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Composition, distribution and biometric aspects of seagrasses beds along the Sudanese Red Sea coast

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Abstract
The qualitative and quantitative data of seagrass meadows using line transects and quadrates were collected at each of Marsa Bashayer, Marsa Dama Dama, Eastern part of Port Sudan Harbour (Green Area), Northern part of Port Sudan Harbour (Shipyard), Marsa Halout and Dungonab Bay in the Sudanese Red Sea Coast. The seagrass species were identified and their distribution, shoots density, shoots height, and above ground biomass were measured. Water depth and transparency, sediment thickness and grain size were analyzed. Ten species of seagrasses were encountered (*Thalassia hemprichii*, *Halophila ovalis*, *Halophila minor*, *Halophila stipulacea*, *Enhalus acoroides*, *Halodule uninervis*, *Syringodium isoetifolium*, *Thalassodendron ciliatum*, *Cymodocea rotundata* and *Cymodocea serrulata*) for the first time in the Sudanese Red Sea coast. The mean shoot density varied between 2 and 8050 shoot/m^2. The mean shoot height ranged between 1 and 72 cm. and the mean above ground biomass ranged between 8.9 and 985.9 g dry weight/m^2.Generally, sites showed no major physical parameters differences among them excluding the water transparency which was lower in sites in the vicinity of high coastal activities area.

Keywords: Seagrass, species, shoots density and height, biomass, Sudan

1. Introduction
Seagrasses are flowering vascular plants that inhabit shallow areas of oceans, estuaries, and lagoons worldwide. They are the only flowering plants that live their entire lives totally in seawater. They have important donation in the feeding production, their habitats are highly productive (Wood *et al.*, 1969; McRoy and Helfferich, 1977; McRoy and Helfferich, 1980; Zieman and Wetzel, 1980; Duarte and Chiscano, 1999) [35, 23, 24, 38, 4], and have high biodiversity (Loneragan *et al.*, 1994) [20].

Seagrasses are considered as feeding, nursery, shelter and refuge areas for many organisms (Zieman, 1982; Fortes, 1986) [36, 9]. Seagrass beds have a potential to control chemical and physical parameters in the water (Radke, 2000) [29]. Recently seagrasses have been a centre of interest due to their role in carbon sequestration and offsetting climate change (Duarte *et al.*, 2013; Macreadie *et al.*, 2021) [5, 21].

Although many studies were carried out dealing with their ecology and structures, these plants need further investigation to verify their complex biological and ecological phenomena. Tropical seagrasses received less attention than temperate ones, not exceeding 8% of all undertaken studies.

The present survey was conducted to examine the seagrass species, shoots density, shoot height, and above ground biomass together with the physical parameters in the Sudanese marine environment they inhabit.

2. Materials and Methods
Six sites in the Sudanese Red Sea Coast were chosen for the seagrass beds spatial comparative study, namely Marsa Bashayer (19º 24.00` N, 37º 16.00` E), Marsa Dama Dama (19º 35` 18.5`` N, 37º 14` 30.4`` E), Eastern Part of Port Sudan Harbour (19º 37` 11`` N, 37º 14` 24.4`` E), Northern Part of Port Sudan Harbour (19º 37` 28`` N, 37º 13` 21`` E), Marsa Halout (19º 47` N, 37º 15` E) and Dungonab Bay (21º 7.066` N, E 37º 7.441`E).

A general survey of the area was done to select the sites and positions for the transects. The position of each transect, which was perpendicular to the shore and parallel the other transects was recorded using the Global Positioning System.
The length of each transect depended on the extension of the seagrass meadows seawards (Kirkman, 1996; English *et al.*, 1997) [19, 8]. The distance between selected transects ranged between 50 and 100 m depending on richness and absence of seagrasses in the area according to English *et al.* (1997) [8]. Regular stations along the transects were used for samples to examine the changes in seagrass beds. Sampling stations in each transect were 10 m apart (Kirkman, 1990) [18]. At each sampling station, four replicate quadrates were prepared.
The composition and distribution of seagrasses species, in addition to some biometric aspects such as shoot density, shoot height and above ground biomass were conducted according to English *et al.*(1997) [8]; Isaac (1968) [14] and Saito and Atobe (1970) [31]. The physical environmental factors such as water depth, sediment thickness and sediment grain size were measured.

The data was entered into excel sheets and analyzed using MINITAB and SPSS statistic programmes. The significant differences between sites were assessed by the analysis of variance (ANOVA).

3. Results

3.1. Species composition and distribution

Ten seagrass species belonging to seven genera were identified at the study sites (Table 1). *Thalassia hemprichii* (Ehrenberg) Ascherson, *Halodule uninervis* (Forsskal) Ascherson and *Halophila ovalis* (R. Brown) Hooker f. were the most common species distribution followed by *Halophila stipulacea* (Forsskal) Ascherson and then *Cymodocea rotundata* Ehrenberg and Hemprich ex Ascherson, while *Halophila minor* (Zollinger) den Hartog, *Enhalus acoroidies* (Linnaeus f.) Royle, *Syringodium isoetifolium* (Ascherson) Dandy, *Thalassodendron ciliatum* (Forsskal) Den Hartog and *Cymodocea serrulata* (R. Brown) Ascherson and Magnus had sporadic distribution at the study sites.

Table 1: Seagrasses species composition and distribution at study sites

Site Species	Marsa Bashayer	Marsa Dama Dama	Eastern Part of Port Sudan Harbour	Northern Part of Port Sudan Harbour	Marsa Halout	Dungonab Bay
Thalassia hemprichii	+	+	+	+	+	+
Halophila ovalis	+	+	+	-	+	+
Halophila minor	-	-	-	-	+	-
Halophila stipulacea	+	+	+	-	-	+
Enhalus acoroides	-	-	-	+	-	-
Halodule uninervis	+	+	+	-	+	+
Syringodium isoetifolium	-	-	-	-	-	+
Thalassodendron ciliatum	-	-	-	-	-	+
Cymodocea rotundata	+	-	-	-	+	+
Cymodocea serrulata	-	+	-	-	-	-

(+) Present, (-) Absent

Dungonab Bay had the highest species number (seven species) followed by Marsa Bashayer, Marsa Dama Dama and Marsa Halout (five species) and then Eastern Part of Port Sudan Harbour (four species) and Northern Part of Port Sudan Harbour (two species).

Most seagrass species were found at shallow water less than one-meter depth, except small patches of *T. ciliatum* at Dungonab Bay near Hysoit island and *H. stipulacea* at Marsa Dama Dama, Eastern Part of Port Sudan Harbour and Dungonab Bay, were recorded at depth more than two meters (Figure 1).

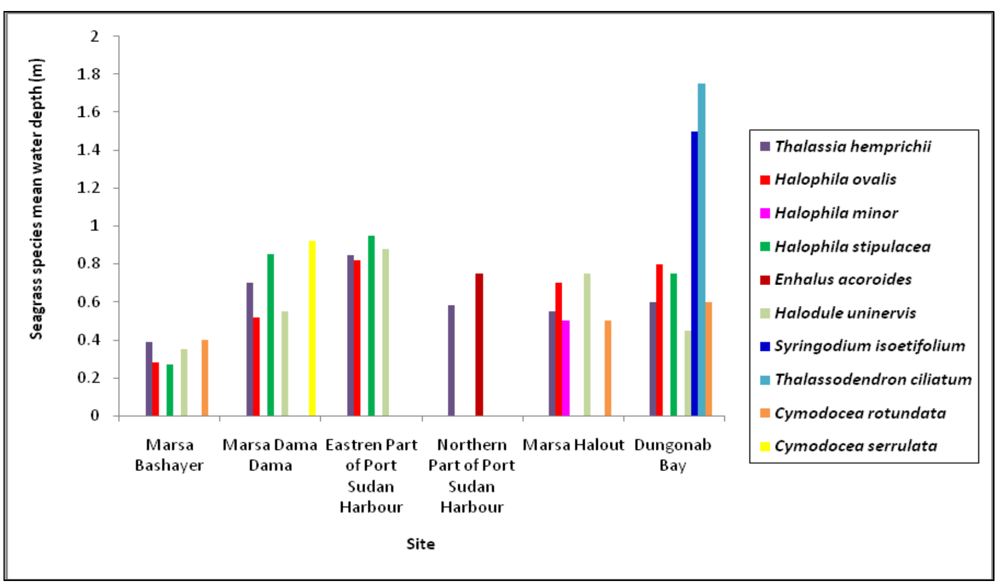

Fig 1: Seagrass species and mean water depth (m) at study sites

Most of the seagrass meadows at study sites were located at mud, soft sand or muddy sand substratum, on sediment thickness ranging between 0.02 and > 2.0 m (Figure 2). *H. ovalis* and *H. minor* were generally located at the sandy bottom.

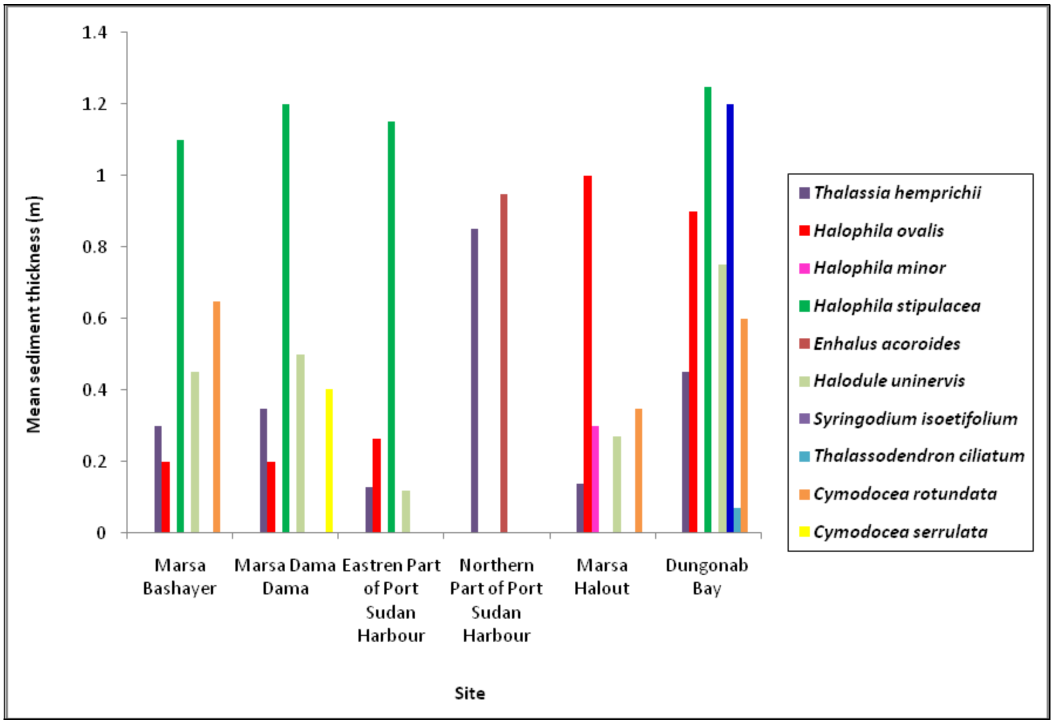

Fig 2: Seagrass species and mean sediment thickness (m) at study sites

Thalassia hemprichii
This was the most broadly distributed species, recorded at all study sites (Table 1). It was sited at mean water depth ranged between 0.35 - 1.20 m (Figure 1), growing on sandy muddy substratum (0.04 - 0.5 m thickness) (Figure 2).

Halophila ovalis
H. ovalis was a very commonly distributed species, found at all study sites, except Northern Part of port Sudan Harbour (Table 1). It inhabited shallow waters (0.1-1.03 m depth) (Figure1), growing on sandy or admixture of sand and coral debris or fragments (0.05-1.90 m thickness) (Figure2).

Halophila minor
H. minor was rarely distributed in the study, recorded only at Marsa Halout site (Table 1). It was found at a water depth ranging between 0.1 and 1.0 m (Figure1), growing on sandy or sandy muddy substratum (0.04 – 0.95 m thickness) (Figure2).

Halophila stipulacea
H. stipulacea was commonly distributed as found at all study sites except Northern Part of Port Sudan Harbour and Marsa Halout (Table 1). It occurred at shallow water at a depth ranging from 0.2 to 2.0 m (Figure1), growing on muddy sandy bottom (0.25 - > 2.0 m thickness) (Figure2).

Enhalus acoroides
E. acoroides was very rarely distributed, recorded only at Northern Part of Port Sudan Harbour (Table 1). It inhabited shallow water (0.40-1.25 m) (Figure 1), growing on muddy sandy bottom (0.20-1.30 m thickness) (Figure 2).

Halodule uninervis
H. uninervis was a very commonly distributed species as *H. ovalis* (Table 1). It was recorded at all study sites except Northern Part of Port Sudan Harbour. It inhabited a wide water depth range (0.1-1.10 m) (Figure 1) and a wide range of substratum (sand, muddy sand and muddy). It was growing on 0.02 to 1.60 m sediment thickness (Figure 2).

Syringodium isoetifolium
S. isoetifolium was a species of rare distribution, recorded only at Dungonab Bay site (Table 1). It was found at water depth ranging between o.5 and 1.75 m (Figure 1), and sediment thickness ranging between 0.5 and 1.70 m (Figure 2). It was occurred on sand muddy or sand bottom.

Thalassodendron ciliatum
T. ciliatum was also a rare species encountered only at Dungonab Bay site (Table 1). It inhabits a water depth ranging between 1.0 and > 2.0 m (Figure 1). It was survived on hard bottom (0.05-0.15 m sediment thickness), (Figure 2).

Cymodocea rotundata
C. rotundata was a species of common distribution (Table 1). It inhabited shallow water depth (0.15-1.17 m), (Figure 1) and was found on sandy or muddy sand bottom (0.07-1.45 m sediment thickness) (Figure 2).

Cymodocea serrulata
C. serrulata was a very rare species, recorded only at Marsa Dama Dama (Table 1). It inhabited sandy or muddy sandy bottom in water depth ranging between 0.75 and 1.0 m (Figure 1), and sediment thickness ranging between 0.08 and 1.20 m (Figure 2).

3.2. Bottom sediment grain size composition

Figure 3 shows the mean percentage values of bottom sediment grain size at study sites. While the Eastern Part of Port Sudan Harbour had the highest very coarse sand percentage (34.5%), Marsa Halout site had the highest silt and clay percentage (7.5%).

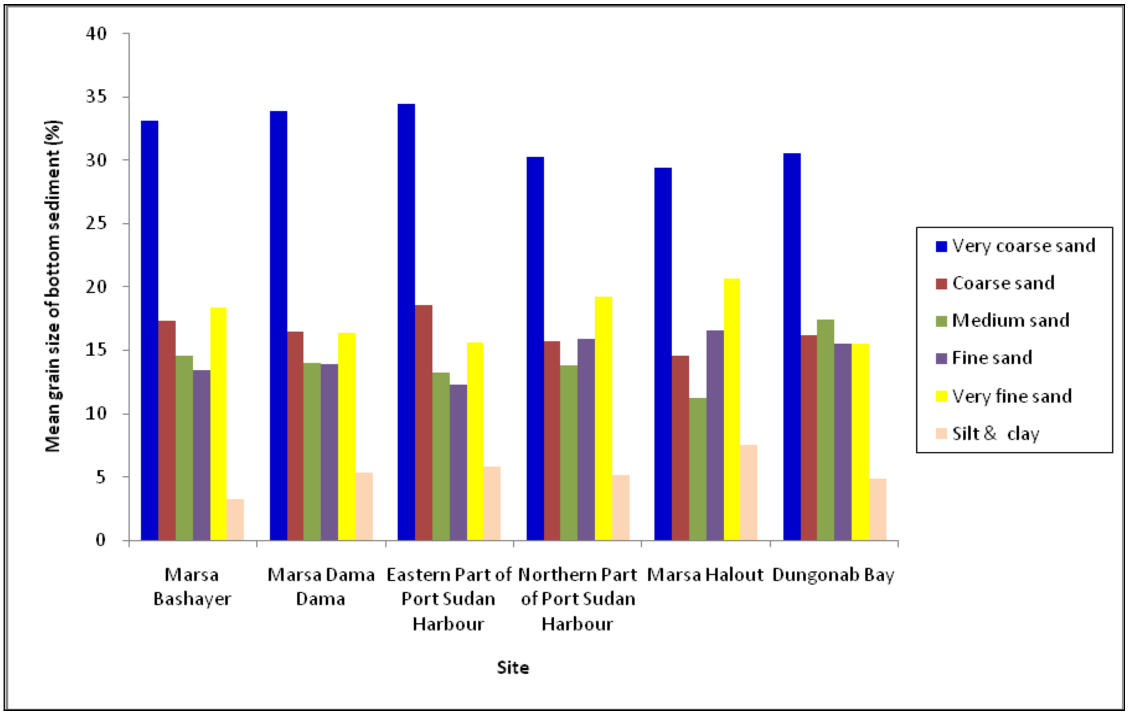

Fig 3: Mean sediment grain size composition (%) at study sites

3.3. The seagrasses shoot density

The averages shoot density of seagrass meadows ranged between 33.25 and 2353.2 shoot/m^2 at Northern Part of Port Sudan Harbour and Dungonab Bay, respectively. The highest mean shoots density of seagrass individual species at study sites was 8025 shoot/m^2 for *S. isoetifolium* at Dungonab Bay and the lowest one was two shoot/m^2 for *T. hemprichii* at Northern Part of Port Sudan Harbour (Figure 4).There were no significant differences of shoot density among all sites (f= 0.59, P = 0.706, df = 5).

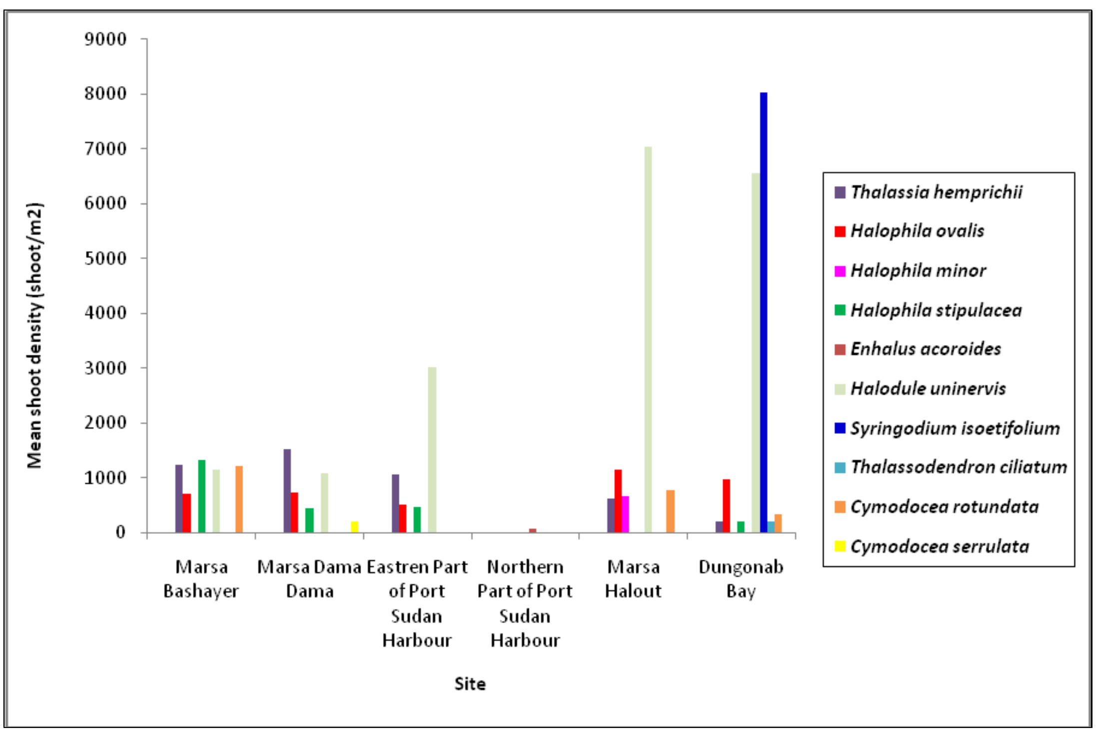

Fig 4: Mean shoot density (shoot/m^2) of seagrass species at study sites

3.4. The seagrasses shoot height
E. acoroides at Northern Part of Port Sudan Harbour had the greatest mean shoot height (71 cm) of seagrass individual species at the study sites during sampling period. *H. minor* at Marsa Halout had the lowest one (1.0 cm), (Figure 5).

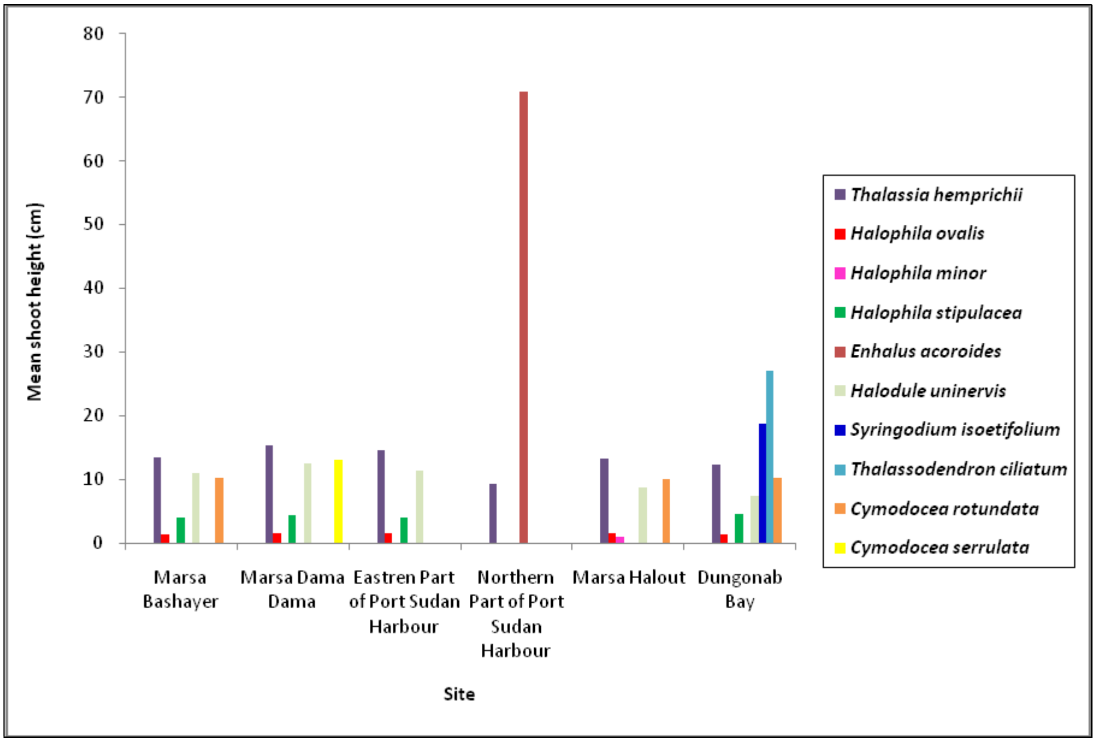

Fig 5: Mean Shoot height (cm) of seagrass species at study sites

3.5. The seagrasses above ground biomass
The averages above ground biomass of seagrass meadows ranged between 224.05 and 408.485 g dry weight/m^2 at Northern Part of Port Sudan Harbour and Dungonab Bay, respectively. *S. isoetifolium* at Dungonab Bay had the highest seagrass individual species mean above ground biomass. (Figure 6).

The results of above ground biomass showed that there were no significant differences among all sites (F = 0.19, P = 0.965, df= 5).

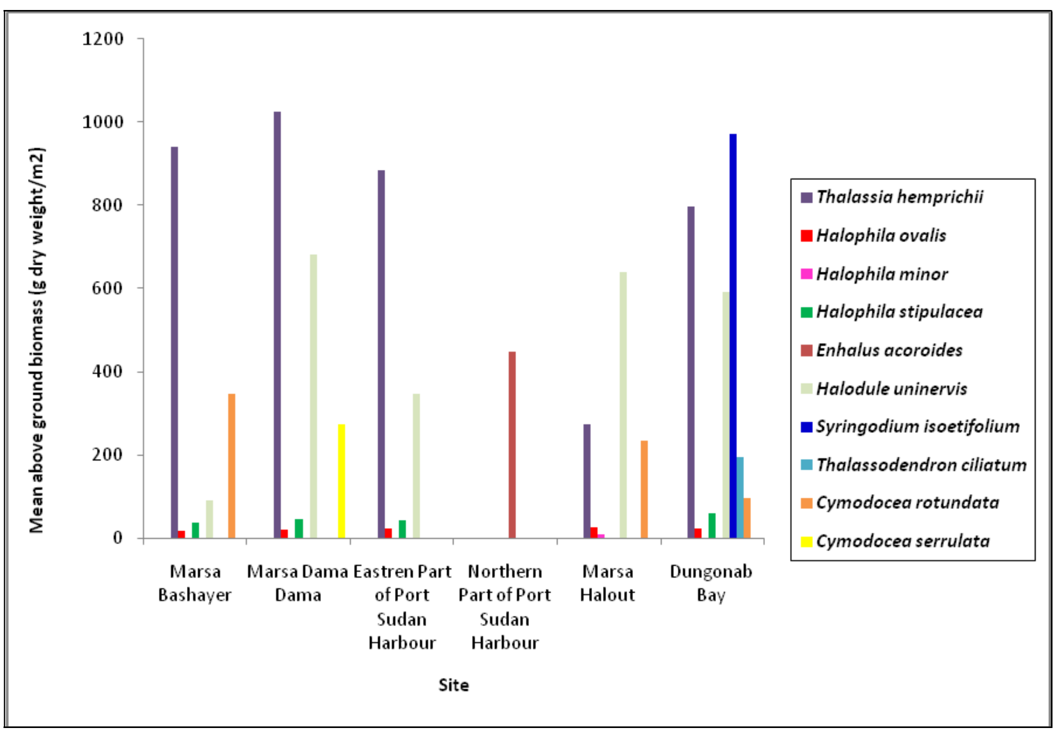

Fig 6: Mean above ground biomass (g dry weight/m^2) of seagrass species at study sites

4. Discussion

Ten species of the twelve species reported in the Red Sea (Price, *et al.*, 1988; Qurban *et al.*, 2019) [27, 28] were encountered during the present study. The two species not encountered are *Halodule pinifolia* and *Halohpila decipiens*, which were encountered in other sites within the Red Sea such as the Egyptian coast of the Red Sea (El Shaffai *et al.*, 2011) [7]. Whereas six seagrass species were identified by Geneid (2009) [10] along the Egyptian Red Sea coast, a total of seven, three and two species were recorded by Osama *et al.* (2010) [25], Mahdy *et al.* (2021) [22] and Ghallab *et al.* (2022) [11] at Hurghada area of the Red Sea of Egypt, respectively. Price *et al.* (1988) [27] reported nine species along the Red Sea coast of Saudi Arabia and North Yemen.

Comparing to these, the number of seagrass species encountered in the present study is the highest. This list of seagrass species in the present study is considered the first record on the Sudanese Red Sea Coast seagrasses at the six different sites.

The variations in species number among sites may be due to the variations in ecological factors among study sites such as bed type, water depth and transparency.

H. uninervis, *H. ovalis*, *T. hemprichii* and *H. stipulacea* were the dominant species that occurred at most of the study sites at the present investigation. Qurban *et al.* (2019) [28] reported *H. uninervis*, *T. hemprchii* and *H. stipulacea* as the most commonly observed species along Saudi Arabian coast of the Red Sea, with *H. stipulacea* as the most dominant at each of the locations studied.

Worldwide, according to Binh (2004) [1], fourteen species of seagrasses were recorded in Vietnam coastline. Of these, nine species were recorded in the Sudanese Red Sea coast during the present study. The dominant species in Vietnam coastline were *E. acoroides*, *T. hemprchii*, *C. rotundata*, *C. serrulata*, *H. unnerves*, *H. ovalis* and *Zostera japonica*. *H. uninervuis* was mentioned by Sheppard *et al.* (1992) [32]; Kenworthy *et al.* (1993) [17] and Elkhidir (2000) [6] as the dominant species in the Arabian Gulf. Hillman *et al.* (1995) [12] reported the dominance of *H. uninervis* and *H. ovalis* in Western Australia. Wide distributed for *H. uninervis*, *H. ovalis* and *T. hemprichii* were reported by Ragavan *et al.* (2016) [30] at Andaman and Nicobar Islands.

The spatial distribution of seagrass species among the different sites in the present study has shown considerable variations in species number. While seven species were recorded at Dungonab Bay, only two species were recorded at Eastern Part of Port Sudan Harbour (Shipyard). Whereas *T. hemprichii* was recorded in all the six study sites, *T. ciliatum* and *S. isoetifolium* were recorded only at Dungonab Bay, *C. serrulata*, *E. acoroides* and *H. minor* were recorded at Marsa Dama Dama, Northern Part of Port Sudan Harbour (Shipyard) and Marsa Halout, respectively. The differences of species number at the sites in the present study could be due to the differences in environmental characteristics in the sites.

The seagrass species were located mainly at mud, soft sand, or muddy sand bottom. Osama *et al.* (2010) [25] mentioned that seagrass species are usually sited at sediment of high amount of sand and infrequently silt with gravels and clay. According to Geneid (2009) [10] the environmental factors influencing the presence and growth of the seagrass species in the Red Sea have been associated to temperature, sediment composition, water movement and salinity.

Mean shoot density of over 400 shoots/m^2 in the Gulf of Aqaba was reported by Wahbeh (1980) [34]. Although this value is larger than the value recorded at Northern Part of Port Sudan Harbour, the shoot density value reported by Wahbeh (1980) [34] in the Gulf of Aqaba was considered low compared with shoot density figures reported in the present study.

Binh (2004) [1] in Vietnam recorded shoot density of 55 and 183 shoot/m^2 for *C. serrulata* and *S. isoetifolium*, respectively. The figures of Binh (2004) [1] were lower (very lower in case of *S. isoetifolium*) than the figures reported for these two species in the present study. Binh also (2004) [1] reported figures ranging between 40-2250, 30-12500, 20-50 and 30-300 shoot/m^2 for *H. ovalis*, *H. uninervis*, *E. acoroides* and *T. hemprichii*, respectively. Although these figures when compared with the present study were high in case of *H. ovalis* and very high in case of *H. uninervis*, they are considered low in case of *T. hemprichii* and within the range in case of *E. acoroides*. Commonly the shoot density in the present study was within the range observed for tropical seagrass.

Mean shoot height ranging between one centimeter (*H. minor*) to 72 cm (*E. acoroides*) was reported during the present study. Shoot height ranging between 3-12 cm for seagrass *H. stipulacea* was recorded in the Red Sea at Gulf of Aqaba by Hulings (1979) [13]. Jones *et al.* (1987) [15] reported a figure of 20 cm for the seagrass *T. ciliatum* in the Red Sea shallow waters. Carpenter *et al.* (1997) [2] reported in Arabian Gulf maximum plant height for *H. univervis* of 15 cm. Comparing to the present study, the shoot height figure reported by Jones *et al.* (1987) [15] for seagrass *T. ciliatum* in the Red Sea was low and the figure reported by Carpenter *et al.* (1997) [2] in Arabian Gulf or *H. uninervis* was high. It is pertinent to mention that the low shoot height recorded for *H. stipulacea* (3.95-4.6 cm) is still within the range recorded by Hulings (1979) [13] at Gulf of Aqaba.

The average of above ground biomass of all seagrass species at the study sites ranged between 224.05 g dry weight/m^2 at Northern Part of Port Sudan Harbour and 408.5 g dry weight/m^2 at Marsa Dama Dama. Species wise, the above ground biomass ranged between 8.9 g dry weight/m^2 for *H. minor* at Marsa Halout and 985.9 g dry weight/m^2 for *S. isoetifolium* at Dungonab Bay.

In the Red Sea Qurban *et al.* (2019) [28] recorded the highest above ground biomass for *H. stipulacea* of 81±24 g dry weight/m^2 and an average above ground biomass for *T. cilatum* of 74 ± 16 g dry weight/m^2. Wahbeh (1980) [34] reported the maximum standing crops for *H. ovalis*, *H. stipulacea* and *H. uninervis* in the Northern Coast of Agaba Gulf of 10, 260 and 400 g dry weight/m^2, respectively. While these figures were low in case of *H. ovalis* and high in case of *H. stipulacea*, they are within the range in case of *H. uninervis* in the present study.

Worldwide Elkhidir (2000) [6] reported the above ground biomass for seagrasses in Abu Dhabi City coastal waters ranged between 1.76 and 34.60 g dry weight/m^2. Average above ground biomass between 28.54±14.4 and 98.36±38.59 g dry weight/m^2 in the central coast of Vietnam was recorded by Tin *et al.* (2020) [33]. Poovachiranon and Chansang (1994) [26] documented that the above ground mean biomasses were about 105.28, 56.75, 13.91, 1.07 and 44 g dry weight/m^2 in Thailand (Andaman Sea) for *T. hemprichii*, *E. acoroides*, *H. ovalis*, *H. uninervis and C. rotundata* respectively. Comparing the present study with these values, the range reported by Elkhidir (2000) [6], the values recorded by Poovachiranon and Chansang (1994) [26] and Tin *et al.* (2020) [33] were low.

Jupp *et al.* (1996) [16] reported a mean total biomass for *H. uninervis* between 1.4-176.5, *H. ovalis* between 0.3 – 23.9 and *T. ciliatum* between 123.5-167.6 g dry weight/m^2 in the coastal water of Oman. Compared to these values, the present values of above ground biomass are higher, except in the case of *H. ovalis* which was within the range of these studies.
Binh (2004) [1] measured the biomass of some seagrass in the coastal water of Vietnam and reported the figures of 16, 12.5, 3246.5, 8.99 and 33.2 g dry weight/m^2 for *H. ovalis*, *H. uninervis*, *E. acoroides, C. serrulata* and *S. isoetifolium*, respectively. When comparing the figures of the above ground biomass in the present study, they are higher than Binh's figures, except in the case of *H. ovalis* which was within the range of his data, whereas in the case of *E. acoroides* the biomass was lower.
The low above ground biomass of species at Eastern Part of Port Sudan Harbour (Green Area) and Marsa Halout may be due to the low light penetration (low transparency) which was observed during the study. According to Zieman (1987) [37], the differences in species and local conditions result in the wide variations in biomass.

5. Conclusion

There is a paucity of information on the seagrass communities in the Sudanese Red Sea coast. The present data could be regarded as the first published on the composition and distribution, in addition to some biometric aspects such as shoot density, shoot height and above ground biomass composition on seagrass beds along the Sudanese Red Sea coast. The study findings augment previous studies that the Red Sea as an ecosystem is conducive to a lush biome of seagrasses. The current information on distribution and composition of seagrass communities in the Sudanese Red Sea coast is very important as laying the basis for further studies including the interaction with other marine biota besides being indispensable for laying plans for their conservation and for coastal zone management. Attention needs to be specifically directed towards the role of seagrasses communities in climate change and the potential threats they are facing due to the increasing human activities on the Sudanese Red Sea coast.

6. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

7. Acknowledgments

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