2011; Fall, 2009).

As a result of growing market demand, the local species *Crassostrea tulipa* is under very strong anthropic pressure (Thiao *et al.*, 2023; Dias *et al.*, 2022; Hayford *et al.*, 2021; Thiam *et al.*, 2011; Diouf *et al.*, 2010). Intense and uncontrolled harvesting leads to disturbances in stock renewal and productivity (Thiao, 2024; Mahu *et al.*, 2022; Christensen and Pauly, 1997).

Faced with these disruptions, which are compounded by the effects of climate change, it is important to implement effective harvest management strategies to ensure the sustainability of the resource.

To achieve this, the biological parameters such as size-weight relationship and condition index must be documented (Akinjogunla and Soyinka, 2022; Hayford *et al.*, 2021, Osei *et al.*, 2020; Asare *et al.*, 2019; Oliveira *et al.*, 2018; Yankson *et al.*, 1996). As these bio-indicators are likely to evolve according to environmental conditions (Mahu *et al.*, 2022) and anthropogenic actions, they need to be updated and contextualized.

Therefore, the main objective of this study was to investigate spatial and seasonal variations in the size-weight relationship and condition index of the mangrove oyster *Crassostrea tulipa* over 2 consecutive years at 5 sites in the Saloum delta, Senegal.

2. Material and Methods

2.1 Study Area and Sampling Sites

The study was carried out in the commune of Dionewar in the Saloum delta, in central western of Senegal (Figure 1). It is an estuarine zone covered with mangrove forests whose stilt roots are the main support for the oyster *Crassostrea tulipa*.

Five sampling sites were chosen (Figure 1). These were Akat (13°51.125'; 016°44.209'), Baobab Rasta (13°51.792'; 016°43.003'), Falia 1 (13°56.253'; 016°40.867'), Falia 2 (13°54.043'; 016°41.819') and Fandiongue (13°49.701'; 016°40.230').

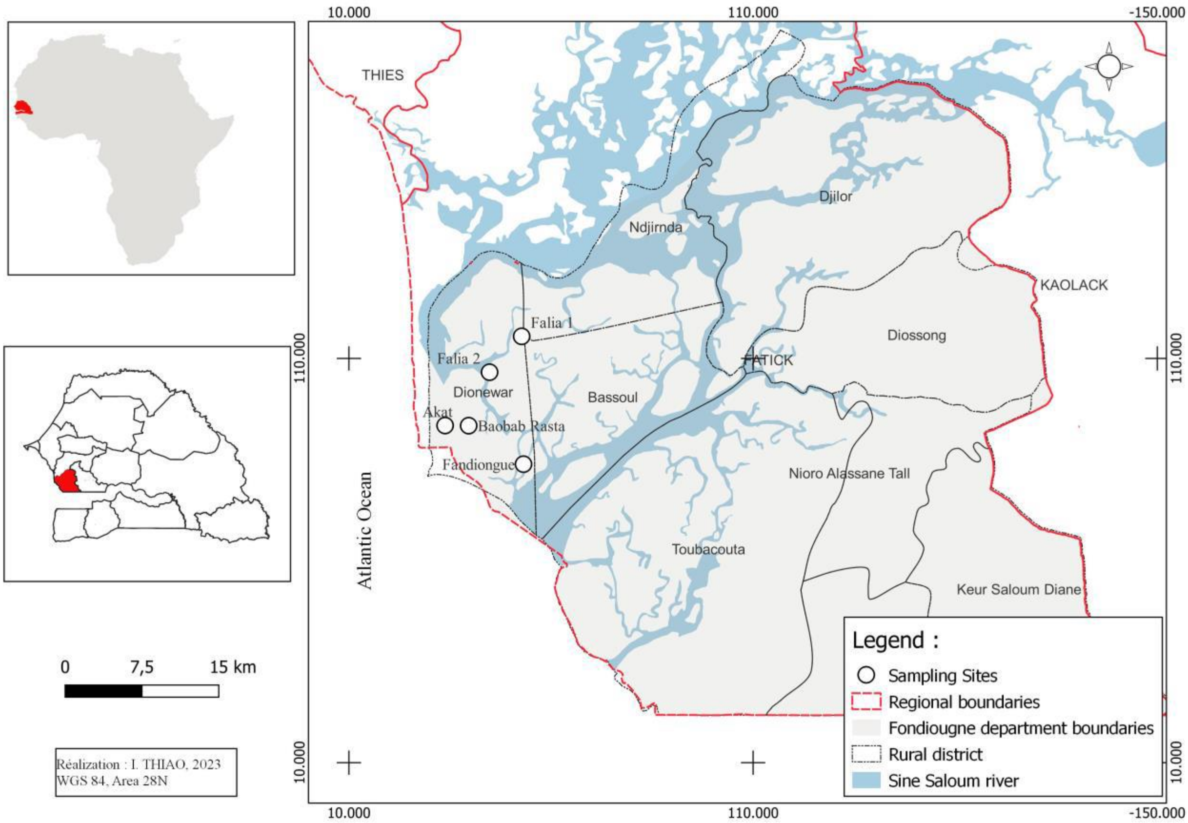

Figure 1. Location of sampling sites in the Saloum Delta (Senegal, West Africa)

The selected sampling sites have contrasting characteristics such as:

- proximity to the ocean;
- accessibility at low tide (depth and proximity to villages);
- density of mangrove cover (light intensity/photosynthesis);
- and exploitation status in 2020 (exploited or in fallow) (Table 1).

Table 1. Geographic coordinates and characteristics of sampling sites

Stations	Proximity to the ocean	Density of vegetation cover	Accessibility (depth and distance from houses)	Left in fallow in 2020
Akat	< 2 km	medium	easily accessible	no
Baobab Rasta	2-5 km	high	not easily accessible	no
Falia 1	>10 km	medium	easily accessible	yes
Falia 2	5-10 km	medium	accessible	yes
Fandiongue	5-10 km	medium	accessible	non

2.2 Sampling Protocole

Monthly sampling was carried out between January 2021 and December 2022 (24 months). The protocol described below is based on the *Guide de suivi participatif des coquillages exploités en Afrique de l'Ouest* (Diouf *et al.*, 2010) with a few modifications. Over a linear meter of mangrove, three types of stilt roots not attached to the substrate were selected: the most heavily loaded, the moderately loaded and the least loaded with oysters. All the individuals attached to these roots were removed, cleaned and placed in a referenced container. In each station, this sampling strategy of one linear meter was repeated three times over a section of mangrove of around 50 to 100 m.

In the laboratory, a separation operation was carried out delicately using a knife in cases where oysters were stuck together and/or superimposed on one another. Each individual was weighed using an electronic balance (XY5002C) accurate to 0.01g and the largest dimension (height) of each shell was measured using an automatic digital caliper (Mitutoyo; CD-20PMX) accurate to 0.01mm.

2.3 Determining the size-weight Relationship

The size-weight relationship is very often used in biology and fisheries resource management. It is used to explain changes in weight as a function of size, and to compare mono-specific populations living in environments with different conditions.

This relationship is highlighted by a non-linear regression based on a cloud of points combining the weights and sizes of the individuals studied. It is based on the following equation:

$$W = a * H^b$$

where W represents the individual wet weight (g) of the live oyster before opening, H the shell height (mm), “a” expresses the quantities of variation in weight when size varies by one unit and “b” is the allometry coefficient which expresses the variations in weight which are not linked to variations in size.

The coefficients (a and b) of the regression model are used when they are significantly different from zero at the 5% threshold (p-value < 0.05).

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 isometric. If, on the other hand, "**b**" is different from 3, the growth is said to be allometric. If "**b**" is less than 3, the allometry is minor. If "**b**" is greater than 3, the allometry is major.

2.4 Condition Index Calculation

To determine the condition index, thirty (30) individuals between 35 and 90 mm in size were sub-sampled at each collection point, in order to have a balance of sizes and enough specimen from each site for the analysis. For each individual, the total weight and the weight of the drained fresh meat were determined. The oyster condition index was calculated using the formula:

$$CI = FW * 100 / TW$$

Where CI = condition index (%), FW = weight of fresh meat (g) and TW= individual total weight (g).

2.5 Statistical Analysis

Data processing and graphing were carried out using Microsoft Office Excel 2013 and R Core Team 2022 software. Pearson's correlation coefficient was used to assess the degree of relationship between individual weights and heights ($-1 < r < 1$).

For the CI, two-factor ANOVA tests were used to assess the season effect at each station for each of the two monitoring years. When the conditions of normality were not met, the equivalent of the two-factor ANOVA (Scheirer-Ray-Hare test) was applied. In the event of a significant effect, this test was followed by Dunn's test, which compares the factors in pairs. Effects were considered significant when the p-value ≤ 0.05.

3. Results and Discussion

3.1 Results

3.1.1 Height-weight Relationship

The results of the study of the height-weight relationship show that, for all the stations combined, the allometry of *C. tulipa* was minoring and weight was strongly correlated with height (Figure 2). The allometry coefficient b was less than 3 (b = 2.54) and the correlation coefficient r was close to 1 (r = 0.88).

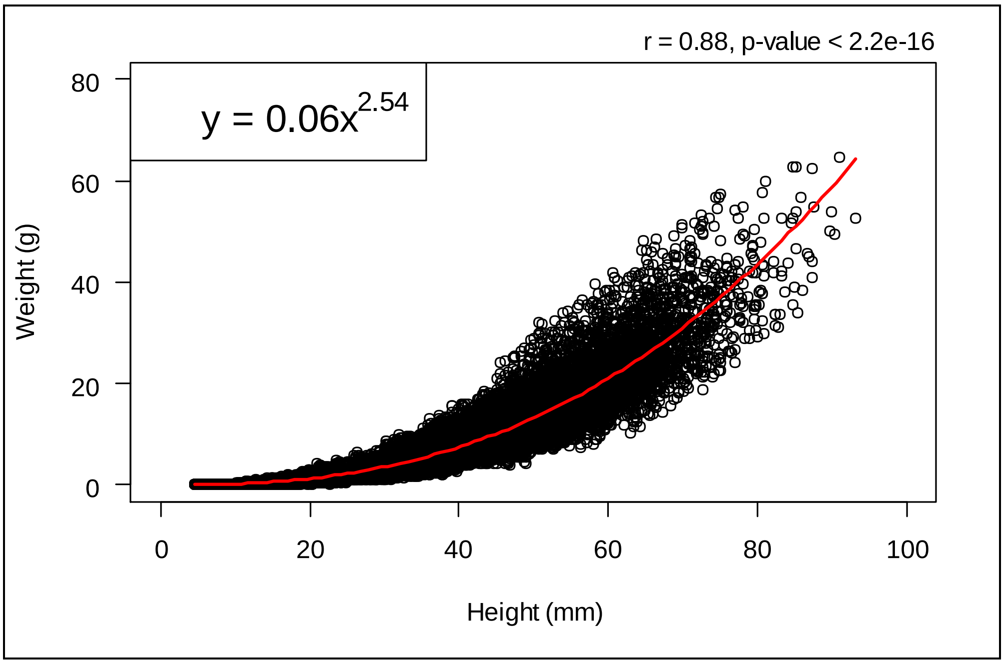

Figure 2. Height-weight relationship of *C. tulipa* when all stations and both sampling years (2021 and 2022) are combined

The same is true for each of the five stations, with b values varying between 2.50 and 2.69 for the year 2021 (Figure 3) and between 2.45 and 2.58 for the year 2022 (Figure 4). From one station to another and for each of the two sampling years, r values varied between 0.86 and 0.89 (Figure 3 and Figure 4).

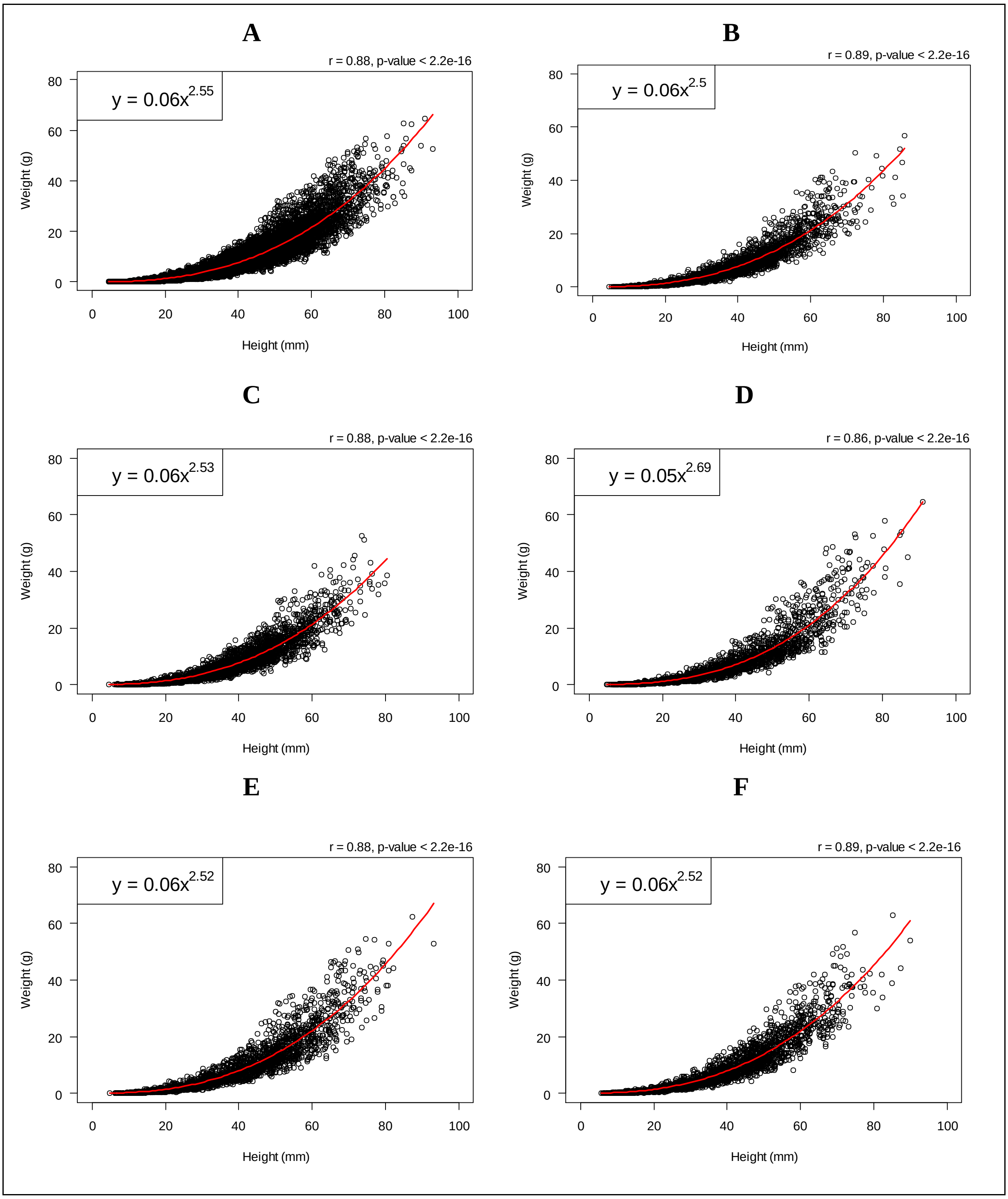

Figure 3. Height-weight relationship of *C. tulipa*. A. all stations combined, B. Akat, C. Baobab Rasta, D. Falia 1, E. Falia 2 and F. Fandiongue, in 2021

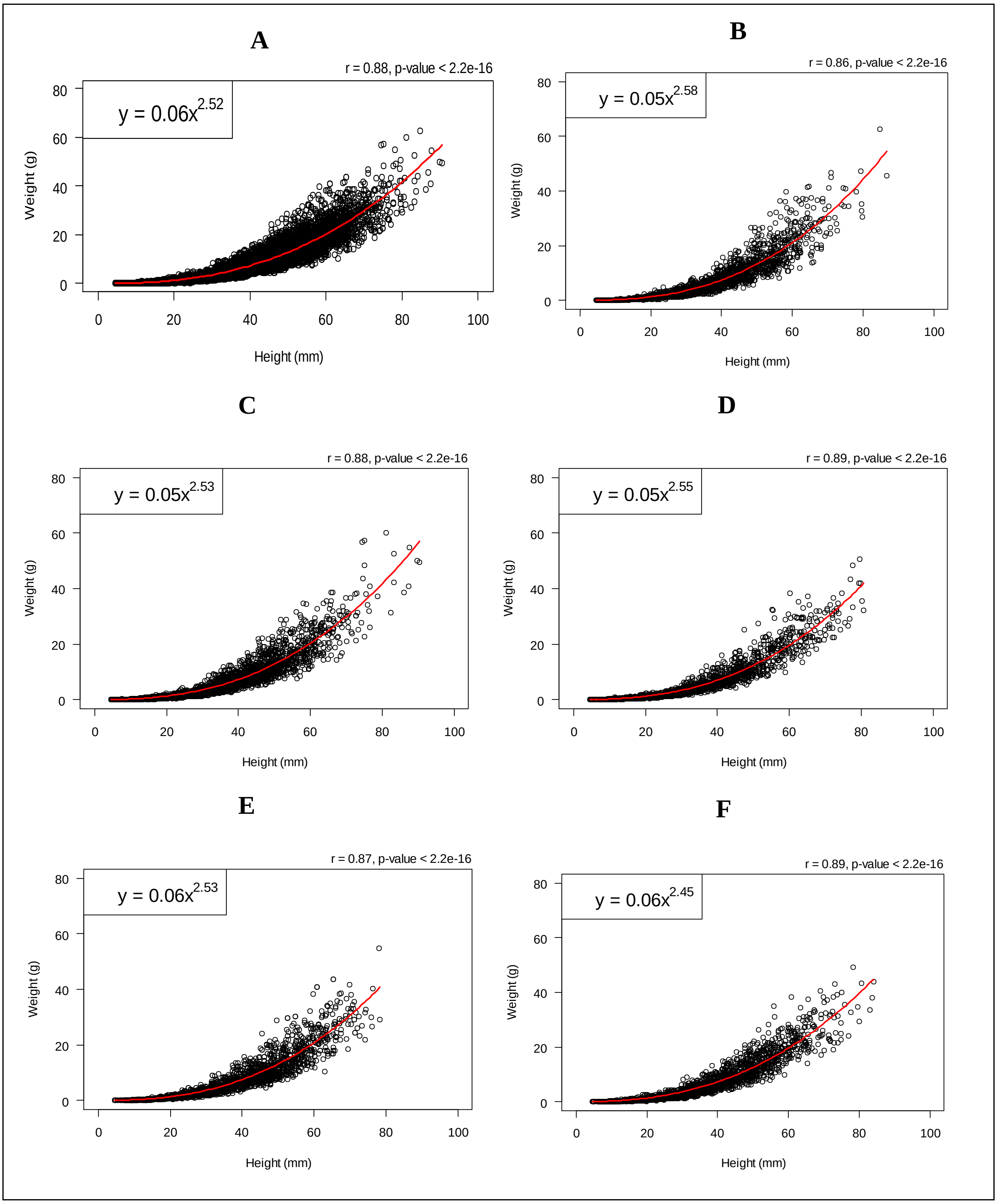

Figure 4. Height-weight relationship of *C. tulipa*. A. all stations combined, B. Akat, C. Baobab Rasta, D. Falia 1, E. Falia 2 and F. Fandiongue, in 2022

Also, regardless of the season and for both years of monitoring, the results indicate a minoring allometry and a strong correlation between the weights and heights of the oysters, since b is less than 3 and r relatively close to 1 (Figure 5 and Figure 6).

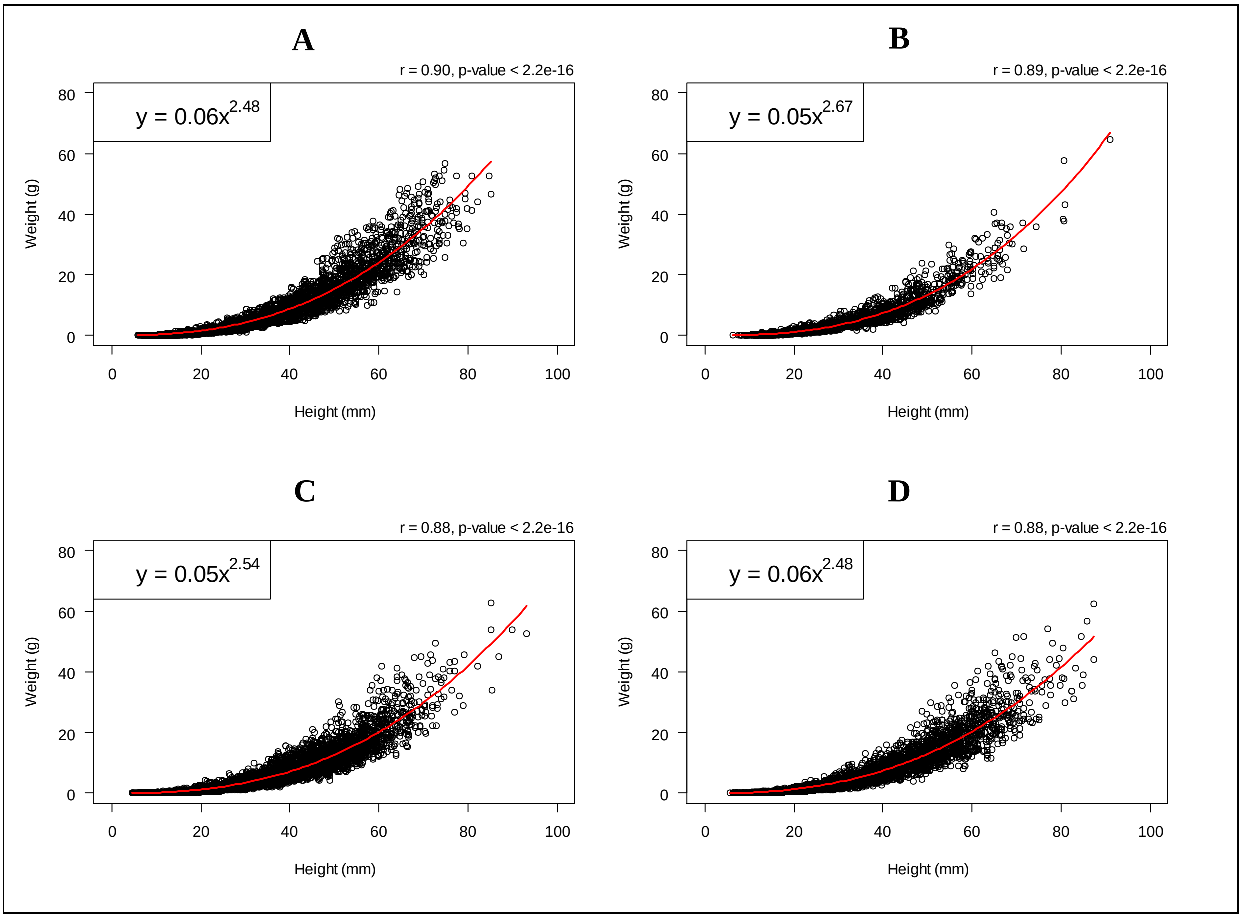

Figure 5. Height-weight relationship of *C. tulipa*. A. cold season, B. hot cold transition, C. hot season, D. cold hot transition, in 2021

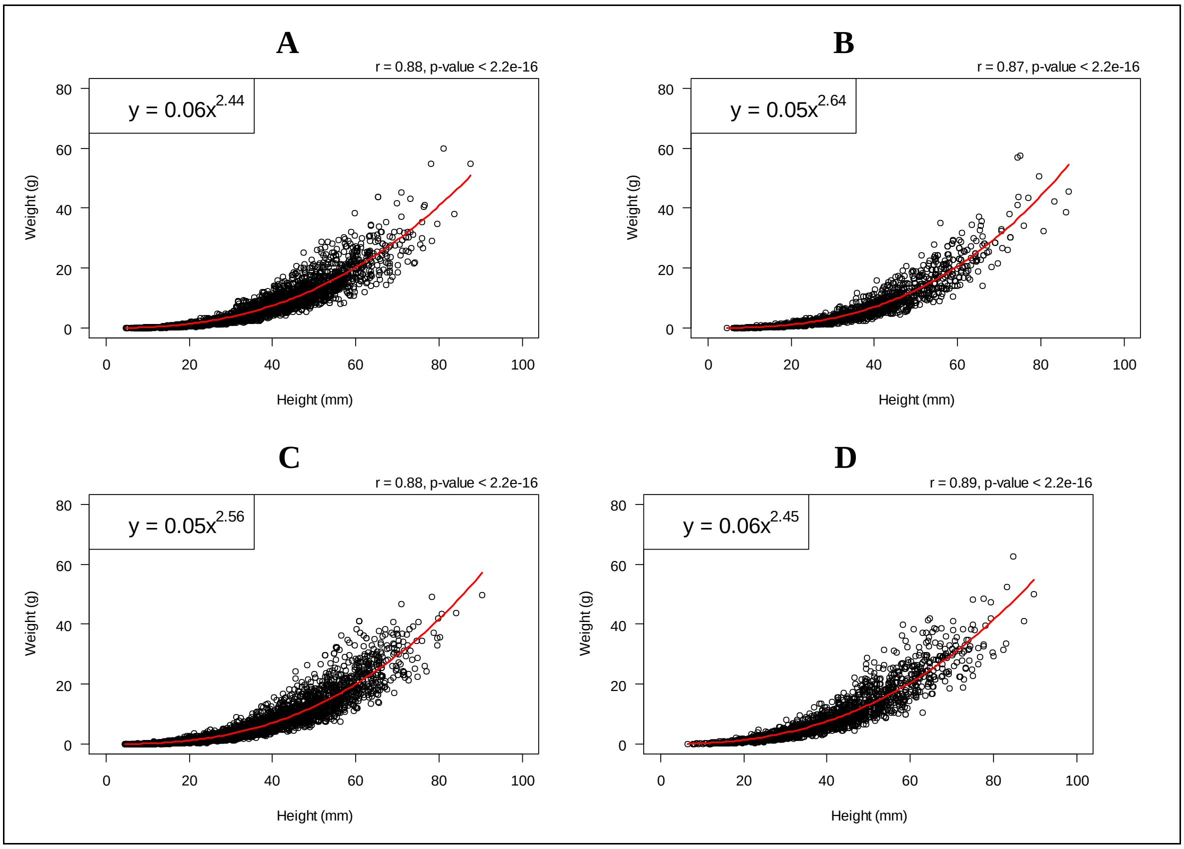

Figure 6. Height-weight relationship of *C. tulipa*. A. cold season, B. cold-hot transition, C. hot season, D. hot-cold transition, in 2022

The values of b and r differed little from one site to another (b ≈ 2.5 except for Falia 1 in 2021 and Fandiongue in 2022 and r ≈ 0.9) (Figure 3 and Figure 4). However, it appears that in both 2021 and 2022, b was always significantly greater during the cold-hot transition period (Figure 5B and Figure 6B) and during the hot season (Figure 5C and Figure 6C) than during the cold season or during the hot-cold transition period.

3.1.2 Condition Index

For all stations combined and for both years, the mean value of the CI for *C. tulipa* was 11.17±2.72%. When considering the different seasons studied, the mean value was greater in 2021 (11.35±2.73%) than in 2022 (10.99±2.70%). The results of the CI variance comparison test showed that the inter-annual differences were highly significant for the cold-hot transition period (p-value = 1.40e-8) and for the hot season (p-value = 1.09e-13), whereas they were not significant for the cold season and the hot-cold transition period (Table 2).

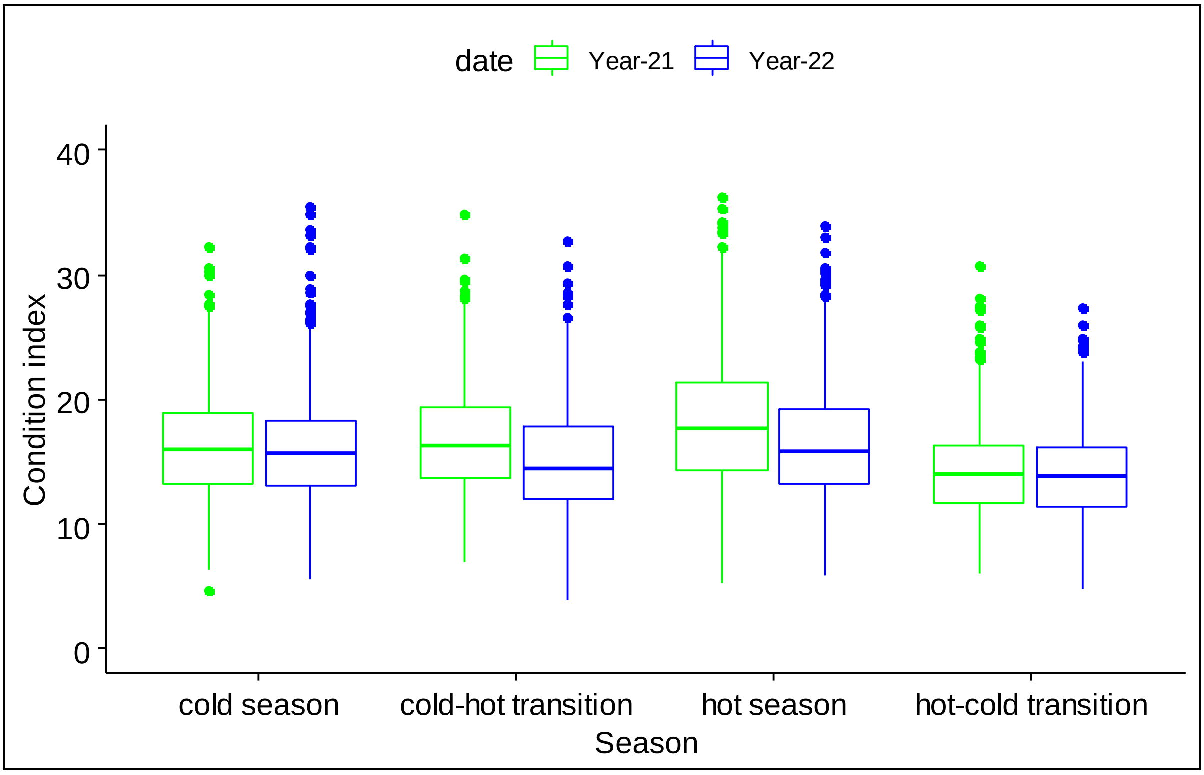

Figure 7. Interannual changes in the oyster condition index during the four seasonal periods (cold season, cold-hot transition, hot season, and hot-cold transition)

Table 2. Comparison of variance test results (Dunn's test): P-values and significance (S) of the difference in CIs between the two years of follow-up for each season

Season	**Years**		**N1**	**N2**	**Stat.**	**p-value**	**S**
Cold	2021	2022	852	993	-1,86	6,26e-2	ns
Cold-hot transition	2021	2022	433	450	-5,67	1,40e-8	****
Hot	2021	2022	1248	1139	-7,43	1,09e-13	****
Hot-cold transition	2021	2022	772	632	-1,35	1,78e-1	ns

*ns = not significant; * = weakly significant; ** = moderately significant; **** = very strongly significant.*

At each station, oyster CIs also varied from season to season in 2021 and 2022 (Figure 8 and Figure 9). In 2021, the highest CI values were generally observed during the hot season, except for the Baobab Rasta oysters, and the lowest values were generally recorded during the hot-cold transition period, with the exception of the Fandiongue station (Figure 8). The differences in CI were highly significant ($p < 0.05$) between these two seasons for all stations (Table 3).

At the Fandiongue, Akat, Falia 1 and Falia 2 stations, in 2021, the CI progressively increased between the cold season and the hot season and thereafter a drop in CI was observed during the hot-cold transition period (Figure 8). In contrast, at the Baobab Rasta station, the CI gradually declined over the four seasons (Figure 8), with highly significant declines between the cold-hot transition period and the hot season (p-value = 6.93e-05) and then between the hot season and the hot-cold transition period (p-value = 1.10e-06).

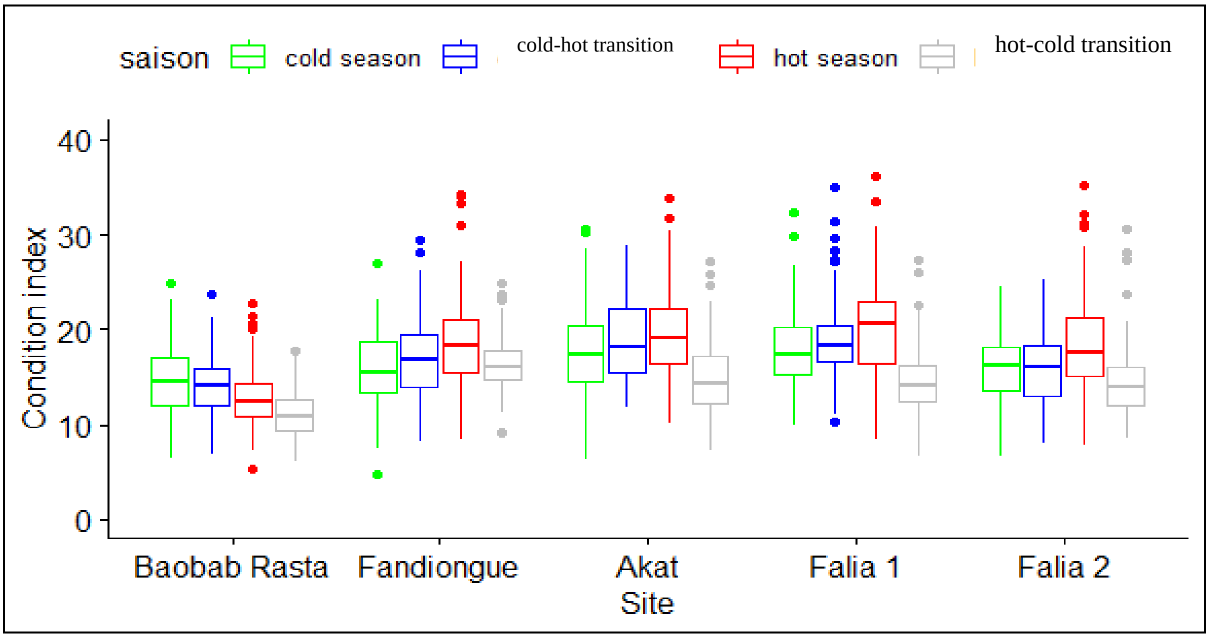

Figure 7. Seasonal variations in the oyster condition index for each sampling station (Baobab Rasta, Fandiongue, Akat, Falia 1 and Falia 2) in 2021

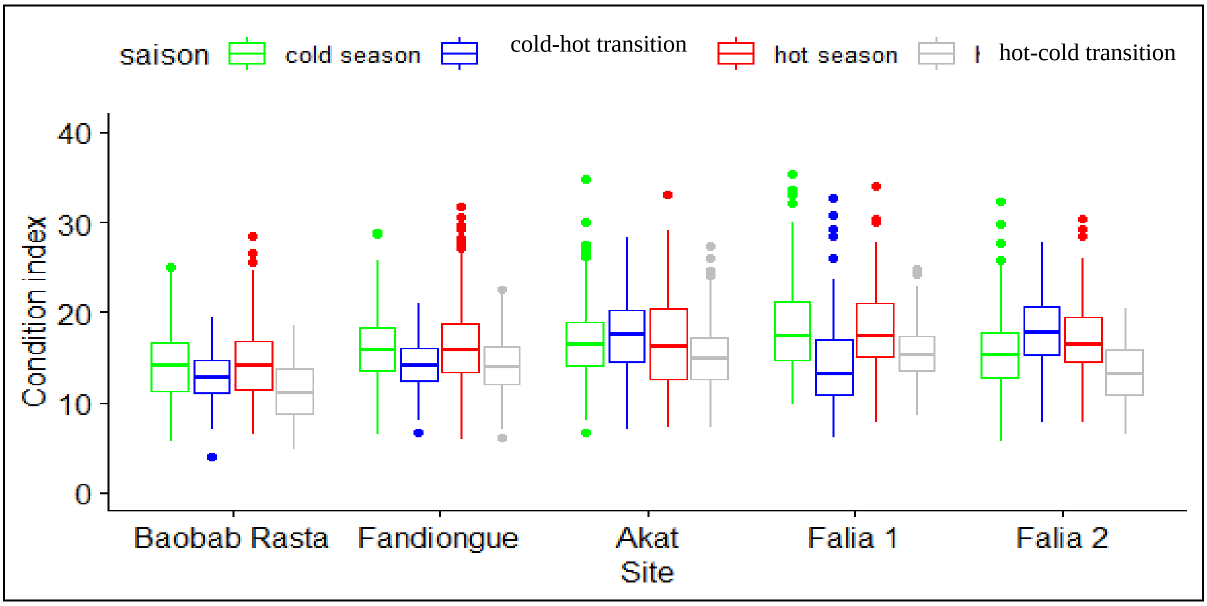

Figure 8. Seasonal variations in the oyster condition index for each sampling station (Baobab Rasta, Fandiongue, Akat, Falia 1 and Falia 2) in 2022

Table 3. Result of the comparison of variances test (Dunn's test): P-values and significance (S) of CI difference between consecutive seasons (groups 1 and 2) in 2021

Station	Group 1	Group 2	N1	N2	Stat.	p-value	S
Baobab Rasta	Cold season	Cold-hot transition	250	124	-0,69	4,89e-01	ns
	Cold-hot transition	Hot season	124	240	-4,14	6,93e-05	****
	Hot season	Hot-cold transition	240	158	-5,09	1,10e-06	****
Fandiongue	Cold season	Cold-hot transition	152	80	2,13	9,96e-02	ns
	Cold-hot transition	Hot season	80	220	2,69	2,84e-02	*
	Hot season	Hot-cold transition	220	153	-4,83	6,94e-06	****
Akat	Cold season	Cold-hot transition	210	103	2,45	2,87e-02	*
	Cold-hot transition	Hot season	103	275	1,15	2,50e-01	ns
	Hot season	Hot-cold transition	275	168	-11,04	1,53e-27	****
Falia 1	Cold season	Cold-hot transition	101	47	1,65	1,96e-01	ns
	Cold-hot transition	Hot season	47	244	1,25	2,13e-01	ns
	Hot season	Hot-cold transition	244	151	-12,27	7,79e-34	****
Falia 2	Cold season	Cold-hot transition	139	79	-0,08	9,33e-01	ns
	Cold-hot transition	Hot season	79	269	3,38	1,71e-03	**
	Hot season	Hot-cold transition	269	142	-8,83	6,20e-18	****

N1 and N2** = number of individuals sub-sampled during the seasons compared; Stat. = statistical difference in CIs: a positive value indicates that the CI for the group 1 is smaller and vice versa. ns = not significant; * = weakly significant; ** = moderately significant; * = very strongly significant.*

In 2022, the CI alternated between significant decreases and increases (p-value < 0.05) for the Baobab Rasta, Fandiongue and Falia 1 stations (Table 4). The highest values were observed in the cold and hot seasons, and the lowest in the transition periods (Figure 9). For Akat and Falia 2, the CI was highest in the cold-hot transition period (Figure 9). It fell slightly in the hot season (p-value > 0.05) and then significantly in the hot-cold transition period (p-value < 0.05) (Figure 9; Table 4).

Table 4. Comparison of variance test (Dunn's test) result: P-values and significance (S) of the difference in CIs between consecutive seasons (group 1 and group 2) in 2022

Station	Group 1	Group 2	N1	N2	Stat.	p-value	S
Baobab Rasta	cold season	cold-hot transition	244	137	-2,70	1,38e-02	*
	cold-hot transition	hot season	137	271	3,27	3,27e-03	**
	hot season	hot-cold transition	271	117	-7,06	1,02e-11	****
Fandiongue	cold season	cold-hot transition	169	64	-3,51	1,35e-03	**
	cold-hot transition	hot season	64	253	3,81	5,54e-04	***
	hot season	hot-cold transition	253	136	-5,08	2,24e-06	****
Akat	cold season	cold-hot transition	213	91	1,22	4,43e-01	ns
	cold-hot transition	hot season	91	215	-1,90	1,71e-01	ns
	hot season	hot-cold transition	215	145	-3,14	6,70e-03	**
Falia 1	cold season	cold-hot transition	134	87	-6,08	5,99e-09	****
	cold-hot transition	hot season	87	201	6,48	5,44e-10	****
	hot season	hot-cold transition	201	100	-4,37	5,04e-05	****
Falia 2	cold season	cold-hot transition	233	71	4,32	4,63e-05	****
	cold-hot transition	hot season	71	199	-1,41	1,60e-01	ns
	hot season	hot-cold transition	199	134	-8,20	1,49e-15	****

*N1 and N2 = number of individuals sub-sampled during the seasons compared; Stat. = statistical difference in CIs: a positive value indicates that the CI of the group 1 is smaller and vice versa ; ns = not significant; * = weakly significant ; ** = moderately significant ; *** = strongly significant ; **** = very strongly significant*

The results also show that, for the two years of the study, notwithstanding the season (Figure 8, Figure 9 and Figure 10), the CI of the Baobab Rasta oysters was significantly lower than the CI of the other stations whereas the CI of the oysters from Falia 1 and Akat were significantly higher than at the other stations (Table 5).

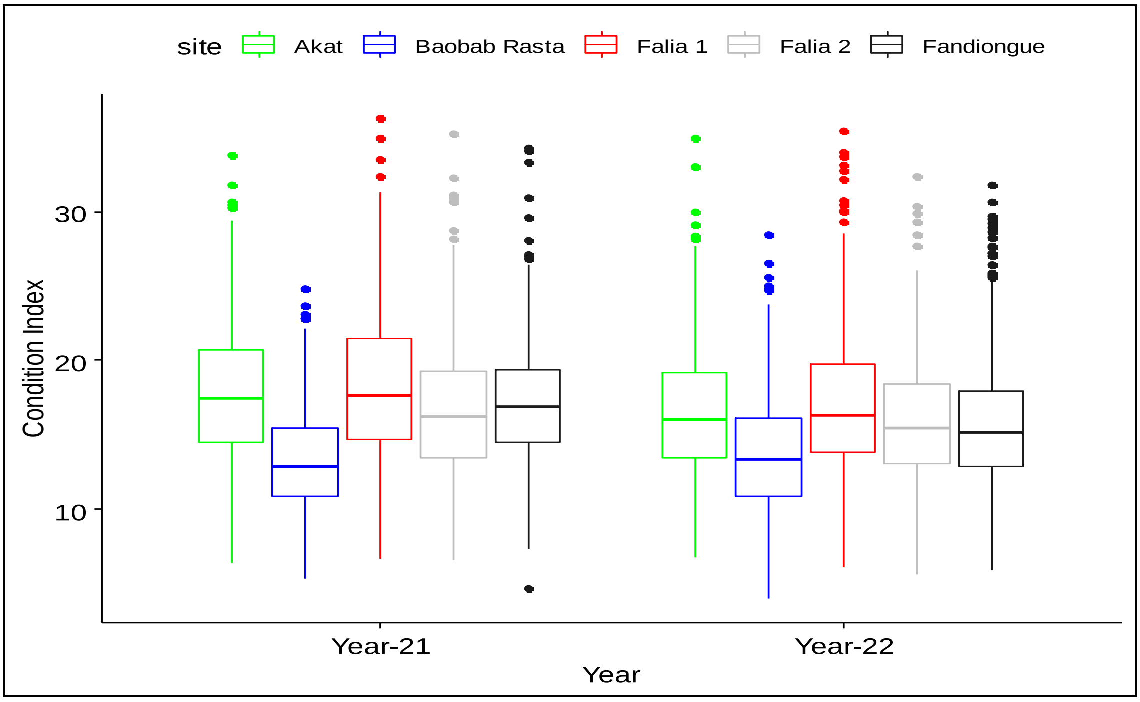

Figure 10. Inter-site changes in the oyster condition index in 2021 and 2022

The results of the comparison of variance test between sites (Table 5) also show that there were no significant differences in CI between oysters sampled at Akat and those collected at Falia 1, both in 2021 (p-value = 4.71e-1) and 2022 (p-value = 2.70e-1), and the same for Akat and Fandiongue in 2021 (p-value = 5.54e-2). For the Falia 2 and Fandiongue stations (Table 5), the difference in CI values was weakly significant in 2021 (p-value = 2.64e-2) and non-significant in 2022 (p-value = 3.68e-1).

Table 5. Comparison of variance test (Dunn's test) result: P-values and significance (S) of the difference in CIs between consecutive seasons (group 1 and group 2) in 2022

Année	**Group 1**	**Group 2**	**N1**	**N2**	**Stat.**	**p-value**	**S**
2021	Akat	Baobab Rasta	756	772	-20,3	1,36e-90	****
	Akat	Falia 1	756	543	0,720	4,71e-1	ns
	Akat	Falia 2	756	629	-5,06	2,04e-6	****
	Akat	Fandiongue	756	605	-2,20	5,54e-2	ns
	Baobab Rasta	Falia 1	772	543	19,3	9,26e-82	****
	Baobab Rasta	Falia 2	772	629	14,2	3,32e-45	****
	Baobab Rasta	Fandiongue	772	605	16,9	2,76e-63	****
	Falia 1	Falia 2	543	629	-5,36	5,05e-7	****
	Falia 1	Fandiongue	543	605	-2,72	2,64e-2	*
	Falia 2	Fandiongue	629	605	2,69	2,64e- 2	*
2022	Akat	Baobab Rasta	664	769	-12,8	1,01e-36	****
	Akat	Falia 1	664	522	1,49	2,70e-1	ns
	Akat	Falia 2	664	637	-2,57	3,09e- 2	*
	Akat	Fandiongue	664	622	-3,46	2,17e- 3	**
	Baobab Rasta	Falia 1	769	522	13,5	1,10e-40	****
	Baobab Rasta	Falia 2	769	637	10,0	8,97e-23	****
	Baobab Rasta	Fandiongue	769	622	9,02	1,26e-18	****
	Falia 1	Falia 2	522	637	-3,89	5,00e- 4	***
	Falia 1	Fandiongue	522	622	-4,72	1,39e- 5	****
	Falia 2	Fandiongue	637	622	-0,900	3,68e-1	ns

N1 et N2 = Number of individuals sampled during the seasons compared; Stat. = statistical difference in CIs: A positive value indicates that the CI of the group 1 season is smaller and *vice versa*; ns = not significant; * = low significance; ** = moderately significant; *** = highly significant; **** = very strongly significant

3.2 Discussion

For all the stations studied, oyster weight was strongly correlated with size ($r \geq 0.86$). Other authors (Akinjogunla and Soyinka, 2022 and Asare *et al.*2019) who worked on the same species reported smaller r-values (Table 6). These differences in correlation values could be explained by the fact that the individuals sampled by these authors were larger in size, with modal classes equal to 55-64 and 55-69). Indeed, as they grow, the morphology of these oysters varies greatly depending on the shape of the support (Dioh, 1976).

The size-weight relationship shows, in all the sampling stations, a minoring allometry ($b < 3$), which translates into a growth in height that is greater than the growth in weight. Similar work on the same species in Ghana (Asare *et al.*, 2019) and Nigeria (Akinjogunla and Soyinka, 2022) also showed a minoring allometry, but with much smaller b values (Table 6). The results of the present study also corroborate those of Lopes *et al.* (2013) who stated that, in *C. tulipa*, height growth is faster in young individuals than in adults. This is not the case for all species of the genus *Crassostrea*, since in the United States, Grizzle *et al.* (2017) showed that the American oyster *C. virginica* was characterized by a majoring allometry (Table 6).

Table 6. Comparison of results of height-weight relationships from different species of the genus *Crassostrea*

Auteurs (year)	**Especies**	**Country**	***b***	***r***
This study	*C. tulipa*	Sénégal	2,54	0,88
Akinjogunla and Soyinka (2022)	*C. tulipa*	Nigéria	Log b = 0,2864 (=> b = 1,93)	0,58
Asare *et al.* (2019)	*C. tulipa*	Ghana	1,36	0,53
Grizzle *et al.* (2017)	*C. virginica*	*USA*	3,37	0,92

The continuity of reproduction in the *C. tulipa* species could be at the origin of this difference, which seems to be specific and/or geographical (Cohen *et al.*, 2020; Antonio *et al.*, 2021; Gomes *et al.*, 2014). According to Wellesley-Cole and Kamara (1978), stored glycogen is used to form gonads in tropical oysters, unlike oysters from temperate countries, which only have one spawning period per year and can therefore use glycogen for weight growth during the rest of the year.

The oyster condition index showed seasonal variations in 2021 and 2022, with an overall mean of 11.17±2.72% for the 5 stations. For the same species in Ghana, Asare *et al.* (2019) obtained a CI approximately equal to 8% (Table 7). In Nigeria, Akinjogunla and Soyinka (2022) found CIs varying between 6.5 and 10.5% (Table 7). Based on the CI value, these authors concluded that the oysters were in good health, which would indicate that this was also the case for oysters from the Dionewar commune in Saloum. The results of the present study are similar to those of Rebelo *et al.* (2005) who reported seasonal variations in CI for *C. tulipa*.

Table 7. Comparison of results of condition index of *Crassostrea tulipa*

Auteurs (year)	**Especies**	**Country**	**CI (%)**
This study	*C. tulipa*	Sénégal	11.17
Akinjogunla et Soyinka (2022)	*C. tulipa*	Nigéria	6.5-10.5
Asare *et al.* (2019)	*C. tulipa*	Ghana	≈ 8

The increases in condition index observed in the hot season could be explained by better food availability and/or by the maturation of reproductive cells. Planktonic microalgae are the main source of food for oysters (Turner, 2014). Phytoplankton abundance and composition were not measured in the present work. However, several studies like Morales (2014) suggest that increasing temperature stimulates phytoplankton metabolism and increases phytoplankton production. Gomes *et al.* (2014) also wrote that in Brazil the condition index (CI) of *C. gazar* was associated with water temperature and, in their study, the highest CI values were observed during the months when seawater temperature gradually increased.

In addition to temperature, light and nutrient availability regulates phytoplankton growth (Harrison and Platt, 1980). Indeed, during part of the hot season in Senegal, rainwater run-off drains dissolved nutrient (N and P) into the bolongs, and the strong winds characteristic of the rainy season enhance the mixing of these nutrient in the water (Adame *et al.*, 2010; Diaw *et al.*, 1993), which could increase the abundance of food and the condition index of oysters. As a counter example, in contrast to the other stations, Baobab Rasta was characterized by the lowest CI values. At this station, the bolong is deep, narrow, sheltered and the water is only slightly agitated. The shading from the mangroves reduces light radiation and the warming of the water and this situation may reduce local primary productivity of the plankton.

All these considerations underline the need for a phytoplankton and particulate organic matter survey to better understand the changes in oyster growth and meat yields.

The transition periods during which significant decreases in the condition index were observed overall are probably linked to reproduction (Thiao *et al.*, 2024). It is well known that in oysters and more generally in bivalves, the release of gametes is accompanied by a reduction in their weight (Wellesley-Cole and Kamara, 1978). According to Dawood *et al.* (2023) and Gomes *et al.* (2014), reproduction is closely linked to environmental factors including salinity and temperature. These authors have clearly shown that a decrease in salinity causes egg-laying in *C. tulipa*. This could also be the case in the Saloum delta, which receives large inflows of fresh water during the rainy season, especially in the August-September period. Given that, according to His (1991), an individual can lay eggs between 4 and 9 times during the same season, the low CI values observed just after the rainy period (hot-cold transition) suggest that the oysters released most of their gametes and are practically empty.

Consistent with this, the significant interanual differences in CI during the cold-hot transition period and the hot season could be linked to the change in rainfall noted in the study area between 2021 and 2022. The arrival of the first rains was earlier in 2022 (26 May) than in 2021

(28 July), which could have had an impact on the oyster reproductive cycle. In 2022, the Baobab Rasta, Falia 1 and Fandiongue sites, which are further away and less connected to the open ocean, displayed a decrease in CI during the cold-hot transition period in June, earlier than Akat and Falia 2, which are closer and more connected to the ocean (Table 1). This could be since the bolongs that are more distant from and less connected to the ocean are also more subject to variations in salinity linked to evaporation and the influx of fresh rainwater.

4. Conclusion

In the Saloum delta, *C. tulipa* shows a minoring allometry with a strong correlation between total individual weight and shell height. Overall, the CI values indicate that the oysters have a good meat yield. The highest CI values are observed mainly during the hot season. Harvesting during this period would give better meat yields.

This information is essential in the management of oyster harvesting as it can be used to redefine the period of biological rest. They are also important for the practice of oyster farming as periods that offer better meat yields will be targeted for harvesting.

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Competing interests

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Obtained.

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References

Adame, F., Virdis, B., & Lovelock, C. (2010). Effect of geomorphological setting and rainfall on nutrient exchange in mangroves during tidal inundation. *Marine and Freshwater Research*, *61*(10), 1197-1206. https://doi.org/10.1071/MF10013

Akinjogunla, V. F., & Soyinka, O. O. (2022). Morphometric Assessment and Condition Factor of the Mangrove Oyster from a Tropical Mangrove Swamp, off Lagos Lagoon, South-West, Nigeria. *Omni-Akuatika*, *18*(1), 62-71. https://doi.org/10.20884/1.oa.2022.18.1.957

Antonio, I., Sousa, A., Lenz, T., Funo, I., Lopes, R., & Figueiredo, M. (2021). Reproductive cycle of the mangrove oyster, *Crassostrea rhizophorae* (Bivalvia: Ostreidae) cultured in a macrotidal high-salinity zone on the Amazon mangrove coast of Brazil. *Acta Amazonica, 5*, 113-121. https://doi.org/10.1590/1809-4392202003582

Asare, B., Obodai, E. A., & Acheampong, E. (2019). Mangrove oyster farming: Prospects as supplementary livelihood for a Ghanaian fishing community. *Journal of Fisheries and Coastal Management*, *1*, 8-17. https://doi.org/10.5455/jfcom.20190311090846

Christensen, V. & Pauly, D. (1997). Placing fisheries resources in their ecosystem context. *EC Fisheries Cooperation Bulletin*, *10*(2), 9-11. https://doi.org/10.1016/j.ecolmodel.2003.09.002

Cohen, J., Yankson, K., Acheampong, E., & Wubah, D. (2020). Effects of Tidal Exposure on Bivalve Molluscs: First Stab at the Case of West African Mangrove Oyster (*Crassostrea tulipa*) in Benya Lagoon, Elmina, Ghana. *Journal of Fisheries and Coastal Management, 1*, 35-42. https://doi.org/10.5455/jfcom.20200317105716.

Dawood, M., Sühnel, S., Lagreze-Squella, F. J., Legat, J. F. A., Puchnick-Legat, A., Strand, A., Lagreze, S. S., & de Melo, C. M. R. (2023). Effects of Salinity on the Reproductive Cycle of the Mangrove Oyster *Crassostrea tulipa* in Hatchery Conditions. *Aquaculture Research,* vol. *2023*, Article ID 7409585, p.12. https://doi.org/10.1155/2023/7409585

De Morais, L. T. (2011). Convention de recherche entre l'IRD et la FIBA - Programme « Femmes et Coquillages », volet Recherche/Écologie. Rapport de recherche - IRD Dakar. 38 p. ffhal-01483078. https://hal.science/hal-01483078

Dia, I. M. M. (2003). Elaboration et mise en œuvre d'un plan de gestion intégrée : la réserve de biosphère du delta du Saloum, Sénégal. International Union for the Conservation of Nature and Natural Resources (IUCN), Gland, Suisse et Cambridge, Royaume-Uni. Xiv + 130 p. ISBN: 2-8317-0750-1

Dias, G. A., Vasconcelos, M. J., & Catarino, L. (2022). Examining the socioeconomic benefits of oysters: A provisioning ecosystem service from the mangroves of Guinea-Bissau, West Africa. *Journal of Coastal Research, 38*(2), 355-360. https://doi.org/10.2112/JCOASTRES-D-21-00055.1

Diaw, A. T., Bâ, A., Bouland, P., Diouf, P. S., Lake, L. A., Mbow, M. A., Ndiaye, P., & Thiam, M. D. (1993). Gestion des Ressources Côtières et Littorales du Sénégal: Actes de l'Atelier de Gorée 27-29 juillet 1992. UICN, Gland, Suisse, x + 484 pp. ISBN: 2-8317-0145-7

Dioh B. C. (1976). L'ostréiculture au Sénégal. Thèse de Doctorat présentée et soutenue publiquement le 4 juin 1976. Ecole Inter-Etats des Sciences et Médecine vétérinaire de Dakar. 111 p.

Diouf, J. E., Faye, A., Dione, E.N., Fall, J., Sané, B., & Diouf, M. (2021). Size Distribution, Length Weight Relationship and Condition Index of *Tagelus adansonii* Bosc 1801(Mollusca: Bivalvia, Solecurtidae) in the Joal Fadiouth Lagoon (Senegal). *Journal of Biology and Life Science*, *12*(1), 13-47. https://doi.org/10.5296/jbls.v12i1.18323

Diouf, M., Sarr, A., Ndoye, F., Mbengue, M., & Tandia, A. (2010). Guide de suivi bioécologique des coquillages exploités dans les îles de Niodior, Dionewar, Falia et de Fadiouth. ENDAGRAF, SAHEL, IRD, IUPA, FIBA. 16 p.

Drago, N., Kourgansky, A., Thiao, D., Mbaye, A., Bernard, I., & Le Bihan, E. (2023). Chaîne de valeur des huîtres au Sénégal : Rapport d'analyse et de conception de la chaine de valeur. Rome, FAO. 354 pages. http://www.unido.org/

Fall, M. (2009). S'adapter à la dégradation de l'environnement dans le Delta du Saloum: Variabilité des stratégies chez les femmes socés et niominkas du Sénégal, *9*(2). https://doi.org/10.4000/vertigo.8651

Gomes, C. H. A. M., Silva, F. C., Lopes, G. R., & Melo, C. M. (2014). The reproductive cycle of the oyster *Crassostrea gasar*. *Braz J Biol.*, *74*(4), 967-976. https://doi.org/10.1590/1519-6984.04912

Grizzle, R. E., Ward, K. M., Peter, C. R., Cantwell, M., Katz, D., & Sullivan, J. (2017). Growth, morphometric, and nutrient content of farmed eastern oysters, *Crassostrea virginica* (Gmelin), in New Hampshire, USA. *Aquac. Res.*, *48*(4), 1525-1537. https://doi.org/10.1111/are.12988

Harrison, W. G., & Platt, T. (1980). Variations in assimilation number of coastal marine phytoplankton: effects of environmental covariates. *J. Plankton Res., 2,* 249-260. https://doi.org/10.1093/plankt/2.4.249

Hayford, A., Effah, J. E., Fuseina, I., Abednego, P., & Richard, Y. (2021). Women in west african mangrove oyster (*Crassostrea tulipa*) harvesting, contribution to food security and nutrition in Ghana. *Oceanogr Fish Open Access J.*, *14*(1), 555-878. https://doi.org/10.19080/OFOAJ.2021.14.555878

His, E. (1991). Biologie et écotoxicologie des véligères de *Crassostrea gigas* (Thunberg) dans le bassin d'Arcachon. PhD Thesis, Université Bordeaux 1. https://archimer.ifremer.fr/doc/00000/3347/

Lopes, G. R, Gomes, C. H. A. M., Tureck, C. R., & de Melo, C. M. R. (2013). Growth of *Crassostrea gasar* cultured in marine and estuary environments in Brazilian waters. *Pesq. Agropec. Bras., 48*(7), 975-982. https://doi.org/10.1590/S0100-204X2013000800024

Mahu, E., Sanko, S., Kamara, A., Chuku, E. O., Effah, E., Sohou, Z., Zounon, Y., Akinjogunla, V., Akinnigbagbe, R. O., Diadhiou, H. D., *et al.* (2022). Climate resilience and adaptation in West African oyster fisheries: an expert-based assessment of the vulnerability of the oyster *Crassostrea tulipa* to climate change. *Fishes*, *7*(4), 205. https://doi.org/10.3390/fishes7040205

Morales, J. S. (2014). Liens entre la météorologie et l'abondance de phytoplancton dans l'océan à partir d'images satellites. Essai. Maitrise en environnement. Université de Sherbrooke. 61 pages. https://savoirs.usherbrooke.ca

Oliveira, L. F. S., Ferreira, M.A.P., Juen, L., Nunes, Z.M.P., Pantoja, J.C.D., da Paixão, L.F., de Lima, M.N.B. & da Rocha, R.M. (2018). Influence of the proximity to the ocean and seasonality on the growth performance of farmed mangrove oysters (*Crassostrea gasar*) in tropical environments, *Aquaculture*, *495*, 661-667, ISSN 0044-8486.

Osei, I. K., Yankson, K., & Obodai, E. A. (2020). Demographic and profitability analyses of the West African mangrove oyster (*Crassostrea tulipa*) fishery in the Densu delta, Ghana. *Journal of Fisheries and Coastal Management*, *2*, 12-22. https://doi.org/10.5455/jfcom.20190528122752

Rebelo, M. F., Amaral, M. C. R., & Pfeiffer, W. C. (2005). Oyster condition index in *Crassostrea rhizophorae* (Guilding, 1828) from a heavy-metal polluted coastal lagoon. *Braz. J. Biol., 65*(2), 345-351. https://doi.org/10.1590/S1519-69842005000200019

Sarr, M. (2009). Les effets de la dégradation des écosystèmes de mangroves dans la dynamique migratoire des populations des iles du Saloum : cas des villages de Bassoul et de Niodior. Ecole Nationale d'Economie Appliquée / Université Cheikh Anta DIOP de Dakar. Mémoire en ligne. https://www.memoireonline.com/05/11/4539/

Thiam, N., Clotilde Bâ, F. L., & Sy, M. D. (2011). Inventaire, étude biométrique et variabilité de l'abondance locale de *Crassostrea gasar* (Adanson, 1891) dans deux sites de la Réserve de Biosphère du Delta du Saloum. *J. Sci. Hal. Aquat., 4,* 134-142.

https://doi.org/10.5296/jbls.v14i2.20932

Thiao, I. (2024). Bioécologie et essais d'élevage de l'huître de mangrove *Crassostrea tulipa* Lamarck, 1819 dans le delta du Saloum. Thèse de doctorat, Université Cheikh Anta Diop de Dakar, 13/02/2024. 123 p.

Thiao, I., Diouf, J. E., Diouf, M., Tamigneaux, É., Fall, J., Houménou, A. K., & Fontaine, P. O. (2024). Histological Study of the Sex Ratio and Reproductive Cycle of the Mangrove Oyster *Crassostrea tulipa* (Lamarck, 1819) in the Saloum Delta (Senegal). *Journal of Biology and Life Science*, *15*(2), 16-32. https://doi.org/10.5296/jbls.v15i2.22079

Thiao, I., Fall, J., Tamigneaux, E., Diouf, J. E., Houménou, A. K., & Diouf, M. (2023). 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. *Journal of Biology and Life Science*, *14*(2), 75-89. ISSN 2157-6076. https://doi.org/10.5296/jbls.v14i2.20932

Turner, J. P. (2014). Oysters: Biology, Consumption and Ecological Importance. Nova Science Publishers Inc, USA. 138 p. ISBN: 978-1-62948-806-6

Wélé, M., Chuku, E. O., Abrokwah, S., Kent, K., & Crawford, B. (2021). Participatory Assessment of Shellfisheries in the Estuarine and Mangrove Ecosystems of Senegal. Centre for Coastal Management (Africa Centre of Excellence in Coastal Resilience) University of Cape Coast, Ghana and Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island. Narragansett, RI, USA. 29 p. https://doi.org/10.13140/RG.2.2.19295.9488.1

Wellesley-Cole, C., & Kamara, A. B. (1978). Studies on the condition factor of the Sierra Leone mangrove oyster (*Crassostrea tulipa*). *Bulletin of the Institute of Marine Biology & Oceanography*, Fourah Bay College, University of Sierra Leone, *3*(1), 27-33. http://hdl.handle.net/1834/21796.

Yankson, K., Plamar, W. A., & Obodai, E. A. (1996). Seasonal changes in biochemical composition of the mangrove oyster, *Crassostrea tulipa* (Lamarck, 1819) occurring in two coastal water bodies in Ghana. *Ghana Journal of Sciences*, *31*(36), 37-43. https://doi.org/10.4314/gjs.v36i1.47981