Journal of Sustainability Science and Management
Volume 15 *Number* 4, June 2020: 2-17
eISSN: 2672-7226

DIEL VARIATIONS IN DENSITY AND DIVERSITY OF MICRO-PHYTOPLANKTON COMMUNITY IN AND AROUND A BARACHOIS-BASED OYSTER CULTURE FARM

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Submitted: 12 September 2019 Accepted: 20 January 2020
http://doi.org/10.46754/jssm.2020.06.002

Abstract: Knowledge of diel variations in phytoplankton communities is important to set up and plan a successful and sustainable bivalve aquaculture industry. This study investigated the diel (24-hour cycle) variations in micro-phytoplankton community during two high and two low tides over two alternate days in summer at a barachois-based oyster farm in Mauritius, a micro-tidal tropical island. Micro-phytoplankton density and diversity, sea surface chlorophyll *a* concentration, and physico-chemical parameters, such as sea surface temperature, dissolved oxygen, pH and salinity, were assessed each day during high and low tides, at an interval of approximately six hours at 11 stations. Despite the small tidal range, significant diel variations in micro-phytoplankton density were noted throughout the tidal cycle. Highest densities of micro-phytoplankton and diversity of diatoms, dinoflagellates and cyanobacteria were recorded at stations three and six (S3 and S6). The range of total micro-phytoplankton at S3 and S6 varied above 2.0 x 10^5 cells L^{-1} and for the other stations, it varied mainly between 1 to 2 x 10^5 cells L^{-1} throughout all the tides, except on the second sampling day, where at S1 and S7, the density was slightly above 2 x 10^5 cells L^{-1}. The diatom *Coscinodiscus* (14 %), the dinoflagellates *Peridinium* (18 %) and the cyanobacteria *Anabaena* (24 %) were dominant. S3 and S6 within the barachois having a low flushing rate were characterized by the highest availability of food stock, inferring that these stations may sustain an optimal growth of bivalves. These findings may be useful in directing the barachois-based bivalve culture site towards a more effective and sustainable management by locating the most appropriate culture areas in the system.

Keywords: Barachois, chlorophyll *a*, diel variation, micro-phytoplankton, oyster culture farm.

Introduction

Coastal ecosystems are diverse regions that encompass a wide array of social, economic, and environmental resources (Coleman & Williams, 2002). However, if action is not taken at the opportune time, the overexploitation of these resources can lead to habitat degradation, pollution, and modification of ecosystem functions (Lauck *et al*., 1998). Worldwide, it has been noted that fish abundance is declining and thus, to overcome the collapsing fisheries sector, big companies and small entrepreneurs are turning towards aquaculture to farm fish, oysters, mussels, and other shellfish. However, when establishing aquaculture sites in coastal zones, it should be noted that complex interactions with other coastal services will occur and hence, one should know how to optimize the farm in ensuring good carrying capacity while maintaining the ecosystem's health (Browman & Stergiou, 2004).

Typically, oyster farms are dependent on several parameters, such as availability of micro-phytoplankton species like as *Chaetoceros* and *Thalassiosira* (Hashimoto *et al*., 2008; McCausland *et al*., 1999), optimum sea surface temperature, level of chlorophyll *a*, dissolved oxygen (DO) and a suitable salinity regime (Brown & Hartwick,1988; Gagnaire *et al*., 2006). The main food sources for oysters, which are filter feeders, are microscopic phytoplankton. To sustain an oyster farm, there should be an adequate supply of phytoplankton coupled with optimal water temperature (Bernard *et al*., 2011). A drastic change in temperature has been proven disastrous for these shellfish, whereby an increase result in high mortality rates (de Kantzow *et al*., 2016).

Furthermore, when there is fresh water discharge into the seawater of a shellfish farm, this leads to changes in the salinity gradient and thus, impacts marine life. Moreover, many studies have shown that some micro-phytoplankton are toxic when present in high densities (blooming). The filter feeders that feed on these phytoplankton may become toxic, causing fatalities when they, in turn, are consumed by those on top of the food chain, i.e. humans (Jiang *et al*., 2017). Phytoplankton blooms generally occur when there is a density of around 10^7-10^8 cells/L (Carstensen *et al.*, 2015). Among the toxic phytoplankton are the diatom *Nitzschia*, which contains domoic acid (Bates *et al*., 1991), the dinoflagellates *Gonyaulax* and *Dinophysis* (Tangen, 1983), and dinoflagellate *Alexandrium*, which produces the spirolide shellfish toxin (Cembella *et al*., 2000). Hence, it is of prime importance to determine the species of phytoplankton present in aquaculture farms to monitor the presence of toxic genera.

Assessment of variations in phytoplankton during the whole diel (24-hour) cycle is needed to thoroughly understand their dynamics in terms of density and diversity, their implications on coastal waters, optimization of operations, and productivity of the oyster farm. During a diel cycle, we have two alternating low and high tides (four tide levels), and during each tide, there is exchange of water in and out of different ecosystems, whereby several parameters like oxygen level and nutrient concentration, are replenished, (Gianesella *et al*., 2000). Tidal change also brings about stabilization in the salinity and pH of the seawater. An in-depth study on the phytoplankton community throughout a 24-hour period will provide an insight on the carrying capacity of the ecosystem in terms of food availability (Jiang & Gibbs, 2005). It is of prime importance to know the food availability, especially in an aquaculture system, to ensure optimal growth of cultured bivalves and other marine organisms.

Around Mauritius Island, several studies have been carried out to determine changes in different physico-chemical parameters (Turner *et al*., 2002 Bhagooli; Taleb-Hossenkhan, 2012; Bhagooli & Kaullysing, 2019) and some studies have focused on their association with phytoplankton (Bhagooli & Hidaka, 2004; Sadally *et al*., 2014a; Sadally *et al*., 2014b; Sadally *et al*., 2015). It is also predicted that the marine environment is going to become warmer within a short period of time (Bhagooli & Sheppard, 2012). Limited study on the variation of phytoplankton across a fish aquaculture system has been conducted (Sadally *et al*., 2015). Recently, a study in the northeast of Mauritius Island has provided the baseline data over a few months on micro-phytoplankton communities at a barachois-based oyster farm (Armance *et al*., 2019). However, details are limited on complete cycles of phytoplankton variation during a whole diel period focusing on each tidal change, and the effects they cause on a semi-enclosed barachois culture system are not known. The barachois, as such, is an enclosed coastal lagoon with limited water exchange from the ocean, which increases the residence time of the water inside. Thus, this study investigated the diel variations in density and diversity of the micro-phytoplankton community in a barachois oyster farm, and the factors affecting their growth. Furthermore, physico-chemical parameters, such as temperature, salinity, pH and DO, were recorded at different tides over two alternate days.

Material and methods

Study Site

The oyster culture site at Poudre d'Or is approximately 0.04 km^2 and is situated in the northeast coast of Mauritius (Figure 1A). Figure 1B shows the different stations within and outside the barachois. Stations one to seven (S1-7) were inside the barachois and stations eight to 11 were (S8-11) outside. These different stations were selected based on different water ecosystems, depths, flow directions, flow rates and transparency (Table 1).

At this region of Mauritius, there was higher tidal change, which was over 40 cm on average, especially inside the barachois, whereby the oysters were exposed to sunlight during low tides. This was very beneficial for the oysters as sunlight would ensure proper growth and decrease their mortality rate. The barachois water was influenced by different environmental factors, owing to the presence of river discharge and other ecosystem like small mangrove patches. Furthermore, Poudre d'Or is a highly populated region and hence, in some ways, there could be anthropogenic activities

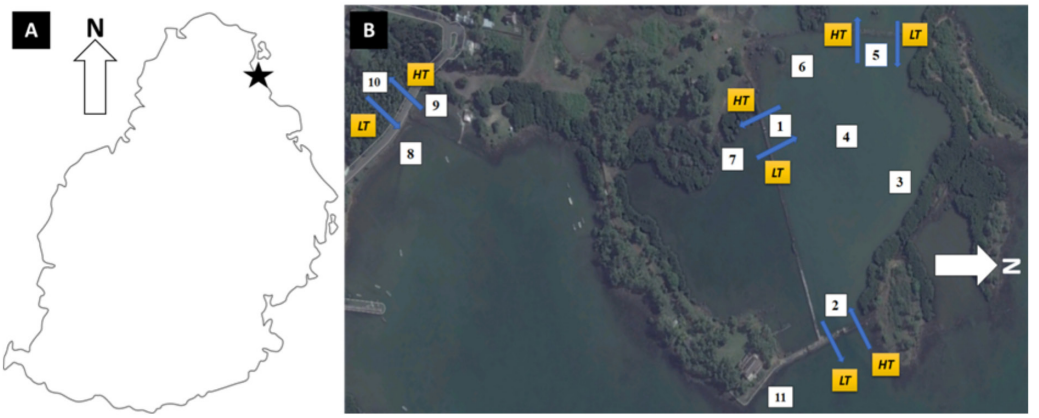

Figure 1: The map of Mauritius Island located within the latitude 20° 17 S and longitude 57 º 33 E, where the star symbol marks the study site at Poudre d'Or; B: The site at Poudre d'Or with stations one to seven inside the farm and stations eight to 11 outside. North is denoted by the symbol "N"

Table 1: The stations at the aquaculture farm at Poudre d'Or with their respective water depths, ecosystem differences, water flow rates and water transparency

Station	Water Depth	Ecosystem/Water flow direction	Water flow rate	Water Transparency
1	0.8-1.0 m	Exchange point of mangrove water in/out of farm	Turbulent	< 0.5 m
2	1.8-2.0 m	Adjacent seawater outside barachois moving in and out	Well-flushed	< 0.5 m
3	0.3-0.5 m	Near the mangrove	Calm	< 0.2 m
4	1.8-2.0 m	High depth with high water flow	Turbulent	< 0.5 m
5	0.8-1.0 m	Water flow in and out continuously	Turbulent	< 0.5 m
6	0.3-0.5 m	Oyster and crab aquaculture site	Calm	< 0.2 m
7	0.3-0.5 m	Near the mangrove	Calm	< 0.2 m
8	0.8-1.0 m	Mixing of river and seawater	Turbulent	< 0.5 m
9	0.3-0.5 m	The river estuary meeting the sea	Turbulent	< 0.2 m
10	1.8-2.0 m	Riverbed of fresh water in/out into sea	Turbulent	< 1.0 m
11	0.8-1.0 m	Well mixed coastal seawater	Well-flushed	< 0.5 m

that degraded the quality of water in that area. The diel variation of micro-phytoplankton was investigated, and samples were taken at the 11 stations in triplicates at an interval of six hours for two alternate days (March 31 and April 2, 2018). The sampling was conducted in such a way that it included different tides (two high tides (HT) and two low tides (LT)) in 24-hour cycles (Table 2). The first sampling was conducted on March 31, 2018, and it was during a spring tide, whereby the tidal change was the highest. The second sampling was done on April 2, 2018, which was one day after the spring tide.

Sample Collection and Processing

Micro-phytoplankton

Samples were collected in triplicates at each station on each sampling day. For micro-phytoplankton samples, 10 L of seawater were filtered through a 5 µm plankton mesh. Eventually the residue was collected and centrifuged at 3500 rpm for 10 minutes (Sadally *et al*., 2014a) to concentrate the micro-phytoplankton, followed by counting on a Sedgwick Rafter counting chamber (Devassy & Goes, 1991) placed under a microscope to determine diversity and abundance (Tomas, 1996). The density of micro-phytoplankton was calculated as cells L^{-1}. The cyanobacteria were mainly filamentous, and, on average, there were 15 cells in each filament.

Chlorophyll a

Chlorophyll *a* samples were collected in triplicates at each station on each day. A total of 500 ml of seawater was collected and filtered through a 0.45 µm pore size Whatman glass fibre filter paper. The filter paper was placed in a tube wrapped in aluminum foil, followed by the addition of 10 ml of 90 % acetone for the extraction of chlorophyll *a* pigments and stored at 4 ^{0}C in the dark. The absorbance was read using a UV spectrophotometer at wavelengths of 630, 647, 664 and 750 nm after 24 hours to determine chlorophyll *a* concentration (Jeffrey & Humphrey, 1975).

Physico-chemical Parameters

The Hanna HI 9142 dissolved oxygen meter (Hanna Instruments, Woonsocket, RI, USA) was used to measure the DO level at the surface of the seawater. For salinity, a refractometer (ERMA) was used. Water temperature and pH at stations were measured using a thermometer and pH meter, respectively.

Statistical analysis

Data analysis was carried out using the PASW Statistics 18, SPSS software. Two-way ANOVA, Pearson's Correlation and Tukey's HSD post-hoc tests were performed. Model assumption for normality was verified and non-normally distributed data was transformed using the $\log_{10}$ or Arcsine transformation. Shannon-Wiener, Equitability and Evenness diversity indices were used to determine the variability of the different micro-phytoplankton genera. Statistical tests were considered significant at α=5 % level.

Table 2: The two sampling days with the tidal range and tidal time change

	1st High Tide		*1st Low Tide*		*2nd High Tide*		*2nd Low Tide*	
Date	**Time**	**Height**	**Time**	**Height**	**Time**	**Height**	**Time**	**Height**
31/03/2018	01:13 a.m	86 cm	07:31 a.m	29 cm	13.10 p.m	86	19:36 p.m	27 cm
	Tidal Range=57 cm				***Tidal Range=59 cm***			
02/04/2018	02.00 a.m	83 cm	08.33 a.m	29 cm	14.18 p.m	82 cm	20.30 pm	35 cm
	Tidal Range=54 cm				***Tidal Range=47 cm***			

Results

Micro-phytoplankton Density

The Total Phytoplankton Density (TPD) was highest at S3 and S6, and this trend was followed by diatoms, dinoflagellates, and cyanobacteria (Figure 2). Two-way ANOVA showed that there was significant diel variation, i.e., difference on average, for the TPD during the study period. Significant diel variation was also noted for the densities of diatom, dinoflagellates, and cyanobacteria (Table 3). Furthermore, there were also significant spatial variations among the stations for the density phytoplankton, diatoms, dinoflagellates and cyanobacteria at $p < 0.001$, whereby S3 and S6 had the highest densities. When the effect of tides and stations were combined, there were low significant differences for TPD, and the densities of

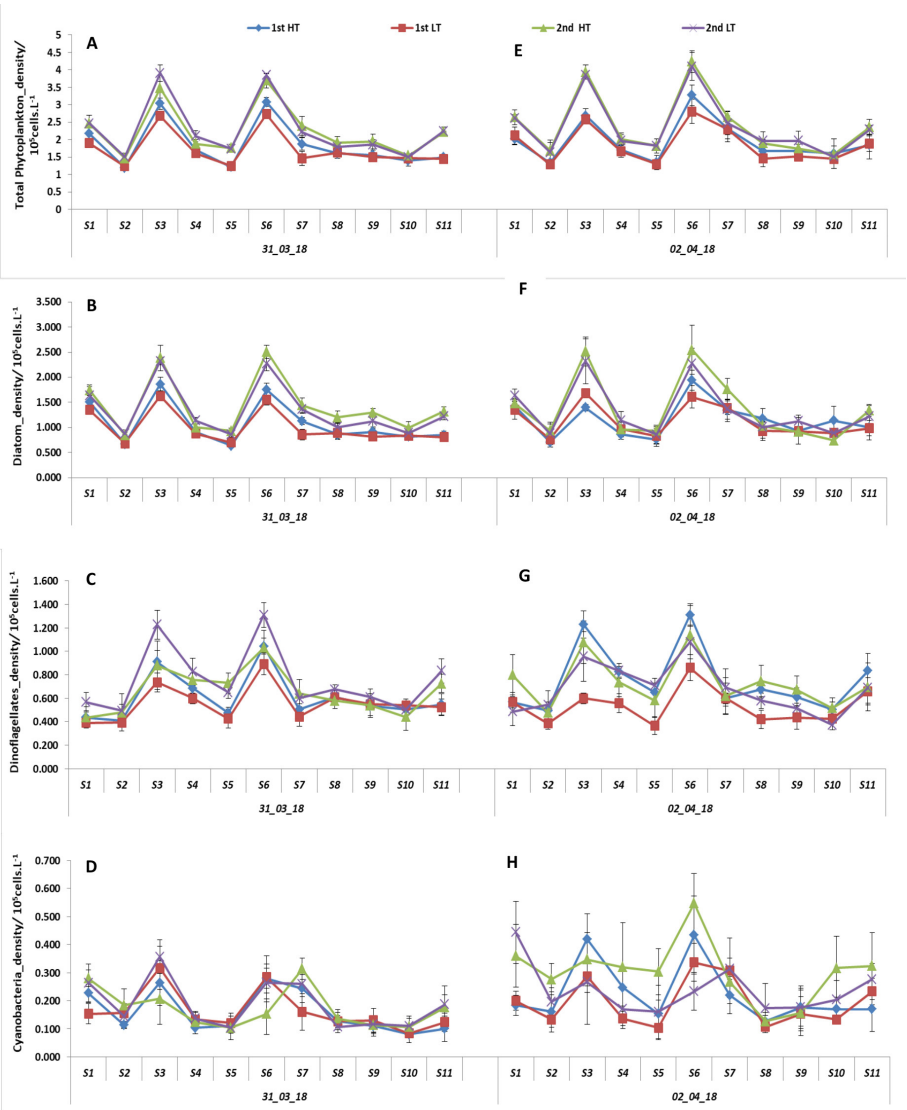

Figure 2: A, B, C and D represent the densities of total phytoplankton, diatoms, dinoflagellates and cyanobacteria, respectively, on March 31, 2018, at four different tides; E, F, G and H represent the densities of total phytoplankton, diatoms, dinoflagellates and cyanobacteria, respectively, on April 2, 2018, at four different tides, where HT= High tide and LT= Low tide. Bars represent standard deviation (n=3)

diatoms and dinoflagellates. For cyanobacteria, the combined difference was not significant.

The 2nd HT and 2nd LT had higher density of total micro-phytoplankton compared to the 1st HT and 1st LT (Figure 2). Tukey's HSD post-hoc test was performed to compare the mean densities of diatoms, dinoflagellates, cyanobacteria, and phytoplankton at different tides. On average, there were strong significant differences ($p < 0.001$) in TPD under mostly all four tidal pairwise comparisons (1st HT, 1st LT, 2nd HT and 2nd LT), except for just a significant and non-significant difference between the pairs 1st HT/1st LT ($p < 0.05$) and 2nd HT/2nd LT, respectively. Similarly, for diatom and dinoflagellates densities, all pairwise differences were strongly significant except for the comparisons between 1st HT/ 1st LT and 2nd HT/2nd LT. Furthermore, for cyanobacteria density, significant differences existed only between 1st HT/2nd HT and 1st LT/2nd HT (Table 4).

Table 3: Two-way ANOVA comparing the densities of diatoms, dinoflagellates, cyanobacteria and total phytoplankton at different tides and stations

		SS	*df*	*MS*	*F*	*p-value*
TDP						
	Tides	0.669	3	0.223	104.639	***
	Stations	3.990	10	0.399	187.340	***
	Tides * Stations	0.106	30	0.004	1.665	*
Diatom						
	Tides	0.668	3	0.223	59.956	***
	Stations	5.176	10	0.518	139.318	***
	Tides * Stations	0.222	30	0.007	1.989	**
Dinoflagellates						
	Tides	0.588	3	0.196	27.779	***
	Stations	3.041	10	0.304	43.069	***
	Tides * Stations	0.318	30	0.011	1.499	*
Cyanobacteria						
	Tides	0.496	3	0.165	5.698	***
	Stations	5.112	10	0.511	17.623	***
	Tides * Stations	0.947	30	0.032	1.088	NS

p <0.001= ***, p <0.01= **, p <0.05= *, NS= Not Significant.

Table 4: Tukey's HSD post-hoc test for comparing means of the densities of diatoms, dinoflagellates, cyanobacteria, and total phytoplankton at different tides

		Diatom p-value	**Dinoflagellates p-value**	**Cyanobacteria p-value**	**TPD p-value**
1st_High Tide	1st_Low Tide	NS	NS	NS	*
	2nd_High Tide	***	***	**	***
	2nd_Low Tide	***	***	NS	***
1st_Low Tide	2nd_High Tide	***	***	***	***
	2nd_Low Tide	***	***	NS	***
2nd_High Tide	2nd_Low Tide	NS	NS	NS	NS

p <0.001= ***, p <0.01= **, p <0.05= *, NS= Not Significant

Diversity of Micro-phytoplankton Genera

The highest densities of phytoplankton were recorded at S3 and S6 and hence, a more detailed investigation was carried out for these stations as they could be the best zones for aquaculture because of abundant food source. The percentage of different micro-phytoplankton genera was calculated based on S3 and S6, and the figure was averaged for the four tides and for both sampling days. Diatoms were observed to be dominant, followed by dinoflagellates and cyanobacteria. For diatom groups, the percentage contribution mostly varied around 2 % except for the genera *Chaetoceros, Coscinodiscus, Fragillaria, Licmorphora, Navicula* and *Nitzschia*. In the top six dominant diatoms, the percentage contribution was highest at S6 compared to S3 for *Coscinodiscus, Fragillaria, Licmorphora, Navicula* and *Nitzschia*, except *Chaetoceros*, where S3 had higher percentage contribution. For dinoflagellates, *Ceratium* and *Peridinium* were the most abundant. For both these dinoflagellates, the percentage were higher at S6 compared to S3. Among the seven cyanobacteria genera, the *Anabaena, Lyngbya, Nodularia* and *Oscillatoria* were the most dominant, followed closely by *Phormidium, Snowella and Spirulina* (Figure 3).

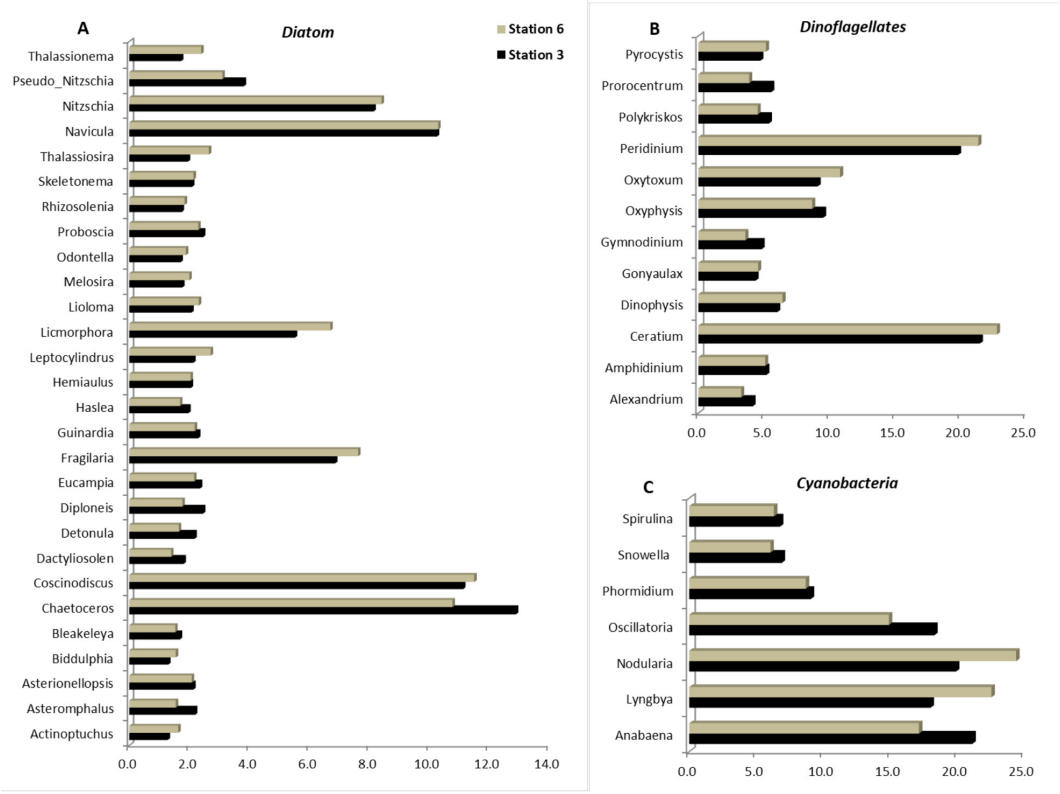

Figure 3: Percentage of different micro-phytoplankton genera calculated separately for the three groups of micro-phytoplankton, namely diatoms, dinoflagellates and cyanobacteria, accounting for 100% each at stations 3 and 6 on average for two sampling days (31/03/18 and 02/04/18): A: Percentage of different diatom genera (100% total); B: Percentage of dinoflagellates (100% total); C: Percentage of cyanobacteria (100% total)

Stations 3 and 6 were chosen to perform different diversity indices (Shannon-Wiener, Equitability and Evenness) for both sampling days. S6 was the area where oysters were cultured. During this study, both stations had the highest TPD, hence they were chosen to perform the indices to see whether they resembled each other in terms of genera variation during the two 24-hour cycles. The highest values for Shannon-Wiener, Equitability and Evenness for 28 different genera of diatoms were recorded at the 1st HT for both stations and on both sampling days. The trends for the different indices for both days resembled each other (Figure 4).

Physico-chemical parameter and Chlorophyll a Concentration

Two-way ANOVA revealed that there were strong significant differences on average ($p < 0.001$) for pH, temperature, and chlorophyll *a* concentration at different tides, except for salinity and DO, which were not significantly different. Furthermore, it was found that there were strong significant differences ($p < 0.001$) for pH, salinity, DO, temperature, and chlorophyll *a* concentration station-wise. Higher pH and DO were recorded on April 2, 2018, compared to March 31, 2018, when all four tidal changes occurred, and salinity was inversed. Temperature was higher on April 2, 2018, except during the 2nd LT and tide-wise, the highest temperature was recorded during the 2nd HT on both days. Higher chlorophyll *a* concentration was recorded on April 2, 2018, except during the 1st HT. Moreover, the 1st HT had resulted in the lowest chlorophyll *a* concentration on both days.

The Tukey's HSD post-hoc test showed that there were strong significant differences ($p < 0.001$) during all the tides for pH and chlorophyll *a* concentration. It was fairly the same case for temperature; except for 1st LT/ 2nd LT, where the difference was not significant. For salinity and DO, there were no significant differences irrespective of tide. Pearson correlations between the densities of diatoms, dinoflagellates, cyanobacteria and total phytoplankton with chlorophyll *a*, pH, salinity, DO and temperature

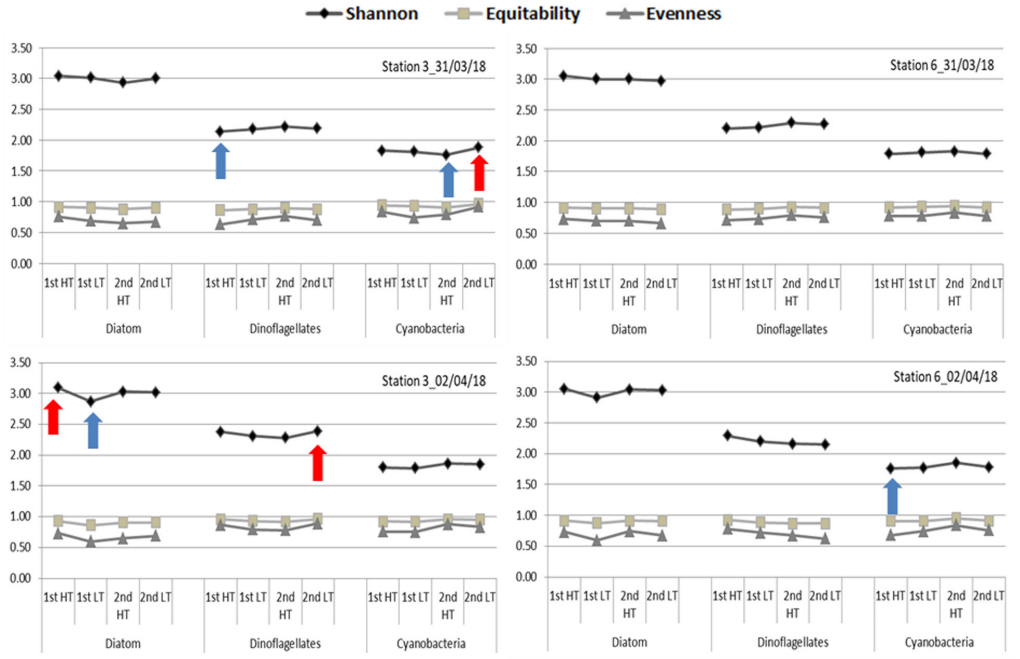

Figure 4: Shannon-Wiener diversity index, Equitability and Evenness of the different genera of diatoms, dinoflagellates and cyanobacteria at stations 3 and 6. Red arrow: highest values; Blue arrow: lowest values

were positive. Strongly positive correlations ($p < 0.01$) were noted between salinity and DO with all micro-phytoplankton densities. But there was no significant correlation between cyanobacteria density and chlorophyll *a* compared to other micro-phytoplankton densities. No significant correlation between diatom and dinoflagellate densities were observed with pH.

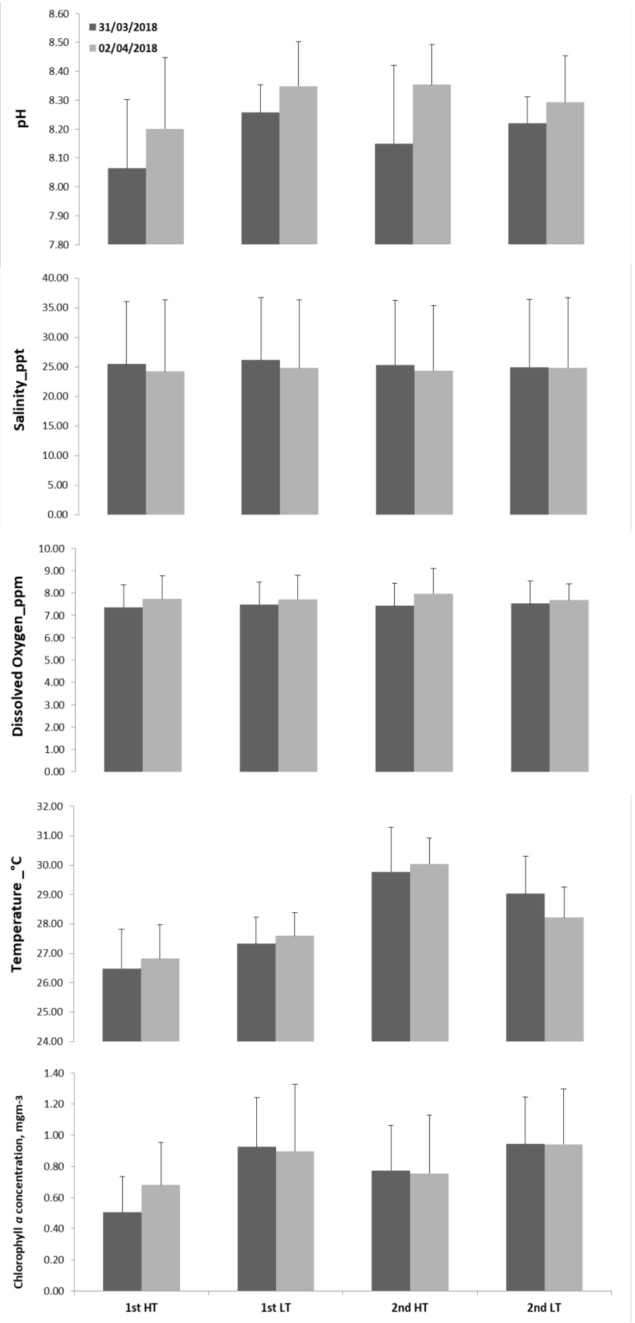

Figure 5: Physico-chemical parameters and chlorophyll *a* variation during each tide for the two sampling days (March 31 & April 2, 2018). HT: High tide and LT: Low tide. Bars represent standard deviation (n=3)

Table 5: Two-way ANOVA for comparing pH, salinity, dissolved oxygen, temperature and chlorophyll *a* concentration at different tides and station

Parameters	*Effect*	*SS*	*df*	*MS*	*F*	*p-value*
pH						
	Tides	0.003	3	0.001	12.810	***
	Stations	0.007	10	0.001	8.841	***
	Tides * Stations	0.008	30	0.001	3.458	***
Salinity						
	Tides	0.028	3	0.009	1.254	NS
	Stations	40.436	10	4.044	545.072	***
	Tides * Stations	0.713	30	0.024	3.203	***
DO						
	Tides	0.003	3	0.001	1.753	NS
	Stations	0.778	10	0.078	162.592	***
	Tides * Stations	0.118	30	0.004	8.208	***
Temperature						
	Tides	0.096	3	0.032	233.992	***
	Stations	0.023	10	0.002	16.925	***
	Tides * Stations	0.026	30	0.001	6.400	***
Chlorophyll a						
	Tides	0.051	3	0.017	63.602	***
	Stations	0.154	10	0.015	57.374	***
	Tides * Stations	0.069	30	0.002	8.519	***

$p < 0.001$= ***, $p < 0.01$= **, $p < 0.05$= *, NS= Not Significant.

Table 6: Tukey's HSD post-hoc tests for comparing means of pH, salinity, DO, temperature and chlorophyll *a* concentration with different tides

		pH p-value	*Salinity p-value*	*DO p-value*	*Temperature p-value*	*Chla p-value*
1st_High Tide	1st_Low Tide	***	NS	NS	***	***
	2nd_High Tide	***	NS	NS	***	***
	2nd_Low Tide	***	NS	NS	***	***
1st_Low Tide	2nd_High Tide	***	NS	NS	***	***
	2nd_Low Tide	***	NS	NS	NS	***
2nd_High Tide	2nd_Low Tide	***	NS	NS	***	***

$p < 0.001$= ***, $p < 0.01$= **, $p < 0.05$= *, NS= Not Significant

Table 7: Pearson Correlation coefficient, *r*, of the densities of different micro-phytoplankton with different physico-chemical parameters.

	Chlorophyll a	*pH*	*Salinity*	*DO*	*Temperature*
Diatom	0.137*	0.066 (NS)	0.279**	0.336**	0.303**
Dinoflagellates	0.263**	0.109 (NS)	0.317**	0.181**	0.336**
Cyanobacteria	0.036 (NS)	0.246**	0.303**	0.339**	0.140*
TPD	0.177**	0.119 (NS)	0.339**	0.345**	0.344**

$p < 0.001$= ***, $p < 0.01$= **, $p < 0.05$= *, NS= Not Significant

Discussion

Tidal changes during a 24-hour cycle are very important, especially for organisms living in coastal waters, where it would bring fresh water, nutrients, oxygen and other inorganic matters (Gianesella *et al*., 2000). Moreover, in a closed barachois, where this study was conducted, the exchange of water was of utmost importance as there were limited passes for in-flow and out-flow, and this would increase the residence time of the water in the barachois (Mudge *et al*., 2007).

During each 24-hour period, the diel variation of the micro-phytoplankton was observed. The density of micro-phytoplankton was significantly different throughout the four tidal changes (Frempong, 1981; Moser *et al*., 2012; 2017). Micro-phytoplankton, which were passively transported in coastal flows, needed light for photosynthesis to promote cellular growth and reproduction. The high densities of phytoplankton observed during the day tides (2nd high and 2nd low tides) could be attributed to the availability of natural light penetrating through the waters. This eventually promoted a high productivity rate (Behrenfeld & Falkowski, 1997). During the night, the productivity rate decreased drastically in the absence of natural light and, eventually, there was grazing of phytoplankton by zooplankton. It has been shown that zooplankton usually migrated to the upper layer of the water column at night to forage for food and escape predation (Shaw & Robinson, 1998). The zooplankton grazing capacity and oyster consumption would determine the density of the phytoplankton population (Tian *et al*., 2016). The relationship between zooplankton and phytoplankton is inversely proportional (Goldyn & Kowalczewska-Madura, 2007). Depending on size ratio, oysters have high filtration rate ranging from 1 to 4 L/hour of the water containing phytoplankton (Ehrich & Harris, 2015).

Highest densities of phytoplankton are generally found in regions with low depths, muddy bottom and near mangroves (Kristensen *et al*., 2008). Together, these factors were characterized by low water flow rate. The highest density of cyanobacteria was also found in the same areas. Filamentous nitrogen-fixing cyanobacteria like *Anabaena* produce nitrates and nitrites at the bottom of the barachois (Kaneko, 2001; Casareto *et al*., 2008; Charpy *et al*., 2010). Eventually the changing of tides and increasing turbulence in the water column promoted the resuspension of benthic diatoms to the upper water column, together with a bottom-up effect on the nutrients. The assimilation of nutrients for growth by the micro-phytoplankton might explain the high density of the latter in the muddy (high organic and inorganic content) regions adjacent to the mangrove ecosystem.

Throughout the study period, diatoms were found to be dominant, followed by dinoflagellates and cyanobacteria (Bernardi Aubry *et al*., 2006; Bazin *et al.,* 2014). Diatoms have developed the ability to thrive in changing environments, even with temperature fluctuations or even limited light availability (Kokfelt *et al*., 2009). Among the dominant diatoms was *Fragilaria*,

which was usually abundant near the freshwater ecosystem, which confirmed the interaction between the aquaculture system and river discharge nearby (Dauta *et al*., 1990). There was a high abundance of *Nitzschia*, but it was considered indigestible by the oyster compared to *Chaetoceros*, which was a good food source (Tomaru *et al*., 2002). *Chaetoceros sp*. was among the best food for oysters and could promote a growth rup to a ate of 2.21g/month (McCausland *et al*., 1999; Hashimoto *et al*., 2008). Other dominant diatoms found were Coscinodiscus*, Navicula* and *Licmorphora* (Kasim & Mukai, 2006; Carstensen *et al*., 2015).

There was no significant variation in salinity during tidal changes. This may be attributed to the effect of a partially-closed aquaculture system. Salinity was identified as a strong factor affecting phytoplankton community structure (Larson & Belovsky, 2013). The level of DO did not vary significantly. This may imply that there was a low water exchange rate between the aquaculture farm and adjacent waters. The fairly unchanged level of DO was indicative of the proper functioning of the marine ecosystem as consumed oxygen was being replaced to maintain equilibrium. There was a positive correlation between DO and pH during the experiment at all stations, where the pH values were above 8, which implied that the area was well oxygenated and there was no accumulation of carbon dioxide (CO_2), which meant that there was a low respiration rate compared to its production rate.

It has been reported that the level of DO in seawater increases during strong winds (Ridder & England, 2014) because of turbulence, which causes the oxygenation of water (Yamamoto *et al*., 2015). The strong significant variation in temperature during the tidal change could be attributed to insolation whereby the 2nd HT and ^{2nd} LT occurred during daytime. There was no cloud coverage during daytime sampling and thus, insolation was maximum, and the highest temperature recorded was during the 2nd HT and ^{2nd} LT (Dunstan *et al*., 2018). The significant change in pH at different tides could be due to a change in the photosynthetic rate of microalgae in the water. The DO level was supersaturated, coupled with a relatively high pH, and this could promote the growth and reproduction of phytoplankton. The high DO could provide the right conditions to attain optimal oyster growth rate as DO had been shown to be a critical determinant in the health and stress conditions of oysters (Stickle *et al*., 1989; Baker & Mann, 1994).

Conclusion

This study reported the variations in micro-phytoplankton density and diversity throughout two 24-hour cycle period over two diel cycles, together with associated parameters like chlorophyll *a* concentration, pH, salinity, DO and sea surface temperature. The physico-chemical parameters studied give us an insight on the status of the water quality throughout the different tidal changes. Moreover, the high pH variation could be used to predict if the system was functioning properly, whereby we could probably assume that the micro-phytoplankton were uptaking enough carbon diocide to perform photosynthesis, which helped in maintaining the pH of the water at an optimum level. The highest densities of micro-phytoplankton were found at S3 and S6. Diversity indices performed at both stations were comparable. It implied that in addition to S6, S3 was another area where oyster culturing could be practiced with respect to sufficient micro-phytoplankton availability. Owing to the global rise in sea temperature, many small oyster entrepreneurs were reporting cases of mass mortality of their molluscs. One probable solution was to increase the production rate to minimize losses caused by the high mortality rate. Hence, exploring S3 as a potential area to produce more oysters could help move towards a higher optimization of the barachois.

Acknowledgements

The authors would like to thank the Mauritian Ministry of Blue Economy, Marine Resources, Fisheries and Shipping for granting permits for

sample collection, the University of Mauritius for the its laboratory facilities and Persand Khemraj for allowing access to his aquaculture farm. The authors are also grateful to the Western Indian Ocean Marine Science Association (WIOMSA) for providing a travel grant under the MARG-III scheme.

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