Scientific Research Publishing

Journal of Environmental Protection, 2025, 16(8), 809-829
https://www.scirp.org/journal/jep
ISSN Online: 2152-2219
ISSN Print: 2152-2197

Dynamics of Colonization of Artificial Supports by Mangrove Oysters at Touguissouri (Republic of Guinea)

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How to cite this paper: Sangaré, O., Ouedraogo, I., Sawadogo, Y.M.-F., Gbaguidi, A.M and Oueda, A. (2025) Dynamics of Colonization of Artificial Supports by Mangrove Oysters at Touguissouri (Republic of Guinea). *Journal of Environmental Protection*, **16**, 809-829.
https://doi.org/10.4236/jep.2025.168042

Received: June 2, 2025
Accepted: August 26, 2025
Published: August 29, 2025

Abstract

Oysters from mangroves constitute an important food and economic resource for the coastal populations of Guinea. Unfortunately, traditional harvesting on mangrove roots is threatening these ecosystems, and climate change is exacerbating the risk of decline. This study analyses the colonisation of oysters on artificial supports in the Touguissouri estuary, by assessing interactions with barnacles, competing organisms, and the influence of physico-chemical parameters. Collectors were immersed at various depths. Environmental parameters such as salinity, pH, turbidity, etc. were measured, and the settlement of oysters and barnacles was monitored. The data collected was analysed and statistical tests were used to identify the factors influencing colonisation. High seasonal variability was observed, with high salinity in the dry season and increased turbidity in the wet season. pH and nutrients influence biological productivity. Larval settlement is optimal at a depth of 30 cm, where conditions are favourable. Recruitment peaks occur in the rainy season (July-October), correlated with high turbidity and a basic pH. Intermittent competitive exclusion is observed with barnacles and influenced by salinity and substrate availability. Artificial supports, particularly rough ones, improve the settlement of oysters, reducing pressure on mangroves. These results underline the importance of adapting substrates to local conditions for sustainable oyster farming. This study demonstrates the potential of artificial supports for oyster culture in Guinea, while identifying ecological constraints (competition, seasonal variability).

Keywords

Mangrove Oysters, Artificial Supports, Competition, Physico-Chemical

Parameters, Guinea

1. Introduction

Oysters are an essential food and economic resource for people living in coastal areas of Guinea. They are rich in high-quality proteins, omega-3 fatty acids, vitamins (notably B12), and minerals such as zinc, iron and calcium. Harvesting and selling oysters is a key economic activity for many families living along the coast. This activity generates regular income for the fishermen, oyster gatherers and local traders involved in the value chain. The study of the biology of mangrove oysters began in West Africa, with the development of agriculture in Senegal in 1948, followed by Sierra Leone in 1974, the Republic of Guinea in 1985, Gambia in 1988 and Nigeria in 1972, with the aim of satisfying the demand for oysters in hotels [1] [2]. Various research studies have revealed that fluctuations in environmental parameters affect the oyster reproductive cycle; in fact, ovocyte atresia preceding the reproductive periods is frequent (sometimes lasting 4 months), with sex changes revealed by a dominance of males over females, at different times of the year (facts observed between 1992 and 1993) [3]. Numerous research projects have produced highly interesting results on the ecology and biology of oysters in the Republic of Guinea and Senegal [3] [4]. With the exception of Senegal, mangrove oyster cultivation has developed alongside wild oysters, enabling many countries not only to develop an endogenous oyster market, but also to sell oysters on the international market. [5]. In addition, oysters are nutritionally rich, and are therefore capable of improving the nutritional status and health of the consumer; they contribute to the coverage of nutritional requirements. However, despite their high nutritional potential, the level of contamination of oysters sometimes limits their use; in fact, oysters are exposed to contamination by decomposing plant and animal waste, heavy metals such as mercury and other contaminants [6], copper and zinc [7], and pesticide residues. In their search for food, bivalve molluscs filter the water they absorb, retaining a substantial quantity of the bacteria present in the water. Fecal contamination is mainly due to *enterobacteria* (*E. coli*, *S. tuphi*, *S. enteridis*), enterococci (*C. clostredea; C. botulinum*) and *Staphylococci*. These pathogens are responsible for typhoid fever, vibriosis, botulism and hepatitis in humans, among others [8] [9]. Oysters are generally harvested in Guinea from the roots of mangrove trees, the emblematic trees of mangrove swamps, or from rocks where they naturally attach themselves not far from settlements. This settlement is achieved by the secretion of byssus, a set of very resistant protein filaments. Oyster larvae, known as veliger larvae, attach themselves to the roots of mangrove trees, immersed in the water, which provides an ideal support due to their rough surface and their proximity to the nutrients available in the mangrove ecosystem. The larvae develop on these roots and reach maturity, where they can be harvested. Once mature, the oysters are traditionally harvested by cutting the mangrove roots, a practice that can contribute to the gradual disappearance of mangrove species and a consequent reduction in oyster production. The risk of extinction of the species involved in this activity is even greater in the face of the consequences of climate change, manifested in the rise in water surface temperature, the disruption of the rainfall regime and the rise in sea level; in fact, these changes have accentuated the decline in mollusc production and productivity. Against this backdrop of ecological pressure and the search for sustainable solutions, growing oysters on artificial supports is a promising alternative. However, these supports are also colonised by other fixing organisms, notably barnacles, sessile crustaceans that develop in the same habitats as oysters. This cohabitation raises the question of possible ecological competition for space, resources or optimal settlement conditions [10]. Barnacles, although ecologically tolerant and capable of rapidly colonising new substrates, can massively occupy the available surfaces, to the detriment of oysters in the settling phase [11]. Understanding the dynamic interactions between oysters and barnacles on artificial supports is therefore crucial to improving oyster farming techniques in estuarine environments. With this in mind, a number of projects linked to oyster farming are being tested in the Republic of Guinea, particularly at the Ecole Supérieure du Tourisme et de l'Hôtellerie (ESTH). Since 2013, researchers from the ESTH Food Science and Nutrition Laboratory have been carrying out studies on various biological and experimental aspects of oysters in the Guinean coastal zone, with encouraging results [5] [8]. Thus, the general objective of this study is to test the colonisation dynamics of artificial supports by mangrove oysters. Specifically, this study aims to (1) characterise the physico-chemical conditions of the waters of the estuary; (2) determine the dynamics of oyster and barnacle settlement to artificial supports (3) analyse the influence of physico-chemical factors on the dynamics of oyster and barnacle settlement.

2. Materials and Methods

2.1. Study Area

Sangaréa bay, located between the prefectures of Dubréka, Coyah, Boffa and the communes of Ratoma, Dixinn and Kaloum (Conakry), covers an area of 38,000 ha, with a population of 23,480 inhabitants, and a surrounding population estimated at 49,318 inhabitants, grouped in 51 villages, 6 of which are inside the mangrove. The bay is divided into 18 development units, including 17 in mangrove swamps and the 18th behind mangrove swamps. Sangaréa Bay has been recognised as a wetland by the Ramsar Convention since 1992, and is located 50 km from the No. 2 main road (Conakry-Dubréka). Sangaréa Bay is fed to the north by the Konkouré River and to the east by the Soumba and Sonfonia rivers. It faces the Atlantic Ocean and consists of a long strip of coastal plain. Touguissouri Island (or Palm Island) is an area of the Khonia District, in the Khorira sub-prefecture, Dubréka prefecture. It is located in Sangaréah Bay. The proposed site is located on a secondary arm called "Mèlèmèlè" (Station C: Latitude 9˚82'162"N, Longitude 13˚67'311"W) between the Atlantic Ocean and the "Bouramaya" stream, around 500 m from the village of Touguissouri. It is a maritime marsh bordered by a Rhizophora and Avicennia mangrove. The Rhizophora are on the seafront and also line the channel. It is easy to access. From the point of view of the hydrographic network, it has fewer branches and its bed is relatively wide and deep (**Figure 1**).

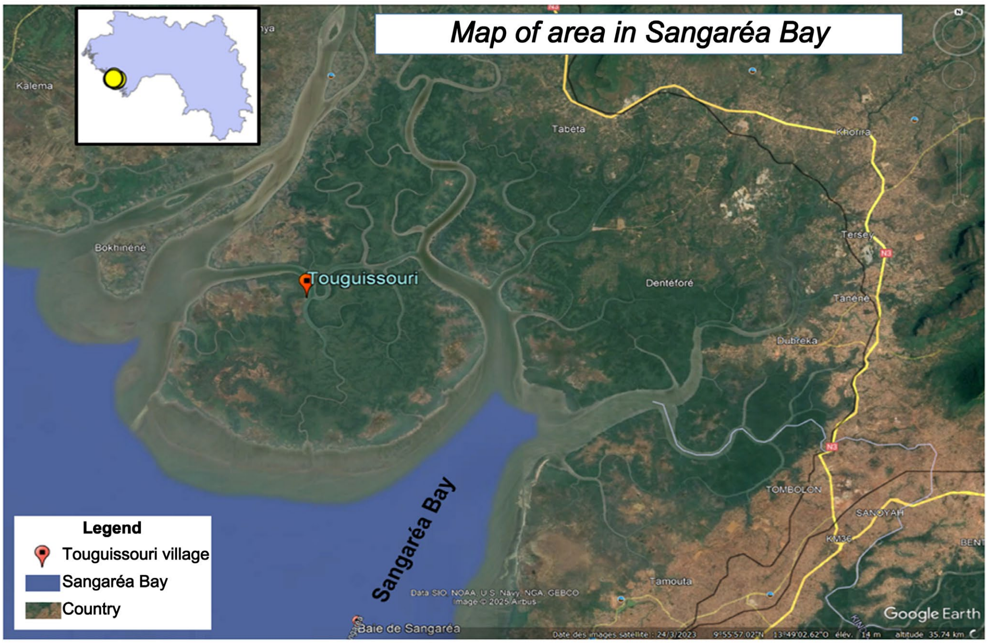

Figure 1. Map of Sangaréa Bay showing the study area.

2.2. Building Rafts and Manifolds

From the tyres and tiles, 10 cm^2 plates were cut, each with two faces: smooth and rough. Five plates were assembled in a string, 10 cm apart and sealed with capron rope and rubber hoses. A total of 8 collectors were made, 4 of rubber and 4 of tile. To make the frames, round timbers (2 m) were planted in the mud at a depth of 80 cm, starting at 1.5 m from sea level, and wooden sleepers were placed on top. The frames thus obtained had the following characteristics: L: 3 m and l = 1.50 m.

2.3. Measurement of Physico-Chemical Parameters

Physico-chemical parameters (salinity, pH, turbidity, dissolved oxygen, conductivity) were determined using a multi-parameter probe, depth using a depth gauge and transparency using a Secchi disc. Current speed and direction were determined using a buoy using the Lagrange method

2.4. Launching, Removal of Collectors and Counting of Biomaterials

During the study, three stations were considered for depth analysis. At each station, the frames were installed at different depths: 10 cm, 20 cm, 30 cm, 40 cm and

50 cm. A total of 88 collectors per depth were installed. Four collectors were placed on each frame; after two weeks, the oysters and barnacles were counted according to the different depths and replaced by four new collectors. The collectors that were removed were placed in plastic bags and transported to the laboratory for counting the specimens (oysters and barnacles). All specimens were counted, taking into account the type of substrate, the collectors and the depth.

2.5. Data Processing and Analysis

The collected data were entered into Excel and then analysed using R version 4.2.1 and Python 3.13.1 software. A descriptive analysis was performed to characterise the measured variables, including the physico-chemical parameters of the water (salinity, pH, etc.) and the attachment densities of oysters and barnacles on artificial substrates. Pearson or Spearman correlation analyses were applied to assess the relationships between the physico-chemical parameters and the attachment density of the organisms. Finally, multiple linear regression was performed to identify the physico-chemical factors that significantly influence the attachment of oysters and barnacles. The statistical significance threshold was set at $p < 0.05$. To identify the depths at which the differences between mangroves and rafts are significant, the Mann-Whitney test was used to compare the abundances between the two habitats with a significance threshold (e.g. $p < 0.05$). Next, the combined effects of depth and substrate (mangrove vs. rafts) on oyster abundance were assessed using a generalised linear model (GLM) with a negative binomial distribution, given the discrete nature and overdispersion of the data. The model included depth, substrate type and their interaction. The adequacy of the model was validated by inspecting the residuals. A Shapiro-Wilk test was used to check normality, and a Levene test was used to check the homogeneity of variances. A post-hoc test (Tukey's test) was used to identify the depths where habitats diverge. To identify the critical depth at which the difference between habitats becomes significant, a breakpoint analysis was used. To do this, a segmented regression was used to detect a change in slope in the difference in abundance (mangroves - structures) using the segmented or strucchange packages in Python.

3. Results

3.1. Physico-Chemical Conditions of the Water in the Estuary

The results of the physico-chemical variables reveal significant seasonal variability (**Figure 2**). The pH gradually increased from January (6.09) to October (8.33). This indicates a transition from a slightly acidic to a basic environment. Nitrate concentrations remain relatively high, varying between 30 and 48 mg/L. Nitrite levels ranged from 0.2 to 1.19 mg/L throughout the study period. Phosphate concentrations showed a marked decline between January and July, dropping from 57.4 mg/L to 25 mg/L, before experiencing a moderate increase to 37.96 mg/L by October. Iron levels remained consistently low, fluctuating only slightly between 0.31 and 0.45 mg/L. In contrast, alkalinity displayed a clear upward trend, nearly

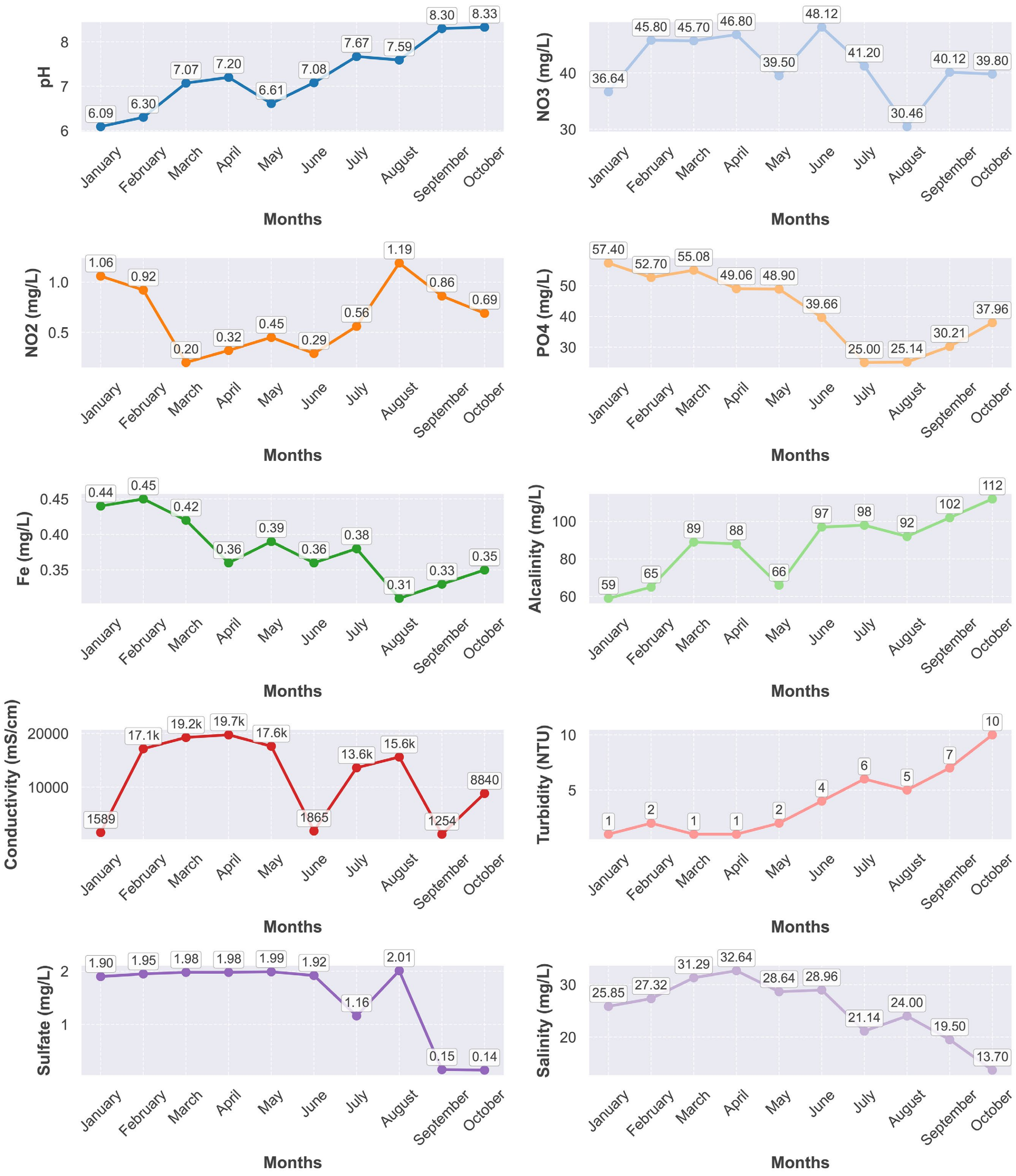

Figure 2. Variation in physico-chemical parameters during the study period.

doubling from 59 mg/L in January to reach 112 mg/L by the end of October. Values are very heterogeneous, with very high peaks between February and May (>17,000 µS/cm), followed by a significant drop in September (1254 µS/cm) and October (8840 µS/cm). Turbidity increased progressively until October (10 NTU), indicating an increase in suspended solids, linked in particular to rainfall, runoff and the resuspension of sediments. Sulphates remained slightly stable (1.9 - 2.01 mg/L) until August, then fell sharply in September (0.15) and October (0.14). Salinity falls sharply from March (31.29 g/L) to October (13.7 g/L), marking a clear transition between the salty dry season and the more diluted rainy season.

3.2. Dynamics of Oyster and Barnacle Settlement

3.2.1. Dynamics of Oyster Settling at the Level of Mangrove Banks and Mangroves

In the mangroves, peaks in oyster abundance were observed in August (6300), October (6300) and July (3500) (**Figure 3**). Periods of low abundance are in February (300), June (200) and December (1000). Peak abundance in the built environment occurred in August (7200), July (5100) and October (5700). The periods of lowest abundance are: January (500), June (300) and December (700) (**Figure 3**). ANOVA was used to compare oyster numbers between months. The result indicates that at mangrove level there is a significant difference ($p < 0.05$), mainly due to the months August/October vs. June/February. The Tukey post-hoc test shows that the homogeneous groups at mangrove level are: Group 1 (low abundance): February, June; Group 2 (medium abundance): January, March, April, December; Group 3 (High abundance); July, August, September, October. At the frame level, the ANOVA shows that the months differ significantly. The Wilcoxon test shows that August vs. June ($p < 0.01$) and July vs. February ($p < 0.05$). The months are grouped into 3 homogeneous groups (based on median abundance): Group 1 (low abundance) June, February, December; Group 2 (medium abundance): January, March, April and Group 3 (high abundance): July, August, September, October.

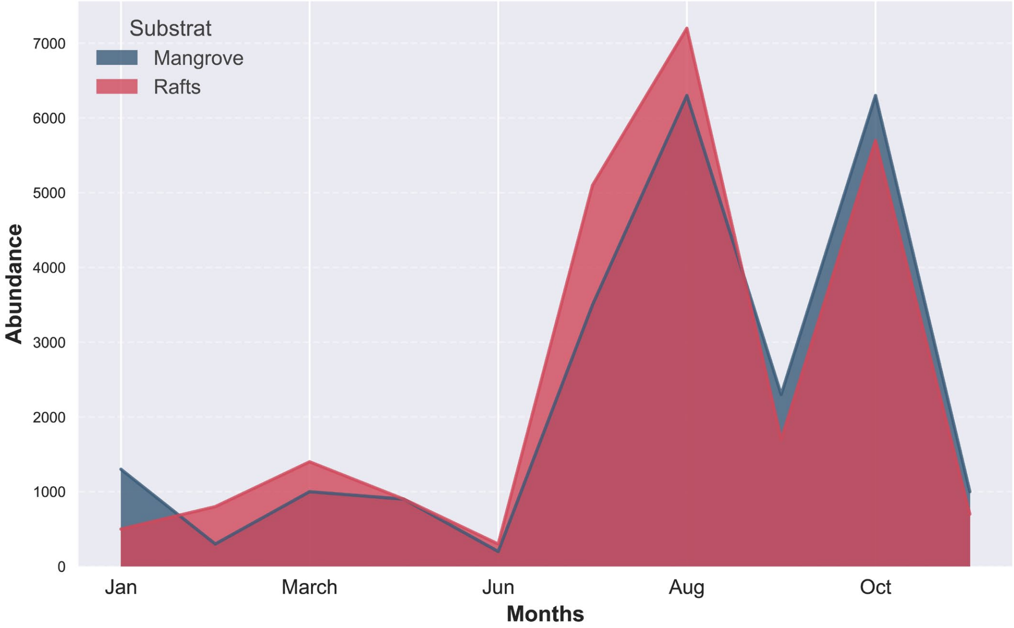

Figure 3. Dynamics of oyster settlement in mangrove swamps and rafts.

3.2.2. Dynamics of Barnacle Settlement to Rafts and Mangroves

Figure 4 shows the dynamics of barnacle settlement in mangroves and buildings. In mangroves, barnacle abundance peaks were observed in October (13,674), March (5066) and December (3836). Periods of low abundance are February, April, August (0 barnacles), and June (147). This indicates high variability, with a maximum in October and a second peak in March. In terms of buildings, peak abundance occurred in September (5207), December (4229) and March (3739), while the periods of lowest abundance were January (70), July (528) and August (651). Statistical analyses show that the distributions are not normal. The Mann-Whitney test ($p = 0.15$) shows that there is no significant overall difference between the two substrates (built-up areas and mangroves). The Kruskal-Wallis test shows a significant difference between the months at mangrove level ($p < 0.01$) and at rafts level ($p < 0.05$). The Wilcoxon pairwise comparisons with Bonferroni correction show that the similar months at mangrove level are: Group 1 (February, April, August); Group 2 (January, June, July, September); Group 3 (March, October, December). In terms of buildings, the homogeneous groups are: Group 1 (January, July, October); Group 2 (February, June, August); Group 3 (March, April, September, December).

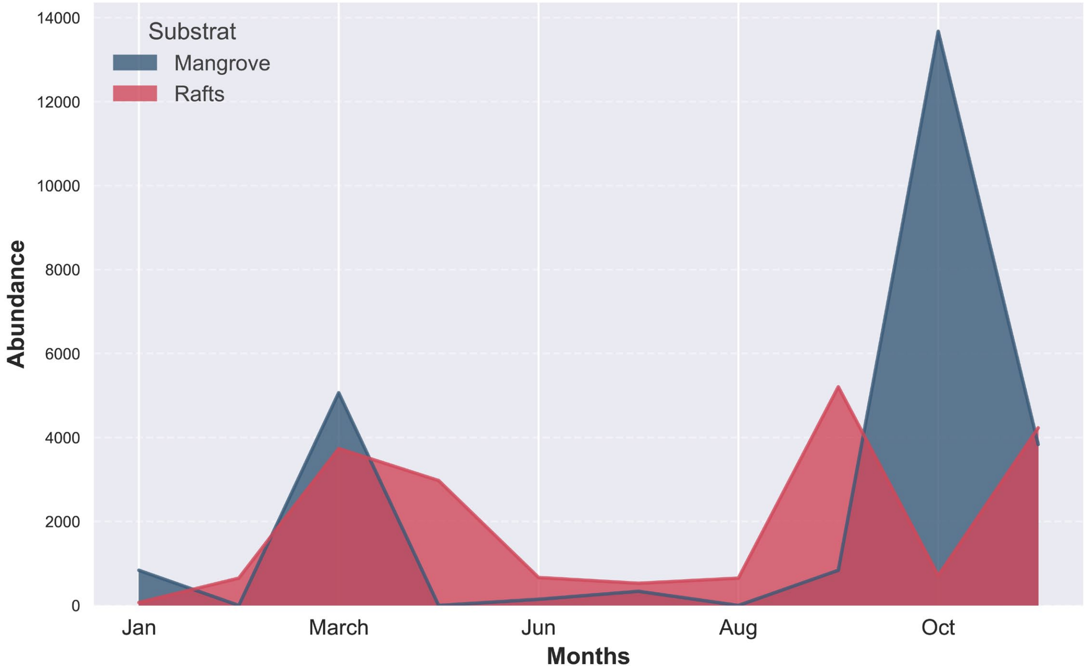

Figure 4. Dynamics of barnacle settlement to mangroves and rafts.

3.2.3. Competitions between Oysters and Barnacles in the Settlement of Mangroves and Mangroves

There is a marked seasonal dynamic in the abundance of oysters and barnacles on mangrove collectors, with wide variations suggesting competition for space and resources (**Figure 5**). In October, barnacles reached a very high peak (13,674), while oysters also peaked (6300). In August, oysters dominated (6300) while barnacles disappeared (0). The abundance of oysters remains high over several months, while barnacles have sudden collapses (February, April, August).

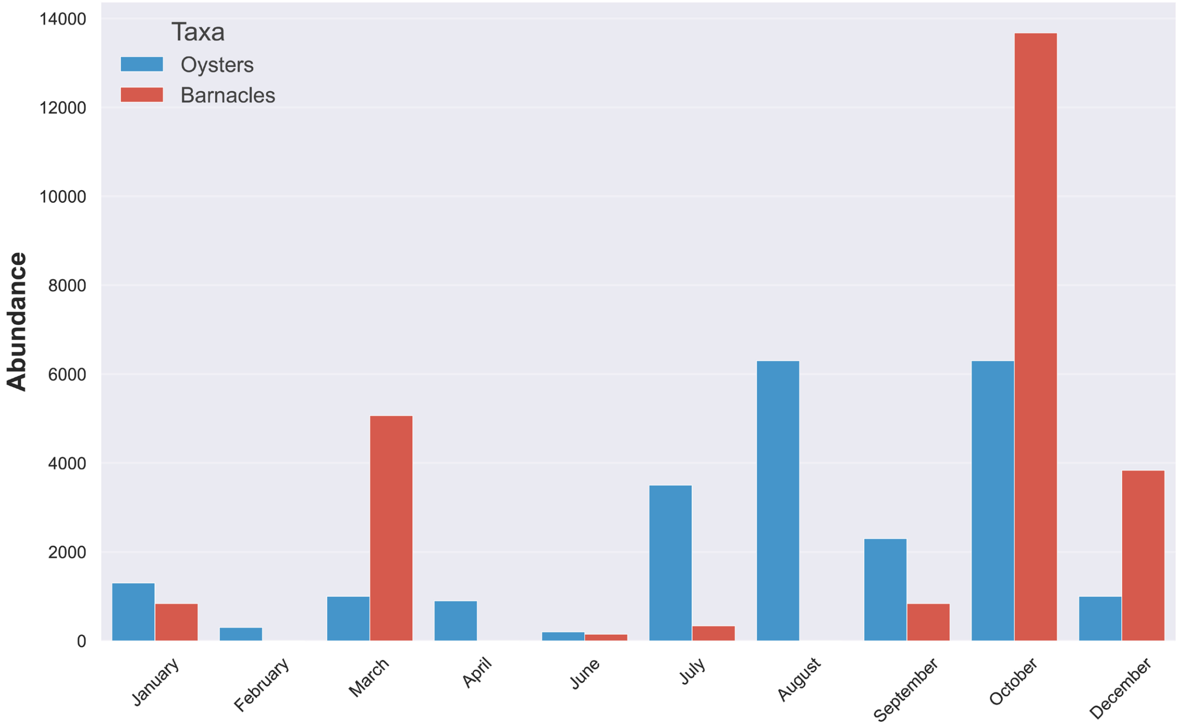

Figure 5. Settlement dynamics of oysters and barnacles in mangroves.

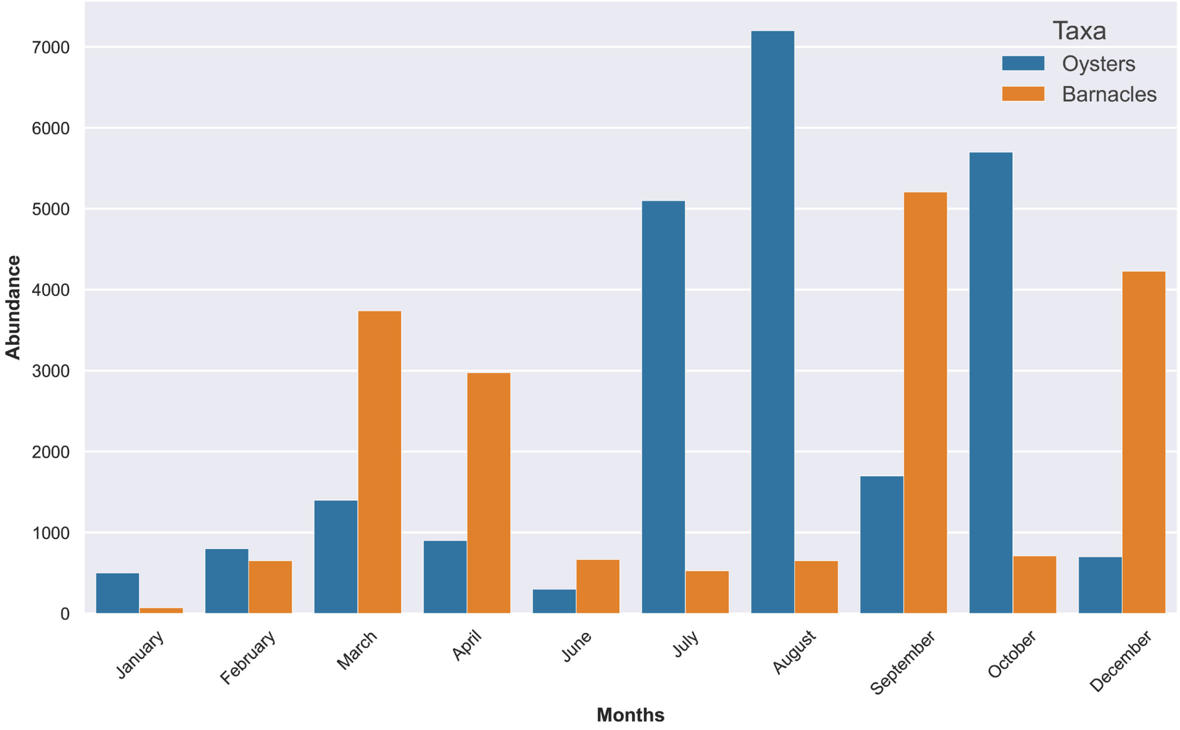

Figure 6. Dynamics of oyster and barnacle settlement to rafts.

The data show dynamic competition between oysters and barnacles on the collectors in the buildings, with marked seasonal variations (**Figure 6**). Unlike the mangroves, where barnacles have extreme peaks (e.g. 13,674 in October), their abundance in rafts is generally more moderate, but with interesting interactions. There are periods of alternating dominance: in March barnacles (3739) dominate oysters (1400); in September barnacles reach a major peak (5207) while oysters (1700) are in decline. In the July-August-October period, oysters dominate (5100 in July, 7200 in August), while barnacles remain low (528 in July, 651 in August). There is no situation where both species simultaneously reach extreme peaks.

When we look at the overall abundance of oysters and barnacles, whatever the type of habitat, we see a sort of exclusive competition; when oysters are very abundant (e.g. August), barnacles fall (0 in mangroves, 651 in houses). Conversely, when barnacles explode (October in mangroves), oysters remain stable (6300), suggesting a temporary coexistence (**Figure 7**). Oysters dominate in the built-up areas and barnacles dominate in the mangroves.

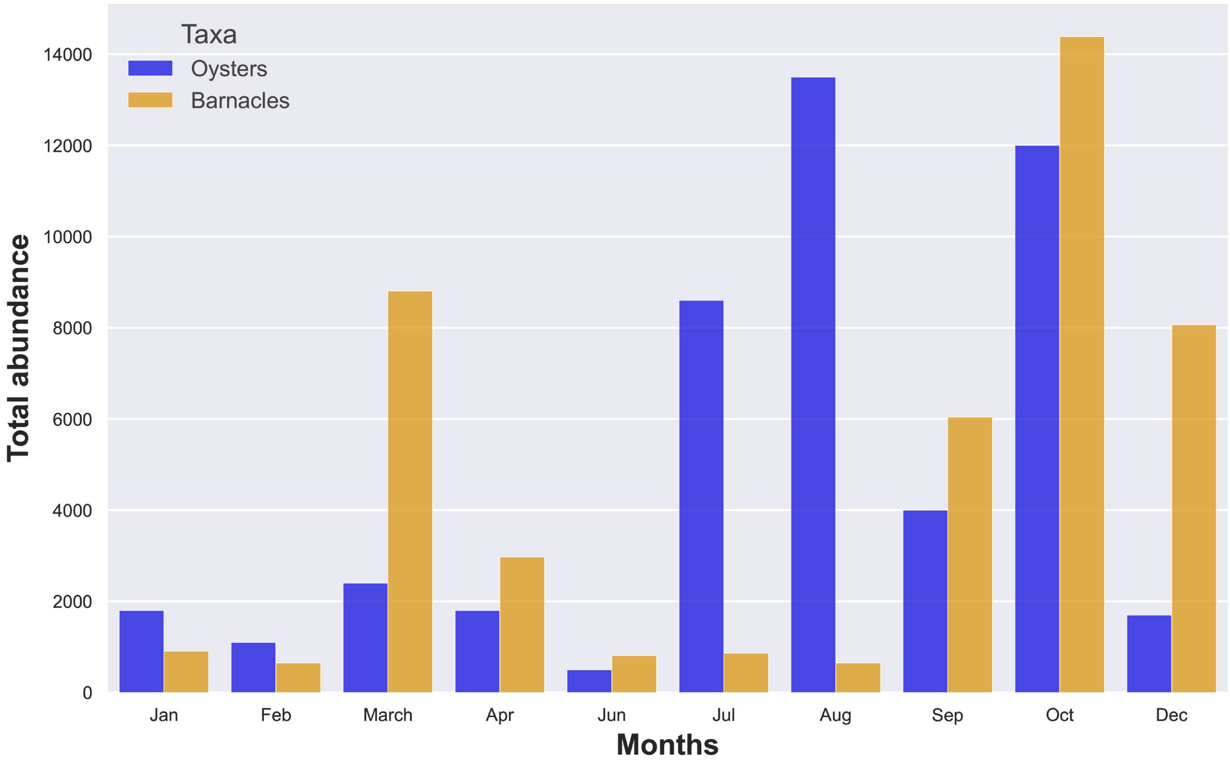

Figure 7. Dynamics of oyster and barnacle settlement.

An overall comparison was made using the Mann-Whitney test. The results show that there is no significant difference between rafts ($p = 0.238$) and mangroves ($p = 0.705$). The spearman correlation shows a negative correlation (−0.33), which is not significant for rafts ($p = 0.347$). The same was true for mangroves (-0.24; $p = 0.503$). The competition index was 0.94 in the rafts, indicating an environment favourable to oysters, and 1.33 in the mangroves, indicating an environment favourable to barnacles. Analysis by key period using a two-factor ANOVA (Species x Month) shows that competition at rafts varies from month to month ($p < 0.05$). In order to identify the months of strong competition, Tukey's post-hoc test shows significant differences in September between oysters and barnacles. In mangroves, the interaction between species and month is very significant. The Tukey post-hoc test shows significant differences for the months of March ($p < 0.05$), where barnacles (5066) > oysters (1000); and October ($p < 0.001$), where barnacles (13674) > oysters (6300).

3.2.4. Fixation of Oysters According to Depth at the Level of Mangrove Swamps and Rafts

Figure 8 shows the abundance of oysters as a function of depth in collectors attached to mangroves and those attached to buildings. In the mangroves, oyster abundance increased from 3596 (10 cm) to 5660 (50 cm). At the level of rafts, it increased from 3296 (10 cm) to 5633 (50 cm). At shallow depths (10 - 20 cm), mangroves are slightly more abundant (3596 vs 3296 at 10 cm). At 20 cm, the banks seem more favourable (4371 vs 3946). At 30 cm and above, the abundance of buildings is systematically higher than that of mangroves up to 40 cm (5615 vs 5469). At 50 cm, the values converge (5660 in mangroves vs 5633 in buildings). It can also be seen that between 40 cm and 50 cm, the increase in abundance slows down in Mangroves and Bâtis. Rack collectors could therefore be promoted to improve oyster production in Guinea. Shapiro-Wilk showed a normality ($p = 0.117$), and the Levene test ($p = 0.998$) and egality of variance. There was a significant interaction between depth and substrate ($p = 0.02$) in the GLM with a negative binomial distribution. Such a result suggests that oyster abundance patterns vary

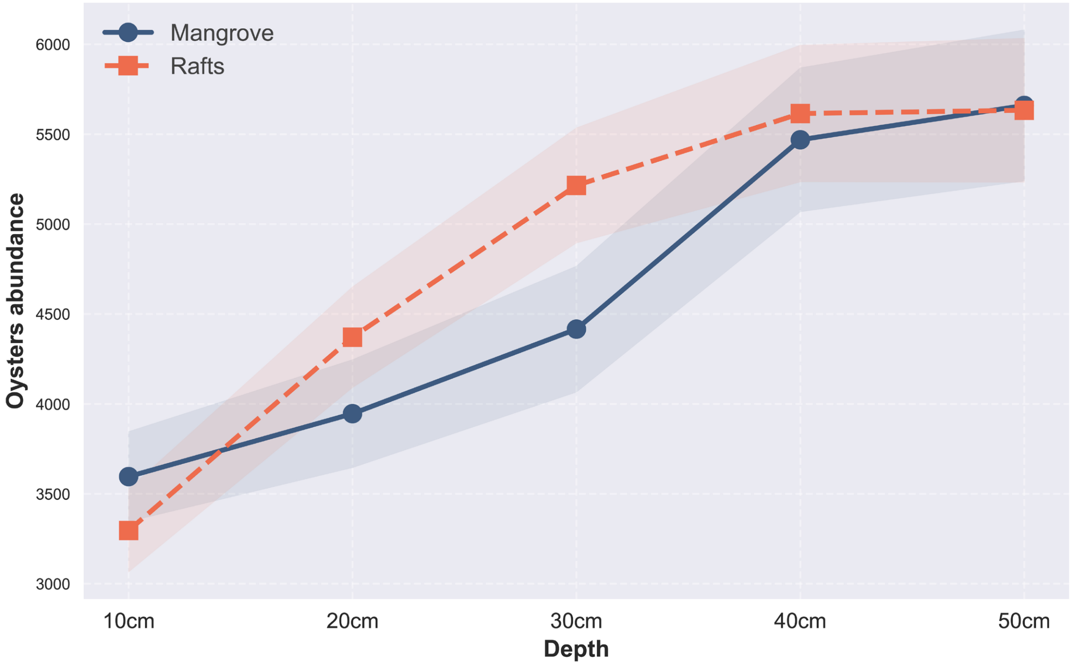

Figure 8. Dynamics of oyster settling according to depth in Mangroves and rafts.

with both depth and habitat. The further analysis using Tukey's correction showed that there were significant differences in oyster abundance between mangrove and rafts at depths of 20 cm ($p = 0.03$) and 30 cm ($p = 0.01$), but not at shallower or deeper depths ($p > 0.05$). This indicates that the substrate effects on oyster abundance are depth-dependent, with the most important differences occurring at intermediate depths. Breakpoint analysis reveals that 30 cm is the critical threshold at which the dynamics of oyster abundance change. At depths < 30 cm, the banks are significantly more favourable, while at depths ≥ 30 cm the mangroves close the gap, with non-significant differences at 40 - 50 cm.

3.3. Influences of Physico-Chemical Parameters on the Dynamics of Oyster and Barnacle Settlement

Oysters seem to be more abundant in turbid waters (+0.70) and high pH (+0.63). However, they seem to avoid waters rich in nutrients and salt (NO_3: −0.72, PO_4: −0.70, Salinity: −0.68). As for barnacles, they show a moderate correlation with pH (+0.40) and turbidity (+0.36); very weak or even negligible correlations with NO_3, PO_4 and salinity and few strong correlations with the other parameters (**Figure 9**).

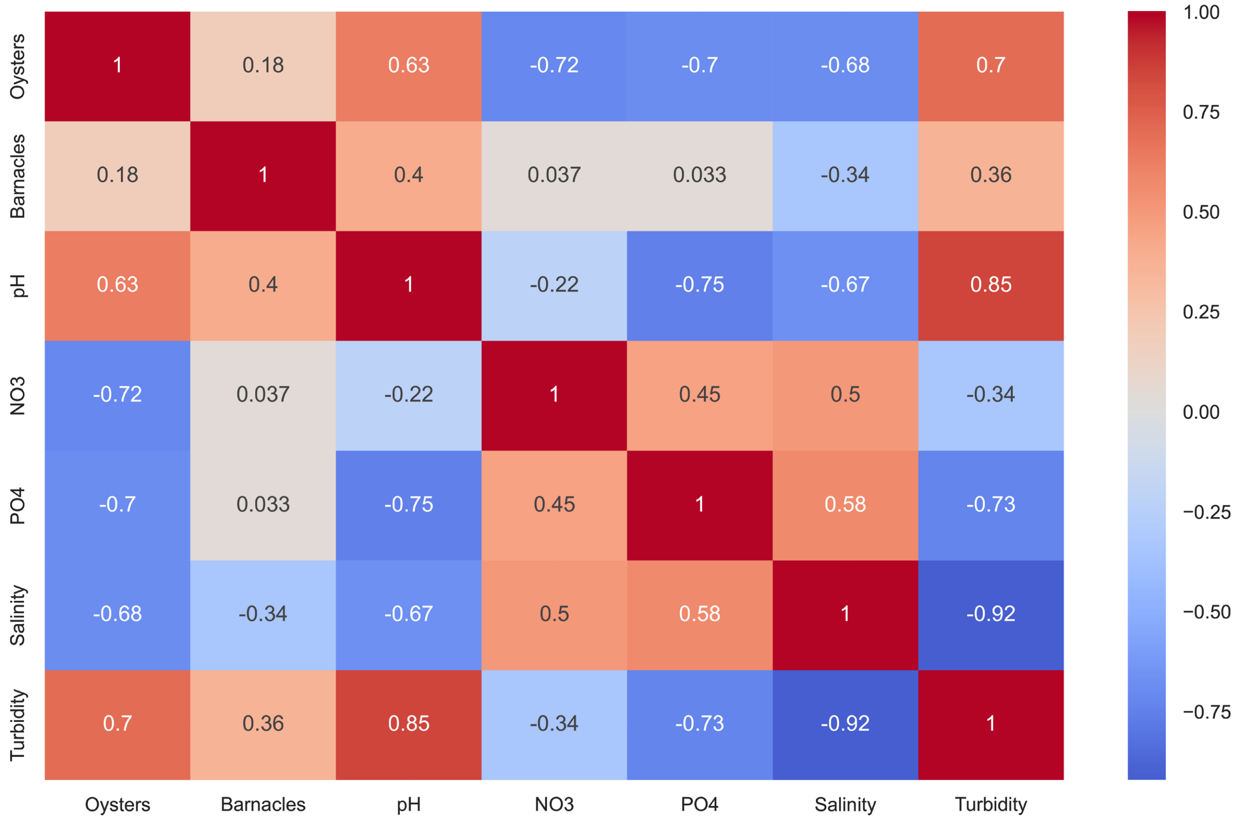

Figure 9. Correlation matrix between physico-chemical parameters and abundance of oysters and barnacles.

The figure shows the key relationships (**Figure 10**). Oyster abundance decreases with increasing salinity. It peaks around 22 - 25 PSU, then falls sharply. As pH increases, oysters are more abundant around pH 7.5 - 8.0, confirming the positive correlation with pH observed. Barnacles show a high abundance at low salinity (around 14 - 15 PSU), with a drastic drop above 20 PSU. With regard to pH, barnacles show a high abundance at pH > 8.0, but the data are more scattered.

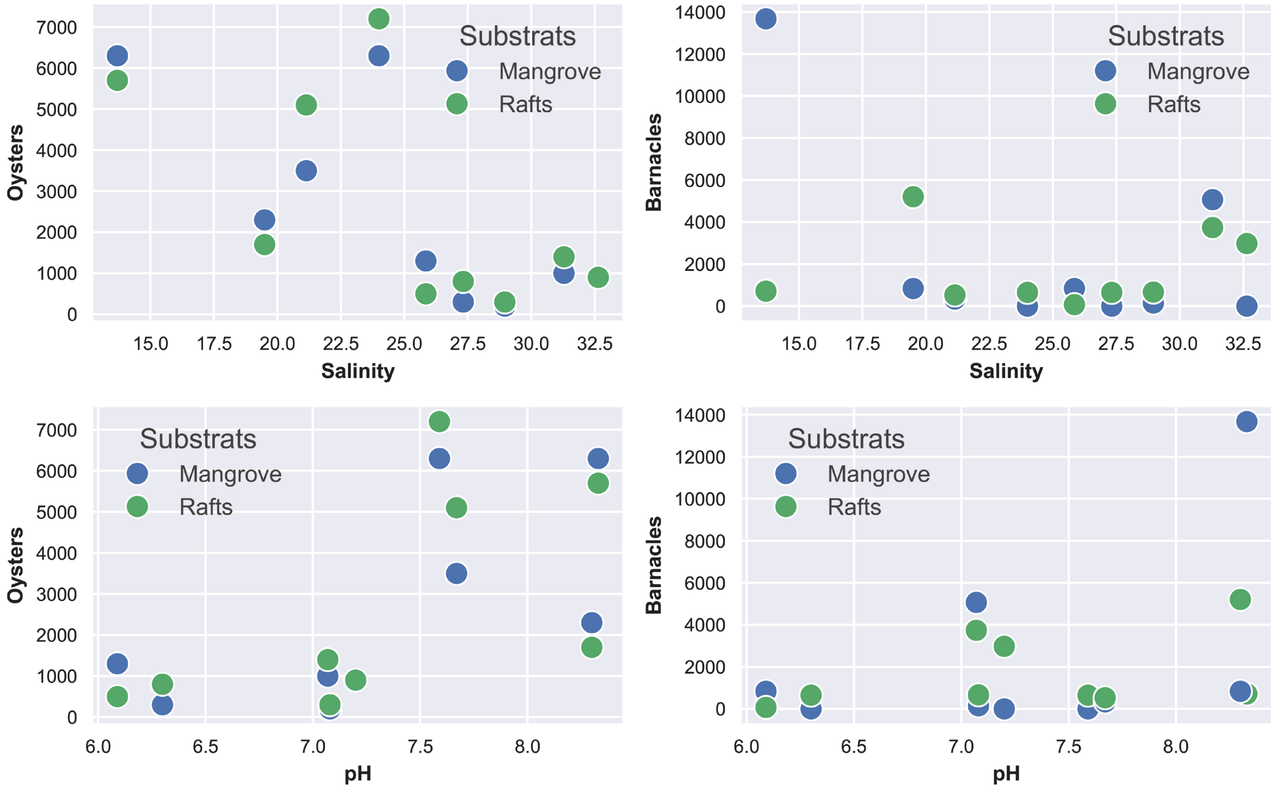

Figure 10. Key relationships between oysters, barnacles and salinity and pH.

Principal component analysis (PCA) of the environmental variables reveals that the first two components explain 86.9% of the total variance in the data, with 69.7% for the first (PC1) and 17.2% for the second (PC2) (**Figure 11**). This high contribution suggests that the environmental gradients studied significantly structure the distribution of oysters and barnacles. The first component (PC1) reflects a gradient strongly influenced by pH and turbidity, which are positively correlated, in opposition to NO_3^- (nitrate) concentrations, which are oriented in the opposite direction. Salinity and phosphates (PO_4^{3-}) contribute moderately to the variance explained, oriented in close but less marked directions. Oyster abundance is mainly associated with conditions characterised by high pH, high turbidity, and built-up type substrates. On the other hand, their presence is limited in areas with high nitrate levels. Barnacles are more widely distributed, with significant abundances in both mangroves and built-up areas, although their maximum abundance is also observed in sites with high pH and turbidity. Nevertheless, some barnacles are observed in areas with high salinity or in the presence of nitrates, reflecting a broader ecological tolerance than that of oysters.

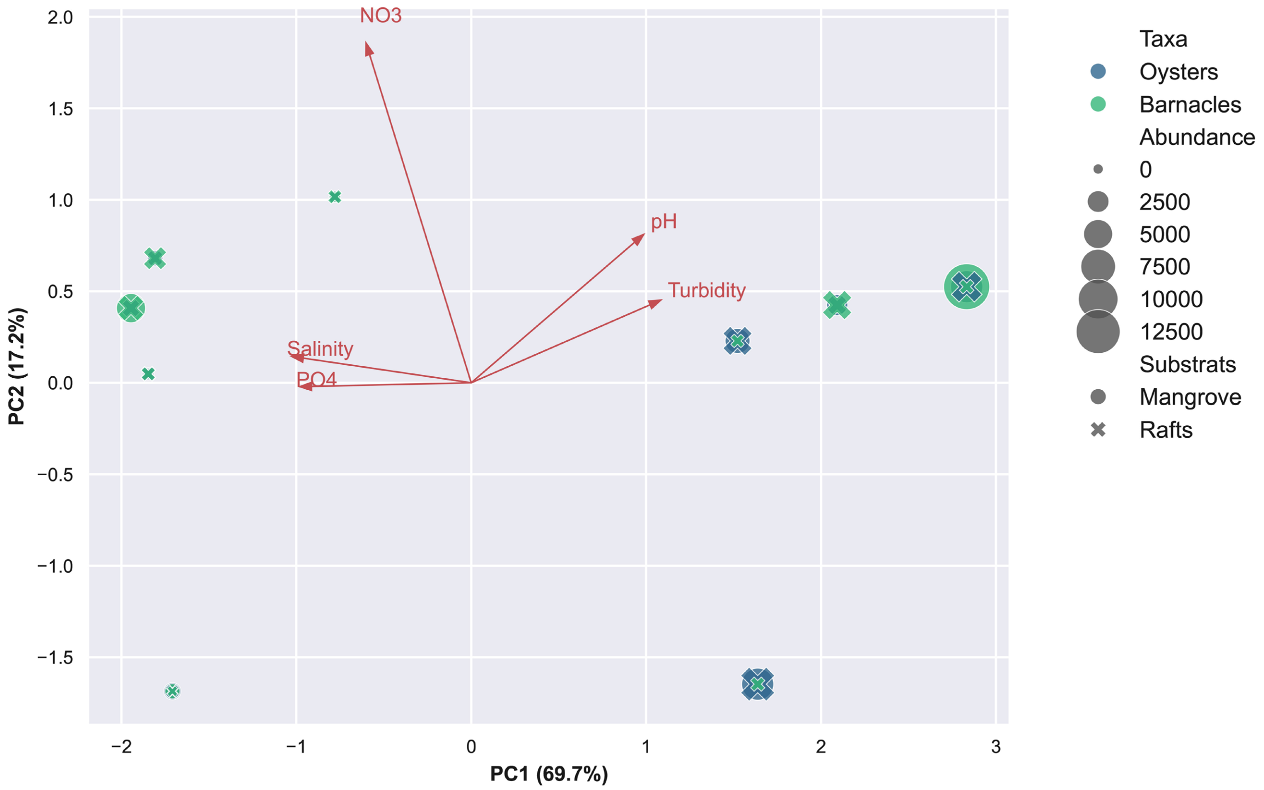

Figure 11. Principal component analysis (PCA) of environmental variables.

4. Discussion

The variability shown by the physico-chemical variables seems to be a direct consequence of the alternating dry and rainy seasons. It is a common feature of tropical estuarine and lagoon ecosystems in the Gulf of Guinea in Cameroon, where variables such as temperature, salinity, total dissolved solids and turbidity show significant seasonal variations [12]. Similar pH variation has been observed in Tabounssou bay (Guinea) with period of basic pH associated with an increase in biological productivity [13]. The relatively high nitrate and nitrite concentrations reveal a high nutrient load, which is probably related to surface water run-off and the decomposition of organic matter. Compared with the values reported by [14] in the estuaries in Côte d'Ivoire, despite being subject to human activity (NO_3^- ≈ 5 mg/L, NO_2^- ≈ 0.04 mg/L), these values are much higher. This richness in nutrients indicates a risk of eutrophication, especially with the concentration of phosphates reaching 57.4 mg/L. The noticed change in alkalinity and the declining salinity over the months can be explained by the growing influence of freshwater during the rainy season. In the Faban estuary, [13] reported a similar dynamic whereby the average salinity noted throughout the rainy season was 14.23 g/L, thereby suggesting dilution of marine water by river inputs. It should be noted, however, that this high salinity in the dry season can be accentuated by evaporation. This evaporation has influence on conductivity. In fact, the high conductivity values observed between February and May indicate a high ionic concentration in the dry season, probably linked to evaporation and the concentration of salts [14]. The increasing turbidity towards October reflects the resuspension of particles due to rainfall and runoff, a process also observed by [12], where turbidity peaks were noted during the wet season. This increase in suspended matter may have an impact on the light available for photosynthesis and modify the structure of plankton communities. Finally, the low concentrations of iron and sulphates may reflect a natural sedimentation and filtration process by the mangrove, which plays an important role in detoxifying aquatic environments. However, the concentrations measured in this study remain well below those found in certain estuaries in Côte d'Ivoire, where sulphates reach an average of 998 mg/L, probably as a result of contamination by industrial effluents [14]. Three main phases are observed in oyster settlement: low settlement during the dry season (February, June, December), an intermediate phase during the transitional season (January to April), and a phase of high settlement during the rainy season (July to October), with a peak in August. This demonstrates strong seasonal variability in oyster settlement. This dynamic is consistent with the observations of [15] on the Amazonian coast, where oyster recruitment occurs throughout the year, although with peaks during periods of higher salinity, often corresponding to the end of the rainy season. The period of high settlement observed, particularly around buildings, may be explained by the greater availability of stable microhabitats, as the following studies have also shown [16]. These authors highlight the importance of physical conditions, in this case the density and structure of the substrate, in optimising the growth and survival of *Crassostrea tulipa* juveniles. The findings support the significant influence of substrate type on larval settlement success. The significant impact of environmental cycles, such as salinity and turbidity, on larval settlement is corroborated by the research conducted by [17]. The authors emphasize the significance of the genetic adaptation of *C. tulipa* to particular ecological conditions in the Gulf of Guinea. Their study shows that this species forms a distinct genetic group, linked to a reproductive and settlement strategy that is locally adapted to West African seasonality. In addition, the work of [18] on Crassostrea gigas also show that genetic structuring is influenced by environmental factors and transport practices in aquaculture. Finally, in view of global trends [19] underline the importance of optimizing culture conditions in a context of high demand for oysters, particularly in developing countries. Our results on the improved performance of constructed substrates reinforce the idea that suitable developments could improve local oyster farming productivity while reducing the pressure on natural ecosystems. Our observations of barnacle settlement dynamics in mangroves and rafts indicate that these processes are affected by environmental factors, substrate characteristics, and barnacle life cycles. The pronounced seasonal variability in settlement, especially the peaks noted in October and March within the mangroves, may be associated with environmental conditions that promote reproduction and larval recruitment. According to [20], the settlement process is particularly sensitive to biofilms and the physico-chemical conditions of the environment at the time of metamorphosis. These periods could favour the adhesion of cypris larvae and the survival of juveniles. The decrease in settlement in February, April and August could reflect periods of environmental stress, such as high turbidity, extreme salinity or low phytoplankton availability, key elements for the larval stages. These results are in line with the observations of [21], These results are in line with the observations of [22], which stresses that underwater settlement depends not only on the biochemical properties of the adhesive produced by barnacles, but also on the nature of the substrate and its immediate microenvironment. At the level of built-up substrates, regular and moderate settlement could be due to the physical and chemical constancy of these surfaces [22]. Indeed, these authors have shown that barnacles have a preference for surfaces that allow good mechanical and chemical adhesion, regardless of their natural or artificial origin. This means that built-up substrates could be more stable and conducive to adhesion, even if their non-biological nature does not necessarily lead to higher fixation rates. Furthermore, the significant monthly differences observed in each type of habitat confirm that cyclical reproduction and the availability of cypris larvae are determining factors in the temporal structuring of colonisation [20]. With regard to competition between oysters and barnacles in the different types of environment, there is an alternation of dominance depending on the season and the habitat. This is typical of benthic communities subject to variations in environmental conditions and competition for space [23]. We observed that in mangroves, barnacles show extreme peaks in October and March, while oysters dominate in August, when barnacles are absent. This temporal shift suggests a model of competition with intermittent competitive exclusion, comparable to that described by [24]. According to these authors, coexistence is only possible when overall abundance remains low. When a density threshold is crossed, one species tends to displace the other, often to less favourable areas. In addition [25] have shown that nutrient enrichment can also stimulate recruitment of oysters and barnacles, but could also lead to post-settlement mortality depending on the species. This is one of the reasons why oysters maintain a stable presence under certain conditions, whereas barnacles show more abrupt fluctuations, reflecting increased sensitivity to larval competition or post-recruitment stress. Competition between oysters and barnacles is more moderate, but continuous. Barnacles dominate from time to time (March, September), but without reaching the peaks observed in mangroves. Oysters are more consistent and perform better in summer. These observations are in line with the work of [26], who demonstrated that the coexistence of species fixed on common substrates may not affect survival or growth, but rather reduce their physiological condition In a variable hydrodynamic context, built-up substrates offer greater physical stability, which could favour oyster settlement, as suggested in the literature on interactions between Mytilus and Crassostrea [26]. The influence of fluid mechanics, specifically water movement, on regulating this competition warrants investigation, especially concerning the findings of [27] regarding the morphological plasticity of barnacles in response to flow. The substrate characteristics and abiotic factors, such as salinity, turbidity, and nutrient levels, significantly influence recruit selection, as evidenced by the studies of [28] and [21], highlighting the relevance of the physico-chemical properties of adhesion. Barnacles and oysters exploit space according to specific settlement mechanisms, which could influence their competitive success depending on the type of support. Analysis of the variation in oyster abundance as a function of depth reveals a breakpoint around 30 cm, which could be interpreted as an optimal zone for larval settlement. This depth marks a favourable ecological balance: sufficiently submerged to limit stress due to emersion, but still well oxygenated and exposed to light, conditions favourable to larval survival and initial development [29] [30]. These observations are confirmed by the results of [31] which show that the relative submersion of the substrate influences hydrodynamic processes, such as wave attenuation and energy dissipation, which in turn affect the stability of attached larvae. Shallow depths (<20 cm) can lead to increased turbulence and frequent aerial exposure, which may decrease settlement rates. In contrast, at depths exceeding 40 - 50 cm, diminished light and oxygen levels, along with heightened sedimentation, may adversely affect juvenile growth [32] [33]. Surface zones, particularly those near 30 cm depth, exhibit enhanced microbial activity associated with biodeposition, which promotes the recycling of labile carbon [32] [33]. This activity enhances oyster growth conditions by improving substrate quality, including nutrients and biofilm structure. Finally, the convergence of performance between built-up habitats and mangroves from 40 cm underlines the importance of substrate type, but also shows that depth can attenuate the differences between habitats: beyond the breaking point, oysters seem to adjust ecologically, taking advantage of the stabilising effects of depth on physico-chemical parameters [30] [33]. The results obtained in this study show a preference for turbid and high pH waters. This can be attributed to improved availability of food particles and more favorable conditions for metabolism [34] studied Crassostrea angulata in Taiwan region and found that periods of high turbidity associated with rainfall correspond to peaks in larval recruitment. This indicates that suspended particles may enhance larval adhesion or improve feeding after fixation. The analyses indicate that oysters exhibit sensitivity to elevated concentrations of nutrients (NO_3^-, PO_4^{3-}). These results corroborate the observations of [25], which show that while nutrient enrichment stimulates initial oyster settlement, it can also promote post-fixation mortality, possibly via indirect effects such as eutrophication or changes in the microbial composition of the substrate. Similarly, [35] demonstrated that oysters subjected to stressful environmental conditions, such as low current velocity and high salinity, exhibited increased susceptibility to parasites, underscoring the vulnerability of Crassostrea virginica to various stressors. Principal component analysis (PCA) indicates that pH and turbidity are the primary factors influencing oyster distribution, supporting the findings of [36]. Oysters modify microhabitat conditions (flow, turbidity, substrates) and favour certain benthic species in specific environmental contexts. This relatively restricted ecological niche explains why oysters have mainly been observed on built-up substrates, probably because of their roughness and stability, factors known to favour larval settlement. Barnacles, on the other hand, appear to be more tolerant. Their moderate correlation with pH and turbidity, combined with their presence in areas of variable salinity, suggests greater ecological plasticity. This flexibility is confirmed by Nishizaki & Carrington [37], who show that Balanus glandula adapts its growth to variations in temperature and current speed, highlighting a broader capacity for physiological adjustment. This means that barnacles can colonise both mangroves and artificial substrates. Finally, the drastic drop in barnacle abundance above 20 PSU of salinity observed in our study is consistent with the results of [38], which identify salinity as a determining factor in the distribution of parasites in oysters, but also as a strong environmental constraint affecting their body condition. Thus, the distribution of barnacles could result not only from tolerance to pH and turbidity, but also from competitive exclusion in areas of high salinity or high parasite presence.

5. Conclusion

The study showed that there was significant seasonal variability in the physico-chemical parameters at the stations. pH and turbidity are the dominant factors structuring the distribution of oysters. At the site, an increasing variation in oyster settlement was observed, from the dry season to the rainy season. In other words, low settlement in the dry season, an intermediate phase in the transition season, and a phase of high settlement during the rainy season. The results of the research work thus show that oysters can be grown sustainably on rafts and give just as good yields as growing oysters on mangrove roots. The completion of this study not only opens up a new perspective in the redefinition of oyster farming in the Republic of Guinea in order to make it sustainable, as it is one of the sectors that creates jobs and wealth, but also the sustainable management of wild oysters.

Conflicts of Interest

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

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