Open Journal of Ecology, 2024, 14, 366-380
https://www.scirp.org/journal/oje
ISSN Online: 2162-1993
ISSN Print: 2162-1985

Diversity, Abundance and Distribution Patterns of Epibenthic Echinoderms in Dungonab Bay, Red Sea, Sudan

Abdelmoneim Karamalla Gaiballa

Department of Biological Oceanography, Faculty of Marine Sciences and Fisheries, Red Sea University, Port Sudan, Sudan
Email: gaiballa44@gmail.com

How to cite this paper: Gaiballa, A.K. (2024) Diversity, Abundance and Distribution Patterns of Epibenthic Echinoderms in Dungonab Bay, Red Sea, Sudan. *Open Journal of Ecology*, **14**, 366-380.
https://doi.org/10.4236/oje.2024.144022

Received: February 29, 2024
Accepted: April 23, 2024
Published: April 26, 2024

Abstract

The abundance, distribution and diversity of epibenthic echinoderm were investigated at Dungonab Bay in the Red Sea coastal water of the Sudan. Four permanent line transects were chosen. Eight (30 × 2) square metre belt transects along each permanent line transect at 20 metre intervals were used to collect data. The data were subjected to univariate and multivariate analyses. Spatial variations of epibenthic echinoderm abundance were assessed with one-way analysis of variance. Hierarchical agglomerative clustering was used to identify and illustrate the similarities in echinoderm abundance between line transects and between belt transects. Indices of richness (*d*), diversity (*H'*), evenness (*J'*) and dominance (*C*) were used to explain the diversity of epibenthic echinoderm species. The distribution pattern of each echinoderm species was determined in each permanent line transect. A total of 986 individuals were recorded within sixteen species of epibenthic echinoderms in the four line transects. Holothuriidae was the dominant family (5 species and 342 individuals). The most abundant echinoderms species was *Pearsonothuria graeffei* (77 individuals, about 7.81%). Abundances intra-transects and intra-families were insignificant (f = 1.67, p = 0.183, df = 3 and f = 3.24, p = 0.083, df = 9, respectively). The highest values of Shannon-Wiener diversity index (*H'*), Pielou evenness index (*J'*), Margalef species richness index (d), and Simpson Dominance index (*C*) were 2.738, 0.9875, 2.791 and 0.07159, respectively. The distribution patterns of all species in the study transects varied between clumped and uniform, with the exception of *Asthenosoma varium* of the Echinothuridae family, which had clumped distribution patterns in all transects. The study concluded that Dungonab Bay supports rich and diverse communities of epibenthic echinoderms.

Keywords

Sudan, Red Sea, Echinoderm, Diversity, Abundance and Distribution

1. Introduction

Echinoderms are benthic marine invertebrates widely distributed throughout the world's marine waters [1]. They are globally widespread at almost all latitudes, depths and marine environments, rich in coral reef environments but widespread in shallow coasts. They can be found from the intertidal zone to the deep sea [2]. Echinodermata is divided into five classes: Crynoidea (sea lilies and feather stars), Ophiuroidea (brittle stars or snake stars), Holothoroidea (sea cucumbers), Echinoidea (sea urchins and sand dollars), and Asteroidea (starfish). Worldwide, there are about 7000 species of echinoderms. Echinoderm communities are useful indicators of the state of the marine community. Echinoderms are essential components of the coral reef environment [3] [4]. Due to their high density, biomass and adaptable ecological roles, echinoderms play an important role in the structure and function of rocky communities in the intertidal and shallow subtidal zones [5]. Ecologically, echinoderm plays an important role in coral reefs and influence coral reef structures in tropical and subtropical regions [6] [7]. Some echinoderms play a role in the environment by degrading leftover organic matter from the food of other animals [8] [9]. Some groups of echinoderms, such as Holothuroids, represent valuable economic returns to coastal communities in poor countries if their resources are cared for and developed by government fisheries agencies in those countries. Some echinoderm species are important suppliers of nutrition and drug manufacturing [10] [11] [12].

Assessing biodiversity in marine systems in terms of species richness is important for recognizing ecological patterns of species distribution, ecosystem functioning, managing marine resource use and ranking conservation priorities [13] [14]. Understanding the composition, diversity and distribution of echinoderms is indispensable, due to their importance in terms of diversity and application in the advancement of coral reef environments [15].

Sudanese coastal waters contain a diversity of echinoderm species, but little is known about their distribution. Ali [16] observed the high diversity and relative richness of marine habitats in the Abu Hashish fringing reefs in the Port Sudan area while studying the species composition of Holothroidea, Crinoidea, Steroidea, Echinoidea and Ophioroidea, where 38 species of echinoderms were found. The present study examines the diversity, abundance and distribution patterns of echinoderm species in the intertidal zone including seagrass, mud, sand and coral habitats in Dunganab Bay on the Sudanese Red Sea coast.

2. Materials and Methods

2.1. Study Area

Dungonab Bay is located about 130 km north of Port Sudan (**Figure 1**). The bay extends in its direction from northwest to southeast, almost in between. The area of the flat bay is about 305 km^2, and its dimensions range from 32 km in length, and between 3.2 and 14.5 km in width, with an average width of about 10.5 km. The bay is relatively shallow but reaches a depth of about 42.5 m [17] [18]. The

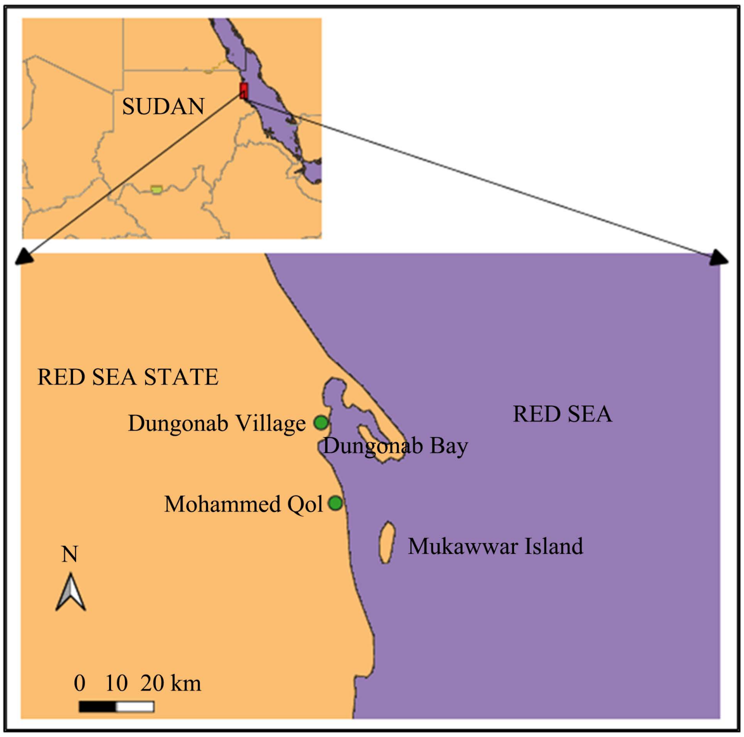

Figure 1. Map showing the study area.

Gulf is one of the oldest aquaculture sites in Sudan, where pearls have been cultured since 1910 [17]. The relatively high temperature and salinity of the bay has created diverse marine ecosystems. On the shore of the bay is a small village called Dungonab, inhabited with a small number of people who practice fishing and a little agriculture and trade.

2.2. Data Collection

The study was conducted between February and August 2018. After initial surveys of the study area, four permanent line transects [19] [20] [21], with a length of 400 metre per line transect, were established. They are coded as follows: T1 at 21˚07.029'N, 37˚07.399'E; T2 at 21˚06.584'N, 37˚07.084'E; T3 at 21˚06.292'N, 37˚07.328'E; and T4 at 21˚04.363'N, 37˚07.233'E. Each permanent line transect was divided into eight (30 × 2) square metre belt transects for data collection. The distances between the different belt transects were about 20 metres apart. The eight belt transects in each line transect are named: belt1, belt2, belt3, belt4, belt5, belt6, belt7 and belt8. Data were collected using the snorkeling methods.

2.3. Species Composition and Distribution

Epibenthic echinoderm species occur at crossways the upper layer of bed from four permanent line transects in intertidal and shallow waters were recognized, classified and recorded in situ, or one to two specimens of each species were collected with hand and preserved in containers containing 5% seawater formalin solution, then transferred to the laboratory for further classification whenever necessary. Taxa of different epibenthic echinoderm species were sorted and identified to the species level whenever possible using morphological identification. Epibenthic echinoderm taxa samples were identified according to the keys, the field Guides and survey methods of Vine [22], Rowe and Richmond [23], Lieske and Myers [24] and Eleftheriou [25].

2.4. Data Analysis

2.4.1. Abundance

The total number of individuals of different epibenthic echinoderm species was counted in each a 30 × 2 square metre belt transect [19] [21] [26] along the four permanent line transects.

Relative abundance is the proportion of species in a community. The relative abundance of each species was calculated as follows:

$$RA = ni \div N \times 100\%$$

where:

RA: The relative abundance of target species;

N: The total number of observed individuals for all species in all transects;

ni: The number of individuals for the target species in all transects.

Spatial differences in abundance of epibenthic echinoderm species between the four line transects and between echinoderm families were assessed by one-way analysis of variance (ANOVA) using the Statistical Package for the Social Sciences (SPSS 16.0). Hierarchical agglomerative clustering with group average data linkage [27] was conducted to explain and find out similarity [28] in echinoderm abundance between permanent line transects and also between belt transects using the Plymouth Routines statistical package in Multivariate Ecological Research (PRIMER 5.0). The results were presented graphically.

2.4.2. Spices Diversity

Univariate analysis was used to determine echinoderm species diversity for each line transect of the study. Margalef species richness index (d); Shannon-Wiener diversity index (H'); Pielou evenness index (J') and Simpson dominance index (C) were used to explain epibenthic echinoderms diversity [29] [30] using the DIVERSE in the statistical package Plymouth Routines in Multivariate Ecological Research (PRIMER 5.0) [28].

The Margalef species richness index (d), [31] quantifies the total number of species present for a given number of individuals. It is calculated as follows:

$$d = (S - 1) \div \log 2N$$

where:

d = Margalef species richness index;

S = Total number of species;

N = Total number of individuals.

The Pielou Evenness index (J'), [32]. The index determines how regularly the individuals are distributed among diverse species. It is estimated as follows:

$$J' = H' \div H'_{\max}$$

$$H'_{\max} = \ln S$$

where:

J' = Pielou Evenness index;

$H'_{\max}$ = Maximum possible diversity;

S = Total number of species.

The Shannon-Wiener diversity index (H'), [33]. This universally used diversity index [34] includes indicators of diversity, species richness and evenness. It is calculated as follows:

$$H' = \sum_{i=1}^{s} \rho_i \left(\ln \rho_i\right)$$

where:

H' = Shannon-Wiener diversity index;

p_i = The ratio of number of individuals of i species.

The Simpson Dominance index (C), [35]. The index determines the dominance of species and weight the abundance of the most common species. It is designed as follows:

$$C = \sum_{i=1}^{s} \left(P_i\right)^2$$

where:

C = Simpson Dominance index;

p_i = The ratio of number of individuals of i species.

2.4.3. Distribution Pattern

The distribution pattern of each species of echinoderms in the four permanent line transects was measured using Morisita distribution index (IM) according to Magurran [36] as the following formula:

$$\text{IM} = n\left(\Sigma x^2 - N \div N\left(N-1\right)\right)$$

where:

IM = Morisita distribution index;

n = Number of plots in the relevant station;

N = Total number of individuals in all plots at relevant station;

Σx^2 = Sum of square of the number of individuals of the relevant species for all plots at the relevant station.

The Morisita distribution index (IM) is an arithmetic measure of dispersion of individuals within a population. The distribution pattern is divided into three categories: random, uniform, and clumped. Whereas, if IM = 1 the distribution pattern is random, if IM > 1 the distribution pattern is clumped and if IM < 1 the distribution pattern is uniform.

3. Results

3.1. Species Composition and Distribution

As shown in Table 1 a total of 16 species within fourteen genera, ten families,

Table 1. Species composition and distribution at the study transects.

Class	Order	Family	Species	T1	T2	T3	T4
Holothuroida	Holothuriida	Holothuriidae	*Actinopyga echinites*	+	+	+	+
			Holothuria atra	+	+	+	+
			Holothuria edulis	+	+	+	+
			Holothuria nobilis	+	+	+	+
			Pearsonothuria graeffei	+	+	+	+
	Apodida	Synaptidae	*Synapta maculata*	+	+	+	+
Echinoidea	Echinoida	Echinometridae	*Echinometra mathaei*	+	+	+	+
	Diadematoida	Diadematidae	*Diadema setosum*	+	+	+	+
	Temnopleuroida	Toxopneustidae	*Tripneustes gratilla*	+	+	+	+
	Echinothurioida	Echinothuriidae	*Asthenosoma varium*	+	+	+	+
Asteroidea Valvatida	Valvatida	Ophidiasteridae	*Fromia ghardaqana*	+	+	+	+
			Linckia multiflora	+	+	+	+
			Gomophia egyptiaca	+	+	+	+
		Acanthasteridae	*Acanthaster planci*	+	+	+	+
Ophiuroidea	Ophiurida	Ophiotrichidae	*Macrophiothrix demessa*	+	+	+	+
		Ophiactidae	*Ophiactis savignyi*	+	+	+	+

(+) Present.

eight orders and four classes of echinoderms were encountered in each of the different transects during the study. The family Holothuriidae has the highest number of species (5 species) followed by the family Ophidiasteridae with three species, while the rest have only one species.

3.2. Abundance of Echinoderms

A total of 986 individuals were encountered during the study. The highest number of individuals was recorded in T2 with 279 individuals (28.3%) followed by T3, T1 and T4 with 256 individuals (25.96%), 235 individuals (23.83%) and 216 individuals (21.91%), respectively.

The highest number of individuals of the species was recorded for *Pearsonothuria graeffei* from Holothuriidae with 77 individuals with a relative abundance of 7.81%, followed by *Synapta maculata* from Synaptidae and *Gomophia egyptiaca* from Ophidiasteridae with 75 individuals with a relative abundance of 7.61%. *Tripneustes gratilla* from Toxopneustidae had the lowest number of individuals with 36 individuals with a relative abundance of 3.65% (Figure 2 and Table 2).

Holothuriidae had the highest number of individuals with 342 individuals (34.69%). The lowest number of individuals was recorded in Toxopneustidae with 36 individuals (3.65%) (Figure 3).

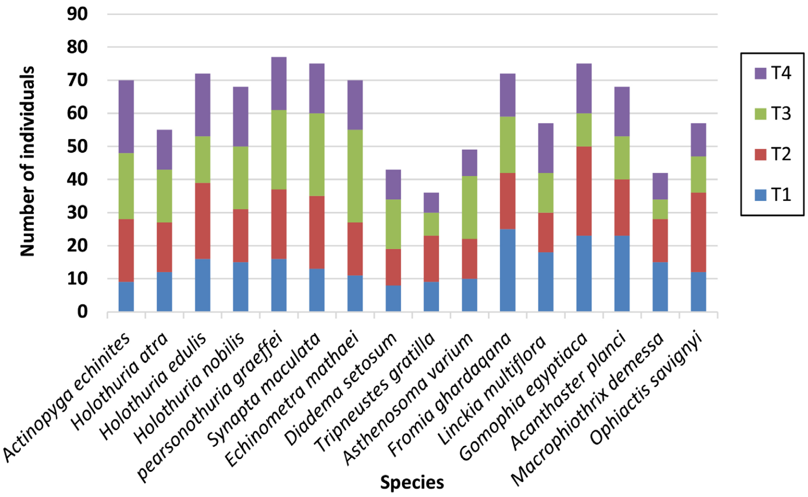

Figure 2. Number of individuals of echinoderm species.

Table 2. The relative abundance (RA) of echinoderm species at study transects.

Family	Species	RA (%)
Holothuriidae	*Actinopyga echinites*	7.1
	Holothuria atra	5.58
	Holothuria edulis	7.3
	Holothuria nobilis	6.9
	Pearsonothuria graeffei	7.81
Synaptidae	*Synapta maculata*	7.61
Echinometridae	*Echinometra mathaei*	7.1
Diadematidae	*Diadema setosum*	4.36
Toxopneustidae	*Tripneustes gratilla*	3.65
Echinothuriidae	*Asthenosoma varium*	4.97
Ophidiasteridae	*Fromia ghardaqana*	7.3
	Linckia multiflora	5.78
	Gomophia egyptiaca	7.61
Acanthasteridae	*Acanthaster planci*	6.9
Ophiotrichidae	*Macrophiothrix demessa*	4.26
Ophiactidae	*Ophiactis savignyi*	5.78

The results showed that there were significant differences in abundance between families ($f = 3.29$, $p = 0.001$, $df = 9$) and no significant differences in abundance between transects ($f = 2.39$, $p = 0.068$, $df = 3$).

While the similarities score between line transects appears to have a similarity level > 57.72% similarity (**Figure 4**), the similarities between belt transects have a similarity level > 47.06% similarity (**Figure 5**).

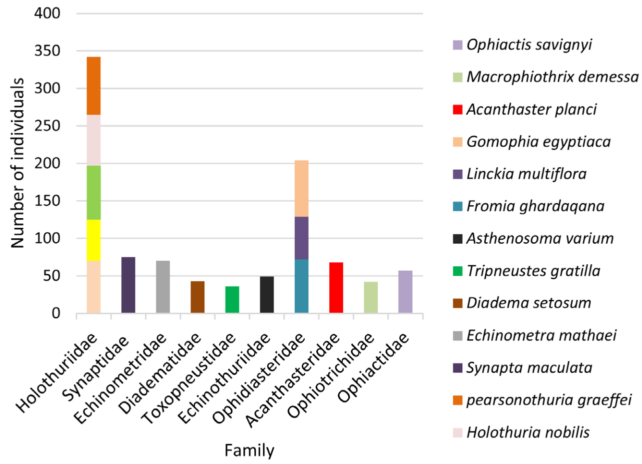

Figure 3. Number of individuals of echinoderm families.

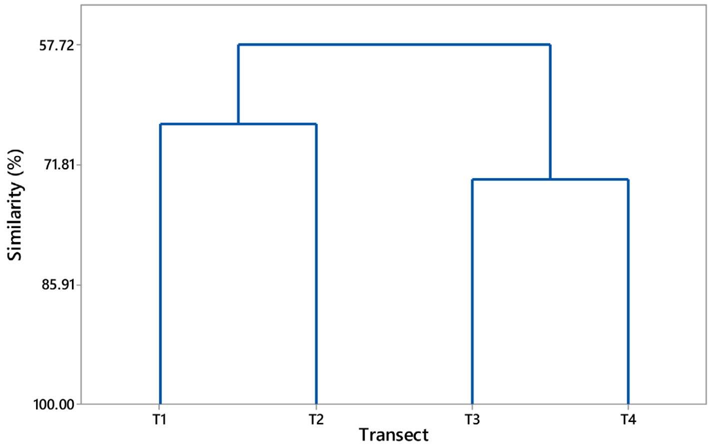

Figure 4. Hierarchical agglomerative clustering of echinoderm abundance showing the average linkages between sampling transects.

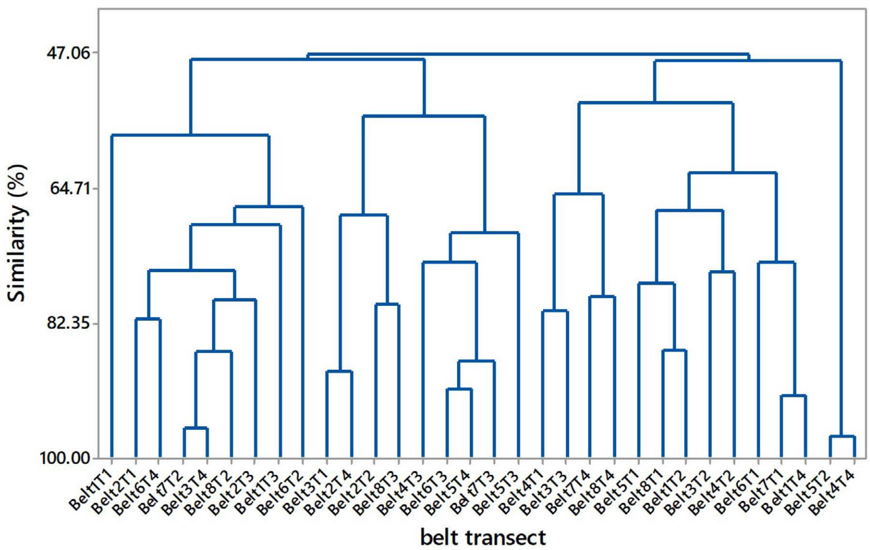

Figure 5. Hierarchical agglomerative clustering of echinoderm abundance showing the average linkages between sampling belt transects.

3.3. Diversity of Echinoderms

T2 had the highest values of Shannon-Wiener diversity index (*H*′) with 2.738 and Pielou evenness index (*J*′) with 0.9875, and the lowest values of Margalef species richness index (*d*) and Simpson dominance index (*C*) with 2.664 and 0.06692 of echinoderms, respectively. T3 had the lowest values of Shannon-Wiener diversity index (*H*′) and Pielou evenness index (*J*′) with 2.698 and 0.9731 for echinoderms, respectively. T4 and T3 had the highest values of Margalef species richness index (*d*) with 2.791 and Simpson Dominance index (*C*) with 0.07159 for echinoderms, respectively (Table 3).

3.4. Distribution Patterns of Echinoderm Species

During the current study, two types of distribution patterns were recorded in the study area: the clumped distribution pattern and the uniform distribution pattern. However, the results of the study showed a difference in the distribution pattern between the study transects. Table 4 shows the distribution patterns of echinoderm species in the study transects. With the exception of the species *Asthenosoma varium* of the Echinothuridae family, whose distribution patterns in the four permanent line transects were clumped, the distribution patterns of the remaining species in the four line transects varied between clumped and uniform. However, for values of the Morisita index (IM) that are less than one, its values are very close to one.

4. Discussion

During the present study, a total of sixteen species within fourteen genera, ten families, eight orders and four classes of echinoderms were observed in the shallow water of Dungonab Bay. Twelve species of holothuroids have been recorded by Hasan [37] in the Red Sea waters of Saudi Arabia, of which five species are among the species documented in the current study (*Actinopyga echinites*, *Holothuria atra*, *Holothuria edulis*, *Holothuria nobilis* and *Pearsonothuria graeffei*). Mahdy *et al.* [38] encountered a total of 33 species of echinoderms at 14 sites on the Red Sea coast of Egypt including different habitats types such as Seagrass, mangrove, coral reef, rocky, sandy and muddy shore, and eleven of these species were recorded in the current study including: *Holothuria atra*, *Holothuria nobilis*, *Pearsonothuria graeffei*, *Synapta maculata*, *Echinometra mathaei*, *Diadema*

Table 3. The values of diversity indices of echinoderms at the study transects.

Diversity Index	Transect			
	T1	T2	T3	T4
Shannon-Wiener diversity index (*H*′)	2.714	2.738	2.698	2.721
Pielou evenness index (*J*′)	0.9788	0.9875	0.9731	0.9812
Margalef species richness index (*d*)	2.747	2.664	2.705	2.791
Simpson dominance index (*C*)	0.07013	0.06692	0.07159	0.06876

Table 4. The distribution patterns of echinoderm species at the study transects.

Species	T1		T2		T3		T4	
	IM	DP	IM	DP	IM	DP	IM	DP
Actinopyga echinites	0.888888	uniform	0.935672	uniform	1.178944	clumped	1.073592	clumped
Holothuria atra	1.21212	clumped	0.761904	uniform	0.933336	uniform	0.969696	uniform
Holothuria edulis	0.933336	uniform	1.549408	clumped	1.142856	clumped	1.309944	clumped
Holothuria nobilis	0.914288	uniform	0.933336	uniform	1.918128	clumped	0.941176	uniform
Pearsonothuria graeffei	0.733336	uniform	1.028568	clumped	0.985504	uniform	0.866664	uniform
Synapta maculata	1.128208	clumped	0.900432	uniform	0.773336	uniform	0.838096	uniform
Echinometra mathaei	0.872728	uniform	0.866664	uniform	0.952384	uniform	1.066664	clumped
Diadema setosum	0.571432	uniform	1.454544	clumped	1.219048	clumped	0.888888	uniform
Tripneustes gratilla	1.111112	clumped	1.054944	clumped	0.761904	uniform	1.066664	clumped
Asthenosoma varium	1.6	clumped	1.333336	clumped	1.356728	clumped	1.142856	clumped
Fromia ghardaqana	0.96	uniform	1.235296	clumped	1.117648	clumped	0.820512	uniform
Linckia multiflora	1.464056	clumped	0.848488	uniform	0.848488	uniform	1.90476	clumped
Gomophia egyptiaca	0.885376	uniform	1.162392	clumped	0.888888	uniform	0.838096	uniform
Acanthaster planci	0.885376	uniform	1.058824	clumped	1.230768	clumped	1.142856	clumped
Macrophiothrix demessa	0.914288	uniform	2.153848	clumped	1.066664	clumped	1.142856	clumped
Ophiactis savignyi	1.333336	clumped	0.985504	uniform	0.872728	uniform	1.244448	clumped

Note: IM = Index of Morisita, DP = Distribution pattern.

setosum, *Tripneustes gratilla*, *Fromia ghardaqana*, *Linckia multifora*, *Acanthaster planci* and *Ophiactis savignyi*. Nasser *et al.* [39] found twenty-nine species of echinoderms in littoral zone of the Red Sea and Gulf of Suez, of these ten species (*Holothuria atra*, *Holothuria nobilis*, *Pearsonothuria graeffei*, *Synapta maculata*, *Echinometra mathaei*, *Diadema setosum*, *Tripneustes gratilla*, *Fromia ghardaqana*, *Linckia multifora* and *Acanthaster planci*) have been recorded in the current study. In contracts to the current study, Klaus *et al.* [40] reported the apparent absence of sea urchins (*Diadema* spp. and *Echinometra* spp.) from several sites while studying the ecological patterns and status of the reefs in Sudan. Ten of the species recorded in the current study (*Holothuria atra*, *Holothuria edulis*, *Holothuria nobilis*, *Echinometra mathaei*, *Tripneustes gratilla*, *Asthenosoma varium*, *Fromia ghardaqana*, *Gomophia egyptiaca*, *Ophiactis savignyi* and *Acanthaster planci*) were included in the list report by Tortonese [41] for echinoderms known from the Gulf of Aqaba. Estimated numbers of echinoderms species in the Red Sea and its two northern bays have been reported by Price [42], Campbell [43] and EL-Sadek [44]. Worldwide Micael *et al.* [45] reported seven species of echinoderms as frequent echinoderms at São Miguel island in the Portuguese archipelago of the Azores, none of which were among the species recorded during this study. Elsewhere in the world, sixty-one echinoderms species within 36 families were recorded from Santa Catarina, southern Brazil by Slivak *et al.* [46], the small number of species in the current study may be due to the limited study area and the small number of transects studied.

During the present study, Holothuriidae had the highest number of species, which is almost similar to the study of shallow-water echinoderms in the Indo West pacific by Clark and Rowe [47] that the holothuriods were the main assemblage. A number of individuals (910 individuals) approximately equal to the total number of individuals recorded in the current study, were recorded by Setyastuti *et al.* [48] in littoral area of Ambon Island, Eastern Indonesia, within nineteen genera, including nine genera recorded in the current study. Bachtier *et al.* [49] in the intertidal zone between Sadranan and Slili Beach, Gunung Kidul, Yogyakarta recorded the highest abundance of *Echinometra mathei* with 19 individuals, and this value is lower than the result of the current study. Among the nine species of echinoderms encountered by Janah *et al.* [2] in the intertidal zone of Nglolang Beach, Gunungkidul, Yogyakarta, they reported relative abundance values of 1.11%, 10% and 8.89% for *Diadema setosum*, *Echinometra mathaei* and *Tripneustes gratilla*, respectively. The values reported by Janah *et al.* [2] are considered low in the case of *Diadema setosum* and high in the case of *Echinometra mathaei* and *Tripneustes gratilla* compared to the current study, taking into consideration the difference in the number of species between the two studies.

The distribution pattern of marine echinoderms is often influenced by some physical factors such as temperature, pressure, dissolved oxygen, sediment types and other local habitat factors, and biological factors such as predation and intra-and inter-specific competition, etc. factors. During the present study, with the exception of *Asthenosoma varium*, the distribution patterns of different species in the study line transects varied between clumped and uniform. However, for the values of the Morisita Idex (IM) that are less than one, its values are very close to one. The results for the distribution pattern of echinoderms species in the present study were relatively similar to those of Bachtier *et al.* [49] in the intertidal zone between Sadranan and Slili Beach, Gunung Kidul, Yogyakarta, and differs from the results of Janah *et al.* [2] in the same regional area, and the results of Rahardjanto *et al.* [50] while studying the community structure, diversity, and distribution patterns of sea cucumber (Holothuroidea) in the coral reef area of Sapeken Islands, Sumenep Regency, Indonesia. In contrast to the results of the present study, Chenelot *et al.* [5] in the rocky nearshore areas of Alaska indicated that no clear patterns were identified on spatial gradients and the diversity and abundance of echinoderms were significantly variable between permanent transects sampling.

This current research paper examined the diversity, abundance and distribution pattern of epibenthic echinoderms in four transects in Dungonab Bay on the Sudanese Red Sea coast during the period from February to August 2018. Despite the limited location and time of the study, the study was able to obtain some important results and indicators regarding the distribution of echinoderms in the Dungonab Bay area on the Sudanese Red Sea coast. The current results obtained can also guide future scientific research efforts and management and conservation policies when considering potential environmental and human impacts and changes in the region. Future research topics on echinoderms in the Sudanese Red Sea coast could also address their distribution over broader areas, in addition to addressing deeper topics and details.

5. Conclusion

Sixteen species within fourteen genera, ten families, eight orders, and four classes of echinoderms were encountered during this present study. The current study provides information quantifying the spatial community structure of echinoderms on intertidal shores of Dungonup Bay. Although obtaining good and reliable information about the distribution of echinoderms requires studying larger areas and different marine habitats, the results of the present study can serve as a basis for further research and monitoring of echinoderms in the coastal waters of the Sudanese Red Sea.

Acknowledgements

Thanks and appreciation to the administration of Faculty of Marine Sciences and Fisheries, Red Sea University, Port Sudan, Sudan for the logistical support.

Conflicts of Interest

The author declares that he has no known competing interests or personal relationships that could influence the work reported in this paper.

References

[1] Souto, V., Escolar, M., Genzano, G. and Bremec, C. (2014) Species Richness and Distribution Patterns of Echinoderms in the Southwestern Atlantic Ocean (34-56˚S). *Scientia Marina*, **78**, 269-280. https://doi.org/10.3989/scimar.03882.26B

[2] Janah, L.N., Rizkyta, A.N., Hidayah, A.N., Gavintri, M.B., Salsabila, N.S., Pratita, S.D., Nurahmah, Z. and Eprilurahman, R. (2021) The Abundance and Distribution Patterns of Echinoderms in the Intertidal Zone of Nglolang Beach, Gunungkidul, Yogyakarta. *Proceedings of the 3rd KOBI Congress, International and National Conferences* (*KOBICINC*, 2020), **14**, 31-36. https://doi.org/10.2991/absr.k.210621.007

[3] Hughes, T.P. (1994) Catastrophes, Phase Shifts and Large-Scale Degradation of a Caribbean Coral Reef. *Science*, **265**, 1547-1551. https://doi.org/10.1126/science.265.5178.1547

[4] Bellwood, D.R., Hughes, T.P., Folke, C. and Nyström, M. (2004) Confronting the Coral Reef Crisis. *Nature*, **429**, 827-833. https://doi.org/10.1038/nature02691

[5] Chenelot, H., Ikeni, K., Konari, B. and Edwards, M. (2006) Spatial and Temporal Distribution of Echinoderms in Rocky Nearshore Areas of Alaska. Kyoto University, Kyoto. https://doi.org/10.5134/70914

[6] Tokeshi, M. and Tanaka, K. (2010) Dominance of Tabular Acroporid Species and

the Abundance of Echinoid Grazers in High-Latitude Coral Assemblages of Amakusa, Southwestern Japan. *Galaxea*, *Journal of the Coral Reef Studies*, **12**, 87. https://doi.org/10.3755/galaxea.12.87

[7] Tokeshi, M. and Daud, J.R.P. (2011) Feeding Electivity in Acanthaster Planci: A Null Model Analysis. *Coral Reefs*, **30**, 227-235. https://doi.org/10.1007/s00338-010-0693-3

[8] Birkeland, C. (1989) The Influence of Echinoderms on Coral-Reef Communities in Jangoux M, Lawrence JM (EDS). Echinoderm Studies, August Aimé Balkema, Rotterdam, 1-79.

[9] Hernández, J.C., Brito, A., García, N., Gil-Rodríguez, M.C., Herrera, G., Cruz-Reyes, A. and Falcón, J.M. (2006) Spatial and Seasonal Variation of the Gonad Index of Diadema Antillarum (Echinodermata: Echinoidea) in the Canary Islands. *Scientia Marina*, **70**, 689-698. https://doi.org/10.3989/scimar.2006.70n4689

[10] Kamarudin, K.R., Rehan, A.M., Hashim, R. and Usup, G. (2010) An Update on Diversity of Sea Cucumbers (Echinodermata: Holothuroidea) in Malaysia. *Malayan Nature Journal*, **62**, 315-334.

[11] Bordbar, S., Anwar, F. and Saari, N. (2011) High Value Components and Bioactives from Sea Cucumbers for Functional Foods—A Review. *Marine Drugs*, **9**, 1761-1805. https://doi.org/10.3390/md9101761

[12] Jontila, J.B.S., Balisco, R.A.T. and Matillano, J.A. (2014) The Sea Cucumbers (Holothuroidea) of Palawan, Philippines. *Aquaculture*, *Aquarium*, *Conservation & Legislation*, **7**, 194-206.

[13] Goumri, M., Cheggour, M., Maarouf, A. and Mouabad, A. (2018) Preliminary Data on the Composition and Spatial Distribution Patterns of Echinoderms along Safi rocky Shores (NW Morocco). *Aquaculture*, *Aquarium*, *Conservation & Legislation*, **11**, 1123-1202.

[14] Gray, J. (2001) Antarctic Marine Benthic Biodiversity in a World-Wide Latitudinal Context. *Polar Biology*, **24**, 633-641. https://doi.org/10.1007/s003000100244

[15] Alvarado, J.J., Guzman, H.M. and Breedy, O. (2012) Distribution and Diversity of Echinoderms (Asteroidea, Echinoidea, Holothuroidea) in the Islands of the Gulf of Chiriqui, Panama. *Revista de Biología Marina y Oceanografía*, **47**, 13-22. https://doi.org/10.4067/S0718-19572012000100002

[16] Ali, M.E. (2001) Biodiversity of Echinoderms at Abu Hashish Fringing Reef, Sudanese Red Sea Coast. M. Sc. Thesis, University of Khartoum, Sudan.

[17] Crossland, C. (1957) The Cultivation of the Mother of Pearl in Red Sea. Australian *Journal of Marine and Freshwater Research*, **8**, 111-170. https://doi.org/10.1071/MF9570111

[18] Farah, O.M. (1982) The Bathymetry, Oceanography and Bottom Sediments of Dongonab Bay, Red Sea, Sudan. PhD Thesis, University of Delaware, Newark, Delaware.

[19] English, S., Wilkinson, C. and Baker, V. (1997) Survey Manual for Tropical Marine Resources. Australian Institute of Marine Sciences, Townsville, 390.

[20] O'Hara, T.D., Norman, M.D. and Staples, D.A. (2002) Baseline Monitoring of Posidonia Seagrass Beds in Corner Inlet, Victoria. Museum Victoria Science Reports 1, 1-44. https://doi.org/10.24199/j.mvsr.2002.01

[21] PERSGA/GEF (2004) Standard Survey Methods for the Key Habitats and Key Species in the Red Sea and Gulf of Aden. PERSGA Technical Series No. 10. PERSGA, Jeddah.

[22] Vine, P. (1986) Red Sea Invertebrates. Immel Publishing, London, 224.

[23] Rowe, F.W.E. and Richmond, M.D. (2002) Echinodermata. Echinoderms. In: Richmond, M.D. Ed., *A Field Guide to the Seashores of Eastern Africa and the Western Indian Ocean Islands*. Sida, Stockholm, 300-331.

[24] Lieske, E. and Myers, R.T. (2004) Coral Reef Guide Red Sea: The Definitive Guide to over 1200 Species of Underwater Life. Harper Collins Publishers Ltd., London, 384.

[25] Eleftheriou, A. (2013) Methods for the Study of Marine Benthos. 4th Edition, John Wiley & Sons, Ltd., New York, 496. https://doi.org/10.1002/9781118542392

[26] Brock, V.E. (1954) A Preliminary Report on a Method of Estimating Reef Fish Populations. *Journal of Wildlife Management*, **18**, 297-308. https://doi.org/10.2307/3797016

[27] Ludwig, J.A. and Reynolds, J.F. (1988) Statistical Ecology: A Primer on Methods Computing. John Wiley and Sons, Inc., New York.

[28] Clarke, K.R. and Warwick, R.M. (1994) Change in Marine Communities. An Approach to Analysis and Interpretation. Natural Environment Research Council, Plymouth, 144.

[29] Krebs, C.J. (1985) Ecology: The Experimental Analysis of Distribution and Abundance. Harper and Row, New York.

[30] Roche, C., Lyons, D.O., Farinas Franco, J. and O'Connor, B. (2007) Benthic Surveys of Sandbanks in the Irish Sea. Irish Wildlife Manuals, No. 29. National Parks and Wildlife Service, Department of Environment, Heritage and Local Government, Dublin.

[31] Margalef, D.R. (1958) Information Theory in Ecology. *General Systems*, **3**, 36-71.

[32] Pielou, E.C. (1977) Mathematical Ecology. Wiley-Water Science Publication, New York.

[33] Shannon, C.E. and Weaver, W. (1949) The Mathematical Theory of Communication. University of Illinois Press, Urbana.

[34] Hauer, F.R. and Resh, V.H. (1996) Benthic Macroinvertebrates. In: Hauer, F.R. and Lamberti, G.A., Eds., *Methods in Stream Ecology*, Academic Press, New York, 339-370.

[35] Simpson, E.H. (1949) Measurement of Diversity. *Nature*, **163**, Article 688. https://doi.org/10.1038/163688a0

[36] Magurran, A.E. (1988) Ecological Diversity and Its Measurement. Princeton University Press, Princeton, 179. https://doi.org/10.1007/978-94-015-7358-0

[37] Hasan, M.H. (2009) Stock Assessment of Holothuroid Populations in the Red Sea Waters of Saudi Arabia. *SPC Beche-de-mer Information Bulletin*, **29**, 31-37.

[38] Mahdy, A., Omar, H.A., Nasser, S.A.M., Abd El-Wakeil, K.F. and Obuid-Allah, A.H. (2018) Community Structure of Echinoderms in Littoral Zone of the Red Sea Coast of Egypt. *Egyptian Journal of Aquatic Biology and Fisheries*, **22**, 483-498. https://doi.org/10.21608/ejabf.2019.26814

[39] Nasser, S.A.M., Mahdy, A., Omar, H.A., Abd El-Wakeil, K.F. and Obuid-Allah, A.H. (2019) Pictorial Key for Identification of Echinoderms Inhabiting Littoral Zone of the Red Sea and Gulf of Suez, Egypt. *The* 6*th International Conference for Young Researchers for Basic and Applied Science* (*ICYS-BAS* 19), Assiut, 27-30 March 2019, 15-30.

[40] Klaus, R., Kemp, J., Samoilys, M., Anlauf, H., El Din, S., Abdalla, E.O. and Chekchak, T. (2009) Ecological Patterns and Status of the Reefs of Sudan. *Presented at the* 11*th International Coral Reef Symposium. Ft.* Lauderdale, Florida, 7-11 July

2008, 1-5.

[41] Tortonese, E. (1977) Report on Echinoderms from the Gulf of Aqaba (Red Sea), Monitore Zoologico Italiano. *Supplemento*, **9**, 273-290. https://doi.org/10.1080/03749444.1977.10736852

[42] Price, A.R.G. (1982) Echinoderms of Saudi Arabia. Comparison between Echinoderm Faunas of Arabia, Red Sea and Gulfs of Aqaba and Suez. *Fauna of Saudi Arabia*, **4**, 3-21.

[43] Campbell, A.C. (1987) Echinoderms of the Red Sea. In: Edwards, A.J. and Head, S.M., Eds., *Key Environments*, *Red Sea*, Pergamum Press, Oxford, 215-232. https://doi.org/10.1016/B978-0-08-028873-4.50016-5

[44] EL-Sadek, A.M.M. (2015) Spatial and Temporal Distribution Patterns of Crustacean and Echinodermata Communities in Abu Galum Protected Area, South Sina. Ms.C. Thesis, Al-Azhar University, Cairo.

[45] Micael, J., Alves, M.J., Jones, M.B. and Costa, A.C. (2010) Quantitative Sampling of Sub-Tidal Echinoderms in the Azores. *Vie et Milieu*, **60**, 327-333.

[46] Slivak, N.N., Lindner, A. and Romanowski, H.P. (2022) Echinoderms from Santa Catarina, Southern Brazil: An Update on Biodiversity and Distribution. *Papéis Avulsos de Zoologia*, **62**, e202262004. https://doi.org/10.11606/1807-0205/2022.62.004

[47] Clark, A.M. and Rowe, F.W.E. (1971) Monograph of the Shallow Water Indo West Pacific Echinoderms. British Museum (Natural History), London, 238.

[48] Setyastuti, A., Purbiantoro, W. and Hadiyanto, H. (2018) Spatial Distribution of Echinoderms in Littoral Area of Ambon Island, Eastern Indonesia. *Biodiversitas Journal of Biological Diversity*, **19**, 1919-1925. https://doi.org/10.13057/biodiv/d190544

[49] Bachtier, F.W., Khalallia, F.B.R., Lesti, H.Y., Rahmani, N.N., Winasti, N.M.S., Maharani, S.E., Andilala, N. and Eprilurahman, R. (2021) Abundance and Distribution Pattern of Echinoderms in Intertidal Zone between Sadranan and Slili Beach, Gunung Kidul, Yogyakarta. *BiosciED*: *Journal of Biological Science and Education*, **2**, 52-58. https://doi.org/10.37304/bed.v2i2.2674

[50] Rahardjanto, A., Hadi, H.S., Rofieq, A. and Wahyono, P. (2020) Community Structure, Diversity, and Distribution Patterns of Sea Cucumber (Holothuroidea) in the Coral Reef Area of Sapeken Islands, Sumenep Regency, Indonesia. *Aquaculture*, *Aquarium*, *Conservation & Legislation*, **13**, 1795-1811.