The Philippine Journal of Fisheries 24(1): 116-139 January - June 2017
DOI: 10.31398/tpjf/24.1.2016A0008

Profile of Salinity, Temperature, Heavy Metal (Pb, Cd, Hg) and Sediment Hydrogen Sulfide Concentration of Manila Bay, Philippines 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

The physical parameters of seawater are important determinants of water quality. Heavy metals are components that are naturally present in a considerable amount in the ocean but are observed to be rising above the allowable level due to pollution outputs of industrialization. Heavy metal contamination is among the environmental pollution problems that the world faces. Additionally, hydrogen sulfide (H_2S) is also a toxic compound that accumulates in the ocean floor posing threat to the marine organisms when present in high concentrations. The objective of this study is to document the distribution of temperature and salinity in the water column, heavy metals (Pb, Cd, Hg) and sediment H_2S in Manila Bay from 2012 to 2015. Stratification in the bay was generally a factor of salinity and less of temperature. Stratification due to salinity was consistently observed in September with the halocline occurring around 10 m to 15 m. Most of the time, the bay had evenly distributed temperatures, but the slightly higher temperatures were usually recorded near the coast. Inverse trends were observed for the salinity and temperature of the bay. Pb, Cd, and Hg concentrations in the bay occasionally exceeded the permissible limits especially the lead concentration in January 2013 (ave: 809.81 μg/L), March 2013 (ave: 1102.88 μg/L) and November 2015 (1507.50 μg/L). Cd and Hg concentrations were generally below the permissible limit and the reported limit of analysis. H_2S concentration ranged from <4 mg/kg to 9.99 mg/kg for all the survey months. Distribution was higher in the northwestern part and southeastern areas of the bay.

Keywords: Manila bay, salinity, temperature, heavy metal, hydrogen sulfide

INTRODUCTION

A number of parameters affect the ocean and its marine life. These physical parameters can either be beneficial or detrimental to the processes of the marine ecosystem. Of these, temperature, and salinity were included in the study. These characteristic properties of seawater can be used to distinguish the layers of the ocean, especially the bottom water from overlying waters. These are important in assessing the overall status of Manila Bay as well as the temporal and spatial distribution of fish species in the bay.

Salinity is the measure of the total salt content of seawater. Together with temperature, salinity can be used to determine the density, an important environmental condition in the marine ecosystem. Plankton and other floating marine organisms are able to float because of the ocean's density. For example, if the density of the water is too high, less food will sink to the bottom of the ocean for the fish to eat.

Other parameters of great importance are the heavy metal pollution of a bay and, the hydrogen sulfide (H_2S) accumulation in sediments. Heavy metals are toxic pollutants and its contamination is detrimental to both marine life and human life. Heavy metals are naturally present in trace amounts in the marine ecosystem but are found to have increased due to industrial and economic growth (Saeed *et al*., 2014; Zeitoun & Mehana, 2014). H_2S is a product of anaerobic decomposition of organic compounds and has a characteristic odor of rotten eggs. H_2S often accumulates in the ocean floor where the dissolved oxygen concentration is recorded to be lowest. It may be indicative of hypoxic conditions.

In the Philippines, the Department of Environment and Natural Resources (DENR) has provided a basis for appraising some of the water qualities. Manila Bay has been classified under Class SB (DENR, 1990). This study made use of the criteria value for heavy metals set by the Department of Environment and Natural Resources (DENR) Administrative Order (DAO) No. 34 (Series of 1990) (McGlone *et al*, 2004) (Table 9.1).

Table 9.1 Water Quality Criteria of Pb, Cd, & Hg (Department of Environment and Natural Resources (DENR) Administrative Order (DAO) No. 34 (Series of 1990) (DENR 1995))

Parameters	Criteria Values
Lead	50 µg/L
Cadmium	10 µg/L
Mercury	2 µg/L

This study aims to analyze the profiles of temperature and salinity of Manila Bay for certain periods of time. This study also includes the distribution of heavy metal concentrations and the sediment H_2S content and distribution in Manila Bay. This will serve as an assessment of the water quality of the bay with regards to the said parameters. Also, the study is to serve as reference material for further studies in Manila Bay, especially those that aim to revitalize the resources of the bay.

MATERIALS AND METHODS

On-site Survey

The investigations were carried out in Manila Bay for four years (2012, 2013, 2014, and 2015) with six survey months every year (January, March, May, July, September, November). A total of 16 transect stations (Figure 9.1) were sampled every field survey. The profiling of physical parameters (depth, temperature, and salinity) was done using the SBE 19 multi-parameter ocean profiler throughout the water column in each station.

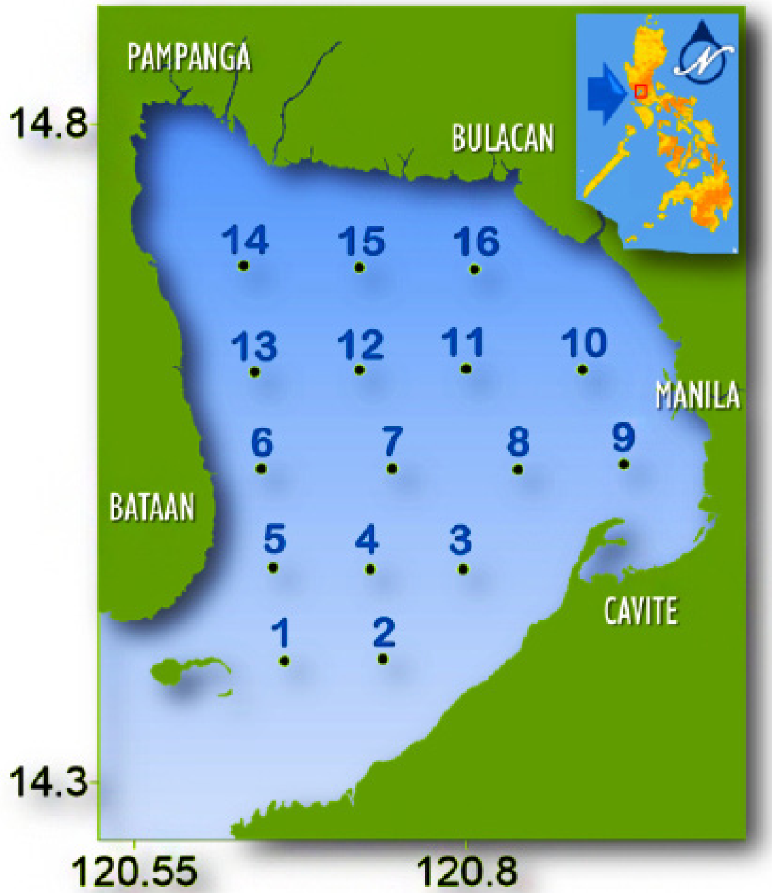


Figure 9.1. Manila Bay Sampling Stations

Laboratory Analysis

Heavy Metals

For heavy metal analysis, 500 ml of surface seawater was collected in each of the 16 designated sampling stations in Manila Bay (2013-2015). A few drops of nitric acid were added as preservation agent. The water samples were kept frozen and then sent to ELARSI, Inc. for heavy metal analysis.

The water samples were subjected to atomic absorption spectroscopy for the determination of lead (Pb), cadmium (Cd), and mercury (Hg) concentrations. Cold vapor technique AAS (Method 3112B, Standard methods for examination of water and wastewater, APHA-AWWA, 21st ed., 2005) was used for Hg analysis; and flame AAS (Method 3111C, Standard methods for examination of water and wastewater, APHA-AWWA, 21st ed., 2005) for Pb and Cd.

Hydrogen Sulfide

For H_2S analysis, a one-inch diameter mud corer was deployed in all 16 sampling stations on September 2015, November 2015 and December 2015. Of the 16 stations, no samples were collected at Station 2 because of the sandy property of the sediments distribution in the said station. As much as 5 cm sediment samples were collected at the surface layer and placed in Nalgene bottles. The samples were treated with a few drops of Zinc acetate, just enough to cover the samples, and kept refrigerated at around 4°C for preservation until further laboratory analysis.

The sediment samples were sent to Mach Union Laboratory, where the samples were subjected to analysis using the 4500-D Methylene Blue method (Method 3050B. Acid Digestion of Sediments, Sludges, and Soils. US EPA. 1996 Standard methods for examination of water and wastewater, 22nd Ed., APHA, AWWA, WEF, Washington D.C. 2012).

RESULTS

Salinity

Salinity profiles during the wet season of 2012 varied through the water column. Whereas the profiles during the dry season of 2012, displayed a well-mixed water column with lower salinity concentration in the east and northeast area near the coast. Surface salinity was lowest during September, averaging to 24.53 ppt, for the whole survey duration. Widest salinity range difference in minimum and maximum values were observed in the September surveys as well. The very low salinity in September and the wet season as a whole may be explained by rain during the survey period as seen in the surface layer. The surface layer is easily affected by different factors. The gradual increase in salinity concentration was observed as the depth increased (Figure 9.2).

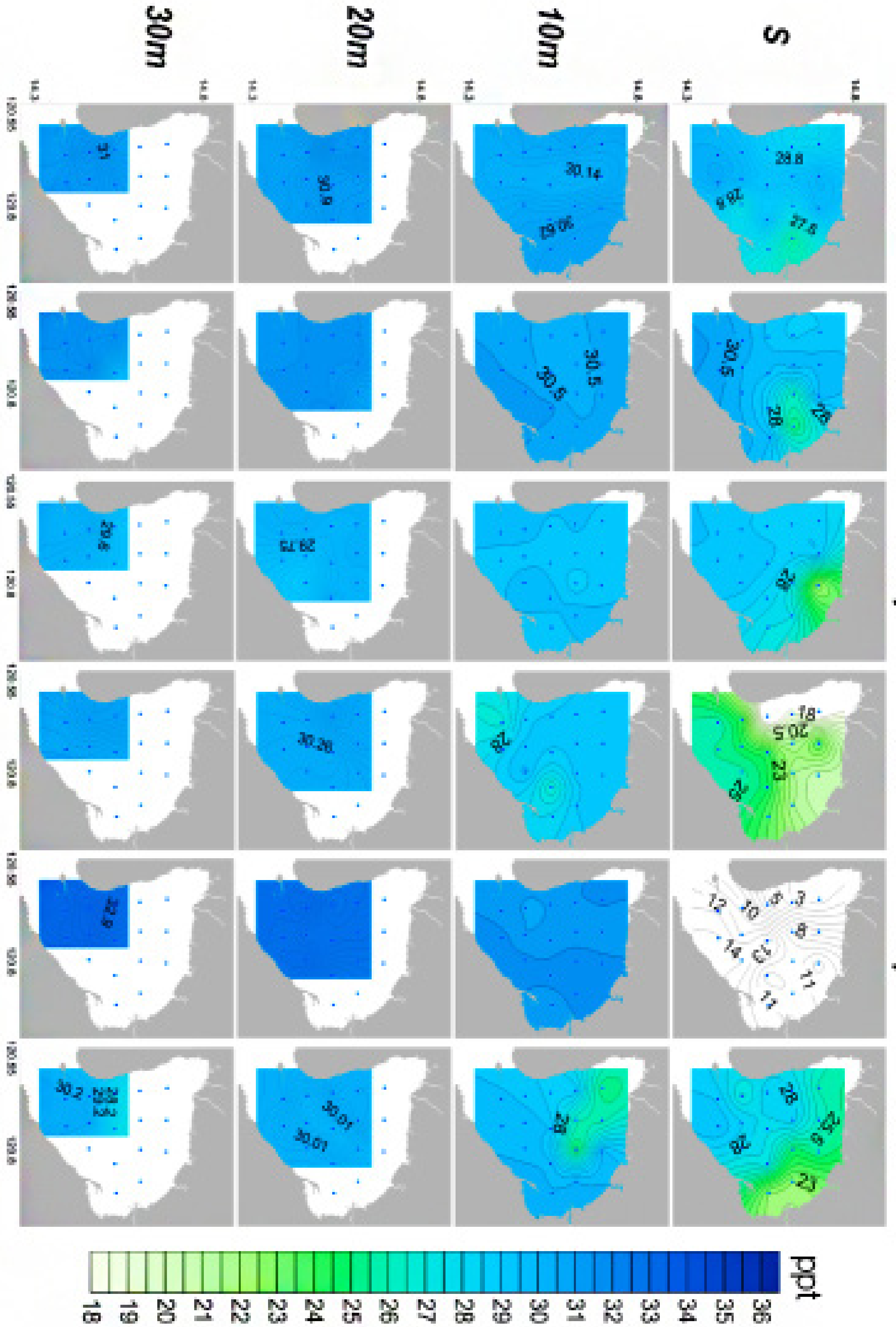
Similar to the previous year, variation in the salinity concentration in the water column was observed in the wet season of 2013. Lowest salinity was from the September survey, with an average of 23.43 ppt. A well-mixed salinity profile through the water column was recorded during the dry season (Figure 9.3). Variation in salinity concentration was most evident in the surface layer. A fairly well-mixed column was observed in the deeper layers for all survey months. Salinity concentration averaged to around 30 ppt for the 20 m and 30 m depths.

In 2014 and subsequent surveys, a change was done in the method to better see the distribution of the parameters in each area of the bay and layer of the water column particularly the near-bottom layer. Samples were collected from the surface (S) (<1 m), middle (M), and bottom (B) (Table 9.2) layers of the entire water column per station instead of the previous surface (10 m, 20 m, 30 m depth).

Table 9.2. Average middle and bottom depths (m) of the Manila Bay survey stations

Station	Middle	Bottom
	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 9.2. 2012 Salinity profile of Manila Bay



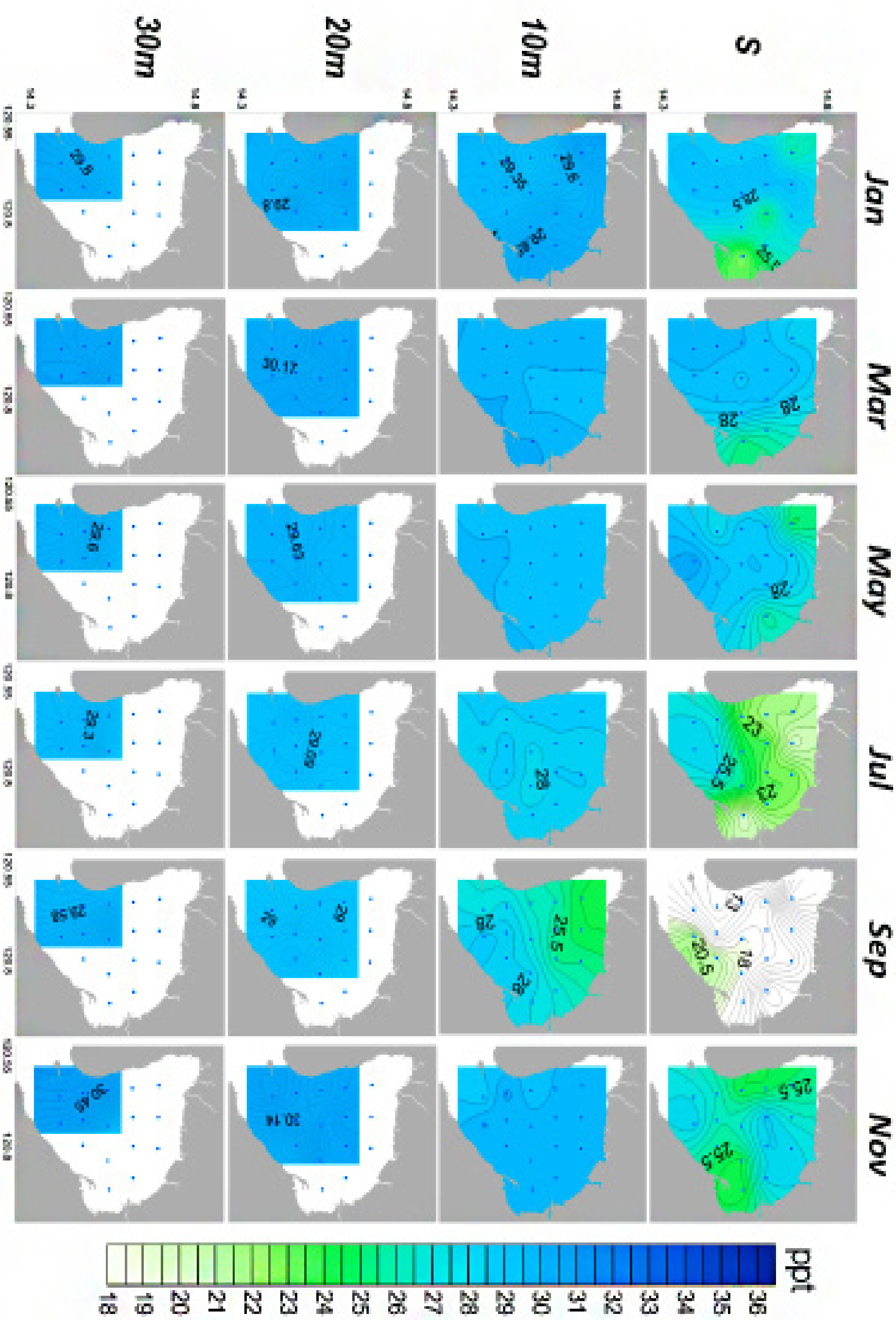


Figure 9.3. 2013 Salinity profile of Manila Bay

Similar to the 2012 and 2013 surveys, surface salinity was lowest during September. Salinity was highest in November and lowest in May and July and the surface of September. Salinity concentration for September reached 22.87 ppt, the lowest salinity value for 2014. A visible change in the bay-wide salinity concentration from the surface to the deeper layers during September was observed. Salinity was well distributed throughout the bay for each sampling period with slightly higher values usually in the middle to the mouth of the bay (Figure 9.4). Gradual continuous increase in salinity, though well distributed, was observed in the deeper areas of the water column. May and July salinity concentrations, with averages of 28.25 ppt and 27.87 ppt respectively, were lower by around 3 ppt than the rest of the 2014 survey months, except for the surface layer of September. The dynamic distribution of salinity concentration in the surface may be attributed to the rain and other weather interferences which greatly affect the surface. Salinity concentration was highest in November, averaging to 32.10 ppt with a range of 28.48 ppt to 33.70 ppt. Apart from the salinity in the surface of September, the bay's salinity was relatively well mixed all throughout the year with slightly decreasing concentrations near the coast. Salinity had increasing concentrations in the deeper middle areas of the bay.

In 2015, recorded salinity was higher in the first quarter (January, March) than in the second quarter (May) regardless of depth. Average salinities were 32.84 ppt and 29.17 ppt for the first and second quarters, respectively. Salinity concentrations were highest in January and March with slightly lower salinity aggregation near the eastern coast. May and July salinity concentrations were around 2 ppt lower than the previous months. Surface salinity for September ranged from 22.65 ppt to 26.67 ppt with an average of 25.07 ppt. The lowest recorded salinity of 2.36 ppt was from November and this was from the abnormality in station 1 in that survey month (Figure 9.5). A yearly increase from 2013 to 2015 in average salinity of ~2 ppt was observed during the January, March, May, and July surveys, while a decrease was seen in the salinity concentration from the September and November surveys of 2014 and 2015.

Surface salinity was lowest near the coast of Cavite and NCR. Similar to the previous reports, salinity increases gradually when nearing the near-bottom areas of the bay. A maximum salinity of 33.82 ppt was recorded in the near-bottom waters. The slightly higher salinity values can be found near the mouth of the bay for the near-bottom layer. Slightly increasing salinity concentration towards the mouth of the bay for all layers was observed for all surveys except November.

While salinity near the mouth of the bay was usually slightly higher compared to the near coastal waters, the opposite was observed for November. November surface salinity concentrations varied widely. Variation in the distribution of the surface salinity of the bay was present with lower concentrations running from the coast of Bataan to the middle of the bay and to the coasts of Bulacan and Manila. Surface salinity in November ranged from 2.36 ppt to 33.07 ppt averaging to 24.05 ppt. The minimum value was from the irregular low salinity concentration recorded in station 1 throughout the column. This varied mixing and aggregation of salinity may be attributed to the turbulent seas during the survey. Unlike in the surface layer, November salinity concentrations were uniformly distributed in the middle and near-bottom layers, both throughout the bay and the water column, except for the recorded very low salinity in Station 1.

Temperature

The temperature ranged from 22.21°C to 31.49°C for field surveys of the year 2012. The highest temperature was observed during the months of May (max: 31.49°C; ave: 29.05°C) and July (max: 30.04°C; ave: 28.33°C), particularly in

Figure 9. 4. 2014 Salinity profile of Manila Bay

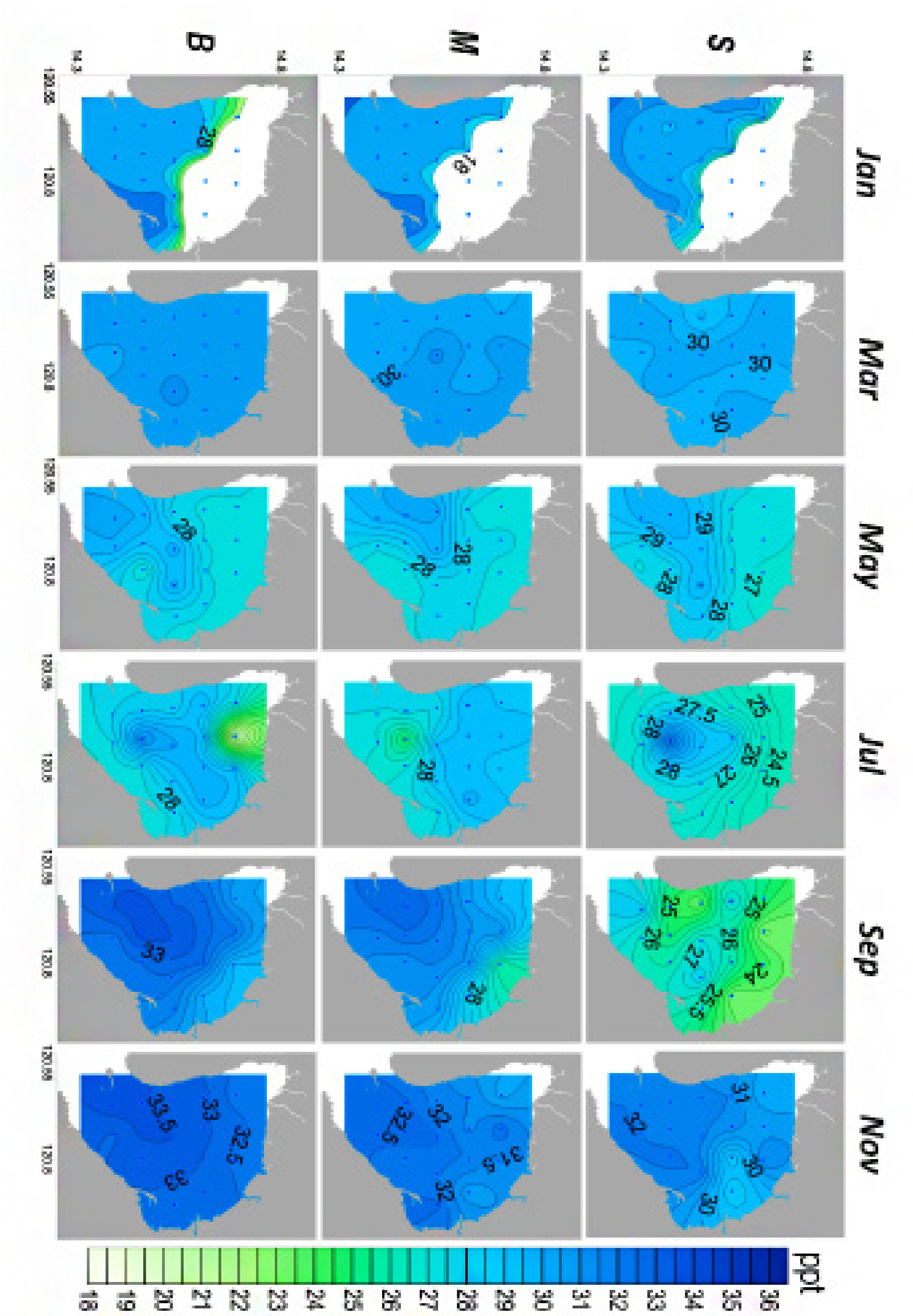
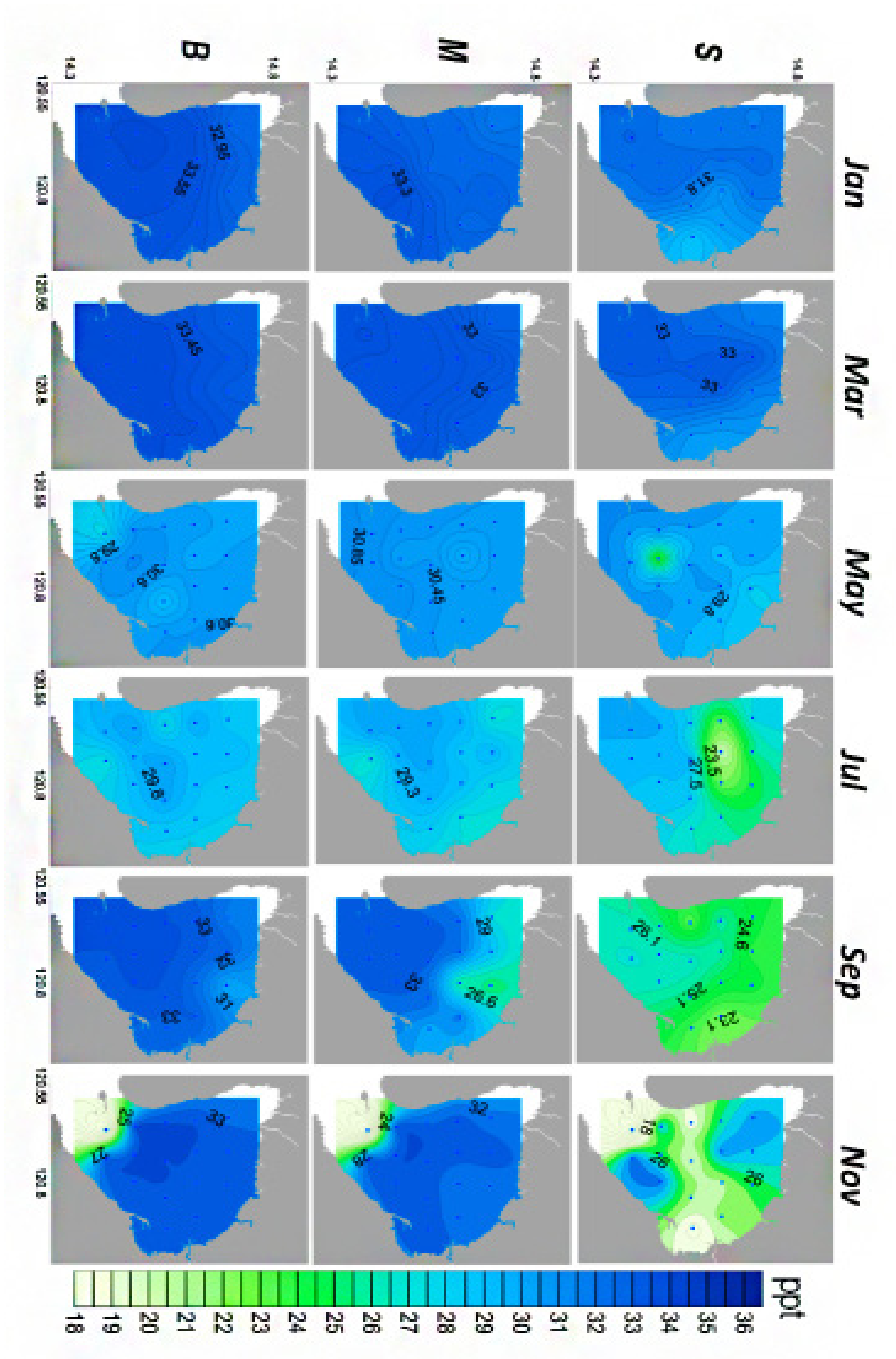


Figure 9.5. 2015 Salinity profile of Manila Bay



the surface layer. The lowest recorded temperature of 22.21°C was from the November survey. Little variation in the water column of each survey was seen. The 2012 temperature vertical profile averaged to 27.39°C. The distribution of temperature for 2012 was well mixed for every layer of each survey month. A gradual decrease in temperature was observed as the depth increased (Figure 9.6).

The temperature for the 2013 surveys ranged from 24°C to around 33°C. Similar to the previous year, May and July remained the hottest months in 2013. Not much variation was seen in the temperature distribution in the bay. There was a very little decrease in temperature as the bay got deeper. The values averaged 27°C in the 30 m depth and 28°C in the Surface and 10 m depth (Figure 9.7). Highest temperature was observed in May followed by the month of July. The temperature becomes cooler in September until March.

The bay was relatively colder in January and March for 2014 (Figure 9.8). Similar to the previous years, May and July remained the hottest months. The bay-wide temperature for January and March ranged from 17.66°C to 24.64°C and 23.44°C to 27.35°C, respectively. The January and March temperature profiles were colder this year compared to previous years by around 2 to 3°C.

The temperature was highest during the May and July surveys and lowest during January. This was consistently observed for three years, 2012, 2013 and 2014, with the maximum temperature increasing ~2°C every year. It was highest in May followed by July for all sampling years because it is the summer season. The highest recorded temperature (35.59°C) was from May 2014. During the May survey, the surface layer gathered the highest temperature of 35.59°C in the northern area while the lowest temperature of 30.27°C in the southern area near the mouth.

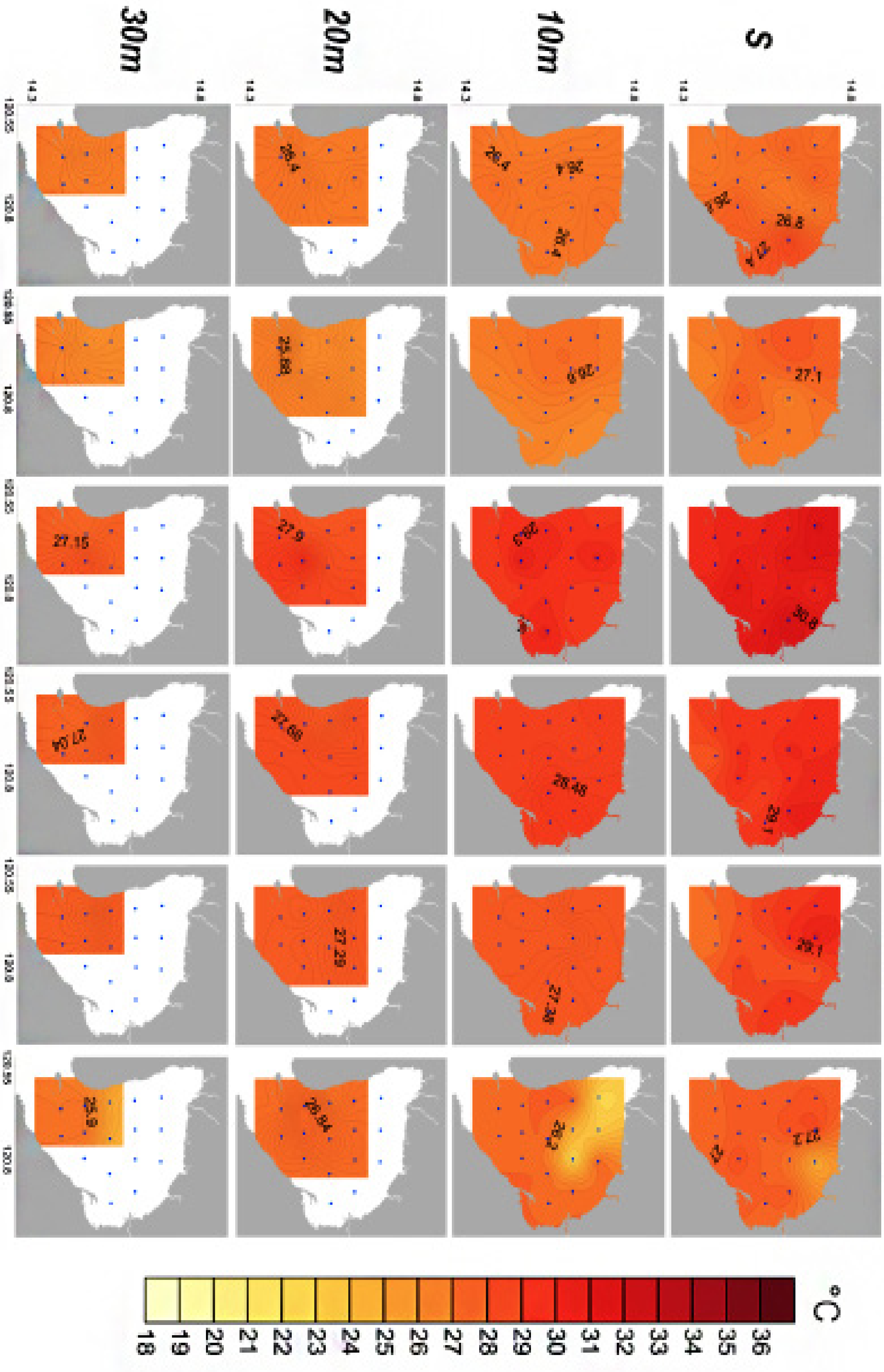
This temperature pattern continued in the deeper middle and bottom layers, except that the lower temperature was more widespread in its distribution from the south-west to the middle part of the bay. The average temperature of the bay recorded for July was at 29.70°C. The temperature was low in the northern area then gradually increased towards the southern part of the bay. This trend in temperature, which was not observed in the 2012 and 2013 data, can be seen in all survey depths of July 2014. The highest recorded July 2014 temperature of 32.91°C was from the southern part of the bay.

The average recorded temperature of the bay for the September 2014 survey was at 29.19°C. An average of 29.37°C was observed at the surface layer, which then increased to up to 30°C towards the northeastern part of the bay. The temperature profile for November 2014 averaged to 28.40°C and ranged from 27.36°C to 29.68°C and was relatively well-mixed compared to the other survey months.

Unlike the previous years, wherein temperature reached its peak in May or July, in 2015 the highest recorded temperatures were from September, ranging from 27.95°C to 32.12°C and averaging to 30.03°C. The temperature had an increasing trend from January to September. A decrease in around 2°C was observed from September to November. The surface layer was found to be ~2°C hotter than the near-bottom layer of the bay. A decrease in temperature was readily observed in the deepening water column. The lowest recorded temperature for 2015 was 24.52°C which is from the bottom layer of the May survey.

The average temperature for January and March sampling periods was around 26°C. The values ranged from 24.57°C to 27.87°C. The temperature for the January 2015 survey was ~2°C higher compared to the January 2014 survey. Compared to January, higher temperatures were recorded for March with values highest in the

Figure 9.6. 2012 Temperature profile of Manila Bay



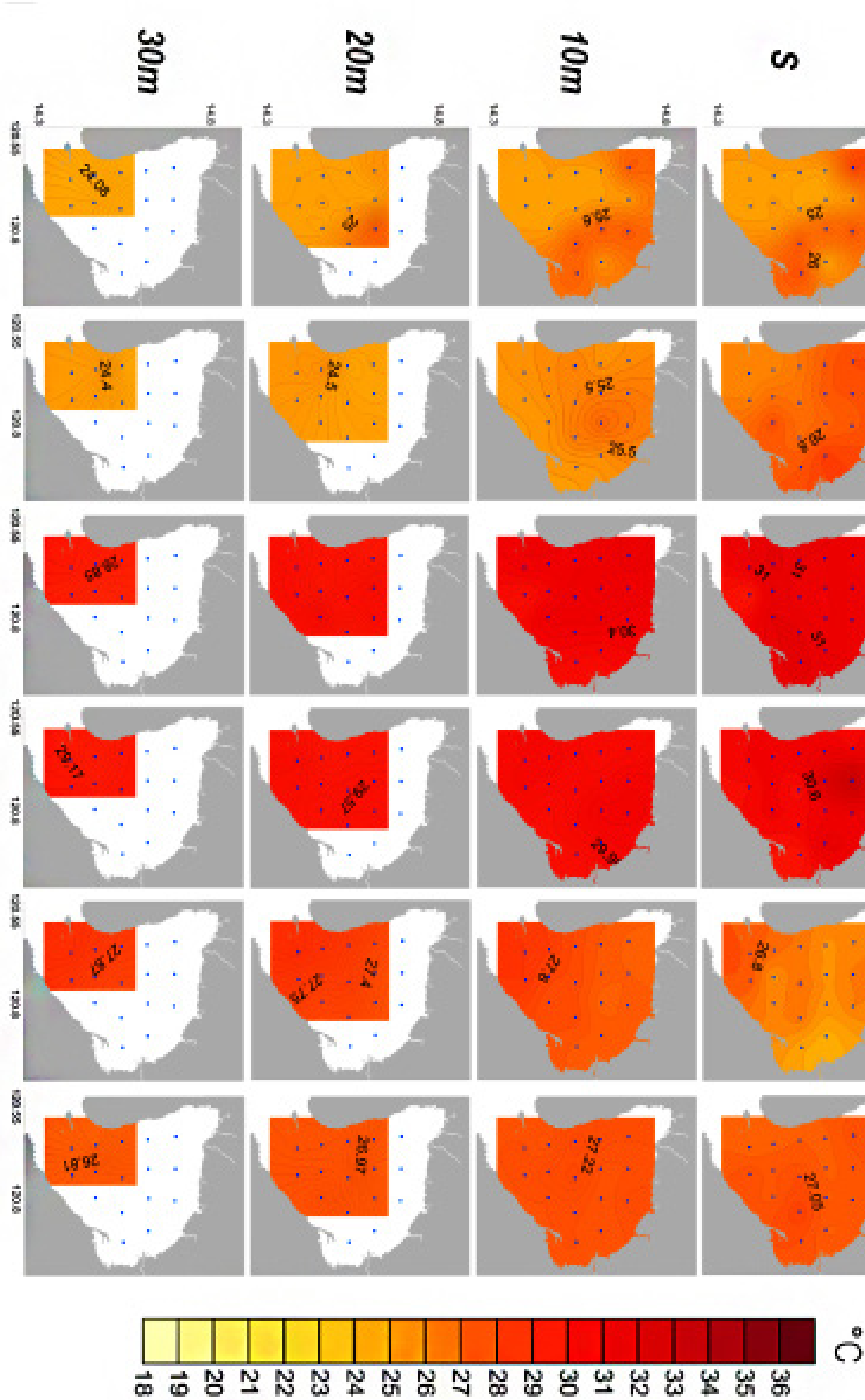


Figure 9.7. 2013 Temperature profile of Manila Bay

Figure 9.8. 2014 Temperature profile of Manila Bay

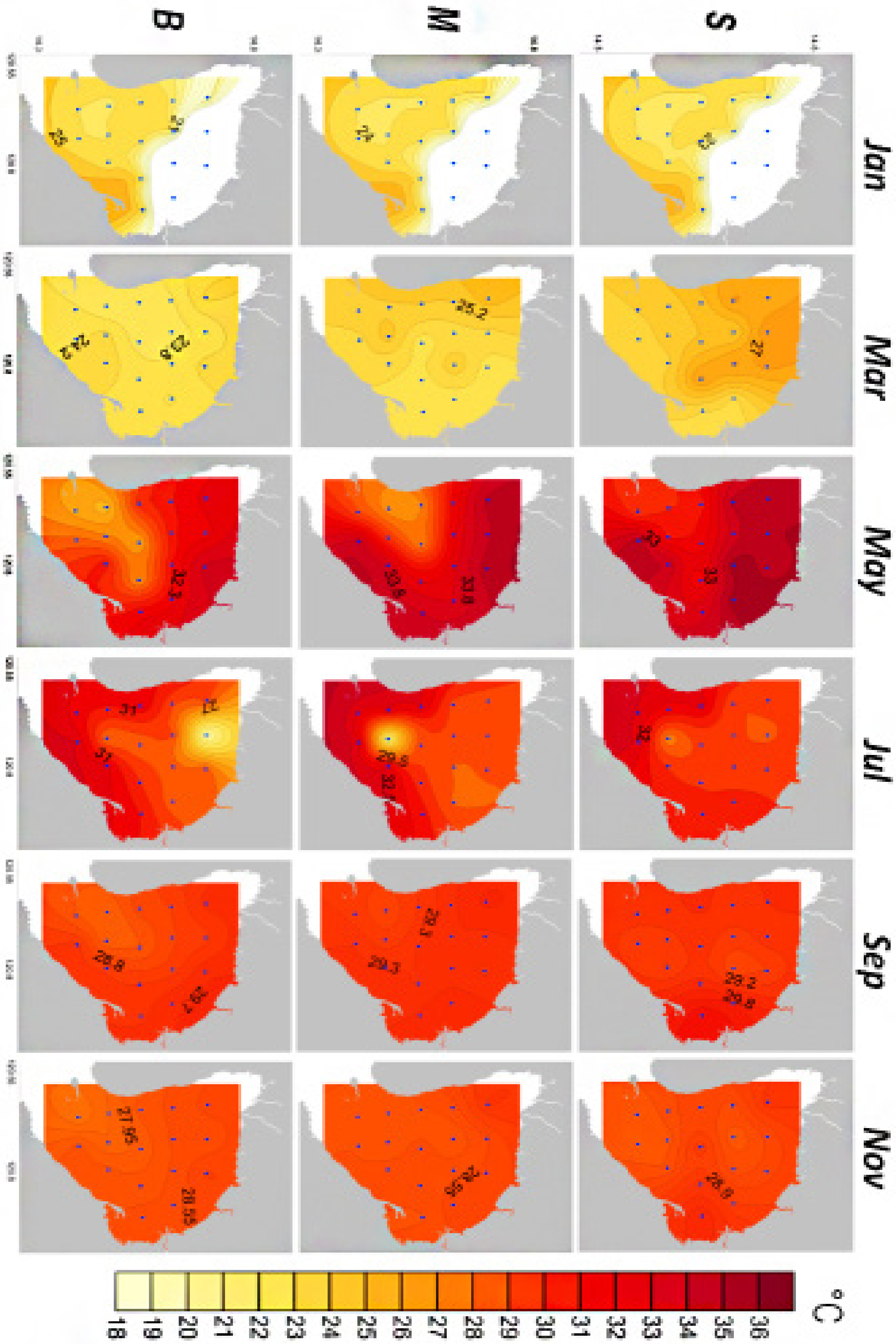
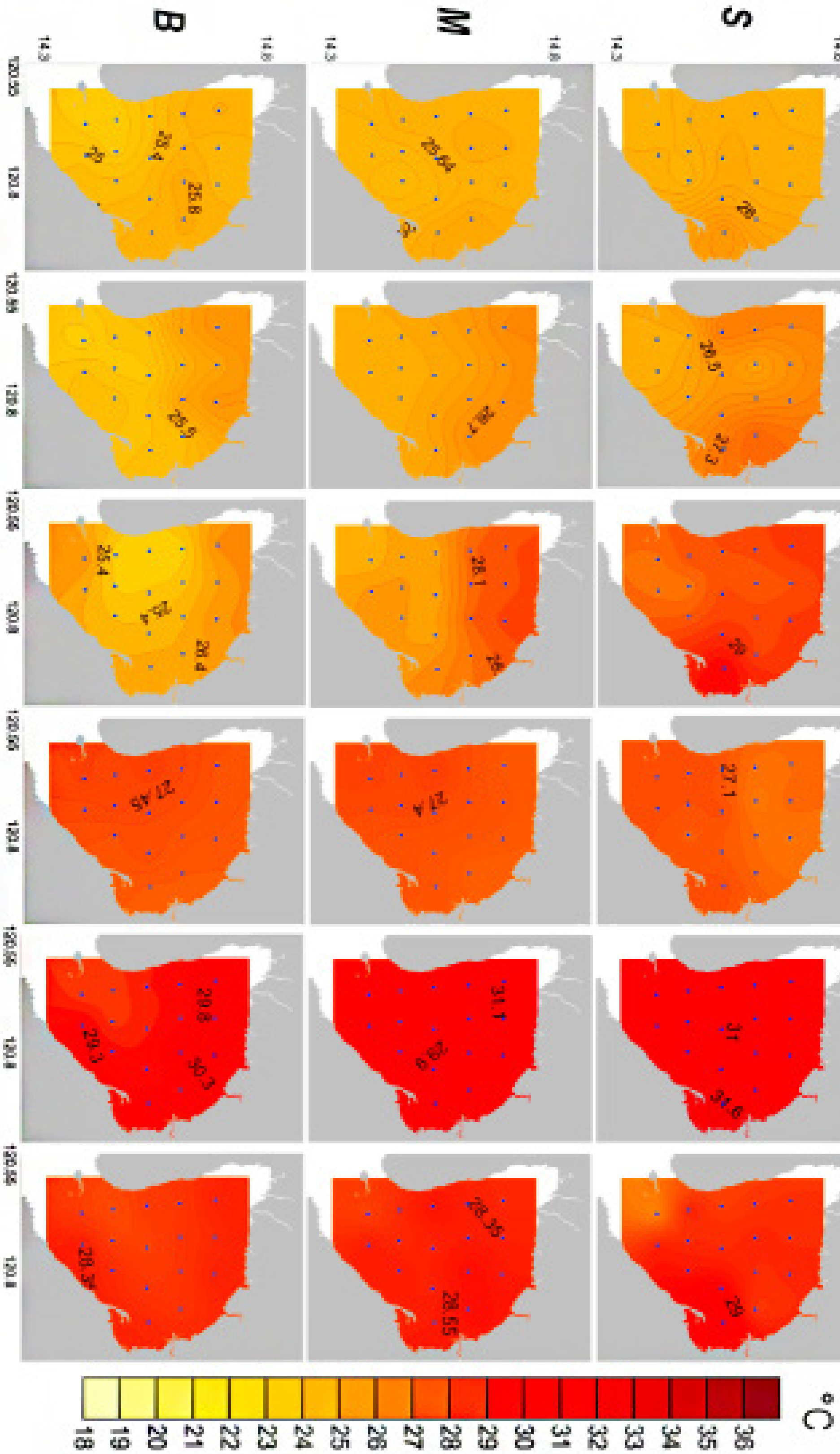


Figure 9.9. 2015 Temperature profile of Manila Bay



northern parts of the bay. The distribution of higher temperature in the northern area of the bay was observed for all sampling depths of March and May. Higher temperatures were recorded near the coast for both months but this observation was more evident for May, especially in the surface layer. May and July 2015, with averages of 27.09°C and 27.20°C, respectively, were relatively colder compared to the previous year's May and July surveys. The maximum temperature of 29.97°C in May 2015 was far lower than that of the May 2014 survey, with a 35.59°C highest recorded temperature. July 2015 was relatively colder compared to last year and the previous years' July surveys as well. For July, the bay's temperature was uniformly distributed both throughout the bay and the column of around 27°C.

The bay-wide temperature for September and November 2015 ranged from 27.95°C to 32.12°C and from 25.93°C to 30.03°C, respectively, with averages of 30.03°C and 28.17°C. September was slightly hotter than November for all depths. A slight increase in temperature near the coasts was observed but the temperature was seen to be uniformly constant throughout Manila Bay for the two survey months (Figure 9.9). The temperatures for the 2015 survey months were generally uniformly distributed throughout the bay and the water column with little noticeable changes.

Heavy Metals

Pb concentration in Manila Bay exceeded the water quality criteria in January 2013, March 2013 and November 2015 with averages of 809.81 μg/L, 1102.88 μg/L, and 1507.50 μg/L, respectively (Figure 9.12). Pb concentration in Manila Bay for the rest of the survey all fell below the set water quality criteria of 50 μg/L and the reported limit (30 μg/L) of the AAS analysis (Table 9.1).

Of the surveys with high Pb concentration, January 2013 garnered the lowest values among the three months. Pb concentration ranged from 29 μg/L to 2260 μg/L for the said month. Values were highest in the mouth and extending to the middle of the bay. The March 2013 survey, on the other hand, ranged from 45 μg/L to 2750 μg/L with aggregation near the coast particularly in the west to the middle part of the bay. As with the January and March 2013 surveys, Pb concentrations in the month of November 2015 have far exceeded the water quality criteria with values ranging from 1050 μg/L to 2370 μg/L. As seen in the contour map, higher concentrations of Pb were more prominent bay-wide in November 2015. The highest recorded value was from Station 3 near Cavite.

Generally, the majority of the Cd concentrations fell below the set standard of 10 μg/L and the reported limit of the analysis (<5 μg/L, Tables 1 & 5). Cd concentrations in the bay occasionally spiked above the criteria value. These were January, March, and November 2013, January, March, September and November 2014, and September 2015 (Figure 9.13).

Except for September 2014, all minimum values were <5 μg/L. The highest recorded value was from March 2013 (186 μg/L) followed by September (308 μg/L) and then January 2013 (186 μg/L). These values were from stations in the northwest part of the bay (Stations 12 and 13).

Hg concentrations were generally below the permissible value of 2 μg/L and the reported limit of analysis of <0.6 μg/L (Tables 9.1 & 9.6). Survey months with exceeding Hg concentrations were January and March 2013, and March, May, July and September 2015 (Figure 9.14). Of these, all averages, except that of September 2015, were below the criteria value. Spikes of Hg concentration were from varying stations, in usually only 1 to 3 stations per survey, of different survey months. Only the September 2015 survey had a consistent recorded Hg concentration of >2 μg/L among the stations. Hg concentrations for

Figure 9.10. (a) 2012, (b) 2013, (c) 2014, (d) 2015 Salinity Vertical Profile of Manila Bay

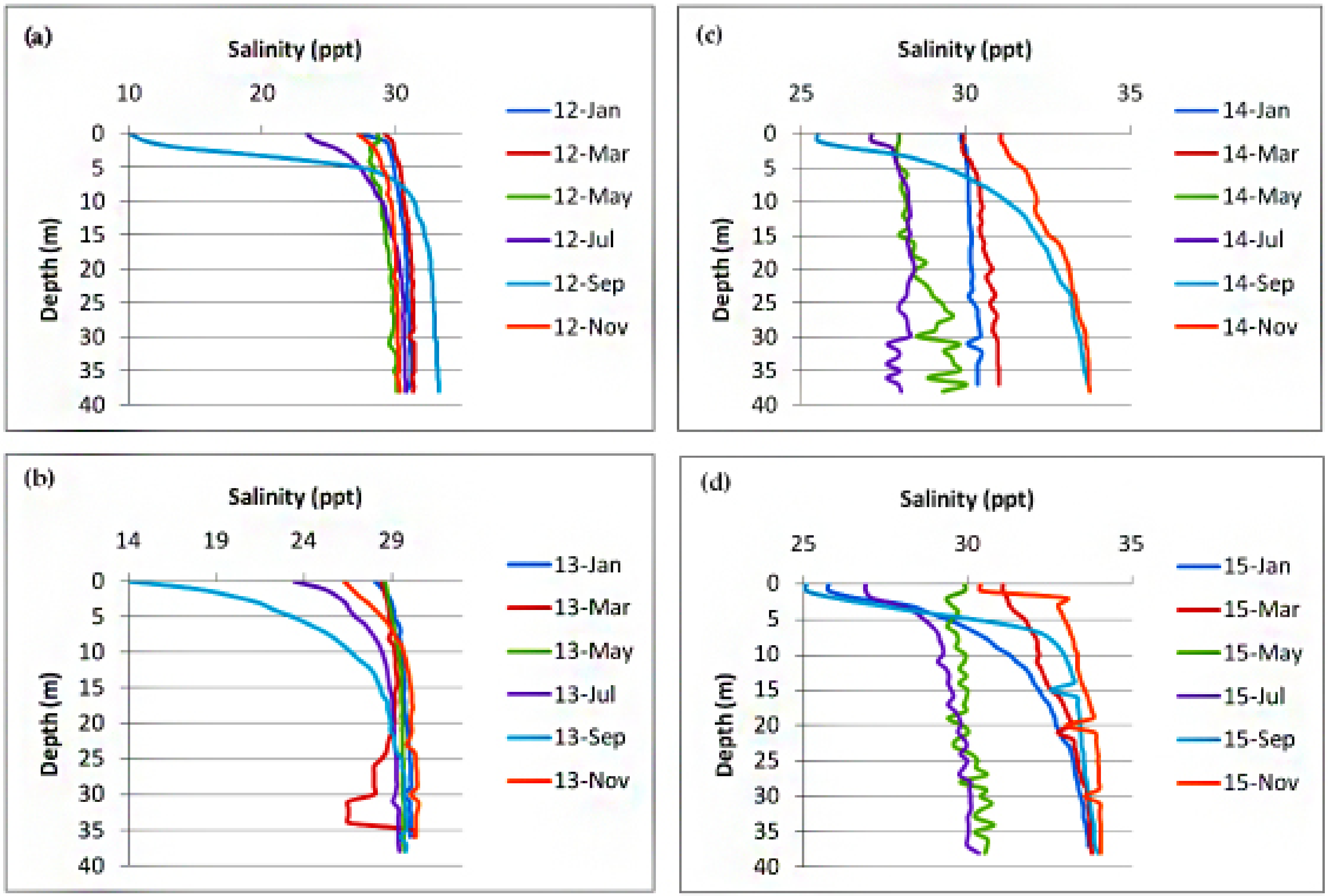


Figure 9.11. (a) 2012, (b) 2013, (c) 2014, (d) 2015 Temperature Vertical Profile of Manila Bay

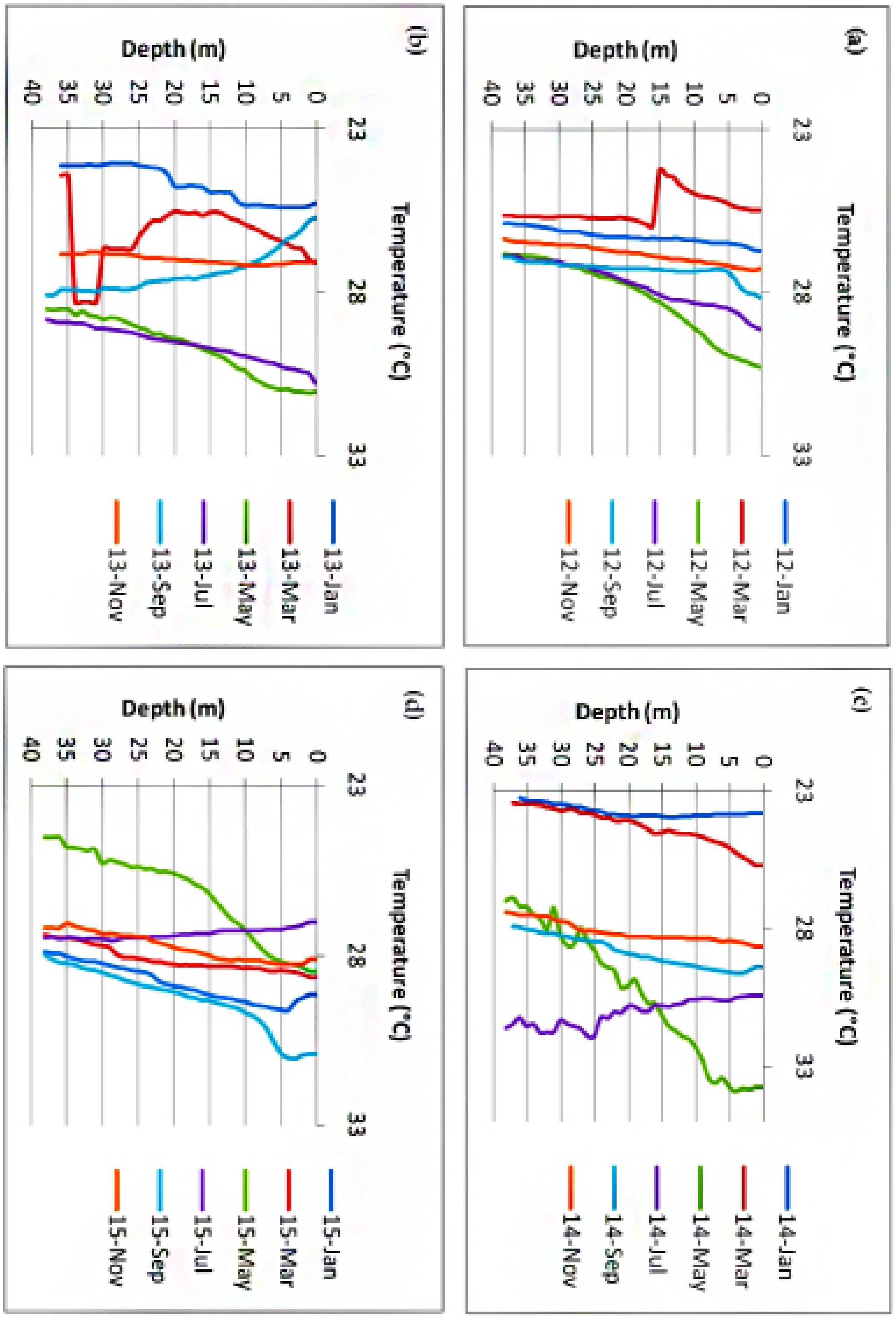


Table 9.3. Ranges of salinity and temperature data from 2012-2015

Ranges		
	Temp (°C)	Sal (ppt)
12-Jan	25.98-28.94	25.30-31.16
12-Mar	25.44-27.73	24.89-31.42
12-May	26.92-31.49	22.08-30.09
12-Jul	26.96-30.04	15.87-30.76
12-Sep	26.81-30.29	2.41-33.10
12-Nov	22.21-27.94	22.48-30.25
13-Jan	23.98-27.56	22.53-30.09
13-Mar	24.17-27.85	25.23-30.26
13-May	28.60-31.42	24.87-30.37
13-Jul	28.92-33.05	19.42-29.39
13-Sep	23.97-28.25	3.25-29.83
13-Nov	26.69-27.69	24.16-30.56
14-Jan	17.66-24.64	22.52-30.73
14-Mar	23.44-27.35	28.86-31.23
14-May	26.34-35.59	26.87-30.26
14-Jul	19.14-32.92	19.68-32.36
14-Sep	27.89-30.65	22.87-33.70
14-Nov	27.36-29.68	28.48-33.77
15-Jan	24.61-26.50	30.51-33.80
15-Mar	24.57-27.87	30.51-33.82
15-May	24.52-29.97	23.33-31.11
15-Jul	26.32-27.64	19.68-30.32
15-Sep	27.95-32.12	22.65-33.95
15-Nov	25.93-30.03	2.36-34.02

Table 9.4. Averages of salinity and temperature data from 2012-2015

Averages						
2012	January	March	May	July	September	November
Sal (ppt)	29.56	30.28	28.83	26.63	24.53	28.96
Temp (°C)	26.46	26.25	29.02	28.32	27.61	26.97
2013	January	March	May	July	September	November
Sal (ppt)	28.99	28.89	29.10	26.02	23.43	28.18
Temp (°C)	25.26	25.95	30.18	29.99	26.77	27.05
2014	January	March	May	July	September	November
Sal (ppt)	29.78	30.39	28.25	27.87	30.38	32.10
Temp (°C)	23.71	24.81	31.91	29.70	29.19	28.43
2015	January	Mar	May	July	September	November
Sal (ppt)	32.62	33.06	30.10	28.25	29.76	29.32
Temp (°C)	25.60	26.11	27.09	27.20	30.03	28.17

2015 ranged from <0.6 µg/L to 16.3 µg/L. The recorded maximum value was from the station 5 of the March 2015 survey.

Hydrogen Sulfide

Stations 1, 8 and 12 had H_2S values ranging from 4.6 – 5.41 mg/kg while the rest of the stations had <4 mg/kg of H_2S for the September 2015 survey. November and December H_2S concentrations averaged to 5.69 mg/kg and 5.84 mg/kg, respectively. The November values ranged from <4 mg/kg to 9.54 mg/kg, while the December values ranged from <4 mg/kg to 9.99 mg/kg. Higher H_2S concentrations were on the northwest part of the bay and near the mouth of the bay (Figure 9.15).

Increased H_2S concentration was more widespread in November and December 2015 compared to September 2015. Distribution of H_2S for November 2015 concentrated on the northwestern part (near station 14 and the coast of Pampanga) and the southeast part (near station 5 and the coast of Cavite) of the bay.

DISCUSSION

Stratification in the bay was generally a function of salinity and less of temperature. The salinity profiles of September from all years consistently showed the same pattern of a gentle slope near the surface. Salinity horizontal profiles of the months of 2012, 2013 and 2015 were closer to each other unlike the vertical profile of the month from 2014. Stratification consistently observed in September plots. From around 10 m to 15 m, a stratified layer can be observed as indicated by the sudden change in salinity concentration (Figure 9.10).

The indistinct variation and homogenous distribution in temperature and salinity of Manila Bay can be attributed to the mixing arising from strong winds and the current system that causes well-mixed waters of the bay. This kind of

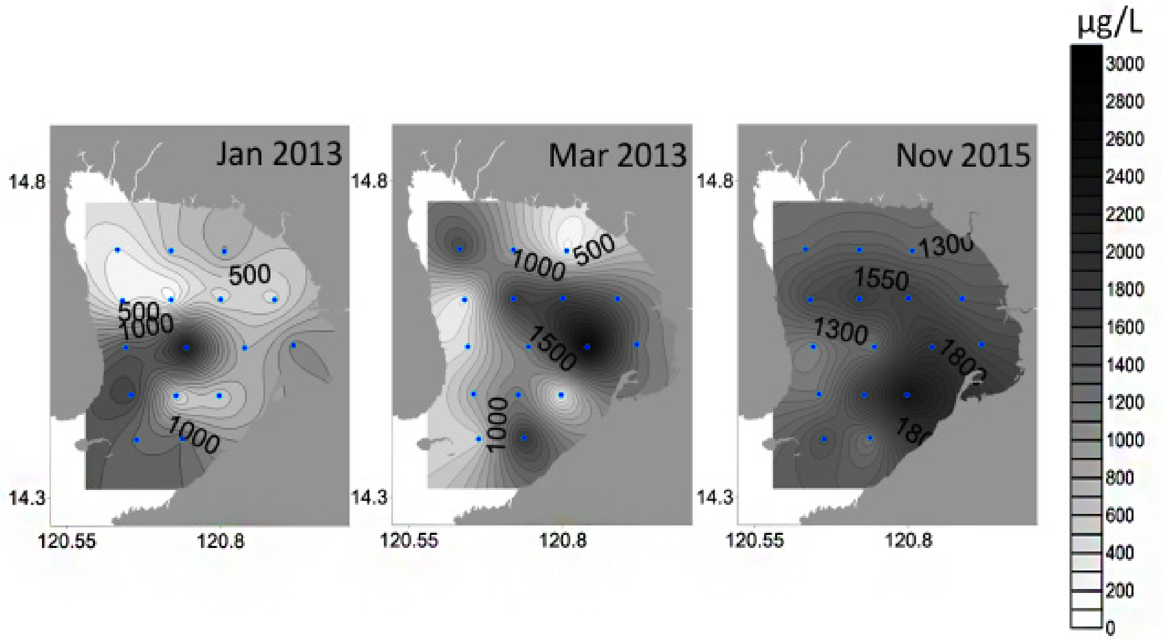


Figure 9.12. Lead Distribution of Surface Seawater in Manila Bay

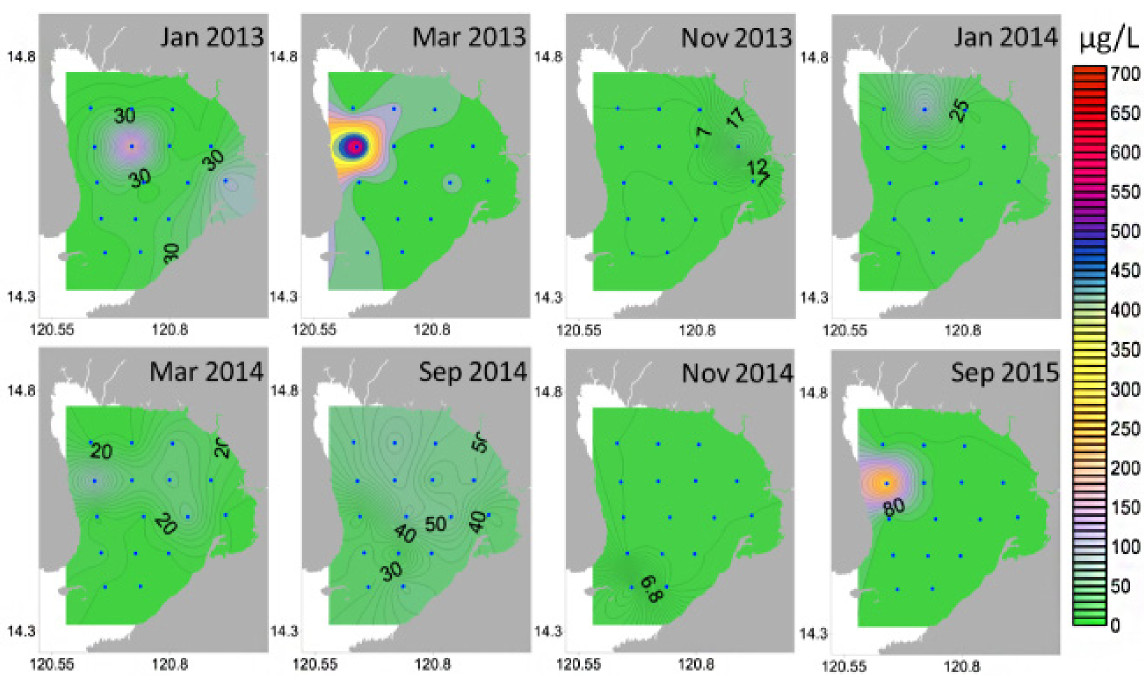


Figure 9.13. Cadmium Distribution of Surface Seawater in Manila Bay

Table 9.5. Ranges and Averages of Cadmium Concentration in the Manila Bay

Unit: µg/L	Jan 2013	Mar 2013	Nov 2015
MIN	29	45	1050
MAX	2260	2750	2370
AVE	809.81	1102.88	1507.50

Table 9.6 Ranges and Averages of Mercury Concentration in the Manila Bay

Unit: µg/L	Jan 2013	Mar 2013	Nov 2013	Jan 2014	Mar 2014	Sep 2014	Nov 2014	Sep 2015
MIN	<5	<5	<5	<5	<5	20	<5	<5
MAX	186	676	27	90	82	62	10	308
AVE	27.625	77.94	5.50	16.50	19.69	43.31	5.31	25.63

mixing usually affects up to the 200-meter depth of the ocean. The deepest parts of the bay are only ~30 m and the average depth of the whole bay is 17 m.

Most of the time, the bay had evenly distributed temperatures with higher temperatures usually recorded near the coast. Inverse trends were observed for the salinity and temperature of the bay. Areas with lower salinity had a higher temperature and vice versa. A slight increase in temperature near the coasts was observed but the temperature was seen to be uniform throughout Manila Bay for most survey months.

In 2012, except for March and May, the freshwater signal can be seen in the salinity vertical profile, as characterized by the almost horizontal-vertical lines from 0m to 5m. This pattern can be evidently seen in the September plot. Stratification can also be observed in the September plot at depths of 5 m to 10 m. Slight stratification was present in the July plot at the 5m to the 15 m depth. Salinity concentrations stabilized in the deeper layers at around 30 ppt for all survey months.

The 2012 and 2013 vertical profiles were fairly similar. The freshwater signal can be seen in the surface layer particularly that of September. Stratification was also observed in September at the 5 m to the 15 m depth. And slight stratification in July and November. Salinity concentrations were found to be around 29 ppt year-round.

The 2014 salinity vertical profile was very dynamic horizontally 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 5m 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.

The 2012 to 2015 temperature plot of Manila Bay (Figure 9.11) showed a range in temperature from 23 C to 34 C. Except in 2015, May was consistently the hottest month with regards to the surface (<1 m). The temperature in May was consistently observed to be decreasing with the increase in depth.

The 2012 temperature plots converge to a cooler temperature in the deeper depths (>20 m). The same can be said in the 2015 plots. The 2012 and 2015 vertical profiles were closer to one another unlike those of 2013 and 2014. The 2014 temperature vertical profile showed variation in the surface even after in the deeper waters. The temperature vertical profiles showed a slightly warmer surface and a cooler bottom. The midsection of the bay is deeper and is exhibiting more water column stratification (Siringan et al, 1998 as cited in Jacinto *et al*., 2011). Stratification hinders the aeration of bottom waters and promotes anaerobic decomposition of organic matter. H_2S is the by-product of anaerobic respiration by sulfate-reducing bacteria in the ocean sediments. Thus, making the presence of H_2S in the marine sediments indicative of hypoxic conditions in the near bottom waters. H_2S is higher near the coast especially in the coasts of Pampanga and Manila.

Stratification in the bay was generally a factor of salinity and less of temperature. Stratification was consistently observed in September plots from around 10 m to 15 m, as indicated by sharp halocline at these depths. Most of the time, the bay had evenly distributed temperatures but

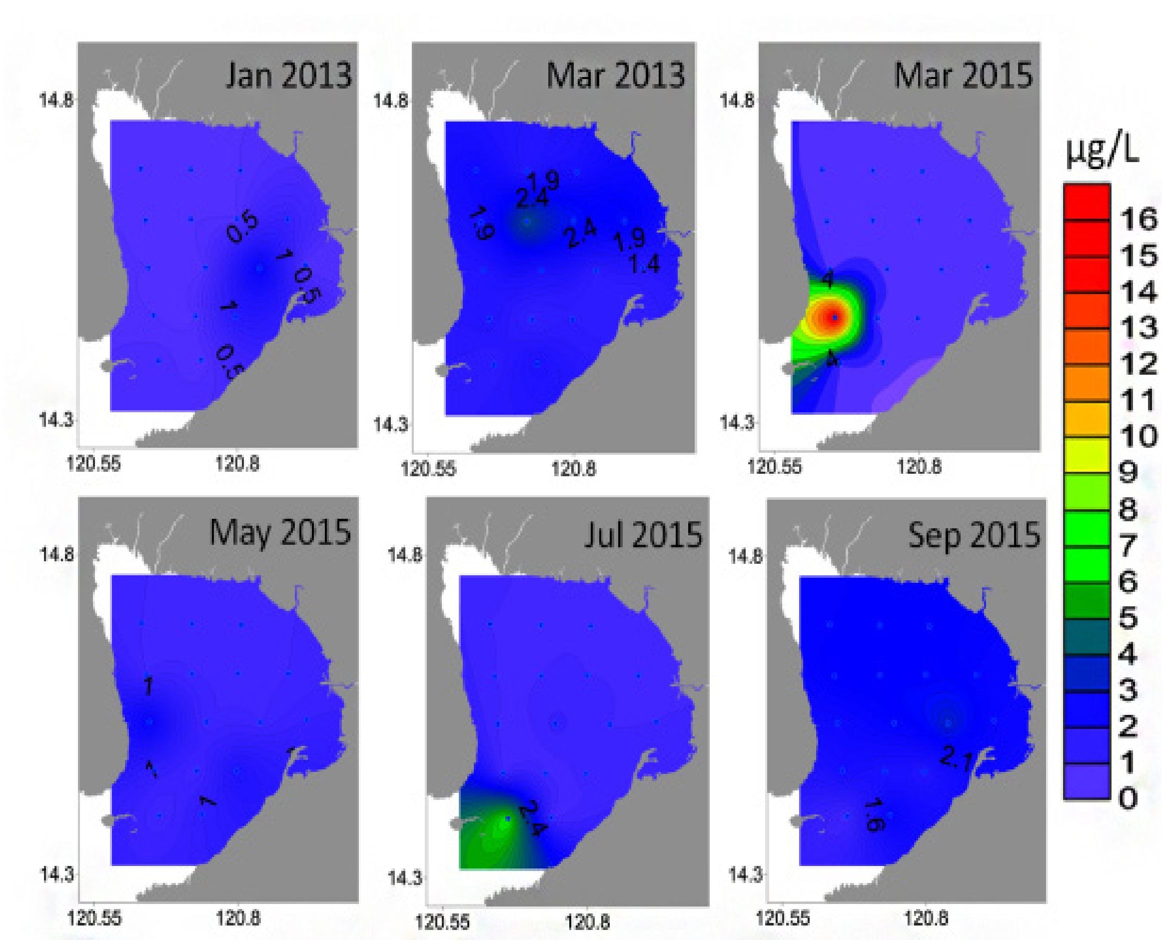


Figure 9.14. Mercury Distribution of Surface Seawater in Manila Bay

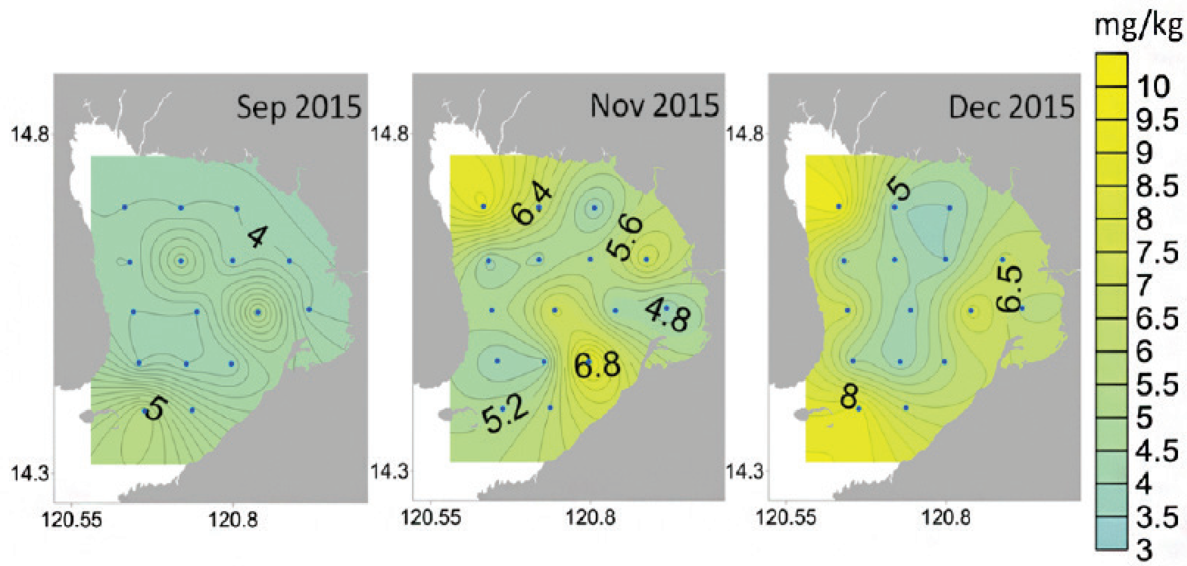


Figure 9.15. Contour maps of H_2S in bottom sediments of Manila Bay for September, November, and December 2015

the slightly higher temperatures were usually recorded near the coast. Inverse trends were observed for the salinity and temperature of the bay.

Pb concentration in Manila Bay exceeded the water quality criteria in January 2013, March 2013 and November 2015 with averages of 809.81 µg/L, 1102.88 µg/L, and 1507.50 µg/L, respectively. Cd and Hg concentrations were generally below the criteria value and the reported limit of analysis. Cd and Hg concentration exceeding the criteria level were from varying stations, of different survey months. Increased H_2S concentration was more widespread in November and December 2015 compared to September 2015. H_2S ranged from <4 mg/kg to 9.99 mg/kg. Further monitoring of the heavy metal concentrations in Manila Bay, especially its accumulation in the sediments, is recommended.

References

Chang, K.H., Amano, A., Miller, T.W., Isobe, T., Maneja, R., Siringan., F.P., Imai, H., and Nakano, S. (2009) Pollution Study in Manila Bay: Eutrophication and Its Impact on Plankton Community. Interdisciplinary Studies on Environmental Chemistry – Environmental Research in Asia, Eds, pp. 261-267.

DENR Administration Order No. 34, Series 1990; Revised Water Usage and Classification/ Water Quality Criteria Amending Section Nos: 68 and 69, Chapter III of the 1978 NPCC Rules and Regulations Criteria of Water Use Regulation (EMB/DENR, March 20, 1990)

Diaz, Robert, Rabalais, Nancy, and Breitburg, Denise. (2012). Agriculture's Impact on Aquaculture: Hypoxia and Eutrophication in Marine Waters. ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT.

Environmental Protection Agency (EPA). (2001). Nutrient Criteria Technical Guidance Manual. – Estuarine and Coastal Marine Waters.

Jacinto, G.S., Sotto, L.P.A., Senal, A.I.S., McGlone, M.L., Escobar, M.T.L., Amano, A., and Miller, T.W. (2011).Hypoxia in Manila Bay, Philippines during the northeast monsoon. Marine Pollution Bulletin 63, 243-248.

Luther, G.W. et al (2004). The Roles of Anoxia, H_2S, and Storm Events in Fish Kills of Dead-end Canals of Delaware Inland Bays. Estuaries Vol. 27, No. 3, p. 551–560.

McGlone, M.L.S.D., G. Jacinto, I. Velasquez and D. Padayao. (2004). Status of water quality in Philippine coastal and marine waters, p. 96-108. In DA-BFAR (Department of Agriculture-Bureau of Fisheries and Aquatic Resources). In turbulent seas: The status of Philippine marine fisheries. Coastal Resource Management Project, Cebu City, Philippines.378 p.

National Science and Technology Council Committee on Environment and Natural Resources (NSTC). (2003). An Assessment of Coastal Hypoxia and Eutrophication in U.S. Waters.

Parsons, T. R., Y. Maita and C. M. Lalli. (1984). A Manual of Chemical and Biological Methods for Seawater Analysis. Pergamon Press, Inc. United Kingdom. Pp 3-8, 22-27, 101-103.

PEMSEA. (2001). Manila Bay: initial risk assessment. PEMSEA Technical Information Report No. 2001/01 112 p. Global Environment Facility/United Nations Development Programme/International Maritime Organization Regional Programme on Building Partnerships in Environmental Management for the Seas of East Asia (PEMSEA), Quezon City, Philippines.

Saeed Shanbehzadeh, Marzieh Vahid Dastjerdi, Akbar Hassanzadeh, and Toba Kiyanizadeh. (2014). Heavy Metals in Water and Sediment: A Case Study of Tembi River. Hindawi Publishing Corporation Journal of Environmental and Public Health Volume 2014, Article ID 858720, 5 pages http://dx.doi.org/10.1155/2014/858720

Samir M. Nasr, Mohamed. A. Okbah, Shaif. M. Kasem (2006). Environmental Assessment of Heavy Metal Pollution in Bottom Sediments of Aden Port, Yemen. International Journal of Oceans and Oceanography ISSN 0973-2667 Vol.1 No.1 (2006), pp. 99-109

Siringan, F.P., Ringor, C.L. (1998). Changes in bathymetry and their implications to sediment dispersal and rates of sedimentation in Manila Bay. Science Diliman10 (2), 12–26.

Zeitoun, M.M., and Mehana, E.E. (2014). Impact of Water Pollution with Heavy Metals on Fish Health: Overview and Updates. Global Veterinaria 12 (2): 2019-231.