Exploring the potential of low-cost portable CO_2 meter in the assessment of soil CO_2 efflux in Philippine mangroves

Sean Paul B. Manalo and Severino III G. Salmo*

Institute of Biology, College of Science, University of the Philippines Diliman

ABSTRACT

Mangroves are critical carbon sinks that play a vital role in the global carbon cycle. However, studies examining soil CO_2 emissions in Philippine mangroves remain limited. This study assessed the soil CO_2 efflux of mangroves in Prieto Diaz, Sorsogon (northeastern Philippines) across different stand types (as natural, recolonized, and restored stands) and examined other ecological parameters influencing it. Using a handheld CO_2 meter in a modified static closed chamber, we observed the highest mean CO_2 efflux in recolonized sites (19.00 ± 4.59 $MgCO_2$ ha^{-1} yr^{-1}), followed by the restored (16.46 ± 4.90 $MgCO_2$ ha^{-1} yr^{-1}) and natural sites (15.30 ± 3.10 $MgCO_2$ ha^{-1} yr^{-1}). However, we found no significant differences across stand types. Additionally, we found that soil CO_2 efflux was positively correlated with canopy cover (r = 0.52) and negatively correlated with faunal burrow density (r – 0.40) and width (r = –0.36). Compared to other studies, our mean CO_2 efflux values were in the lower range, probably due to the lower sensitivity of the handheld CO_2 meter (an acknowledged limitation of this study). Nonetheless, our findings highlight the potential of the low-cost handheld CO_2 meter for community-based monitoring of mangroves, particularly in assessing the contribution of managed mangroves in the reduction of CO_2 emission.

*Corresponding author
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INTRODUCTION

Mangroves are important coastal ecosystems that provide essential ecosystem services, including biodiversity conservation, coastal protection, food provisioning, and carbon sequestration (Leal and Spalding 2024). As carbon sinks, mangrove forests store an average of 693 Mg C ha^{-1} (Alongi 2022) but with a global potential emission of 7.0 Tg CO_2e yr^{-1} (as a result of mangrove loss; Atwood et al. 2017). This highlights the potential of mangrove conservation and restoration in mitigating and offsetting greenhouse gas (GHG) emissions, contributing to global climate change adaptation and mitigation efforts. Among GHGs, CO_2 is relatively frequently studied because it is the primary focus of climate policies and mitigation strategies, particularly in countries' Nationally Determined Contributions (NDC) under the Paris Climate Agreement (Adame et al. 2018; Arifanti et al. 2022). In addition to quantifying changes in carbon stock, measuring CO_2 efflux provides a better understanding of how mangroves capture the exchanges of carbon from the ecosystem to the atmosphere (Howard et al., 2014).

In Asia, CO_2 efflux of mangrove soils have been extensively investigated in countries such as China and Indonesia (Chen et al. 2016; Sheng et al. 2021; Sasmito et al. 2022; Harahap et al. 2023; Arifanti et al. 2024). These studies have provided insights on how land use and other environmental variables influence CO_2 efflux, which reflects the combined contribution of heterotrophic and autotrophic respiration in the soil (Hien et al. 2018; Cameron et al. 2021). Geomorphic position, duration of hydroperiod, mangrove vegetation (e.g. canopy cover, litterfall, root structures), and faunal

KEYWORDS

CO_2 efflux, Philippine mangroves, conservation, restoration, recolonized fishponds

activities (e.g. crab burrowing) have been linked to either high or low efflux (Castillo et al. 2017; Cameron et al. 2019; Royna et al. 2024; Hua et al. 2025). A "natural" or "intact" mangrove (i.e., mature and undisturbed) has lower CO_2 efflux as compared to a disturbed mangrove (Sidik et al. 2019; Sasmito et al. 2022). Restored mangroves that closely resemble natural mangroves may also have lower CO_2 efflux (Sidik et al. 2019). Studies on soil CO_2 efflux in the Philippine mangroves are still limited. To date, only one study, conducted in the mangroves of Honda Bay, Palawan (western Philippines), has been reported (Castillo et al. 2017). This could be due to the lack of research interest or the high cost of conventional equipment in measuring CO_2 efflux. This underscores a significant knowledge gap in the role of Philippine mangroves in the regulation and reduction of CO_2 emissions.

Addressing this gap is essential in understanding how CO_2 emissions are influenced by changes in mangrove environmental conditions and management practices. An understanding of the mangrove CO_2 efflux can help inform sustainable mangrove management and restoration strategies for Philippine mangroves. Therefore, this study aims to assess the soil CO_2 efflux of mangroves in different mangrove stands (as natural, recolonized, and restored) in Prieto Diaz, Sorsogon (northeastern Philippines). Specifically, the study aims to (1) compare soil CO_2 efflux across different stand types, (2) assess the influence of environmental parameters with CO_2 efflux, and (3) explore the potential of using a handheld CO_2 meter in soil CO_2 monitoring in Philippine mangroves.

MATERIAL AND METHODS

Description of study sites

This study was conducted in six mangrove sites across different stand types in Prieto Diaz, Sorsogon: **NF** Natural Fringe, **NI** Natural Interior, **RF** Restored Fringe, **RI** Restored Interior, **CM** Recolonized Fringe**, CY** Recolonized Interior (Figure 1; Table 1). The site is recognized to be one of the earliest "successful" mangrove restoration sites in the Philippines (Labutap et al. 2013). The municipality of Prieto Diaz (13.0179300°, 124.1867900°) is located in the Bicol Peninsula on the southeasternmost portion of Luzon Island and belongs to the North Philippine Sea marine biogeographic region. Prieto Diaz has a tropical rainforest climate based on the Koppen Climate Classification (Beck et al. 2018) and is categorized as open coast with a carbonate sedimentary setting (Worthington et al. 2020). Based on stand type, two sites are classified as 'natural' which are intact mangroves that are neither planted nor recolonized; two sites as 'restored' or planted (ca. 35 yrs); and two sites as 'recolonized' which are secondary mangroves that have undergone succession post-fishpond abandonment (ca. 10–15 yrs). Sites were further classified based on geomorphic position as either fringe or interior (Table 1).

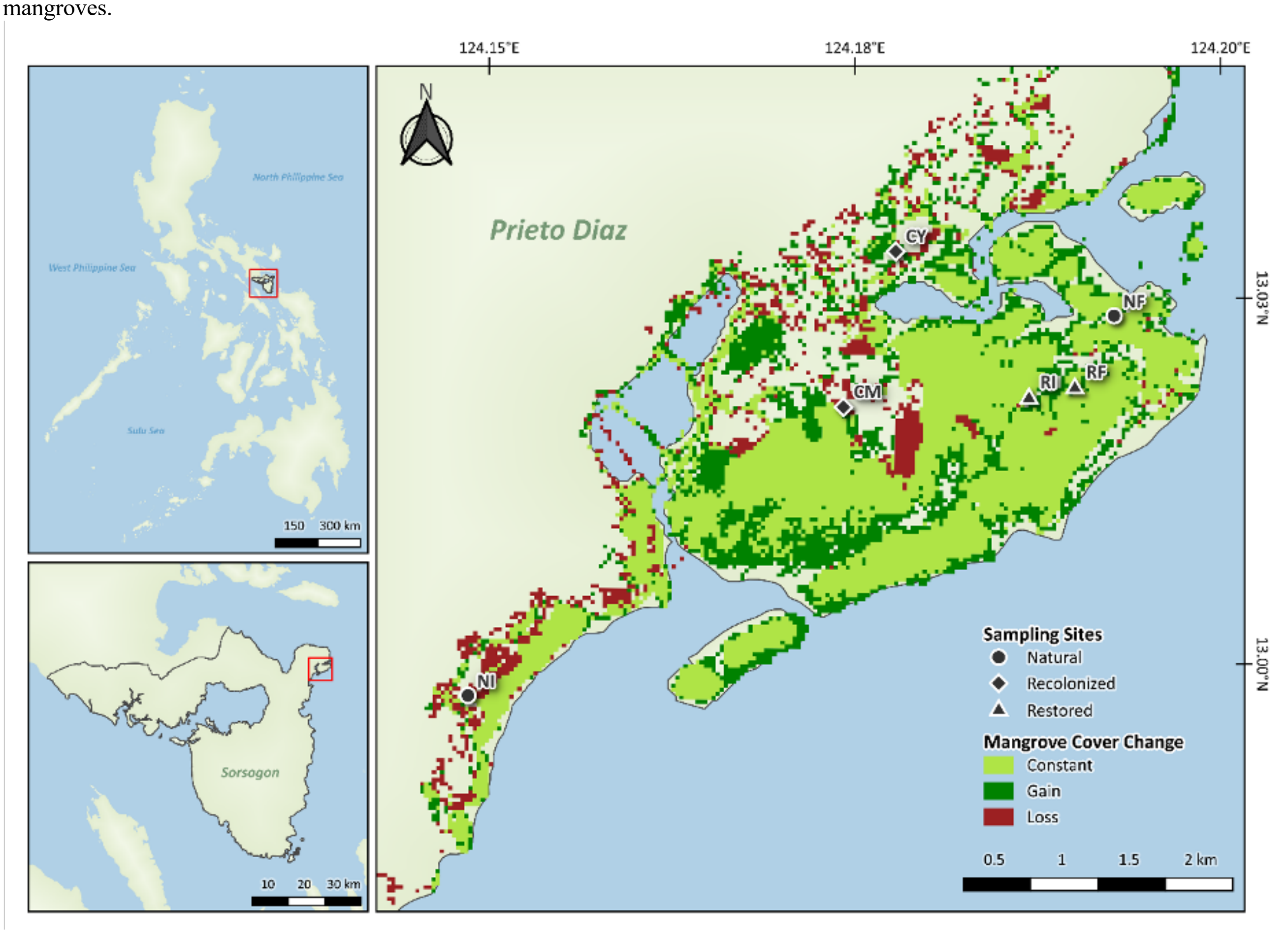

Figure 1: Location of sampling sites and mangrove cover changes from 2000 to 2024 in Prieto Diaz. (NF Natural Fringe, NI Natural Interior, RF Restored Fringe, RI Restored Interior, CM Recolonized Fringe, CY Recolonized Interior). Inset maps show the location of the study area relative to the Philippines.

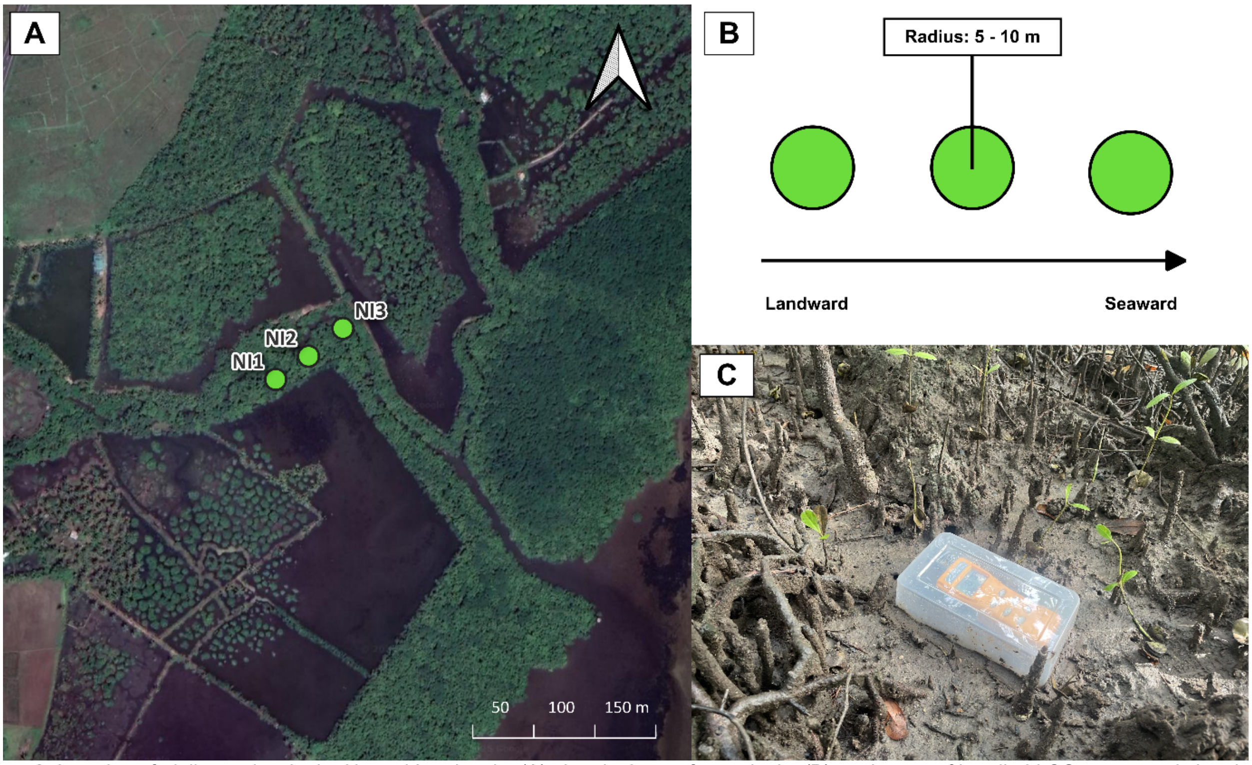

Figure 2: Location of triplicate plots in the Natural Interior site (A), the plot layout for each site (B), and setup of handheld CO_2 meter and chamber in the plot (C).

Table 1: Biophysical profile (**a**), vegetation condition and burrows (**b**), and porewater quality (**c**) of the sampling sites.

(a)

Site	Site Code	Dominant species	Age, yrs
Natural, fringe	NF	Diverse (*Avicennia marina*, *Ceriops* sp.)	Unknown
Natural, interior	NI	Diverse (*Avicennia* sp., *Xylocarpus granatum*)	Unknown
Restored, fringe	RF	*Rhizophora* sp.	35
Restored, interior	RI	*Rhizophora* sp.	35
Recolonized, fringe	CM	*Avicennia* sp.	17
Recolonized, interior	CY	*Avicennia* sp.	8

(b)

Site	Tree diameter (cm)	Tree height (m)	Canopy cover (%)	Pneumatophore height (cm)	Pneumatophore density	Burrow width (mm)	Burrow density
NF	3.65±0.14	2.21±0.07	0.60±0.005	13.37±0.65	60.33±33.33	13.36±0.70	147.67±45.61
NI	8.43±1.10	3.69±0.27	0.81±0.002	13.84±0.65	240.33±16.80	7.50±0.75	33.00±6.08
RF	6.15±0.33	4.77±0.22	0.70±0.000	14.16±0.68	45.33±4.91	14.41±0.83	34.67±3.18
RI	5.83±0.20	4.48±0.14	0.67±0.003	-	-	17.35±0.72	45.67±5.23
CM	4.04±0.15	3.14±0.09	0.73±0.005	12.22±0.87	111.00±17.06	11.88±0.73	35.00±1.73
CY	2.94±0.08	2.73±0.05	0.64±0.007	15.26_0.73	216.33±38.68	8.97±0.72	40.67±7.17

(c)

Site	Temperature (°C)	pH	Electrical conductivity (mS/cm)	Dissolved oxygen (mg/L)	Total dissolved solids (g/L)	Salinity (ppt)
NF	31.05±0.26	7.71±0.03	52.63±0.83	1.76±0.18	31.57±0.49	34.69±0.62
NI	29.05±0.12	7.90±0.04	47.63±1.08	2.93±0.56	29.03=0.65	31.02±0.77
RF	28.67±0.15	7.67±0.04	46.60±2.87	1.84±0.36	28.23±1.63	30.28±2.08
RI	28.49±0.32	7.76±0.04	44.47±5.33	2.36±0.75	27.10=3.25	28.78±3.81
CM	28.85±0.14	7.76±0.07	47.30±0.78	2.32±0.40	28.87=0.46	30.75±0.58
CY	31.31±0.07	7.97±0.05	41.87±0.52	2.01±0.29	25.53=0.32	26.86±0.36

Sampling Design

Sampling was conducted on October 10 - 13, 2024 during low tide, between 7:00 AM and 12:00 PM. For each site, homogenous triplicate circular plots were established across a zonation gradient (as fringe vs interior). Plot radii were either 5, 7, or 10 meters—depending on the density of vegetation and distance between trees. A 1x1 m subplot was also established for pneumatophore and faunal burrow measurements.

Soil CO_2 efflux measurement

CO_2 concentrations were measured on an untrampled area within each plot using a handheld CO_2 meter (7755 CO_2 Temp RH Meter, AZ Instrument Corp., Taiwan). The meter was placed on the soil surface and enclosed in a transparent polypropylene plastic chamber, with the instrument positioned at the center of the plot. The chamber had a volume of 2.14 L and covered a surface area of 0.0306 m^2 (23.5 cm x 13 cm x 7 cm). The CO_2 concentration and air temperature within the chamber were recorded at two-minute intervals over a 30- to 40-minute period. Measurements for each plot were taken consecutively, with each site requiring approximately three hours to complete.

The rate of soil CO_2 efflux was calculated using the following equation (cf. Howard et al. 2014):

$$F = s \times \frac{P \times V}{R \times T \times A}$$

Where F is the rate of soil CO_2 efflux (μmol m^{-2} min^{-1}); S is the slope of CO_2 concentration within the chamber over time (ppm/min); P is the atmospheric pressure (atmos); V is the volume of the chamber (L); R is the universal gas constant (L*atmos/K*mol); T is the air temperature in the chamber (K); and A is the surface area of the soil covered by the chamber (m^2). Afterwards, the CO_2 efflux values were extrapolated to an annual scale (Mg CO_2 ha^{-1} yr^{-1}).

Vegetation and porewater quality measurements

The following vegetation parameters were determined in each plot: average tree diameter, average tree height, canopy cover, pneumatophore density, and average number and height of the pneumatophores. Porewater (i.e. water found between sediment particles) quality parameters such as temperature (°C), pH, electrical conductivity (mS/cm), dissolved oxygen (DO; mg/L), total dissolved solids (TDS; g/L), and salinity (ppt) were measured using a *U-50 Multi-parameter water quality checker* (HORIBA Advanced Techno Co., Ltd., Japan). Measurements were obtained from boreholes created during the collection of 1-meter deep sediment cores. Each hole was widened to approximately 10 cm in diameter using a spade to accommodate the instrument's probe. Readings were taken after sufficient water had filled the cavity (ca. 15-30 minutes). Additionally, the density and average diameter (in mm, using a vernier caliper) of faunal burrows (i.e. crabs) were measured.

Data analysis

CO_2 efflux was analyzed using descriptive statistics and tested for normality through the Shapiro-Wilk test. The nonparametric Kruskal-Wallis test was conducted to determine the differences in CO_2 efflux across sites as the datasets were not normally distributed. The Mann-Whitney U test was conducted to test the differences between zones. Furthermore, Spearman's correlation test and Principal Component Analysis (PCA) were conducted to analyze the relationships of CO_2 efflux with faunal burrows, vegetation, and porewater quality. All statistical analyses were performed using RStudio (Version R.4.2.2; Posit team [2024]).

RESULTS AND DISCUSSION

Soil CO_2 efflux varied across sampling sites

Recolonized fringe mangroves had the highest mean CO_2 efflux (mean ± standard deviation: 23.55 ± 8.90 Mg CO_2 ha^{-1} yr^{-1}), while natural fringe mangroves had the lowest (9.46 ± 1.69 MgCO_2 ha^{-1} yr^{-1}; Fig. 3A). Across stand types, the recolonized mangroves had the highest CO_2 efflux (19.00 ± 4.59 MgCO_2 ha^{-1} yr^{-1}), which is 15% greater than restored mangroves (16.46 ± 4.90 Mg CO_2 ha^{-1} yr^{-1}) and 24% greater than natural mangroves (15.30 ± 3.10 MgCO_2 ha^{-1} yr^{-1}; Fig. 3B). Between zones, the CO_2 efflux of interior mangroves (18.14 ± 3.35 Mg CO_2 ha^{-1} yr^{-1}) were 16% greater than fringe sites (15.70 ± 3.43 Mg CO_2 ha^{-1} yr^{-1}; Fig. 3C). In general, there were no significant differences in mean CO_2 efflux across stand types and geomorphic positions ($p > 0.05$). However, the CO_2 efflux in the natural stands was 123% higher in the interior (21.14 Mg CO_2 ha^{-1} yr^{-1}) than the fringe site (9.46 Mg CO_2 ha^{-1} yr^{-1}).

Consistent with our hypothesis, we observed higher efflux (13-19% greater) in recolonized mangroves compared to natural and restored mangroves, likely due to increased exposure as a result of less developed vegetation. Drier soils, caused by greater exposure to air and high temperatures, have been shown to have high CO_2 efflux (Leopold et al. 2015; Hien et al. 2018). Higher temperatures also increase microbial activity, thereby increasing the contribution of heterotrophic respiration to overall soil CO_2 efflux (Bulmer et al. 2015). But, some studies reported that recolonized mangroves have lower CO_2 efflux compared to natural mangroves despite having less developed vegetation, lower faunal activity, and more disturbed hydrologic regimes (Bali, Indonesia; Sidik et al. 2019; Sulawesi, Indonesia; Cameron et al. 2019). In East Kalimantan (Indonesia), the recolonized mangroves, despite having a disturbed hydrologic regime (due to pond embankments), have lower CO_2 efflux (28.0 ± 2.1 Mg CO_2 ha^{-1} yr^{-1}) compared to those under natural hydrologic conditions (36.9 ± 3.4 Mg CO_2 ha^{-1} yr^{-1}; Arifanti et al. 2024). Similarly, in restored mangroves (in Sulawesi, Indonesia), the more mature mangroves (22.5-29.4 Mg CO_2 ha^{-1} yr^{-1}) have higher efflux than the younger mangroves (0.3-10.1 Mg CO_2 ha^{-1} yr^{-1}), a pattern that can be attributed to greater root complexity in natural and mature mangroves, which enhances autotrophic respiration (Cameron et al. 2019). In addition, faunal burrows, which are known to influence CO_2 efflux, are affected by the varying hydrological conditions and vegetation characteristics across different stand types and zones. Burrowing crabs tend to avoid exposed and frequently submerged areas, instead preferring areas with significant canopy cover and leaf litter (Li et al. 2015; Tomotsune et al. 2019; Cameron et al. 2019). Our results conform with the high variability of CO_2 efflux values which differed in stand ages and therefore different stages of vegetation development and productivity.

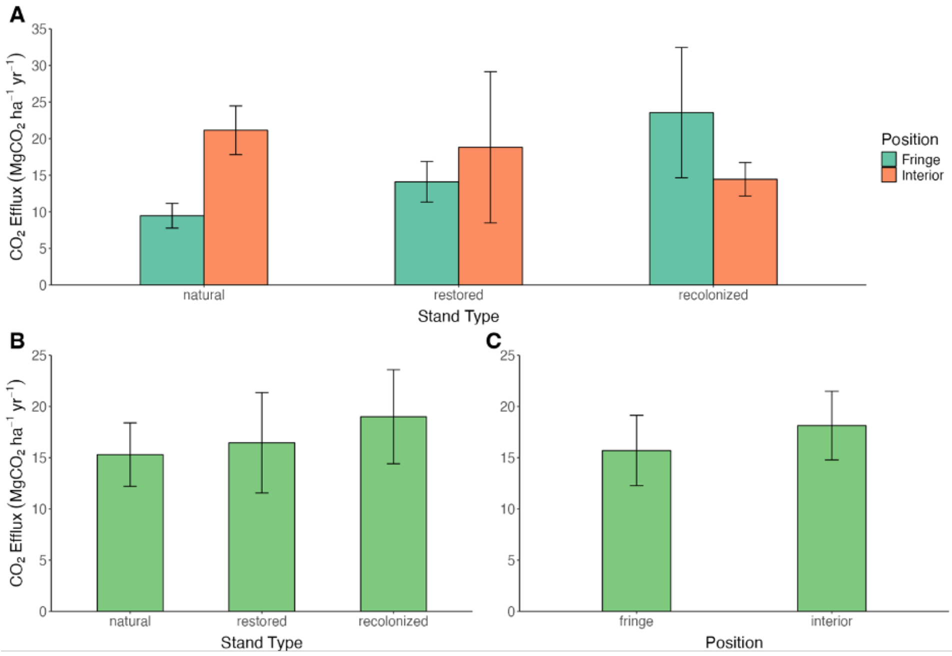

Figure 3: Mean Soil CO2 efflux across sampling sites (**A**), stand types (**B**), and geomorphic position (**C**).

Relationship between CO_2 efflux and environmental variables

The soil CO_2 efflux has a strong positive correlation to canopy cover and a moderate negative correlation to faunal burrow density and width (Table 2). Results of the Principal Component Analysis (PCA) revealed that soil CO_2 efflux was mostly associated with tree height, tree diameter, canopy cover, and DO while it is inversely related to temperature, burrow width, and burrow density (Figure 4).

Table 2: Correlation between soil CO2 efflux and site environmental variables using Spearman's correlation test. Parameters in bold indicate significant relationship.

Variables	Correlation coefficient (r^2)	p-value
Porewater		
Temperature	-0.110	0.65
pH	0.240	0.34
Conductivity	0.003	0.990
Dissolved oxygen	0.270	0.290
Salinity	0.020	0.990
Vegetation	0.200	0.430
Tree diameter		
Tree height	0.250	0.320
Canopy cover	**0.52**	0.030
Pneumatophore density	0.290	0.250
Faunal burrow		
Density	**-0.400**	0.100
Width	**-0.360**	0.140

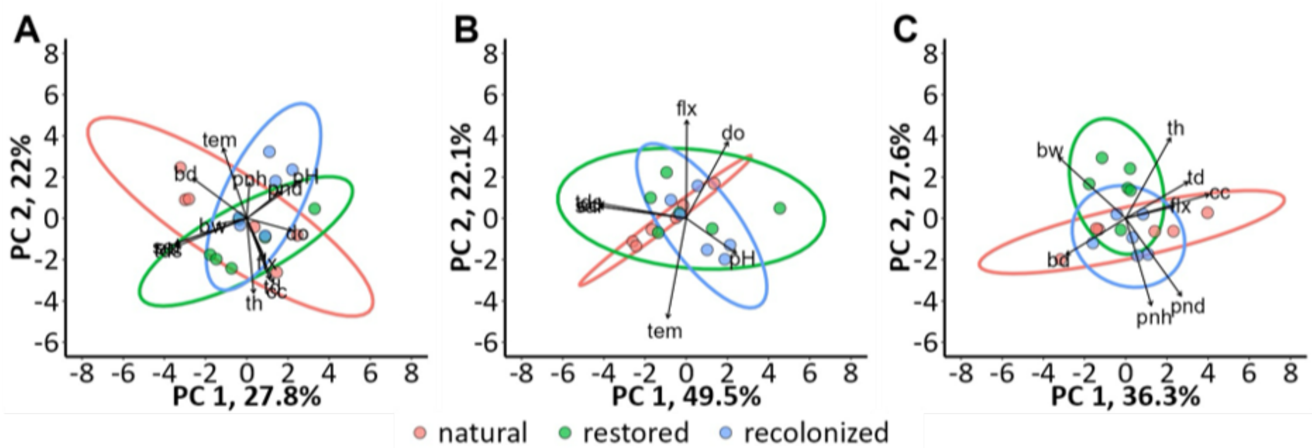

Figure 4: Relationship of CO2 efflux (**flx**) with combined porewater quality and vegetation variables (**A**), porewater quality (**B**), and vegetation and burrows (**C**). Legend: Dissolved oxygen (do), total dissolved solids (**tds**), salinity (**sal**), pH, temperature (**tem**), burrow width (**bw**), burrow density (**bd**), tree height (**th**), tree diameter (**td**), canopy cover (**cc**), pneumatophore height (**pnh**), pneumatophore density (**pnd**).

The soil CO_2 efflux in mangroves is highly variable as it is a dynamic process influenced by biophysical factors such as vegetation, faunal activity, and geomorphic position, among others (Cameron et al. 2019). Among the environmental variables, canopy cover ($r = 0.52$) has the highest correlation with soil CO_2 efflux conforming with the study of Castillo et al. (2017) in Honda Bay, Palawan, western Philippines. Vegetation structure influences the production of leaf litter, which when decomposed will enhance

CO_2 emission (Peng et al. 2022). Additionally, canopy cover influences air temperature, which contributes to variation in CO_2 efflux (as in the case in both the natural and restored mangroves) as opposed to the less developed vegetation (as in the case in the recolonized stands; Table 1b; Leopold et al. 2015).

Although not statistically significant, the negative correlation between the CO_2 efflux and faunal burrow density in this study is consistent with findings in North Sumatra (Harahap et al. 2023; Harahap et al. 2024), where higher densities of faunal burrows (Table 1b) were associated with reduced CO_2 efflux. Conversely, burrow size was reported to have a positive correlation to efflux, as larger burrows increase the soil–air interface and aeration, which enhances microbial activity and stimulates heterotrophic respiration (Cameron et al. 2019; Tomotsune et al. 2019). Our results highlight the need to assess the influence of mangrove fauna (mainly bioturbation and biodiversity) on the reduction of soil CO_2 efflux.

While porewater quality parameters showed no correlation with CO_2 efflux, other research suggests that soil moisture influences CO_2 efflux (see for example Leopold et al. 2015). Drier soils have greater CO_2 efflux compared to inundated soils (Hien et al. 2018). Thus, soils that experience a longer hydroperiod, such as those in seaward fringing mangroves or those influenced by pond embankments, exhibit lower CO_2 efflux (Cameron et al. 2019; Arifanti et al. 2024). This trend is reflected in the findings of this study, where interior natural and restored sites have higher CO_2 efflux than their fringing counterparts.

Limitations and potentials of using handheld CO_2 meters in GHG monitoring in Philippine mangroves

The lack of significant differences in our sites could potentially be due to the lower sensitivity of the equipment used. The handheld CO_2 meter employed in this study has an accuracy of ± 50 ppm (or ± 5% of the reading within the 0-2000 ppm range). Additionally, the simplicity of the chamber may have affected its impermeability, potentially allowing air to enter or exit and thereby could reduce its accuracy. This may also account for the lower CO_2 efflux values observed from our sites compared with those reported in literature (Table 3). While the values from our natural sites can be comparable to, or even greater than, values published in a few studies (8.1–16. 7 Mg CO_2 ha^{-1}; Cameron et al., 2019; Sidik et al., 2019), most values from other natural sites are higher, ranging from 24.00 to 113.62 Mg CO_2 ha^{-1}, or about 1.6 to 7.4 greater than those recorded in our study (Bulmer et al., 2015; Cameron et al., 2019; Sasmito et al., 2022; Harahap et al., 2023; Harahap et al., 2024). Most studies on mangrove CO_2 efflux utilize the static chamber method, which involves trapping gases and measuring gas concentrations over time using either an infrared gas analyzer or gas chromatography (Table 5). The eddy covariance method provides a more direct measurement of gas fluxes across the entire ecosystem using a flux tower. However, this method is more expensive and is challenging to set up in a regularly inundated mangrove site (Howard et al. 2014).

Table 3: Comparison of mangrove soil CO2 efflux studies in the Asia-Pacific region.

Site	Site Type	CO_2 (Mg ha^{-1} yr^{-1})	Method	Reference
Eastern Thailand	Secondary mangroves	6.33 to 12.16	Infrared gas analyzer (LI-840, LI-COR Biosciences)	Poungparn et al. (2009)
South China	Kandelia-dominated mangroves	2.66 to 79.26	Gas chromatography (6890A Gas chromatograph, Hewlett Packard)	Chen et al. (2010)
Sundarban	Mangrove	2.08 to 32.48	Infrared gas analyzer (LI 840A CO_2/H_2O Gas Analyzer, Li-Cor, Inc. USA)	Chanda et al. (2014)
New Zealand	Natural mangroves	27.07 ± 7.36	Infrared CO_2 analyser (EGM-4 Environmental Gas Analyzer, PP Systems, USA)	Bulmer et al. (2015)
South China	Mangroves	-2.72 to 44.85	Gas chromatography (7890A Gas chromatograph, Agilent Technologies, Santa Clara, CA, USA)	Chen et al. (2016)
Honda Bay, Philippines	Rhizophora-dominated mangroves	40.25±3.8	LiCor 8100A Automated Soil CO_2 Flux System (LiCor Corp, USA)	Castillo et al. (2017)
Northern Vietnam	Planted mangroves	15.35 ± 14.34	infrared gas analyzer (IRGA, Licor- 840, LiCor Biosciences, Inc.)	Hien et al. (2018)
Sulawesi	Natural mangroves	8.1±1 to 28±2.3	photoacoustic infra-red gas analyzer (INNOVA 1412i, LumaSense Technologies, Inc., CA, USA)	Cameron et al. (2019)
	Rehabilitating mangroves (EMR-assisted regrowth)	0.3±0.2 to 29.4±1.9		
Bali, Indonesia	Natural	12.2 ± 1.8	LiCor 6400 portable photosynthesis system with LiCor soil CO_2 flux chamber (LiCor Corp, Lincoln, NE, USA)	Sidik et al. (2019)
	Recolonized	7.3 ± 1.6		
North Sumatra	Logged mangroves	42.05 ± 9.11		Sasmito et al. (2022)
	Natural mangroves	24.00 ± 6.22		
North Sumatra	Natural mangroves (dry season)	113.62	Eosense Eosgp CO_2 sensor (Eosense, Dartmouth, NS, Canada)	Harahap et al. (2023)
	Natural mangroves (wet season)	73.15		

	Restored (dry season)	115.72		
	Restored (wet season)	143.23		
Banten, Indonesia	Interior mangroves	13.23 ± 1.05	LGR Ultraportable GHG analyzer	Royna et al. (2024)
North Sumatra	Natural (low tide)	75.86 ± 51.25	Eosense Eosgp CO_2 sensor (Eosense, Dartmouth, NS, Canada)	Harahap et al. (2024)
	Natural (high tide)	99.60 ± 69.38		
	Restored (low tide)	50.39 ± 25.56		
	Restored (high tide)	52.31 ± 15.77		
East Kalimantan	Restored mangroves (Recolonized)	28.0 ± 2.1	LICOR LI-7810 trace gas analyzer	Arifanti et al. (2024)
	Secondary mangroves (Recolonized)	36.9 ± 3.4		
Prieto Diaz, Sorsogon	Natural mangroves	15.30 ± 3.10	Carbon dioxide meter (7755 CO_2 Temp RH Meter, AZ Instrument Corp., Taiwan)	This study
	Restored mangroves	16.46 ± 4.90		
	Recolonized mangroves	19.00 ± 4.59		

CONCLUSION

In this study, a simplified makeshift version of the static chamber method was utilized, using a transparent polypropylene plastic chamber and a handheld CO_2 meter. We acknowledge the limitations of our method as compared to the conventional, more accurate methods and recognize the need to calibrate our instrument against standard gas analyzers. Nevertheless, our study provides empirical *in situ* CO_2 measurements in Philippine mangroves. The use of a handheld meter offers a rapid and inexpensive technique to measure CO_2 efflux, a parameter needed to track the fulfillment of the Philippines' commitment to NDC (Global Mangrove Alliance, 2024). This method may be used in the periodic evaluation and tracking of mangrove recovery in community-led mangrove conservation and restoration initiatives by providing an accessible means to monitor changes in CO_2 efflux over time.

The method can also be used to assess and compare the relative stability of CO_2 efflux in natural mangroves relative to disturbed and restored mangroves. For example, using our results (of 15-24% higher CO_2 efflux in recolonized ponds [Figure 3b]), proactively restoring the abandoned ponds will significantly reduce CO_2 efflux from 35 Mg CO_2 ha^{-1} yr^{-1} to 9 Mg CO_2 ha^{-1} yr^{-1} and may even improve further as the vegetation develops over time. Applying our results to some mangrove sites in the country may have highly variable outcomes because of the inherent differences in biogeomorphology, vegetation conditions, exposure to disturbances, etc. But the lack of assessment, moreso consistent periodic monitoring, will continuously leave unknown information on the role of Philippine mangroves in regulating CO_2 emission. The use of a more sophisticated, but expensive instrument, will definitely contribute to calibrating CO_2 efflux values. But for practicality, and to meet the urgency to monitor CO_2 efflux, the use of a handheld CO_2 meter is justified so long as the caveats on limited accuracy are acknowledged.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

CONTRIBUTIONS OF INDIVIDUAL AUTHORS

Severino III G. Salmo: conceptualization; writing – review and editing; visualization; validation; sampling; supervision; resources; funding acquisition and project administration.

Sean Paul B. Manalo: writing – original draft, review & editing; sampling; formal analysis; visualization; data curation.

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