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Impact of some trace metals on bryozoan occurrences, Red Sea coast, Egypt

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79 bryozoan species have been identified from the recent sediments of 5 stations along the Egyptian Red Sea coast. Thirty sediment samples were selected to chemical analysis of Fe, Zn, Pb, Mn, Ni, Co, Cu, and Cd. The analysis indicated that sediments of El-Hamrawen, Hurghada and El Fanader areas recorded the highest concentrations of almost trace metals in comparison with those of Makadi bay and Al Qweh area. Bryozoan colonies showed high frequency and diversity in Makadi bay and Al Qweh area in comparison with El-Hamrawen, Hurghada and El Fanader lagoon. Differences in frequency and diversity of bryozoans among studied areas are attributed to anthropogenic pollutants resulted from diving and snorkeling activities, as well as phosphate dust, especially in El-Hamrawen area.

[Key words: Bryozoa, Trace metals, Red Sea coast, Egypt].

Introduction

Bryozoa is a group of aquatic, sessile invertebrates with circumglobal distribution and includes about 6000 recent species. Although a bryozoan individual is barely visible with the naked eye, all bryozoans form colonies, which are often macroscopic in size and display a variety of beautiful shapes and forms[1]. Recent sediments along the Red sea coast and their gulfs have been studied from sedimentological, geochemical and faunal points of view[2-8]. From studies on bryozoan content along the Red Sea coast[9-18]. Bryozoans as all marine organisms can be exposed to high metal concentrations resulting of near shore developmental activities, urbanization and over population[19, 20]. Many studies were done on the Red Sea environment, and tourism projects and their impact on coastal zone based on the ecological analysis by several authors[4, 5, 7, 21, 22]. The main objectives of the present study are to evaluate the levels of trace metals in Recent sediments along the Red Sea coast and an attempt to find a relationship between trace metals in sediments (almost of anthropogenic origin) and bryofaunal occurrences.

Five localities were chosen for study (Fig. 1), namely: 1) El Fanader lagoon, 2) Hurghada, 3) Makadi Bay, 4) Al Qweh lagoon, and 5) El-Humrawen harbor. The following are description of the five studied areas:

El Fanader lagoon: This locality lies 10 km in the sea, facing to Hurghada city, between 27°/01′/17′′ - 27°/38′/16′′N and between 33°/49′/49′′ - 33°/40′/49′′E (Fig. 1). The site contains small reef patches and a barrier reef arises from the seabed to about 14m height. This barrier reef includes some mixed species of stony corals and soft ones. Field survey illustrated that El Fanader lagoon is situated under human impacts in the form of diving and snorkeling activities.

Material and Methods

72 sediment samples with depth ranges from beach to 33 m were collected by grab sampler from five localities (Table 1). Bryozoan content is picked and stained by methylene blue then examined by binocular microscope and photographed by scanning electron microscope (SEM) in Egyptian Nuclear Authority. For Fe, Zn, Pb, Mn, Ni, Co, Cu and Cd analysis, 30 sediment samples are washed with sodium hypochloride for 24 h, and then with distilled water. They were oven-dried at 60C and powdered in an agate mortar. 0.2 g of powdered coral sample was digested in 5 mL of HCl and 15 mL HNO_3–$HClO_4$ (5:1). Digested sample was centrifuged at 200 rpm and the centrifuged liquid was used for the determination of trace elements in sediment samples using an Inductively Coupled Plasma Atomic Emission Spectrophotometer (laboratory of Ain Shams University).

Studied areas

Hurghada: This site lies at about 20 km to the north of Hurghada City. It is located within the main Hurghada port between 27˚/56′/12′′ - 27˚/38′/13′′N and between 33˚/04′/01′′ - 33˚/39′/50′′E (Fig. 1).

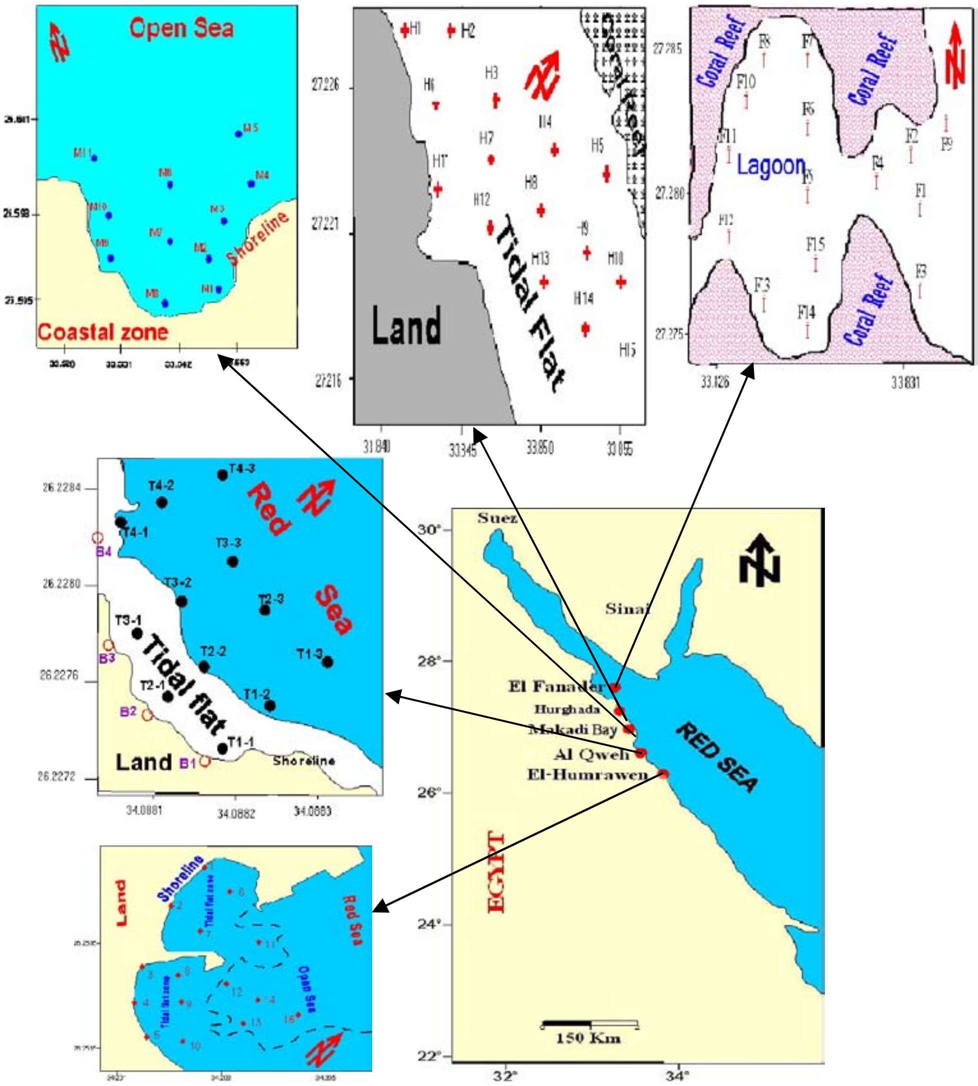

Fig. 1— Location map of the studied areas and sketch maps (not to scale) showing locations of the collected samples.

Generally, coral and other faunal distribution is very rare in this site due to many types of pollutants, such as reject brain water from desalination plant, light oil resulting from basin repair boats, the sewage output from the harbor Mosque and the port and fishing activities.

Makadi bay: Makadi Bay lies at 30km to the south of Hurghada city, between 27˚/00′/58′′ - 26˚/59′/46′′N and between 33˚/ 44′/54′′ - 33˚/54′/17′′E (Fig. 1). It has semi-circular shape and receives all clastic sediments from main tributaries. Beach is relatively wide, while the intertidal zone is narrow with maximum depth of 1.5 m during high tide, and extends to distance about 100 m from the shoreline. Its bottom floor is sandy inhabited with some spots of algae, followed by back reef zone which includes some coral patches.

Al Qweh lagoon: Al Qweh downstream lies at about 44 Km to the south of Safaga city. It lies along the main Safaga–Quseir asphaltic road, between 26˚/36′/22′′ - 26˚/39′/22′′N and between 34˚/58′/07′′ - 34˚/08′/00′′E (Fig. 1). Beach is sandy in the northern part, while the middle and southern parts are of rocky beaches. Tidal flat is shallow, wide, extends 2km and composed of biogenic sand inhabited with seagrass and algae. This zone is followed by high biodiversity of corals, molluscs and sponges.

El-Humrawen harbor: This site lies at about 20 km to the north of Quseir city. It is located between 26°/08′/10′′ - 26°/01′/10′′N and between 34°/05′/12′′ - 34°/02′/12′′E (Fig. 1). Beach zone is very narrow. Width of the intertidal zone is 30 m at the edge of coral reefs. Middle part of the marine area is rich with seagrass and algae. Corals appear at a distance of 1km from the beach and characterized by low diversity as all marine fauna and flora in this site. This may be due to spread of phosphate dust, especially during the shipping process.

Table 1- Depths (m) of the collected samples

Sample No.	El Fanader	Hurghada	Makadi Bay	Al Qweh	El-Humrawen
1	10	8	3	beach	beach
2	2	12	10	1	beach
3	8	15	7	7	beach
4	7	21	10	13	beach
5	6	28	30	beach	beach
6	4	7	13	2	2
7	2.5	14	20	10	3
8	2.5	22	6	14	2
9	14	28	2.5	beach	1.5
10	3	16	23	3	3
11	3	9	11	9	6
12	5	14		13	15
13	3	19		beach	13
14	2.5	32		2	13
15	4	33		5	4
16				16	

Results and Discussion

Bryofaunal content: The identification of the present bryofauna followed the Treatise of invertebrate paleontology[23] and the recent modifications. 79 bryozoan species belong to 48 genera and 30 families have been identified and illustrated. 25 species belong to order Cyclostomata and 54 ones belong to order Cheilostomata (28 belong to suborder Ascophora and 26 ones to suborder Anasca). Because the studied taxa were previously described in numerous publications, only table for occurrences within the studied areas and representatives SEM photography are given (Table 2, Figs. 2-4).

Table 2—Occurrences of bryofauna in the studied areas.

Order	Species	1	2	3	4	5
Cyclostomata	*Crisia denticulata* (Lamarck, 1816)	×		×	×	×
	Crisia eburnea (Linnaeus, 1758)	×	×	×	×	
	Crisia elongata Milne Edwards, 1838		×	×	×	×
	Crisia hornesi Reuss, 1847	×	×	×	×	×
	Crisia hurghadaensis Ziko et al. 2012	×	×	×	×	
	Crisia sertularoides Audouin, 1826	×		×	×	×
	Crisia tenuis Macgillivray, 1879	×	×	×	×	×
	Filicrisia geniculata Milne Edwards, 1838		×	×	×	×
	Tubulipora varians Canu & Bassler, 1929		×	×	×	
	Idmonea mrcrogensis Brood, 1976			×	×	×
	Idmidronea crassimargo Brood, 1976		×	×	×	×
	Platonea hirsute Canu & Bassler, 1922		×	×	×	
	Annectocyma arcuata Harmelin, 1976		×	×	×	×
	Orbigny, 1852)d'*Diapereforma californica* (		×	×	×	
	Filisparsa gracilis (Brood, 1976)			×	×	×
	Filisparsa rugosa Canu & Bassler, 1929		×	×	×	×
	Proboscina dichotoma D'orbigny, 1839		×	×	×	×
	Proboscina projecta Canu & Bassler, 1920	×		×	×	
	Entalophora major (Canu & Bassler, 1929)	×	×	×	×	
	Exochoecia rugosa Canu & Bassler, 1920			×	×	×
	Hornera frondiculata (Lamouroux, 1821)		×	×	×	×
	Hornera pinnata Canu & Bassler, 1929		×	×	×	
	Hornera tuberose Canu & Bassler, 1920			×	×	×
	Tretocycloecia dichotoma (Goldfuss, 1827)		×	×	×	×
	Lichenopora noeae-zelandiae (Busk, 1826)		×	×	×	
Cheilostomata	*Membranipora nobilis* Reuss, 1847		×	×	×	×
	Biflustra savartii (Audouin, 1826)	×		×	×	×
	Antropora ovatum (Canu & Bassler, 1929)	×	×	×	×	
	Onychocella subpyriformis (D'Archiac, 1846)		×	×	×	×
	Velumella philippinesis Canu & Bassler, 1929		×	×	×	×
	Thalamoporella evelinae Marcus, 1939		×	×	×	
	Thalamoporella granulata Levinsen, 1909	×	×	×	×	×
	Thalamoporella inarmata (Soule & Chaney 1992)	×	×	×	×	
	Nellia tenella (Lamarck, 1816)	×		×	×	×
	Venicularia polymorpha (Canu, 1907)		×	×	×	×
	Scrupocellaria diadema Busk, 1852		×	×	×	×
	Scrupocellaria elliptica (Reuss, 1848)	×	×	×	×	×
	Scrupocellaria orinthorhynus Thomson, 1858	×	×	×	×	
	Scrupocellaria scrupea Busk, 1851	×	×	×	×	×
	Amastigia fiordica (Gordon,1986)	×		×	×	

1, El Fanader 2, Hurghada 3, Makadi Bay 4, Al Qweh 5, El-Humrawen

Tab. 2: Continued

Order	Species	1	2	3	4	5
Cheilostomata	*Caberea boryi* Audouin, 1826		×	×	×	×
	Tricellaria aculeate (d'Orbigny, 1847)			×	×	
	Tricellaria gracilis (Smitt, 1867)		×	×	×	×
	Tricellaria monotrypa (Busk, 1852)			×	×	×
	Tricellaria occidentalis (Trask, 1857)		×	×	×	
	Canda arachnoids Lamouroux, 1816	×	×	×	×	×
	Canda Pecten scutata Harmer, 1926	×	×	×	×	
	Canda retiformis Pourtales, 1867	×		×	×	×
	Cribrilaria radiata (Moll, 1803)		×	×	×	
	Cribrilina innominata (Couch, 1844)		×	×	×	×
	Poricellaria alata d'Orbigny, 1854		×	×	×	
	Cosciniopsis coelatus Canu & Bassler, 1927		×	×	×	×
	Schizoporella longirostris Hincks, 1886	×	×	×	×	×
	Schizoporella proditor (Canu & Bassler, 1929)	×	×	×	×	
	Schizoporella pseudoerrata Soule & Chaney, 1995	×		×	×	×
	Schizoporella unicornis (Johnston, 1844)	×	×	×	×	×
	Hippoporina powelli Gordon, 1989		×	×	×	×
	Microporella ciliata (Pallas, 1766)	×	×	×	×	×
	Porella clavula (Canu & Bassler, 1920)		×	×	×	
	Smittina nitida delicatula Busk, 1883	×	×	×	×	×
	Smittina trispinosa (Johnston, 1838)	×	×	×	×	×
	Vibraculina conti Neviani, 1895		×	×	×	
	Retepora cellulose (Linne, 1848)		×	×	×	×
	Retepora (Reteporella) tenuitelivera Canu & Bassler, 1929		×	×	×	
	Iodictyum rubeschi (Reuss, 1848)		×	×	×	×
	Watersipora cucullata (Busk, 1854)	×	×	×	×	×
	Watersipora subtorquata (d'Orbigny, 1852)	×		×	×	×
	Margaretta barbata (Lamarck, 1816)	×	×	×	×	×
	Margaretta cereoides (Ellis and Solander, 1786)	×	×	×	×	
	Lagenipora pinnacula (Hayward, 1980)		×	×	×	×
	Mastigophorella hyndamanni (Jonston, 1847)			×	×	×
	Costazia costazii (Waters, 1879)		×	×	×	×
	Holoporella avicularis (Hincks, 1880)		×	×	×	
	Holoporella polythele (Reuss, 1848)		×	×	×	×
	Celleporaria palmata (Mickelin, 1847)			×	×	×
	Celleporina globulosa (d'Orbigny, 1852)		×	×	×	
	Celleporina spatula (Macgillivray, 1887)		×	×	×	×
	Celleporina tubulata (Uttley and Bullivant, 1972)		×	×	×	×
	Savignyella lafontii (Audouin, 1826)		×	×	×	
	Caberea boryi Audouin, 1826		×	×	×	×

1, El Fanader 2, Hurghada 3, Makadi Bay 4, Al Qweh 5, El-Humrawen

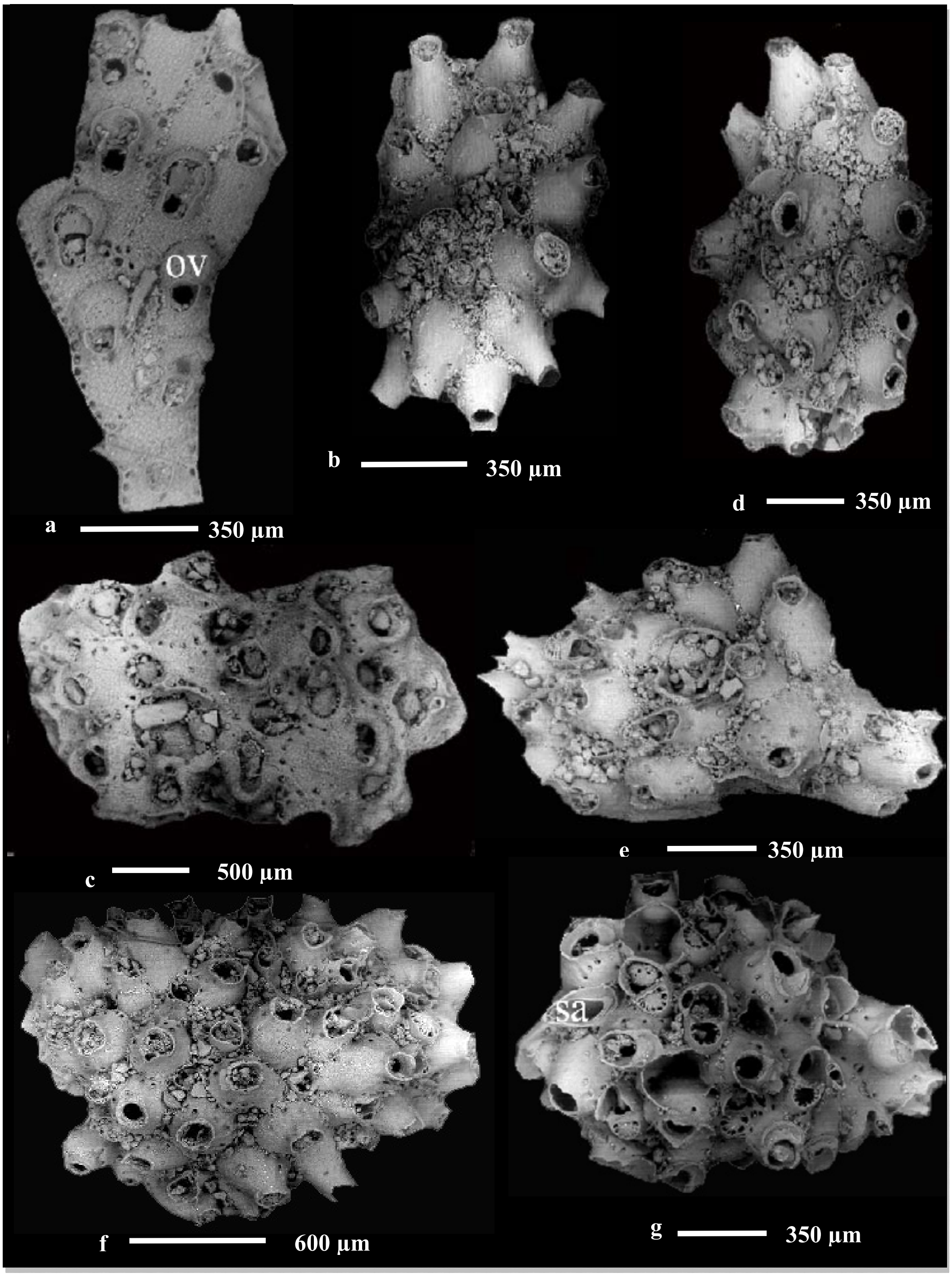

Fig. 2—Examples of encrusting bryozoans. a: *Smittina nitida delicatula* Busk, 1883 showing an ovicell (ov), sample 6, El Fanader. b: *Lagenipora pinnacula* (Hayward, 1980), sample 3, Al Qweh lagoon.c: *Holoporella avicularis* (Hincks, 1880) with vicarious avicularia, sample 6, Hurghada. d: *Holoporella polythele* (Reuss, 1848), sample 9, Makadi Bay. e: *Celleporaria palmata* (Mickelin, 1847), sample 7, Hurghada. f: *Celleporina globulosa* (D'Orbigny, 1852), sample 4, Makadi Bay. g: *Celleporina spatula* (Macgillivray, 1887) showing spatulate avicularia (sa), sample 15, Hurghada.

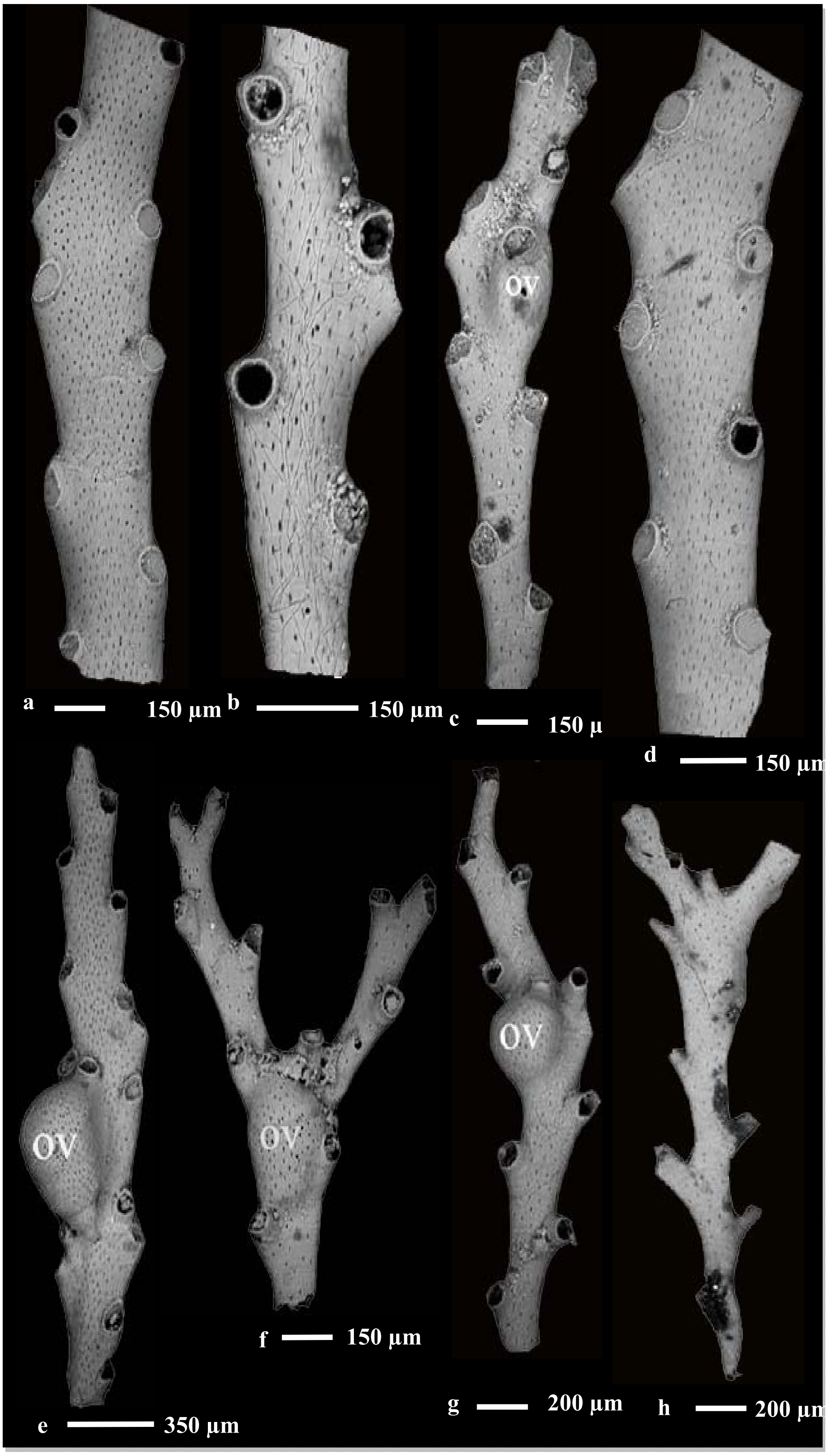

Fig. 3—Examples of erect flexible bryozoans. a: *Crisia denticulata* (Lamarck, 1816), sample 6, Hurghada. b: *Crisia eburnea* (Linnaeus, 1758), sample 11, El-Humrawen harbor. c: *Crisia elongata* (Milne-Edwards, 1838) with an ovicell (ov), sample 7, El Fanader. d: *Crisia hornesi* Reuss, 1847, sample 8, Al Qweh lagoon. e: *Crisia hurghadaensis* (Ziko et al. 2012[46]) with an ovicell (ov), sample 12, Hurghada. f: *Crisia sertularoides* Audouin, 1826, with an ovicell (ov) and pseudopores, sample 8, Makadi Bay. g: *Crisia tenuis* Macgillivray, 1879 with an ovicell, sample 6, El-Humrawen harbor. h: *Filicrisia geniculata* Milne-Edwardsd, 1838, sample 3, Makadi Bay.

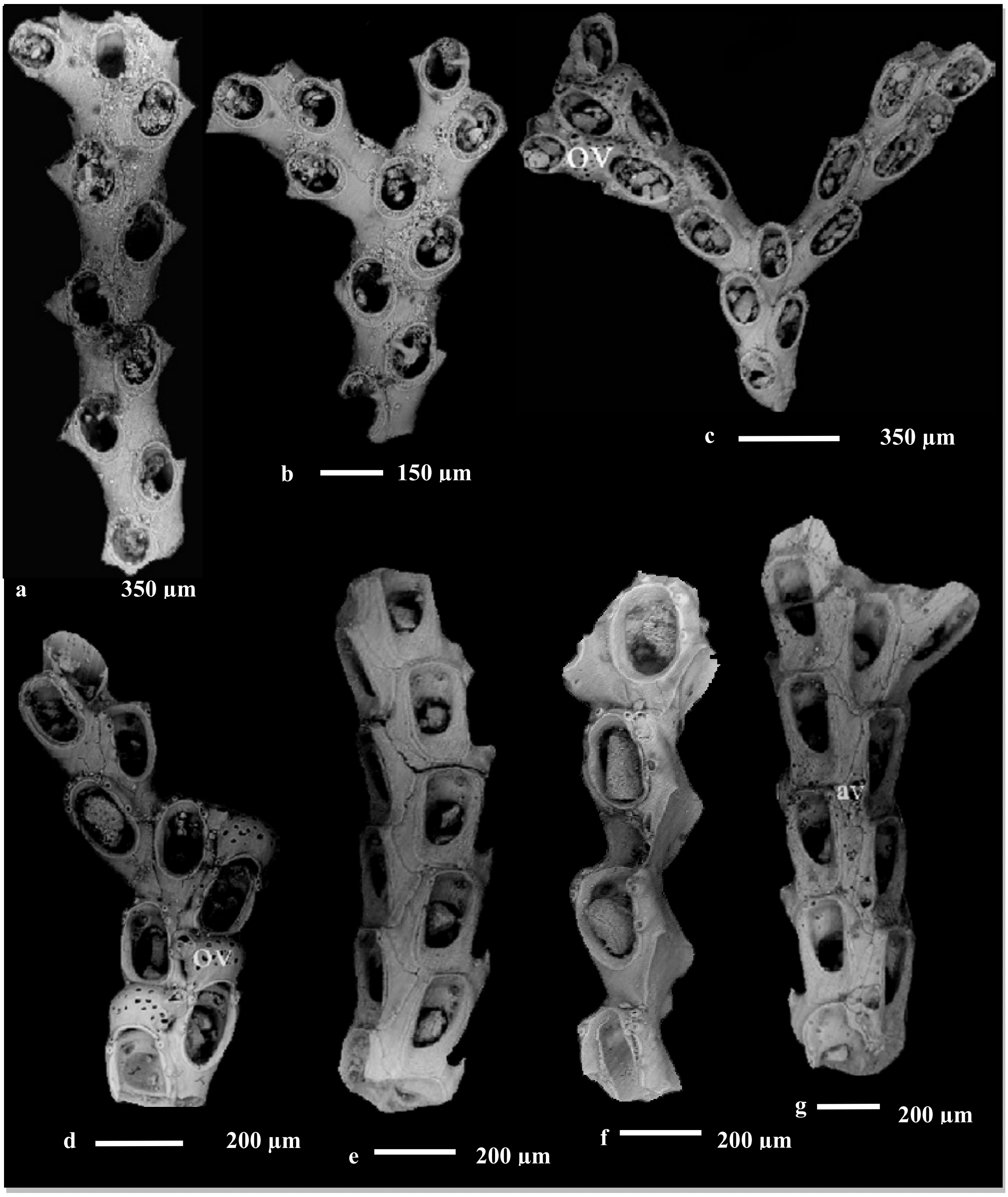

Fig. 4—Examples of erect rigid bryozoans. a: *Scrupocellaria scrupea* Busk, 1851, sample 10, El Fanader. b: *Tricellaria aculeata* (d'Orbigny, 1847), sample 7, Al Qweh lagoon. c: *Tricellaria monotrypa* (Busk, 1852) showing an ovicell (ov), sample 15, El-Humrawen harbor. d:*Tricellaria occidentalis* (Trask, 1857) showing ovicell and pseudopores, sample 2, Makadi Bay. e: *Canda arachnoides* Lamouroux, 1816, sample 10, Hurghada. f: *Canda pecten scutata* Harmer, 1926, sample 13, Al Qweh lagoon. g: *Canda retiformis* Pourtales, 1867 with small avicularia (av), sample 11, Makadi Bay.

The identified bryozoans are recorded from different geologic ages beginning from Eocene to Recent. 23 species are extant to Eocene age and previously recorded from France, North America, Germany, Hungary, Poland, Italy, Romania and Egypt. 24 species extant to Oligocene age and recorded from Oligocene sediments of Germany, France, Italy, Hungary, Poland, and CSSR. 46 species extant to Miocene age and recorded from Austria, France, Italy, Poland, Morocco, Algeria, Ukraine, Egypt, Hungary, Portugal, and Australia. 48 species extant to Pliocene age and 50 ones to Pleistocene age. Pliocene and Pleistocene species are previously recorded from Belgium, Netherlands, Italy, France, Egypt, Tunisia, Morocco, Spain, Portugal, England, Argentina, Venezuela, Australia and Japan.

On the basis of their present-day and fossil distributions, the 79 species of bryozoans identified from the Red Sea coast have been distributed into six paleobiogeographical groups: Indo-Pacific group (34 species), Mediterranean group (24 species), Atlantic group (24 species), Endemic Red Sea group (14 species), Cosmopolitan group (8 species), and Arctic group (7 species). Bryozoan growth forms have been correlated with various factors of the environment such as water depth, substrate type, water energy, and rate of sedimentation[24-28]. Two essential zoarial growth forms comprise the present bryofauna:

Encrusting growth form: Unilaminar or multilaminar sheets encrust mostly hard substrates such underside of coral fragments and molluscan shells (Fig. 2). It may constitute nodular massive or branching multilaminar masses. 34 species belong to this growth form and subdivided into membraniporiform (24 species), celleporiform (9 species) and lichenoporiform (One species).

Erect growth form: Tree-like colonies fixed with substrate by their bases. 45 of the studied species belong to this type subdivided into erect flexible (Fig. 3) and erect rigid growth forms (Fig. 4). The former has long segments articulated by chitinous joints, attached to loose or solid substrates by its chitinous rootlets and subdivided into cellariiform (17 species) and catenicelliform (One species). The second is erect rigid colonies with subcylindrical dichotomous branches, cemented by their basis to a solid substrate and subdivided into vinculariiform (24 species), reteporiform (2 species), adeoniform (one species).

Trace metals: The concentrations of heavy metals in 30 sediment samples from the studied areas are illustrated in table 3 and figures 5 and 6. The concentrations of heavy metals were decreased in the order: Fe > Zn > Mn > Pb > Ni > Co > Cu > Cd.

Table 3— Concentration of heavy metals in the studied areas.

S. No.	Location	Depth	Fe	Zn	Pb	Mn	Ni	Co	Cu	Cd
F1	El Fanader	---	122.48	109.67	48.34	6.70	23.53	14.45	5.13	3.90
F5		6	211.21	**851.97**	51.87	7.4	25.17	18.44	**4.13**	4.8
F8		---	210.11	841.97	50.11	7.00	26.29	17.44	6.84	4.00
F10		3	121.48	215.52	46.34	6.18	21.53	12.45	6.36	3.54
F12		---	159.23	392.05	49.61	6.61	24.66	15.95	6.11	4.40
F15		4	144.99	**108.67**	50.61	6.25	27.29	16.97	7.84	4.86
H1	Hurghada	---	145.67	171.24	47.00	8.77	25.90	18.90	9.00	4.77
H5		28	153.44	147.1	51.08	**5.77**	26.3	19.11	8.98	5.3
H8		---	700.95	190.69	51.05	11.25	27.00	19.17	9.11	5.00
H10		16	142.67	141.74	**52.05**	6.13	**27.72**	20.17	9.11	4.83
H12		---	362.69	163.18	49.79	9.05	26.07	19.39	9.01	4.85
H15		33	791.95	200.69	46.24	15.25	24.2	18.89	8.95	4.43
M1	Makadi	---	373.33	250.7	43.00	19.34	18.99	17.39	11.99	3.76
M4		10	574.67	223.7	45.32	15.72	21.69	17.74	10.03	3.86
M5		---	918.94	260.01	51.00	25.67	22.40	18.00	13.33	4.22
M8		6	277.33	229.66	51.99	11.84	25.42	18.01	15.89	4.81
M9		---	685.65	247.46	45.61	21.08	21.83	17.58	11.64	4.04
M11		11	1204.94	289.01	39.52	35.67	18.38	16.99	8.99	3.46
Q1	Qweh	---	156.48	138.107	19.62	9.13	19.39	12.81	8.11	**2.00**
Q5		Beach	245.94	315.68	48.79	10.62	24.68	22.19	9.95	4.02
Q8		---	260.04	311.09	30.68	12.11	19.04	18.89	10.00	3.37
Q10		3	176.43	295.67	49.68	10.33	25.04	**22.89**	9.55	4.29
Q12		---	**228.14**	310.48	49.06	11.06	24.69	22.42	10.14	4.23
Q15		5	262.04	320.09	48.71	12.23	24.35	22.17	10.93	4.37
W1	El-Humrawen	---	1112.04	300.17	20.62	100.77	14.39	12.81	11.10	4.00
W5		Beach	1082.04	319.85	24.79	72.6	**12.69**	10.81	6.15	2.28
W8		---	2800.61	322.27	30.78	122.64	20.92	18.39	14.58	5.00
W10		1.5	**3089.61**	342.27	38.78	**132.64**	24.92	19.39	**16.58**	**6.11**
W12		---	1865.65	319.96	26.73	88.00	15.67	14.04	10.18	3.55
W15		4	1425.29	297.77	**16.62**	58.77	9.39	**11.93**	7.82	2.25
	Aver.		**666.87**	**287.61**	**42.51**	**28.89**	**22.32**	**17.53**	**9.58**	**4.14**

Iron: Fe is mostly associated with the carbonate fraction in the Red Sea sediments, probably absorbed on the surfaces of the particles[29]. The concentration of Fe in the present samples ranges from 228.14 to 3089.61 ppm, with an average value of 666.87 ppm. The highest value is recorded in El-Humrawen Hurbour and the lowest one is recorded in Al Qweh sediments. (Table 3, Fig. 5). The higher Fe values in El-Humrawen sediments than other localities are probably due to the phosphate shipment and the effects of wadi El-Humrawen high flux of terrigenous sediments. The correlation matrix (Table 4) indicates that Fe is positively correlated with Mn. This may point to the bioaccumulation in marine organisms. Fe values (from 189 ppm to 2209 ppm) in some island sediments of the Egyptian Red Sea coast[30] are located within our Fe values.

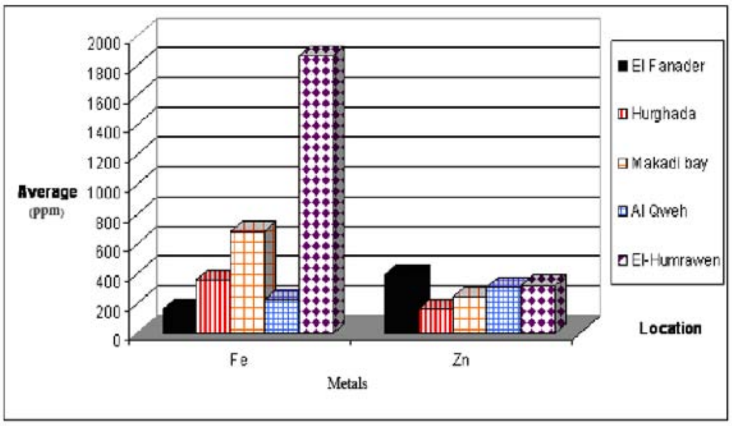

Fig. 5—The average concentration of Fe and Zn in the studied areas.

Manganese: The tendency of soluble Mn-compounds to adsorb into sediments depends mainly on the cation exchange capacity and the organic composition[31]. Generally, the upper layers of marine sediments are often enriched in oxidized manganese and iron precipitates as a result of biogeochemical processes[31]. Mn values

Our Mn values are agreed with those recorded in some lagoons along the Red Sea coast[32]. Mn in Recent sediments of the study area range from 5.77 to 132.64 ppm, with an average value of 28.99 ppm (Table 3 and Fig. 5). Highest value is recorded in El-Humrawen harbor, while the lowest one is recorded in Hurghada area. High Mn contents in El-Humrawen may be due to the phosphate shipment.

shows no clear correlations with Zn, Pb, Ni, Co, Cd and Cu metals (Table 4).

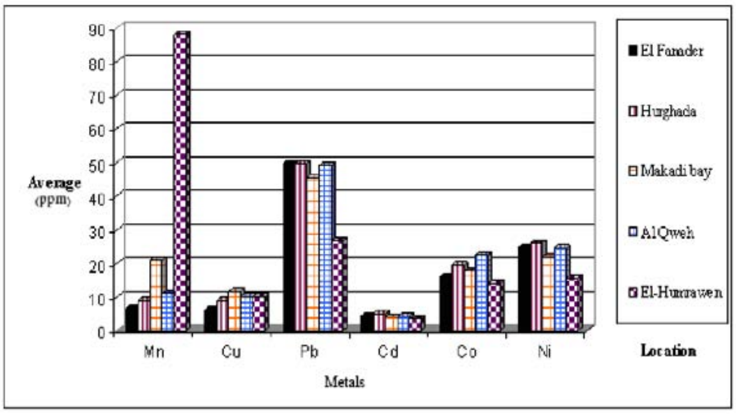

Fig. 6—The average concentrations of Mn, Cu, Pb, Cd, Co and Ni in the studied areas.

Zinc: Zn is a necessary micronutrient for normal living cell differentiation and growth in both plants and animals. The concentration of Zn in sediment is related to particle size, mineralogy, and input sources. Their biological effect is not related to total concentrations but with the binding of zinc by sulfide, organic matter and metal oxides and the concentration ratio of Zn/Cu[33, 34].

In the present study, the concentration of Zn ranges from 108.67 to 851.97 ppm, with an average value of 287.61 ppm. The lowest and highest values are recorded in El Fanader area (Table 3 and Fig. 6). The high contents of Zn in El Fanader area may be attributed to high terrigenous and the anthropogenic impacts from the shipyards whereas zinc sulphate is widely used in ship painting. The correlation matrix shows that the Zn is very weakly correlated with other seven metals (Table 4). This can be explained by the availability of Zn is not directly related to the total concentration of the metal in the environmental compartment[33].

Our Zn values are larger than those from Hurghada[35] (11 to 90 ppm), in the front of thirteen areas along the Egyptian Red Sea coast from Hamata to Hurghada[36] (8 to 164.4 ppm) and 0.02 to 8.81 ppm from some island sediments of the Egyptian Red Sea coast[37].

Table 4—Ccorrelation matrix of heavy metals in the studied areas.

	Fe	Mn	Cu	Zn	Pb	Cd	Co	Ni
Fe	1.00							
Mn	0.96	1.00						
Cu	0.44	0.39	1.00					
Zn	0.10	0.11	-0.31	1.00				
Pb	-0.60	-0.65	0.14	-0.03	1.00			
Cd	0.10	-0.02	0.51	0.00	0.72	1.00		
Co	-0.21	-0.30	0.40	0.04	0.70	0.70	1.00	
Ni	-0.40	-0.43	0.30	-0.08	0.94	0.90	0.80	1.00

Lead: Coastal waters may receive significant inputs of Pb from industry, sewage sludge, domestic waste water and the combustion of fossil fuels[38]. Sorption of lead by sediment is correlated to the organic content, the grain size and the anthropogenic pollution[39, 40].

Marine sediments in the study area Pb values range from 16.6 to 52.0 ppm, with an average value of 42.51 ppm. Highest value is recorded in Hurghada, while the lowest one is recorded in El-Humrawen Hurbour (Table 3 and Fig. 6). High Pb content may attribute to the lubricating oil from diesel and gasoline powered motors and engines from boat and ships. Correlation matrix shows that Pb is strongly correlated with Cd, Co and Ni, this may be attributed to the possible sources of Pb such as anti-knocking additive in gasoline, marine paints and oil shipping (Table 4). Also, Pb is highly negative correlated with Fe, Mn, and Zn, this may be attributed to that the Fe, Mn, and Zn are mostly associated with the carbonate fraction and probably absorbed on the surface of the particles[29].

Nickel: Ni may be deposited into the sediment by various processes such as precipitation, complex addition, adsorption on clay particles, and via uptake by biota. Contribution of Ni to the marine environment can be attained through many anthropogenic ways such as crude oil seepage, diesel fuel, drilling mud, marine paints, tourist activities, sewage landfill and also naturally from terrigenous sediments[41].

The studied area is characterized by high Ni content, ranges from 12.69 to 27.72 ppm, with an average value of 22.32 ppm. Lowest value is recorded in El-Humrawen area, whereas the highest one is recorded in Hurghada area (Table 3 and Fig. 6). The high Ni contents in the present sediments may be due to the anthropogenic impacts. Ni is intimately correlated with Pb, Cd and Co (Table 4). This may be due to the anthropogenic ways such as diesel fuel, marine paints, tourist activities and sewage landfill.

Cobalt: The main anthropogenic sources of Co are oil fuels, marine pigments and landfilling. In the present study, Co vales range from 11.93 to 22.89 ppm, with an average value of 17.53 ppm. Highest value is recorded in El-Humrawen Hurbour, while the lowest one is recorded in Al Qweh area (Table 3 and Fig. 6). Co shows clear negative correlations with Fe and Mn, and low positive correlations with Cu and Zn, while strongly positive correlation with Pb and Cd (Table 4).

The concentration of Co in the studied areas is nearly similar to those recorded in northern Gulf of Aqaba[42], in the northern Red Sea[29] and in Hurghada area[43].

Copper: The dissolution of Cu from sediments to water depends on the pH and salinity, while adsorption of Cu from sediments is very low compared with other metals[44]. Cu values in the investigated area range from 4.13 to 16.58 ppm, with an average value of 9.58 ppm. Highest value is recorded in El-Humrawen Hurbour, while the lowest one is recorded in El Fanader locality (Table 3 and Fig. 6). Present values are low, in comparison with those reported for the sediments of the northern Red Sea[29, 41] for the mangrove sediments from Wadi El Gemal and Wadi Abu Ghusun. Cu has low correlations with the other seven metals (Table 4).

Cadmium: Cd can move between air and water and once reach the water; it will find its way into sediment. Also, Cd is used in manufacturing of plastic and pigments and as burning of fossil fuels. There was no interaction of Cd with organic matter but large amounts were found in exchangeable and carbonate fractions[45].

The concentrations of Cd in the study area range from 2.00 to 6.11 ppm, with an average value of 4.14 ppm (Table 3 and Fig. 6). Lowest value is recorded in Al Qweh, while the highest one is recorded in El-Humrawen area. This may be due to the gasoline resulting from the from the phosphate shipment. The present Cd values are much less than values reported in the coastal sediments of the Egyptian Mediterranean Sea[46, 47].

Trace metals and distribution of bryofauna

Based on field observations, El-Hamrawen area considers the most polluted of the studied areas may be due to spread of phosphate dust, especially during the shipping process. Sediment samples of this area recorded the highest concentrations of Fe, Mn, Co, Cu and Cd. Also recorded the lowest bryozoans colonies (18 encrusting zoaria, 15 erect flexible, 20 erect rigid) in comparison with other studied areas.

Hurghada area subject to many types of anthropogenic pollutants, such as reject brain water from desalination plant, light oil resulting from basin repair boats, the sewage output from the harbor Mosque and the port and fishing activities. Its sediments recorded the highest concentrations of Pb and Ni; and gave 20 encrusting zoaria, 18 erect flexible and 23 erect rigid ones. With El-Hamrawen area, they recorded the lowest frequency and diversity of the studied bryozoans (Table 2). This depletion is not in bryozoa only but field observation indicated that corals and other fauna are also very rare.

As mentioned before, field survey illustrated human impacts in the form of diving and snorkeling activities in El Fanader lagoon. Sediments of El Fanader area recorded the highest concentration of Zn and recorded 24 encrusting zoaria, 27 erect flexible ones. No erect rigid forms are recorded in that area, which may attribute to diving and snorkeling activities which make a disturbed substrate, as well as the highly agitated water due to locating the area 10 km inside the sea.

Makadi bay and Al Qweh area, from the field point of view, they represent the most pristine areas. Their sediments gave trace metals concentrations less than the three other studied areas, since sediments of Al Qweh area recorded the lowest concentrations of Fe, Co and Cd. Makadi bay and Al Qweh area recorded the highest number of bryozoans, from frequency and diversity points of view (37, 41 encrusting zoaria, 46, 51 erect flexiable and 46, 44 erect rigid). The increase in bryozoan zoaria is associated by high diversity of corals, algae, sea grass and other invertebrates. Also the size of encrusting zoaria in Makadi bay and Al Qweh area occupy areas on coral and molluscan fragments reaching 2 folds and sparsely 4 folds than those found in the other studied areas.

Conclusions

79 bryozoan species belong to 48 genera and 30 families have been identified from the recent sediments of the Red Sea coast. 25 species belong to order Cyclostomata and 54 ones belong to order Cheilostomata. 34 of the identified species have encrusting growth form, 18 species have erect growth form and 27 ones of erect rigid growth. Sediment samples of El-Hamrawen area recorded the highest concentrations of Fe, Mn, Co, Cu and Cd. Sediments of Hurghada area recorded the highest concentrations of Pb and Ni, while those of El Fanader area recorded the highest concentration of Zn. Sediments of Makadi bay and Al Qweh area gave the least trace metals concentrations representing more or less pristine areas. El-Hamrawen, Hurghada and El Fanader lagoon recorded the lowest occurrences (frequency and diversity) of bryozoan colonies in comparison with Makadi bay and Al Qweh area. This may attribute to enrichment of trace metals in these areas and to the diving and snorkeling activities which make a disturbed substrate, as well as phosphate dust, especially in El-Hamrawen area.

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