

## VARIATIONS IN THE DENSITY AND DIVERSITY OF MICRO-PHYTOPLANKTON AND MICRO-ZOOPLANKTON IN SUMMER MONTHS AT TWO CORAL REEF SITES AROUND MAURITIUS ISLAND

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**Abstract:** Variations in micro-phytoplankton and micro-zooplankton communities on healthy coral reefs were evaluated at Flic en Flac (FEF) in the west coast and Belle Mare (BM) in the east coast of Mauritius island during the summer months from October 2018 to March 2019. Total micro-phytoplankton density (TMPD) varied significantly between the studied sites ( $p < 0.05$ ) and months ( $p < 0.05$ ) but did not bloom. The micro-phytoplankton diversity decreased from October 2018 to March 2019 at BM but increased gradually at FEF. Although diatoms were dominant in March 2019, dinoflagellates were also present in relatively high numbers. Total micro-zooplankton density (TMZD) varied significantly throughout the months ( $p < 0.001$ ). TMZD was lowest in October 2018 and highest in March 2019 at both sites. TMZD and sea surface temperature (SST) correlated positively at BM ( $r = 0.719$ ) and FEF ( $r = 0.910$ ). A strong positive correlation ( $r = 0.946$ ) was also noted between TMPD and TMZD at BM. A Canonical Correspondence Analysis (CCA) revealed that SST, salinity and TMZD were linked with variations in the composition of micro-phytoplankton community, while SST, salinity and dissolved oxygen affected micro-zooplankton distribution. Variable density and diversity of micro-plankton communities on reefs may have implications for coral reefs' responses to and recovery from high SST anomalies.

Keywords: Coral reefs, density, diversity, Mauritius, micro-phytoplankton, micro-zooplankton.

### Introduction

Plankton are key to marine ecosystems since they represent the base of the marine food chain. Half the global primary production depends on phytoplankton (Field *et al.*, 1998). Marine phytoplankton are also a major source of dimethyl sulfide (Keller, 1989) and therefore, contribute to global atmospheric processes by enhancing cloud formation (Charlson *et al.*, 1987). The diversity of a phytoplankton community impacts the structure of the marine food web (Cushing, 1989) and influences the ability of the oceans to store carbon (De La Rocha & Passow, 2007). A highly diverse phytoplankton community can increase the total primary production in the marine environment (Loreau, 2010).

Even though phytoplankton populations often increase under optimal conditions, they usually decline in diversity. Species are known to become dominant when their abundance increases significantly but the number of species in the community remains unchanged or decreases (Sidabutar *et al.*, 2016). This condition eventually leads to blooms. Phytoplankton species can be very sensitive to small environmental changes and thus, monitoring their density and diversity can provide a good insight on water quality (Brettum & Andersen, 2005) as well as the ecosystem's ecological status (Barić *et al.*, 1992; Legović *et al.*, 1994). A highly dynamic relationship was previously observed between phytoplankton and the availability of nutrients (Weyl, 1970; Odum,

1971; Chattopadhyay *et al.*, 2003). Physico-chemical parameters, such as sea surface temperature (SST) (Hutchins, 1947; Takarina *et al.*, 2017; Vajravelu *et al.*, 2017), pH (Berge *et al.*, 2010; Takarina *et al.*, 2017; Vajravelu *et al.*, 2017), dissolved oxygen (DO) (Takarina *et al.*, 2017) and salinity (Larson & Belovsky, 2013; Takarina *et al.*, 2017; Vajravelu *et al.*, 2017) are also known to affect phytoplankton communities.

Micro- and macro-nutrients are partially recycled in the marine environment by zooplankton. The excretion of zooplankton is mostly ammonium and is hence, a source of nitrogen to phytoplankton (Bougis, 1976; Coello-Camba *et al.*, 2017). Although zooplankton may control phytoplankton population through the excretion of nutrients and grazing activity (Coelle-Camba *et al.*, 2017), the percentage of ammonium taken up by phytoplankton varies spatially and seasonally (Dagg *et al.*, 1982). Zooplankton are primary consumers in the ocean, feeding mostly on phytoplankton, and they are also essential in the trophodynamics since they represent the link between the latter and species from higher trophic levels (Calbet & Landry, 2004). In coral reef ecosystems, zooplankton are the main source of food for fish and other planktivores on the benthos, especially reef-building coral polyps like scleractinians (Glynn, 1973; Sebens *et al.*, 1996; Coma *et al.*, 1999).

Copepods account for approximately 70 to 90 % of the zooplankton abundance in coral reefs (Heidelberg *et al.*, 2004; McKinnon *et al.*, 2005; Nakajima *et al.*, 2014). There is an absence of seasonal variation in their community (Webber & Roff, 1995; Yang *et al.*, 2017) in tropical waters because of the relatively stable environmental parameters and small changes in physico-chemical factors. Zooplankton are vulnerable to changes in SST, pH, salinity and DO compared to phytoplankton, that are capable of acclimatization (Morgan, 1986; Berge *et al.*, 2010). Yang *et al.* (2017) observed the dependence of zooplankton communities on water circulation and eddies, and their abundance in high productive waters.

Areas rich in micro-phytoplankton and micro-zooplankton may act as nursery sites, and eventually become fishing grounds for the fishermen community. Limited scientific studies have been carried out on micro-phytoplankton and micro-zooplankton around the island of Mauritius. Ramdonee and Appadoo (2015) reported that sites characterised by mangroves were more diverse in terms of zooplankton compared to a non-mangrove site. Armance *et al.* (2019) recorded a total of 20 genera of micro-phytoplankton at a mangrove-based oyster culture farm along the north-east coast of Mauritius, where temporal variations affected micro-phytoplankton density more than spatial variations. Sadally *et al.* (2012; 2014) reported that the east coast of Mauritius, Belle Mare, harboured a higher micro-phytoplankton density as compared to Flic en Flac in the west coast, and at both the sites, the reefs had the lowest micro-phytoplankton density. Phytoplankton and zooplankton have been studied in isolation in different coastal ecosystems around Mauritius, with the exception of Modoosoodun *et al.* (2010), who reported phytoplankton and zooplankton abundance and diversity simultaneously at Balaclava Marine Protected Area (MPA), more specifically at various ecosystems, namely sandy and rocky stretches of the beach, estuary and river. Sixteen and 19 families of phytoplankton and zooplankton, respectively, were identified down to the family level at the MPA, and phytoplankton diversity was positively correlated with salinity and pH. In Mauritius, there are reports of variations in environmental parameters, such as seawater temperature and nutrient levels on coral reefs and in the lagoons (Bhagooli & Taleb-Hossenkhan, 2012; Kaullysing *et al.*, 2016; Bhagooli & Kaullysing, 2019). However, there has been no detailed scientific study on whether or how these environmental factors influence the composition of micro-plankton communities in a tropical island. This study aims to investigate the structure and composition of both micro-phytoplankton and micro-zooplankton communities on healthy coral reefs around Mauritius, and whether changes in environmental factors can affect their density and diversity.

## Materials and Methods

### Study Sites

Mauritius is a tropical island east of Madagascar in the Indian Ocean, and it is part of the Mascarene Islands. Samples were collected at coral reefs in Flic en Flac (FEF) in the island's west coast and Belle Mare (BM) in the east coast of Mauritius island (Figure 1) between October 2018 and March 2019, (considered as summer months in Mauritius).

### Sampling Strategy

For each micro-phytoplankton sample, 10 L of seawater were collected from the surface of reefs using a graduated bucket and filtered through a 5 µm plankton mesh. The filtrate was stored in 50 mL conical tubes. For each micro-zooplankton sample, 100 L of seawater were filtered through a 100 µm plankton mesh and the filtrate was kept in 50 mL conical tubes. The micro-phytoplankton samples were fixed in Lugol's solution while the micro-zooplankton

were placed in 10% formalin before storing at 4°C. Seawater was collected in triplicates of 500 mL bottles and stored at -20°C for chlorophyll *a* and nutrient analyses.

### Micro-plankton Analysis

The conical tubes were left to stand in a dark and cold environment for a week, allowing the micro-plankton to settle at the bottom. The water was decanted, and the concentrate was carefully transferred to 1.5 mL microcentrifuge tubes. Both micro-phytoplankton and micro-zooplankton samples were identified and counted using a Sedgwick-Rafter counting chamber under a light inverted microscope (magnifications x100 and x200). Micro-phytoplankton and micro-zooplankton were morphologically identified down to the genus level (Perry, 2003; Verlencar & Desai, 2004; Al-Yamani *et al.*, 2011; Sadally *et al.*, 2012; Al-Handal *et al.*, 2016; Sadally *et al.*, 2016; Tan *et al.*, 2016).

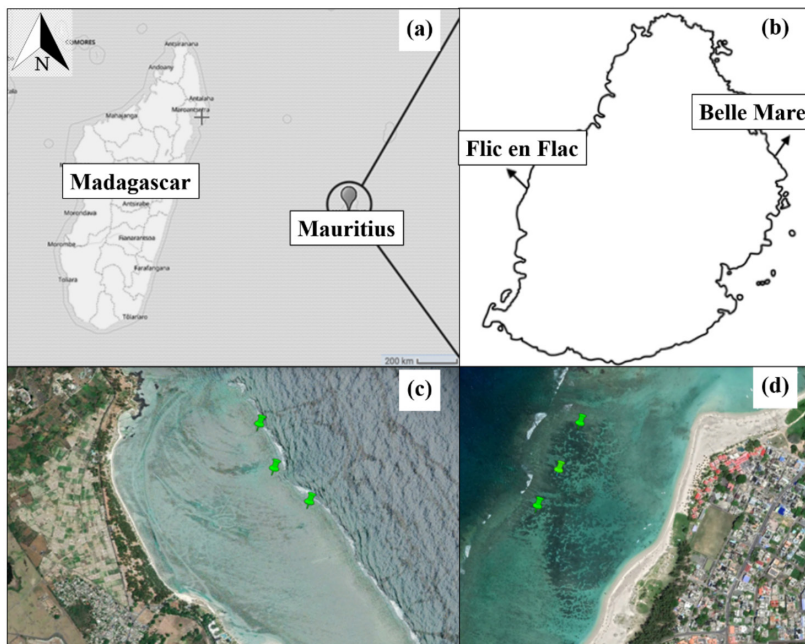


Figure 1: Location of the study sites. (a) Mauritius island in the Indian Ocean, east of Madagascar; (b) map of Mauritius showing the study stations in Belle Mare (BM) on the east coast and Flic en Flac (FEF) on the west coast; and, satellite images of (c) BM and (d) FEF (Photo Source: [www.scribblemaps.com](http://www.scribblemaps.com) and Google Earth Pro, 2019)

### ***Chlorophyll a Estimation and Measurement of Physico-Chemical Parameters***

Each 500 mL bottle of seawater collected was filtered through 47 mm diameter Whatmann GF/F filter papers. Chlorophyll *a* was extracted with 10 mL of 90 % (v/v) acetone. The filter papers were stored at -20°C and after 24 hours, chlorophyll *a* was estimated according to the method by Aminot & Rey (2000). An ultraviolet 16 PC spectrophotometer was used to determine the pigment concentrations at the wavelengths of 630 nm, 647 nm, 664 nm and 750 nm wavelengths. Nitrate (NO<sub>3</sub>) and nitrite (NO<sub>2</sub>) concentrations were determined following the protocols described by Margeson *et al.* (1980), phosphate (PO<sub>4</sub>) using the colorimetric method described by Murphy-Riley (1968) and silicate (SiO<sub>4</sub>) according to the protocols of Strickland & Parsons (1972). Physico-chemical parameters, such as temperature, salinity, DO and pH, were measured *in-situ* using standard instruments, namely a waterproof thermometer, a refractometer, a HANNA HI 9146 DO meter (Hanna Instruments, Woonsocket, RI, USA) and the OAKLON pH 300 series waterproof pH meter, respectively.

### ***Statistical Analyses***

The diversity, equitability and evenness of the micro-plankton communities were evaluated using Shannon-Wiener's equation, H' (1949), Pielou's equation, E<sub>H</sub> (1966), and Smith & Wilson, E<sub>var</sub> (1996), respectively. A two-way ANOVA was conducted to observe the variations in micro-plankton densities. The correlations between the micro-plankton densities and biological and physico-chemical parameters were determined using Pearson's correlation. The RStudio Version 1.1.463 software (RStudio Inc, Boston, MA, USA) was used to perform statistical tests and the Canonical Correspondence Analysis (CCA) and Shannon-Wiener's diversity index were calculated using the Vegan: community ecology package (Oksanen *et al.*, 2016).

## **Results and Discussion**

### ***Micro-phytoplankton Density, Diversity and Composition***

The micro-phytoplankton density varied significantly between the sites ( $p < 0.05$ ) and months ( $p < 0.05$ ) (Table 1). The lowest densities were recorded in October 2018, ranging from  $1.72 \pm 0.02 \times 10^6$  cells L<sup>-1</sup> in BM and  $1.90 \pm 0.55 \times 10^6$  cells L<sup>-1</sup> in FEF. From December 2018 to March 2019, the micro-phytoplankton density increased at all sites and the highest value was recorded in March 2019 in FEF (Figure 2a).

The diversity of the micro-phytoplankton, however, showed the highest values in October 2018 which were 2.89 in BM and 2.59 in FEF, before decreasing in December 2018. In BM, there was a continuous and gradual decrease in diversity and the lowest value of 1.06 was recorded in March 2019. Meanwhile, in FEF, there was a slight increase in February and March the same year. Equitability measurements also showed highest values in October 2018 in BM (0.88) and FEF (0.91). There was also a decrease from the start of the study until March 2019 (Figure 2b). The evenness of the community was highest in October 2018 in BM (0.65) and FEF (0.74) and was significantly lower in March 2019 (Figure 2b).

From October 2018 to February 2019, the community of micro-phytoplankton at both sites consisted mostly of diatoms (82 to 96 %). The percentage of dinoflagellates increased in March 2019 (Figure 2c), reaching up to 40 % in BM in March 2019. The temperature, salinity and phosphate levels were the most dominant variables affecting the growth of *Asterionellopsis* sp., *Licmophora* spp., *Coscinodiscus* spp., *Biddulphia* spp. and *Cerataulina* sp., with high canonical values of 1.027, 0.596, 0.564, 1.206 and 1.139, respectively (Figure 3a). Nitrate, micro-zooplankton density and chlorophyll *a* seemed to have an influence on *Cocconeis* spp., *Fragilaria* sp. and *Lyngbya* sp., with strong canonical values of 1.275, 1.210 and 1.215, respectively, in axis 1 (Figure 3a). *Skeletonema* sp. had a strong canonical value with DO in

axis 2, while other species, such as *Striatella* sp. and *Fragilariopsis* sp., were negatively correlated with nitrate, chlorophyll *a* and micro-zooplankton density (-2.316 and -2.344).

In FEF, salinity, temperature and micro-zooplankton density were strongly positively correlated with species, such as *Amphora* sp. and *Diploneis* spp., with canonical values of 1.163 and 0.568, respectively, in axis 1 (Figure 3b). A positive relationship with pH and salinity was found with *Coscinodiscus* spp., *Striatella* sp.,

*Oscillatoria* sp., and *Synedra* sp. (0.707, 1.243, 1.784 and 1.014) in axis 2, while *Fragilaria* sp., *Chaetoceros* spp., *Prorocentrum* sp., and *Cerataulina* sp. were strongly negatively correlated with micro-zooplankton density and temperature (-2.345, -2.345, -2.357 and -2.355). In both axes 1 and 2, *Asterionellopsis* sp., *Licmophora* spp., *Climacosphenia* spp., *Alexandrium* sp., *Fragilariopsis* sp. and *Cyclotella* sp., showed a strong positive canonical value.

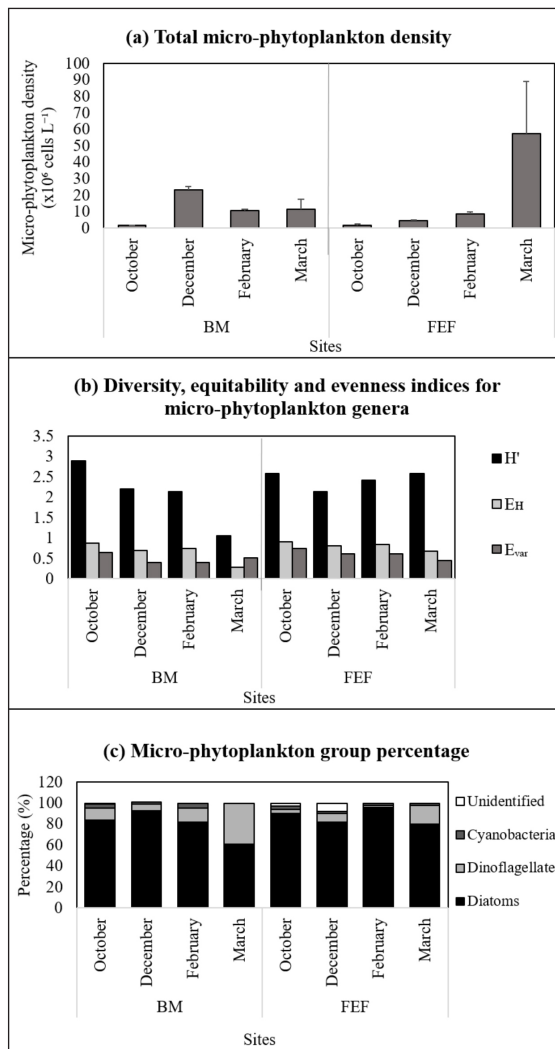


Figure 2: Variation in (a) total micro-phytoplankton density, (b) Shannon-Wiener's diversity, Pielou's equitability and, Smith and Wilson's evenness indices in micro-phytoplankton genera in BM and FEF during the study, (c) the percentage of micro-phytoplankton groups. Data for (a) represent mean ± standard deviation (n=3)

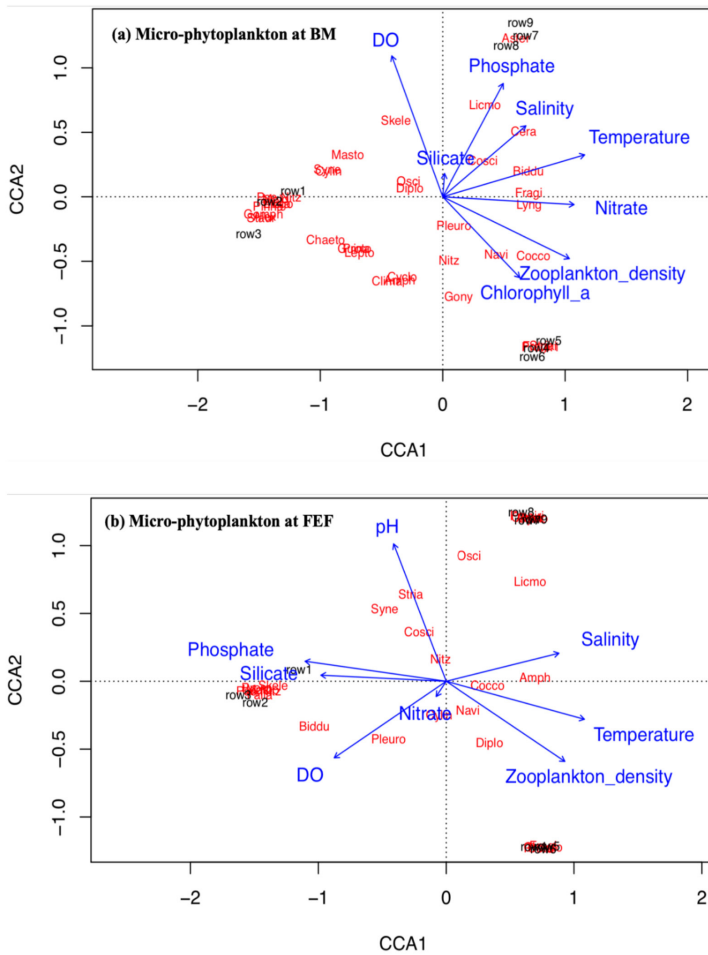


Figure 3: Canonical Correspondence Analysis (CCA) biplot of environmental factors, represented by long arrows, and the micro-phytoplankton genera, represented by code names, in (a) BM and (b) FEF. The length of the arrows shows the correlation between the environmental variables and the genera. (DO – dissolved oxygen, Zooplankton\_density – total micro-zooplankton density; row 1, row 2, row 3 – October 2018; row 4, row 5, row 6 – December 2018; row 7, row 8, row 9 – February 2019; Alex – *Alexandrium* sp., Amph – *Amphora* sp., Aster – *Asterionellopsis* sp., Biddu – *Biddulphia* spp., Cera – *Cerataulina* sp., Chaeto – *Chaetoceros* spp., Clima – *Climacosphenia* spp., Cocco – *Cocconeis* spp., Cosci – *Coscinodiscus* spp., Cyclo – *Cyclotella* sp., Cylin – *Cylindrotheca* sp., Diplo – *Diploneis* spp., Falla – *Fallacia* sp., Fragi – *Fragilaria* spp., Fragiri – *Fragilariopsis* spp., Gomph – *Gomphonema* sp., Gony – *Gonyaulax* sp., Guina – *Guinardia* sp., Lepto – *Leptocylindrus* spp., Licmo – *Licmophora* sp., Lingo – *Lingulodinium* sp., Lyng – *Lynbya* sp., Masto – *Mastogloia* sp., Melo – *Melosira* sp., Navi – *Navicula* spp., Nitz – *Nitzschia* spp., Osci – *Oscillatoria* sp., Pleuro – *Pleurosigma* spp., Pinnu – *Pinnularia* sp., Pse-Nitz – *Pseudo-Nitzschia* sp., Proro – *Prorocentrum* sp., Proto – *Protoperidinium* sp., Skele – *Skeletonema* sp., Staur – *Stauroneis* sp., Stria – *Striatella* sp., Syne – *Synedra* sp., Thala – *Thalassionema* sp.)

**Micro-zooplankton Density, Diversity and Composition**

There was no significant difference in the micro-zooplankton density between the different sites

( $p > 0.05$ ). The lowest values of  $1.59 \pm 0.49 \times 10^6$  cells  $L^{-1}$  in BM and  $0.53 \pm 0.11 \times 10^6$  cells  $L^{-1}$  in FEF were recorded in October 2018. A significant difference was noted throughout the

study period (Table 1). The highest density in BM occurred in December 2018 and FEF in March 2019. The highest micro-zooplankton density was recorded in BM in December 2018 ( $22.56 \pm 3.29 \times 10^6$  cells  $L^{-1}$ ) (Figure 4a).

The micro-zooplankton community was most diverse in March 2019 in BM (2.67) and FEF (2.15). Diversity was relatively low from October 2018 to February 2019, and the lowest values were observed in FEF in October 2018 and February 2019 (Figure 4b). The equitability of the community varied mostly from 0.72 to 0.98, with the highest value recorded in FEF in October 2018. The evenness also peaked at the same location in October 2018 (0.96) and in BM in February 2019 (0.71). Very low values of evenness were generally observed in March 2019 (Figure 4b).

Species like *Euterpina* spp., *Microsetella* sp., gastropod veliger, bivalve veliger and *Discorbis foraminifera* had strong canonical values (1.108, 1.149, 1.078, 1.903 and 1.817) in axis 1 (Figure 5a) and negative correlations

were also found with cirripede naupli, calanoid copepod, and *Oithona* sp. (-1.200, -0.891 and -0.709). In axis 2, strong positive canonical values were found with *Oithona* sp., *Sabellaria* sp. and cyclopoid copepod (1.544, 1.304 and 1.868) with pH and salinity. Calanoid naupli, cirripede naupli and harpacticoid copepod were negatively correlated with temperature and micro-phytoplankton density, while *Microsetella* sp. was negatively correlated with DO and silicate. In axis 1 of the FEF CCA biplot (Figure 5b), *Oithona* sp., *Sabellaria* sp. and harpacticoid copepod showed strong canonical values (0.744, 0.740 and 0.761) with micro-phytoplankton density and salinity, while cirripede naupli and calanoid copepod were positively correlated to temperature (0.774 and 0.763). *Euterpina* sp., *Miracia* sp., bivalve veliger and cyclopoid copepod had strong positive canonical values in both axes. In axis 2, however, cyclopoid naupli, *Oithona* sp. and *Sabellaria* sp. were negatively correlated to micro-phytoplankton density and salinity.

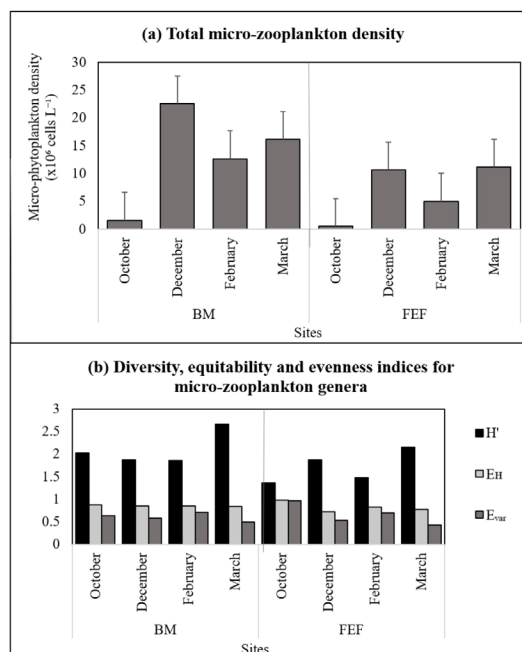


Figure 4: Variation in (a) total micro-zooplankton density and (b) Shannon-Wiener's diversity, Pielou's equitability and Smith and Wilson's evenness indices in micro-zooplankton genera at BM and FEF during the study period. Data for (a) represent mean  $\pm$  standard deviation (n=3)

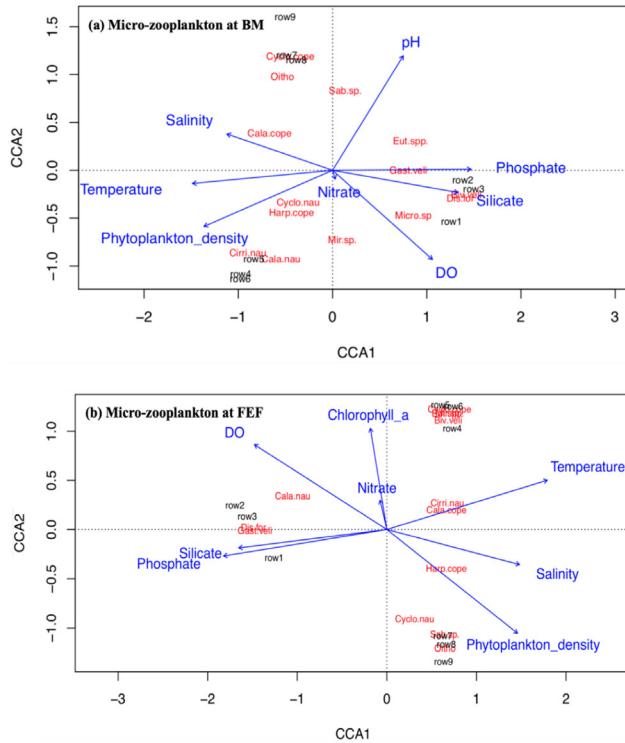


Figure 5: Canonical Correspondence Analysis (CCA) biplot of the environmental factors, represented by long arrows, and the micro-zooplankton genera represented by code names, in (a) BM and (b) FEF. The length of the arrows shows the correlation between the environmental variables and the genera. (DO – dissolved oxygen, Phytoplankton\_density – total micro-phytoplankton density; row 1, row 2, row 3 – October 2018; row 4, row 5, row 6 – December 2018; row 7, row 8, row 9 – February 2019; Cala.nau – Calanoid naupli, Cyclo.nau – Cyclopoid naupli, Cirri.nau- Cirripede naupli, Cala.cope – Calanoid copepod, Oitho – *Oithona* sp., Eut.spp. – *Euterpina* spp., Mir.sp. – *Miraacia* sp., Gast.veli – Gastropod veliger, Biv.veli – Bivalve veliger, Sab.sp. – *Sabellaria* sp., Harp.cope – Harpacticoid copepod, Cyclo.cope – Cyclopoid copepod, Dis.for – *Discorbis foraminifera*, Micro.sp – *Microsetella* sp.)

Table 1: Two-way ANOVA comparison of the total micro-phytoplankton density (TMPD) and total micro-zooplankton density (TMZD) throughout the study in Belle Mare and Flic en Flac, Mauritius island

Parameters	Source of variations	DF	SS	MS	F	Pr (>F)
TMPD	Site	1	1.423	1.423	5.895	*
	Months	3	3.427	1.142	4.734	*
	Sites * Months	3	1.543	5.144	2.132	NS
TMZD	Site	1	1.239	1.239	0.686	NS
	Months	3	5.902	1.967	10.887	***
	Sites * Months	3	1.005	3.351	1.855	NS

(\* =  $p < 0.05$ ; \*\* =  $p < 0.01$ ; \*\*\* =  $p < 0.001$ ; NS = Not Significant)



### Chlorophyll *a* and Physico-chemical parameters

The lowest concentrations of chlorophyll *a* in BM and FEF were recorded in February 2019, while higher values were in December 2018 (Figure 6a). The maximum chlorophyll *a* concentration was noted in BM in December 2018 ( $0.161 \pm 0.023 \text{ mgm}^{-3}$ ). However, the concentrations recorded there were very low compared to a previous study (Sadally *et al.*, 2012). There were strong positive correlations between TMPD and chlorophyll *a*, and TMZD and chlorophyll *a* in BM (Table 2).

Nitrate levels in the seawater collected in BM and FEF were also very low compared to Sadally *et al.* (2012), ranging from  $0.003 \pm 0.003 \text{ mgL}^{-1}$  to  $0.010 \pm 0.010 \text{ mgL}^{-1}$ . The highest concentrations were recorded in December 2018 and February 2019 in BM (Figure 6b), where they were strongly correlated with TMPD and TMZD (Table 2). The concentration of phosphate peaked in October 2018 at FEF, but the recorded values remained generally low, varying from  $0.447 \pm 0.286 \text{ } \mu\text{molL}^{-1}$  to  $1.009 \pm 0.057 \text{ } \mu\text{molL}^{-1}$  (Figure 6c). A strong negative correlation was found between the TMZD and phosphate in FEF (Table 2). Silicate concentrations were very low and ranged from  $4.036 \pm 2.121 \text{ } \mu\text{molL}^{-1}$

to  $7.682 \pm 2.492 \text{ } \mu\text{molL}^{-1}$ , except in October 2018 in FEF (Figure 6d). Silicate had a strong negative correlation with TMPD and TMZD in FEF (Table 2).

October 2018 was the transition period from winter to summer, and therefore, the lowest SST was recorded at both locations. SST increased from  $25.3 \pm 0.6^\circ\text{C}$  in October 2018 to  $30.0^\circ\text{C}$  in February 2019 in BM. In FEF, it rose from  $25.7 \pm 0.6^\circ\text{C}$  in October 2018 to  $29.8 \pm 0.3^\circ\text{C}$  in December the same year (Figure 6e). A very strong correlation was observed between TMPD and temperature in BM (Table 2). Salinity was also lowest in October 2018 ( $32.7 \pm 1.6 \text{ ppt}$ ) and increased gradually until February 2019 ( $35.0 \text{ ppt}$ ). DO did not vary significantly and fluctuated from  $7.37 \pm 0.34 \text{ ppt}$  to  $8.72 \pm 0.18 \text{ ppt}$ . It showed strong negative correlations with TMPD in BM and FEF, but with TMZD in BM only. There were small variations in pH values (Figure 6h), but the lowest measurement was obtained in December 2018 in FEF ( $5.91 \pm 0.5$ ). pH was negatively correlated with TMPD at BM, and TMZD at BM and FEF.

Micro-phytoplankton variations in density and diversity had been studied at coral reefs, including around Mauritius island (Sadally

Table 2: Pearson's correlation coefficient (r value), tested among TMPD, TMZD and environmental factors at BM and FEF in October and December 2018 and February 2019

Sites	BM		FEF	
	TMPD	TMZD	TMPD	TMZD
TMZD	0.946***	-	0.355	-
Chlorophyll <i>a</i>	0.842**	0.799	-0.505	0.241
Nitrate	0.796*	0.833	0.067	0.004
Phosphate	0.015	0.097	-0.631*	-0.860**
Silicate	-0.048	-0.005	-0.730*	-0.803**
Temperature	0.677*	0.719	0.583	0.910***
Salinity	0.267	0.342	0.686*	0.526
Dissolved Oxygen	-0.751*	-0.700	-0.935***	-0.448
pH	-0.732*	-0.731	0.269	-0.777*

(\* =  $p < 0.05$ ; \*\* =  $p < 0.01$ ; \*\*\* =  $p < 0.001$ )

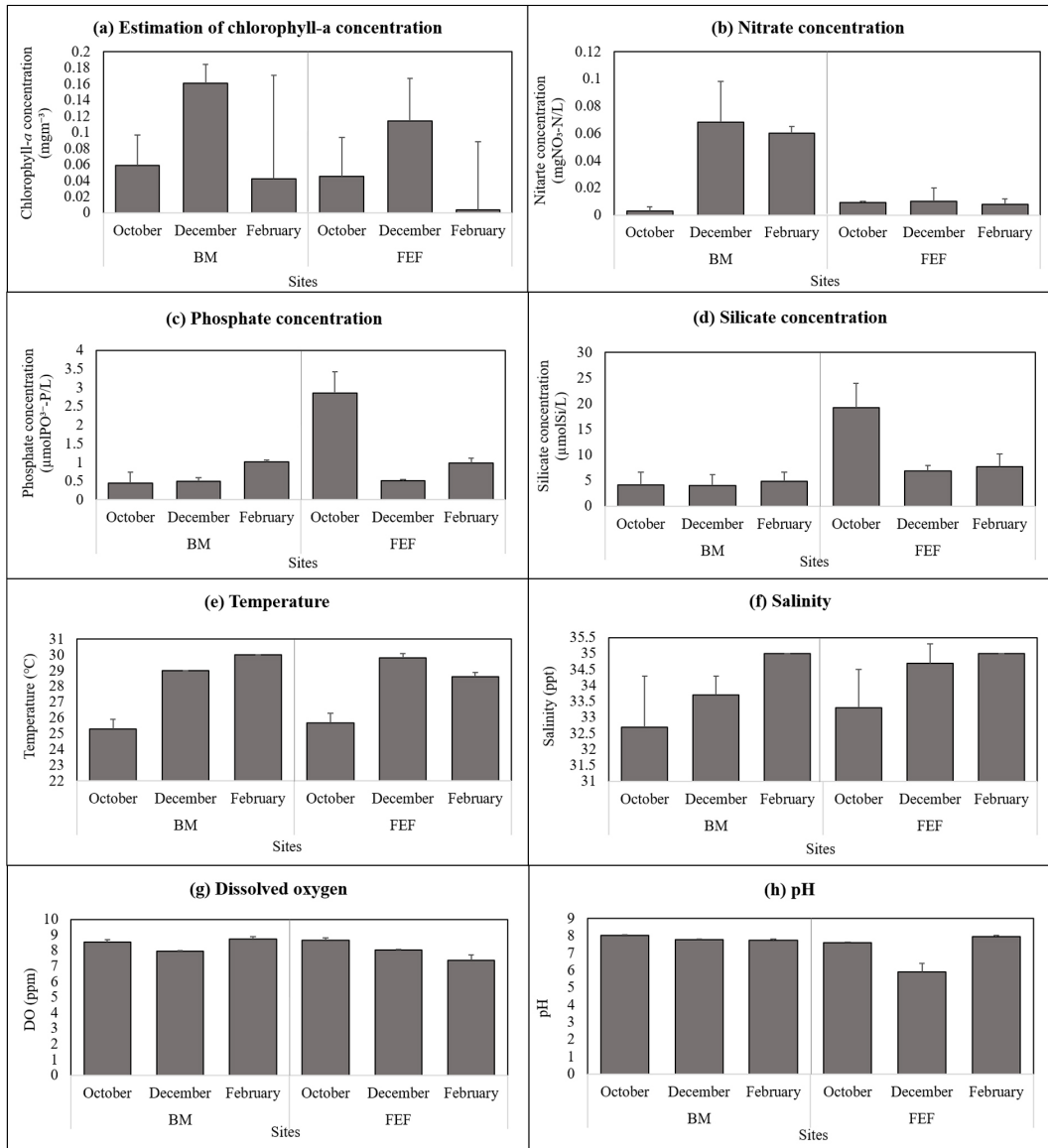


Figure 6: Variation in the biological and physico-chemical parameters. (a) estimation in chlorophyll-a concentration at BM and FEF and physico-chemical parameters, (b) nitrate concentration, (c) phosphate concentration, (d) silicate concentration, (e) temperature, (f) salinity, (g) dissolved oxygen and (h) pH in BM and FEF. Data represent mean ± SD (n=3)

et al., 2014). However, the data on micro-zooplankton was limited (Moodosoodun et al., 2010) and there were no studies on both species conducted simultaneously. This study reports the variations in both micro-phytoplankton and micro-zooplankton density and diversity, and their inter-relationships.

**Micro-phytoplankton Community Structure**

The lowest TMPDs occurred in October 2018, which was the transition between winter and summer. In December 2018, a higher temperature anomaly was detected in the eastern part of Mauritius for 10 days (Mauritius

Meteorological Services, 2018). There was also heavy rainfall during this month, especially in the east, which could have caused an increase in nitrate levels through terrestrial run-offs. Therefore, a warmer temperature and a higher level of nitrate could have favored the growth of phytoplankton in BM.

The relatively strong correlation between TMPD and chlorophyll *a* in BM indicated that the phytoplankton community consisted mostly of micro-phytoplankton. This finding is in accordance with the temperature-size rule, which indicated that warmer temperatures favored the growth of smaller diatoms (Daufresene *et al.*, 2009; Winder *et al.*, 2009), while species grown at cooler temperatures could reach larger sizes (Forster *et al.*, 2012). The rainfall pattern, however, decreased in February 2019, causing a decline in nitrate levels in BM. There was high insolation and higher temperature anomalies all over the island, except for FEF, which was covered by clouds due to sea breeze effect (Mauritius Meteorological Services, 2019). Cyclone Gelena, that struck Mauritius on a south-easterly trajectory in February 2019, had cooled the seawater in BM. The month of March in 2019 was the warmest since 1971 due to longer daylight hours.

The micro-phytoplankton diversity generally showed an inverse relationship with TMPD, a result which corroborated with the findings of Sidabatur *et al.* (2016). The diversity of the micro-phytoplankton community declined with an increase in temperature in contrast with Rajasegar *et al.* (2000) and Mani (1992). Changes in the environmental variables might have led to intraspecific competition, leading to a decrease in diversity throughout this study (Spatharis *et al.*, 2007). A decrease in the evenness from October 2018 to March 2019 indicated species dominance within the micro-phytoplankton community. Even if the nutrients in the seawater were not significantly high, the micro-phytoplankton community consisted mostly of diatoms (61-96%) in BM and FEF, therefore contradicting the findings of Halac *et al.* (2013), who reported that diatoms were

not major contributors in the phytoplankton community in tropical regions, unless the nutrients were available in high concentrations.

Silicate occurred in very low concentrations in the oceans, but the amount was sufficient to let diatoms grow. The very strong negative relationship between TMPD and silicate indicated a rise in micro-phytoplankton density with a decrease in silica content. This occurred when silica was used by diatoms to build their frustules. However, the factor which seemed to enhance the growth of dinoflagellates was not clear, since diatoms usually outcompeted dinoflagellates which, in turn, would thrive in calm conditions (Hays *et al.*, 2005), and this was not the case at coral reefs due to high wave action. The micro-phytoplankton community composition in BM depended on phosphate, salinity, micro-zooplankton density and SST. In FEF, it was SST, salinity and micro-zooplankton density that influenced the structure of the community.

#### ***Micro-zooplankton Community Structure***

Even if TMZD was lowest in October 2018, no clear temporal variation could be deduced in the micro-zooplankton community, which was one of its characteristics in tropical reefs (Morales & Murillo, 1995; Yang *et al.*, 2017). Compared to phytoplankton, zooplankton were generally affected by physical processes, such as currents, turbulences and water circulation (Waffer *et al.*, 1983; Yang *et al.*, 2017).

The TMZD was found to be the highest in December 2019, when heavy rainfall occurred around the island (Monthly Report, Mauritius Meteorological Services). The strong correlation between TMZD and SST in BM and FEF potentially suggested an increase in grazing activity, encouraging a form of competitive exclusion within the micro-zooplankton community (Soccolato *et al.*, 2016), which occurred when interactions between two or more species prevented the survival of one of those species in that particular environment. This could explain the fluctuation in diversity and relatively low evenness recorded in March

2019. Grazing was an activity which changed the micro-phytoplankton community and its increase would reduce the micro-phytoplankton abundance as observed in BM.

Micro-zooplankton could increase diversity in the micro-phytoplankton community through selective grazing, by feeding on dominant species and allowing equilibrium or rare species to grow and proliferate. An example could be seen in FEF from December 2018 to March 2019. In March 2019, TMPD in FEF increased significantly while TMZD remained low, which could be due to higher micro-phytoplankton production and rapid growth counteracting the grazing activities. A negative relationship between TMZD and DO was found in BM, implying that micro-zooplankton thrived less in a low oxygen environment. The very strong correlation between TMPD and TMZD in BM suggested a sort of co-existence through stimulation in the growth of micro-phytoplankton species, which were resistant to micro-zooplankton grazing (Goldyn & Kowalczywska-Madura, 2007), or the increase in grazing activity could have allowed for rapid recycling through the excretion of nutrients.

A higher concentration of nitrate in BM, however, did not sustain the theory of rapid recycling of nutrients in the water, which would otherwise not have been detected in the seawater analysis. The strong correlation between TMZD and chlorophyll *a* in BM, therefore, further supported the former theory of co-existence. The availability of prey was also an important factor that determined the zooplankton community structure. The diet of different zooplankton in tropical reefs should be taken into consideration while studying marine plankton ecology. The reproductive patterns of zooplankton in Mauritian waters were also unknown, which could influence the density of the zooplankton community. To better understand the relationship between coral reefs and marine plankton, predators of the zooplankton should be studied as well.

## Conclusion

This study provided an insight into the variation in the micro-plankton communities and their structure in coral patches at two sites in a tropical region. While many studies had focused mostly either on phytoplankton or zooplankton only, it was important to investigate both communities with a holistic approach as their survival was affected by each other. The micro-phytoplankton species were largely impacted by SST, salinity, phosphate, micro-zooplankton density and nitrate, while the micro-zooplankton were controlled by temperature, salinity, DO and micro-phytoplankton density. While micro-phytoplankton density increased during summer, no significant temporal variation could be detected in the micro-zooplankton density. *Asterionellopsis* sp. and *Licmophora* sp. showed high tolerance to broad environmental variations. The study and constant monitoring of micro-plankton communities are very important for better understanding of the water quality and the preservation of coral reefs, especially at a time when the latter is declining due to global warming.

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