

Spatio-Temporal and Bathymetric Variability in the Intensity of *Crassostrea tulipa* Spat Collection in the Village of Niodior (Saloum Delta, Senegal)

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Abstract

In Senegal, natural stocks of *Crassostrea tulipa* mangrove oysters are overexploited and oyster farming is very underdeveloped. The development of oyster farming in the mangrove ecosystems of Senegal and West Africa requires the modernization of techniques, both for spat collection and for grow-out in oyster beds. The objective of this study was to assess the seasonal and bathymetric variability of spat collection. To do this, limed cups were deployed every three months between November 2021 and November 2022 at two contrasting sites. Spat collection was observed during the four quarterly periods and was more intense during the rainy season. Alternately submerged collectors showed the best collection rates (53 ± 28 spats per cup) compared to permanently submerged collectors (2 ± 2 spats per cup) and observations indicate that exposure of collectors to air at low tide limited predation and the development of marine fouling. When comparing the sites, spat collection was better at Baobab Rasta for permanently submerged collectors and, conversely, at Akat for collectors that were alternately submerged and exposed.

Keywords

Spat Collection, Oyster, Mangrove, Saloum Delta

1. Introduction

In Senegal, oysters are of considerable socioeconomic importance. For communi-

ties living in mangrove areas, this resource is the second largest source of protein after fish [1]. National oyster production is estimated at around 16,000 tons, of which 15,600 tons come from harvesting (97.5%) and 400 tons from oyster farming (2.5%) [1]. There are two main sales channels: processed oysters, a traditional product with low added value, and fresh oysters, sold at a higher price in supermarkets, restaurants, and hotels. Harvesting is seasonal and generally takes place between January and June. With growing market demand, pressure on natural stocks has become very intense. Particularly in the Saloum Delta, overexploitation has reached alarming levels. A recent study showed that, after two years of monitoring, only 6% of oyster populations had reached the minimum market size of 6 cm, as required by national regulations [2].

Oyster farming has changed very little in technical terms. The use of the oyster string cultivation technique, which is the most common, has several limitations. Thus, the sizes of the oysters at harvest are heterogeneous, resulting in the smaller ones being discarded. Furthermore, it is difficult to obtain individual oysters, which, when sold by the dozen, have greater added value. To sell the oysters grown on ropes by the dozen, farmers must separate them after harvesting. The disadvantage is that the separation process can damage the shells of several oysters, sometimes resulting in significant losses.

Large-scale oyster farming requires the use of effective methods for supplying high-quality spat to the farmers. Research on hatchery techniques for the mass production of *C. tulipa* spat is limited [3]. Although *C. tulipa* spat production has already been successfully achieved in the laboratory [4], the high cost of marine microalgae culture facilities to feed larvae and spat and the difficulty of replicating these facilities in some countries are significant barriers to the adoption of this strategy [5] [6]. Due to these limitations, and as is done for other oyster species in different parts of the world [3] [7], the alternative is to collect spat from the wild using artificial substrates such as plastic cups, which are the most effective and widely used technique in countries where oyster farming is highly developed.

To date, no studies have been conducted in the Saloum Delta on the collection of *C. tulipa* oyster spat on artificial substrates. However, in order to develop sustainable oyster farming based on the collection of spat in the natural environment, it is essential to select the right sites, the ideal depth and the best periods for deploying collectors.

In this context, the objectives of this study were to monitor the variability in spat collection intensity according to the season and the bathymetric level of the collectors in the water column at two sites with distinct characteristics.

2. Material and Methods

2.1. Study Area

The study was conducted in the village of Niodior, located in the Saloum Delta in central-western Senegal (Figure 1). This is an estuarine area with a mangrove forest whose stilt roots provide the main support for the *C. tulipa* oyster. In Niodior,

fishing and fish processing play an important role in the socio-economic activities of the communities.

The spat collection sites were Akat ($13^{\circ}51.125'$; $016^{\circ}44.209'$) and Baobab Rasta ($13^{\circ}51.792'$; $016^{\circ}43.003'$) bolongs. At these sites, located near the mouth of the delta, the tidal range varies between 1.2 m at high tide and 0.5 m at low tide. Salinity varies considerably, with an average of between 25‰ and 43‰, and an average of 33.16‰ [8]. The Akat bolong is closer to the ocean (Figure 1) and it is also wider (more than 100 meters) and shallower than the Baobab Rasta bolong with a width of less than 10 meters and an average depth of around 3 meters at low tide. During low tide at Akat, approximately more than 80% of the seabed is exposed, and the deepest parts do not exceed 2 meters. The substrate is sandy-muddy at Akat, while it is muddy at Baobab Rasta. The mangrove is also denser at the Baobab Rasta site than at Akat site (Figure 1).



Figure 1. Location of the two spat collection sites around the village of Niodior (Saloum Delta, Senegal, West Africa).

2.2. Collection Equipement

The collectors used in this study are strings of cups (Intermas brand from Inter-mas Group, No. 45). They were limed by dipping them in a mixture of cement, lime, and sand to cover them with a thin film (Figure 2). To ensure that this coating layer hardened properly, the limewashed cups were dried and sprayed with water for four days, in the shade and sheltered from the wind. The limewashing mixture consisted of 30 kg of lime, 50 kg of Portland cement, and 50 kg of fine sand.

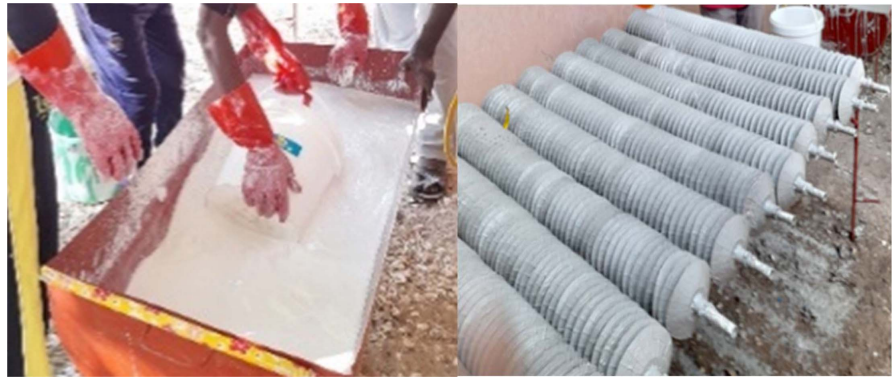


Figure 2. Lime wash and whitewashed cups.

2.3. Experimental Procedure

At each site, twelve strings, each containing forty-five plastic cups, were deployed horizontally on metal supports. The supports were installed at the edge of the mangrove, near the roots of the mangrove trees. The depth of the locations was such that the collectors were flush with the water surface during low tide periods and were always covered by water. They were collected and replaced every three months between November 2021 and November 2022. In other words, over the course of a year, four quarterly collection series were carried out on these low supports during the periods November 2021-February 2022 (Q1), February-May 2022 (Q2), May-August 2022 (Q3), and August-November 2022 (Q4).

To monitor bathymetric and inter-site variation, higher supports were deployed during the period August-November 2022 (Q4) so that the cups were at the same level as the roots colonized by oysters. The collectors placed on the tall supports allowed the cups to be completely exposed at low tide.

2.4. Assessment of Spat Collection Intensity

At the end of each quarterly period, three strings of cups were sampled at random. From each of these strings, three cups were subsampled: one in the middle and one at each end. This corresponds to nine cups per site. The count was made on both sides of the cups and included all visible and living spats.

The average number of spats captured per cup (N) was calculated using the following formula:

$$N = \frac{(n1 + n2 + n3 + n4 + n5 + n6 + n7 + n8 + n9)}{9}$$

With $n1, n2, n3, n4, n5, n6, n7, n8, n9$ the number of spats found on each of the nine cups considered.

2.5. Statistical Analyses

Data processing and graphs were produced using Microsoft Office Excel 2013. One-way analysis of variance (ANOVA) and the minimum significant difference test (Z-test) were used to study differences in capture intensities, highlighting the

effect of season, site, and exposure. Differences were considered significant when the p-value is ≤ 0.05 .

3. Results and Discussion

3.1. Results

3.1.1. Spatio-Temporal Variations in Collection

The results showed seasonal and spatial variations in spat collection. For both sites combined, the average number of spats collected per cup was 14 ± 5 , 15 ± 6 , 23 ± 16 , and 12 ± 15 for the quarterly periods Q1, Q2, Q3, and Q4, respectively. When comparing the two sites, the results showed that the Baobab Rasta site had the best capture rate in all of the four monitoring periods (Figure 3). The analysis of variance, the results of which are presented in Table 1, shows a significant inter-site effect for the quarterly periods Q1, Q3, and Q4.

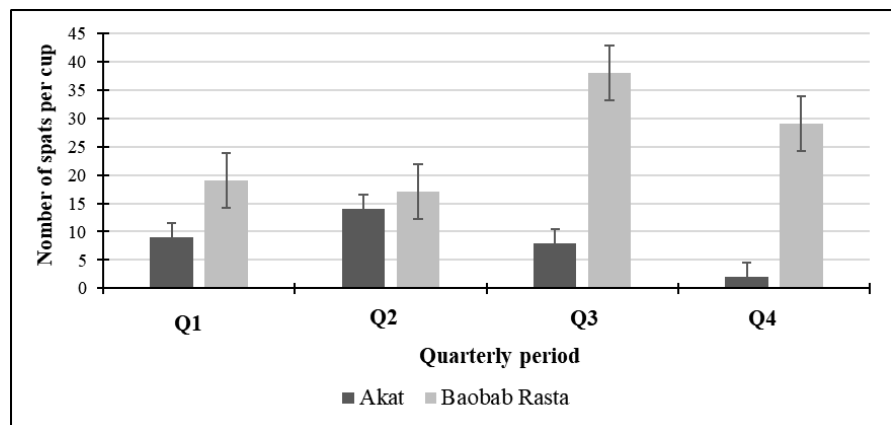


Figure 3. Average number of spats collected per cup ($n = 3$) at the different sites and over the four quarterly periods. Q1 = November 2021 - February 2022; Q2 = February-May 2022; Q3 = May-August 2022; Q4 = August-November 2022.

Table 1. Comparison of the variance in capture intensity between sites for each monitoring period.

Source of variations	p-value	Interpretation code
Q1 Akat vs Baobab Rasta	0.000008	****
Q2 Akat vs Baobab Rasta	0.11	ns
Q3 Akat vs Baobab Rasta	0.00001	****
Q4 Akat vs Baobab Rasta	0.00004	****

ns = non-significant; **** = very highly significant.

Within each site, there were seasonal differences in the intensity of spat collection and comparison tests showed significant differences depending on the quarterly periods (Table 2). For Akat, uptake was higher in Q2 and lower in Q4. For the Baobab Rasta site, the differences in spat collection were highly significant between Q3 and Q1 on the one hand, and between Q3 and Q2 on the other (Table 2).

Table 2. Comparison of the variance in spat collection intensity between monitoring periods for each site: p-value and significance of differences.

Source of variations	p-value	Interpretation code
Akat Q1 vs Q2	0.108	ns
Akat Q1 vs Q3	0.478	ns
Akat Q1 vs Q4	0.0006	****
Akat Q2 vs Q3	0.032	*
Akat Q2 vs Q4	0.00008	****
Akat Q3 vs Q4	0.002	***
Baobab Rasta Q1 vs Q2	0.018	**
Baobab Rasta Q1 vs Q3	0.0006	****
Baobab Rasta Q1 vs Q4	0.335	ns
Baobab Rasta Q2 vs Q3	0.0001	****
Baobab Rasta Q2 vs Q4	0.042	*
Baobab Rasta Q3 vs Q4	0.005	***

ns = non-significant; * = marginally significant; ** = moderately significant; *** = highly significant; **** = very highly significant.

3.1.2. Bathymetric Variation in Spat Collection

The average number of spats collected per cup for each site and according to the bathymetric positions of the collectors are reported in **Table 3** and presented in **Figure 4**. When the spat collection between August and November 2022 is analyzed according to the bathymetric positions of the collectors, there are very significant differences in collection at Akat (p-value = 0.000007) and no significant differences at Baobab Rasta (p-value = 0.13) (**Table 4**). At Akat, collection on cups exposed during low tide was 29 times greater than on those permanently submerged (**Table 3**). At Baobab Rasta, average collection was 47 ± 30 spat per cup for exposed collectors and 29 ± 13 spat per cup for those permanently submerged (**Table 3**). For permanently submerged collectors, there was a significant difference in collection between the two sites (p-value = 0.00004), with Akat recording more than 14 times greater collection than Baobab Rasta (**Table 3**), while the difference was not significant for alternately exposed collectors (p-value = 0.44) (**Table 4**).

Table 3. Bathymetric variations in spat collection and observations at the Akat and Baobab Rasta sites during the rainy season (mean \pm standard deviation).

Position of the collector at low tide	Akat (spats per cup)	Baobab Rasta (spats per cup)	Observations
Submerged	2 ± 2	29 ± 13	High amount of biofouling (algae, tunicates, colonial and non-colonial ascidians, sponges, barnacles, etc.), predators (thais, crabs, melongena) especially in Akat
Emerged	58 ± 26	47 ± 30	Very low amount of biofouling and predators

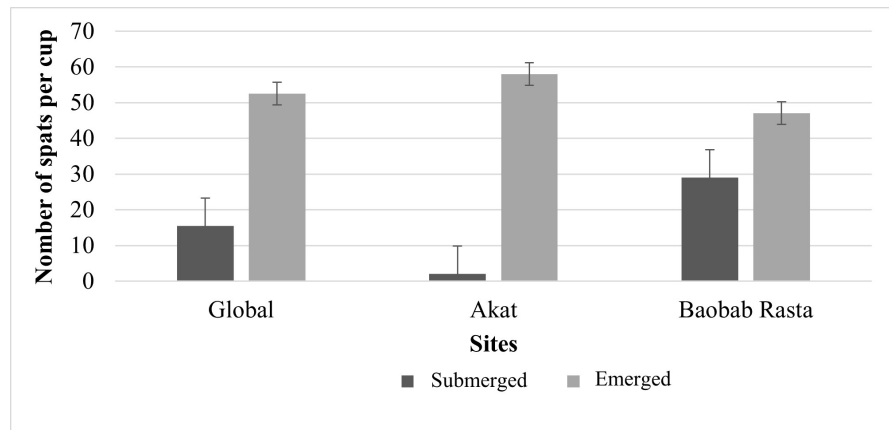


Figure 4. Bathymetric variations in spat collection at Akat and Baobab Rasta sites during the rainy season between August and November 2022 (mean \pm standard deviation).

Table 4. Comparison of the variance in capture intensity highlighting the exposure/immersion effect for each site and the site effect for each bathymetric position.

Source of variations	p-value	Interpretation code
Emerged and submerged Akat	0.000007	****
Emerged and submerged Baobab Rasta	0.13	ns
Submerged Akat et Baobab Rasta	0.00004	****
Emerged Akat et Baobab Rasta	0.44	ns

3.2. Discussion

The use of plastic cups is very common in developed countries, but in tropical areas, this culture strategy remains poorly documented [9] [10]. Several studies have tested the effectiveness of different types of collectors for capturing *C. tulipa* spat [3] [11] [12]. The investigations generally consisted of comparing collection intensities according to the types of collectors, their upper and lower surfaces, their horizontal, vertical and oblique orientations, etc.

The aim of this study was to investigate the possibility of collecting spat throughout the year and to identify the period(s) that are most conducive to successful collection. The investigations also focused on the effects of collectors being exposed during low tides (bathymetric level) and on the distinctive characteristics of two contrasting sites.

Analysis of the results revealed that, in the region studied, it is possible to collect *C. tulipa* spat in all seasons, as young oysters were found on the cups during all four quarterly periods. This confirms the findings of Thiao *et al.* [2], who concluded, based on a histological study, that reproduction was continuous in this species. In Ghana, Chuku *et al.* [3], who monitored the collection of spat of this species on different types of collectors monthly for one year, found similar results.

As for the periods offering the best catchments, they differ between the two sites. These differences, as they stand, could be due to the fact that oyster spawning is not synchronized at the individual or population level for oysters of this species

[2]. In fact, it has been reported that oysters of the genus *Crassostrea* can spawn several times during the same reproductive season [11]. In addition, gamete maturation is closely linked to environmental factors, particularly temperature and nutrition [13] [14] which may not be uniform for distant sites with distinct characteristics. The Baobab Rasta site offered the best spat collection results throughout the monitoring period, especially during periods Q3 and Q4 (May-August and August-November), both of which correspond to the rainy season. The highest catches in the cups at Baobab Rasta during the rainy season are consistent with the information from the histological study of the reproductive cycle conducted by Thiao *et al.* [2], but also with the dynamics of recruitment in the natural environment [8] [15]. Furthermore, 20 years ago, July-November period (hot and rainy season) had already resulted in better spat collection at two sites in Casamance [16].

For Akat site, which is less sheltered, the strong turbulence may have made it more difficult for the larvae to attach themselves to the cups. In addition, the fact that light probably penetrates to the bottom of this wide, shallow bolong would encourage algae to invade the collectors. This could cause the death of spat already attached by suffocating them and prevent the attachment of larvae arriving after the development of these invasive organisms, thus reducing the density of spat on the cups. Rayssac *et al.* [10] found similar phenomena when studying the effects of exposure and permanent immersion on the collection of *Crassostrea gigas* spat in the Mediterranean and the Thau basin in 2011. According to them, the exposure of collectors to air limits the development of marine fouling and improves the intensity of spat collection.

In addition to these factors limiting larval attachment, predation may also play a role, intensifying during the winter season (end of Q3 and beginning of Q4). Indeed, based on our field observations, a high presence of predators was noted during this period, especially in Akat. In the study done by Chuku *et al.* [3], predation was put forward as an explanation for the lower abundance of oyster spat on the upper sides of the collectors used.

This hypothesis is also corroborated by the fact that the intensity of spat collection was much greater on cups that were completely exposed at low tide. This phenomenon can be explained by the fact that predators, particularly Thai species, cannot survive prolonged exposure to air, unlike oysters, which are able to remain alive out of water for up to 24 to 48 hours, at least if they are in the shade [8].

In France, part of the Velyger project, where the collector chosen as a reference was the cup, the average spat collection (*C. gigas*) in 2010 were 17 spats per cup, 71 spats per cup, and 63 spats per cup in the areas of Rade de Brest, Baie de Bourgneuf, and Pertuis de Marennes Oléron, respectively [17]. The intensity of these catches was described as moderate [17]. The same source considers a catch of less than 10 individuals/cup to be low and a catch of more than 100 individuals/cup to be excellent [17].

In comparison, the amount of spat collected on the permanently submerged

collectors would be considered low at Akat site for periods Q1, Q3 and Q4 and moderate at Baobab Rasta for all four quarterly periods.

In another study, an average catch of 57.08 spat per cup obtained also with *C. gigas* in France were found to be good [10]. This value is like those obtained in period Q4 of the present study with collectors exposed at low tide (58 ± 26 and 47 ± 30).

4. Conclusions and Suggestions

This study gathered important information that can guide the selection of sites, periods and bathymetric levels favorable to the successful collection of *C. tulipa* spat in the Saloum Delta. It emerged that the Baobab Rasta site, which is less turbulent, more shaded and has fewer predators, was more favorable to spat collection overall. It also appears that the alternation between immersion and emersion of the collectors increased the intensity of the collection, or the survival of the spat collected. Finally, this study also revealed that deploying the collectors at the beginning of the rainy season could well lead to optimal collection, especially if the design and bathymetric position of the cup support prevent or limit predation.

With these information, oyster farmers should be able to improve their production and achieve greater economic profitability. Collecting spat using limed cups and developing oyster farming could provide an alternative to harvesting oysters from mangrove roots, which has become an intensive practice, and would therefore have a protective effect on the mangrove.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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