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Possible Index for Marine Pollution from of Scleractinean Corals in Northern Gulf of Aqaba, Jordan

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Abstract
The coral nubbins of *Stylophora* sp., *Pocillopora* sp., *Acropora* sp., *Fungia* sp., and *Porites* sp. were taken from shallow depths of about 5 m by SCUBS diving. Another set of coral samples were collected in front of the Marine Science Station for incubation experiments to study the resistance of corals to different concentrations of heavy metals ranged between 0.1 to 50 ppm. The skeleton and tissue layers of all coral samples were isolated for samples, digested (using a mixture of Nitric and Hydrochloric acids) and were analyzed to determine the concentrations of Cd, Cu, Pb, Cr, Zn, and Ni using Flame Atomic Absorption Spectroscopy (FAAS). However, the lowest concentrations were found along the marine park including the Marine Science Station, with lower contamination of ambient waters as heavy metals concentration in corals reflects the health of marine environment. The highest concentrations of all heavy metals (Cd, Cu, Pb, Zn, Cr, and Ni) in the coral skeletons were accumulated in *Pocillopora* species whereas the lowest concentrations were recorded in *Porites* species and the rest coral species could be arranged in the following ranking order (from high to low concentrations): *Pocillopora* sp.> *Acropora* sp.> *Stylophora* sp.> *Fungia* sp.> *Porites* sp. The incubation experiment showed that the toxicity of the individual metals increased in all coral species with increasing metal doze and time of exposure until total death was reached. The coral species resistance to death for all heavy metals (except for Nickel) can be arranged in the following ranking order (from low to high): *Stylophora* sp.< *Acropora* sp.< *Pocillopora* sp.< *Fungia* sp.< *Porites* sp. The coral species *Porities* was the most resistant species. Copper was found as the most toxic metal to all coral species compared with the toxicity of Pb, Cd or Zn. The toxicity of the studied heavy metals (except Ni) to all corals species can be arranged in the following order (from high to low): Cu>Pb>Cd>Zn. It is generally concluded that the pollutions levels of heavy metals along the Jordanian coast of the Gulf of Aqaba are still relatively low and the coral reef communities are healthy. Corals are suitable to be used as proxy tools to record environmental pollution (bio-indicators) from the Gulf of Aqaba and the Red Sea.
Keywords: Heavy metals, Corals, Gulf of Aqaba, Red Sea.

1. Introduction

Heavy metal constitute one of the most insidious and dangerous pollutants known to human. Once in the environment, they are not readily converted into harmless components. They are often accumulated in the tissue of organisms, which can't excrete them [1]. Yet they have great ecological significance due to their toxicity and accumulation properties. These elements contrary to most pollutants are not biodegradable and undergo a global eco-biological cycle [1]. Heavy metals are important in several ways: many are industrially used in technologically in advanced countries, some are physiologically essential for plants and animals and thus have a direct bearing on human health and agriculture and many are significant as pollutants to ecosystems through out the world [2, 3, 4]. Heavy metals in marine habitats are usually measured in one or more of the three main components; water, sediments, and biota. Measurement of dissolved heavy metal concentrations in seawater involves considerable analytical complication. These concentrations being typically low may require pre-concentration and are liable to inadvertent contamination during collection and analysis. Dissolved concentration, moreover, may vary greatly over short time, for example for tidal cycle, fresh water runoff, storms, etc… [5]. Monitoring of heavy metal contamination needs to be intensive over extended periods. Thus measurement in the seawater soon become expensive in laboratory time and analytical chemicals. Most importantly, measure of dissolved heavy metal concentration provide an assessment of total metal present rather than the fraction biologically available for uptake and accumulation by marine organisms.

1.1. Coral reefs study area, sampling and analytical methods

Coral reefs cover about 15% of the shallow see floor, and through their roles in marine calcification and fisheries, they are quantitatively significant ecosystem on global scale latitudes of 30^{o} North and 30^{o} South, where temperature ranged between 18^{o} C and 30^{o} C [6]. Coral reefs are characterized by very high biodiversity

with more than hundred thousand species, of which many are not yet identified by science [7, 8]. They are highly productive in tropical seas, productivity may be many thousands of times higher compared to the open sea [7, 9]. The Gulf of Aqaba is considered to be semi-enclosed water body as it is connected with the Red Sea through the relatively shallow Straits of Tiran, A narrow passage preventing free exchange between the waters on its two sides. It has still depth of about 265 m [10]. The Jordanian coastline runs south for about 27 km from the northeastern tip of the Gulf to the Saudi border (Fig.1). On either side of the Gulf of Aqaba, beyond the shoreline, barren mountains rise to highest of approximately 1000 m.

2. Experimental

2.1. Extraction of heavy metal

For the coral samples which were stored in refrigerator the heavy metals were investigated for both coral skeleton and tissue layer separately. While for coral samples which were used in accumulation experiments only the heavy metals were investigated in coral skeleton. The procedure described by Esslemonet et al. [11] was followed to separate the skeleton and tissue layers, the coral branches were treated as follows: 5 g from each species were rinsed with water, then dried on plastic trays (60±10 °C for 48±1 hrs), and weighed. After that the dried sample was transfer to a jar and followed with addition of 15 ml of hydrogen peroxides (9.7 M, pH adjusted to 8.2 with sodium hydroxide), samples were lifted for 1 hr at room temperature of about 28°C. Jars were then heated in a water bath (70°C) for 3.5 hrs to complete tissue removal, then the solutions which contain the tissues were filtrated on a Whatman filter paper No. 41 and stored in a refrigerator for digestion.

2.2. Digestion

Two different procedures were adapted to digest the skeleton and tissue of the corals as follow.

To digest skeleton for heavy metal analysis in corals (using Teflon beaker), the standard procedure for soil and biota from EPA (#3050) was performed: 10ml of HNO_3-H_2O 1:1, 5ml of HNO_3 conc. 4ml of H_2O_2 36% and 5ml of HCl conc., heated to 90°C to near dryness, after that 5ml of 1N Hydrochloric acid was added to each sample and boiling for about 5 min, then the sample was filtered using Whatman filter paper No. 41 in a 50 ml volumetric flask and diluted to the mark with distilled water.

Coral tissue digestion was done following the procedure described by Esslemonet et. al., [11], seventy gram of ascorbic acid had been added to the solution that contain the tissue to recover metal oxides that may have precipitated from solution during tissue digestion. The solution were then acidified (1ml of 12 M hydrochloric acid), and evaporated on hotplate to about 20 ml. For about 100g concentrated hydrogen peroxide/ nitric acid (70ml of 1:1 concentrated reagents) were added to complete digestion, and samples were evaporated to near dryness. After that, 5ml of 1N Hydrochloric acid was added to each sample and boiling for about 5 min, Lanthanum chloride (2 ml of 0.18M) was added to compensate for possible calcium interference during analysis, then the sample was filtered using Whattman filter paper No.41 in a 50 ml volumetric flask and diluted to the mark with distilled water.

2.3. Heavy metal analysis

All samples were analyzed using Flame Atomic Absorption Spectrophotometry (FAAS), (Shimadzu AA-620), for corals which were collected along the Jordanian coast of the Gulf of Aqaba, Cd, Cu, Pb, Zn, Ni, and Cr have been measured in coral skeleton and tissue separately. For incubation experiments a specific element was analyzed using air-acetylene flame. The basic instrument parameters are shown in Table (3).

2.3. Chemicals and instruments

All chemicals and reagents used in this study were analytical grade purity. Hydrogen Peroxide (30%) (BDH, ENGLAND), Nitric Acid assay 69-71%, sodium hydroxide, hydrochloric Acid (BDH, ENGLAND).

The following instruments were used throughout this work:

1. pH-meter: WTW197.
2. Ultrasonic device: Type UW 2070, BANDELIN electronics.
3. Flame Atomic Absorption Spectrophotometry (FAAS).

3. Results

The results showed that all metal concentrations measured in all coral species were consistently higher in the tissue fraction compared with the skeleton fraction. The highest concentrations of the measured heavy metals in corals were recorded at Public Café and Ferry Port sites suggesting the presence of pollution sources. However, the lowest concentrations were found along the marine park including the Marine Science Station, with lower contamination of ambient waters as heavy metals concentration in corals reflects the health of marine environment. The highest concentrations of all heavy metals (Cd, Cu, Pb, Zn, Cr, and Ni) in the coral skeletons were accumulated in *Pocillopora* species whereas the lowest concentrations were recorded in *Porites* species and the rest coral species could be arranged in the following ranking order (from high to low concentrations): *Pocillopora* sp.> *Acropora* sp.> *Stylophora* sp.> *Fungia* sp.> *Porites* sp. The incubation experiment showed calibration curves for both tissue and skeleton analysis are shown in Figures (4) .The mean Cu concentration in

the five coral species differ from each other (Fig. 3). The highest and lowest concentrations in the coral skeleton were accumulated in *Pocillopora* sp. And *Porites* sp. And followed the following order (from high to low concentration): *Pocillopora* sp.> *Acropora* sp.> *Stylophora* sp.> *Fungia* sp.> *Porites* sp. For example, at the PP site the skeletal concentration of Cu in *Pocillopora* sp., *Acropora* sp., *Stylophora* sp., *Fungia* sp., and *Porites* sp. Were: 6.38; 5.82; 4.67; 2.56; 1.35 $mg.kg^{-1}$, respectively.

3.1. Lead concentrations in coral skeleton and tissue

Summary statistics for the average concentrations of lead ($mg.kg^{-1}$) in the skeleton and tissue of the five coral species (*Stylophora* sp., *Pocillopora* sp., *Acropora* sp., *Fungia* sp., and *Porites*) in the seven study sites (Public Cafe, Phosphate Port, Clinker Port, Ferry Port, Marine Science Station, South Beach, and Industrial Complex) are shown in Table (3.5).The concentrations of Pb in the coral skeletons ranged between 4.29 and 12.45 $mg.kg^{-1}$ for *Stylophora* sp.; 9.00 and 25.40 $mg.kg^{-1}$ for *Pocillopora* sp.; 4.45 and 17.30 $mg.kg^{-1}$ for *Acropora* sp.; 2.25 and 11.20 $mg.kg^{-1}$ for *Fungia* sp.; and 2.10 and 10.60 $mg.kg^{-1}$ for *Porites* coral species (Table 3.5). Whereas the concentrations of Pb in coral tissue ranged between 11.02 to 39.43; 10.03 to 33.75; 6.66 to 38.64; 6.01to 19.81 and 5.03 to 47.88 $mg.kg^{-1}$ for *Stylophora* sp., *Pocillopora* sp., *Acropora* sp., *Fungia* sp., and *Porites* sp. coral species, respectively (Table.5). Lead concentration in all coral species from this study were lower in skeleton part compared to the tissue part (Table .5, Fig. 3). For example the concentration of Pb in tissue and skeleton of *Acropora* sp. at CP site were 16.50 $mg.kg^{-1}$; and 9.65 $mg.kg^{-1}$, respectively. Corals have been widely used worldwide as marine biomonitors for marine pollution with trace metals, such as Hg, Cu, Zn, Pb, Mn, Fe, V, Cd, and others [12, 13, 14, 15, 16]. Scleractinian corals meet several of the prerequisites for biological monitors suggested by Phillips [17]. They are long-lived, sessile organisms that are common in many tropical and semi-tropical marine ecosystems when compared with other potential indicator species, and they yield adequate tissue and skeletal material for analysis of trace metals. There is still a gap of information for heavy metals concentration in corals from the Gulf of Aqaba which is a semi enclosed body of water in which pollution effects may be magnified.

3.2. Metal concentration in coral skeletons and tissues

A wide range of techniques have been used to extract and measure trace metals in a variety of coral species, and due to the differences in the methods used, many studies are not directly comparable. Some studies use tissue and skeleton combined [18, 19], while many other studies have analyzed the skeleton only [20, 21, 22, 23]. The most useful studies in terms of investigating the potential for corals to be used as bio-monitors are those that provide metal concentrations for both the skeleton and the tissue separately [16, 24, 25, 26, 27, 28]. In this study, metal concentrations in coral tissue and skeleton were measured separately. It is clear from the results that all metal concentrations measured in all coral species were consistently higher in the tissue fraction compared with the skeleton fraction. For example, the ratio of Zn concentration between tissue and skeleton in the corals *Stylophora* sp. and *Porites* sp. were 12.7 and 13.1, respectively (Table 4.1). These results are similar to those obtained by Howard and Brown [24]; McConichie and Harriot [25]; Bastidas and Garcia [26]; Esslemont [27]; [16]; Reichelt-Brushett and McOrist [28]. This suggests that not all the metals taken up by the living coral are transferred to the skeleton [28] where much of the metals remains associated with tissue in organic rind of the coral body [29]. This also supports the idea that corals discriminate against metals in their biogenic precipitation of the aragonite skeleton [20]. The brown layer that living polyps occupied is usually 2-3 mm in thickness, with a thin burrowing green algae layer directly between it. McConchie and Harriot [25] found that metals are 10-80 times more concentrated in organic phases in coral tissue than in their exoskeletons. However, corals may regulate the concentration of some trace metals in their tissues and may modify how trace metals are transferred to skeletons [16, 30]. This limits the usefulness of coral tissues for bio-assay purposes to a few metals.

3.3. Heavy metal concentrations in different coral species at different study sites along the Jordanian coast

Accumulation of heavy metals in bio-indicator organisms are primarily dependant on ambient metal concentration in seawater, however, several other factors such as seasonal effects also affect metal concentration. Along the Jordanian coast of the Gulf of Aqaba, variations in ecological factors such as pH, salinity, temperature and conductivity that can be neglected [32]. Thus, the effects of variations of metal concentrations in this study can only be reasoned to the conditions of the sites which is due to different human impacts on the sites studied. Human use of coastal resources including the construction and operation of industrial activities has an important effect on heavy metal concentrations in biological indicators (e.g., corals). For example, many metals are found in agriculture products are enriched by addition of fertilizers (such as, Cd, Cu, Cr, Ni, Mn, Mo, and Zn), [32]. Sewage sludge and wastewaters are also considered as one of the most important sources produced by urban and industrial activities [33, 34].

One of the objectives of this study was to investigate the seawater environmental quality along the Jordanian coast of the Gulf of Aqaba. Assessing and identifying the likely sources responsible for heavy metal pollution in the Gulf of Aqaba are difficult, and although it is beyond the scope of this study, the possible causes for this pollution will be discussed briefly for each

3.4. Comparisons with published results throughout the world

Overall mean value of heavy metal concentration in coral skeleton and tissue of the results are compared with published data of other surveys using other coral species from different areas throughout the world (Table 7). The mean value along the Jordanian coast of the Gulf of Aqaba from this study is not different from those reported from the Red Sea by Hanna and Muir [14] . However, the values were higher than some values reported by other authors over a wide geographical range (Table 7).This could be attributed to many factors such as the use of different coral species, different digestion and analytical methods used, and the geographical variations. Furthermore, Esslemont [16] found that metal concentration in coral tissues differed with extraction procedure.

4. CONCLUSIONS

Metal concentrations in all coral species were consistently higher in tissue part compared to the skeleton part. The highest Cd concentrations were found at Public Café site. This suggested the increase the sewage and solid waste significantly at this site due to the existence of the two public cafés in addition to swimming activity at this site. High Cd concentrations were also observed at the Clinker Port and Industrial Complex sites. The coastal waters in these sites receive solid and liquid effluents containing heavy metals from operations and loading of clinker and fertilizer plants. The elevated Cu concentrations were found at the Public Café site suggesting that the presence of anthropogenic source for Cu. One of Cu sources could be coral damage by anchoring and boat grounding. The high Pb concentration was found in Ferry Port site. Through the Ferry Port site, Boat and human activities are generally extensive in this site; this may increase Pb content by enhancement of solid waste and uncontrolled wastewater. Also there is possibility of lead souring from solid wastes disposed of by passenger. Other suggestion could be the presence of Pb source like oil and fuel pollution from ships that transport the passengers since the fuel used for boats has usually a percent of lead. The highest Zn, Cr concentrations were found at the Ferry Port followed by the IC site. Ships and passengers activity may affect this site by uncontrolled wastewater and solid waste discharge that increase solid waste significantly. This may cause elevated Zn concentrations at this site. Similarly, sewage sludge and wastewater from the industrial activities site may lead to increase Zn at the Industrial Complex. The highest concentrations of Ni were found at the Ferry Port and Industrial Complex sites. At the IC site, the fertilizer industries could be the reason for high concentrations of nickel. However, the high values at the Ferry Port site could be attributed to ships and passengers activity that increase the uncontrolled wastewater and solid waste discharge to the sea.The lowest concentrations of most of the heavy metals were found along the marine park which includes the Marine Science Station site. This indicates the absence of significant contamination of ambient waters as heavy metals concentration in corals reflects the health of marine environment. The highest and lowest concentrations of all heavy metals (Cd, Cu, Pb, Zn, Cr, and Ni) in the coral skeletons were accumulated in *Pocillopora* sp. and *Fungia* sp., respectively.

The coral species used in this study could be arranged in the following ranking order (from high to low concentrations): *Pocillopora* sp.> *Acropora* sp.> *Stylophora* sp.> *Fungia* sp.> *Porites* sp. The incubation experiment showed that the toxicity of the individual metals increased in all coral species with increasing metal doze and time of exposure until total death was reached. The coral species resistance to death for all heavy metals (except for Nickel) can be arranged in the following ranking order (from low to high): *Stylophora* sp.< *Acropora* sp.< *Pocillopora* sp.< *Fungia* sp.< *Porites* sp. The coral species *Porities* was the most resistant species. The coral resistance for nickel in the incubation experiment is different from other heavy metals. The coral species can be arranged as follows (from low to high): *Fungia* sp.<*Porites* sp.< *Stylophora* sp.<*Acropora* sp.<*Pocillopora* sp. The coral species *Pocillopora* was the most resistant species. **C**opper is more toxic to all coral species than Pb, Cd or Zn. The toxicity of the studied heavy metals (except Ni) to all corals species can be arranged in the following order (from high to low): Cu>Pb>Cd>Zn. The pollution levels of heavy metals along the Jordanian coast of the Gulf of Aqaba are relatively low and the coral reef communities are healthy. Corals are suitable to be used as proxy tools to record environmental pollution (bio-indicators) from the Gulf of Aqaba and the Red Sea.

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Table 1: Summary of one year meteorological conditions in Aqaba

Month	Wind speed (ms^{-1})			Wind dir. (°)	Relative humidity (%)			Air temperature (°C)		
	mean	min	max	mean	mean	min	max	mean	min	max
Jan.	3.23	0.00	8.63	4.87	56.02	23.32	83.45	16.30	8.97	26.29
Feb.	3.71	0.50	8.80	1.99	50.97	22.40	82.47	17.16	10.16	26.91
Mar.	3.86	0.37	9.98	352.78	47.56	19.00	78.51	20.45	13.45	31.15
Apr.	4.40	0.33	9.19	353.12	42.26	12.91	75.38	24.45	16.49	38.21
May.	4.20	0.41	9.12	355.48	38.17	13.94	71.63	29.30	20.66	40.45
Jun.	4.64	0.60	8.95	359.48	38.19	15.49	71.50	31.51	24.33	41.92
Jul.	3.80	0.59	9.22	354.24	38.67	16.60	78.99	33.56	26.14	42.40
Aug.	4.42	0.67	9.26	359.49	47.78	21.23	81.12	32.88	26.61	40.80
Sep.	4.95	0.42	10.53	0.46	49.92	16.92	88.79	30.56	20.26	41.23
Oct.	4.25	0.31	9.46	357.95	53.11	17.86	84.65	26.25	17.52	36.80
Nov.	3.86	0.66	9.46	5.70	52.36	24.54	85.21	22.53	14.25	29.93
Dec.	3.24	0.37	8.87	3.90	57.87	25.13	88.54	17.25	10.07	26.91

Table 2: GPS readings for the sampling stations along the Jordanian coast of the Gulf of Aqaba.

Site number	Location	Latitude N	Longitude E
1	Public Café (PC)	29° 31 549	34° 59 957
2	Phosphate Port (PP)	29° 30 191	34° 59 465
3	Clinker Port (CP)	29° 28 536	34° 58 729
4	Ferry Port (FP)	29° 27 900	34° 58 560
5	Marine Science Station (MSS)	29° 27.555	34° 58.435
6	South Beach (SB)	29°26 386	34° 58 148
7	Industrial Complex (IC)	29° 22 705	34° 57 602

Table.3: The basic instrumental parameters for FAAS used in this study.

Element	D.L (ppb)	λ (nm)	Air Flow (L/min)	Acetylene flow (L/min)	Slit (nm)	Lamp Current (mA)
Cd	1.0	228.8	3.5	1.5	0.7	8.0
Pb	10.0	283.3	3.5	1.5	0.7	10.0
Cu	2.0	324.8	3.5	1.5	0.7	6.0
Ni	5.0	232.0	3.5	1.5	0.2	12.0
Zn	2.0	213.9	3.5	1.5	0.7	8.0
Cr	3.0	357.9	3.5	1.5	0.7	10.0

Table.4: Summary of Cu concentration ($mg.kg^{-1}$) in the coral skeleton of the five coral species at the seven sites along the Jordanian coast of the Gulf of Aqaba.

	Site						
Coral species	**PC**	**PP**	**CP**	**FP**	**MSS**	**SB**	**IC**
Stylophora	8.72	4.67	7.11	8.19	7.79	6.75	6.91
Acropora	8.96	5.82	7.52	8.34	8.02	6.99	7.29
Pocillopora	10.44	6.38	7.54	9.35	8.16	7.22	7.49
Fungia	8.55	2.56	7.08	8.18	7.09	3.77	6.73
Porites	7.41	1.35	0.48	6.17	4.78	2.60	3.81

Table 5: Statistical summary of Pb concentration ($mg.kg^{-1}$) in coral skeleton and tissue of the five coral species at all sites along the Jordanian coast of the Gulf of Aqaba.

Coral species	Tissue/skeleton	Min	Max	Mean	SD
Stylophora	Skeleton	4.29	12.45	8.11	3.13
	Tissue	11.02	39.43	21.36	9.08
Acropora	Skeleton	4.45	17.30	9.85	4.90
	Tissue	6.66	38.64	18.96	10.52
Pocillopora	Skeleton	9.00	25.40	12.94	6.41
	Tissue	10.03	33.75	19.85	8.44
Fungia	Skeleton	2.25	11.20	6.50	3.72
	Tissue	6.01	19.81	11.78	4.64
Porites	Skeleton	2.10	10.60	5.25	3.96
	Tissue	5.03	47.88	18.67	15.61

Table.6 : Average ratio between heavy metal concentration in coral tissue and coral skeleton for the five coral species collected along the Jordanian coast of the Gulf of Aqaba.

	Coral species				
Heavy metal	***Stylophora***	***Acropora***	***Pocillopora***	***Fungia***	***Porites***
Cd	4.8	1.7	1.0	2.9	4.0
Cr	2.6	2.6	2.6	1.7	3.2
Zn	12.7	4.6	6.7	5.2	
Cu	3.8	4.3	3.4	2.4	5.7
Pb	2.6	1.9	1.5	1.8	3.5
Ni*	--	--	--	--	--

* Heavy metal was not detected in the coral tissue.

Table .7: Average heavy metal concentrations ($mg.kg^{-1}$) in coral tissue and skeleton of different coral species from different geographical areas compared to this study.

Location	Reference	Coral		Heavy metal conc. ($mg.kg^{-1}$)					
		species	matrix	Cd	Cu	Pb	Zn	Cr	Ni
Gulf of Aqaba	This study	*Stylophora* sp.	T	2.58	7.16	8.11	2.96	9.04	6.20
			S	11.77	27.45	21.36	37.64	24.10	N.D
		Acropora sp.	T	2.88	7.56	9.85	4.77	9.77	6.70
			S	4.99	33.15	18.96	22.42	26.19	N.D
		Pocillopora sp.	T	1.90	8.08	12.94	5.03	10.34	6.96
			S	5.07	27.62	19.85	33.76	27.50	N.D
		Fungia sp.	T	1.30	6.28	6.50	2.49	8.80	5.85
			S	3.79	15.42	11.78	13.02	15.60	N.D
		Porites sp.	T	2.17	3.80	5.25	1.29	7.90	5.60
			S	4.32	21.67	18.67	16.90	25.29	N.D
1	Guzman & Jimenez [96]	*Siderastrea siderea*	S	7.5	2.0	31.0	10.2	7.3	-
2				7.6	3.8	32.3	8.9	9.9	-
3				7.6	3.3	0.0	9.2	9.3	-
4	Esslemont [89]	*G. aspera*	S	0.09	3.8	0.33	28	29	-
5		*A. formosa*		0.19	7.2	0.24	37	67	-
6		*G. aspera*		0.09	14	8.2	447	31	-
7	Bastidas and Garcia [81]	*Montastrea annuligera*	S	-	0.80	1.40	10.67	-	-
8				-	2.00	1.10	9.12	-	-

Continued Table (7)

9	Hanna & Muir [87] (Acid Soluble Method)	*Porities lutea*	S	-	0.83	0.51	9.28	-	0.15
		Goniastrea retiformis		-	0.92	47.0	2.85	-	0.21
		Pocillopora verrucosa	Polluted	-	1.94	55.0	5.60	-	0.18
		Porities lutea	S	-	0.78	44.0	3.38	-	0.11
		Goniastrea retiformis		-	0.82	36.0	1.00	-	0.11
		Pocillopora verrucosa	Unpolluted	-	1.32	36.0	259.0	-	0.07
10	Khaled et al. [108]	*Acropora*	S	1.31	7.58	5.56	6.47	-	-
11	Howard and Brown [85]	*Pacillopora damicornis*	T S	- -	50.90 11.60	- -	347 0.10	- -	44.30 -
12	St. John et al. [93]	*Acropora* *Poritidae*	S S	0.03 0.05	- -	0.02 0.027	1.40 3.40	- -	0.06 0.17
13	David [102]	*Porites*	S	- - -	0.70 3.10 1.40	- - -	1.00 1.80 2.00	- - -	- - -
14	Esslemont [88]	*Acropora nobilis*	T S	1.60 <0.01	2.60 0.32	2.20 0.09	- 0.86	- -	- 0.45

1: Costa Rica; 2: Pa-ma; 3: Central America; 4: Pioneer Bay; 5: Nelly Bay; 6: Townsville Harbor; 7: Punta Brava; 8: Bajo Caiman 9: Red Sea, Egypt; 10: Red Sea, Egypt.; 11:; Phuket, Thailand 12: Heron Island, Australia; 13: Caganhao Reef, Philippines; 14:Heron Island, Australia. N.D: Not Detected.

Table.8: Average death time (hour) of the five coral species (*Stylophora* sp., *Pocillopora* sp., *Acropora* sp., *Fungia* sp., *and Porites* sp.) exposed to 1 ppm concentration of Cd, Cu, Pb and Zn.

	Death time of coral species (hour)				
Metal	***Stylophora***	***Acropora***	***Pocillopora***	***Fungia***	***Porities***
Cd	58±11	64±12	78±18	150±0	156±0
Cu	4±1.5	6±1.5	7±1.9	10±0	12±0
Pb	18±4.6	24±4.6	30±4.6	67±0	74±0
Zn	62±14	99±21	105±21	220±0	301±0

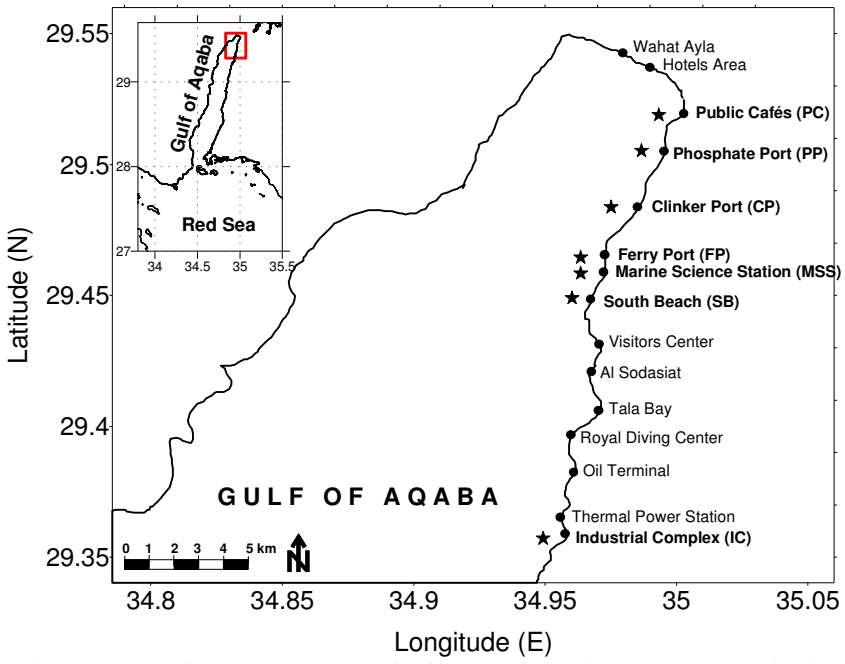

Fig. 1: Map of the northern Gulf of Aqaba showing the main activities along the Jordanian coast. Coral sampling sites are represented by the stars.

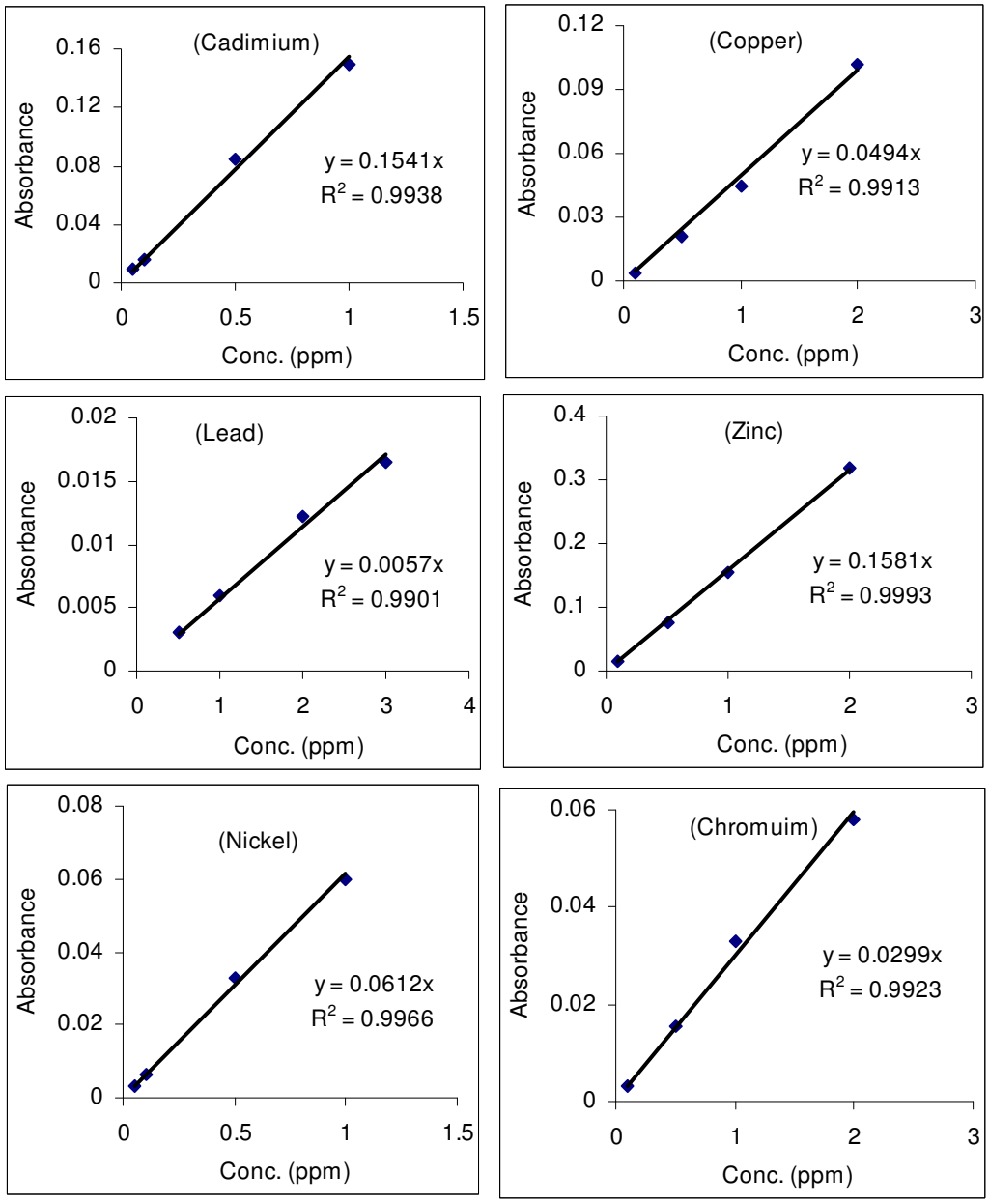

Fig. 2.: Calibration curves for the analyzed elements in coral skeletons.

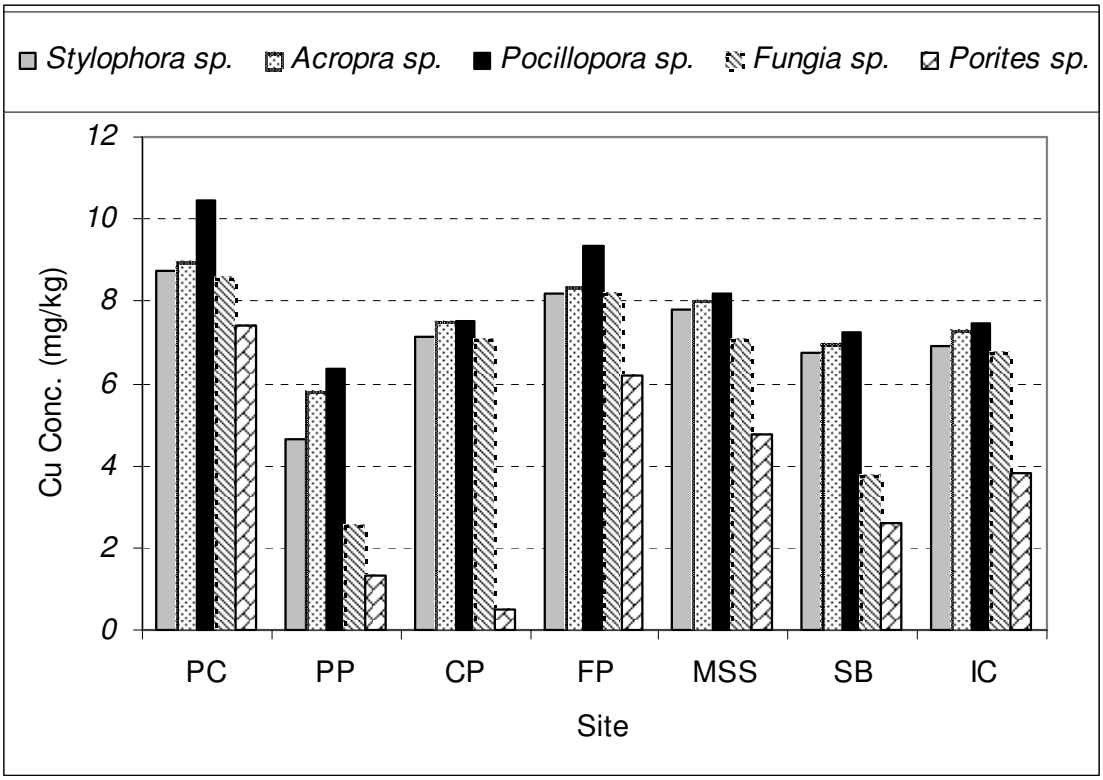

Fig. 3 : Copper concentration ($mg.kg^{-1}$) in coral skeleton of the five coral species at the seven sites along the Jordanian coast of the Gulf of Aqaba.

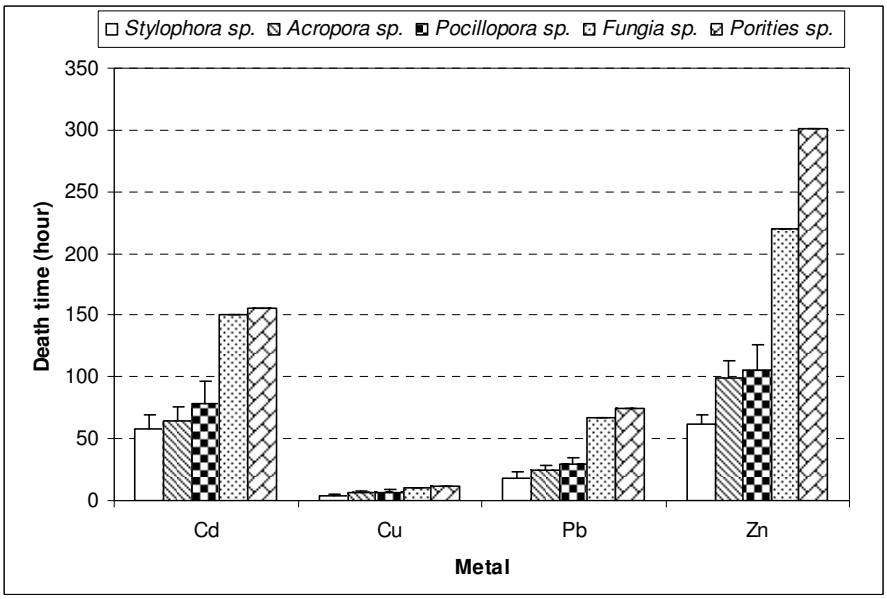

Fig.3 : Average death time (hour) of the five coral species (*Stylophora* sp., *Pocillopora* sp., *Acropora* sp., *Fungia* sp., *and Porites* sp.) exposed to 1 ppm concentration of Cd, Cu, Pb and Zn.

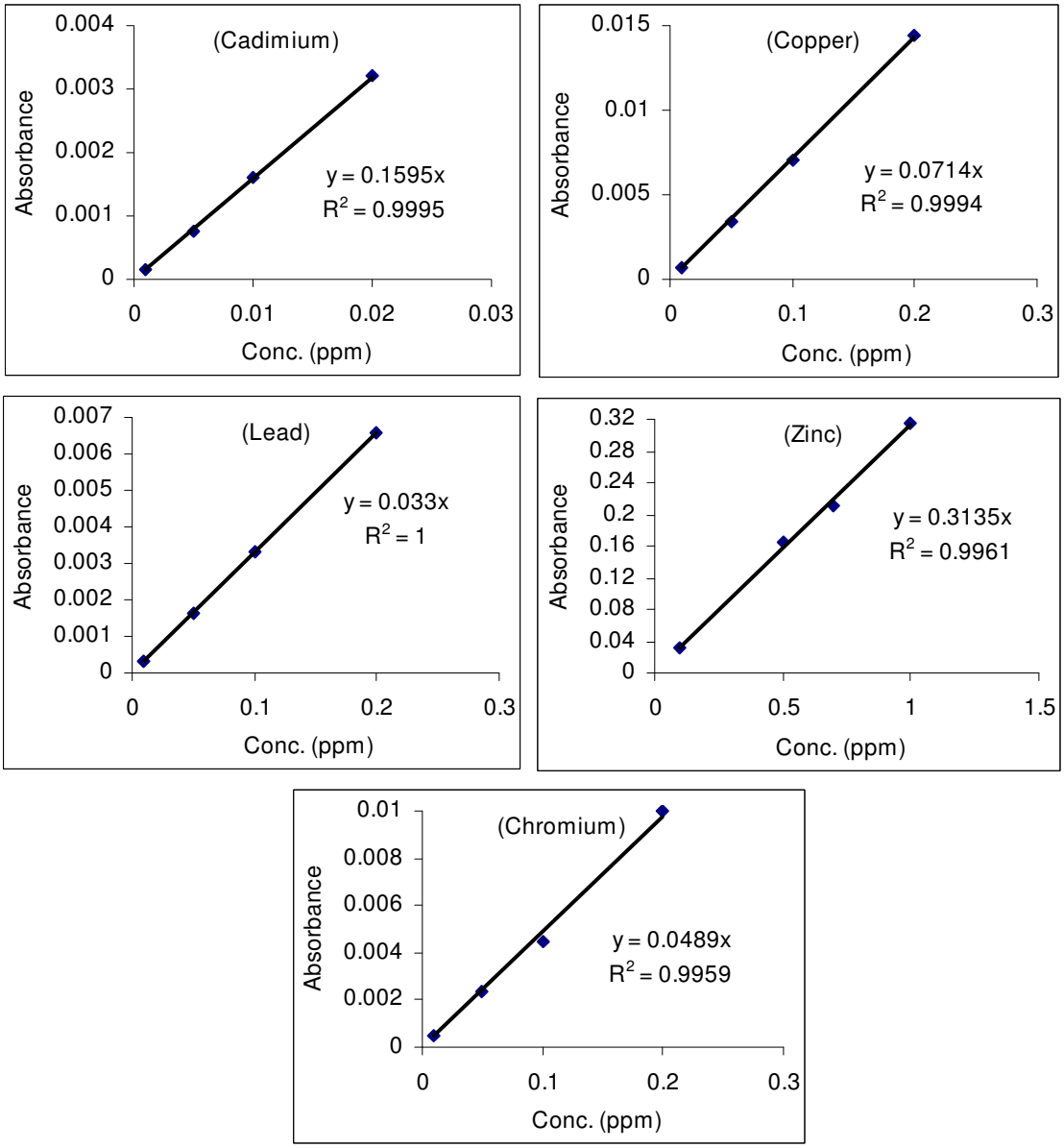

Fig. 4: Calibration curves for the analyzed elements in coral tissues.

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