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Spatio-Temporal Variability of Hypoxia and Eutrophication in Manila Bay During the Northeast and Southwest Monsoons from 2012 to 2015

Angelica Gabrielle A. Sy[1], Marvin L. Tobias[1], Valeriano M. Borja[1],
Norvida C. Gatdula[1] , Mudjekeewis D. Santos[2] , and Elsa F. Furio[1*]

[1]*Aquatic Ecology Section*
[2]*Vertebrate Section*
Capture Fisheries Research and Development Division
National Fisheries Research and Development Institute

*Corresponding Author: efurio2010@yahoo.com

Abstract

Manila Bay is a major source of livelihood for the fishermen living around the area. The occurrence of hypoxia, a state where dissolved oxygen (DO) is not enough to support marine life, poses a serious threat to the bay and consequently to its fisheries sector. This study documents the variation of hypoxia throughout the bay for a sampling period of four years, from January 2012 to November 2015, with a monthly interval each survey. A total of 24 field surveys on 16 designated sampling stations, at varying depths, were conducted. Results show that hypoxia was present all year round but was more severe during the wet season (July, September, November) compared to the dry season. The averages of bay-wide DO concentration ranged from 3.42 to 7.63mg/l during the 4-year survey. Low DO concentrations were associated with high concentrations of nutrients, particularly nitrate. Nitrate spiked to a 44.6 μM concentration while bay-wide DO concentration dropped to as low as 0.01 mg/l in the wet season. An occurrence of hypoxia along the coasts, transitioning from western, northern and eastern areas, was observed as a common trend for all surveys. However, DO concentrations in areas near the coast, in depths around 5m to 15m, and in the deeper areas near the mouth of the bay, from around 10m to 35m depths were noted to be lower. In conclusion, hypoxia has been occurring year-round in Manila Bay with varying intensity but more prominent during the wet season.

Keywords: Manila bay, hypoxia, eutrophication, dissolved oxygen

INTRODUCTION

Manila Bay, located at the southwest portion of Luzon, is a semi-enclosed estuary that is linked to the West Philippine Sea. It is a recipient of about 17,000 km^2 of watershed made up of 26 catchment areas (PEMSEA, 2001). Economic activities around the coast of Manila Bay include agriculture, fisheries, aquaculture, and industrial. Fisheries is one of the major livelihood sources in the Philippines. It provides livelihood to about 5% of the Philippines' total labor force (Barut et al., 2004). The occurrence of hypoxia will cause fish kills and lead to the formation of dead zones in the sea where very little marine life could survive.

Hypoxia and anoxia, or the presence of low to none dissolved oxygen (DO), has been a recurring problem in coastal and marine waters throughout the world (Diaz and Rosenberg, 2008). These occurrences are a serious threat in the maintenance of high-value fisheries of the affected coastal ecosystems. Of the fishing grounds in the Philippines, Manila Bay is said to be among those already experiencing hypoxia as confirmed by previous studies (Chang *et al*., 2009; Jacinto *et al*., 2011; Sotto *et al*., 2014). Hypoxia was attributed to the increased nutrient loading or eutrophication in the bay (Jacinto *et al*., 2011).

Hypoxia is a state wherein the level of DO, an aspect of the marine ecosystem that is important for marine life sustainability, drops to a low enough concentration causing conditions that can be detrimental to both the marine ecosystem and aquatic organisms (NSTC, 2003). In the Philippines, the Department of Environment and Natural Resources ((DENR) has provided basis for appraising some of the water qualities. Manila Bay has been classified as under Class SB (DENR, 1990). Thus for this study, hypoxia is defined as DO falling to <5 mg/l, the set required minimum value of DO for Class SB waters, as mandated by the DENR Administration Order No. 34, Series 1990.

A typical hypoxic condition can be detrimental to both the marine ecosystem and aquatic organisms by causing physiological stress and worse, even death (NSTC, 2003). Many factors contribute to hypoxia. One of which is the eutrophication or "nutrients over-enrichment" of coastal ecosystems. Nutrients are essential to marine life but too much of these lead to eutrophication, an occurrence that poses a problem to the marine ecosystem. Eutrophication may lead to phytoplankton blooms or, worse, harmful algal blooms. These initially affects the dissolved oxygen levels in the bay and then eventually on the organisms and the environment itself (PEMSEA, 2001).

Previous studies on hypoxia in Manila Bay during the northeast (February 2010 and February 2011) and southwest monsoon (July 2010, August 2011, August 2012) had been conducted (Sotto *et al*., 2014). For this study, a total of 24 surveys were conducted, covering the northeast monsoon (January and November 2012, 2013, 2014 & 2015), southeast monsoon (March and May 2012, 2013, 2014 & 2015) and southwest monsoon (July and September 2012, 2013, 2014 and 2015).

This study aims to document the occurrence of hypoxia in Manila Bay at varying depth and time. Included are the effects of seasons, monsoons and parameters such as salinity and temperature in the occurrence of hypoxia in the bay. This study also serves as an evaluation tool for the correlation of hypoxia and eutrophication in the bay. This will serve as a basis for further studies to help monitor and revitalize the aquatic resources of Manila Bay.

MATERIALS AND METHODS

On-site Survey and Field Collection

The investigations were carried out in Manila Bay for four years with six survey months every year (January 2012, March 2012, May 2012, July 2012, September 2012, November 2012; 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, September 2015, November 2015, December 2015). A total of 16 transect stations (Figure 11.1) were sampled every field survey. DO profiling was done using the SBE 19 multi-parameter vertical profiler throughout the water column in each station. Other physical parameters of the water (depth, temperature, salinity) were also measured using the same equipment. The water samples for the inorganic nutrient content (nitrate, nitrite, phosphate, and silicate) analysis were collected using a 2.5-L Niskin

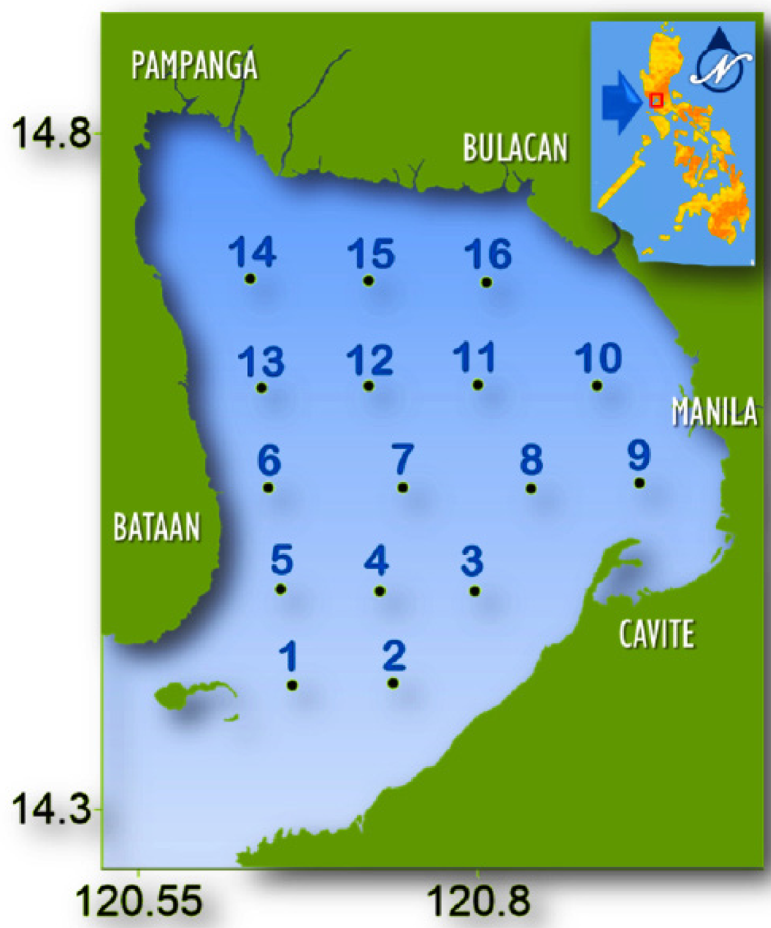


Figure 11.1. Manila Bay Sampling Stations

bottle from various depths (surface (S), middle (M), and bottom (B) (Figure 11.2) of each station. The water samples were filtered through a 0.45 µm membrane disc filter and kept frozen until further analysis.

Laboratory Analysis

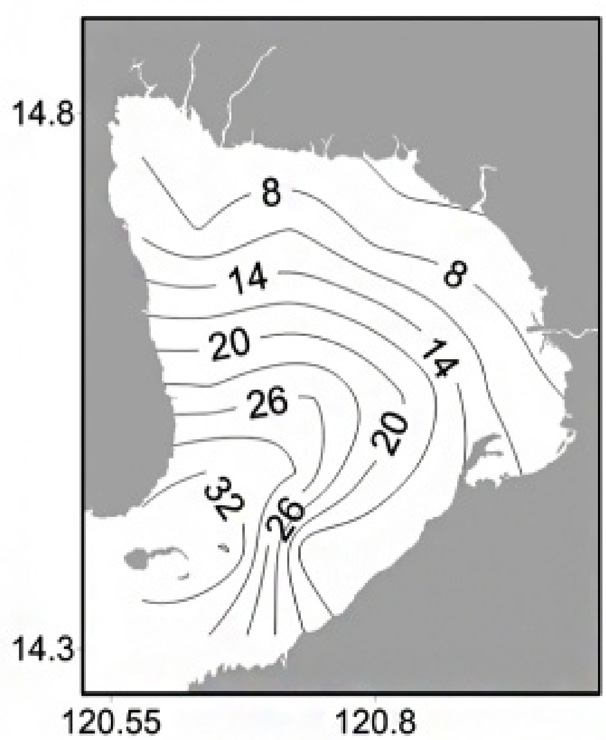
The inorganic nutrient content of the water samples was measured spectrophotometrically (Parsons et al., 1984). The contour maps of the different parameters were generated using the Golden Software 11 (Golden Software Inc., 2012). The IBM SPSS Statistics 21 software was used to analyze was used to analyze the gathered data.

RESULTS

Hypoxia

2012

In 2012, the surface water of Manila Bay was highly oxygenated. Surface DO ranged from 4.61 - 9.77 mg/l and averaged to 6.52 mg/l. The distribution of DO in the surface water of the bay varied, with slightly higher values in the western and northern areas of the bay. Dropping DO concentration was observed from the middle depth onwards (Figure 11.3). Very low DO concentration, referred to as hypoxia, was predominant, especially in the month of September, in the



	Middle	Bottom
Station	Average Depth (m)	
1	18	35
2	7	14
3	10	19
4	15	29
5	17	32
6	12	24
7	13	26
8	10	19
9	5	10
10	5	10
11	8	15
12	9	18
13	8	17
14	4	8
15	6	11
16	3	6

Figure 11.2. (a) Map of the depth (in meters) of the bottom layer of Manila Bay; (b) Average middle and bottom depths (in meters) of the Manila Bay survey stations

northern areas of the bay, near the coasts of Pampanga, Bulacan, and Manila. Values dropped to as low as 0.687 mg/l for the middle depth. Hypoxic conditions became more pronounced in the bottom depth, with DO concentrations ranging from 0.328 mg/l to 5.46 mg/l and averaging to 2.36 mg/l. Bottom hypoxia was most intense in September. Hypoxia was observed in the western, eastern and northern parts of the bay near the coast extending up to the middle of the bay. Low bottom DO concentrations were common near the coast for all surveys. Hypoxia was least observed in July but the same DO concentration distribution pattern was observed. DO concentrations for the 2012 surface layer were higher near the mouth of the bay for the dry season (January, March, and May). Hypoxic conditions occurred near the coast of Bataan, Manila, and Cavite (east and northeast area) for the dry season. Generally, all the 20 m and 30 m deep water were hypoxic. Values ranged from 5.30 mg/l to as low as 0.332 mg/l (Figure 11.3).

2013

The surface layer of Manila Bay in the dry season of 2013 had DO values above the criteria value of <5 mg/l. Unlike that of 2012, low DO was present in the surface layer during the wet season (July, September, and November). DO concentrations were lowest near Pampanga for July, near Bataan and Cavite for September and lowest in Manila and Bulacan areas for November. Hypoxia was observed throughout the bay for all depths during the wet season of 2013. All monthly minimum values were far below the criteria level of 5 mg/l and the highest attained maximum value was 8.46 mg/l. The following averages for January, March, May, July, September, and November were 4.47, 4.86, 4.17, 2.91, 2.99, 2.03 mg/l, respectively. While the ranges for the same months were 0.45 - 7.38 mg/l, 0.61 – 7.91 mg/l, 0.30 – 8.44 mg/l, 0.082 – 7.74 mg/l, 0.85 – 5.83 mg/l and 0.34 – 3.91 mg/l , respectively (Figure 11.4).

2014

Surface DO concentrations were above the criteria value for the January, September and November 2014 surveys, with averages of 8.12 mg/l, 6.94 mg/l, and 7.01 mg/l, respectively (Figure 11.5). Surface DO for March, May, and July fell slightly below the critical value with the lowest DO concentration near the mouth of the bay for March and in the north to the west and southwest areas of Manila Bay for May and June. DO concentrations for January were homogeneously distributed in the water column, with a gradual decreasing pattern. It ranged from 4.55 mg/l to 9.76 mg/l with an average of 7.63 mg/l. March DO concentrations were relatively lower compared to the January survey. Higher concentrations were recorded near the mouth of the bay particularly the bottom layer with the highest DO value of 7.75 mg/l from the said layer for this month. For the May (average: 3.42 mg/l) and July (average: 3.79 mg/l) surveys, the DO concentrations were generally below the criteria value of <5 mg/l throughout the bay regardless of depth. The range of values decreased with depth, however. This was a general trend throughout the year.

DO concentrations were lowest in the west to the center of the bay and for the middle and bottom depth layers. DO values reached as low as 0.02 mg/l for the bottom layer of all sampling stations. September and November DO distribution had similar patterns of hypoxic areas from the middle to the western and mouth part of the bay, though the September profile had more widespread hypoxia, particularly in the bottom layer. The average bottom DO values of 2.88 mg/l for September and 4.21 mg/l for November were recorded.

Figure 11.3. 2012 Dissolved Oxygen Profile of Manila Bay

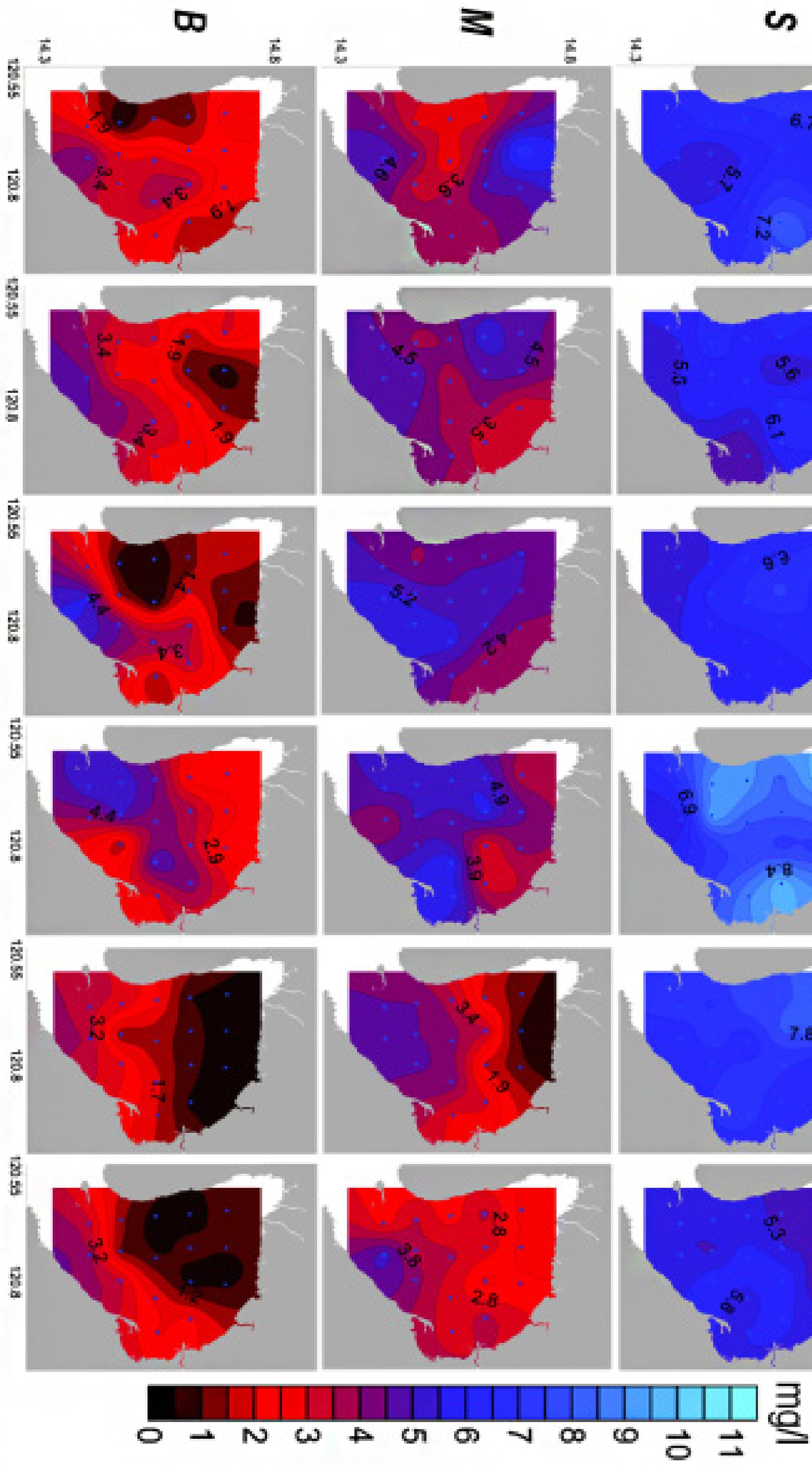
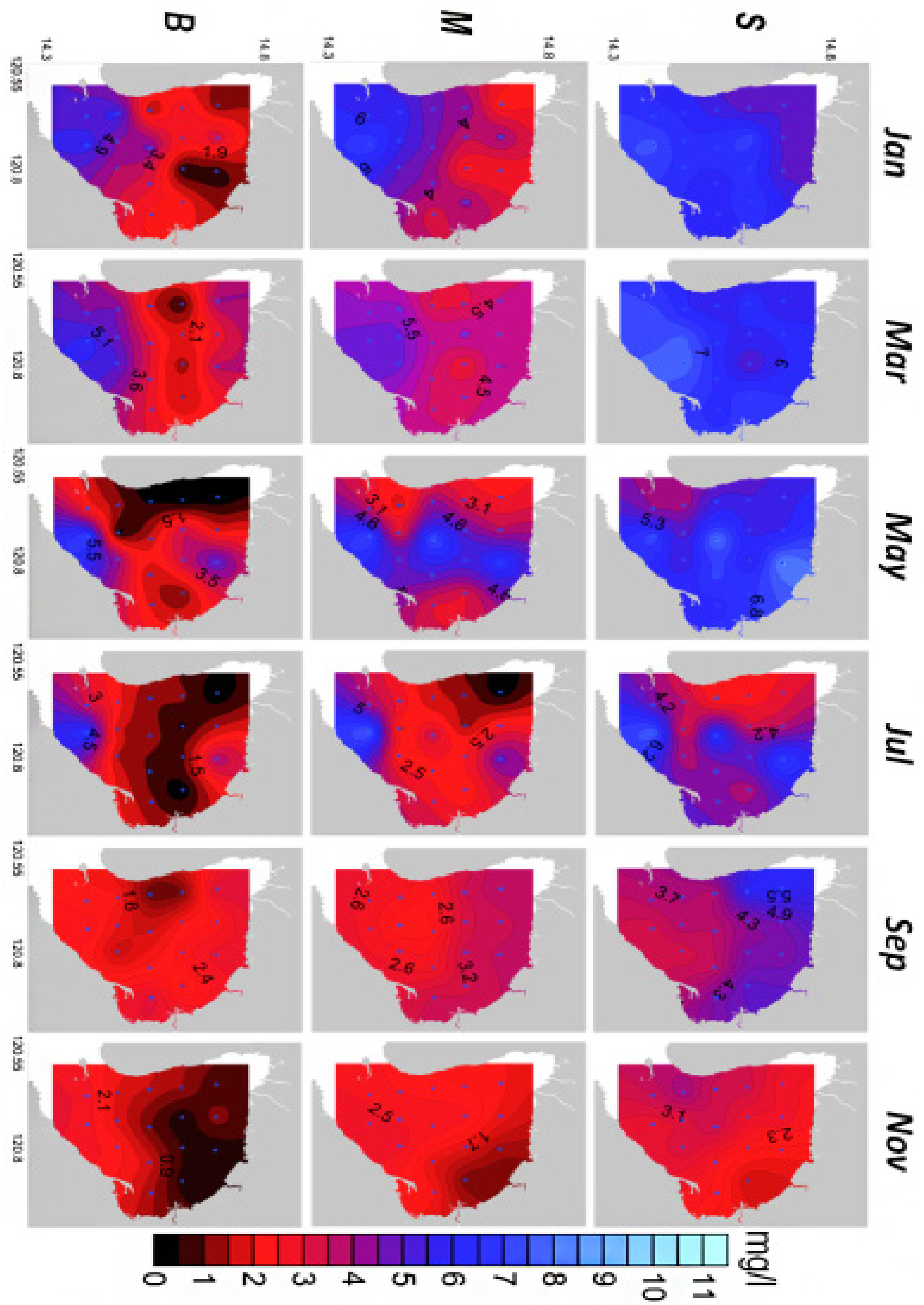


Figure 11.4. 2013 Dissolved Oxygen Profile of Manila Bay



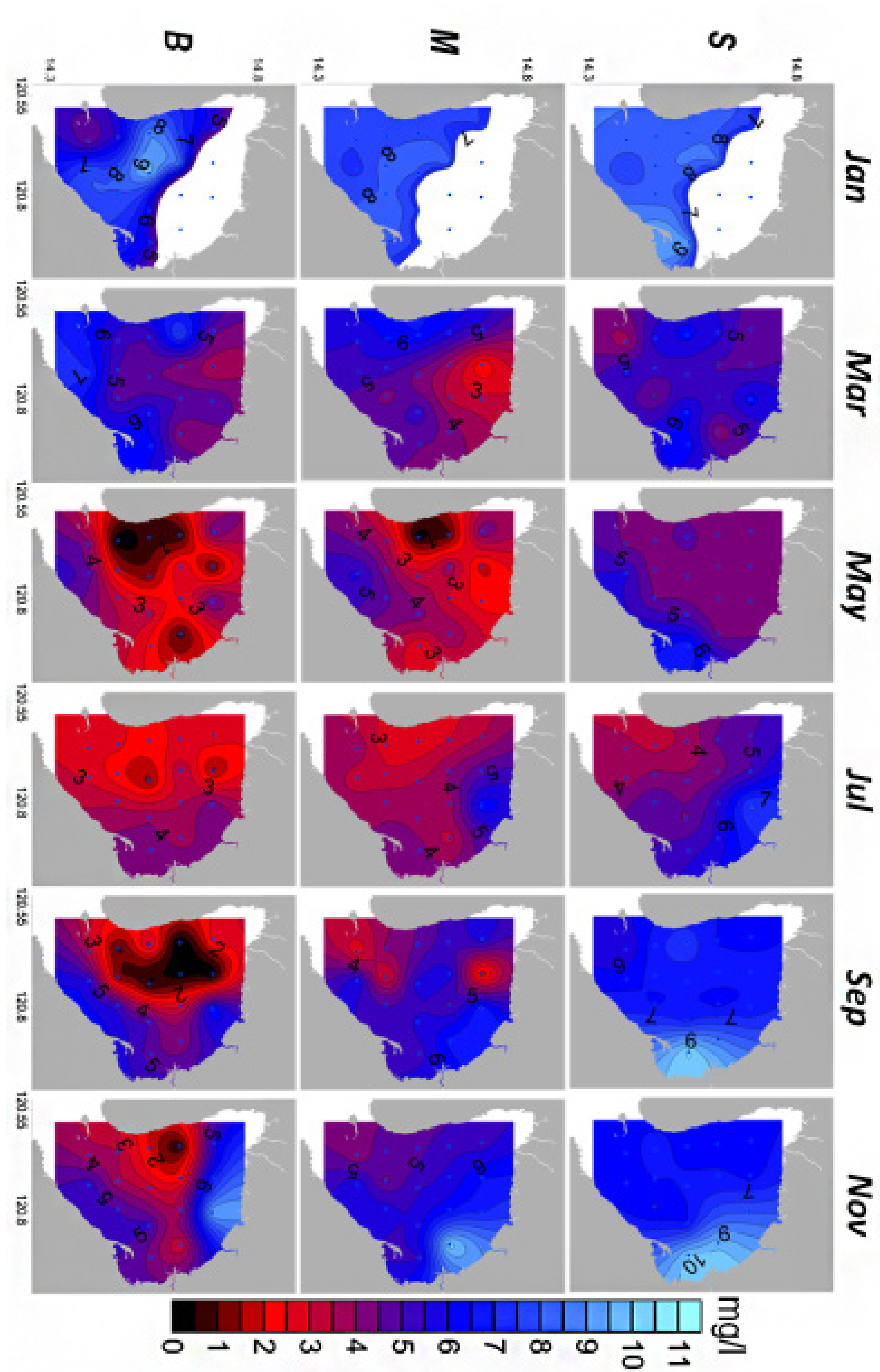


Figure 11.5. 2014 Dissolved Oxygen Profile of manila Bay

2015

Similar to the 2014 DO profile of Manila Bay, in 2015, the hypoxic areas concentrated in the west passing through the middle and northern parts of the bay (Figure 11.6). Near-bottom DO also concentrated in the west spreading to the middle part of the bay, as observed in every survey. The surface DO for 2015 in Manila Bay averaged to 6.16 mg/l with the lowest surface average being 5.82 mg/l, recorded in May, and the highest being 6.78 mg/l, recorded in September. Similar to the previous years, the surface of the bay was very well oxygenated year-round for 2015. The decrease in DO concentration in the middle layer was observed. Unlike the other survey months, the drop of DO concentration in the middle layer was very pronounced in September, particularly in the western side of the bay near the Bataan coast. The middle DO concentrations for the other months were only slightly lower compared to the concentrations in the surface layer.

DO concentrations dropped further in the near-bottom layer of the bay. Near bottom DO values ranged from 0.86-8.38 mg/l, 1.39-5.98 mg/l, 1.34-5.32 mg/l, 0.12-10.97 mg/l, and 0.59-7.44 mg/l in the months of January, March, May, September, and November, respectively. The minimum DO concentration of 0.12 mg/l for the 2015 surveys was recorded in the near-bottom layer of September and the maximum value in the surface layer of the same month. Of the near bottom layers, low DO concentrations were more widespread in May and September.

Table 11 .1. Water Quality Criteria Values (Department of Environment and Natural Resources (DENR) Administrative Order (DAO) No. 34 (Series of 1990) (DENR 1995))

Parameters	Criteria Values
Dissolved Oxygen	<5 mg/l
Nitrate – N	4.29 μM
Nitrite – N	3.95 μM
Phosphate – P	0.48 μM
Silicate – Si	-

Generally, the lower DO concentrations for January and March were near the coast of Cavite; bay-wide for May; and near the coast of Bataan for September and November. Bay-wide averages of DO were lowest in May, September, and November with concentrations of 4.48 mg/l, 4.46 mg/l, and 4.94 mg/l, respectively. The lowest recorded DO, 0.12 mg/l, was from the near-bottom layer of September. All minimum values were lower than the declared <5 mg/l critical level of dissolved oxygen. All survey months, however, had minimum DO values below the critical level. As a commonly observed trend, DO values dropped further in the near-bottom layers with a lower recorded DO in the west to the northern areas of Manila Bay for all months.

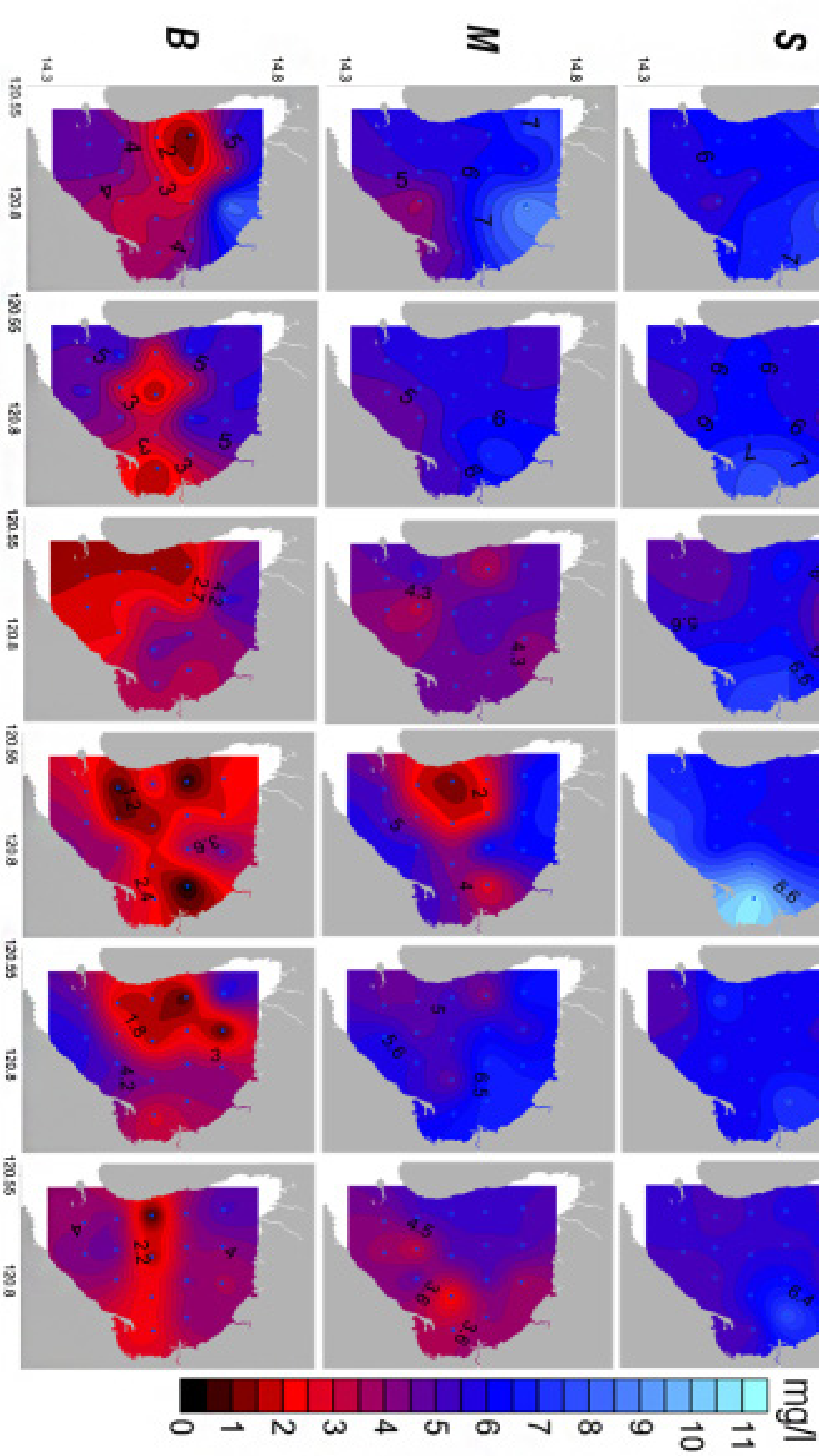
Nutrients

According to the study of Vergara *et al.* (included in this book), inorganic nutrients Bulacan, Manila, and Cavite areas with values even higher in deeper areas of the bay. Nitrate abundance was bay-wide, horizontally and vertically, and was highest in the northern part of the bay. In most areas, the Nitrate concentration exceeded the criteria value for pollution of 4.29 μM (Table 11.1) as set by the Association of Southeast Asian Nations (ASEAN) (McGlone *et al.*, 2004). Nitrite concentration did not exceed these criteria value for pollution, but was considerably high on the eastern side of the bay, near the Metro Manila area. The same pattern was also observed for the nutrient Phosphate, which did not reach its criteria value. Silicate concentrations were lower during the dry season compared to the wet season. Spatially, the Silicate concentration was higher in the northern part of the bay.

Temperature

The temperature ranged from 24°C to 34°C for field surveys of the year 2012 to 2015 (Figure 11.7). Except that of 2015, the highest

Figure 11.6 2015 Dissolved Oxygen Profile of manila Bay.



temperature was consistently observed during the month of May, particularly in the surface layer. The temperature in May was consistently observed to be decreasing with the increase in depth. The 2012 and 2015 temperature vertical profiles converge to a cooler temperature in the deeper depths (>20 m). The 2012 and 2015 temperature plots were closer to one another unlike those of 2013 and 2014. Temperatures of the 2013 and 2014 survey months were too dynamic compared to the 2012 and 2015 survey months. 2014 Manila Bay surface temperature ranged from 24°C to 34°C. The 2014 temperature vertical profiles (24°C to 32°C) showed greater variation even below the surface. The temperature vertical profiles of Manila Bay showed a warmer surface and a slightly cooler bottom.

Salinity

Salinity profiles for July 2012, July 2013, September 2012, September 2013, November 2012, and November 2013, sampling months during the wet season, showed stratification in the water column (Figure 11.8). Whereas the sampling months during the dry season, January 2012, January 2013, March 2012, March 2013, May 2012, and May 2013 displayed a well-mixed water column. Salinity concentrations were observed to be lowest during September for both 2012 and 2013. Widest salinity range difference was observed for the September surveys as well. The 2014 salinity vertical profile was very dynamic as seen in the differences among the plots of the different survey months. Salinity concentration varied from one another with January and March lumping together at around 30 ppt; the May and July at around 27 to 28 ppt; and the November at around 31 to 33 ppt. As with previous years, the same observation can be said with the September 2014 plot. January and September 2015 showed stratification in the 5 m to the 15 m depths. Slight stratification can also be seen in July. May and July salinity concentrations were around 29 ppt while the rest of the survey months lumped at around 33 ppt.

DISCUSSION

Generally, no hypoxia was observed throughout the surface layer of the bay for the 2012 surveys. But low DO levels were observed in the middle section (~5 m to15 m depth) of the bay and in areas near the coast.

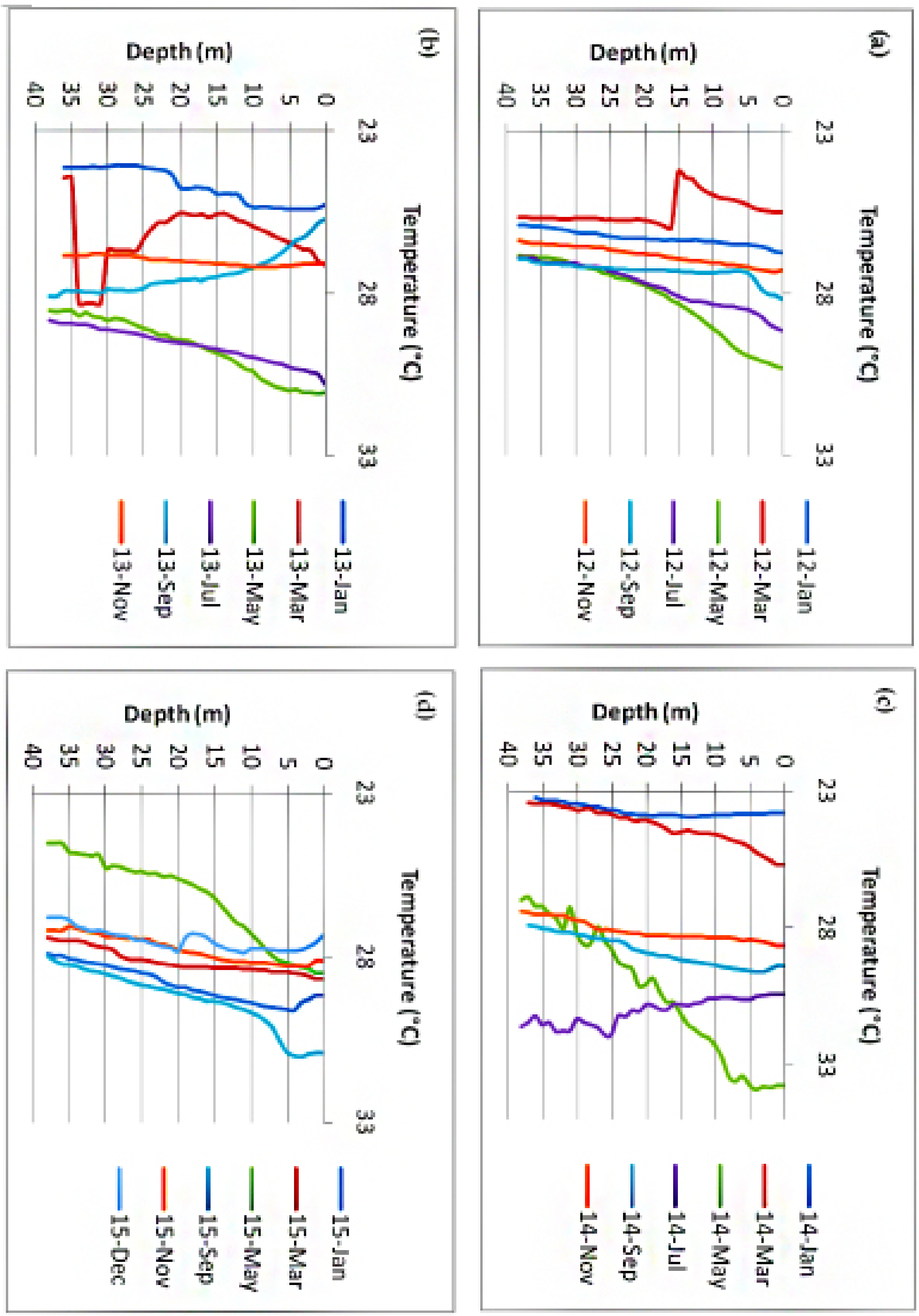
Hydrodynamic studies in Manila Bay revealed two major gyres (Siringan, 1998). These two gyres that converge in the middle can cause organic matter to accumulate and settle in the center of the bay and result to hypoxia because of the increase in oxygen demand for the organic matter decomposition (Siringan, 1998; Villanoy, 1997).

The midsection of the bay is relatively deep compared to other parts of the bay, according to Siringan *et al*. (1998) (as cited in Jacinto *et al*., 2011). Deeper waters have more water column stratification that hinders aeration of the bottom waters and the mixing of nutrients throughout the column. Low bottom DO and high bottom nitrate were found in the midsection of the bay.

Hypoxia is more widespread in stratified systems compared to vertically mixed systems. This is because of the limited downward movement of oxygen from the atmosphere due to stratification. Stratification also causes retention of nutrients in the photic zone, thus more growth of phytoplankton (Environmental Protection Agency, 2001).

In general, surface nutrient levels were higher in sampling stations along and near the coast. There was no over-enrichment of nitrite, phosphate, and silicate in the bay. Among the nutrients, nitrate concentration was observed to have far exceeded the set criteria value. Similar to the results of the study by Chang et al., (2009), Manila Bay is considered as highly eutrophicated with nitrogen species. The concentration of nitrate in the bay for this study is higher

Figure 11.7. (a) 2012, (b) 2013, (c) 2014, (d) 2015 Temperature Vertical Profile of Manila Bay



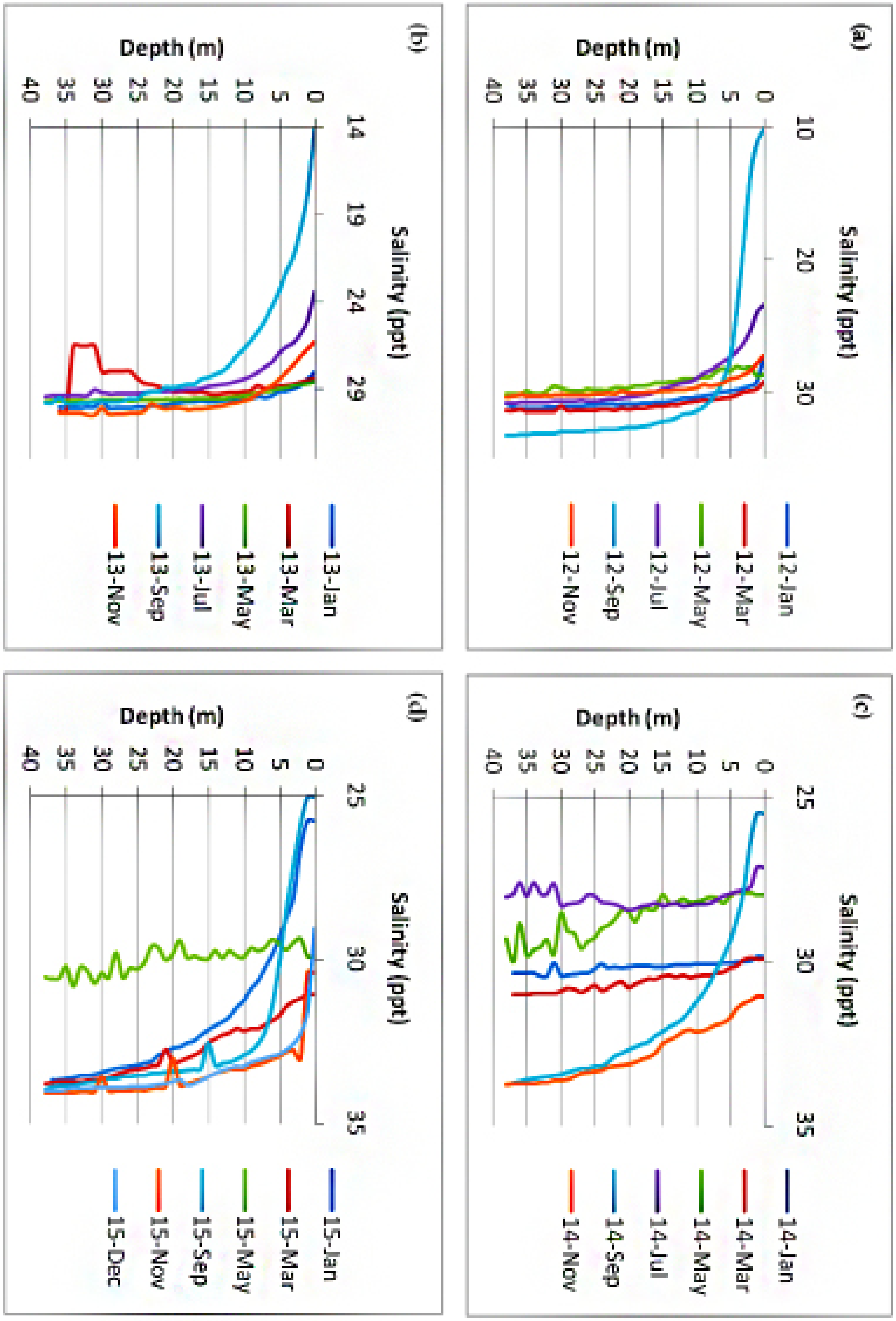


Figure 11.8. (a) 2012, (b) 2013, (c) 2014, (d) 2015 Salinity Vertical Profile of Manila Bay

compared to previous similar studies (Chang, *et al*., 2009; Jacinto, *et al*., 2011; Sotto, *et al*., 2014).

The variation in distribution and concentration of nutrients in the bay may be attributed to the difference in inflow from surrounding catchment areas and to the seasonal differences in nutrient cycling in the bay (Hayashi *et al*., 2006).

Nitrification is a major cause of DO depletion. Though other nutrients cannot be disregarded as reasons for eutrophication, nitrogen loading is the most common cause of estuarine eutrophic conditions (EPA, 2001). Nitrogen runoff is greatly affected by the activities, mainly agricultural and urban, caused by the increased population in the surrounding coast waters (NSTC, 2003).

The susceptibility of a body of water to hypoxia and eutrophication is affected by depth, freshwater inflow, tidal exchange, and variations in climate (NSTC, 2003). In this study, it was observed that DO is negatively correlated with depth, nutrient concentration, and salinity. DO has a moderately significant correlation with depth. Hypoxia in Manila Bay is also affected by season and eutrophication, particularly nitrate enrichment and seasonal heavy rainfall.

In summary, the amount of DO decreased with the increase in depth. It was also observed to be lower near the coast. High nutrient concentration, particularly nitrate, was found to be accompanied by low DO concentration. Furthermore, hypoxia in the bay was greater during the wet season compared to the dry season, when there is less rain and discharge from surrounding fresh waters. It was widespread throughout the bay especially in the bottom layer during the wet season.

The focus of this paper is on the documentation of variations of the occurrence of hypoxia in Manila Bay across space and time. Hydrographic surveys were carried out for this purpose to give the recent information of the distribution of DO concentrations in the bay at varying depth and time.

Hypoxia in Manila Bay can be attributed to varying factors. Dissolved oxygen concentrations vary with season. Hypoxia is more prominent in the bay during the wet season likely because of more rain thus more discharge from surrounding fresh bodies of water like the Pampanga and Pasig rivers. Influx from rivers promotes nutrient input in the bay. This, in turn, results in an increase in organic matter production that aids in DO depletion in the system. No over-enrichment was observed for other nutrients except nitrate. However, the same trend of aggregation of the nutrients, especially for the surface layer in the eastern and northern coasts of the bay, was observed. High level of nutrients is associated with low DO level. Nitrate enrichment was present in the midsection of the bay where hypoxia was most prominent. Both hypoxia and eutrophication in Manila Bay varied in space and time.

This study gave some insight of the threatening occurrences of hypoxia and eutrophication in the bay with updated figures on every two months concentrations of DO in the entire bay and these can be compared to earlier studies (Chang *et al*., 2009; Jacinto *et al*., 2011; Sotto *et al*., 2014). Thus, the results of this study could be forwarded to fishery managers and other stakeholders that could be the basis for proper planning and management for the restoration and improvement of Manila Bay.

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