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Spatio-Temporal Variability of Zooplankton Distribution and Abundance in Manila Bay from 2013-2015

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Abstract

The study characterized the spatiotemporal variations in composition, abundance, and diversity of zooplankton community in Manila Bay. Zooplankton samples were collected every two months within three years from 2013 to 2015. The zooplankton composition of Manila Bay includes 29, 52, and 50 taxa in 2013, 2014, and 2015, respectively belonging to the following major groups: Copepoda, Decapoda, Cladocera, Chordata, Annelida, Mollusca, Chaetognatha, Ciliophora, Foraminifera, Echinodermata, and Chromista. Copepod nauplii consistently dominated the zooplankton community in the bay from 2013 to 2015 followed by Tintinnids, *Oithona* spp., *Euterpina acutifrons*, and *Paracalanus* spp. The highest concentration of zooplankton was specifically observed in the southwestern side near the mouth of the bay (Station 4) in July 2015. In 2014, the highest recorded zooplankton density was in the month of November in the eastern side (Station 10). In general, relatively high diversities of zooplankton community were recorded in many months in 2015 as compared to 2013 and 2014 although the highest recorded diversity occurred in March 2014. Redundancy Analysis revealed salinity, temperature, dissolved oxygen, chlorophyll *a*, PO_4, SiO, and NO_3 to have a strong correlation with the zooplankton abundances and distribution.

Keywords: Zooplankton, Diversity, Environmental Factors, Redundancy Analysis

INTRODUCTION

Manila Bay is one of the most important bodies of water in the Philippines because of its socio-economic impact (Jacinto et al., 2006). The natural resources available have been the primary source of livelihood for people living in the coastal areas surrounding the bay. The rapid increase in population and industrialization in the watershed cause the bay to suffer from serious water quality deterioration (Chang et al., 2009).

Zooplanktons are essential in the marine ecosystem because they serve as consumers of microbial production. They also influence the resources available to microbes by revitalizing and discharging dissolved organic matter (Lalli and Parsons, 1993). Their distribution is influenced by biotic (Isari *et al*., 2007) and abiotic (David *et al*., 2005; Marques *et al*., 2007a, b) factors. Zooplankton plays a major role in the functioning and the productivity of aquatic ecosystems through its impact on the nutrient dynamics and its key position in the food webs (Etilé *et al*., 2009). Zooplankton community is highly sensitive to environmental change (Joseph and Yamakanamardi, 2011) and they respond to disturbances in the environment like nutrient loading (Pace, 1986; Dodson, 1992) and fish densities (Canfield and Jones, 1996).

Several studies have examined and reported about zooplankton, both locally and internationally in different parts of the world (Joseph and Yamakanamardi, 2011). Studies have been conducted on zooplankton as indicators of water quality done in Discovery Bay in Jamaica (Webber *et al*., 2005); and the identification of water quality and zooplankton characteristics in Daya Bay in China (Wang *et al*., 2011) however, in Manila Bay, despite the studies done concentrating on the pollution of the bay especially regarding its water quality and harmful algal bloom issues, only a very few studies are presently available on the structure of zooplankton community, one study was done by Chang *et al*. in 2009.

The study aimed to describe the spatio-temporal variations in composition, abundance, and diversity of zooplankton community in Manila Bay.

MATERIALS AND METHODS

Study Site

The investigations were carried out in Manila Bay for three years with six survey months every year (January 2013, March 2013, May 2013, July 2013, September 2013, November 2013; January 2014, March 2014, May 2014, July 2014, September 2014, November 2014; January 2015, March 2015, May 2015, July 2015, September 2015, November 2015).

Sixteen transect stations in Manila Bay were established for investigation (Figure 7.1). Manila Bay has an area of 1,994 km^2 (769.9 sq mi) with an average depth of 17 m (55.8 ft). It is bounded by the province of Cavite and Metro Manila in the east, Bulacan and Pampanga on the north and the province of Bataan on the west. (Jacinto *et al*., 2006)

Physico-chemical Analysis of Water

Physico-chemical parameters like temperature, salinity, dissolved oxygen and chlorophyll-*a* concentration were measured using CTD 19 Plus, SeaBird Electronics, Inc., USA. The particulate and dissolved matter was separated by filtration. The water samples were filtered through a 0.45 μM membrane filters. Dissolved nutrients such as phosphate, nitrate, nitrite, and silicate were analyzed by spectrophotometry.

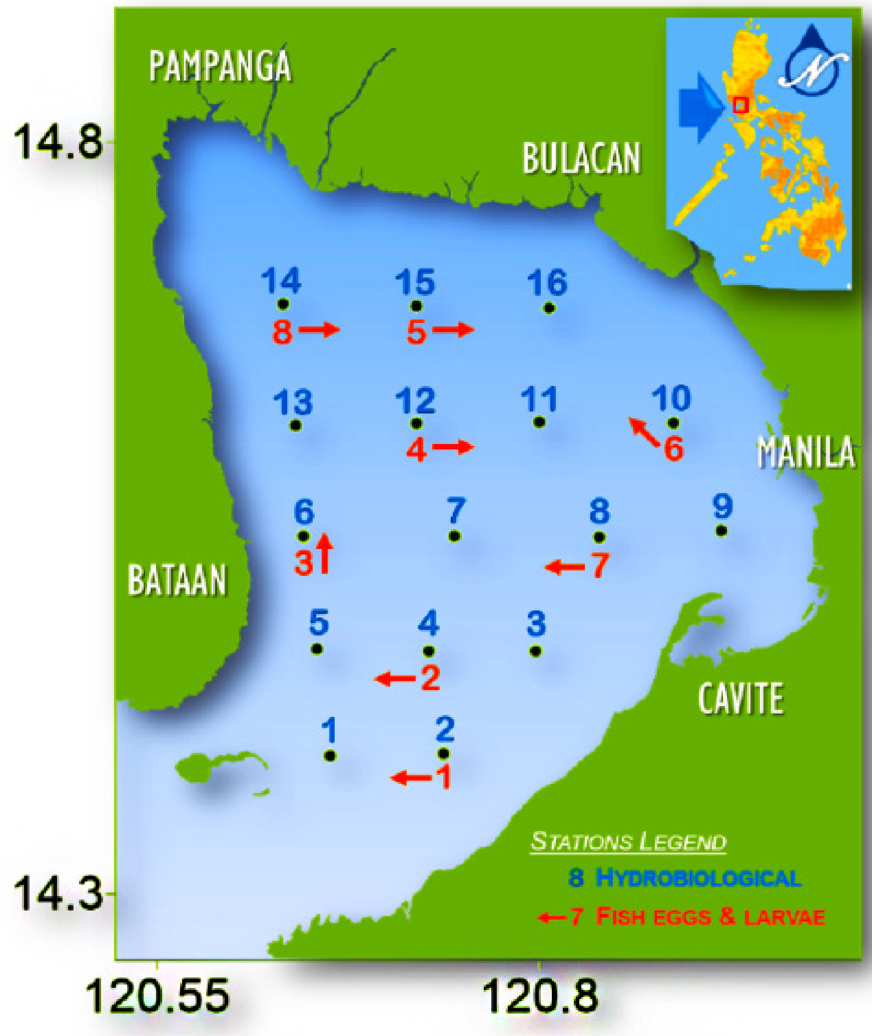


Figure 7.1. Study Site: Manila Bay (14°31′00″N120°46′00″E) showing 16 pre-established sampling stations

Collection and Analysis of Zooplankton Samples

Zooplankton samples were collected using a conical plankton net about two feet in length with 64μM mesh size. The plankton net is slowly vertically towed from near bottom layer to the surface layer to collect the zooplankton samples throughout the water column in each station. Each filtered seawater sample was placed in a bucket, poured into a polyethylene plastic bottle then reduced to 100 ml and preserved in 4% formalin solution. An aliquot of 1 ml was subjected to counting and identification of the specimen.

The zooplankton samples were observed and counted using Sedgewick Rafter Counting Cell under a microscope with 400x magnification. Individual zooplankton was identified up to lowest possible taxa. The density expressed in ind/m^3 was computed using the formula:

$$\text{Density} = \frac{\text{Number of individual x Volume of Sub} - \text{sample}}{\text{Volume of original water filtered}}$$

The zooplankton taxonomic diversity was measured using the Shannon-Wiener Index.

Shannon-Wiener (H') was computed using the formula:

$$H' = \sum_{i=1}^{S} \frac{n_i}{n} \times \ln \frac{n_i}{n}$$

Redundancy analysis was done using CANOCO 5 software (Lepš and Šmilauer, 2003).

RESULTS AND DISCUSSION

The zooplankton composition of Manila Bay includes 29, 52 and 50 zooplanktonic taxa in 2013, 2014 and 2015, respectively belonging to the major groups: Copepoda, Decapoda, Cladocera, Chordata, Annelida, Mollusca, Chaetognatha, Ciliophora, Foraminifera, Echinodermata, and Chromista. Copepod nauplii constantly dominated the zooplankton community in the bay from 2013 to 2015 (Figure 7.2) with a total abundance of 2,929,864 ind/m^3 followed by copepodite with total abundance of 1,048,691 ind/m^3, Tintinnids (892,427 ind/m^3), *Oithona* spp. (774,197 ind/m^3), *Euterpina acutifrons* (475,376 ind/m^3), *Paracalanus* spp. (455, 202 ind/m^3), *Microsetella norvegica* (428,320 ind/m^3) *Oikopleura* sp. (284,607 ind/m^3), *Oncaea* sp. (155,697 ind/m^3), and *Corycaeus* spp. (162,774 ind/m^3).

Generally, the highest concentrations of zooplankton species were recorded in 2015, specifically the highest density was observed in the southwestern side near the mouth of the bay (station 4) in July (Figure 7.3). In 2014, the highest recorded density was in the month of November. In general, high diversities of zooplankton community were recorded in many months in 2015 as

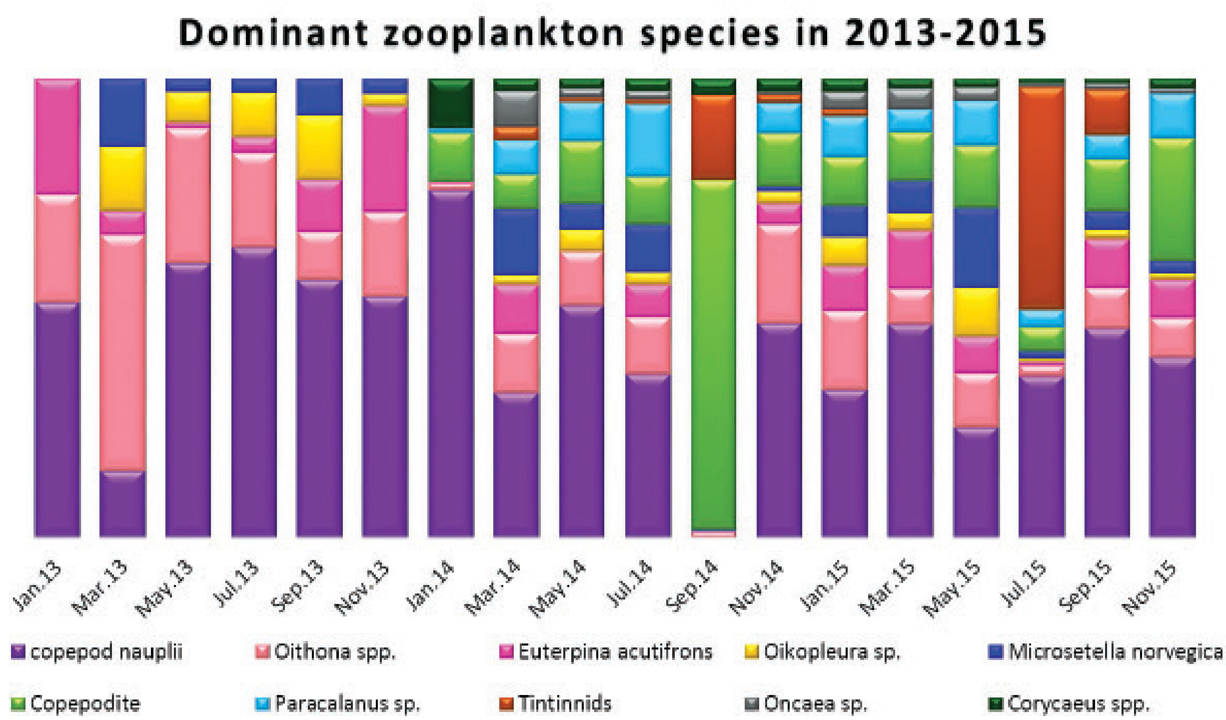


Figure 7.2. Dominant zooplanktonic taxa in 2013-2015 in Manila Bay

compared to 2013 and 2014 although the highest diversity recorded occurred in the month of March 2014.

The zooplankton composition of Manila Bay in the sampling months in 2013 includes 29 zooplanktonic taxa belonging to the major groups: Copepoda, Decapoda, Cladocera, Chordata, Annelida, Mollusca, Chaetognatha, Ciliophora, Foraminifera, Echinodermata, and Chromista. Copepod nauplii dominated the zooplankton community in 2013 (Figure 7.2) reaching a density of 274,663 ind/m^3.

Zooplanktons are most abundant near the mouth and in the northern part of the bay near Bulacan (Figure 7.3). Station 2 (near the mouth) has the highest density while station 12 (near Manila) has the lowest density. The zooplankton population of those stations was found to be dominated by adults and nauplii of copepods both in number and families followed by tunicates (*Oikopleura*) and chaetognath. The zooplankton community was the most diverse in the month of September in general while the lowest diversity was recorded in the month of January (Figure 7.4).

There was an increase in the total number of zooplanktonic taxa found in the bay from 29 in 2013 to a total of 52 zooplanktonic taxa identified in 2014 belonging to the major groups: Copepoda, Decapoda, Ostracoda, Maxillopoda, Cladocera, Chordata, Cnidaria, Annelida, Mollusca, Chaetognatha, Ciliophora, Foraminifera, Echinodermata, and Chromista. The dominant species are shown in Figure 2, copepod being the most abundant with a density of 823,072 ind/m^3. In this study, it was noted that the total density of zooplanktons varied from 4,812 to 103,185 ind/m^3 during the months of January to November 2014. An increase in the total densities was observed in 2014 compared to 2013.

Zooplanktons were most abundant in the eastern part of the bay near Manila and Cavite, in the western part of the bay and near the mouth (Figure 7.3). The highest density of zooplankton was recorded in the month of November reaching about 105,000 ind/m^3 which occurred in station 10 near Manila. There was an increase in the highest density recorded in 2013 from 73,000 ind/m^3 in 2013 to 103,000 ind/m^3 in 2014. The zooplankton community of those stations was found to be dominated by adults and nauplii copepods both in number and families. The zooplankton community was generally most diverse in the month of May while lowest diversity was recorded in the month of November (Figure 7.4).

The zooplankton composition of Manila Bay during the survey in 2015 includes 50 zooplanktonic taxa belonging to the major groups: copepods, decapods, ostracods, branchiopods, maxillopods, echinoderms, ciliophorans, chordates, annelids, mollusks, and nemerteans. Copepod nauplii still comprised the bulk of zooplankton in the bay in the sampling months of 2015 with a density of 1,723,849 ind/m^3, other dominant species observed in 2015 was shown in Figure 2.

The zooplankton concentrations were observed generally in the central to the eastern part of the bay, near Bulacan and Manila area, for the whole year of 2015 (Figure 3). There was an increase in densities of zooplankton in 2015 as compared to 2013 and 2014. The zooplankton community was the most diverse in the months of January, March, and May while the lowest diversity was observed in the different stations in the month of July (Figure 4).

Copepod nauplii consistently dominated the zooplankton community in the three years of sampling. Copepod nauplii are widespread, abundant and productive in marine waters and they are food for many fish larvae. Harpacticoid species such as *Microsetella norvegica* and *Euter-*

Figure 7.3. Spatio-Temporal Variations in Zooplankton Abundance in 2013-2015 (density= ind/m³)

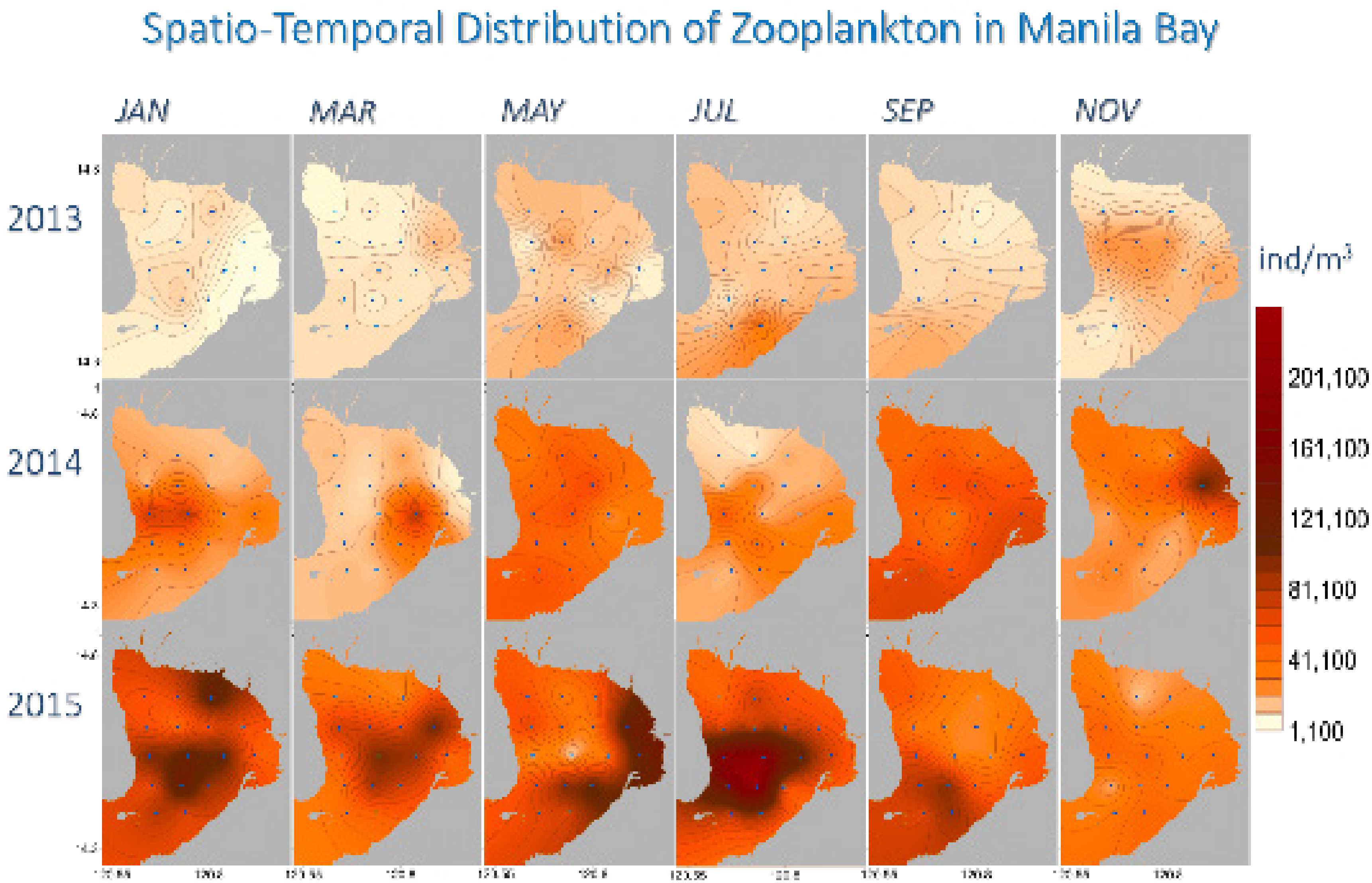
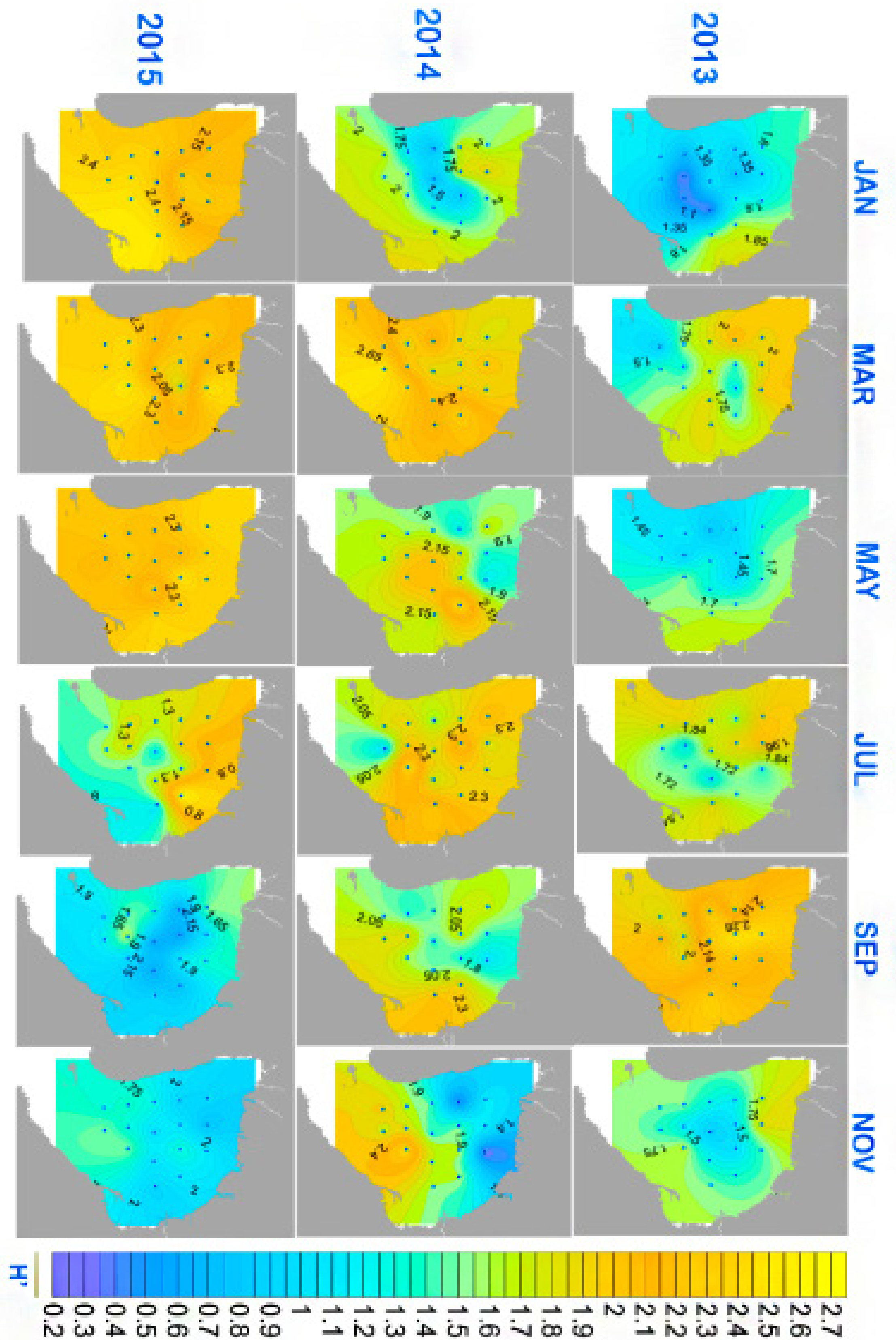


Figure 7.4. Spatio-Temporal Variations in Zooplankton Diversity in 2013-2015



pina acutifrons, were also observed to belong in the most abundant species from 2013-2015. This group usually occupy superficial or interstitial sediments and for the most part live in a benthic environment (Dussart and Defaye, 2001). The high abundance of harpacticoid species could be attributed to the turbidity of the bay. Cyclopoid species (*Corycaeus, Oithona,* and *Oncaea*) were also recorded to be one of the most abundant groups in the three years of sampling (2013-2015). Cyclopoids act as intermediate hosts to different parasitic worms that parasitize a variety of vertebrates; including fish, domestic animals, and humans (Dussart and Defaye, 2001). They first serve as intermediate hosts and are eaten up by fish, which in turn will be the second intermediate hosts. Some cyclopoid copepods are beneficial being known to be ravenous predators of mosquito larvae and have been utilized in large-scale mosquito control programs (Marten et al. 1994).

Measures of diversity indices are sensitive to the extent of dominance and the number of species present in the community (Mcgowan and Miller, 1980). Months with recorded high diversities was shown to have low abundance.

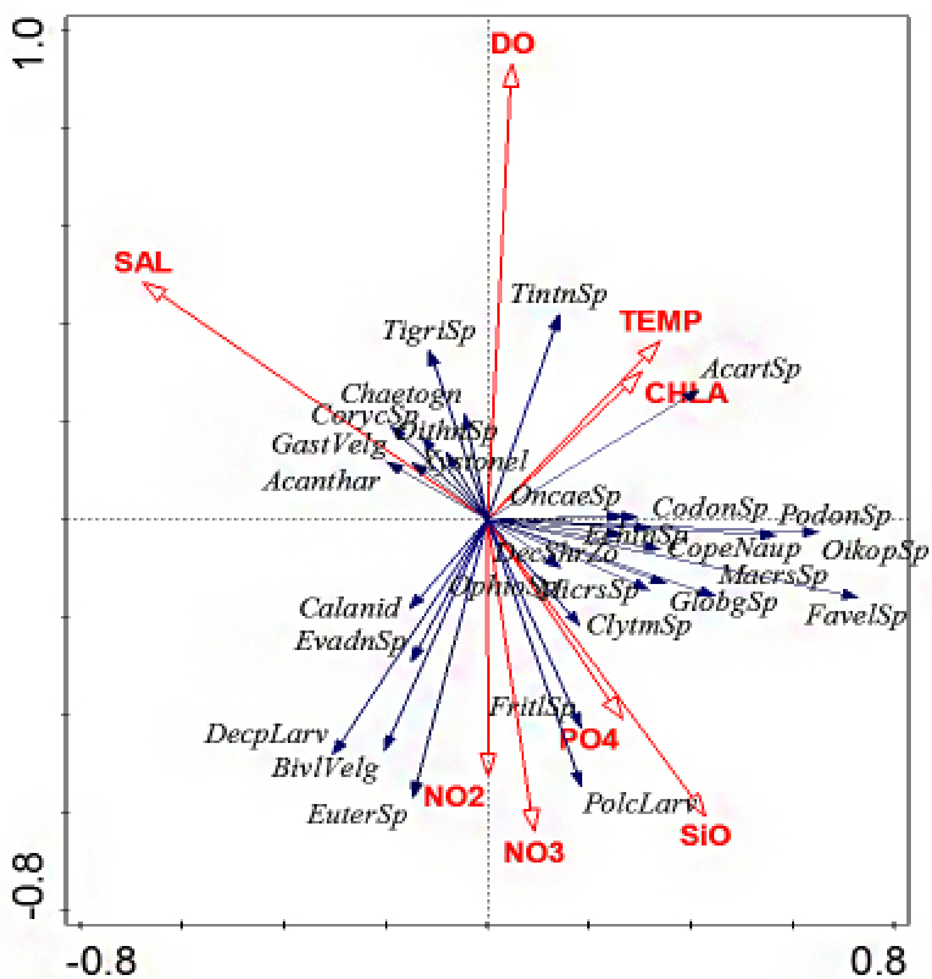


Figure 7.5. Biplot of Environmental factors x Zooplankton Composition in 2013 (RDA)

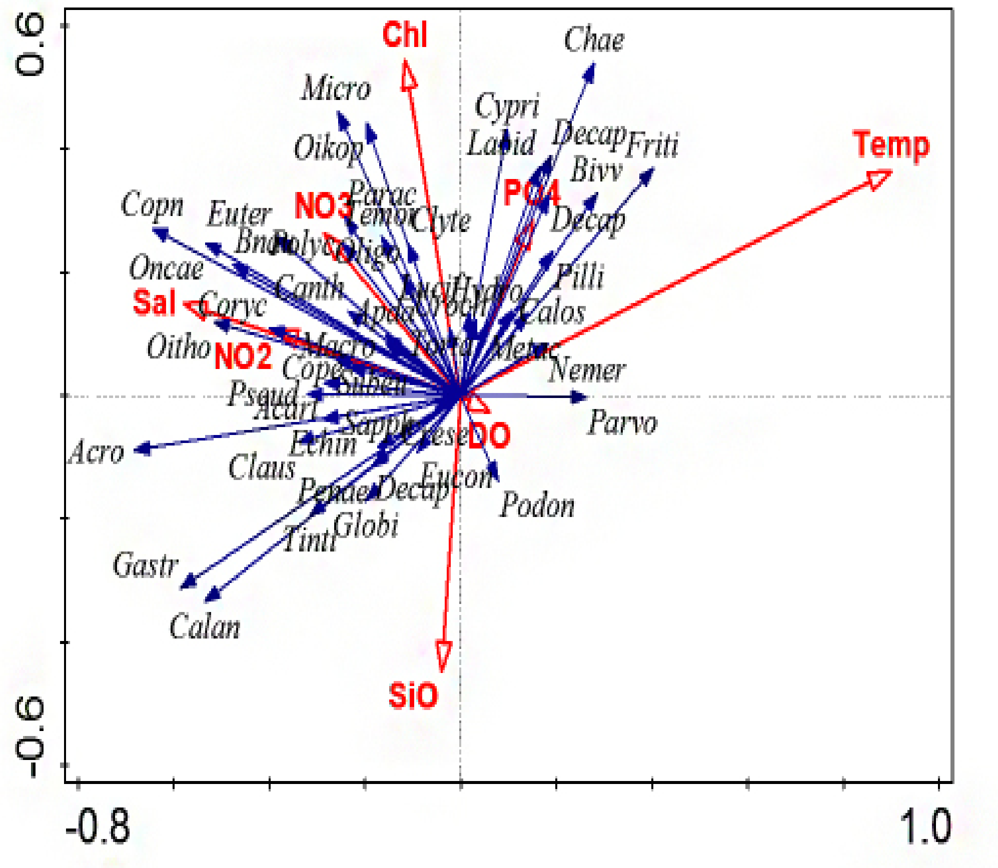


Figure 7.6. Biplot of Environmental factors x Zooplankton Composition in 2014 (RDA)

There are significant correlations between zooplankton abundances and environmental parameters in 2013. RDA revealed that the 30.5% of the zooplankton composition and abundance variance was explained by the following parameters: salinity (F = 7.2, p =0.002); temperature (F= 6.4, p =0.002); dissolved oxygen (F= 6.6, p =0.002); phosphate (PO_4) (F= 2.6 p =0.006); and chlorophyll-*a* (F= 1.6, p =0.084), although P value of chlorophyll *a* suggests a not so strong correlation (Figure 7.5). In 2014, significant correlations were found between zooplankton distribution and abundances and environmental parameters such as salinity (F= 15.3, p =0.002), phosphate (PO_4) (F= 10.7, p =0.002), temperature (F= 4.9, p =0.002), silicate (SiO) (F= 2.6, p =0.002) and dissolved oxygen (F= 2.5, p =0.01). RDA explains 35.6 of the variance in the species-environment relationships (Figure 7.6). In 2015, temperature (F= 9.5, p =0.002), chlorophyll-*a* (F= 2.9, p =0.002), silicate (SiO) (F= 2.6, p =0.004), nitrate (NO_3) (F= 2.5, p =0.006) were found to have effect on the abundance and distribution of zooplankton in Manila Bay RDA explains 31% of the variance of the species-environment relationships (Figure 7.7).

Most zooplankters abundance is affected by the fluctuations in environmental factors. Salinity is known to bring an immense change in aquatic communities, it causes the disappearance of species that cannot adapt to increase in salt

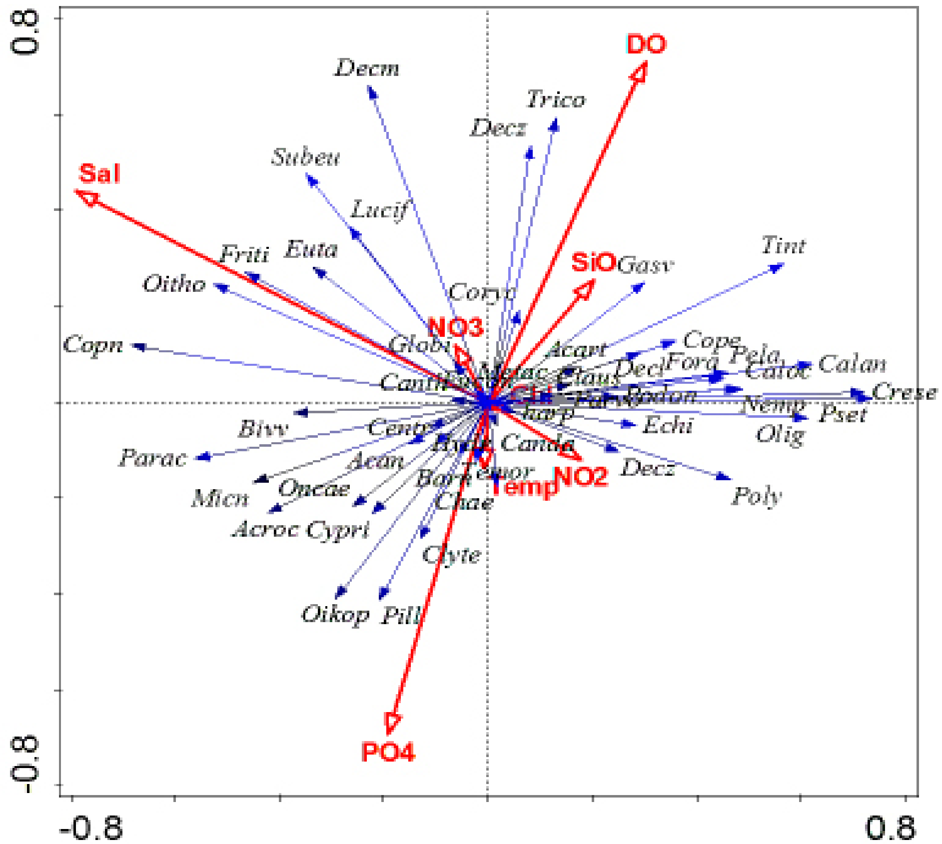


Figure 7.7. Biplot of Environmental factors x Zooplankton Composition in 2015 (RDA)

concentrations. Also, in a study done by Pardo and Armengol in 2011 CCA ordination showed that chlorophyll *a*, dissolved oxygen, and pH seemed to be important variables in structuring zooplankton community. Hypoxic/anoxic conditions may play a role in the decrease of zooplankton abundance in eutrophic systems (Soetaert and Van Rijswijk, 1993; Yacobi *et al.*, 1993; Stalder and Marcus, 1997; Park and Marshall, 2000). Our results showed the same result having dissolved oxygen and chlorophyll *a* and salinity as key factors in determining the community of zooplankton in the bay. Distribution of zooplankton can also be affected by the circulating current of which there are two present in the bay, one coming from the northern part and the other from the southern part. These two gyres move in opposite directions depending on the prevalent wind (de Las Alas and Sodusta, 1985).

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Spatio-Temporal Distribution and Abundance of Phytoplankton in Manila Bay

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Abstract

Understanding the dynamics and production of phytoplankton may contribute to the elucidation of the status of fishery resources and may be the key for better fisheries management since phytoplankton is at the base of the food chain. The changes and succession of phytoplankton community structure in Manila Bay was studied by conducting hydrobiological survey every other month from January 2012 to November 2015. It was determined from this study that diatoms dominated the phytoplankton composition all throughout the survey period and the total phytoplankton density was generally highest during southwest monsoons. Dinoflagellates and cyanobacteria, on the other hand, were relatively most dense during tradewinds. Although causative species for harmful algal blooms and fish kills were present, only the bloom of red *Noctiluca scintillans* was observed in January 2014 albeit no harmful implication to consumers was reported. Phytoplankton typically converged in the coasts of the bay, particularly at the eastern portion, but it is noteworthy to say that the sporadic pattern seen maybe attributed to the presence of their predators. The dramatic drop in the phytoplankton densities seem to coincide with the spawning of *Sardinella fimbriata* and *Sardinella gibbosa.*

Keywords: phytoplankton, Manila bay, ichthyoplankton, Sardinella fimbriata, Sardinella gibbosa

INTRODUCTION

Management of fisheries resources is likely to succeed if there is a genuine appreciation of the environment. The elements that are vital to the preservation and conservation of fish must be taken into account so that scientific decisions may be made not only for management but for the marine habitat's eventual revitalization.

The deterioration of the water quality to a highly eutrophicated state of Manila Bay was due to the increased anthropogenic activities along its surrounding coastal areas (Chang et al., 2009). Water quality is affected by the physicochemical and hydrobiological parameters. The biological components of the said parameters include phytoplankton, a community of microscopic alga that is at the base of the food web. They are an important resource that supports the higher trophic levels in the bay (MBRRA, 2004). Generally, increase in phytoplankton density is actually a beneficial condition to the fisheries (Legendre 1990) since they fuel the production of the food of fish. However, the algal bloom may become so dense that they become the cause of fish kills due to oxygen depletion and the cause of shellfish poisoning to humans (Hallegraeff 2002).

Phytoplankton, as a primary producer, can be an indicator of ecological problems (MBRRA, 2004). Algal monitoring is a very useful tool in surveillance of harmful algal blooms and early warning for shellfish toxicity (Aune et al. 1995). Because of this, studies of phytoplankton in Manila Bay were either usually limited to the areas previously affected by toxic shellfish poisoning and fish kills or conducted in a short survey period–phytoplankton was included in the study as a support parameter in an attempt to prove or disprove the hypothesis. With the many changes in the ecosystem, there were claims that there is a decline in the phytoplankton population, but there are no concrete data to support this (Bidaure, 2009). Nonetheless, an investigation was made to know the extent of the phytoplankton population change. This information may lead to a cohesive understanding of the dynamics of the present marine environment. This study shall assess the changes and succession in phytoplankton community structure and correlate the results with the studies on the distribution of ichthyoplankton and spawning of *Sardinella* spp.

MATERIALS AND METHODS

Collection of phytoplankton samples was done in Manila Bay (lat. 14°53′ N, long. 120°76′ E) every two months starting January 2012 up to November 2015. Plankton net (ca. 20 µm mesh size, 30cm mouth diameter, 1m long) was vertically towed from surface waters down to 10m depth throughout the water column of the 16 established stations (Figure 8.1). Plankton samples were placed in Nalgene bottles, treated with 10% buffered seawater-formalin solution for its preservation and stored in a cooler on board prior to its analysis.

In the laboratory, the volume of samples was measured using a graduated cylinder. A 1 ml aliquot sample was taken for light microscopy using Sedgewick Rafter counting chamber. Quantitative and taxonomic analysis of phytoplankton was done using the method of Omura *et al.* (2012).

RESULTS

Phytoplankton population was composed of diatoms, dinoflagellates, and cyanobacteria (Figure 8.2). Diatoms dominated the phytoplankton community throughout the survey period. There were 15 families of dinoflagellates, 24 families of diatoms and 1 species of cyanobacteria (Table 8.1). *Thalassiosira* sp., *Skeletonema* spp. and *Chaetoceros* spp., were the most dominant species among the diatoms while *Ceratium* spp., *Protoperidinium* sp. and *Noctiluca scintillans* dominated the dinoflagellates population. *Trichodesmium* spp. also occurred in densities high enough to be included in the list of 10 most dominant species (Figure 8.3). Relative abundance of all species from 2012 to 2015 are shown in Table 8.1.

By and large, phytoplankton was most dense during the southwest monsoon (July and September) (Figure 8.4). On the other hand, the

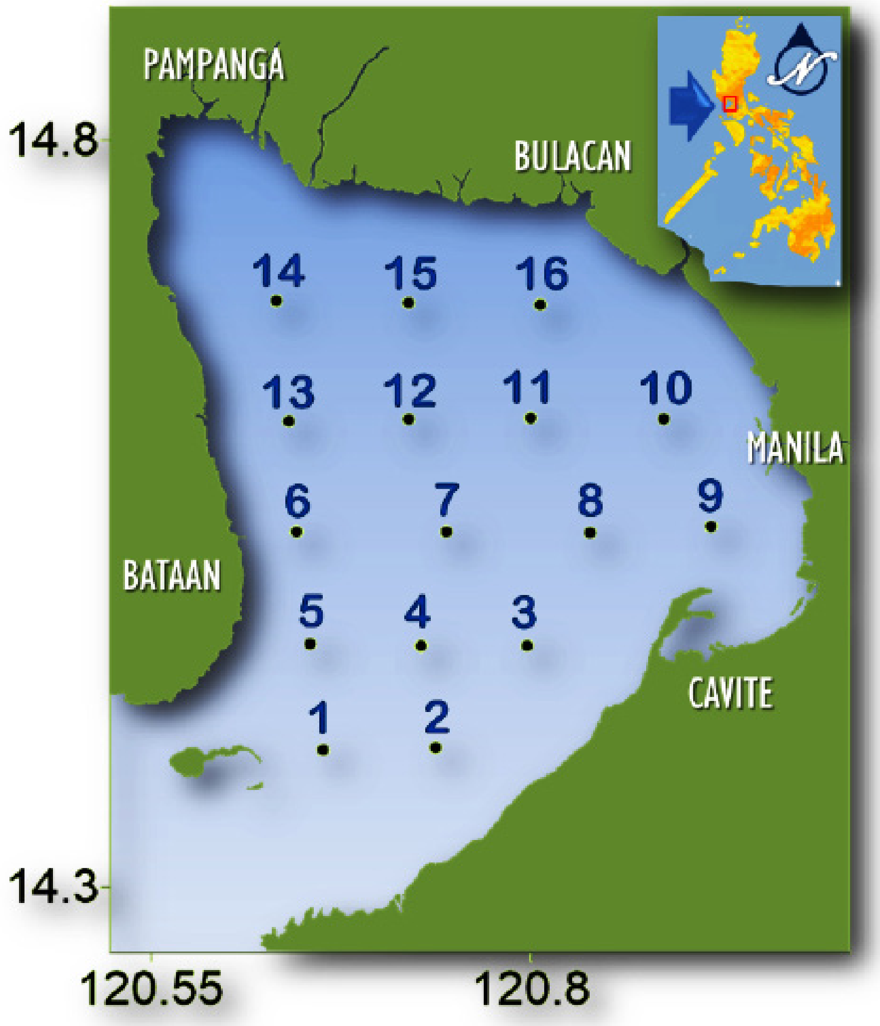

Figure 8.1. Sampling stations for hydrobiological surveys in Manila Bay (2012-2015)

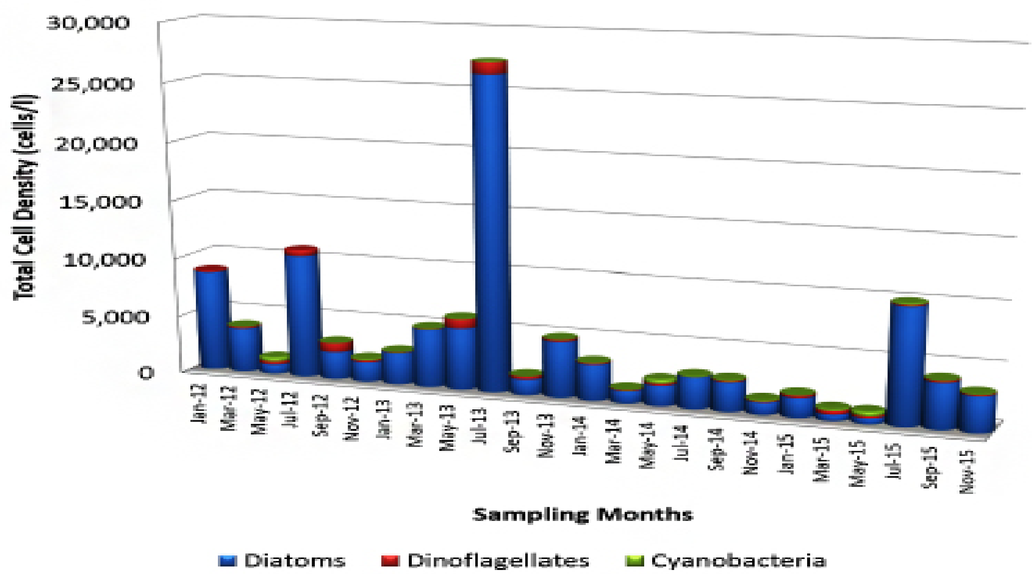

Figure 8.2. Densities of Diatoms, Dinoflagellates and Cyanobacteria in Manila Bay (2012-2015)

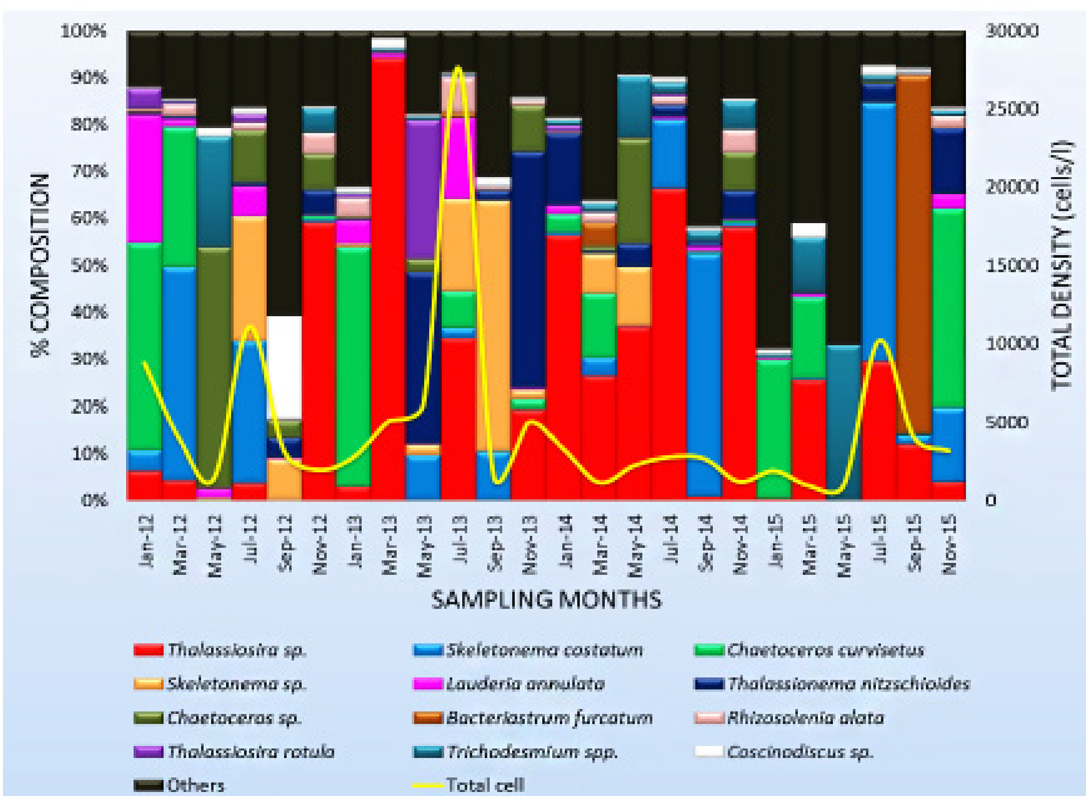

Figure 8.3. Twelve most dominant phytoplankton species found in Manila Bay (2012-2015)

Table 8.1. List of phytoplankton identified in Manila Bay 2012-2015. (a) Diatoms; (b) Dinoflagellates and Cyanobacteria

Family	Species	Family	Species
DIATOMS			
Asterolampraceae	*Asterolampra sp.*	Hemiaulaceae	*Climacodium frauenfeldianum*
Bacillariaceae	*Bacillaria paxillifera*		*Eucampia sp.*
	Nitzschia sp.		*Hemiaulus hauckii*
	Pseudo-nitzschia sp.		*Hemiaulus indicus*
Catenulaceae	*Amphora sp.*		*Hemiaulus membranaceus*
Chaetocerotaceae	*Bacteriastrum delicatulum*		*Hemiaulus sinensis*
	Bacteriastrum elongatum		*Hemiaulus sp.*
	Bacteriastrum furcatum	Hydrodictyaceae	*Pediastrum sp.*
	Bacteriastrum hyalinum	Lauderiaceae	*Lauderia annulata*
	Bacteriastrum sp.		*Lauderia sp.*
	Chaetoceros castracanei	Leptocylindraceae	*Leptocylindrus sp.*
	Chaetoceros coarctatus	Lithodesmiaceae	*Ditylum brightwellii*
	Chaetoceros compressus		*Ditylum sol*
	Chaetoceros constrictus	Naviculaceae	*Navicula sp.*
	Chaetoceros convolutus	Pleurosigmataceae	*Pleurosigma sp.*
	Chaetoceros costatus	Rhizosoleniaceae	*Dactyliosolen fragilissimus*
	Chaetoceros curvisetus		*Dactyliosolen phuketensis*
	Chaetoceros debilis		*Guinardia cylindrus*
	Chaetoceros decipiens		*Guinardia striata*
	Chaetoceros didymus		*Rhizosolenia alata*
	Chaetoceros laevis		*Rhizosolenia cylindrus*
	Chaetoceros pseudocurvisetus		*Rhizosolenia hebetata*
	Chaetoceros sp.		*Rhizosolenia imbricata*
Cocconeidaceae	*Cocconeis sp.*		*Rhizosolenia robusta*
Corethraceae	*Corethron sp.*		*Rhizosolenia setigera*
Coscinodiscaceae	*Coscinodiscus granii*		*Rhizosolenia simplex*
	Coscinodiscus sp.		*Rhizosolenia sp.*
Dictyochaceae	*Dictyocha fibula*		*Rhizosolenia styliformes*
	Dictyocha speculum	Skeletonemataceae	*Skeletonema costatum*
Eupodiscaceae	*Odontella aurita*		*Skeletonema sp.*
	Odontella longicruris	Stephanopyxidaceae	*Stephanopyxis sp.*
	Odontella mobiliensis		*Streptotheca tamesis*
	Odontella sinensis	Thalassionemataceae	*Thalassionema frauenfeldii*
Fragilariaceae	*Asterionella gracialis*		*Thalassionema nitzschioides*
	Asterionella japonica	Thalassiosiraceae	*Thalassiosira mala*
			Thalassiosira rotula
			Thalassiosira sp.

Family	Species	Family	Species
DINOFLAGELLATES			
Ceratiaceae	*Ceratium biceps*	Gymnodiniaceae	*Gymnodinium sanguineum*
	Ceratium boehmii	Noctilucaceae	*Noctiluca scintillans*
	Ceratium breve	Oxytoxaceae	*Oxytoxum elegans*
	Ceratium declinatum		*Oxytoxum scolopax*
	Ceratium deflexum	Podolampadaceae	*Podolampas bipes*
	Ceratium dens		*Podolampas elegans*
	Ceratium falcatiforme		*Podolampas spinifera*
	Ceratium falcatum	Prorocentraceae	*Prorocentrum gracile*
	Ceratium furca		*Prorocentrum micans*
	Ceratium fusus		*Prorocentrum sigmoides*
	Ceratium humile	Protoperidiniaceae	*Protoperidinium claudicans*
	Ceratium inflatum		*Protoperidinium compressum*
	Ceratium macroceros		*Protoperidinium crassipes*
	Ceratium massiliense		*Protoperidinium denticulatum*
	Ceratium teres		*Protoperidinium depressum*
	Ceratium trichoceros		*Protoperidinium divergens*
	Ceratium tripos		*Protoperidinium mite*
	Ceratium vultur		*Protoperidinium oceanicum*
Dictyochophyceae	*Dictyocha fibula*		*Protoperidinium pallidum*
	Dictyocha speculum		*Protoperidinium pentagonum*
Dinophysiaceae	*Dinophysis caudata*		*Protoperidinium pyriforme*
	Dinophysis hastata		*Protoperidinium quinquecorne*
	Dinophysis miles		*Protoperidinium sp.*
	Dinophysis ovata		*Protoperidinium steinii*
	Dinophysis rotundata	Pyrocystaceae	*Pyrocystis fusiformis*
	Ornithocercus magnificus		*Pyrocystis sp.*
	Ornithocercus steinii	Pyrophacaceae	*Pyrophacus horologium*
Goniodomataceae	*Alexandrium spp.*		*Pyrophacus steinii*
	Alexandrium tamiyavanichii		
	Goniodoma polyedricum	**CYANOBACTERIA**	
Gonyaulacaceae	*Gonyaulax digitalis*	Microcoleaceae	*Trichodesmium spp.*
	Gonyaulax jollifei		
	Gonyaulax spinifera		

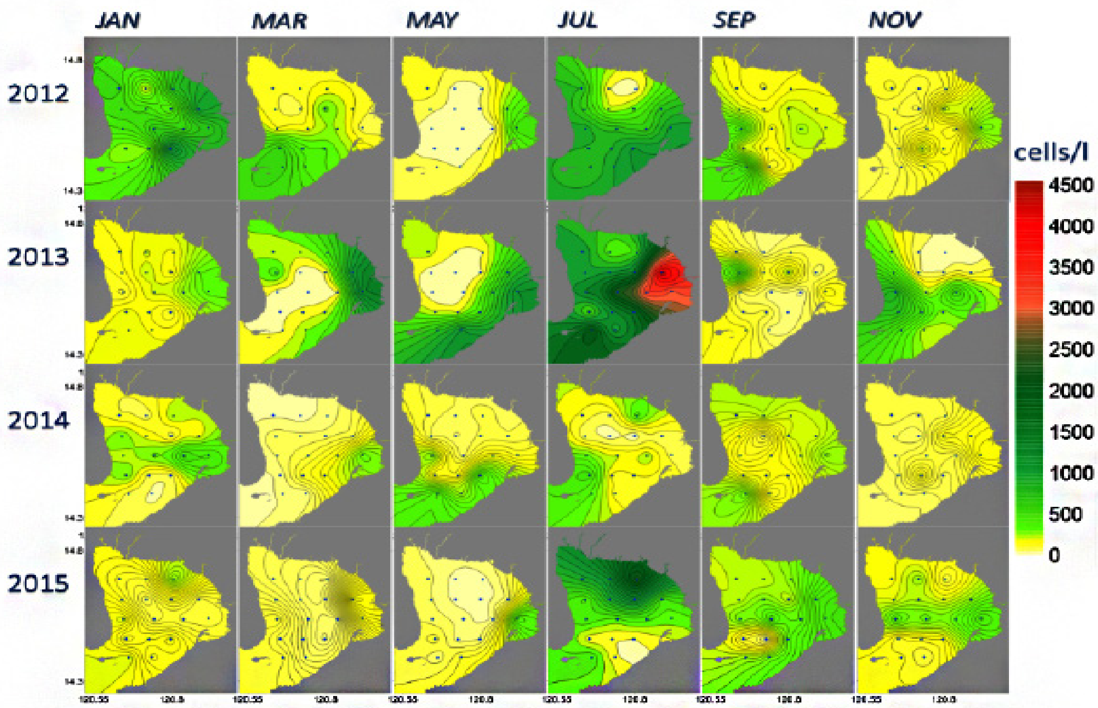

Figure 8.4. Spatiotemporal abundance of phytoplankton in Manila Bay (2012-2015)

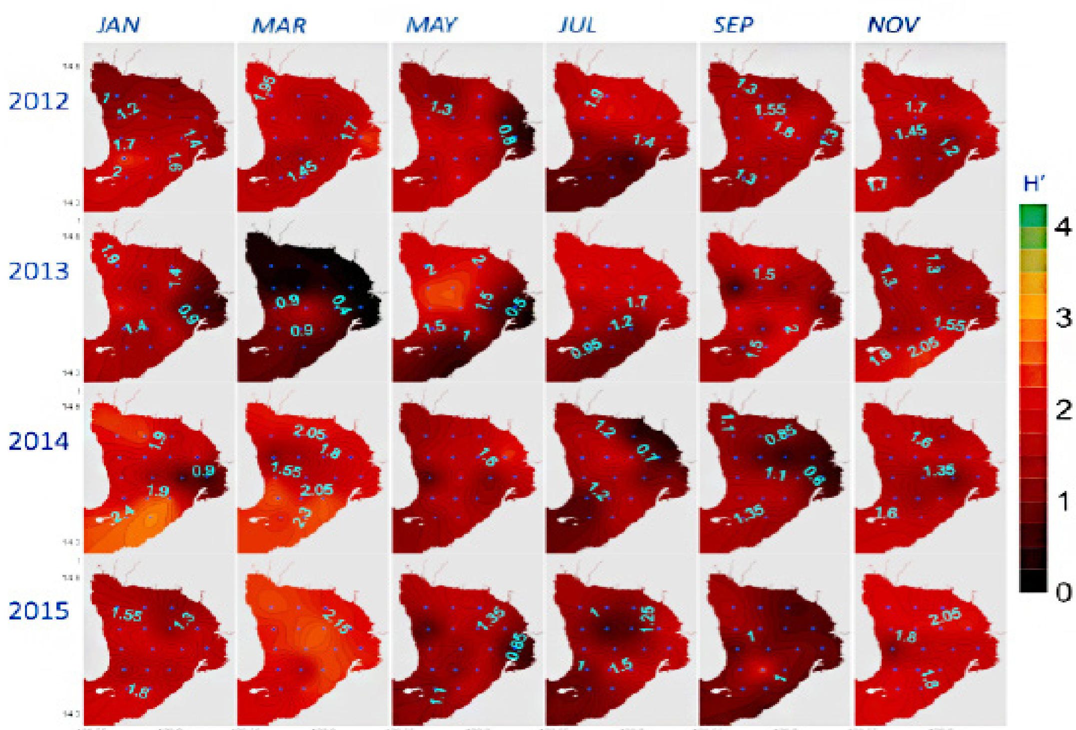

Figure 8.5. Spatiotemporal diversity index (H′) of phytoplankton in Manila Bay (2012-2015)

density of dinoflagellates and cyanobacteria increased during tradewinds or Southeast (SE) Monsoon. The highest record of phytoplankton abundance was observed in July 2013 while the lowest was recorded in March 2015.

The coast of Manila Bay was where phytoplankton often abounds. It is usually observed in the eastern portion of the bay at Manila area which characteristically had the highest phytoplankton concentrations (Figure 8.4). These accumulations seemed to 'flush out' into the mouth of the bay located in the southwestern side on the succeeding months of sample collections. This could be the effect of the double-gyre horizontal water circulation system in Manila Bay located on the western side and eastern side (Yniquez *et al*., 2000). Aggregations on the northern portion of the bay were rare.

Phytoplankton communities were typically more diverse in the northwestern, western and southeastern parts of the bay (Figure 8.5). The lowest diversity was recorded on March 2013 while the highest was on March 2015. November had the most fairly moderate diversity (0.9 – 2.3) albeit the inconsistencies at what portions of the bay these occur. The phytoplankton species diversity indices (Shannon-Weiner Index) measured in the bay within the span of four years (2012 – 2015) ranged from 0.1 to 2.8, an indication that the bay has a low to moderate species diversity.

DISCUSSION

The identified phytoplankton species from this study is lower compared to the 61 genera that were identified by Bidaure in the same bay (1999). The result of the phytoplankton composition and dominant species echo the results of Azanza and Miranda (2001). However, in the present study, *Coscinodiscus* sp. was bumped into the last place by *Lauderia annulata, Thalassionema nitzschioides, Chaetoceros sp., Bacteriastrum furcatum, Rhizosolenia alata, Thalassiosira rotula*, and *Trichodesmium* spp. (Figure 8.3) in terms of total abundance for the whole duration of the survey. Although species known to cause harmful algal bloom were present (*Alexandrium tamiyavanichii, Noctiluca scintillans, Dinophysis* spp., *Nitzschia* spp.), their densities did not reach densities high enough to cause an alarm. However, a short-lived bloom of red *Noctiluca scintillans* was observed on January 2014 at the eastern portion of the bay. The appearance of red *N. scintillans* coincided with the coldest temperature (17.66°C) recorded during the survey. *Trichodesmium* spp. is a cyanobacterium known to form blooms which cause fish mortality. Several species possess neurotoxin similar to anatoxin-a (Rorig et.al. 1997). Thus, this species should be kept in check.

It can be said that the prevalence of dinoflagellates during tradewinds or SE monsoon is an indication that they thrive in warmer water temperature. However, during an exceptionally hot water surface temperature of 35.59°C in May 2014 (Sy *et al*., unpublished, also included in this chapter), dinoflagellates community were relatively lower. Perhaps the temperature exceeded the required optimum for most of the dinoflagellates' growth as in the laboratory experiment conducted by Boyd *et al*. (2013), where the maximum tolerated temperature of the dinoflagellates, *A. sanguinea,* is only 35°C while *P. donghaiense* is only 30°C. Even though the phytoplankton exhibited thermal adaptation in the study of Padfield *et al*. (2012), it took about 10 generations of culture before the phytoplankton finally adapted to the temperature increase. In this regard, the abrupt increase in the water temperature may also have triggered the decrease in the population.

No remarkable values of temperature, salinity, dissolved oxygen (DO), silicates, chlorophyll-*a* and nutrients in July 2013 to explain the extraordinary increase in the phytoplankton density (Vergara *et al*., unpublished, also included in this chapter). In fact, the abundance may even be the culprit for the dissolved oxygen depletion in the water column since it recorded the lowest DO value for the said year. Afterall, phytoplankton can also modify the aspects of its physical environment (Jenkinson and Wyatt, 1993).

Interestingly, the study of Harvey et al. (2012) about the fleeing behaviors of phytoplankton away from predators seemed to be one of the factors for the phytoplankton distribution when the occurrence of the zooplankton and fish larvae is factored in. Phytoplankton was observed to be usually abundant at the opposite side of the adjacent portion of the bay where zooplankton and fish larvae are distributed (Jose, *et al*., and Tobias *et al*., unpublished, also included in this chapter). This perspective might explain the intermittent pattern in the phytoplankton distribution even though the physicochemical parameters of the bay was relatively consistent with the seasons.

Obviously, the possibility of prey-predator factor cannot also be discounted on this especially since phytoplankton diet provides the reserve material needs of the highly opportunistic feeder, sardines (Garrido and van der Lingen, 2014). The decrease in the density of the phytoplankton was observed to correspond with the major peak of the spawning seasons of *Sardinella gibbosa* from October to December and *Sardinella fimbriata* from October to December and February (Bendaño, 2016). There was also a drop in the density during the minor peaks in March, April, and August for *S. gibbosa* and from May to June for *S. fimbriata*. It appears that *S. gibbosa* is a more voracious eater than *S. fimbriata* because phytoplankton density can recover more easily after the minor peak of the latter. Needless to say, although the spawning of these species occurs all year round, the peak for spawning appears to commence at the height of the phytoplankton population. Unfortunately, the survey periods for phytoplankton sampling did not cover the exact months of the spawning peak of these two species to be able to infer the relationship.

Species diversity indices are also a good indicator of pollution in the aquatic ecosystem. Diversity index value greater than 3.00 indicates clean water. Values in the range of 1.00 to 3.00 are characteristics of moderately polluted water and values less than 1.00 characterize heavily deteriorated condition (Mason, 1998). With the recorded diversity index value ranges of 0.1 to 2.8, Manila bay can be classified as moderately heavy to heavily polluted. Diversity is better during northeast monsoon though especially just before the onset of tradewinds.

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