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Spatial and tidal profiles of seawater properties, and their relation to coral cover of selected reefs in Iligan City, Lanao Del Norte, Philippines

Angelo A. Responte*, **Jonalyn B. Galorio, Mary Dorothy Anne Y. Seno, Immanuel N. Galorio, Frence Eliza E. Elecho**

Department of Marine Science, College of Science and Mathematics, MSU-Iligan Institute of Technology, Iligan City, Philippines

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ABSTRACT

A hydrographic investigation was conducted in coral reefs along the coast of Iligan bay to evaluate the influence of tides to the spatial distribution of water parameters and determine the relation of the water parameters to the coral cover in the area. Water samples were collected at 0m, 5m and 8m using 1.5L Niskin bottle and water parameters were immediately measured using calibrated handheld meters on board. Coral assessment was done using Photo-transect technique and estimation of hard coral cover was done using Coral Point Count with Excel Extensions (CPCe). Salinity increased with depth and values were higher at high tide. The observed suboptimal salinity may account for the poor cover of hard corals. Temperature was highest at the surface and decreases with depth in both tides. Reef1 had the coldest waters in both tides, warmest at the farthest reefs 3 and 4 from the estuary. Dissolved oxygen decreases with depth in both tides and higher during high tide. At low tide, pH was highest at surface; at high tide pH highest at 5m. At low tide pH was highest at reef1, and lowest at reef4. During high tide pH was uniform at 8.1 in all four reefs. Temperature, pH and dissolved oxygen were within the ideal range for optimum growth and coral reef development. Therefore, the observed poor coral cover was not associated with the status of these parameters.

***Corresponding author:** Angelo A. Responte ✉ angelo.responte@g.msuiit.edu.ph

INTRODUCTION

Surface water quality within a region is influenced by both natural processes and anthropogenic activities (Pejman, 2009). It has become a matter of serious concern because of its effects on human health and aquatic ecosystems including marine life (Gupta *et al.*, 2009). Physico-chemical characteristics are indeed vital water quality parameters for monitoring due to their instability (Efe, 2005), where significant variations in physicochemical parameters affect the quality of water resources. Water temperature can impact individual estuarine species through a variety of processes, including thermal stress (Madeira *et al.*, 2012), through increasing bioaccumulation of pollutants by increasing metabolic processes (Dijkstra *et al.*, 2013), by altering the chemicals present in the water through pollutant volatilisation or degradation (Kibria *et al.*, 2021), or by altering food-web interactions in an ecological community (Chevillot *et al.*, 2017). Waters with low dissolved oxygen conditions impacts the survivability of species (hypoxia) or where DO is completely removed from the water (anoxia). Under such conditions, many species come under extreme stress which may ultimately lead to forced emigration or mortality (Díaz *et al.*, 2011; Jorgensen, 1980). Salinity, especially hyposalinity affected the rates of photosynthesis of zooxanthellae. Beyond that the reduction in salinity in surface waters caused massive mortality of coral reef organisms (Ferrier-Pages *et al.*, 2000). Calcification and saturation state showed a positive correlation for a marine calcareous alga, *Porolithon* sp., by controlling CO3'- concentration with pH (Mackenzie *et al.*, 1989).

Coral reefs are one of the ecosystems with diversity, complexity, and high productivity on earth which are a place for hatcheries, enlargements, and places to find food for another marine biota (Isdianto *et al.*, 2020). Live coral cover is a key indicator in assessing overall reef health. It is a proportion (%) of the reef covered by live hard corals (Eddy *et al.*, 2018). The magnitude of LCC in a coral reef ecosystem depends on the coral calcification performance, with higher calcification rates corresponding to an increase in hard coral cover (Davis *et al.*, 2021). Factors that can affect coral reef life are salinity, pH, DO, nitrate and phosphate, temperature (Luthfi *et al.*, 2017; Luthfi *et al.*, 2019; Isdianto *et al.*, 2020).

The purpose of this study was to determine how temperature, salinity, dissolved oxygen and pH fluctuate with depth, with tide and geographic location, as well as determine the relationship between these water parameters and the hard coral cover of selected coral reef environment in Iligan Bay, Mindanao, Philippines. Due to the absence of data in this particular area in Iligan Bay, this in-situ measurements will serve a crucial role in understanding regional oceanic processes, provides the local community and the local government with information related to the status of reef health in this specific region of Iligan Bay. Further, this study will serve as a source of information for future studies on coral reefs in the region.

MATERIALS AND METHODS

Description of sampling sites

This study was conducted in the coral reefs located in the three coastal barangays of Iligan City, Mindanao, Philippines from January 1, 2022 to December 31, 2022. Reef1 was located in Timoga of barangay Buruun with coordinates 124°10'21" East, 8°12'22" North. The reef was found in the boundary between the barangays of Maria Cristina and Buruun. Reef2 was in barangay Buruun with coordinates 124°11'01"East , 8°12'38" North facing the mouth of the Agus V river with the bridge as its prominent landmark. Reef3 was the first reef in barangay Maria Cristina with coordinates 124°11'22"East , 8°12'55" North fronting a demolished concrete infrastructure on land. Reef4 was the second reef in barangay Maria Cristina with coordinates 124°11'39" East, 8°13'08" North with the Iligan Forest Green Incorporated building as its landmark. The reefs were aligned and separated by a distance of approximately one kilometer and equidistant of approximately 2 kilometers from the shoreline. The four sampling stations were marked by green-colored softdrink bottles used as bouys (Fig. 1).

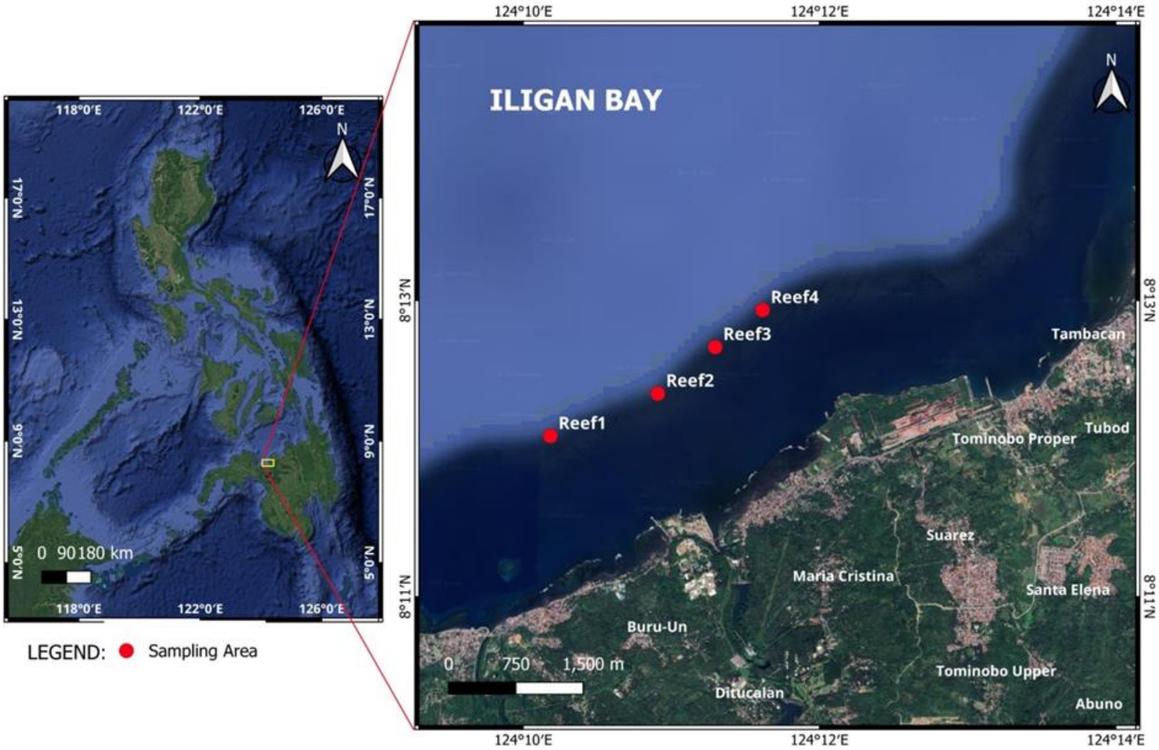

Fig. 1. Location map of the study areas in barangay Buruun and barangay Maria Cristina, Iligan City, Mindanao, Philippines (Source: QGIS v. 3.34.0)

Collection of water samples

The 6 months field sampling started March 1, 2022 to August 30, 2022. Water samples were collected at 0m (surface), 5m, 10m and 15m depths using 1.5 liter Niskin water sampler. The Niskin bottle was lowered from the motorboat to the desired depth by a calibrated nylon rope with attached 10 kilos weight to maintain the vertically upright position of the sampler when currents were very strong. Water sampling for three high tides and three low tides of each month was conducted on separate dates with 1-2 days interval for 6 months at the same time in the morning from 9:00 A.M. to 10:00 A.M. Water sample collection and data recordings from reef1 to reef4 were completed within one hour.

Determination of water parameters

Aliquots of 200 ml water sample from the Niskin bottle were poured to mugs immediately after collection for measurement of water parameters on board the boat. Mugs were used to position the sensors upright while waiting for the readings to stabilize. Dissolved oxygen was measured using a calibrated dissolve oxygen meter (Milwaukee MW600). Water pH, temperature, and salinity were measured using a calibrated multifunction water quality tester. Each parameter was read in triplicates per sample.

Estimation of coral cover

Coral reefs found 7-10 m depth in the four sampling stations were assessed by Digital Photo-transect technique, a modification of the video transect technique (Osborne *et al.*, 1997; Hill *et al.*, 2004). An underwater digital still camera was attached facing downward at the upper end of an aluminum distance bar. The length of the stick was predetermined before the dive to ensure that the area of the substrate to be captured is 1.0 m². During the dive, a 100 m transect line was divided into 3 transects each measuring 20 meters with a 5m interval between transects. Photograph of the substratum was taken at every meter of each 20m transect using an underwater digital still camera (NIKON COOLPIX W300). Twenty frames or photoquadrats per transect line were saved with a total of 60 photoquadrats for the three transects. Photographs were enhanced and analyzed in the laboratory using Coral Point Count with Excel Extensions (CPCe, version 4.1, Kohler *et al.*, 2005) to identify different coral life forms and calculate the percentage cover, which is a key indicator of reef health.

Data analysis

Data on temperature, salinity, dissolved oxygen and pH was analyzed using One-Way ANOVA in Graph Pad Prism software to test for significant difference across depths, across reefs and between tides.

RESULTS AND DISCUSSION

Salinity

The vertical profile of salinity is increasing with depth in both low tides (LT) and high tide (HT) and generally salinity was higher during high tide across depths (Fig. 2a). Salinity range from 8.31 ppt at the surface (0m) to 31.79 ppt of the bottom waters in the coral reef (8m) during low tide and 14.7 ppt (0m) - 33.3 ppt (8m) during high tide.

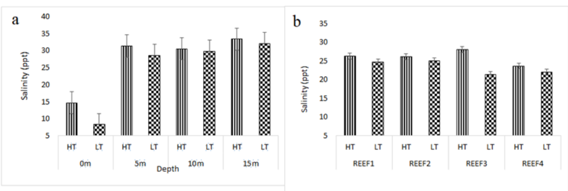

Fig. 2. Salinity variation across depths during high tide (HT) and low tide (LT) (a); horizontally across reefs during HT and LT (b)

Salinity increased with depth and values were higher during high tide in all depth levels. Highest salinity was at 15m with 33.33 ppt and 32.0 ppt in high and low tide respectively while lowest salinity was at the surface with 14.7 ppt and 8.31 ppt during high and low tide (LT) respectively (Fig. 2a). There was an increase in salinity value along with the increase in depth both during high tide and low tide. During high tide, the salinity vertical profile was also higher than at low tide (Rusdi *et al.*, 2019). Salinity values were significantly different in all depths during high tide (p=0.0001).

Using the average salinity of the water from 0m, 10m and 15m in each reef, salinity range was 21.3 ppt-25 ppt at low tide and 26.13 ppt-27.92 ppt at high tide in all studied reefs (reefs 1-4) (Fig. 2b). ANOVA showed no significant difference in salinity in the 4 reefs during low tide (p= 0.6658) and high tide (p=0.5686).

The salinity in all depth levels and in all reefs was higher at high tide because of the intrusion of high saline oceanic waters inshore. When freshwater inputs are low, an estuary can become as salty as the adjacent ocean. When freshwater inputs from Agus V River were high, the estuary became entirely fresh. Salinity is lower during low tide because freshwater is moving out as the ocean level is receding (Havens, 2018). There was no significant variation in salinity from surface to bottom in all the four reefs (p=0.0837).

Temperature

Surface temperature was 28.70C, 28.8°C at 10m and 28.6°C at 15m beyond the reef during low tide. During high tide surface temperature was 28.8°C, 29.1°C at 5m, and 28.9°C at 10m and 28.5°C at 15m beyond the coral reef (Fig. 3a).

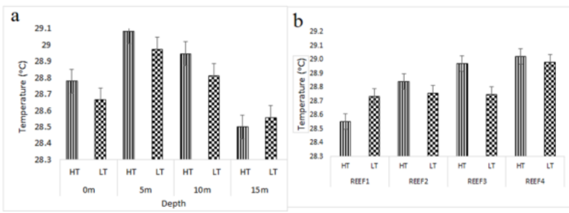

Fig. 3. Average temperature at various depths (a); across reefs (b) during high and low tides

The average temperature of the seawater did not vary significantly from surface to bottom of the reef during low (p=0.2143) and high tide (p=0.0856). This was because the waters were shallow (average depth 6 – 7m) and was easy to experience stirring (Leidonald *et al.*, 2017).

Reef1 had the lowest temperature of 28.6°C (HT) and 28.7°C (LT). Temperature was higher at 28.8°C in reef2 and highest at 29°C in the farthest reefs 3 and 4 from the estuary in both high and low tides. Warmer waters were recorded at the most distant reefs 3 and 4 from the estuary (Fig. 3b). Differences in temperature across reefs was significant only at low tide (p=0.0069). During ebb tide the massive freshwater input from Agus V River appreciably cooled the waters in the estuary and subsequently affected the adjacent reefs1 and 2. The distant reefs 3 and 4 were not affected by the cold, river discharge and showed warmer, stable water temperature of 29°C.

Dissolved oxygen (DO)

The vertical profile of dissolved oxygen showed threshold values at the surface and decreasing DO with depth. Dissolved oxygen range from 5.32 mgL^{-1} at the surface to 4.81 mgL^{-1} at 8m during low tide. At high tides DO was 6.25 mgL^{-1} at surface to 5.93 mgL^{-1} at 8m (Fig. 4a).

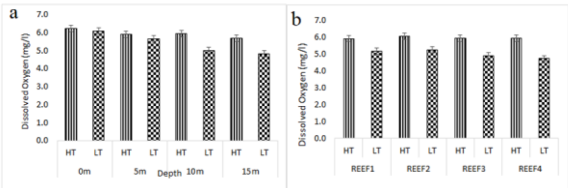

Fig. 4. Average dissolved oxygen across depths (a); across reefs (b) during low and high tide

The highest dissolved oxygen concentration in each reef was at the surface layer of the water because the presence of sunlight in the surface layer of the water helped the photosynthesis process in supplying oxygen to the waters (Sinaga, 2016) and because of the increase in the amount of water mass as well as diluted organic matter during the high tide (Ye *et al.*, 2013). The decrease in dissolved oxygen with increasing depth was thought to occur because oxygen supply from photosynthesis and diffusion processes decreased (Sinaga, 2016); and waters oxygen diffusion became slower, except in conditions of strong turbulence (Araoye, 2009).

On the horizontal scale, dissolved oxygen values were higher during high tide in all the reefs with values ranging from 5.92 mgL^{-1} to 6.05 mgL^{-1}. During low tide DO was lower between 4.73-5.25 mgL^{-1} only (Fig. 4b). Reef2 nearest to the estuary, had a higher DO of 6.05 mgL^{-1} while the other 3 reefs distant to the estuary have relatively lower DO values ranging from 5.92 mgL^{-1}- 5.95 mgL^{-1}. In freshwater, DO reaches 14.6 mgL^{-1} at 0°C and approximately 9.1, 8.3, and 7.0 mgL^{-1} at 20, 25, and 35°C, respectively. At sea level and at 20°C the DO value is 9.1 mgL^{-1} in freshwater (Bozorg-Haddad *et al.*, 2021). There was no significant difference in DO across reefs during HT (p=0.6658) and LT (p=0.8155).

pH

At low tide, pH range was 8.11-8.18, highest at surface. Conversely, pH range at high tide was 8.07-8.20, lowest at surface (Fig. 5a). The decrease in pH at the bottom during low tide was due to increase in microbial activity to decompose organic matter so that oxygen decreased and carbon dioxide increased. Increased CO_2 would make the waters became more acidic (pH decreases) (Araoye, 2009; Sinaga , 2016). There was no significant difference in pH across depths during low tide (p=0.3943) and high tide (p=0.6565). pH was consistently higher at low tide, highest at reef1, 8.18 and lowest at 8.11 at reef4. During HT pH was uniform at 8.1 in all the four reefs (Fig. 5b). There was no significant difference in pH across the reefs during low tide (p=0.2634) and high tide (p=0.6564).

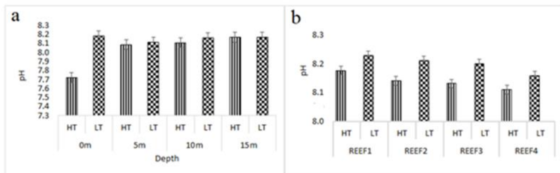

Fig. 5. pH at various depths (a); across reefs (b) during high and low tide

Percentage coral cover

The average scleractinian coral cover in the studied reefs estimated using the Coral Point Count with Excel extension (CPCe) was 23.39%, classified as poor (0-24.9% poor) using the quartile scale established by Gomez *et al.* (1981, 1994a, 1994b) and the Department of Environment and Natural Resources (DENR) Administrative Order (DAO 2013). The findings of this recent study confirmed reports of national assessment that more than 90% of the Philippine reefs are in poor (76 out of 166 stations) and fair (80 out of 166 stations) conditions (Licuanan *et al.*, 2017).

Results of the current study was lower compared to neighboring coastal municipality of Lugait, Misamis Oriental with hard-coral cover of 30.11% (Tabugo *et al.*, 2016) and Baliangao, Misamis Occidental with 34% (Licuanan *et al.*, 2017). Factors that can affect coral reef life based on chemical oceanography are salinity, pH, DO, nitrate and phosphate. Almost all types of corals are very sensitive to changes in physical and chemical waters (Luthfi *et al.*, 2017).

Corals flourish in salinities which are approximately close to optimal salinity value of about 35‰ (Bakus, 1973). Salinity of 30–35 psu at 25°C led to the best *Goniopora columna* growth and survival mainly because of their enhanced nutrient absorption rate, polyp expansion rate, metabolic rate and adaptability (Ding *et al.*, 2022). In this current study, salinity of the reef waters which range from 21.3-25 ppt at LT and 26.13-27.92 ppt at HT is significantly lower than the requirement for corals which is 30-35 ppt. Pearson correlation test showed that salinity is negatively correlated with hard coral cover (r= -0.263). This suboptimal salinity value may account for the poor cover of hard corals in the region.

Sea surface temperatures (SSTs) considered to be ideal for reef development lie between 25°C-29°C (James *et al.*, 1992; Clansen *et al.*, 1975); 17°C-34°C (Guilcher, 1988). The calcification and upward growth rates of many coral species increase linearly with annual SST (Brachert *et al.*, 2006; Lough *et al.*, 2011). However, this trend seems to reverse above an annual temperature of 26–27°C with a reduction of the calcification and extension rate at higher temperatures (Lough *et al.*, 2014). SSTs that rise by 1°C or 2°C above their average value over an extended period of time can inhibit coral growth and cause coral bleaching (Cahyarini, 2011; Rajabson *et al.*, 2023).

In the current study the average temperature of the waters was 29°C which suggests that water temperature was within the permissible range of 26-30°C required by the DENR and within the ideal temperature for optimum growth and coral reef development. Pearson correlation test showed low positive correlation between temperature and scleractinian coral cover (r=0.123). Therefore, the temperature of the reef waters was not associated to its observed poor coral cover.

The ideal pH range for marine life is 6.5-8.5 (Corvianawatie *et al.*, 2018). The standard pH value set by the DENR is 7.0-8.5. The alkaline pH observed could be due CO_2 utilization in photosynthesis. Higher seawater pH would help in the precipitation of calcium carbonate which in turn would help in the formation of interstitial lime paste most useful for the coral development (Vacelet, 1984). In the present study pH remained alkaline with ranges 8.11-8.18 LT and 8.07-8.2 HT and an average of 8.1. There was no significant fluctuation in water pH in various depths and between reefs. pH is within the ideal range of the seawater quality standards necessary to support marine life and does not explain the observed poor coral cover of the studied reefs.

Oxygen concentration is one of the main environmental factors limiting the occurrence of species in nature (Dodds *et al.*, 2007). Through metabolism, ingested food and stored reserves are converted into energy to fuel any function in organisms (Claireaux *et al.*, 2016). Oxygen works as the terminal electron acceptor in aerobic energy (ATP) production (Wang *et al.*, 2014).

Dissolved oxygen in coral reefs in the Tropical Eastern Pacific typically ranges from 3.4 to 13.6 mg L^{-1} at 27°C (Nelson *et al.*, 2019). The mean dissolved oxygen concentration in different coral reef sites around the world is 4.5 mgL^{-1} (Upwelling season)–6.6 mg L^{-1} (Downwelling season) (Castrillón-Cifuentes, 2023). The dissolved oxygen values in these reefs met the minimum water quality standard of 6.0 mgL^{-1} set by the DENR. The average DO of 6 mgL^{-1} reported in this study approaches the maximum value of the mean DO in the global scale. Pearson correlation test showed low positive relation between dissolved oxygen with scleractinian coral cover (r=0.137). Therefore, the poor coral cover was not associated with the DO status of the reef waters.

CONCLUSION

Salinity increased with depth during low and high tide and values were higher during high tide. Salinity varied significantly in all depths only during high tide and did not vary significantly between reefs with tide. Salinity of the reef was significantly lower than the requirement for corals which is 30-35 ppt. This suboptimal salinity value may account for the poor cover of hard corals in the region. In both tidal cycles temperature was low at the surface and decreased without significant difference until the reef bottom. Temperature increased from reef1 near the estuary to the most distant reef4. Oxygen showed threshold values at the surface and decreased with depth without significant difference across reefs during high and low tides. Dissolved oxygen values were higher during high tide in all the four reefs. pH was highest at surface , lowest at 5 m at low tide. Conversely, pH at high tide was lowest at surface, highest at 5m. There was no significant difference in pH across the reefs during low and high tide.

Dissolved oxygen, temperature and pH met the minimum water quality standard for Class SA of the Water Quality Guidelines for Primary Parameters set by the Department of Environment and Natural Resources (DENR). The observed values were within the ideal range for optimum growth and coral reef development; therefore, the parameters did not explain the poor coral cover in the barangay.

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