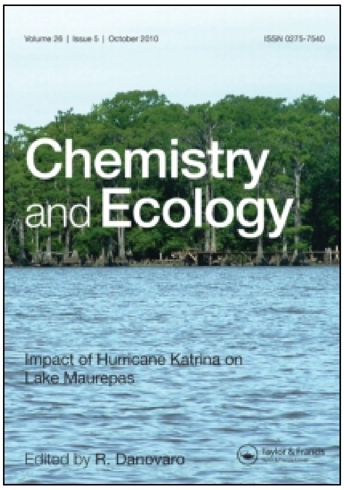

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Ecological and geochemical characteristics of bottom habitats at the northern Jordanian coast of the Gulf of Aqaba

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Ecological and geochemical characteristics of bottom habitats at the northern Jordanian coast of the Gulf of Aqaba

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A detailed study to assess the environmental conditions of the benthic habitats at the northern tip of the Gulf of Aqaba has been carried out during the summer of 2003. The texture, geochemical, and biogenic characteristics of bottom sediments as well as a description and distribution of corals, seagrass, fish species, and fish assemblages have been investigated. Results showed that the sea bottom at the study site is mainly a non-coralline sandy bottom covered with seagrass. Well-developed seagrass beds covered about 70–98% of the bottom. No coral cover was recorded. This is to be expected because of the absence of hard substrate and because of high loads of suspended matter. The seagrass habitat in the area serves as important nursery grounds for the fish larvae and hosts sea urchins and sea cucumbers. The bottom sand in the area was undisturbed, animal tracks were rare, but bioturbated holes and mounds were abundant. Bottom surface sediments were fine-grained, black with high quartz, feldspar, and mica, and low in mud content. Chemically, these sediments had low calcium carbonate, organic nitrogen, and high total phosphorus concentrations, suggesting that the sediment mineral composition is derived from existing metamorphic rocks, by weathering and erosion. The biogenous part of the sediments was mainly calcium carbonate, consisting of shells or coverings of some micro- and macro-organisms. The number and diversity of fish species inhabiting the survey site are typical of seagrass-bed sandy-bottom habitats. Some of the fish species observed are characteristic of this site and very rarely found elsewhere on the Jordanian coast. About half the fish population in the area belong to six families: Labridae (12%), Pomacentridae (7%), Mullidae (7.%), Apoginidae (6%), Chaetodontidae (6%), and Gobiidae (6%).

Keywords: Seagrass beds; Bottom habitat; Fish assemblages; Bottom sediments; Gulf of Aqaba

1. Introduction

The main habitats at the northern coast of the Gulf of Aqaba include coral reef, seagrass, and sandy bottoms. Seagrasses are the only group of higher plants that have adapted to life submerged under the sea. They inhabit soft-bottom, shallow-water areas of temperate, subtropical, and tropical seas where they may form large meadows [1, 2]. Seagrass habitats have recently been considered to be of fundamental ecological importance as primary producers in

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the sea [3]. They are found from the mid-tidal level, on shores receiving regular tides, to about 70 m depth in the Red Sea [1]. In the northern Gulf of Aqaba, Wahbeh [4] found more than 49 species of invertebrates (mostly molluscs) living in seagrass beds, either on the seagrass (e.g. gastropods) or buried in the sediment (e.g. bivalves). These well-developed seagrass beds serve also as important nursery grounds for the fish larvae. These can settle down in the seagrass and find protection against predators until they grown up [5, 6].

Coral reefs are considered as one of the most productive and highly diverse ecosystems; they are the marine equivalents of the rain forests [7]. They are tropical shallow water ecosystems restricted to seas between the latitudes 30° north and 30° south. Coral reefs in the Gulf of Aqaba are present on the upper limit of coral distribution in the world (29° 32′N), they show a very diverse ecosystem, in which more than 158 species of hard corals flourish [8]. The Jordanian Coast is fringed by a discontinuous belt of reefs along 13 km of the shoreline. Well-developed reefs on the Jordanian coast have the typical structure of the four zones: Lagoon, reef flat, fore reef, and reef slope [9]. However, these reefs vary considerably in physical size to the extent that the minimal 'contour' reefs are sometimes only 3–4 m wide [10]. Typical fringing reefs along the Jordanian coast of the Gulf of Aqaba cease to be present beyond the northern limit of the Aqaba Marine Park area (29° 45′N, 34° 97′E), where the Marine Science Station (MSS) is located. The coral cover and structure decrease gradually to the north of the MSS until they disappear at the northernmost tip of the Gulf of Aqaba, dominated by sand bottom habitats and seagrass beds.

The Red Sea Ichtyofauna is quite well known compared with other parts of the tropical Indo-Pacific Ocean. About 350 fish species have been recorded in the Gulf of Aqaba [11], but new records are being made continuously. Eleven new records were added to the fishes of the Gulf of Aqaba [12]. Randall [13] added 22 new records, and Khalaf [14] added four more new records. The number of fish species recorded in the Red Sea is about 1300 [15]. It might be only a matter of time and more research effort until a similar number will be recorded in the Gulf of Aqaba.

Biogenic sediments are generally remains of organisms, mainly calcium carbonate (calcite, aragonite), opal (hydrated silica), and calcium phosphate (teeth, bones, crustacean carapaces). They arrive at the site of deposition either by *in situ* precipitation or through settling via the water column. Clastic sediments on the other hand are composed of fragments or grains derived from existing rocks, by weathering, erosion, transportation, and deposition. They include clays, silts, sands, and gravels [16]. Both sediment types are present in varying proportions at different parts of the Jordanian coast of the Gulf of Aqaba [17, 18].

The objective of the present study was to carry out a thorough and detailed survey of the northernmost section of the Jordanian Gulf of Aqaba, an area distinguished from most of the other parts of the Jordanian coast and subject to heavy human activities, mainly tourism. The main elements of the study were the physical–biogeochemical properties of bottom sediments, the percent coverage of corals, seagrass and sandy bottoms, and the distribution of fish species and fish assemblages in the area.

2. Materials and methods

2.1 *Study site and fieldwork*

Six stations (St. 1–St. 6) have been selected along the northernmost section of the Gulf of Aqaba, covering a heavily exploited area by several hotels and a marina (figure 1). In addition, the site of the MSS carbonate and silicate bottom sediments was selected to serve as a control. The MSS (carbonate) site consists mainly of carbonate sediments, while the MSS (silicate)

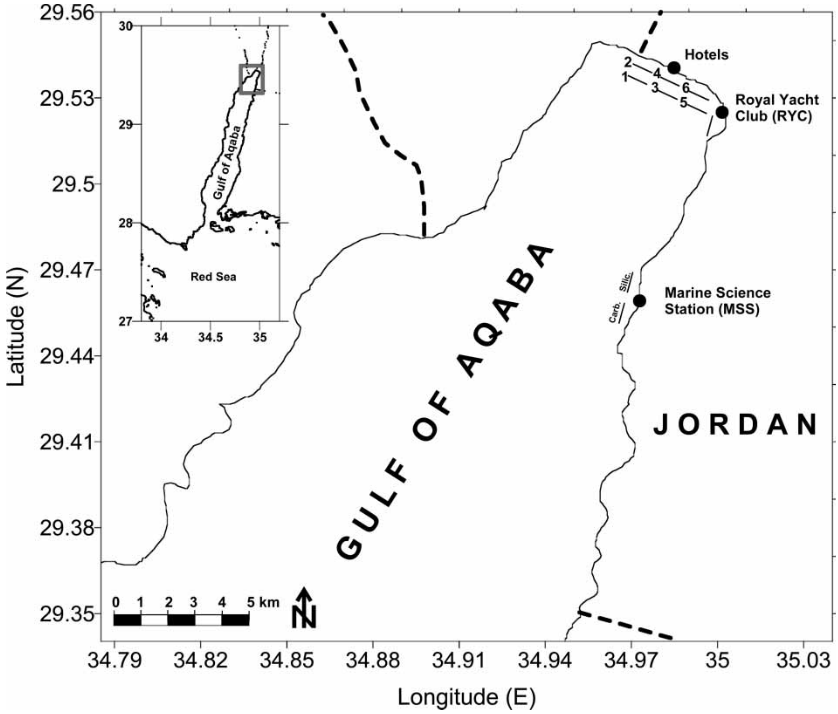

Figure 1. Location map of the northern tip of the Gulf of Aqaba showing the biological survey transects along the study area.

site is silicate-rich sediments. At each individual site, two different depths (4 and 9 m) were selected for bottom surveys. The surveys were conducted along line transects, run at sea bottom above the benthic communities. Three ropes of 100 m long were fixed at each depth parallel to seashore (T1, T2, and T3). The total investigated length within each depth/site extended 300 m.

Observations were focused on coral, seagrass, and sandy-bottom percentage cover and distribution, as well as associated benthic communities. Two sediment samples were taken per transect. Both samples were taken from 0 to 5 cm; a core sample using a cylindrical plastic tube of 2.5 cm diameter was collected for microscopic studies, and a grab sample using a stainless steel grab was collected for the physical and geochemical analysis.

2.2 *Fish-survey methods*

Fish communities were surveyed by the visual census technique following the English method [19]. At each site, a visual census was conducted along the three transects to cover a total area of 1500 m^2 at depths of 4 and 9 m. Two underwater observers carried out the field investigation simultaneously and independently. During the survey and after laying the transect line, the observers waited for about 10 min to allow the fish to resume their normal behaviour. Subsequently, the observers recorded the number of individuals of all fishes encountered within a distance of 2.5 m on each side of the line and 3 m above it. All fishes with a total length of 30 mm or more were identified to the species level and recorded on a plastic slate. The count duration for each transect lasted for about 20–30 min. At the Royal Yacht Club (RYC) fish fauna and the other ecological surveys were counted approximately within a 50-m-long and 5-m-wide transect.

2.3 *Laboratory analysis*

In the laboratory, the grab sediment samples were dried to a constant weight at 60 °C (for 24 h), desegregated, and homogenized. Representative sub-samples were taken from the dried samples by quartering. Sub-samples were then subjected to grain size analysis using US standard sieves with a size interval of 1 phi. Another part of the sub-sample was used for chemical analysis. Organic carbon (OC) content was measured following the method of Gaudette and Flight [20], where 0.2 g of sediment was treated with H_2SO_4 (12 M), and potassium dichromate was then titrated with ferrous ammonium sulphate solution. The samples were treated with 1 N HCL first to remove any inorganic carbon in the samples as suggested by Muller [21]. The calcium carbonate content ($CaCO_3$) was determined by the complexometric titration of calcium as suggested by Muller [22]. Kjeldahl digestion was used to determine the total organic nitrogen in the sediment. Organic nitrogen was converted to inorganic nitrogen (TN) by concentrated H_2SO_4 (12 M), which was measured as ammonium following the standard method of Strickland and Parson [23]. Total phosphorus (TP) was determined using the ignition method for particulate phosphate analysis [24] where 0.2 g of the sample was combusted in a furnace at 450 °C, and the ash was boiled in 1 N HCL for 15 min. The sample was then diluted to 100 ml with distilled water, and phosphate was measured spectrophotometrically following the method of Strickland and Parson [23]. Ignition loss was determined by weight difference before and after combusting over 24 h in a furnace at 500 °C. All analyses were carried out in duplicate.

For microscopic study, the small sediment cores were cut into two 5 cm sections (0–5 and 5–10 cm). Sediments were wet-sieved with sieves of 63, 150, and 250 µm mesh size, and dried in an oven at 55 °C. From the 250 µm fraction from both sections, the microbenthic fauna as well as the clastic and biogenic debris were identified and counted per cm^2 under a microscope.

3. Results and discussion

3.1 *Coral reefs vs. seagrass beds*

The hotel area represents the northern most part of the Gulf of Aqaba. The hard substrate bottoms are absent, and the area is covered mainly by seagrass beds, characterized by the presence of scattered soft sandy bottoms and absence of reef-building corals.

The absence of coral cover in the northern coast area could be attributed to the absence of hard substrates, which are important for larval settlements. Furthermore, the sandy bottoms lead to increased resuspension near the bottom, especially if benthivorous fish are present [25], resulting in decreased light availability and available space for the new larval settlements. Resuspended sediments and increased particle load in the water also enhance mucus production by corals which is an energy-consuming process [26, 27]. Most importantly, the northern part of the Gulf of Aqaba has been historically known before development as the mouth of Wadi Araba. The northern winds that blow about 90% of the time on the Gulf of Aqaba [28] arrive mainly via Wadi Araba carrying with them substantial amounts of fine sediments that nourish the northern beach and maintain it as a sandy rather than a rocky habitat. However, few transplanted hard coral colonies were found at St. 5 (figure 2) where hard rock and cement blocks were placed. At typical healthy coral reef sites, such as the MSS protected area, serving here as a reference site, the average living percent of hard coral cover in the studied transect is 32% ± 7.44 (figure 2). Hard coral cover in the Gulf of Aqaba is reported to be highest between

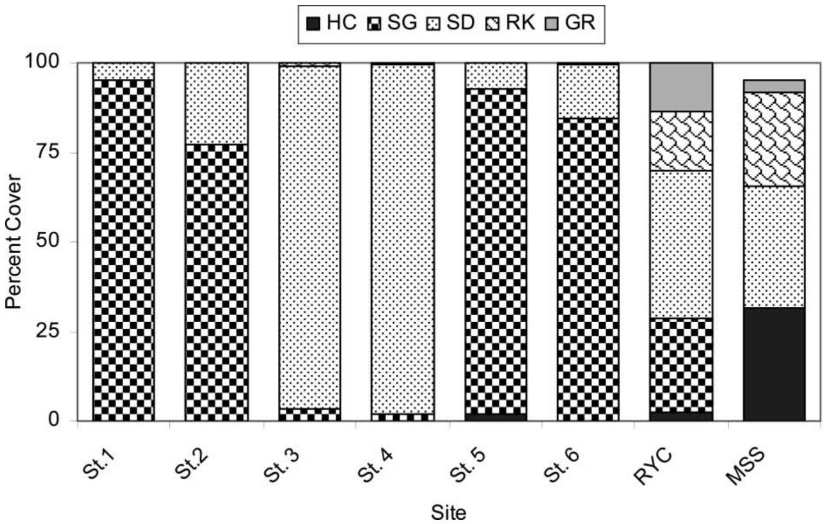

Figure 2. Percentage cover (%) for substrate types at the investigated sites along the study area, where SG = seagrass, SD = sand, RK = rock, HC = hard corals, and GR = gravel.

10 and 20 m. Besides, coral reefs are not continuous: they are quite often intercepted by sand flats [29].

The seagrass beds in the area cover 95.3% ± 2.7, 77% ± 10.1, 90.7% ± 2.7 and 84.3% ± 11.2 of the bottom at Sts 1, 2, 5, and 6, respectively. The dominant species found in the area is *Halophila stipulacea* as reported by Wahbeh [4, 30]. Seagrass does not exist at depths shallower than 2 m and increases in abundance with increasing depth to about 18 m (Al-Rousan, unpublished data). This can be partially attributed to high swimming and boating activities in the shallow areas, which may have affected the development and growth of these beds [31], or to a tide effect which has an annual range of 1.6 m (0.3–1.1 m minimum and maximum daily ranges, respectively) with a horizontal displacement of about 9 m [32]. Also, in contrast to sea weeds, seagrasses do not live in the inter-tidal area but need to be submerged all the time. The same depth distribution pattern was also seen at the RYC, which serves as a marina hosting high boating and boat-servicing activities. The average seagrass cover at the RYC was only 26% ± 4.6 (figure 2). Most of the bottom area (41% ± 6.4) was fine sand, and 17% ± 5.2 was rocks and cement blocks. It is interesting here that 14% ± 4.0 of the bottom was covered by gravel and rubble on which some hard coral colonies have grown (figure 2). At Sts 3 and 4, the situation was different, and the sediment covered 95.7% ± 4.6 and 97% ± 2.1 of the bottom, leaving less than 5% covered by seagrass (figure 2). Construction work and dredging during the period of our study can be the main reason for this, and hence, it can be safely concluded that the conditions here were circumstantial and did not represent the normal conditions of the site.

3.2 *Sediment structure and benthic communities*

The surface structure of the unconsolidated bottom sediments along the study site showed that most of the sediments were undisturbed bottoms, animal tracks were rare, but bioturbated holes and mounds were abundant. Most of the mounds have their tops rounded off; some of them exhibit small depressions. The occupants of these structures could be shrimps.

The microscopic study showed that sediments at the area were from the clastic type, the inorganic components of the sediments were mainly quartz, feldspar, mica, and other minerals (figure 3). On the other hand, biogenous parts of the sediments were mainly calcium carbonate ($CaCO_3$), which was typically shells or coverings, made by some organisms, such as foraminiferans. Coral debris was absent in this area.

The most abundant inorganic compound in the sediment at all stations was the quartz. This ranged from 30 to 120 g cm^{-2}. The highest number (100–130 g cm^{-2}) was found at Sts 3, 4, and the RYC (figure 3). The area at Sts 3 and 4 was an active construction site with substantial dredging activities taking place during the study. In the case of the RYC, the most likely source of the high numbers of quartz grains is recent deposits from the boat and yacht activities. Other stations showed a similar distribution of quartz comparable with the concentrations in the silica sand at the MSS. The carbonate fragments were low at all stations ranging between 2 and 8 g cm^{-2} compared with a range of 22–32 g cm^{-2} in the MSS carbonate sediment (figure 3).

3.3 *Faunal distribution in sediments*

The faunal densities in the studied sediments were generally low compared with other parts along the Jordanian coast of the Gulf of Aqaba, such as the MSS. The coral reef sediments are mainly generated from reef rock, calcareous algae, fragmented solid biogenic material, and calcium carbonate skeletal remains such as foraminiferan tests and molluscan shells [33, 34]. These well-oxygenated permeable sediments favour rapid recycling of organic matter [17, 35] which enhances their capacity to support infauna.

The absence of hard substrates at St. 1–St. 6 might well also explain the low densities of epifauna present in the study area (figure 3). The epifauna found on the northern coast were restricted to some sea anemones and hydrozoa. The vagile or mobile fauna, including fish and shrimps, are relatively abundant, whereas other fauna like gastropods and echinoidea are rare and inconspicuous. The infauna group can be divided into two subgroups. The macrofauna (larger than 1 mm), main groups found in the study area belonging to this part, include molluscs, bivalves, and scaphopods. The meiofauna (smaller than 1 mm) were few in number and included planktonic and benthic foraminifera and ostracods.

The number of small shells and tests of mollusc in the study area ranged from 2 to 10 ind cm^{-2} (figure 4). This value tended to be higher in the 0–5 cm section of the cores than in the 5–10 cm section. However, it was absent at the RYC site (figure 4). For benthic foraminifera, *Amphisorus hemprichii* (species) was found to be abundant. The distribution of this species follows the vegetation cover, and this species occurs on *Halophila* leaves [36]. This is the most likely reason why this species was absent in the RYC and MSS sites (figure 4). In the study

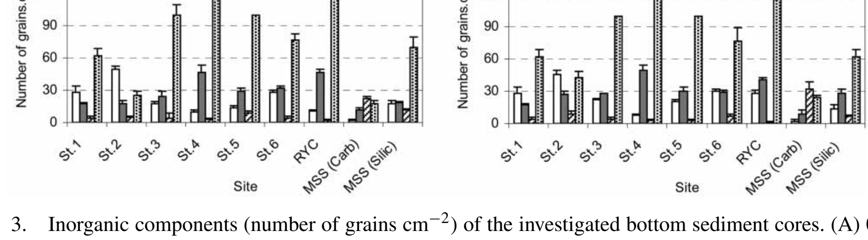

Figure 3. Inorganic components (number of grains cm^{-2}) of the investigated bottom sediment cores. (A) 0–5 cm sections and (B) 5–10 cm section at the study area, MSS (Carb), MSS (Silic) and RYC sites.

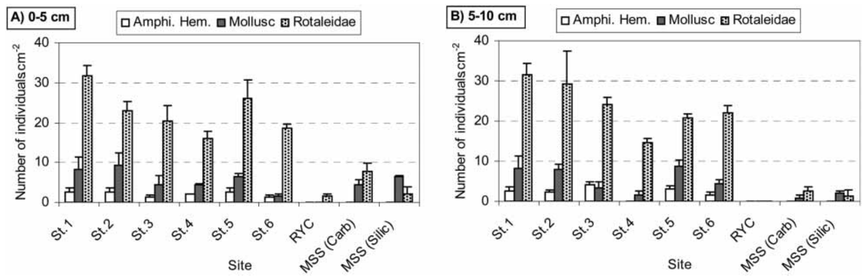

Figure 4. Faunal densities (number of individuals cm^{-2}) in the investigated bottom sediment cores. (A) 0–5 cm sections and (B) 5–10 cm section at the study area, MSS (Carb), MSS (Silic) and RYC sites.

area, this species ranged from 2 to 4 ind cm^{-2}; this value decreased at Sts 3 and 4, most likely due to the construction work taking place at these stations.

Smaller benthic foraminifera 'cf. *Rotaliids*' were found to be the most abundant species, numbering some 14–32 ind cm^{-2}. The number decreased toward the RYC area. No differences were found in species distribution between the 0–5 cm and 5–10 cm sections of the cores (figure 4). In the Red Sea, this species is believed to live on *Halophila*-covered soft substrate, and in the shallowest environments around mangroves [36].

3.4 *Physical and geochemical characteristics of bottom sediments*

3.4.1 Colour, odour, and grain-size distribution. Surface sediments at the different stations along the study site were similar in appearance. Sediments at Sts 1–6 were mainly black, while at the RYC and MSS (silicate), sediments were grey in black colour. The sediments at the MSS (carbonate) site were whitish. These are calcium carbonate sediments that are naturally white in colour. In spite of the black sediment colour at the study site, no distinctive smell was detected for any sample at any station, indicating well-oxygenated conditions.

With respect to textural properties, Sts 1, 2, 3, and 4 had a similar textural composition, while sediments from the other Sts 5, 6, RYC, and MSS were different. The median-grain-size (MGZ) diameters calculated were 1.7, 1.5, 1.5, and 2 phi for Sts 1, 2, 3, and 4, respectively (table 1). These sediments are classified as medium sand. The median grain size at Sts 5, 6, RYC, MSS (carbonate), and MSS (silicate) was about 2.4, 2.11, 2.85, 2.86, and 2.13 phi, respectively. Sediments here were classified as fine-grained sand. The sediment at Sts 1, 2, 3, 4, MSS (carbonate), and MSS (silicate) were moderately sorted while they were moderately to well sorted at Sts 5, 6, and the RYC. At the study site, sediments had low mud contents ranging between 0.16 and 1.6% (figure 5). These values tended to increase from east to west, but the highest value around 12% was recorded for the MSS carbonate sediment.

3.4.2 Chemical constituents. Chemical constituents of sediments from Sts 1–6 as well as the RYC and MSS are shown in table 1 and figure 5. The study area showed a very low calcium carbonate ($CaCO_3$) concentration in sediments at all stations, ranging from 3 to 10% in contrast to a high concentration of about 70% in the surface sediment at the MSS (carbonate). The calcium carbonate concentration was also significantly higher at the MSS (silicate) station (17%) than all stations at the northern coast. These sediments are just next to carbonate coral

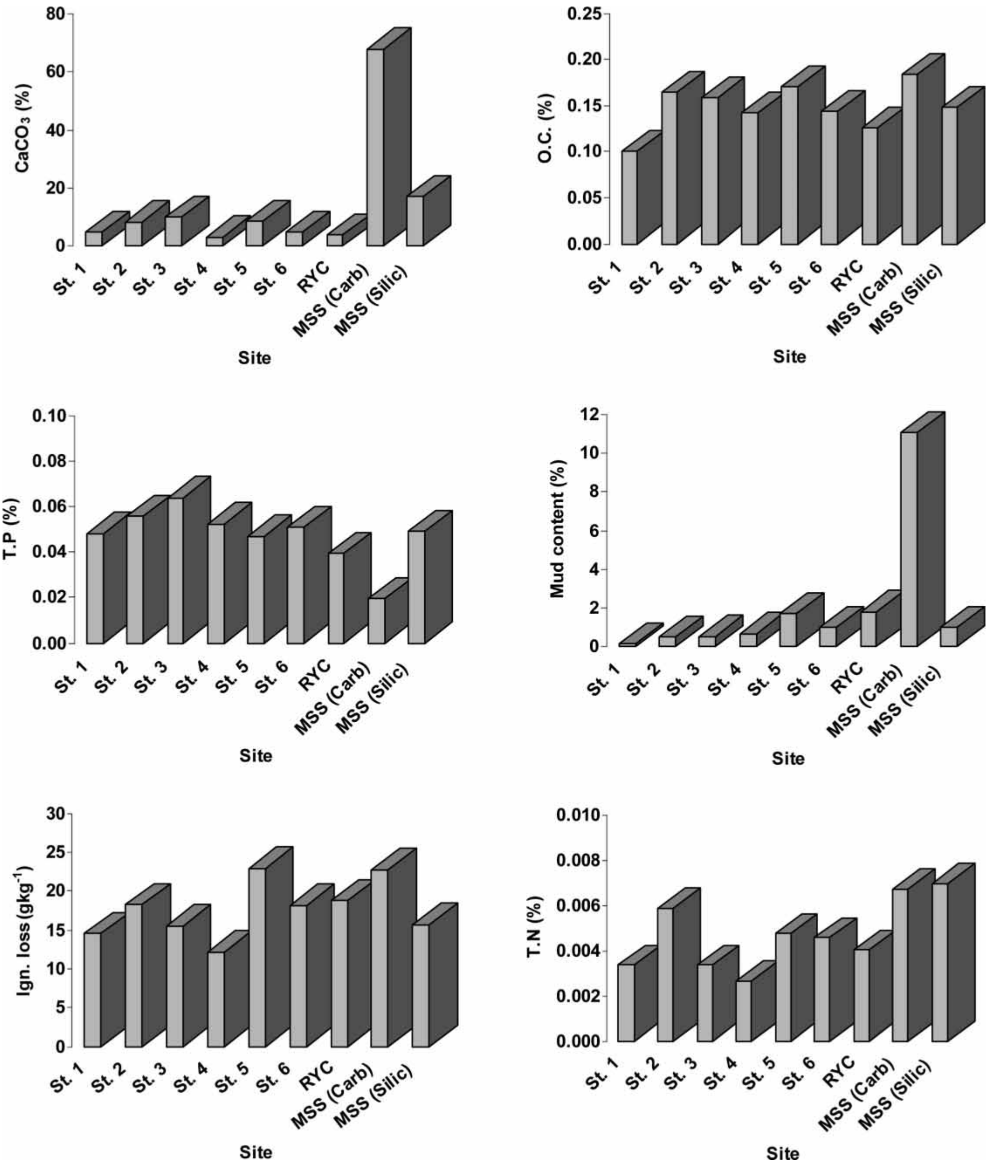

Figure 5. Chemical characteristics of the investigated bottom surface sediments from all stations, including: organic carbon (OC%), ignition loss ($g\,kg^{-1}$), mud content (%), $CaCO_3$ (%), total phosphorus (TP%) and organic nitrogen (TN%).

reef sediments where resuspension, wave, and current actions can result in some restricted redistribution of calcium carbonate.

Total phosphorus (TP), at the study area (Sts 1–6) showed a relatively high concentration ranging from 0.047 to 0.064%, as compared with MSS (carbonate) or even the RYC sites (table 1; figure 5). These concentrations were not associated with any higher concentrations of organic carbon or nitrogen. These results are different from those reported in earlier studies [37–40], which found that phosphate has a strong affinity for being adsorbed on reef carbonate sediments and can be trapped within the crystal lattice of carbonate granules. Therefore, the higher TP concentrations in the study area could be attributed to construction and dredging as

Table 1. Summary of the physical and chemical characteristics of the investigated bottom sediments from all stations: organic carbon (OC%), calcium carbonate ($CaCO_3$%), total nitrogen (TN%), total phosphorus (TP%), median grain size (MGZ, phi), mud content (%), and ignition loss.

Station	OC%	$CaCO_3$%	TN%	TP%	MGZ (phi)	Mud%	Ignition loss (g kg^{-1})
St. 1	0.100	4.882	0.003	0.048	1.7	0.163	14.560
St. 2	0.165	8.248	0.006	0.055	1.5	0.490	18.240
St. 3	0.159	9.763	0.003	0.064	1.5	0.523	15.490
St. 4	0.142	3.030	0.003	0.052	2	0.673	12.210
St. 5	0.170	8.585	0.005	0.047	2.4	1.683	22.980
St. 6	0.144	4.882	0.005	0.051	2.11	0.960	18.180
RYC	0.126	3.788	0.004	0.039	2.85	1.807	18.760
MSS (Carb)	0.184	67.923	0.007	0.020	2.86	11.092	22.760
MSS (Silic)	0.148	16.918	0.007	0.049	2.13	0.997	15.690

well as swimming and boating activities that may receive uncontrolled discharges of wastewater and elevate the phosphate contents in the sediment [41, 42]. Otherwise, this could be a compositional characteristic of these sediments.

The organic carbon (OC) concentration at most of the study stations exhibited similar concentrations ranging between 0.10 and 0.19% (table 1). Ignition loss values ranged between 1.2 and 2.3%, and followed a similar distribution to that of organic carbon (figure 5). The highest OC concentration and ignition loss were recorded at the MSS (carbonate) site (table 1) and so was the highest organic nitrogen concentration (TN). Concentrations of TN at the study area (Sts 1–6) showed moderate values ranging from 0.003 to 0.006% (table 1; figure 5). The higher values of MSS can be a direct result of deposition and sinking of living material in the immediate vicinity of the coral reef [43, 18]. St. 5 and the MSS (carbonate) exhibited relatively higher values than other stations, which may reflect the high total organic matter content (figure 5).

3.5 *Fish assemblages and community indices*

A total of 85 348 fishes were counted in the present study, representing 85 species that belong to 33 families, all inhabiting the shallow water with an average of 4741.6 fish per transect. The percentage of species per family showed the following rank: Labridae (11.76%), Pomacentridae and Mullidae (7.06%, each), Apoginidae, Chaetodontidae and Gobiidae (5.88%, each). These six families account for 43.53% of the total population. In terms of relative abundance per family, the ichthyofauna showed the following rank: Lethrinidae (55.54%), Carangidae (13.11%), Mullidae (8.79%), Siganidae (5.48%), Nemepteridae (4.15%), Pomacentridae (3.71%), and Labridae (2.98%). These seven families account for 82.92% of the total population.

The most abundant species (table 2) were *Lethrinus borbonicus* (38.56%), *Lethrinus variegatus* (16.97%), *Trachurus indicus* (8.78%), *Siganus rivulatus* (5.20%), *Decapterus macrosoma* (4.33%), *Scolopsis ghanam* (4.15%), *Parupeneus forsskali* (3.67%), and *Parupeneus macronema* (3.28%). These eight species made up 84.94% of the total population. The frequency of appearance (table 2) suggests that the most common species were *Scolopsis ghanam* (88.89%), *Parupeneus forsskali* (77.78%), *Upeneus pori* (72.22%), *Dascyllus trimaculatus* and *Pteragogus pelycus* (66.67% each), *Gerres oyena, Lethrinus borbonicus, Parupeneus macronema, Heniochus diphreutes, Teixeirichthys jordani, and Oxycheilinus orientalis* (55.56% each).

The number of species ranged from two species per transect in St. 3 in transect No. 2 to 34 species at transect No. 3 within the same station with an average of 17.8 species per transect

Table 2. Average relative fish abundance (RA) and frequency of appearance (FA) of the most common fish species per (500 m^2) in the study area (seagrass site) compared to the coral reef site at the Marine Science Station (MSS).

	MSS		Study area	
Fish species	FA	RA	FA	RA
Pseudanthias squamipinnis	100.0	13.9	5.6	0.0
Pseudanthias taeniatus	66.7	7.4	0.0	0.0
Decapterus macarellus	0.0	0.0	22.2	4.3
Trachurus indicus	0.0	0.0	11.1	8.8
Caesio suevicus	25.0	4.7	0.0	0.0
Caesio varilineata	33.3	5.6	0.0	0.0
Scolopsis ghanam	0.0	0.0	88.9	4.1
Lethrinus borbonicus	44.4	0.0	55.6	38.6
Lethrinus variegatus	33.3	0.1	50.0	17.0
Parupeneus forsskali	100.0	0.4	77.8	3.7
Parupeneus macronema	100.0	0.3	55.6	3.3
Chromis dimidiata	100.0	4.5	0.0	0.0
Chromis viridis	66.7	2.8	0.0	0.0
Dascyllus aruanus	100.0	2.8	0.0	0.0
Dascyllus marginatus	100.0	4.0	0.0	0.0
Neopomacentrus miryae	41.7	0.7	22.2	3.0
Pomacentrus trichourus	100.0	15.3	11.1	0.0
Cirrilabrus rubiventralis	0.0	0.0	38.9	2.4
Paracheilinus octotaenia	58.3	18.0	11.1	0.2
Siganus rivulatus	0.0	0.0	44.4	5.2

(figure 6I). The number of fish individuals ranged from 71 to 12,054 individuals at St. 5 in transect No. 3 with an average of 4741.6 fish per transect (figure 6II). The average species richness ranged from 0.23 at St. 3; transect No. 2 to 4.26 at St. 3; transect 3 with an average of 2.07 fish (figure 6III). The Shannon–Wiener diversity index ranged from 0.25 at St. 3; transect No. 2 to 2.15 at St. 4; transect No. 1 with an average of 1.3 (figure 6IV).

At the RYC port, the results indicated that the most abundant species were schools of robust silverside fish *Atherinimorous lacunosus* (30.37%), rivulated rabbitfish *Siganus rivulatus* (24.30%), squaretail rabbitfish *Siganus luridus* (6.83), zooplanktivore fish *Neopomacentrus miryae* (5.81%) and the Red Sea goatfish *Parupeneus forsskali* (5.16%). These five species made up 74.92% of the total population within the RYC port.

At the MSS, a coral-reef-dominant site, the most abundant fish species were (table 2) *Paracheilinus octotaenia* (18%), *Pomacentrus trichourus* (15.3%), *Pseudanthias squamipinnis* (13.9%), *Pseudanthias taeniatus* (7.4%), and *Caesio varilineata* (5.6%). These five species made up 60.1% of the total population within the coral-reef-dominated site (MSS).

3.6 *Dominant taxa and fish community parameters*

Lethrinus borbonicus was the most abundant species on the northern part (seagrass habitat) surveyed area, followed by *Lethrinus variegatus*, *Trachurus indicus*, *Siganus rivulatus*, *Decapterus macrosoma*, *Scolopsis ghanam*, *Parupeneus forsskali*, and *P. macronema*, whereas the coral reef fish assemblages at the MSS (coral reef habitat) showed a completely different picture.

In terms of relative abundance of families, the coral reef fishes along the Jordanian coast are dominated by Pomacentridae, followed by Anthininae (subfamily of Serranidae) and Labridae [44]. Visual censuses of fish assemblages in this study revealed the dominance of Lethrinidae, followed by Carangidae, Mullidae, Siganidae, and Nemipteridae.

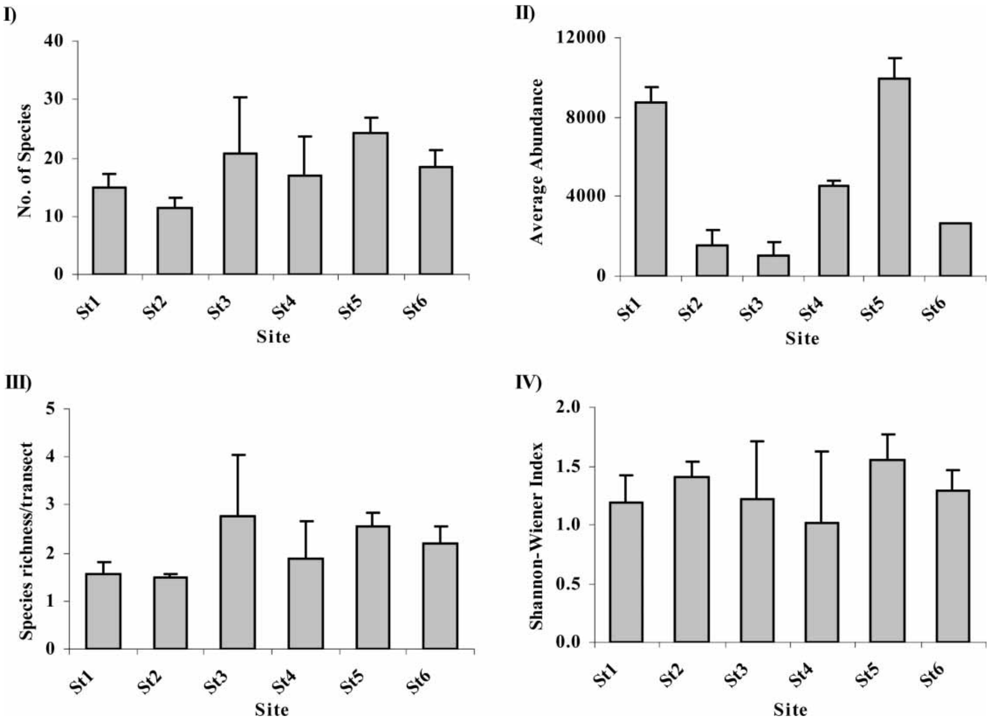

Figure 6. (I) Number of species, (II) number of individuals, (III) species richness, and (IV) Diversity (Shannon–Wiener Index) (average ± SE) of fish assemblages at stations along the northern part of the Jordanian coast ($n = 18$).

The seagrass beds play a significant role in harboring juveniles of various commercial fish (e.g. Lethrinids, Siganids, and Mullids). The availability of food, shelter, and protection from predators within the seagrass lattice contributes to the nursery functions of these habitats. Hence, this helps us to understand the contribution of seagrass beds to coastal fisheries in terms of fish distribution, species composition, and spawning seasons.

The seagrass biomass was not measured here but is considered to be the highest in comparison with other seagrass beds along the Jordanian coast [4]. The average number of fish species in Al-Mamlah Bay (seagrass dominated site) within the 50-m-long transect line ranged from 17.9 species at 6 m depth to 58.5 species at 12 m depth. In addition, the average abundance within the similar transect was 3397 at 12 m depth [44]. In the study area, our survey indicates even fewer species (17.8) within a 100 m transect line. The reason for such a difference is that the seagrass beds at Al-Mamlah Bay are adjacent to a coral reef, a rich ecosystem of different fauna. The present survey revealed an average of 4741.6 fish per 100 m transect line. The average Shannon–Wiener diversity ranged from 0.25 to 2.15, whereas at Al-Mamlah Bay, the diversity reported ranged from 1.3 at 6 m depth to 2.3 at 12 m depth within a 50 m transect [44].

4. Conclusions

The results of the present survey showed that the sea bottom at the northernmost section of the Gulf of Aqaba is mainly a non-coralline seagrass and sandy bottom habitat. The coral cover in the area is negligible. The well-developed seagrass beds cover about 70–98% of the bottom. These seagrass beds have a highly significant ecological value as they serve as nursery grounds for the larvae of several fish species. Other important species in the area are sea urchin and sea cucumbers. Swimming and boating activities in shallow areas such as the RYC were found to affect the development and growth of these beds, and disturb their natural distribution. Bottom surface sediments are clastic in nature derived from existing metamorphic rocks, by weathering and erosion. They are characterized by high contents of terrigenous materials (quartz, feldspare, and mica) and low carbonate (some shells of foraminiferans, gastropods, and bivalves) and organic carbon contents mainly due to the absence of coral cover. The number and diversity of fish species inhabiting the survey site are typical of seagrass beds and sandy bottom habitats. Some of the fish species observed are characteristic of this site and not abundant elsewhere on the Jordanian coast. The abundance of fishes in the Royal Yacht Club port includes several coral fish species that appear to have succeeded in colonizing this originally sandy bottom enclosed habitat.

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