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Physicochemical Monitoring and Assessment of the Water Quality in the Mangrove Forest of Del Carmen, Siargao, Philippines

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Water quality monitoring is essential in determining the basic factors affecting the water's conditions and identifying monthly trends in the aquatic ecosystem. This study monitored and assessed the water quality in the mangrove forests of Del Carmen, Siargao Island. For a period of four months, five stations were examined for several physicochemical characteristics. Temperature, pH, and dissolved oxygen (DO) were measured using a multiparameter probe, while phosphate and nitrate concentrations were determined using commercially available test kits. Aside from DO, all physicochemical parameters met the standard for marine protected waters, based on the Department of Environmental and Natural Resources Administrative Order 2016–08 (DAO 2016–08). The mangroves' soil contains bacteria that rely on DO for their metabolic processes, which explains the comparatively low DO levels that are typically measured in these habitats. Appropriate statistical analyses revealed significant temporal changes in the temperature and DO levels, as well as spatial changes in pH levels. The fluctuations brought about by the monsoonal cycles resulted in warmer temperatures in July and August, while October and November had higher DO levels. Additionally, lagoonal stations showed increased pH levels due to reduced freshwater input. Overall, the water quality of the mangrove forests in Del Carmen is within the standard level for marine protected waters and only varies spatiotemporally due to monsoonal cycles and the type of coastal area.

Keywords: DAO 2016–08, mangrove ecosystems, marine protected area, spatiotemporal variability, water quality assessment

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Introduction

Water quality changes with time and space, so continuous water quality monitoring and assessments are necessary to diagnose the present condition of aquatic ecosystems (Satheeshkumar & Khan, 2011). With the growth of human populations and commercial industries, tremendous pressure is generated on the ecosystem, leading to declining water quality and biodiversity (Herrera-Silveria & Morales-Ojeda, 2009; Prasanna & Ranjan, 2010). One naturally recognized solution involves using mangroves as water quality filters through deposition, absorption, and accumulation of pollutants (Cochard, 2017; Pham et al., 2022). Despite the ecological and economic benefits, however, a rapid decline in mangroves' complexity, structure, and function can be observed worldwide (Lee et al., 2014).

The Philippines, for example, logged a vast majority of its mangroves for firewood and tanbarks and converted large areas of mangroves into fishponds for the culturing of milkfish (*Chanos chanos*) and shrimps during the 1950s and 1960s (Melana et al., 2005). Significant efforts to rehabilitate the destroyed mangroves only began in the 1980s and 1990s. One of the key efforts included the declaration of Siargao Island Protected Landscape and Seascape (SIPLAS) on October 10, 1996, through Presidential Proclamation No. 902. As a result, the island's mangrove forests have expanded, increasing from 42.95 km² in 2011 to 48.71 km² in 2018 (DENR, 2015; Mascariñas, 2019). Moreover, the recent biodiversity survey of Del Carmen's mangrove forest in 2021 showed that it is a home of interesting species, a host to unique floral assemblages, and a haven of high floral diversity (Daquioag, 2021). This has contributed to the recent move to declare Del Carmen's mangrove forest as a Ramsar site. This recognition underscores its global importance in maintaining healthy ecosystems and supporting biodiversity, protected under an international

agreement (Conventions on Wetlands Secretariat, 2024). Despite the attention brought by the recent development, there is no published literature on the present condition of the water quality of Del Carmen's mangrove forest.

DENR Administrative Order No. 2016-08 (DAO 2016-08) was introduced to establish classification guidelines for water bodies in the country and to monitor enhancement or degradation in water quality, including SIPLAS under Class SA for protected marine waters (DENR, 2015). This guideline sets standard values for essential water quality parameters affecting mangrove biota, such as dissolved oxygen, temperature, pH, and nutrients (Kumar et al., 2006). As such, a four-month water quality monitoring program of Del Carmen's mangrove forest was conducted to assess compliance with the DAO 2016-08's Class SA standards and evaluate spatiotemporal variations. The parameters were chosen explicitly with the consideration that they could be monitored by trained community members or local government units using cost-effective methods, thus ensuring the facilitation of long-term data collection in the future.

Materials and Methods

Study Area

Del Carmen is one of the nine municipalities of Siargao located on the central westernmost point of the island. The mangrove forest in Del Carmen is the thickest and most extensive mangrove population on the island, covering a total of 8,620 ha. To assess the water quality of Del Carmen's mangrove forest, the researchers strategically selected five sampling stations across various environmental settings within the forest (Figure 1). Station 1, located near the Del Carmen boardwalk, reflects potential impacts from human activity due to it being an eco-park. Station 2, situated northeast of Binoscogan Island, captures conditions near an outlet for inland waters. Station 3, positioned off the coast of the Del Carmen port, targets a potential area of urban influence. Station 4, downstream of Baban Lagoon, represents a lagoon that is a potential ecotourism site. Station 5, located near Sugba Lagoon, was chosen since it is near a famous ecotourism destination of the municipality (Supplementary Figure 1).

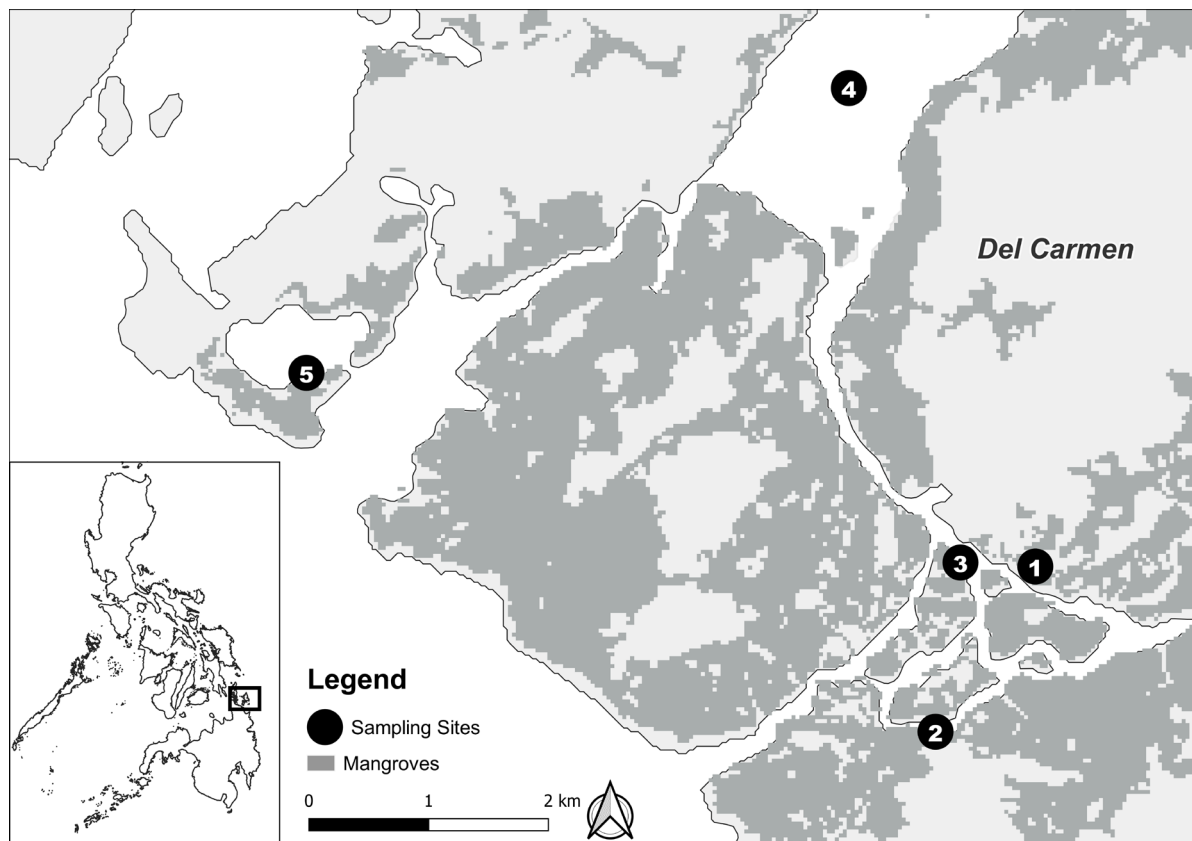


Figure 1. Map of the five sampling stations along Del Carmen's mangrove forest : (1) Del Carmen boardwalk, (2) Northeast of Binoscogan island, (3) Coast of Del Carmen port, (4) downstream of Baban Lagoon, and (5) near Sugba Lagoon.

Data Collection

To assess seasonal variations, water quality was evaluated and monitored for two sampling periods (July – August 2022 and October - November 2022), representing both southwest monsoon (July and August) and northeast monsoon (October and November). *In situ* measurements of temperature, pH, and dissolved oxygen (DO) were obtained at subsurface depths using a pre-calibrated multiparameter probe (YSI EX01 Multiparameter Sonde) to ensure data accuracy. Concurrently, grab samples were collected for phosphate and nitrate analysis in triplicate using API® test kits. While acknowledging limitations in precision and accuracy compared to laboratory methods, these cost-effective kits were chosen for their ease of use, promoting citizen science initiatives, particularly in resource-limited areas. The kits can detect nitrate within 0 mg/L to 160 mg/L and phosphate within 0 mg/L and 10 mg/L. All sampling collection was conducted between 9:00 AM – 4:00 PM in adherence to the guidelines outlined in DAO 2016-08.

Data Analysis

The DENR Administrative Order No. 2016-08 (DAO 2016-08) provides a comprehensive set of water

quality guidelines and general effluent standards across the different water bodies in the Philippines. It sets specific limits for various physicochemical parameters such as DO, pH, and temperature, among others, which are essential for assessing and monitoring the water quality to ensure the health of aquatic ecosystems and safety for human use. The SIPLAS, classified under Class SA, represents designated protected marine waters with high ecological importance. Table 1 presents standard values for our selected physicochemical parameters, which were compared with the data obtained in this study.

Table 1. Water quality guidelines for the five chosen parameters for protected marine water (Class SA).

Parameter	Unit	Value
Temperature	°C	26–30
pH	Range	7.0–8.5
Dissolved oxygen	mg/L	6
Nitrate	mg/L	10
Phosphate	mg/L	0.1

One-way Analysis of Variance (ANOVA) and Kruskal-Wallis were used to determine if there were significant spatiotemporal variations in the physicochemical parameters. Normally distributed data were analyzed through one-way ANOVA, and those that did not achieve the homogeneity of variance (Levene's tests) were $\log(x+1)$ transformed. Kruskal-Wallis, a non-parametric one-way ANOVA, was conducted to the data that were not normally distributed after the transformation (Zar, 1984). Physicochemical parameters in which a significant spatiotemporal difference was observed underwent Tukey's test as a post hoc analysis. All statistical analyses were performed on SigmaPlot 14.0.

Results

Comparison with DAO 2016-08 standard guidelines

The temperature in all sampling months predominantly passed the DAO 2016-08 standard for marine-protected waters ($26^{\circ}\text{C} - 30^{\circ}\text{C}$) except for the temperature in Station 2 during July and August, which was slightly above the standard (Figure 2). The pH was primarily within the neutral levels ($7.0 - 8.5$) regardless of the sampling month or station. However, DO was observed to be below the standard level ($< 5.5 \text{ mg/L}$) except in Station 5 during the months of October and November. Phosphate levels were below the detection limit of the phosphate test kit (0 mg/L) at any station throughout the sampling period, whereas the nitrate levels were within the standard ($<10 \text{ mg/L}$).

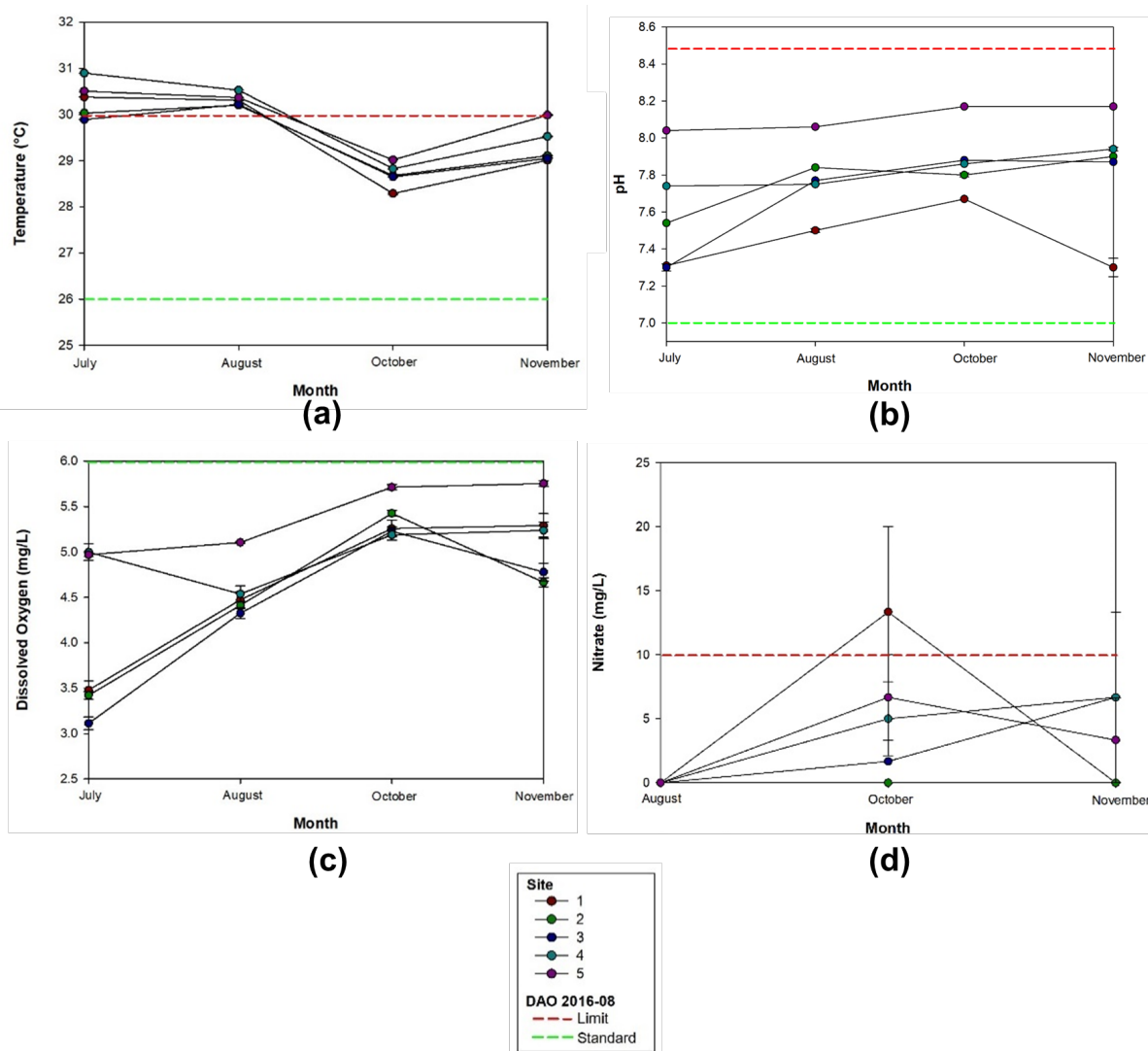


Figure 2. Monthly variation of physicochemical parameters: (a) temperature, (b) pH, (c) DO, and (d) nitrate along five sampling stations. Error bar represents standard error.

Spatiotemporal variations in water quality parameters

Temperature, DO, phosphate, and nitrate levels were found to be constant across stations. Table 2 reveals spatial variation in pH, ranging from 7.45 to 8.11, with higher values recorded at stations 4 and 5 compared to stations 1 and 3.

Table 2. Grand mean \pm standard error of temperature ($^{\circ}\text{C}$), pH, dissolved oxygen (DO mg/L), phosphate (mg/L), and nitrate (mg/L) measured at the five sampling stations in Del Carmen's mangrove forest.

Parameters	Stations					ANOVA		Kruskal Wallis		Tukey's Test
	1	2	3	4	5	F	p	H	p	
Temperature ($^{\circ}\text{C}$)	29.50 ± 1.02	29.50 ± 0.73	29.45 ± 0.73	29.94 ± 0.94	29.97 ± 0.67			2.24	0.69	
pH	7.45 ± 0.18	7.77 ± 0.16	7.71 ± 0.28	7.82 ± 0.10	8.11 ± 0.07	7.84	0.00*			S5 > S1, S3; S4 > S1
DO (mg/L)	4.63 ± 0.85	4.48 ± 0.83	4.36 ± 0.91	4.99 ± 0.32	5.39 ± 0.41	1.39	0.28			
Phosphate (mg/L)	DL	DL	DL	DL	DL					
Nitrate (mg/L)	3.33 ± 6.67	DL	2.08 ± 3.15	2.92 ± 3.44	2.50 ± 3.19			2.71	0.61	

Note. DL = Detection Limit (< 0 mg/L). Significant differences ($p < 0.05$) of post hoc tests are indicated by superscripts. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Significant temporal variations were observed for temperature and DO (Table 3). The temperature levels ranged from 28°C to 30°C , and July and August were warmer than October and November. Contrastingly, DO levels were higher during October and November. Throughout the monitoring period, pH levels remained stable, while phosphate levels were constantly at the detection limit, and nitrate levels also often approached or were at the detection limit.

Table 3. Grand mean \pm standard error of temperature ($^{\circ}\text{C}$), pH, dissolved oxygen (DO mg/L), phosphate (mg/L), and nitrate (mg/L) per month in Del Carmen's mangrove forest.

Parameters	Stations				ANOVA		Kruskal Wallis		Tukey's Test
	July	August	October	November	F	p	H	p	
Temperature ($^{\circ}\text{C}$)	30.34 ± 0.40	30.33 ± 0.13	28.69 ± 0.27	29.34 ± 0.42	30.77	$< 0.001^{***}$			Jul., Aug. > Oct. > Nov.
pH	7.59 ± 0.31	7.78 ± 0.20	7.88 ± 0.18	7.84 ± 0.32	1.20	0.34			
DO (mg/L)	4.00 ± 0.91	4.57 ± 0.31	5.36 ± 0.21	5.15 ± 0.43	6.48	0.00*			Jul. < Oct., Nov.
Phosphate (mg/L)	DL	DL	DL	DL					
Nitrate (mg/L)	DL	DL	5.33 ± 5.19	3.33 ± 3.33					

Note. DL = Detection Limit (< 0 mg/L). Significant differences ($p < 0.05$) of post hoc tests are indicated by superscripts. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Discussion

Comparison with DAO 2016-08 standard guidelines

Four of the five critical physicochemical parameters (temperature, pH, phosphate, and nitrate) met the standard water quality for marine protected waters set under DAO 2016-08. These parameters are critical indicators of a healthy environment for the mangrove ecosystem. For instance, temperature can affect the mangroves' ability to assimilate CO₂. While mangroves thrive at temperatures around 30°C, exceeding this range (between 40°C - 55°C) can lead to heat damage and hinder CO₂ assimilation (Ball et al., 1988; Krauss et al., 2008). An acidic environment, on the other hand, can result in mangrove mortality even though mangroves have been prospected to reduce ocean acidification (Hossain et al., 2015). Moreover, nitrate and phosphorus levels significantly influence mangrove development (Reef et al., 2010). Nitrate is crucial for photosynthesis, whereas sufficient phosphorus uptake ensures proper mangrove tissue growth (Pradipta et al., 2021). The observation that all physicochemical parameters met the required DAO 2016-08 standard suggests good water quality in Del Carmen's mangrove forest. However, it is essential to acknowledge the limitations of using test kits for nitrate and phosphorus analysis due to their limited detection range. Further studies employing a broader range of parameters and potentially more advanced techniques such as spectrophotometry, flow injection analysis, and high-performance liquid chromatography, could provide a more comprehensive water quality assessment (Li & Liu, 2018).

DO was the sole physicochemical parameter falling below the DAO 2016-08 standard, with concentrations measured at less than 5.5 mg/L. Notably, DO levels were very low in July and August, coinciding with high temperatures nearly exceeding the DAO 2016-08 threshold of 30°C. This inverse relationship between temperature and DO is well-established, as oxygen is less soluble as temperature increases (Garcia-Soto et al., 2021). Although the relatively low DO observed in the mangrove waters of Del Carmen may raise concerns, similar observations have been well-documented in other healthy mangrove ecosystems (Satheeshkumar & Khan, 2011; Behera et al., 2014). Variations in DO levels can result from various interactions, including diurnal biological processes, photosynthesis and respiration, and tidal variations in water levels (Gardner & Gorman, 1984; Buffoni & Cappelletti, 1999). Moreover, mangroves'

soil contains bacteria that can strip DO from the water to perform metabolic functions (Mattone & Sheaves, 2017).

Spatiotemporal variations in water quality parameters

The consistent temperature, DO, phosphate, and nitrate readings across all sampling stations and the findings that the water quality passed the DAO 2016-08 requirements suggest good overall water quality of Del Carmen's mangrove forest. It is well-documented that healthy mangrove ecosystems can support clean water by acting as natural filters for suspended particles from rivers, stormwater runoff, and tidal water (Adame et al., 2010; Lacerda et al., 1988). Future studies comparing water quality within and outside Del Carmen's mangrove forest could offer a clearer understanding of these mangroves' role in maintaining water quality within the area.

The only spatially varying physicochemical parameter was pH, which was higher in stations 4 (Baban Lagoon) and 5 (Sugba Lagoon), both of which are lagoons surrounded by mangrove vegetation. According to Palmer (2011), lagoons receive a low inflow of freshwater leading to an inverse relationship between salinity and pH, as observed in stations 4 and 5 where increased salinity correlates with lower pH levels. On the other hand, freshwater influx lowered the salinity of the water body in non-lagoonal areas, resulting in a reduction in pH, as seen in stations 1-3.

According to Saraya (1984), one of the two dominant factors that substantially control the environmental conditions of mangrove waters is seasonal variations brought about by the monsoonal cycles. The southwest (SW) monsoon and northeast (NE) monsoon may be responsible for this study's significant observation of temperature and DO fluctuation, respectively. In the Philippines, the SW monsoon occurs from May to September, while the NE monsoon lasts from October to March (PAGASA, 2022).

The warmer sampling months, July and August, are part of the SW Monsoon. As observed in the studies of Arthur (2000), the warm, moist winds from the SW monsoon increase the water's temperature. Pawar (2013) also noted the higher water temperature in mangrove ecosystems during the SW monsoon. The SW monsoon's clear skies would have encouraged intense radiation, raising the air's temperature and, consequently, the surface water's

temperature (Kumar et al., 2006). In particular, temperature differences are due to factors such as solar radiation, cloud cover intensity, wind direction, and thermal exchanges through tidal currents.

The sampling months, October and November, which fall during the NE monsoon season, displayed higher DO levels. Weather factors such as low light intensity due to high cloud cover, runoff, and strong turbulence by wave action characterize the NE monsoon (Kannan & Kannan, 1996). Since the solubility of oxygen depends on the temperature of the water, cold winds that are common during the NE monsoon may have contributed to this increase in DO levels (Kamarudin et al., 2020). This indicates that cooler waters may contain greater DO than warm waters to achieve 100% air saturation.

Conclusion

All physicochemical parameters, except for DO, meet the requirements for marine protected waters' standard water quality as specified by DAO 2016-08. Due to the monsoon seasons, temperatures were higher in July and August, while DO levels were higher in October and November. Moreover, higher pH levels were observed in lagoonal stations, likely influenced by reduced freshwater input. Overall, the study provides a broad picture of Del Carmen's mangrove forest's current state through a four-month trend of its water quality. These parameters were selected for cost-effective monitoring of local stakeholders, long-term data collection, and community involvement. The study's baseline assessment, along with future monitoring efforts, can aid local authorities in formulating sustainable ecosystems and enhancing current implementations.

Recommendation

While the study provided a valuable snapshot of the water quality status of Del Carmen's mangrove forest, further research is necessary for a comprehensive understanding. A sustained, long-term monitoring effort spanning several years is crucial to reveal seasonal trends and fluctuations in water quality over time. Additionally, investigating the influence of anthropogenic activities on water quality is essential for identifying potential threats and implementing targeted conservation measures.

Authors Contribution

DMGQD Conceptualization, Methodology, Validation, Formal Analysis, Investigation, Data Curation, Writing – Original Draft, Writing – Review & Editing, Visualization. **AVHN** Conceptualization, Methodology, Validation, Investigation, Writing – Review & Editing. **PASC** Conceptualization, Methodology, Validation, Investigation, Writing – Review & Editing. **DTD** Conceptualization, Methodology, Validation, Investigation, Supervision, Project Administration, Writing – Review & Editing

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Declaration of Conflicting Interests

The authors declare that there are no conflicts of interest concerning the research, authorship, and/or publication of this article.

Ethics Statement

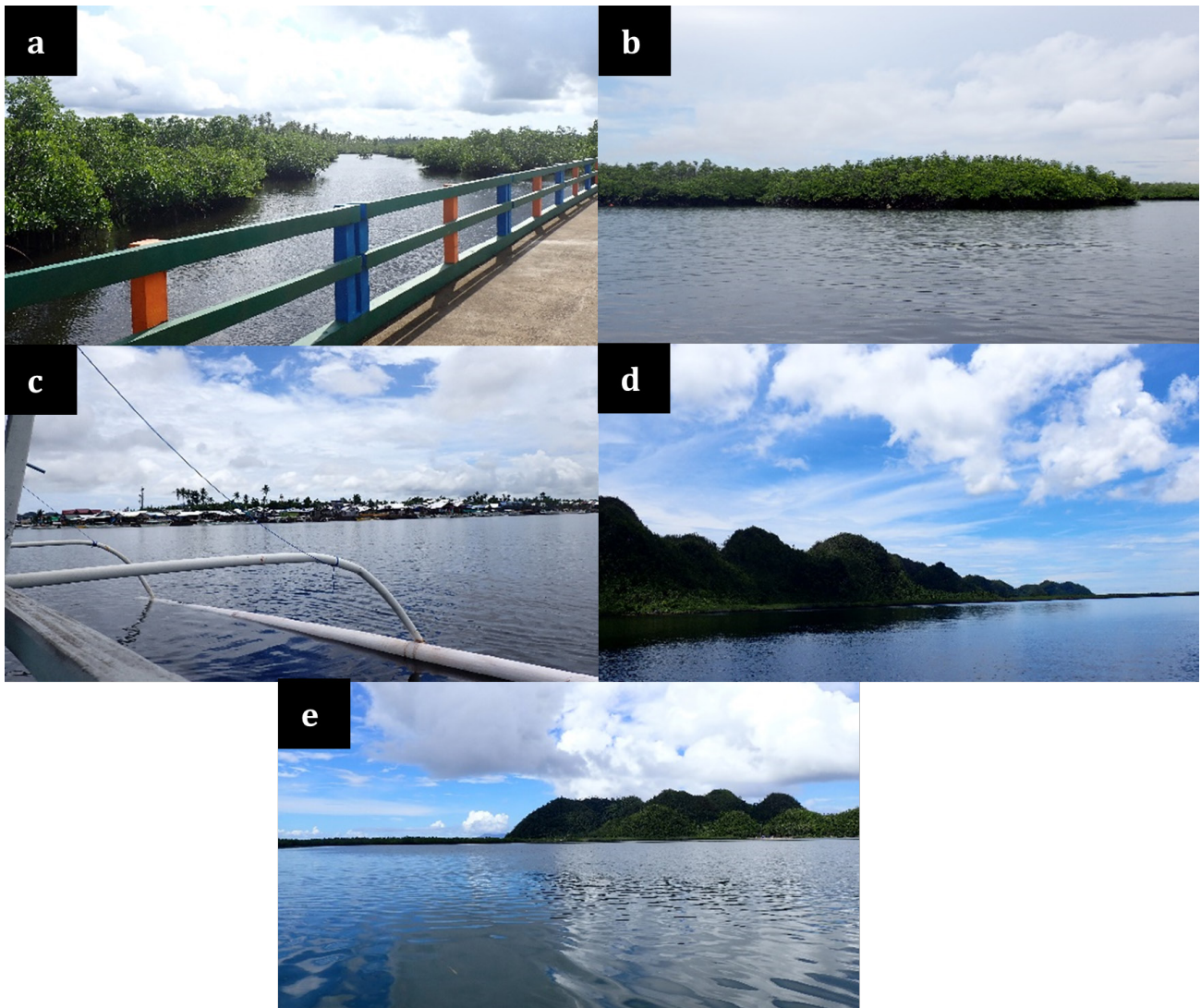
The research followed ethical principles throughout data collection and analysis to ensure the well-being of the environment. Proper permissions and permits were obtained from relevant authorities.

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SUPPLEMENTARY FIGURE 1.

Images of sampling stations in Del Carmen's mangrove forest: (a) Del Carmen boardwalk, (b) Northeast of Binoscogan island, (c) Del Carmen port, (d) near Baban Lagoon, and (e) near Sugba Lagoon.