

# Micro-phytoplankton density and diversity at a pilot oyster culture barachois site of Mauritius Island

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**Abstract.** Armance MEA, Mattan-Moorgawa S, Bhagooli R. 2019. Micro-phytoplankton density and diversity at a pilot oyster culture barachois site of Mauritius Island. *Ocean Life 3*: 1-12. The density and diversity of marine micro-phytoplankton were studied at 4-6 stations from October to December 2014 within and around a pilot culture site of the oyster *Crassostrea cuculata* in the north-east of Mauritius Island to evaluate the water quality of the marine ecosystem suitable for oyster culture. Three micro-phytoplankton samples were taken at each station and the physicochemical parameters such as temperature, pH, and salinity were measured *in situ* while turbidity was measured *ex-situ*. No bloom was observed but a gradual increase in micro-phytoplankton density occurred from October to December 2014. The micro-phytoplankton density was positively correlated with temperature. A total of 20 genera of micro-phytoplankton were observed belonging to the classes of Bacillariophyta, Dinophyta, and Cyanophyta. The genera observed were *Bacteriastrium*, *Chaetoceros*, *Coscinodiscus*, *Leptocylindrus*, *Cylindrotheca*, *Nitzschia*, *Pseudo-Nitzschia*, *Asterionellopsis*, *Licmophora*, *Striatella*, *Flagilariopsis*, *Navicula*, *Pleurosigma*, *Thalassionema*, *Dinophysis*, *Gymnodinium*, *Alexandrium*, *Peridinium*, *Nitzschia*, and *Pleurosigma* in the Bacillariophyta and in Dinophyta, *Gymnodinium* and *Prorocentrum* were the dominant genera, while only *Lyngbya* was observed as Cyanophyta. Simpson's diversity index revealed an increase in species diversity from October to December 2014 at studied stations. These findings indicate spatiotemporal variations in micro-phytoplankton density and diversity at the oyster culture site and further long-term studies are warranted to identify the optimal stations for oyster culture.

**Keywords:** Bacillariophyta, *Crassostrea cuculata*, Cyanophyta, Dinophyta, micro-phytoplankton, physicochemical parameters, species diversity

## INTRODUCTION

Phytoplankton is a large group of tiny drifting photosynthesizing organisms that comprises different subgroups according to their size ranges. Micro-phytoplankton size ranges between 20 µm to 200 µm (Reynolds 2006). There is a wide range of micro-phytoplankton classes around the globe but the main ones are diatoms, dinoflagellates, and cyanobacteria. Being at the base of the marine food web, these microorganisms play a key ecological role in the marine environment. Moreover, the abundance of the micro-phytoplankton can be used as a toolkit to evaluate the water quality of the marine ecosystem (Sagert 2008).

These photosynthesizing microorganisms depend on several factors for their growth, survival, and reproduction and have a direct effect on their density and diversity. These factors can either be physical, chemical or biological. The physical factors affecting the abundance of micro-phytoplankton are notably temperature, salinity, turbidity, currents, wind, light radiation as well as freshwater input from nearby rivers or precipitation (Gilbes et al. 1996). The chemical factors are dissolved oxygen, pH, as well as nutrient availability, mainly of phosphate, silicate, and nitrate (Gilbes et al. 1996). Biological factors are their interaction with other marine organisms, such as

the grazing activities of zooplankton and oysters (Chung et al. 2012). Furthermore, it is known that micro-phytoplankton density differs spatially and temporally (Chandy et al. 1991; López-Flores et al. 2011; Sadally et al. 2012; 2014b).

Oysters are filter-feeding organisms that feed on phytoplankton, including the micro-phytoplankton. Evidence has shown that oysters reduce the abundance of phytoplankton in the sea and thus increase water quality (Newell et al. 2007). Algal blooms are the rapid proliferation of phytoplankton on the sea surface resulting in the decrease of the penetration of light radiation to the hydrosphere. In the coastal waters of Poudre d'Or and Anse La Raie, located in the north of Mauritius, microalgal blooms have been reported along with death of corals (AFRC, 2009). The main impact that an algal bloom has on marine environment is that it depletes oxygen to a level that is insufficient to maintain the biodiversity of the marine ecosystem and may pose a threat to aquaculture activities and the surrounding ecological system (Kibria 2014).

Very few scientific studies have so far been published on the density and diversity of micro-phytoplankton at oyster culture sites in Mauritius, though a few studies have been undertaken on micro-phytoplankton abundance and distribution within the coastal waters of Mauritius Island and at Poudre d'Or Barachois. These studies have shown

that the dominant micro-phytoplankton type observed in the Mauritius lagoon are diatoms (Modoosoodun et al. 2010; Sadally et al. 2012; Sadally et al. 2014a,b).

Both as a bioindicator and the foundation of the marine food web, it is important to analyze the abundance and diversity of this micro-phytoplankton at oyster culture sites. The abundance and diversity will result in a better understanding of the growing environment of the oysters ensuring that the oysters, grown for commercial purposes, have adequate food for their growth and development, ultimately resulting in a better yield. The study of micro-phytoplankton density and diversity along with the prevailing physicochemical parameters is important for the comprehension of the structure and dynamics of the marine biota and their trophic interactions. It is noteworthy that environmental parameters do vary spatially in coastal waters of islands. For instance, there are significant variations in seawater temperature at a coast-reef scale at some coastal sites around Mauritius Island (Bhagooli and Taleb-Hossenkhan 2012). Recurrence of high sea surface temperature anomalies is also going to recur more frequently around Mauritius Island (Bhagooli and Sheppard 2012). Sadally et al. (2012; 2014b) report variable micro-phytoplankton distributions at coast-reef scale. However, spatiotemporal variations in micro-phytoplankton and environmental factors are yet to be thoroughly investigated in potential coastal barachois-based aquaculture sites around islands.

The aim of this study was to assess the effect of the physicochemical environment and spatial-temporal variations in micro-phytoplankton density and diversity within and around an oyster culture site at Poudre d'Or Barachois. The objectives of the study were to (i) measure the physicochemical parameters (seawater temperature, salinity, pH and turbidity) at each station during each field sampling; (ii) determine the density of total micro-phytoplankton, diatoms, dinoflagellates and cyanobacteria; (iii) analyse the spatial variation on micro-phytoplankton density (within and around the culture site); (iv) analyse the temporal variation on micro-phytoplankton density (October-December 2014); (v) correlate the physicochemical parameters and the biological parameters (total micro-phytoplankton, diatoms, dinoflagellates and cyanobacteria densities); and (vi) analyse the taxonomic group composition of micro-phytoplankton up to generic level within and around the study site.

## MATERIALS AND METHODS

### Study site

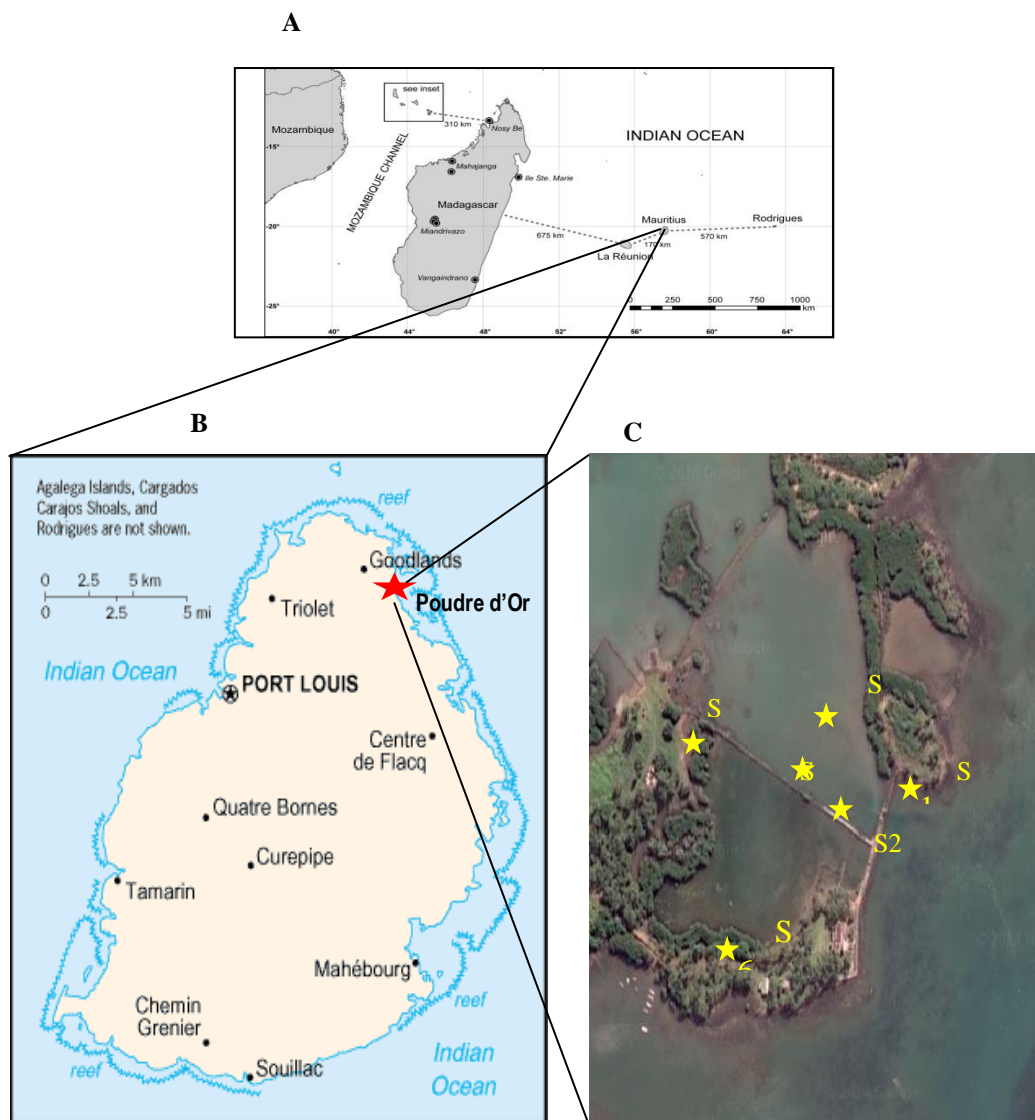
Poudre d'Or is a coastal village located in the north-east of Mauritius Island, Western Indian Ocean, (Figure 1A, B) (20° 4' 37" S, 57° 38' 52" E). The seawater of Poudre d'Or is usually muddy and brown throughout the year. The mouth of the river known as 'Citronnier' (Figure 1A) in Poudre d'Or is quite near the sampling site. Since July 2014, a pilot project for culturing the oyster *Crassostrea cuculata* has been located in Poudre d'Or Barachois. The Barachois was still under renovation when sampling was carried out and due to this sample collection was restricted to only one part of it. Moreover, the oyster culture site was under environmental stress due to animal waste run off from a nearby animal farm, especially during heavy rains. The GPS points and characteristics of the sampling stations are given in Table 1.

### Measurement of physico-chemical parameters

Temperature was monitored in three consecutive sampling months (October-December 2014). Seawater salinity, pH and turbidity were monitored only in December 2014. Temperature was measured in situ during sample collection by using a thermometer-Comark as temperature fluctuates easily as soon as the sample is removed from its environment (Scheel 2008). The seawater temperature was taken five times at each station and the mean temperature was then calculated for each station. During this study the pH of the seawater was measured in situ by using a pH meter (Hanna HI 9024C). The pH meter was calibrated prior going on field for sample collection. pH values range from 1 to 14. Below pH 7 the water sample contains a greater number of H<sup>+</sup> ions compared to OH<sup>-</sup> ions. pH meter is a qualitative method to measure pH as it converts electrode voltage in the seawater sample to pH value. The pH value was taken five times at each station and the mean pH value of each station was then calculated. Salinity was measured in situ by using a refractometer. During the sample collection, a few drops of seawater sample were placed on the glass prism of the refractometer and the latter measures the salinity of the seawater by refractive index. Refractive index is the ratio of the speed of light through the vacuum to the speed of light through the seawater sample. The eyepiece of the refractometer was focused and the refractive index was read through it (Scheel 2008).

**Table 1.** GPS coordinates and brief description of the sampling stations

| Stations | GPS coordinates |               | Brief description  |
|----------|-----------------|---------------|--|
|          | South           | East          |  |
| S1       | 20° 03' 29.9    | 057° 41' 27.0 | Open Coastal Sea-outside the oyster culture site (OS)                      |
| S2       | 20° 03' 31.0    | 057° 41' 24.3 | Flushing area between the oyster culture site and the coastal waters (FA1) |
| S3       | 20° 03' 28.5    | 057° 41' 24.0 | Mangrove ecosystem inside the barachois of the oyster culture (ME1)        |
| S4       | 20° 03' 30.6    | 057° 41' 21.6 | Oyster culture site in the barachois (OC)                                  |
| S5       | 20° 03' 28.7    | 057° 41' 17.7 | Flushing area between the oyster culture site and another barachois (FA2)  |
| S6       | 20° 03' 34.2    | 057° 41' 19.6 | Mangrove ecosystem outside the barachois of the oyster culture (ME2)       |



**Figure 1.** Map of Indian Ocean (A) (Source: Chan et al. 2011), Map of Mauritius where the red star indicates the location of Poudre d'Or (B) (Source: Exotic Mauritius 2005-2012) and the Barachois of Poudre d'Or (C) (Source: Google map 2014) where the yellow stars indicate the sampling stations. S1= Outside the oyster culture site (open sea), S2= the flushing area the oyster culture site and the coastal waters, S3= Mangrove ecosystem inside the barachois of the oyster culture site, S4= Oyster culture site, S5= Flushing area between the oyster culture site and another barachois, S6= Mangrove ecosystem outside the barachois of the oyster culture site

Five refractive indexes were taken at each station during the month of December and the mean indexes were then calculated. Turbidity was measured ex-situ by using a 2100A turbidimeter. In the laboratory, the turbidimeter was allowed to stabilize for 30 minutes before the water sample was put into it for reading. The water sample was poured into a small glass and then put in the turbidimeter where the turbidity value was recorded. Turbidity values recorded at each of the five stations during the month of December and the mean values were then calculated.

#### Micro-phytoplankton collection and processing

Micro-phytoplankton sampling was undertaken on a monthly basis from October 2014 to December 2014 within

and around Poudre d'Or Barachois. A plankton net was used to collect the samples. This type of net ( $< 20 \mu\text{m}$ ; the size of micro phytoplankton) should collect plankton which is bigger than the mesh size (Verlencar and Desai 2004; Hötzel and Croome 1999). In this study, plankton net of mesh size  $5 \mu\text{m}$  was used to collect micro-phytoplankton at the selected stations within and around the oyster culture site. Triplicate samples were taken at each station. Each micro-phytoplankton sample was obtained by filtering 10L of seawater sample which was taken within 0.5 m depth of the seawater surface. The samples were fixed by Lugol's solution (according to Hötzel and Croome 1999; Verlencar and Desai 2004) and kept in opaque 250 mL plastic bottles and stored immediately in a cold isotherm box to preserve

the samples during transportation before being taken to the laboratory for further analysis. The solution used was prepared one week prior going on field sampling. The fixed phytoplankton samples were kept at 4 °C until further analysis.

Centrifugation is important to concentrate the micro-phytoplankton cells for enumeration and identification, A 250 mL sample of fixed micro-phytoplankton was divided into 5 centrifugation tubes of 50 mL. The tubes were centrifuged at 3500 rpm for 10 minutes by using a REMI R-8CBL bench top centrifuge). After 10 minutes, the supernatant water was decanted. After vortexing, the pellets formed from the 5 centrifugation tubes were put in a 15 mL centrifugation tube and filtered seawater (0.22 µm) was added up to 15 mL. The samples were then allowed to centrifuge a second time at 5500 rpm for 15 minutes in a CENTROMIX P-SELECTA centrifuge. After 15 minutes, the supernatant water was decanted and 1 mL of micro-phytoplankton was put in an aliquot tube (adapted from Sadally et al. 2014a). The aliquot tubes were then stored at 4 °C for further analysis.

Micro-phytoplankton identification was performed by using a Sedgewick rafter counting chamber of dimension of 50 mm x 20 mm x 1 mm depth and an ocular microscope of eyepiece lens ×10 and objective lens of ×10, ×20, ×40 and ×100 (Verlencar and Desai 2004). 1 mL of the micro-phytoplankton sample was run from one corner of the Sedgewick rafter counting chamber by using a micropipette of 1 mL. During this step, the coverslip was placed at an angle across the Sedgewich rafter counting chamber and it was moved to the whole chamber once the latter was filled (Hötzel and Croome 1999). The micro-phytoplankton sample was allowed to settle into a single layer for 10 minutes in the Sedgewick rafter counting chamber before identification. The micro-phytoplankton samples were identified under the objective lens ×20 of the ocular microscope (Verlencar and Desai 2004). Identification of micro-phytoplankton was done along the rows of the Sedgewich rafter counting chamber. Several phytoplankton manuals were used to identify the micro-phytoplankton genera (Verlencar and Desai 2004; Perry 2003; Botes 2003) of the three main micro-phytoplankton groups (diatoms, dinoflagellates, and cyanobacteria).

Micro-phytoplankton enumeration was done parallel to the micro-phytoplankton identification. The counting was done horizontally along the row of the Sedgewich rafter counting chamber from one corner to the next. This step was repeated for the second row and so forth until 100 micro-phytoplankton genera were identified (Huber 2012). The total number of quadrants that were used to identify the 100 micro-phytoplankton genera was recorded. The average number of micro-phytoplankton cells in the 1 mL sample was calculated by multiplying the number of phytoplankton count (i.e. 100) with the ratio of the whole chamber of counted quadrants (modified from Verlencar and Desai 2004). The total number of phytoplankton present in 1 mL of seawater was calculated by using the following formula (Verlencar and Desai 2004):

$$N = [(n \times v)/V] \times 1000$$

Where,

N: total number of phytoplankton cells per liter of water filtered

n: average number of phytoplankton cells in 1 mL of plankton sample

v: volume of plankton concentrate ( mL)

V: volume of total water filtered (L)

The diversity of the observed micro-phytoplankton genera at each sampling stations for the three consecutive months was analyzed by using the following Simpson's diversity index (Oksanen 2015) as it takes into consideration both the richness and evenness of the micro-phytoplankton genera:

$$D = 1/\sum (P_i)^2 ; (P_i = N_i/N)$$

Where,

D: Simpson's diversity index

$\sum$ : Means sum of all  $(P_i)^2$

P<sub>i</sub>: The proportion of individuals of genus 'i' in the community

N<sub>i</sub>: Number of individuals of genus 'i'

N: Total number of genera)

### Statistical analysis

The micro-phytoplankton densities observed during this study were analyzed by using the software SPSS 16.0 at 5 % level of confidence interval. The data were first tested for normality by using the Shapiro-Wilk test. Correlation between the physicochemical parameters and the micro-phytoplankton densities were analyzed by using Spearman correlation test due to the non-parametric data of the physicochemical parameters. Before conducting the two-way ANOVA analysis, the micro-phytoplankton densities were log transformed. The two-way ANOVA analysis was followed by Tukey's Post hoc test for pairwise comparison of the means. A hierarchical cluster analysis (HCA) was used to explore and reveal the natural grouping of the micro-phytoplankton density among the stations during each month (Ogbuagu and Ayoade 2012).

## RESULTS AND DISCUSSION

### Variations in physicochemical factors

An increase in seawater temperature occurred from October to December 2014. In October 2014, the minimum seawater temperature was recorded at the OS Station (24.5 ± 0.0°C) and the maximum one was recorded at FA2 (28.2 ± 0.29°C). In November 2014, the minimum one was recorded at the ME1 and FA1 with mean temperature and SD of 28.0 ± 0.04°C and 28 ± 0.00°C, respectively, and the maximum one was recorded at OC (29.0 ± 0.00°C). In December, however, the minimum sea temperature was recorded at three stations namely FA1, ME1 and OC with 31.0 ± 0.23°C, 31.0 ± 0.21°C and 31 ± 0.34, respectively. The maximum one was recorded at the other three stations: OS, FA2, and ME2 32 ± 0.30°C, 32 ± 0.41°C and 32 ± 0.22°C, respectively.

A narrow range of pH values was found at the sampling site during the study. This narrow range was between  $7.66 \pm 0.05$  to  $7.87 \pm 0.04$ . The lowest pH values were recorded at ME1 and ME2 with a pH and SD of  $7.66 \pm 0.05$  and  $7.68 \pm 0.05$  respectively. The highest one was recorded at the OS station with a pH and SD of  $7.78 \pm 0.07$ .

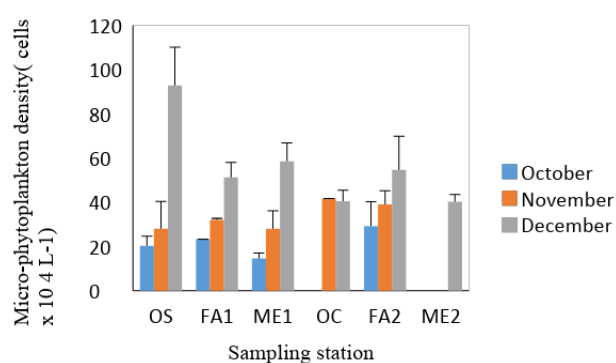
Salinities at all stations within the oyster culture site (FA1, ME1, OC, FA2) were all uniform ( $30 \pm 0.00$  ‰) while the salinities at the two stations outside the oyster culture site were different. At OS, the salinity of the seawater observed during December 2014 was  $32 \pm 0.35$  ‰ and at ME1 the salinity in December 2014 was  $28 \pm 0.00$  ‰. The lowest turbidity observed in December 2014 was at the OS station with a turbidity of 6 Nephelometric Turbidity Units (NTU) and the highest one was observed at the ME2 with a turbidity of 10 NTU.

### Micro-phytoplankton density (TMPD)

A gradual increase of the TMPD was observed (Figure 2) from October to December 2014 at all stations except at OC station where no visible differences were observed between November and December 2014. This increase in micro-phytoplankton density was apparent at the OS station with a mean micro-phytoplankton density difference of  $7.25 \times 10^5 \text{ L}^{-1}$  between October and December 2014.

The two-way ANOVA analysis (Table 2) revealed that there were significant differences in TMPD ( $P < 0.001$ ), diatom density ( $P < 0.001$ ), dinoflagellate density ( $P < 0.001$ ) and cyanobacteria density ( $P < 0.01$ ) from October to December 2014. However, only TMPD ( $P < 0.05$ ) and dinoflagellate density ( $P < 0.05$ ) had significant differences among stations. In addition to that, the Tukey's Post hoc analysis support the two-way ANOVA analysis by revealing that there were significant temporal differences from October 2014 to December 2014 for TMPD ( $P < 0.001$ ), Diatom density ( $P < 0.001$ ) and dinoflagellate density ( $P < 0.001$  and  $P < 0.01$ ). However, for cyanobacteria density, a significant temporal difference ( $P < 0.05$ ) was recorded only between October and December.

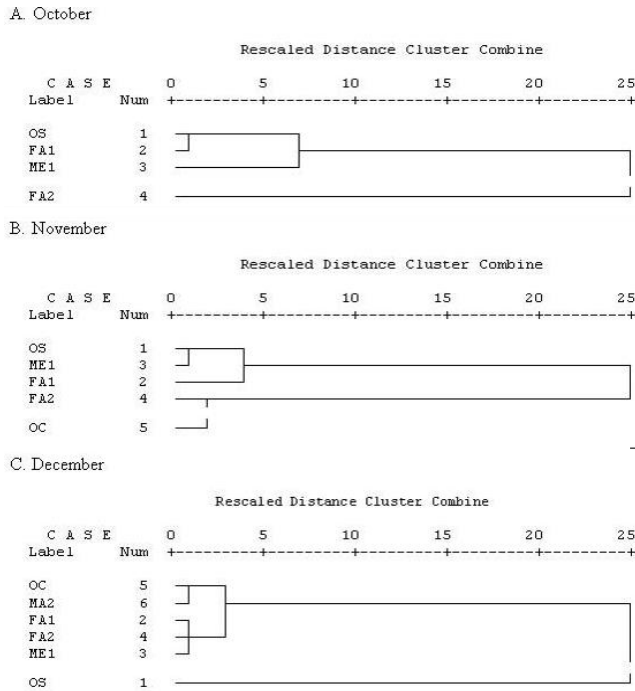
Moreover, the Tukey's Post hoc analysis also revealed statistical spatial variations of TMPD, diatoms density, dinoflagellates density and cyanobacteria between certain sampling stations in October and December 2014. For example, in October spatial variation of TMPD was revealed between OS-ME1 ( $P < 0.05$ ), FA1-ME1 ( $P < 0.05$ ) and FA2-ME2 ( $P < 0.05$ ) while in December 2014, the significant spatial variations for TMPD were between OS-OC ( $P < 0.01$ ), OS-FA2 ( $P < 0.05$ ) and FA1-OC ( $P < 0.01$ ). In addition to that the hierarchical cluster dendrogram (HCD) (Figure 3) showed marked differences in micro-phytoplankton density at FA2 in October, at OC in November and at CS in December 2014.



**Figure 2.** Total Micro-phytoplankton density (cells  $\times 10^4 \text{ L}^{-1}$ ) for the month of October, November and December 2014. Data represent mean  $\pm$  SD ( $n=3$ ). OS= Open sea, FA1= Flushing area between the oyster culture site and the open coastal waters, ME1=Mangrove ecosystem inside the oyster culture site, OC= Oyster culture station, FA2= Flushing area between the oyster culture site to another Barachois, ME2= Mangrove ecosystem outside the oyster culture site. Data is unavailable for OC station during the month of October and for ME2 during the months of October and November 2014.

**Table 2.** Two way ANOVA for temporal comparison (October-November 2014) and spatial comparison (S1-S6) of the micro-phytoplankton density. Asterisks indicate the significant differences at 5% level: \* $P < 0.05$ ; \*\* $P < 0.01$ ; \*\*\* $P < 0.001$

| Parameters                        | Source          | Df | SS    | MS    | F      | P value |
|-----------------------------------|-----------------|----|-------|-------|--------|---------|
| Total micro-phytoplankton density | Month           | 2  | 0.999 | 0.5   | 59.469 | 0***    |
|                                   | Station         | 5  | 0.119 | 0.024 | 2.827  | 0.036*  |
|                                   | Month * Station | 7  | 0.34  | 0.049 | 5.788  | 0***    |
| Diatom density                    | Month           | 2  | 0.89  | 0.445 | 43.633 | 0***    |
|                                   | Station         | 5  | 0.124 | 0.025 | 2.43   | 0.062   |
|                                   | Month * Station | 7  | 0.305 | 0.044 | 4.273  | 0.003** |
| Dinoflagellate density            | Month           | 2  | 3.653 | 1.825 | 37.285 | 0***    |
|                                   | Station         | 5  | 0.753 | 0.151 | 3.074  | 0.027*  |
|                                   | Month * Station | 7  | 1.053 | 0.15  | 3.07   | 0.018*  |
| Cyanobacteria density             | Month           | 2  | 0.741 | 0.370 | 4.951  | 0.015*  |
|                                   | Station         | 5  | 0.407 | 0.081 | 1.087  | 0.391   |
|                                   | Month * Station | 7  | 2.842 | 0.402 | 6.253  | 0.001** |



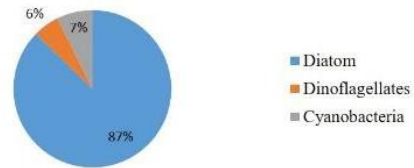
**Figure 3.** Hierarchical Cluster Dendrogram of the total micro-phytoplankton density from October 2014 to December 2014 at the sampling stations. OS = Open Coastal sea, FA1 = Flushing area between the oyster culture site and the open coastal waters, ME1 = Mangrove ecosystem inside the oyster culture site, OC = Oyster culture station, FA2 = Flushing area between the oyster culture site and the other Barachois, ME2 = Mangrove ecosystem outside the oyster culture site.

The dominant micro-phytoplankton was observed during this study at all stations was diatom with a percentage abundance of 87% in October 2014 (Figure 4A), 89 % in November 2014 (Figure 4B) and 83% in December 2014 (Figure 4C). Moreover, diatom density increased from October to December 2014 (Figure 5A). The lowest diatom density was observed in October at the stations ME1, OS, and FA1, FA2, respectively (Figure 5A). In addition to that, the highest diatom density in October and November was recorded at FA2 and that of December was observed at the OS station (Figure 5A).

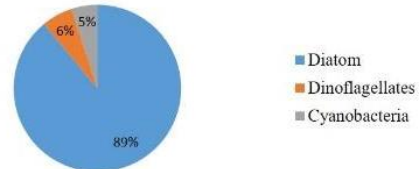
Low dinoflagellate densities (Figure 5B) were observed in October, November and December 2014 at FA1 and FA2, FA1 and OC In October and November, the lowest dinoflagellate density recorded was  $1.2 \times 10^4 \text{ L}^{-1}$  whereas in December, the lowest dinoflagellate density recorded was  $3.3 \times 10^4 \text{ L}^{-1}$ . The highest dinoflagellate density for the three consecutive months was recorded at station OS with a mean density of  $1.7 \times 10^4 \text{ L}^{-1}$  in October,  $2.5 \times 10^4 \text{ L}^{-1}$  in November and  $11.6 \times 10^4 \text{ L}^{-1}$  in December 2014.

The lowest cyanobacteria density (Figure 5C) recorded in October, November and December 2014 was at ME1, FA1 and OC stations with mean densities of  $0.9 \times 10^4 \text{ L}^{-1}$ ,  $1.2 \times 10^4 \text{ L}^{-1}$  and  $1.6 \times 10^4 \text{ L}^{-1}$ , respectively. The highest density of cyanobacteria for October, November, and December, on the other hand, has been recorded at FA1, ME1, and OS, respectively. The cyanobacteria densities observed at FA1, ME1 and OS in December were  $4.2 \times 10^4 \text{ L}^{-1}$ ,  $4.0 \times 10^4 \text{ L}^{-1}$  and  $5.8 \times 10^4 \text{ L}^{-1}$ , respectively.

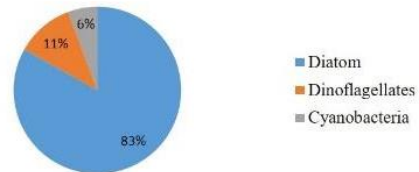
**A. October**



**B. November**

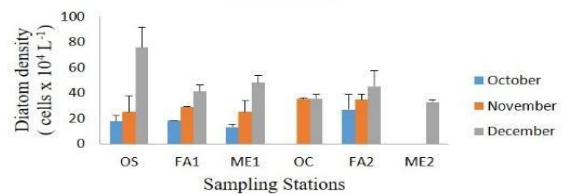


**C. December**

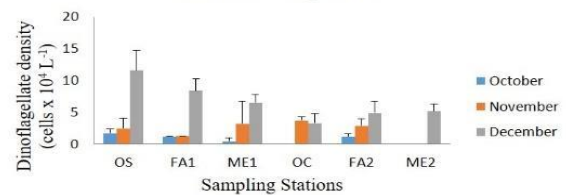


**Figure 4.** Percentage abundance of the three main groups of micro-phytoplankton during October (A), November (B) and December 2014 (C)

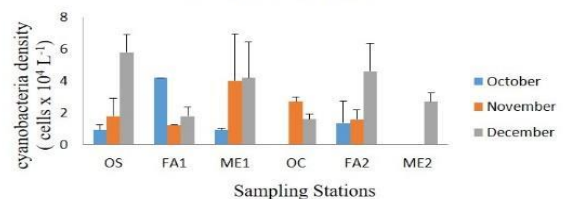
**A. Diatom**



**B. Dinoflagellate**



**C. Cyanobacteria**



**Figure 5.** Distribution of the abundance of Diatom (A), Dinoflagellates (B) and Cyanobacteria (C) during the month of October, November and December 2014. Data represent mean  $\pm$  SD (n=3). Data is unavailable for OC station during the month of October and for ME2, data is unavailable for October and November 2014.

**Table 3.** Spearman Correlation test,  $r$  value, tested within and around the oyster culture site at Poudre d'Or Barachois from October 2014 to December 2014. Asterisks indicate significant differences at 5% level of confidence. (\* $P < 0.05$ , \*\*  $P < 0.01$ , \*\*\*  $P < 0.001$ )

| Parameters                        | Temp.    | Salinity | pH    | Turbidity |
|-----------------------------------|----------|----------|-------|-----------|
| Total micro-phytoplankton density | 0.874*** | 0.845*   | 0.319 | -0.058    |
| Diatoms                           | 0.834**  | 0.845*   | 0.319 | -0.058    |
| Dinoflagellates                   | 0.825**  | 0.507    | 0.464 | 0.029     |
| Cyanobacteria                     | 0.566*   | 0.507    | 0.203 | 0.551     |

### Correlations between physic-chemical parameters and micro-phytoplankton density

The total micro-phytoplankton density (TMPD) ( $P < 0.001$ ), diatom density ( $P < 0.001$ ), dinoflagellate density ( $P < 0.001$ ) and cyanobacteria density ( $P < 0.05$ ) showed a strong positive correlation with seawater temperature during this study (Table 3). No significant relationship was recorded between the micro-phytoplankton densities and pH during December 2014. A significant correlation ( $P < 0.05$ ) was recorded between the seawater salinity and the TMPD and diatom density. No significant correlation occurred between the micro-phytoplankton density and the seawater turbidity.

### Micro-phytoplankton diversity

The micro-phytoplankton genera observed during this study belong to three main micro-phytoplankton groups namely diatoms, dinoflagellates, and cyanobacteria. In total, 20 micro-phytoplankton genera were identified from October to December 2014 (Table 4). 14 genera of diatom were recorded namely *Bacteriastrium*, *Chaetoceros*, *Coscinodiscus*, *Leptocylindrus*, *Cylindrotheca*, *Nitzschia*, *Pseudo-Nitzschia*, *Asterionellopsis*, *Licmophora*, *Striatella*, *Flagilariopsis*, *Navicula*, *Pleurosigma*, and *Thalassionema*.

Dinophyceae, on the other hand, comprises 5 genera namely *Dinophysis*, *Gymnodinium*, *Alexandrium*, *Prorocentrum*, and *Peridinium*. For Cyanophyceae, only one genera were detected-*Lyngbya*.

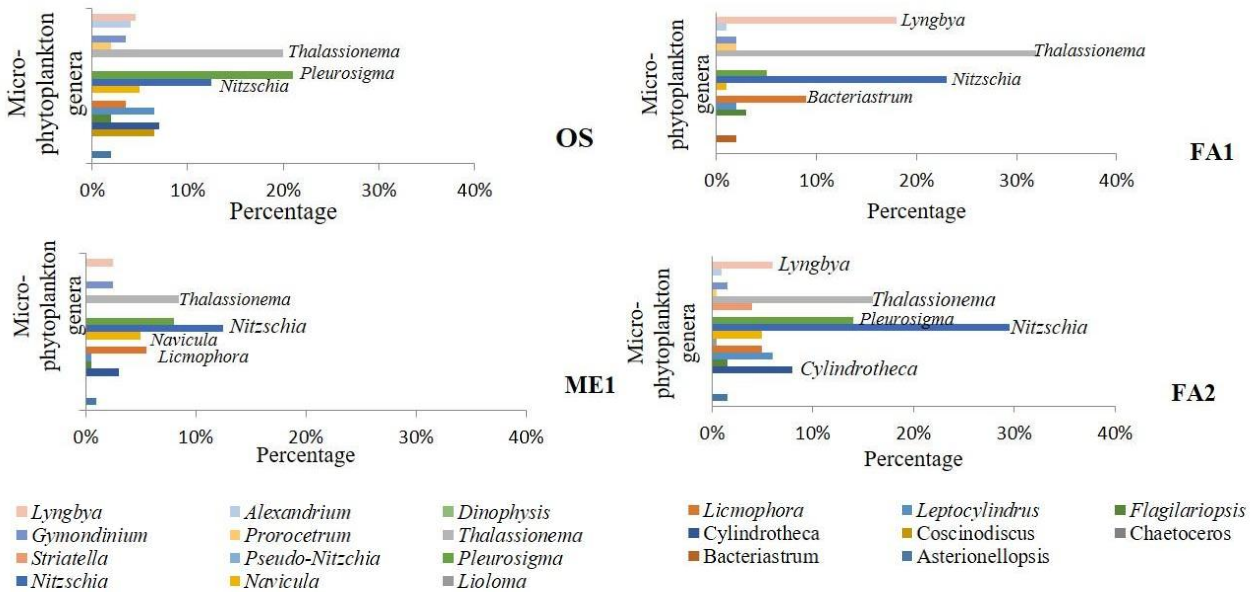
For diatom, both pennate and centric diatoms were observed during this study. During October 2014, the dominant micro-phytoplankton genera at the OS and FA1 stations were *Pleurosigma* (21%) and *Thalassionema* (20%), respectively (Figure 6). However, at the ME1 and FA2 stations, the dominant micro-phytoplankton genus observed within that month was *Nitzschia* with 12.5% and 29.5% abundance, respectively. During November 2014, the dominant micro-phytoplankton genus observed at the OS, FA1 and OC stations was *Nitzschia* with 18.0%, 27.0%, and 28.5% abundance, respectively (Figure 7). At the ME1 and FA2 stations, the dominant micro-phytoplankton genera observed during that month were *Pleurosigma* (25.0%) and *Thalassionema* (22.5%). During December 2014, other micro-phytoplankton genera tended to be abundant (Figure 8). For example, at the OS and OC stations, the dominant micro-phytoplankton genera were *Cylindrotheca* (13.0%) and *Bacteriastrium* (12.0%) respectively. The abundant genera observed at the ME1 and FA2 stations were *Thalassionema* (13.0%) and *Pleurosigma* (15.5%) whereas *Nitzschia* was abundant at the FA1 and ME2 stations during December 2014.

**Table 5.** Simpson's diversity index for micro-phytoplankton genera at the sampling stations from October to December 2014. ND represents no data available.

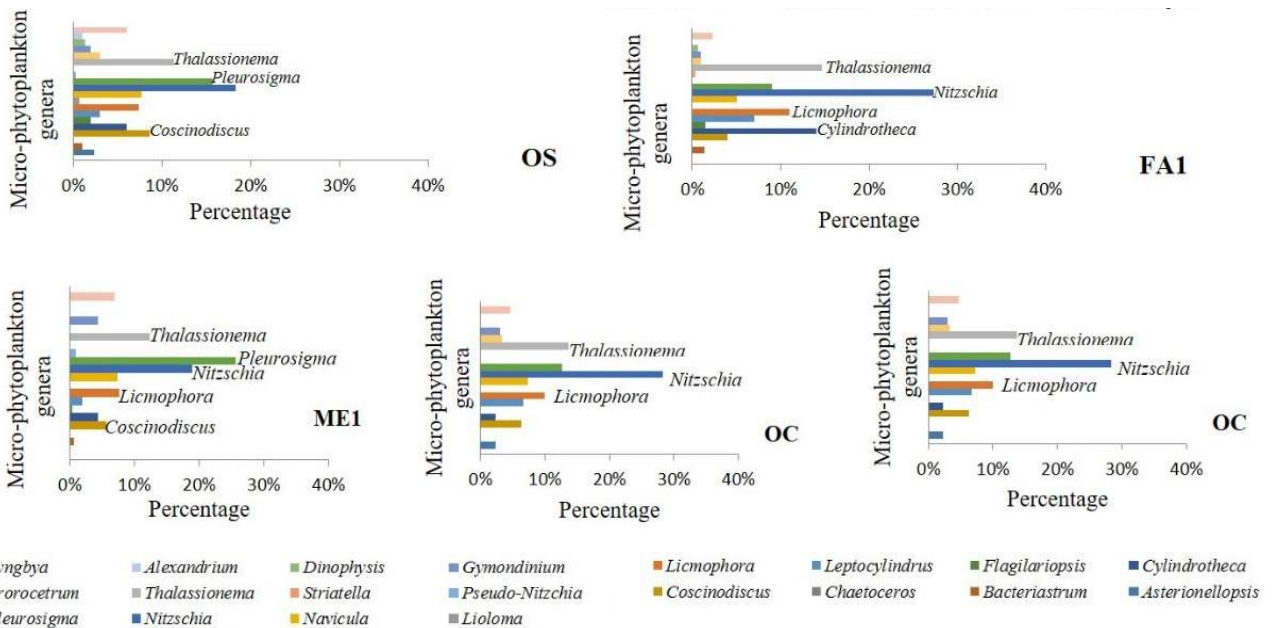
| Month    | Simpson's index |       |       |       |       |       |
|----------|-----------------|-------|-------|-------|-------|-------|
|          | OS              | FA1   | ME1   | OC    | ME2   | FA2   |
| October  | 0.877           | 0.798 | 0.844 | ND    | 0.847 | ND    |
| November | 0.895           | 0.853 | 0.851 | 0.858 | 0.871 | ND    |
| December | 0.907           | 0.904 | 0.902 | 0.911 | 0.917 | 0.907 |

**Table 4.** Taxonomic classification of the three main groups of micro-phytoplankton observed within and around the oyster culture site from October to December 2014

| Micro-phytoplankton |                     |                   |   |  |                    |
|---------------------|---------------------|-------------------|---|--|--------------------|
| Class               | Order               | Family            | Genus                                       |  |                    |
| Bacillariophyceae   | Biddulphiales       | Chaetocerotaceae  | <i>Bacteriastrium</i><br><i>Chaetoceros</i> |  |                    |
|                     |                     | Coscinodiscaceae  | <i>Coscinodiscus</i>                        |  |                    |
|                     |                     | Leptocylindraceae | <i>Leptocylindrus</i>                       |  |                    |
|                     |                     | Bacillariales     | Bacillariaceae                              | <i>Cylindrotheca</i><br><i>Nitzschia</i><br><i>Pseudo-nitzschia</i>                        |                    |
|                     |                     |                   | Fragilariaceae                              | <i>Asterionellopsis</i><br><i>Licmophora</i><br><i>Striatella</i><br><i>Flagilariopsis</i> |                    |
|                     |                     |                   | Naviculaceae                                | <i>Navicula</i><br><i>Pleurosigma</i>  |                    |
|                     |                     |                   | Thalassionemataceae                         | <i>Thalassionema</i><br><i>Lioloma</i>   |                    |
|                     |                     | Dinophyceae       | Dinophysiales                               | Dinophysiaceae   | <i>Dinophysis</i>  |
|                     |                     |                   |   | Gymnodiniaceae   | <i>Gymnodinium</i> |
|                     |                     |                   |   | Gonyaulocales  | <i>Alexandrium</i> |
| Prorocentraceae     | <i>Prorocentrum</i> |                   |   |  |                    |
| Cyanophyceae        | Oscillatoriales     | Oscillatoriaceae  | <i>Lyngbya</i>                              |  |                    |



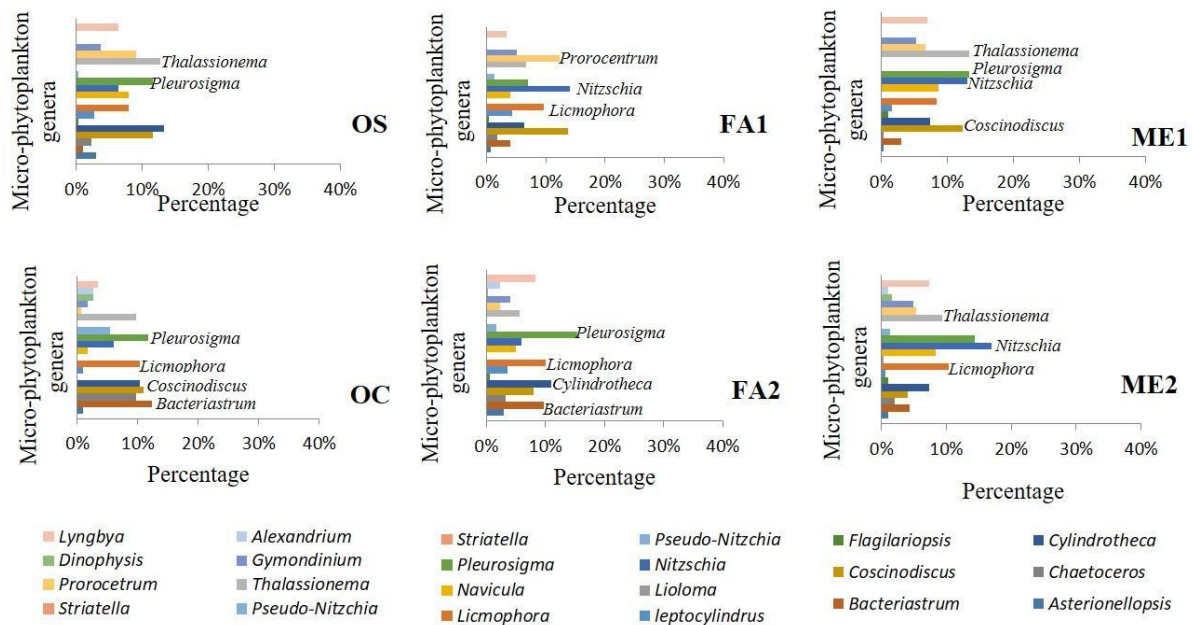
**Figure 6.** Micro-phytoplankton genera abundance within and outside the oyster culture site during the month of October 2014. OS= Open Sea, FA1= Flushing area between the oyster culture site and the open sea, ME1= Mangrove ecosystem inside the oyster culture site, FA2= Flushing area between the oyster culture site and another barachois



**Figure 7.** Micro-phytoplankton genera abundance within and outside the oyster culture site during the month of November 2014. OS= Open Sea station, FA1= Flushing area between the oyster culture site and the open sea, ME1= Mangrove ecosystem inside the oyster culture site, D = Oyster culture station, FA2= Flushing area between the oyster culture site and another barachois

Simpson's diversity index (Table 5) showed that there was a high diversity of micro-phytoplankton genera during the whole study. It also revealed that micro-phytoplankton diversity increased slightly from October 2014 to December 2014. In October 2014, the lowest diversity was recorded at the FA1 station in October with a Simpson

index of 0.798 and the highest one during that month was recorded at the OS station with a Simpson index of 0.877. In December, however, the lowest diversity was recorded at the ME1 station with a Simpson index of 0.902 and the highest one (0.917) was recorded at the ME2 station.



**Figure 8.** Micro-phytoplankton genera abundance within and outside the oyster culture site during the month of December 2014. OS= Open Sea, FA1= Flushing area between the oyster culture site and the open sea, ME1= Mangrove ecosystem inside the oyster culture site, OC = Oyster culture, FA2= Flushing area between the oyster culture site and another barachois, ME2 = Mangrove ecosystem outside the oyster culture site

## Discussion

This study reports for the first time distribution of micro-phytoplankton density and diversity in a small-scale pilot oyster aquaculture farm in Mauritius. Both the density and diversity varied temporally among the studied months and spatially within the studied oyster farm. The implications of these findings with respect to oyster farming and surrounding marine environment are discussed.

### Spatial variation of the micro-phytoplankton density

The significant spatial variation of the micro-phytoplankton density observed in October and December 2014 might be the result of combined factors such as nutrient availability from nearby coastal activities, seawater temperature, salinity, pH, grazing activities and turbidity which might differ among the different sampling stations. Previous studies have shown that variations in these parameters were significantly related to the variation of the micro-phytoplankton density (Gaul et al. 1999; Melo et al. 2007; Sahu et al. 2012; Saddy et al. 2014). Specifically, for each month (October-December 2014), the highest micro-phytoplankton density was recorded at the station exhibiting the highest seawater temperature. For example, in October 2014, the highest seawater temperature and micro-phytoplankton density were recorded at the FA2 station. Similar observations were made in November and December 2014 at the OC and OS stations. These observations were further supported by the Spearman correlation analysis which revealed that the micro-phytoplankton density had a highly significant correlation

with seawater temperature.

No significant spatial micro-phytoplankton variation was recorded in November 2014. The most likely explanation for this is the windy conditions in November which could have favored mixing of the seawater, though previous studies have shown that wind-induced the horizontal variation of micro-phytoplankton density (Moreno-Ostos et al. 2012). In addition, it was observed that during that month the FA2 and OC stations showed a slight difference compared to the other studied stations. This observation might be due to the fact that the FA2 and OC stations had a slightly higher micro-phytoplankton density than the other stations. In October 2014, a significant spatial difference of the micro-phytoplankton density between the ME1 station and the other sampling stations (OC, FA1, and FA2) was noted. This significant difference might be the result of the low micro-phytoplankton density at the ME1 station during that month. However, the HCD revealed that FA2 was the most distant station during October 2014. The most probable reason for that is to be related to the micro-phytoplankton density which was highest at the FA2 station during that month. In contrast to the spatial variation of the micro-phytoplankton density in October, in December we observed that the OS station was significantly different compared to the OC and FA2 stations. This significant difference observed could be due to the high micro-phytoplankton density observed at the OS station during that month. Moreover, it was noted that OC was significantly different to the FA1 station which could be a result of the lower micro-phytoplankton density recorded at

OC station as compared to FA1 station in December.

The spatial variation of diatoms found between the ME1 and FA1 stations in October 2014 could be a result of a high nutrient influx from a nearby river causing increased phytoplankton density at the FA1 station as compared to the ME1 station. Previous studies have found that diatoms are physiologically adapted to live in nutrient-rich environments (e.g. Wilkerson et al. 2006). The high diatom density observed at the OS station in December could be due to the presence of oyster inside the barachois which decreased the micro-phytoplankton abundance. The presence of oysters may have affected the micro-phytoplankton abundance (Ulanowicz and Tuttle 1992). The likely cause of the higher diatom density at the FA2 station compared to the OC and FA1 stations is the high nutrient influx coming from a nearby animal farm.

For dinoflagellates, the higher density at the ME1 station compared to the OS, FA1 and FA2 stations could be due to the lower abundance of diatoms observed at the ME1 station during October 2014. Previous studies have shown that heterotrophic dinoflagellates were more abundant in the presence of high diatom density (Hansen 1991; Archer et al. 2000; Verity 2002; Sherr and Sherr 2007). The difference between some stations within the oyster culture site and the OS station in December 2014 could be related to the presence of oysters. It has been previously observed that dinoflagellate abundance was lower in the presence of oyster culture and once the latter was removed, the dinoflagellate abundance increased (Huang et al. 2008).

The difference in cyanobacteria density recorded between the ME1 and FA1 stations could be a result of highly turbid water at the ME1 station. Previous studies have shown that cyanobacteria are more adapted to live in low turbid water (Karakassis et al. 1998). In addition, the spatial variation of the cyanobacteria abundance recorded in December 2014 could be due to variation in the nutrient availability. There might be more nutrient available at the FA2 and OS stations during December 2014 and thus resulting in the higher abundance of cyanobacteria. Nutrient availability is known to increase the abundance of benthic cyanobacteria (Armitage and Fong 2004).

#### **Temporal variation of the micro-phytoplankton density**

The significant temporal differences in the total micro-phytoplankton, diatom and dinoflagellate densities observed during this study could be primarily due to an increase in seawater temperature from October to December 2014. The cause of this increase in seawater temperature might be due to a gradual increase of the atmospheric temperature as seen in previous study (Al-Banaa and Rakha 2009). Several studies have shown that temperature is directly proportional to phytoplankton abundance (Nowrouzi and Valavi 2010; Dogiparti et al. 2013). Evidence shows that an increase in seawater temperature also increases nutrient levels in the eutrophic zone by the mixing of the bottom seawater nutrients with the sea surface nutrients (Chandy et al. 1991; Huertas et al. 2011). It has also been suggested that an increase in seawater temperature promotes an increase of dissolved

carbon dioxide in the marine ecosystem triggering an increase in the photosynthetic rate of the phytoplankton (Li et al. 2012).

Differences in diatom density could be due to a significant increase in the silica and iron availability between each month from October to December 2014. Unfortunately, this study did not quantify iron levels. Previous studies have shown that diatom proliferation increased significantly in the presence of high silica and iron availability (Hutchins and Bruland 1997; Egge and Aknes 1992; Lasternas et al. 2008; Sadally et al. 2014b).

The most likely reason for the significance temporal difference observed for cyanobacteria between the month of October and December 2014 is the significant increase of the seawater temperature and irradiance between these two months. Previous studies have shown that cyanobacteria proliferate in response to these factors (Pilkaitytė and Razinkovas 2007; Blanco et al. 2008). However, no significant temporal differences were observed between October and November 2014, nor between November and December 2014. This could be due to similarity in the alkalinity (Sadally et al. 2014a,b), water turbulence (Blanco et al. 2008), turbidity (Karakassis et al. 1998) and nitrogen to phosphorus ratio (Vrede 2008) of the seawater in these months.

#### **Patterns in micro-phytoplankton diversity**

The pattern of dominance of the micro-phytoplankton groups observed in October 2014 was in accordance with the study done by Devassy and Goes (1991) in the EEZ of Mauritius. Diatom abundance was higher than cyanobacteria which were, in turn, more abundant than dinoflagellates. However, the observed micro-phytoplankton patterns in November and December 2014 (diatoms > dinoflagellates > cyanobacteria) were in accordance with recent studies done in Mauritius (Sadally et al. 2012; Sadally et al. 2014a,b).

The most likely reason for the high abundance of diatom during this whole study could be due to the fact that only micro-phytoplankton consisting mainly of diatom and dinoflagellates (Kennish 2000) was taken into account during this study. The dominance of diatom over dinoflagellates could also be a result of high light intensity at Poudre d'Or during this study. Studies have shown that dinoflagellates prefer to live in low light radiation (Jones and Gower 1990) as compared to diatoms which are physiologically adapted to live in both low and high irradiance conditions (Post et al. 1985). In addition, it has been shown that dinoflagellates are able to move from the sea surface to the bottom zone during high light intensity due to their capability to sustain directed swimming (Jones and Gower 1990). Furthermore, the high abundance of diatoms could be a result of a high silica and iron availability during the whole study. It has been shown that diatoms proliferate rapidly in the presence of these nutrients (Hutchins and Bruland 1997; Egge and Aknes 1992; Lasternas et al. 2008; Sadally et al. 2014b). The low abundance of dinoflagellates could be a result of their lower affinity to nutrients compared to diatoms (Smayda 1997).

The high abundance of cyanobacteria in October 2014 compared to dinoflagellates could be a result of high alkalinity in October resulting in an increase in the proliferation of cyanobacterial density. Sadally et al. (2014a) have proposed that cyanobacteria may fare better in alkaline conditions. However, in November 2014, the higher abundance of dinoflagellates compared to cyanobacteria could be a result of the windy conditions in November when the sample collection was carried out. The wind could have induced the upwelling of the water, thereby increasing the phosphate availability at the water surface. Previous studies have shown that phosphate is one of the main limiting factors for dinoflagellate abundance (Sadally et al. 2014a,b).

The high abundance of pennate diatoms (for example *Nitzschia*, *Thalassionema*, and *Pleurosigma*) as compared to centric diatoms in October and November 2014 could be the result of high silicate concentration compared to nitrogen levels. Previous studies have shown that pennate diatoms are more able to increase and compete with centric diatoms in a high silica environment (e.g. Pilkaitytė and Razinkovas 2007). However, it is noteworthy that in December 2014, the centric diatoms *Coscinodiscus* and *Bacteriastrum* had quite high abundance. This observation might be explained by an increase in the nitrogen level in December, as it has been shown previously that centric diatoms are more likely to proliferate in a nitrogen-rich environment (Pilkaitytė and Razinkovas 2007).

The high abundance of the genus *Nitzschia* could also be a result of low alkalinity. *Nitzschia* have a maximum growth rate in low alkaline conditions (less than pH 8) whereas some species of *Navicula* have a maximum growth rate at pH 8 (Hinga 2012). It has also been reported that the species *Nitzschia closterium* are able to tolerate a wide array of salinities (Hulburt and Rodman 1963). This characteristic of the genus *Nitzschia* could be one the factor that increased their abundance during this study. In addition, the increase in species diversity from October to December 2014 may be due to differences in seawater salinity as plankton diversity depends greatly on this (Kouwenberg 1994; Panda et al. 2012)

In conclusion, this study found that micro-phytoplankton density and diversity varied greatly on a short temporal (monthly) basis. The study sites, though occupying a small area, exhibited spatially variable micro-phytoplankton density and composition. Spatial variation in micro-phytoplankton density tended to be less than temporal variation. The main temporal factor that affected the micro-phytoplankton density was temperature and also probably nutrient levels. In addition, the high percentage of pennate diatoms observed during this study indicated the presence of a high concentration of silica within and around the oyster culture sites and low abundance of nitrogen. The absence of any algal bloom suggested that the oyster culture sites may not be under direct bloom-causing environmental stresses. However, further in-depth quantitative and qualitative studies on the relationship of the micro-phytoplankton abundance to a range of physicochemical parameters are needed to fully characterize and understand the dynamics of micro-

phytoplankton and optimal stations for oyster farming in the North-East coastal barachois of Poudre D'Or, Mauritius.

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