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Water Quality and Seasonal Dynamics of Phytoplankton and Zooplankton in the West Bay of Laguna De Bay, Philippines

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ABSTRACT

The variability of phytoplankton and zooplankton is investigated in the West Bay of Laguna de Bay located along Sta. Rosa area. Water quality, aquatic communities and lead concentrations were analyzed during the dry and wet seasons. Water quality met the Class C standards of Department of Environment and Natural Resources Administrative Order No. 08 Series of 2016. Moreover, the lake water in the study sites was classified as mesotrophic according to chlorophyll a readings but eutrophic to hypertrophic based on Secchi disc tranparency. This study recorded 36 phytoplankton genera and 53 zooplankton genera. The phytoplankton communities showed that Class Bacillariophyta, specifically Aulacoseira sp. dominated the lake. Zooplankton communities were dominated by Order Rotifera during the dry season while Order Copepoda was abundant during wet season. Graphical representations revealed seasonal variability in phytoplankton and zooplankton communities as affected by changing water quality.

Keywords: *Laguna de Bay, Phytoplankton, seasonal dynamics, water quality, zooplankton*

INTRODUCTION

Laguna de Bay is the largest inland body of water in the Philippines with total surface area of 900 km^2. It has 22 major river tributaries and only one outlet which is Napindan Channel. It is one of the most important natural resource that provides wide array of ecosystem services including food source, flood water reservoir, power generation, irrigation, industrial cooling water, source of potable water, navigation, recreational and cultural activities as well as waste sink (LLDA 2009).

The declining water quality of Laguna de Bay continues to be a major concern that makes the lake a focal point of research studies. Households, industries, aquaculture and agriculture in the region continually dispose solid and liquid wastes through its tributaries and on the lake itself (Nepomuceno 2010). Periodic algal blooms in 1970's depleted the dissolved oxygen during die –offs . It caused massive fish kills that devastated the economy in the region (Barica 1976). Studies revealed that 60% of the fish kills were caused by low dissolved oxygen and more than half of this was linked with algal blooms of blue green algae. Forty six percent of the fish kills from 1972–1998 were identified in the central bay and then 38% were recorded in the west bay of Laguna de Bay (Cuvin–Aralar *et al.*,2001). Because of this, regular monitoring of water quality is done by Laguna Lake Development Authority (LLDA) but only few plankton studies were published.

Plankton profiles and trophic organization are often associated with various physico–chemical and biological factors such as water temperature, pH and nutrients in water. However, the most significant factors are temperature, food availability, competition and predation (Sampaio *et al.* 2002). In the open waters, phytoplankton is the basal species since it can photosynthesize and does not consume other organism (Williams & Martinez 2004). These are eaten by the primary consumers which are the zooplankton groups (herbivorous zooplankton). Zooplankton usually consists of calanoid copepod, cyclopoida, *Diaphanosoma*, and some species of rotifers and these are comparable to the results. Zooplankters are filter–feeders of bacteria, algae and detritus and some are predators of smaller species. Vertical diel migration is unique to limnetic species. The zooplankters tend to move upward at night time and downward at daytime (around 6pm to 6am) (Odum 1971).

Seasonal studies of plankton is important to understand the trophic linkages between the primary producers (phytoplankton) and the primary consumers (zooplankton) in the pelagic food webs (Murrell & Lores 2004). Diversity is a measure of the complexity of form and function within the community while dominance expresses the success of one or a few species. Natural community is composed of unequally successful species. The successful dominants control the presence of subordinate species, thus manipulating the structure and diversity of communities. According to Thienemann's biocoenotic laws, a good quality of environment could support higher number of species (but only a few individuals of each species) which are able to reach near their optimum. In contrast, harsh environment could lower the number of species present

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wherein only the 'best–fitted' species could exist in high abundance (Lampert & Sommer 2007).

Previous records showed varying phytoplankton species in Laguna de Bay. In 1973 to 1977, LLDA reported 62 phytoplankton species that was dominated by blue–green algae specifically *Microcystis, Anabaena* and *Oscillatoria*. In 1981, *Microcystis aeruginosa* predominated the lake in summer but there were shifts among blue–green algae, green algae and diatoms throughout the year (Pullin 1981). In 1997, twenty species were observed that was dominated by *Microcystis, Oscillatoria, Anabaena* and *Calothrix* (NSCB 1999). In 2006, decreased number of taxa was observed with thirteen species (Santos–Borja 2006; Nepomuceno 2010). Moreover, the average genera observed in the lake is 4 to 6 species (Tamayo–Zafaralla pers. comm.).

For zooplankton records, 64 species were recorded from 1975 to 1995 (Mamaril 2001). Cladocerans such as *Alona davidi, Alona pulchella, Euryalona orientalis, Guernella raphaelis, llyocryptus spinifer, Kurzia longirostris,* and *Oxyurella singalensis* are few of the listed species. In 2012, Papa *et al.* identified 20 species which was dominated by the copepod *Mesocyclops thermocyclopoides*.

The aims of the study are to investigate the physicochemical characteristics and seasonal variations of phytoplankton and zooplankton communities in Laguna de Bay.

METHODOLOGY

Study Area

The study was conducted in the West Bay of Laguna de Bay along Santa Rosa City shoreline. The research focused on the lakeshore barangays namely Sinalhan, Aplaya and Caingin. In each barangay, three lake zones (nearshore, farshore and offshore) were established in the open waters (Table 1 and Figure 1). Three replicates of water and plankton samples were collected for each sampling site. One–time sampling was done in each of the dry and wet seasons (May 2013 and November 2012).

Table 1. Coordinates of the sampling sites in the West bay of Laguna de Bay.

LAKE ZONES	COORDINATES		
	Sinalhan	Aplaya	Caingin
Nearshore	N 14°19'11.75" E 121°07'34.32"	N 14°20'05.87" E 121°07'16.93"	N 14°17'54.21" E 121°07'47.91"
Farshore	N 14°18'44.86" E 121°07'49.03"	N 14°20'08.19" E 121°07'05.35"	N 14°17'58.90" E 121°07'01.80"
Offshore	N 14°18'54.99" E 121°08'17.14"	N 14°19'34.18" E 121°07'03.64"	N 14°18'10.86" E 121°08'31.36"

Water samples

In situ measurements of the following parameters were recorded: pH and water temperature (YSI EcoSense pH100 Instrument) and dissolved oxygen (YSI 5700 Series oxygen meter). Water samples were collected to quantify total hardness (Hach test kit), total alkalinity (Hach test kit) and chlorophyll a (chlorophyll a determination via ethanol extraction) using the APHA AWWA standard methods (2005).

Biological samples (Phytoplankton and Zooplankton)

Plankton nets were used in collecting samples by vertical sampling method. Phytoplankton and zooplankton samples were obtained using plankton net with mesh size of 30 and 56 microns, respectively (Jara–Marini *et al.* 2009). The depth of the water column for vertical haul was one meter since the average depth of the lake was only 2.5 meters. The samples were transferred in 500 mL polyethylene (PE) bottles. Plankton samples for identification and counting were fixed in 10% formalin.

Identification and counting of phytoplankton and zooplankton were done to evaluate the community structure in terms of species composition and species abundance. For plankton identification, several field manuals, picture keys and dichotomous keys were used (Shiel 1995; Bellinger and Sigee

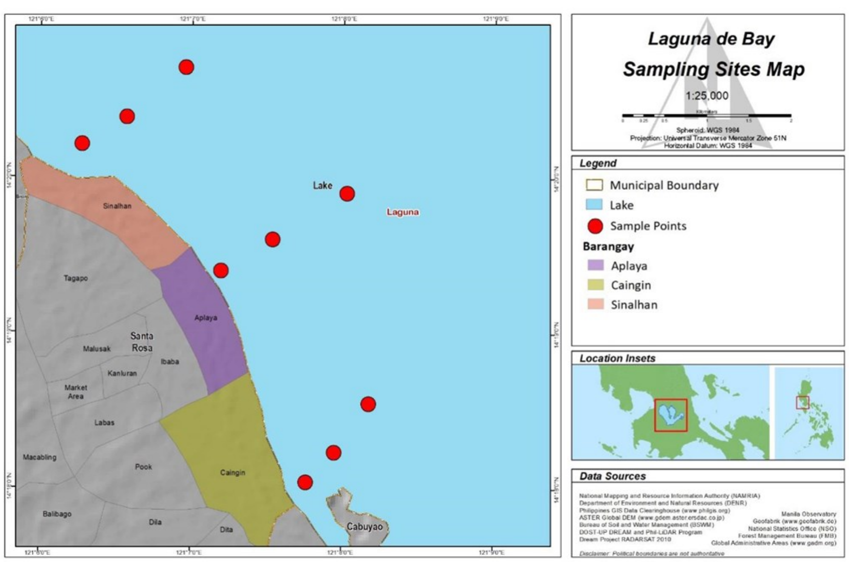


Figure 1. Map of Sampling Points in the West bay of Laguna de Bay.

2010). For counting, Hemacytometer counting chamber was used for phytoplankton while Sedgewick–Rafter counting chamber for zooplankton. An electric compound microscope was used for plankton observation. Diversity indices such as Dominance index and Shannon diversity index were determined using Paleontological Statistics (PAST), version 3.16 (Hammer *et al.* 2001). Phytoplankton and zooplankton raw counts were analyzed in PAST 3.16 using the following formula:

Dominance Index

$$D = \sum_i \left(\frac{n_i}{n} \right)^2$$

where n_i is number of individuals of taxon *i*.

Shannon diversity index

$$H = -\sum_i \frac{n_i}{n} \ln \frac{n_i}{n}$$

where *n* is the total number of individuals

Statistical Analysis

Independent two–sample t–test was used to determine the significance in seasonal differences between phytoplankton and zooplankton ($p<0.05$). Canonical correspondence analysis was used to study the interrelationships of biophysico–chemical factors (pH, dissolved oxygen, temperature, secchi disk transparency, chlorophyll a and lead concentration) and plankton communities. Computations and graphical representation was performed using Paleontological statistics (PAST) version 3.16 and RStudio version 0.99.484.

RESULTS AND DISCUSSION

Physico–chemical Characteristics of Water

Seasonal variations in water quality is illustrated in Figure 2. Average surface water temperature in dry season was 31.60°C and 28.56°C in wet season. This follows the criteria for fresh waters in which there should be an allowable temperature rise over the ambient temperature by 3°C (DAO 2016–08). Water temperature (WT) has an essential role in aquatic environment since it regulates various biological processes such as growth and reproduction (ANZECC 2000).

The average surface dissolved oxygen during dry season was relatively higher (9.66 mg/L) than during wet season (7.77 mg L^{-1}). These values are acceptable since the minimum requirement for warm–water biota ranges from 5–9.5 mg L^{-1}. Dissolved oxygen (DO) is the amount of oxygen present in the water which is a basic requirement for aquatic life. Lower DO levels are usually due to nutrient pollution (biodegradable organic substances), high water temperature and minimal water flow (ANZECC 2000).

Secchi disc transparency (SDT) for dry season was 0.63 m and 1.47 m for wet season. Lower transparency in dry season signifies a hypertrophic lake while eutrophic during wet season. Historical records showed lower SDT values compared to this study. In 1996–1999, LLDA measured 0.10 m. In 1997, SDT was 0.15 m (NSCB 1999). In 2012, LLDA reported 0.4 m SDT. Majority of the historical SDT values classified the lake as hypertrophic (Villadolid 1933; SOGREAH 1974; Barril 1995; Zafaralla *et al.* 1997–1999 as cited by Lasco & Espaldon 2005). SDT is a measure of water clarity and higher reading means clearer water. The rule of the thumb is that light penetration in water should be 2–3 times the Secchi disc depth. Water clarity is affected by a number of factors like algae, soil particles and suspended materials in the water. SDT values in this study indicated relatively clearer lake water than that of the previous records from 1996 to 2012.

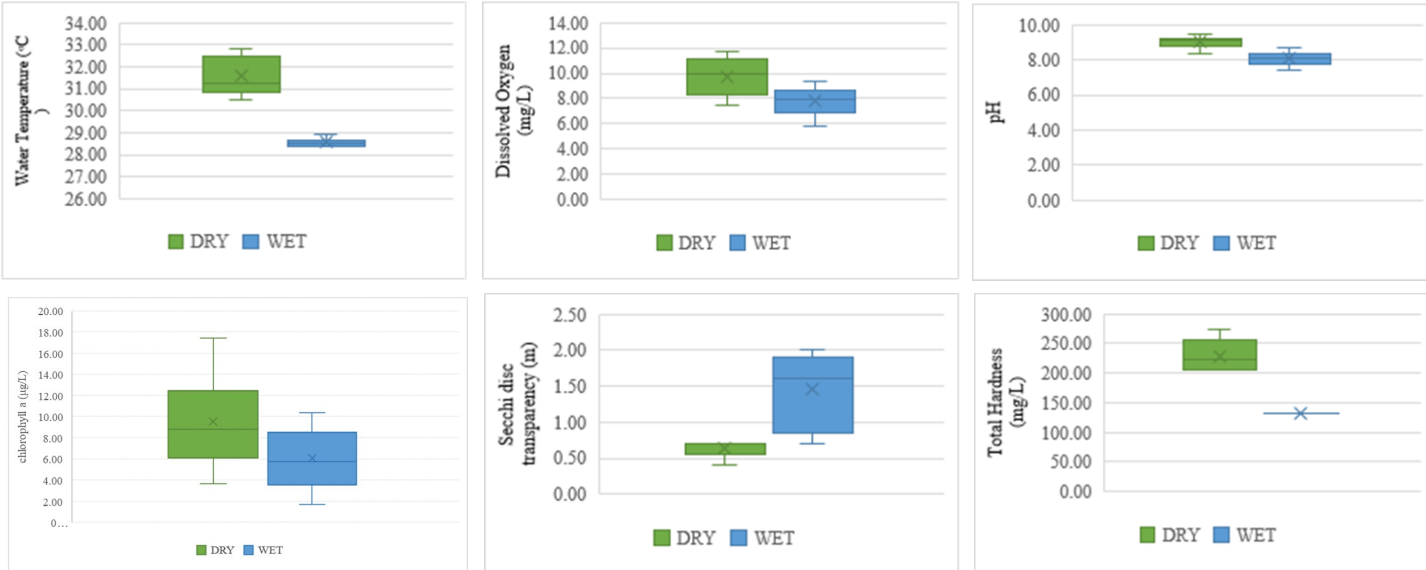
Higher chlorophyll a was measured in dry season (9.54 µg L^{-1}) than in wet season (6.06 µg L^{-1}). These values classified the lake as mesotrophic at the time of the sampling. This trophic status is only limited to the open waters along Sta. Rosa City shoreline. In previous years, significantly lower chlorophyll a values were observed with 29.9 µg L^{-1} in 1998 and 33.8 µg L^{-1} in 1999. These values classified the lake as eutrophic (Lasco & Espaldon 2005). Chlorophyll a is an estimate of the biomass of planktonic algae. Lower chlorophyll a values in this study denotes lower phytoplankton biomass in the sampling sites.

The pH values were 9.02 and 8.08 for dry and wet seasons, respectively. These pH values are normal for tropical lakes (pH 5.0–10.0) but the ideal pH value for freshwater species production is 6.5–9.0 (ANZECC, 2000). Higher pH in summer was due to heightened photosynthetic activities. Phytoplankton uses up free carbon dioxide in the water, causing the pH to rise. High pH (>11.0) is lethal to aquatic organisms so it is important to maintain the standard values. Moreover, pH determines the solubility and biological availability of nutrients such as phosphorus and nitrogen (ANZECC 2000).

The pH of water is interdependent to parameters like alkalinity and hardness. Total alkalinity (TA) showed 17.1 mg L^{-1} for dry season while 89 mg L^{-1} in wet season according to 2012 LLDA water quality data. The standard value for TA is more than 20 mg L^{-1} (ANZECC 2000).

The total hardness (TH) was 228 mg L^{-1} during dry season while 133 mg L^{-1} during wet season (LLDA 2012). These values signify hard water. The acceptable values for aquatic organisms are between 100 to 300 mg L^{-1}. This is important for some aquatic species since it helps in exoskeleton formation and osmoregulation (ANZECC 2000). Hard water is more concentrated than soft water, thus less energy spent for osmoregulation in fishes. Hardness values of at least 20 mg L^{-1} should be maintained for optimum growth of aquatic organisms (ANZECC 2000).

Based on the water quality measurements, the lake waters in the sampling sites during collection are classified as Class C inland water based on standards set by the Department of Environment and Natural Resources 2016–08. This implies that the lake can be used in fisheries, recreational activities (*e.g.* boating) and industrial purposes. Moreover, SDT readings classified as hypertrophic waters in the study area during dry season while eutrophic during wet season. However, chlorophyll readings classified the open waters as mesotrophic for both season.



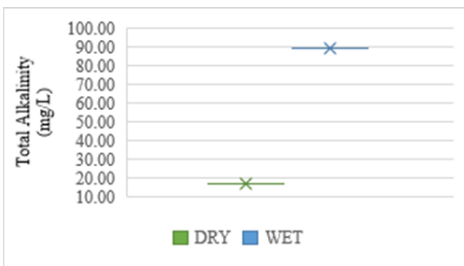


Figure 2. Boxplot of water quality parameters (left to right): water temperature, dissolved oxygen, pH, chlorophyll a, Secchi disc transparency, total hardness and total alkalinity during dry and wet seasons.

Phytoplankton Community Structure

A total of 36 phytoplankton taxa belonging to six classes were recorded: Chlorophyceae (15), Cyanophyceae (9), Bacillariophyceae (8), Dinophyceae (2), Chysophyceae (1), Euglenophyceae (1). The number of algal genera was higher during wet season with 30 species compared to dry season with 27 species.

Seasonal patterns of phytoplankton community structure were observed. During the dry season, the overall phytoplankton communities were composed of four families namely Bacillariophyceae (diatoms), Chlorophyceae (green algae), Cyanophyceae (blue–green algae) and Dinophyceae (dinoflagellates). During wet season, there were six families namely Bacillariophyceae, Chlorophyceae, Chrysophyta (brown algae), Cyanophyceae, Dinophyceae, and Euglenophyceae (euglenoids) (Table 2).

A significant increase was observed in the average density of phytoplankton in May ($8.36x10^{12}$ cells m^{-3}) than in November ($1.81x10^{12}$ cells m^{-3}) (p=0.0385) (Table 2). The average densities of phytoplankton families during dry season showed that the diatoms were the most abundant with $7.94x10^{12}$ cells m^{-3}, followed by blue–green algae with $2.44x10^{11}$ cells m^{-3}, green algae with $1.71x10^{11}$ cells m^{-3} then dinoflagellates with $1.39x10^{08}$ cells m^{-3}. Similarly, the wet season phytoplankton mean density showed that the diatoms were the most abundant with $1.00x10^{12}$ cells m^{-3} followed by blue–green algae with $7.99x10^{11}$ cells m^{-3}, green algae with $7.82x10^{09}$ cells m^{-3}, euglenoids with $1.16x10^{09}$ cells m^{-3}, dinoflagellates with $5.56x10^{08}$ cells m^{-3}, then brown algae with $4.63x10^{07}$ cells m^{-3}.

The foremost species in dry season were the following in rank order: *Aulacoseira* sp. > *Aphanizomenon* sp. > *Closterium* sp. 2 > *Microcystis* sp. > *Pediastrun simplex*. During wet season, the dominant species were *Aulacoseira* sp. > *Microcystis* sp. > *Melosira* sp. > *Cyclotella* sp. > *Pediastrum simplex*.

The values obtained for Shannon–Weiner Index (H') and dominance index (D) varied among sites. During dry season, diversity obtained ranged from 0.10 to 1.13 and dominance from 0.49 to 0.97. During wet season, diversity ranged from 0.26 to 1.7 and dominance with 0.28 to 0.91. In both seasons, it is evident that there was an inverse relationship between diversity and dominance. During dry season, highest diversity was observed in the nearshore of Brgy. Caingin (1.25) but had the lowest dominance (0.49) amongst the study sites (Figures 3 and 4). The dominant diatom (*i.e Aulacoseira* sp.) could have affected the proliferation of other phytoplankton classes because of its high mean density resulting in low diversity and high dominance values throughout the study sites. During wet season, similar patterns in the diversity indices were observed wherein diversity and dominance had inverse relationship.

Diatoms, specifically *Aulacoseira* sp., could have been the 'best –fitted' species for the given environment since they were able to dominate the study sites during the dry and wet seasons. They were able to tolerate the water quality in the sampling sites compared to other species. *Aulacoseira* species is one of the most common and most successful diatom taxa in lakes and large rivers. It is known to attain high biomass in shallow lakes. Some species of this genus is characteristic of eutrophic waters. *Aulacoseira* has the ability to form chains but its cells are

Table 2. Mean density of Phytoplankton in West Bay, Laguna de Bay.

TAXA		Mean Density (cells m^{-3}) Dry Season	Wet Season
Bacillariophyceae	*Aulacoseira* sp.	7.94E+12	9.53E+11
	Cyclotella sp.	4.17E+08	5.00E+09
	Melosira sp.	5.90E+08	3.86E+10
	Navicula sp.		9.26E+07
	Nitzschia sp. 1	1.81E+09	1.16E+09
	Nitzschia sp. 2		1.39E+08
	Stauroneis sp.	1.53E+09	
	Surirella sp.	1.81E+09	1.76E+09
Chlorophyceae	*Cladophora* sp.	6.29E+02	
	Closterium sp. 1	1.39E+08	
	Closterium sp. 2	1.65E+11	2.78E+08
	Closterium sp. 3		
	Eudorina sp.	6.80E+03	1.34E+09
	Pandorina sp.		4.63E+08
	Pediastrum simplex	3.19E+09	3.89E+09
	Pediastrum duplex	1.39E+08	9.26E+07
	Scenedesmus cuminatus	1.39E+08	9.26E+07
	Scenedesmus quadricauda	1.39E+08	1.85E+08
	Scenedesmus sp.	1.39E+08	
	Selenastrum sp.	1.39E+08	
	Staurastrum sp.	1.39E+08	4.63E+08
	Volvox aureus	2.78E+08	3.70E+08
	Zygnema sp.	1.84E+09	6.48E+08
Chrysophyceae	*Uroglena* sp.		4.63E+07
Cyanophyceae	*Anabaena* sp.	2.78E+08	3.56E+09
	Aphanizomenon sp.	2.17E+11	9.26E+07
	Aphanocapsa sp.		3.52E+09
	Arthrospira sp.		2.31E+08
	Chroococcus sp.		3.43E+09
	Lyngbya sp. 1		4.17E+08
	Lyngbya sp. 2		4.63E+07
	Microcystis sp.	2.50E+10	7.88E+11
	Oscillatoria sp.	1.53E+09	4.63E+07
Euglenophyceae	*Euglena* sp.		1.16E+09
Dinophyceae	*Peridinium* sp.	3.14E+03	4.63E+07
	Ceratium sp.	1.39E+08	5.09E+08

heavily silicified, thus the chains have the tendency to sink in still waters (Buczko *et al.* 2010; Manoylov *et al.* 2009). The turbulent waters in Laguna de Bay could have supported its growth and reproduction.

Visible response to nutrient enrichment can be perceived when a species or a group of species dominate. During the extent of the study, high abundance of *Aulacoseira* was indicative of conditions leading to biomass accumulation. Also, *Microcystis* increased in density during wet especially in nearshore sites. This could be attributed to higher nutrient concentrations in the nearshores due to domestic liquid and solid wastes from the

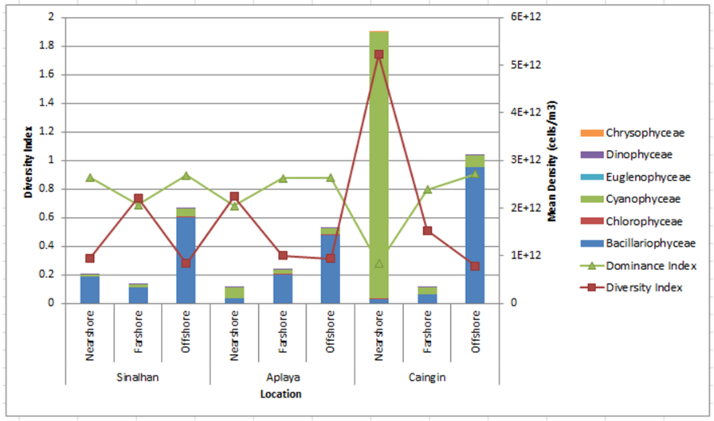


Figure 3. Comparison among phytoplankton mean density, diversity and dominance during dry season in West Bay of Laguna de Bay.

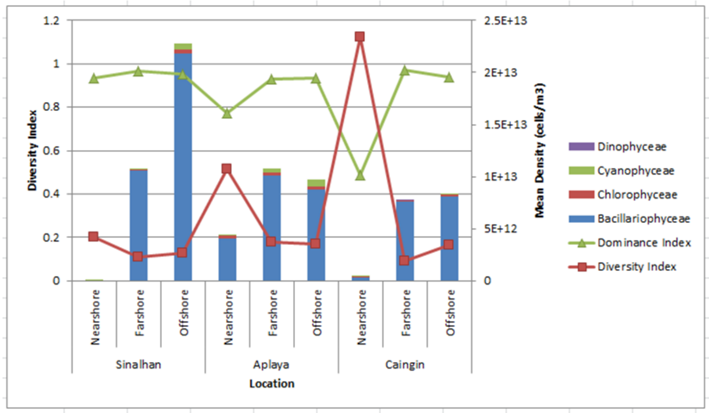


Figure 4. Comparison among phytoplankton mean density, diversity and dominance during wet season in West Bay of Laguna de Bay.

informal settlers in the coastal zones of the lake. *Microcystis* is a cosmopolitan genus in freshwaters. It is known to form algal blooms in Laguna de Bay since the early 1970s (Lasco & Espaldon 2005). The growth and proliferation of *Microcystis* are mainly due to high nutrient levels (nitrogen and phosphorus) in eutrophic waters. Several factors also contribute to its abundance such as water temperature, light intensity, buoyancy, zooplankton and fish grazing (Smith 1983 as cited by Strakova *et al*. 2013; Sivonen & Jones 1999 as cited by Homma *et al*. 2008).

Zooplankton Community Structure

A diverse zooplankton community existed in the study sites in Laguna de Bay. A total of 53 zooplankton taxa belonging to three zooplankton orders were recorded: Rotifera (35), Cladocera (13) and Copepoda (5). Zooplankton genera were greater in dry season (47 species) than wet season (40 species) (Table 3).

The overall species composition revealed that the dominant zooplankton group differed between seasons. During dry season, Rotifera (rotifers) was most dominant followed by Cladocera (cladocerans) then Copepoda (copepods). During wet season, zooplankton groups were composed of rotifers, cladocerans and copepods (Table 3). Higher zooplankton average density was observed during dry season (3.26 x10^5 individuals m^{-3}) than in wet season (6.39 x10^4 individuals m^{-3}) but not statistically significant (p=0.0651). The average densities of zooplankton orders during dry season showed that the rotifers were the most abundant with $1.80x10^5$ individuals m^{-3} followed by copepods with $1.01x10^5$ individuals m^{-3} then $4.85x10^4$ individuals m^{-3}. During wet season, copepods were the most abundant with $3.82x10^4$ individuals m^{-3} followed by cladocerans with $1.39x10^4$ individuals m^{-3} then rotifers with $1.18x10^4$ individuals m^{-3} (Table 3).

The most abundant species in dry season were the following in rank: copepodite nauplius dominated the sites followed by *Trichocerca* sp. 1, *Brachionus angularis,* Bdelloidea and then by *Bosmina longirostris*. In wet season, copepodite nauplius predominated followed by juvenile copepoda, *Bosmina longirostris,* cyclopoida and then by calanoida.

The diversity values obtained for both seasons were relatively high. During the dry season, diversity ranged from 1.71 to 2.81 while dominance values were low from 0.08 to 0.32. During wet season, diversity ranged from 1.82 to 2.61. The dominance values varied from 0.09 to 0.25. Figures 5 and 6 illustrated the inverse relationship between diversity and dominance of zooplankton communities throughout the study sites. For instance, a high diversity (2.81) was observed in the farshore of Brgy. Caingin but low dominance value (0.08) during the dry season. During wet season, diverse zooplankton communities (2.61) and low dominance (0.09) were observed in the nearshore of Brgy. Caingin.

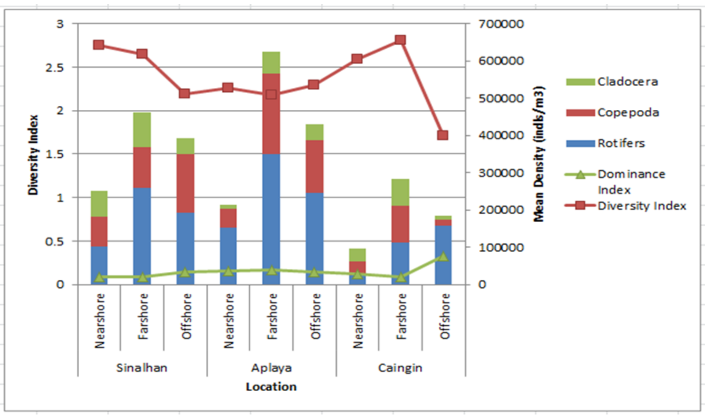


Figure 5. Comparison among zooplankton mean density, diversity and dominance during dry season in West Bay of Laguna de Bay.

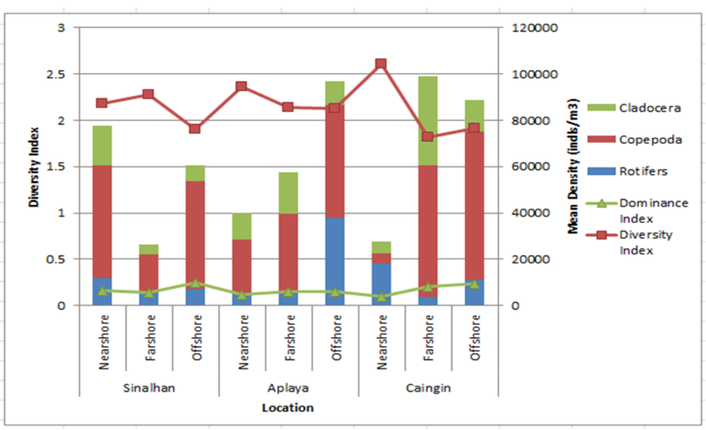


Figure 6. Comparison among zooplankton mean density, diversity and dominance during wet season in West Bay of Laguna de Bay.

Table 3. Mean density of Zooplankton in West Bay, Laguna de Bay.

TAXA	Mean Density (individuals m^{-3})	
	Dry Season	Wet Season
Rotifera		
Anuraeopsis fissa	7.47E+02	1.05E+02
Aneuropsis sp.	9.56E+02	
Ascomorpha ovalis	6.22E+02	4.98E+02
Brachionus angularis	3.82E+04	
Brachionus budapestinensis	1.83E+02	2.62E+01
Brachionus calyciflorus	1.44E+02	7.86E+01
Brachionus caudatus		2.62E+01
Brachionus sp.	4.98E+02	
Collotheca sp.		2.36E+02
Collotheca cf. pelagica		5.24E+01
Conochilus unicornis	1.53E+04	
Conochilus sp.	1.98E+03	4.98E+02
Euchlanis sp.		5.24E+01
Filinia opoliensis	6.34E+03	1.31E+02
Filinia longiseta	1.88E+03	2.62E+01
Hexarthra intermedia	6.84E+03	6.55E+02
Keratella cochlearis	3.26E+03	6.55E+02
Keratella tropica	3.86E+02	2.10E+02
Lecane bulla	2.62E+02	1.05E+02
Lecane luna	1.05E+02	
Lecane sp.		1.05E+02
Lepadella sp.	5.63E+02	1.83E+02
Monostyla sp.		7.86E+01
Mytilina sp.	1.05E+02	
Platyias leloupi	5.76E+02	
Platyias quadricornis	4.19E+02	2.62E+01
Polyarthra vulgaris	1.12E+03	1.60E+03
Rotaria sp.	7.34E+02	2.62E+01
Testudinella patina	2.49E+02	7.86E+01
Trichocerca sp. 1	4.51E+04	1.68E+03
Trichocerca capucina	4.00E+03	7.34E+02
Trichocerca inermis	5.28E+03	1.31E+02
Trichocerca pusilla	1.05E+02	3.14E+02
Trichocerca sp. 2	1.30E+04	
Bdelloidea	2.83E+04	3.46E+03
Copepoda		
Cyclopoida	1.27E+04	4.98E+03
Calanoida	1.16E+04	1.65E+03
Harpacticoida	7.07E+02	4.45E+03
Copepodite Nauplius	5.50E+04	1.41E+04
Juvenile Copepoda	2.07E+04	1.30E+04
Cladocera		
Bosmina longirostris	2.35E+04	8.72E+03
Ceriodaphnia cornuta	1.27E+04	3.93E+02
Ceriodaphnia sp. 1	5.24E+02	2.54E+03
Ceriodaphnia sp. 2	1.74E+03	
Daphnia sp.	4.19E+02	
Diaphanosoma sp. 1	2.31E+03	1.31E+02
Diaphanosoma sp. 2	2.17E+03	7.07E+02
Diaphanosoma sp. 3	3.67E+02	4.72E+02
Moina micrura	1.05E+02	1.05E+02
Moina sp.	1.44E+02	4.45E+02
Daphniidae	5.24E+02	
Monidae	2.83E+03	7.86E+01
Sididae	1.18E+03	3.14E+02

Variability in zooplankton species was shown in the study sites. The most dominant group in summer was rotifers. Rotifers like *Trichocerca* sp., *Brachionus angularis* and bdelloids are small–sized zooplankters with body size of less than 150 μ. This group has higher chance of survival over Cladocera and Copepoda because of the following features: frequent reproduction through ameiotic parthenogenesis; can undergo anhydrobiosis (form of dormancy); they are r–strategists (opportunistic, short life cycle and small in size) and have less specialized feeding structures. Moreover, rotifers can also ingest even small particles like bacteria, small algae and organic residues. These traits enable them to live in eutrophic (Sampaio *et al.* 2002; Badsi *et al.* 2010). Since rotifers could exist in unfavorable conditions, they can be used as indicators of high biological trophic level (Badsi *et al*. 2010; Pecorari *et al*. 2005). One bioindicator of eutrophic waters is *Brachionus angularis,* in which it was observed to be one of the dominant zooplankton in the study sites.

Moreover, lesser copepods and cladocerans in summer could be attributed to competition with dominant rotifers as well as predation by fishes such as *Hypophthalmichthys nobilis* ("Mamaling") that feeds mainly on larger zooplankton species. On that account, the increase in number of copepods and cladocerans during wet season may be due to less predation from invertebrates (Sampaio *et al.* 2002; Badsi *et al.* 2010). Moreover, *Bosmina longirostris* is one of the abundant zooplankton in both seasons. This species is known to dominate when there is intense predation by planktivores (Brooks 1965 as cited by Brooks & Dodson 1965). The presence of *B. longirostris* supports the idea that there was higher predation activities during summer. Copepodite nauplii had the highest average densities than any other zooplankters during both seasons. This resulted in continuous reproduction. It ensures the adult succession of copepods in the lake.

Phytoplankton and Zooplankton Seasonal Dynamics

Variations in plankton composition is highlighted in Figure 7. Higher phytoplankton and zooplankton densities are observed during dry season due to longer time for photosynthesis. As the phytoplankton increased, the zooplankton also increased. This trend revealed prey–predator relationship in plankton communities (Cropp & Norbury 2009).

The synergistic interactions of water quality variables influence plankton composition, density and diversity. CCA analyses (Figures 8 & 9 respectively) indicated that dry season had two distinct groups based on selected biophysico–chemical parameters (Figure 8). The first group comprised of WT, SDT and TA. The second group comprised of chl a, TH, DO and pH. Variables in the first group negatively correlated with the second group. For instance, a high chl a was accompanied by a low SDT reading. This implies an organic rather than an inorganic cause of light attenuation. The grouping also signified a closer correlation among the parameters included (ter Braak & Verdonschot 1995). For example, in the second group, DO was correlated with chl a and pH was correlated with TH. Also, Bacillariophyceae (diatoms) which was the most abundant group, correlated with all the water quality parameters compared to other plankton groups. Diatom density, mostly that of *Aulacoseira* sp., was proximal to chl a. This shows a strong relationship between the two which implies that high densities of *Aulacoseira* sp. largely contributed to chl a in all of the study sites.

Species that are close in the CCA biplot are expected to have similar distribution across sites (ter Braak & Verdonschot 1995). There is an association between rotifers and green algae (Figure 8). This co–occurrence could be due to a prey–predator relationship. Rotifers prefer microalgae such as *Chlorella* and *Chlamydomonas* (Bogdan & Gilbert 1982 as cited by Massana 1996; Glime *et al.* 2013).

Another type of grouping manifested during the wet season. The first group included pH, TA and TH while the second group was WT, SDT, chl a and DO (Figure 9). In the first group, pH in water was positively influenced by TH and TA. Stability of pH signifies a buffering effect of TA in hard water. In second group, WT supported the proliferation of diatoms that in turn improved DO content through photosynthesis. Diatom density influenced SDT that made its mark on the chl a readings.

It is important to note that Cyanophyceae, Euglenophyceae and Chrysophyceae were closer to CCA biplot during the wet season than in dry season. On the other hand, Cyanophyceae formed high densities in the nearshore along Sta. Rosa City during wet season. Euglenophyceae and Chrysophyceae were present during wet season only. The close proximity of the three algal classes to the CCA biplot indicates a favorable effect of water quality on their growth and reproduction during the wet season.

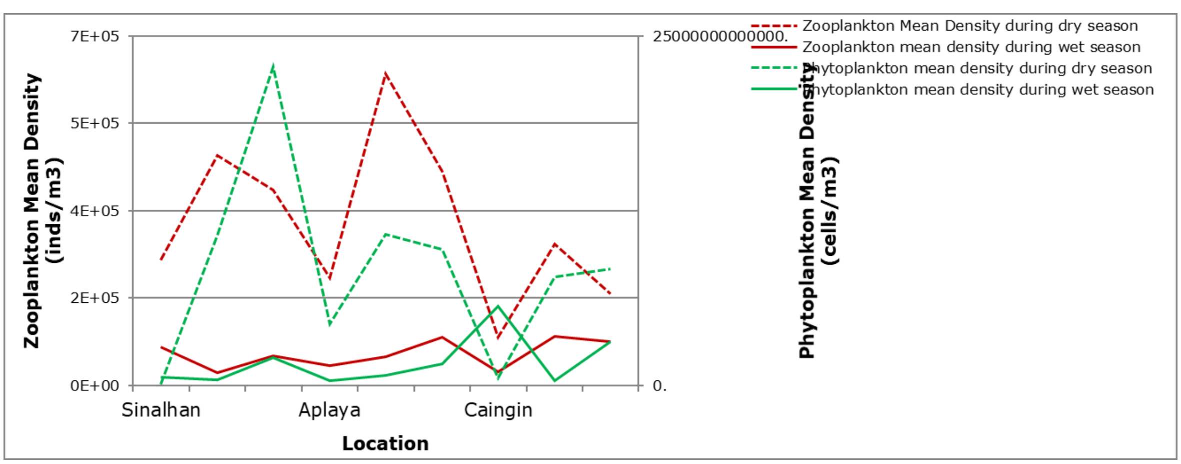


Figure 7. Phytoplankton and zooplankton seasonal dynamics in the West Bay of Laguna de Bay during dry season and wet season.

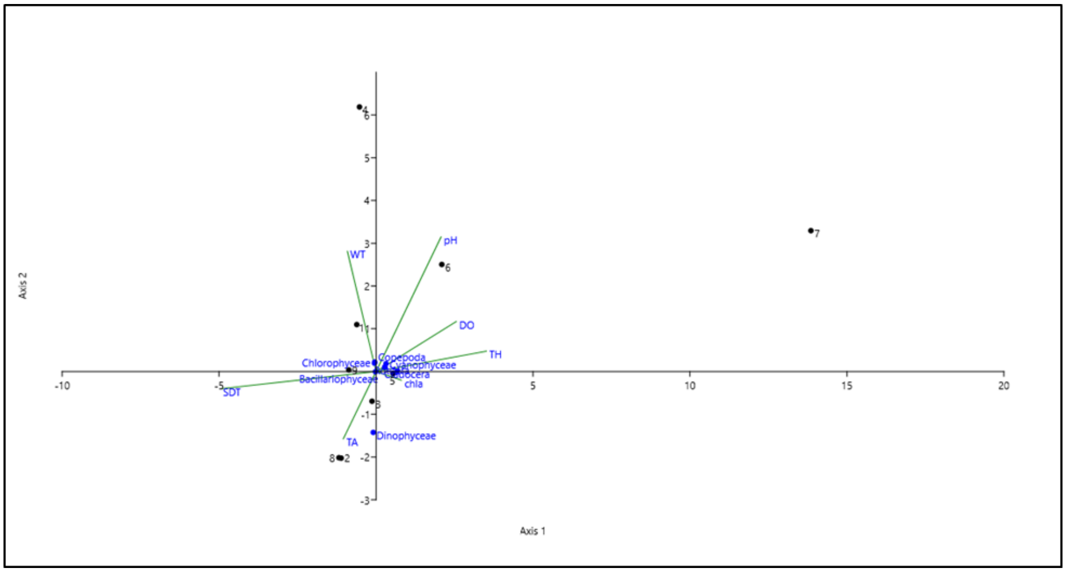


Figure 8. CCA ordination among phytoplankton, zooplankton and water quality parameters: WT = water temperature, DO = dissolved oxygen, pH, SDT = Secchi disc transparency, chl a = chlorophyll a, TA = total alkalinity and TH = total hardness during dry season.

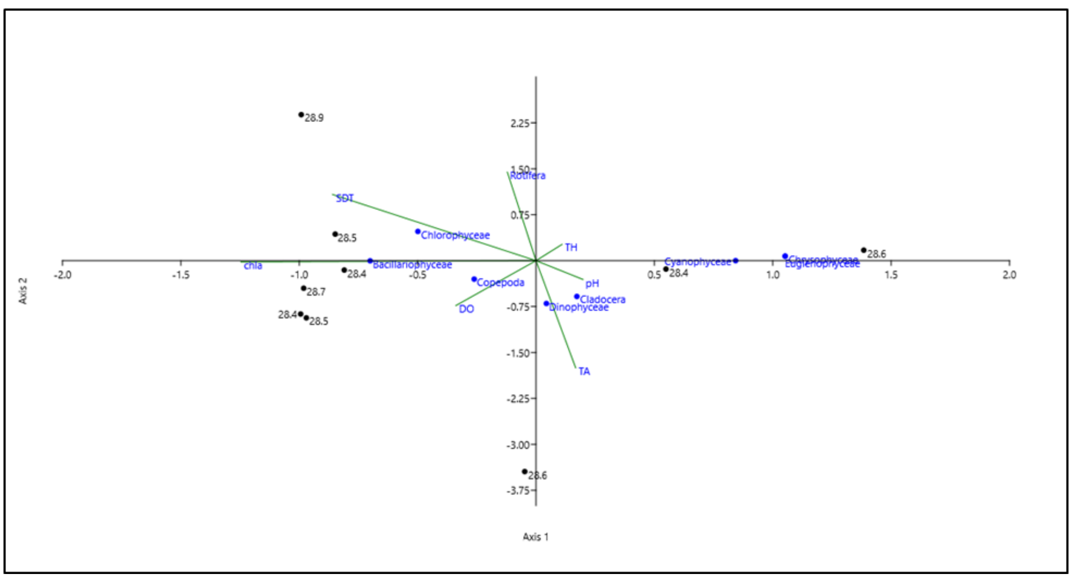


Figure 9. CCA ordination among phytoplankton, zooplankton and water quality parameters: WT = water temperature, DO = dissolved oxygen, pH, SDT = Secchi disc transparency, chl a = chlorophyll a, TA = total alkalinity and TH = total hardness during wet season.

Photographs during phytoplankton and zooplankton sampling in the West Bay of Laguna de Bay (Photo courtesy of Keshia Tingson)

Copepoda, the most dominant zooplankton group during the wet season, was the nearest zooplankton order to the CCA biplot. The group was apparently benefitted by the abundance of primary producers for food and a diminished predation pressure. Planktivorous fishes are size–selective giving preference the larger zooplankters like copepods and cladocerans. Some zooplankters have "visual cues" like eyespots and pigmentations that increase their visibility to planktivores in open waters (Papa *et al*. 2008). High turbidity during wet season could blur the vision of their predators resulting in a lower predation pressure by fishes. This may suggest that the lower grazing pressure gave way to improved copepod reproduction which was supported by higher number of copepodite nauplius, juvenile copepods and cyclopoid species.

CONCLUSION AND RECOMMENDATION

The dynamics of plankton community structure through time could be attributed to changing water quality of the lake. Best–fitted organisms dominated the given environment. There are substantial evidences for water qualities and its relationship with plankton communities during dry and wet seasons. As the phytoplankton densities increased so thus the zooplankton densities. Phytoplankton serves as the main food source of zooplankton. Thus, the more available phytoplankton present in the lake, more zooplankton could be observed. Plankton abundance peaked during the dry season wherein the most dominant phytoplankton was the diatom *Aulacoseira* and zooplankton Rotifera. This could be attributed to higher availability of nutrients, dissolved oxygen, water temperature, wave action and light intensity. The limiting factor in phytoplankton growth in Laguna de Bay is light intensity and water clarity. Increased rainfall caused higher siltation during the wet season which regulated plankton growth and reproduction.

This research was able to provide an update on the seasonal patterns of phytoplankton and zooplankton in association with the water quality. Annual monitoring during dry season can be done to check the dominant plankton to avoid further fish kills. Regular water quality assessment of effluents from households and industries located in Sta. Rosa City should be done by LLDA and Sta. Rosa City Government to check if the lake waters follow the standards set by DENR DAO 16–08.

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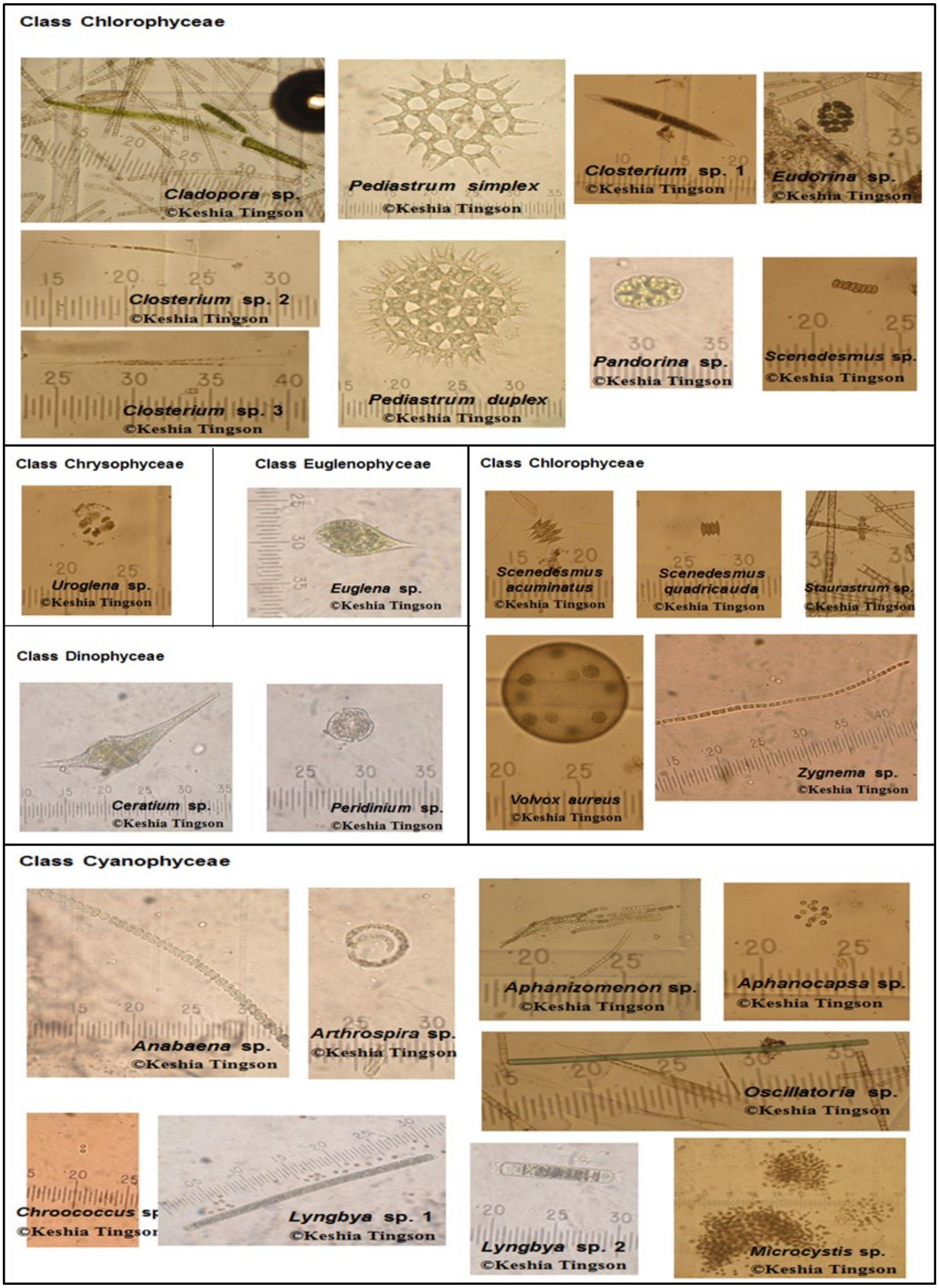
Plates of Phytoplankton in the West Bay of Laguna de Bay



Plates of Zooplankton in the West Bay of Laguna de Bay