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SOIL CARBON SEQUESTRATION OF SALT MARSHES IN BILU ISLAND, MYANMAR

Htway Thiri Htun[1], Nway Thiri Htun[2], Kyaw Thura[3]

Abstract

In this study, vertical soil cores were collected from two habitats (mudflat and salt marshes) in Zeekone, Tawpun, Kalwi, and Karaikdo. The aim was to examine the organic carbon content and physicochemical properties of the soil's vertical profile (within 0-60 cm). Eight salt marsh species were identified based on their vegetation cover, including *Sesuvium portulacastrum*, *Phragmites australis*, *Distichlis spicata*, *Puccinellia* species, *Paspalum* species, *Spartina maritima*, *Typha angustifolia, and Schoenoplectus americanus*.The results showed that soil organic carbon (SOC) content decreased with depth in the Zeekone, Tawpun, and Karaikdo stations. In contrast, an increasing trend was observed in the Kalwi station. For soil physical properties, dry bulk density (gcm^{-3}) increased with depth at Zeekone, Tawpun, and Karaikdo, but not at Kalwi. The mudflat in the Kalwi station had the highest soil salinity value (5.98 ± 0.67), while the *Phragmites australis* salt marsh at the Zeekone station had the lowest (0.06 ± 0.01). Soil pH values across all stations ranged from weakly acidic to weakly alkaline.The highest SOC content was found in the *Sesuvium portulacastrum* salt marsh at Zeekone and the mudflat at Tawpun, with mean values of 1.00 ± 0.57% and 1.16 ± 0.71%, respectively. The sediment types in the Zeekone and Tawpun stations were sandy loam and sand. Kalwi station consisted of loamy sand and sand, and Karaikdo station had loam and sandy loam sediment types.

Keywords: Salt marsh, organic carbon, bulk density, soil pH, soil salinity

Introduction

Salt marshes are intertidal, vegetated wetland ecosystems that dominate protected shorelines and estuaries in a wide range of climates (Mitsh et al., 1994; Butler and Weis, 2009). These intertidal habitats are vital for healthy fisheries, coastlines, and communities (NOAA, 2024). They typically occur in the upper intertidal zones, between mangrove fringes and terrestrial vegetation, and are usually flooded by spring tides rather than daily tides (Johns, 2006).

Coastal wetlands, including salt marshes, are significant global carbon sinks, storing more carbon per unit area than terrestrial forests (Duarte et al., 2005; McLeod et al., 2011; Temmink et al., 2022). The carbon sinks in salt marshes consist of aboveground biomass, belowground biomass, and soils. Soil plays a crucial role, often storing more carbon than the vegetation itself (Dalal and Allen, 2008). In tidal salt marshes, prolonged flooding can create anoxic conditions, which reduces the efficiency of organic matter decomposition and promotes soil carbon sequestration (Megonigal et al., 2004).

The drivers of blue carbon stock in salt marshes include several factors. Environmental characteristics such as elevation and local hydrology influence the supply of sediment and allochthonous carbon (Wollenberg et al., 2018; Rogers et al., 2019; Mossman et al., 2022).

[1] Department of Marine Science, Mawlamyine University
[2] Department of Marine Science, Mawlamyine University
[3] Department of Marine Science, Mawlamyine University

Sedimentary characteristics like particle size affect the preservation of carbon stocks (Kelleway et al., 2016; Ford et al., 2019). Additionally, vegetation community composition and diversity affect both the supply of autochthonous carbon from primary production and the trapping of allochthonous carbon (Ouyang and Lee, 2014).

While numerous studies on blue carbon stock in salt marsh sediments exist globally, research on this topic is limited in Myanmar. Previous studies have focused on the soil organic carbon of mangrove areas in the Ayeyarwady Region (Ya Min Thant et al., 2012) and the Mon Coastal Area (Htwe Yee Lin, 2022; Min Thu Aung, 2023). However, there has been no specific study on soil carbon sequestration in salt marshes and mudflats. Therefore, this study was conducted to contribute to the understanding of the organic carbon status of salt marshes in Bilu Island. The research also covered soil organic carbon variations with depth and among different species. The specific objectives were to evaluate soil organic carbon (SOC) at different depth intervals, compare SOC variations among salt marsh species, and assess the relationship between SOC and physicochemical properties.

Materials and Methods

Study Area

The sampling sites selected for this study were Tawpun (Lat. 16°22' 4.92"N, Long. 97° 28' 15.16"E), Zeekone (Lat. 16°18' 32.89"N, Long 97° 27' 27.44"E), Karaikdo (Lat. 16°17' 0.79"N, Long. 97° 31' 2.12"E), and Kalwi (Lat. 16° 30' 4.69"N, Long. 97° 31' 34.10" E) on Bilu Island in the Thanlwin River. The Tawpun, Zeekone, and Kalwi sites are located in coastal regions, while Karaikdo is situated in a tidal creek. These areas contain various habitats, including mudflats, salt marshes, brackish marshes, and mangroves. All stations experience a semidiurnal tide. The Bilu Deltaic Island is significantly influenced by the influx of the Thanlwin River. The region has a monsoon-influenced tropical climate with five distinct seasons and an annual precipitation of 148.72 mm (Lwin, 2002).

Sampling Procedure

Soil samples were collected to a depth of 60 cm using a custom-made steel soil auger (5 cm in diameter, 1.5 m in length). All samples were sealed in polyethylene bags and transported to the laboratory for analysis of SOC, dry bulk density, soil pH, and soil texture.

Depth-aggregated sampling techniques were employed at depth intervals of 0-10, 10-20, 20-30, 30-40, 40-50, and 50-60 cm, as soil carbon content typically changes slowly with depth (Kauffman et al., 2011; Donato et al., 2011). To ensure proper identification and avoid confusion, each core was labeled with a unique ID.

Figure 1. Map showing the study areas

Analysis of Soil Organic Carbon Content (%SOC)

The dry bulk density (DBD) of the soil was determined by quantifying the mass of the dry soil and its original volume. Samples were placed in polyethylene bags and dried in an oven at 60°C until a constant weight was reached, which took between 48 and 72 hours, and sometimes longer. The dry bulk density was calculated using the equation:

DBD = (mass of dry soil) / (original sample volume)

Before analysis, the oven-dried soil was manually pulverized with a mortar to a consistent particle size and then passed through a 2 mm sieve. To determine the %SOC, 5 g of the homogenized soil was weighed into a crucible and heated in a muffle furnace at 450°C for four hours to completely ignite the organic matter. The temperature was gradually decreased, and the samples were cooled in a desiccator before being weighed again. The weight before and after burning was compared to calculate the loss on ignition (%LOI).

The %LOI was calculated as follows:

%LOI = [(Initial dry weight - Final weight after ignition) / Initial dry weight] × 100

The %Corg (organic carbon) for tidal salt marshes was then calculated using the following equation (Craft et al., 1991):

$\%Corg = 0.40 * \%LOI + 0.0025 * (\%LOI)^2$

Furthermore, SOC storage (Mg C ha^{-1}) within the 60 cm soil depth of mudflats and salt marshes was calculated using the equation:

SOC storage (Mg C ha^{-1}) = SOC (%) × DBD (gcm^{-3}) × SD (cm)

Where DBD is the dry bulk density and SD is the soil depth.

Determination of Physicochemical Parameters

Soil salinity and soil pH were determined by mixing soil samples with distilled water at a 1:2.5 (soil:water) ratio, following the method of Gao et al. (2019). After shaking the mixture thoroughly and allowing it to settle for 30 minutes, the soil pH was measured using a pH meter (Fisher brand, Accumet AB 150). Soil salinity was then measured with an electrical conductivity meter. Soil particle texture was determined using the soil hydrometer method (Allen et al., 1974).

Data Analysis

The mean and standard deviations for replicates were analyzed using Excel and SPSS. Vertical trends for each core were graphed using OriginPro.

Results

Eight salt marsh species with different vegetation covers were recorded. Summary statistics for SOC, DBD, soil pH, soil salinity, and soil texture (sand, silt, clay) are shown in Tables 1 and 2. The average soil salinity of the vertical profile ranged from 0.06 to 5.98‰. In most vertical soil cores, salinity declined from 0-20 cm and increased thereafter (Figures 2b, 3b, 4b, and 5b). Soil pH values across all stations ranged from weakly acidic to weakly alkaline (Figures 2a, 3a, 4a, and 5a). Soil DBD gradually increased with depth at Zeekone, Tawpun, and Karaikdo stations (Figures 2c, 3c, and 4c), but this trend was not observed at Kalwi station (Figure 5c).

Four soil texture types were found. Sandy loam sediment was found in the salt marshes of *Sesuvium portulacastrum*, *Distichlis spicata*, *Puccinellia* species, and *Schoenoplecus americanus*. Loamy sand sediment was found in the *Spartina maritima* salt marsh. Loam sediment was found in the *Typha angustifolia* salt marsh, and sand sediment was found in the *Phragmites australis* and *Paspalum* species salt marshes (Figure 6).

Soil Organic Carbon

The variations of soil organic carbon (SOC) with depth are shown in Figures 2d, 3d, 4d, and 5d. Carbon content in the surface soil layer (0-20 cm) was relatively higher than in the deeper layers at Zeekone, Tawpun, and Karaikdo (Figures 2d, 3d, and 4d). A decreasing trend of SOC with depth was observed in these three stations. In contrast, the SOC content in the bottom soil layer (30-60 cm) was higher than in the upper layers at the Kalwi station (Figure 5d).

Table 1. The mean values of physical and chemical properties and organic carbon contents (mean ± standard deviation, n = 12) within 60 cm soils in mudflats and salt marshes

Parameters	Zeekone				Tawpun		
	Mudflat	*Sesuvium portulacastrum*	*Phragmites australis*	*Distichlis spicata*	Mudflat	*Puccinellia* sp.	*Paspalum* sp.
Soil salinity	4.22 ± 1.01	4.33 ± 0.90	0.06 ± 0.01	3.38 ± 1.12	3.89 ± 0.93	4.32 ± 1.36	3.19 ± 0.62
Soil pH	7.87 ± 0.20	7.59 ± 0.22	7.89 ± 0.07	8.19 ± 0.14	7.96 ± 0.23	7.91 ± 0.23	7.61 ± 0.14
Sand (%)	71.3 ± 4.60	74.07 ± 13.79	98.5 ± 0.59	59.72 ± 5.18	70.72 ± 4.97	70.63 ± 6.30	95.78 ± 0.53
Silt (%)	20.5 ± 3.36	19 ± 11.42	0.60 ± 0.52	28.53 ± 2.98	21.95 ± 6.71	22.47 ± 6.19	1.78 ± 0.60
Clay (%)	8.2 ± 1.56	6.93 ± 2.59	0.90 ± 0.49	11.75 ± 2.5	7.33 ± 2.06	6.9 ± 1.20	2.43 ± 0.27
Soil type	Sandy Loam	Sandy Loam	Sand	Sandy Loam	Sandy Loam	Sandy Loam	Sand
DBD (gcm^{-3})	1.24 ± 0.11	1.25 ± 0.12	1.31 ± 0.06	1.26 ± 0.06	1.01 ± 0.31	1.10 ± 0.15	1.51 ± 0.07
SOC (%)	0.69 ± 0.23	1.00 ± 0.57	0.08 ± 0.01	0.60 ± 0.13	1.16 ± 0.71	0.83 ± 0.17	0.19 ± 0.03
$SOC_{storage}$ ($Mg\ C\ ha^{-1}$)	50.57	71.41	6.27	47.6	61.02	54.25	16.85

Table 2. The mean values of physical and chemical properties and organic carbon contents (mean ± standard deviation, n = 12) within 60 cm soils in mudflat and salt marshes

Parameters	Karaikdo		Kalwi	
	Typha angustifolia	*Schoenoplectus americanus*	Mudflat	*Spartina maritima*
Soil salinity	1.14 ± 0.21	2.96 ± 0.54	5.98 ± 0.67	4.34 ± 0.59
Soil pH	6.41 ± 1.37	7.52 ± 0.04	7.55 ± 0.10	7.44 ± 0.09
Sand (%)	46.57 ± 3.61	64.90 ± 4.63	87.90 ± 5.52	80.55 ± 8.79
Silt (%)	30.20 ± 1.26	26.23 ± 2.98	7.47 ± 4.34	12.62 ± 6.14
Clay (%)	23.23 ± 2.87	8.87 ± 1.83	4.63 ± 1.42	6.83 ± 2.7
Soil type	Loam	Sandy Loam	Sand	Loamy Sand
DBD (gcm^{-3})	0.68 ± 0.07	0.79 ± 0.13	1.11 ± 0.11	1.17 ± 0.11
SOC (%)	0.86 ± 0.10	0.87 ± 0.11	0.36 ± 0.07	0.44 ± 0.16
$SOC_{storage}$ ($Mg\ C\ ha^{-1}$)	34.67	41.64	24.05	30.35

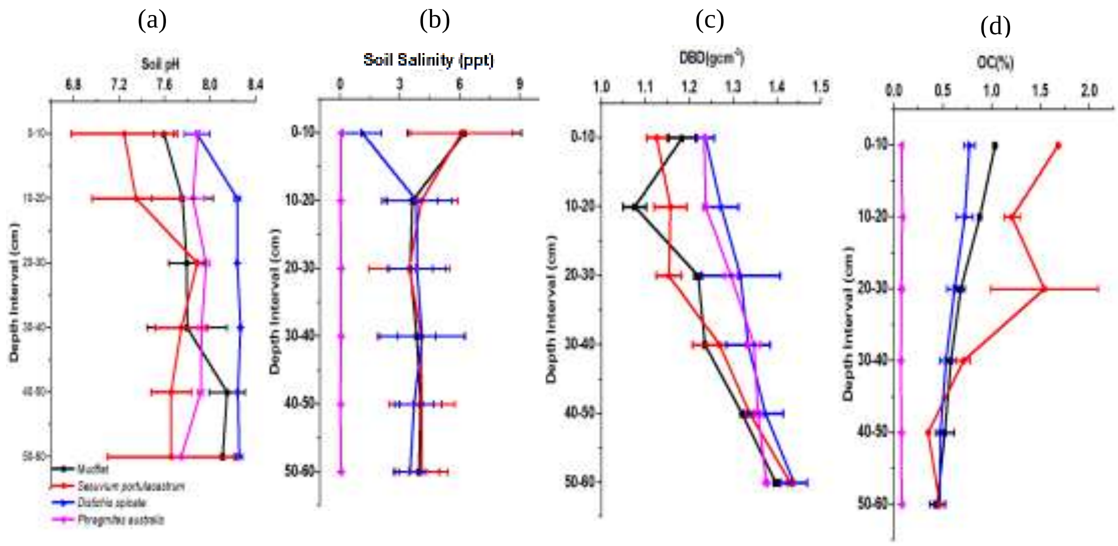

Figure 2. Physicochemical parameters and soil organic carbon in Zeekone: a) soil pH, b) soil salinity, c) DBD (dry bulk density) and d) %OC

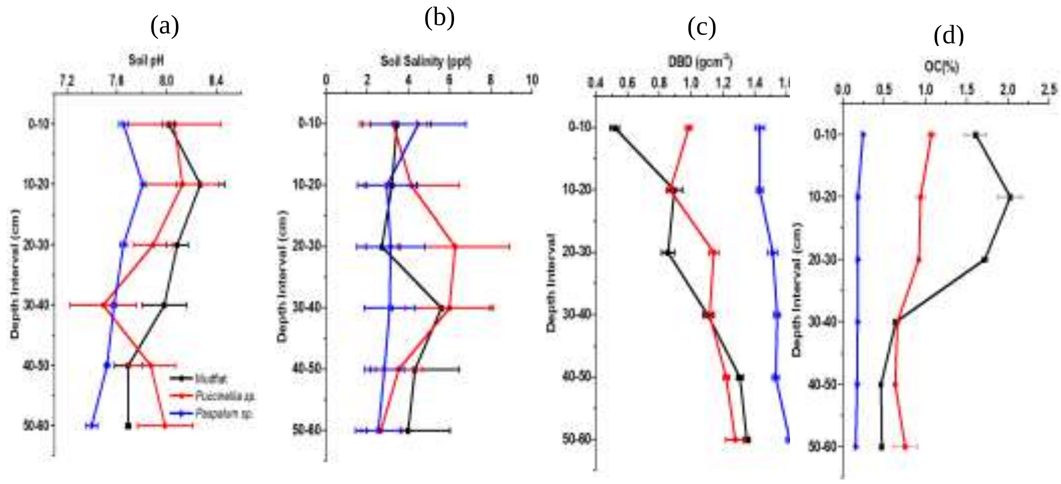

Figure 3. Physicochemical parameters and soil organic carbon in Tawpun: a) soil pH, b) soil salinity, c) DBD (dry bulk density) and d) %OC

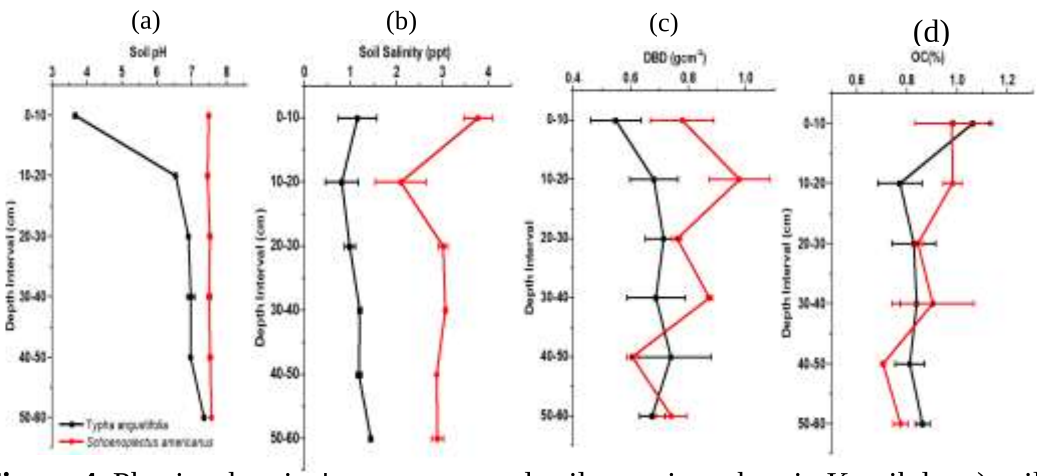

Figure 4. Physicochemical parameters and soil organic carbon in Karaikdo: a) soil pH, b) soil salinity, c) DBD (dry bulk density) and d) %OC

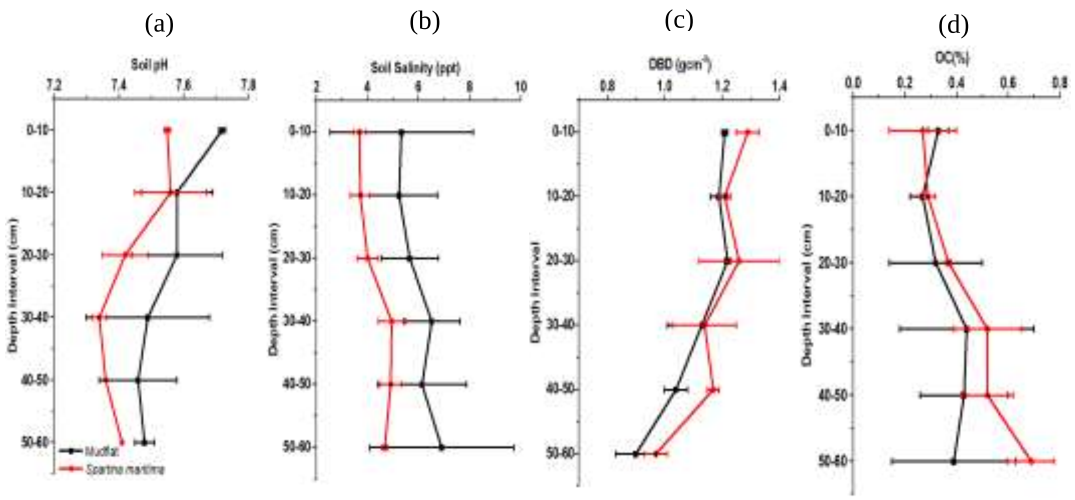

Figure 5. Physicochemical parameters and soil organic carbon in Kalwi: a) soil pH, b) soil salinity, c) DBD (dry bulk density) and d) %OC

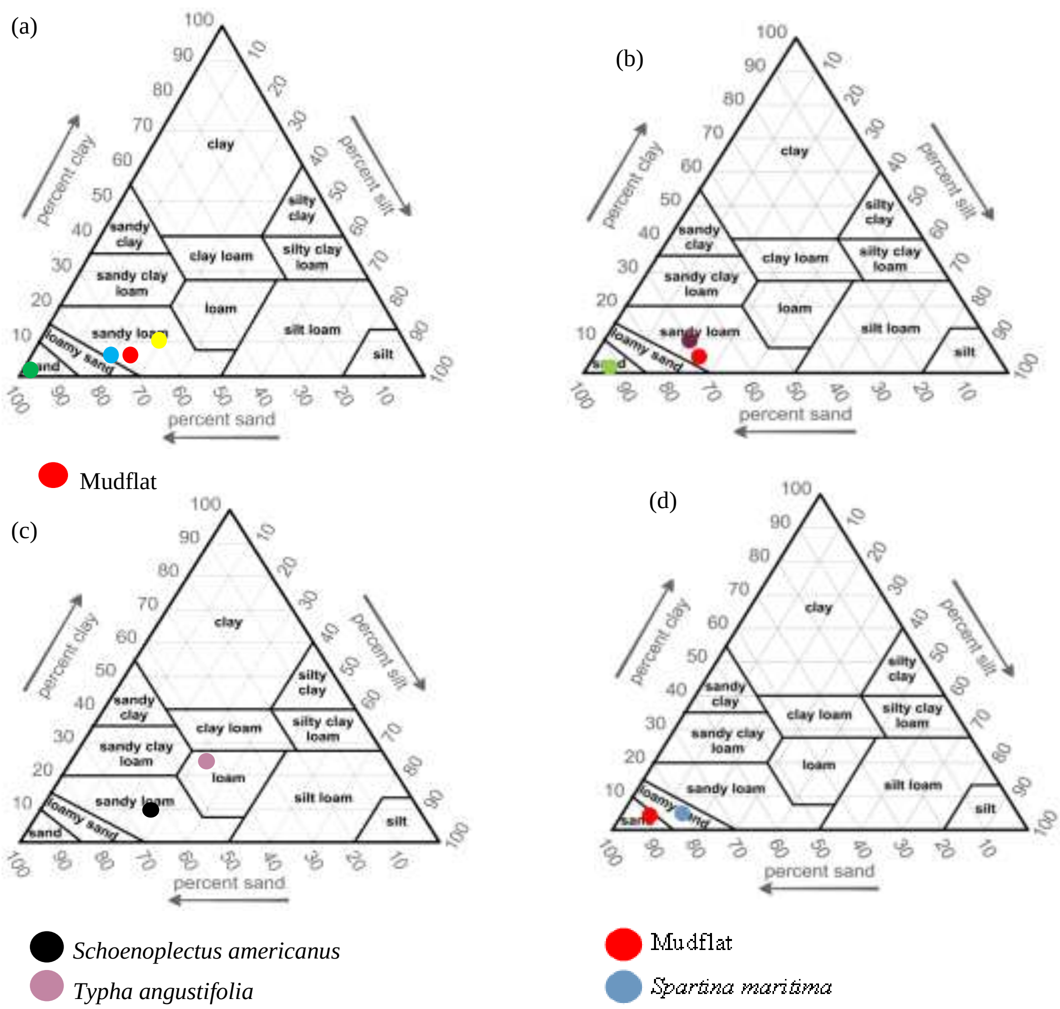

Figure 6. Soil texture types of mudflat and different salt marshes in: a)Zeekone, b)Tawpun, c)Karaikdo and d)Kalwi

Discussion

Variation in salinity across a marsh can alter the vegetation community (Deleeuw et al., 1993). Elevation is a key factor driving these salinity changes. In this study, the highest salinity values were observed at lower elevation sites in some habitats at Zeekone, Tawpun, and Kalwi stations, which experienced frequent tidal inundation. The lowest salinity values were found at the Karaikdo station, which is located on the landward side and has a higher freshwater influence.

According to previous research, salt marsh soils can be either acidic or weakly alkaline. Kadiri and Spencer (2011) found mean pH values of 6.8–7.7 in natural salt marshes and 7.0–7.5 in mudflats in Southeast England. Similarly, Bai et al. (2016) reported a mean soil pH of 8.05–8.30 in salt marshes of China's Yellow River Delta. The soil pH values in this study were consistent with these findings, ranging from weakly acidic to weakly alkaline. The average soil pH in the *Typha angustifolia* salt marsh was relatively low (6.41 ± 1.37), possibly due to the input of allochthonous organic matter (dried paddy straws) from adjacent paddy fields via water runoff.

Dry bulk density (DBD) is an indicator of soil compaction and water permeability (Han et al., 2010; Drewry et al., 2008). The observed increase in soil DBD with increasing depth at Zeekone, Tawpun, and Karaikdo stations is consistent with findings from salt marshes in the Yellow River Delta (Bai et al., 2016) and Tasmania (Ellison and Beasy, 2018). This trend can be attributed to autocompaction, where recent sediments become more compacted over time (Allen, 2000; Bird et al., 2004). However, this trend was not observed at the Kalwi station, where autocompaction may not be apparent at depths up to 60 cm, a finding similar to Valerie (2015). Dry bulk density is also strongly related to particle texture. In this study, sites with high sand concentrations (60-98%) showed higher bulk density than soils with high silt (1-30%) and clay (1-23%) concentrations. The study area is influenced by the Thanlwin River and the Gulf of Martaban, which transport an estimated 108 to 237 million tonnes of sediment annually (Baronas et al., 2020).

Within each vertical soil profile, the percent soil organic carbon (%SOC) showed a similar distribution pattern among different vegetation communities and mudflats, with the exception of the Kalwi station. SOC profiles decreased with depth at Zeekone, Tawpun, and Karaikdo stations, consistent with previous studies on salt marshes in China (Bai et al., 2016), Australia (Ellison and Beasy, 2018), and the southern Red Sea coast (Eid et al., 2022). These studies also reported that most soil organic carbon is concentrated in the top 20 cm, a finding that aligns with the results from most of the sampling sites in this study. In contrast, at the Kalwi station, %SOC content increased with depth, which could be due to the downward migration of soil organic carbon through leaching and microbial activities in the surface soil (Wang et al., 2010; Dosskey and Bertsch, 1997). The decreasing dry bulk density with depth at Kalwi also contributed to the higher SOC in deeper soil layers.

At Zeekone, the SOC content in the *Sesuvium portulacastrum* salt marsh was relatively high, which can be attributed to primary production by the vegetation (autochthonous carbon) and the input of allochthonous carbon from the adjacent mangrove area via tidal creeks. A different situation was observed at the Tawpun station, where the SOC content in the mudflat was significantly higher than in other mudflats and salt marsh species. This could be due to particulate organic matter and allochthonous carbon input.

At the Karaikdo station, the *Schoenoplectus americanus* salt marsh was located on a narrow tidal creek bank, and the *Typha angustifolia* salt marsh was adjacent to paddy fields in a high-tide zone. These sites had a lower chance of receiving organic matter from the tide. However, the SOC contents were higher than those in some of the other studied areas. This may be explained by their proximity to paddy fields and other terrestrial forests.

At the Kalwi station, the mudflat and the *Spartina maritima* salt marsh stored lower amounts of SOC compared to other areas. Within these two habitats, the *Spartina maritima* salt marsh had a higher %SOC than the mudflat, as it receives both autochthonous and allochthonous organic matter from neighboring mangrove habitats.

The %SOC values in this study (0.08–1.16%) were higher than those reported by Yu et al. (2014) and Bai et al. (2016) in the Yellow River (0.04–1% and 0.16–0.4%, respectively), but significantly lower than those from Dutch salt marshes (2.4–4.2%) (Van Deelen, 2018). The %SOC in the salt marsh species studied was: 1.00 ± 0.57% in *Sesuvium portulacastrum*; 0.60 ± 0.13% in *Distichlis spicata*; 0.08 ± 0.01% in *Phragmites australis*; 0.83 ± 0.17% in *Puccinellia* species; 0.19 ± 0.03% in *Paspalum* species; 0.86 ± 0.10% in *Typha angustifolia*; 0.87 ± 0.11% in *Schoenoplectus americanus*; and 0.44 ± 0.16% in *Spartina maritima*. These differences in %SOC may be influenced by the daily tidal range and vegetation cover types, which affect the depth distribution pattern of SOC (Bai et al., 2016).

Among the different salt marsh species, the highest SOC storage was found in *Sesuvium portulacastrum* (71.41 Mg C ha^{-1}), and the lowest was in *Phragmites australis* (6.27 Mg C ha^{-1}). For mudflats, the highest SOC storage was at the Tawpun station (61.02 Mg C ha^{-1}), while the lowest was at Kalwi (24.05 Mg C ha^{-1}). These differences are likely related to variations in elevation, accretion and erosion rates, vegetation cover, and soil texture (Van Deelen, 2018).

Conclusion

This study highlights the depth distribution patterns of organic carbon content in the mudflats and salt marsh species of Zeekone, Tawpun, Kalwi, and Karaikdo on Bilu Island, Myanmar. These findings are valuable for future monitoring and assessment of salt marshes and their biodiversity. The *Phragmites australis* salt marsh at Zeekone had the lowest carbon content (0.08%) among all habitats. The highest SOC content was found in the mudflat at Tawpun (1.16%), which can be attributed to allochthonous organic matter from adjacent mangrove areas during tidal inundation and tidal feedback. Regular monitoring and assessment of these salt marshes can provide further insights into their protection and restoration, which is crucial for enhancing carbon sequestration and mitigating climate change on Bilu Island.

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