Advances in Environmental Biology, 11(2) February 2017, Pages: 52-59

AENSI Journals

Advances in Environmental Biology

ISSN-1995-0756 EISSN-1998-1066

Journal home page: http://www.aensiweb.com/AEB/

Effect of Sewage Pollution on Macroalgal Diversity and Heavy Metal Accumulation along Al-Hanyaa Coastline, Libya

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Received 18 December 2016; Accepted 12 February 2017; Available online 26 February 2017

ABSTRACT

Background: Some aquatic organisms can tolerate anthropogenic pollution but others are vulnerable to disappearance. **Objective**: To study the effect of sewage pollution on macroalgal diversity and heavy metal accumulation along Al-Hanyaa coastline, Libya during winter 2014. The seawater content of Cu, Zn, Mn, Pb and Cd as well as algal diversity were investigated at three nearby sites differing in the nature of substratum and load of pollutants. **Results:** The concentrations of these heavy metals in seawater were in general low, with Zn being the most abundant (5.4-7.4 µg l^{-1}) and Cd the least abundant metal (0.02-0.07 µg l^{-1}). Despite of the limited spatial variation in metal concentrations of water the variation in floristic composition was radical. Most of the encountered species were brown and red algae. The preference of heavy metal accumulation differed according to the degree of water pollution and the macroalgal species; with a particular preference of Cu, Zn and Pb by *Corallina elongata*, of Mn by *Jania adhaerens* and of Cd by *Cystoseira corniculata* and *Dictyota dichotoma*. In absolute terms Cd was the least accumulated metal irrespective of site and species but due to its low levels in sea water Cd exhibited a fairly high bioaccumulation factor. *Janin adhaerens* showed unique ability to accumulate heavy metals (having the highest metal pollution index) followed by *C. elongate* and *D. dichotoma*. **Conclusion:** The substratum nature and the pollution status of water substantially affect diversity of macroalgae.

KEYWORDS: Bioaccumulation; Heavy Metal; Pollution; Seaweed

INTRODUCTION

Continuous release of heavy metals from point and non-point sources disrupts the metabolic and physiological activities of aquatic organisms which in turn reflect the prevailing health status of the aquatic ecosystem [1]. Improper treatments of industrial and domestic effluents are the major sources of heavy metals load in water which contribute to the steadily increasing metallic contaminants in aquatic environments all over the world [2]. It has been claimed that biological indices are more reliable than chemical indices for the assessment of environmental pollution. Therefore, macroalgal diversity and density can be used as good indicators for biological monitoring of water pollution [3]. Sewage pollution, for example, has been found to affect the macroalgal diversity and growth. Also, macroalgae can be manipulated as efficient bioindicators of heavy metal pollution in sea water [4], because of their high capacity to bind heavy metals, and hence to concentrate them to several orders of magnitude higher than the ambient water [3 and 5]. The accumulation efficiency of algae for a given metal depends on the affinity of the alga for the metal and the availability of the metal in water. Moreover, the ability of macroalgae to accumulate various substances depends strongly on their morphology and physiology, which can be related to their taxonomical group [6]. For example, the unique ability of brown algae to accumulate several heavy metals such as Pb^{2+}, Cu^{2+}, Cd^{2+} and Zn^{2+} can be related to the predominance of carboxylic groups within the alginate polymer which constitute more than 70% of titratable sites in dried brown algal biomass [7]. In addition to brown algae, red algae have high efficiency for treating industrial effluents [8]. Along the Libyan coast, Al-Hanyaa rocky shore suffers from considerable anthropogenic impacts especially sewage discharge, which largely seepages on the coast, thereby affecting the macroalgal distribution. The present work is geared towards studying the capacity of some macroalgae to accumulate heavy metals in relation to the degree of water pollution at Al-Hanyaa, Libya in a way to characterize the dynamics of macroalgal distribution and their activities under anthropogenic impacts.

MATERIALS AND METHODS

Study area:

The study area included three sites at Al- Hanyaa along the Libyan coast, which are exposed to different degrees of sewage pollution. The nature of substratum at S1 and S3 is rocky but sandy at S2. Based upon the pollution status, site 1 was clean sea water, S3 was exposed to sewer pipes and thus was the most polluted site and site 2 was partially affected by site 3. The location of the three sites is shown in Fig. 1 and their characteristics are presented in Table 1.

Fig. 1: Map of the Libyan coast at Al- Hanyaa, showing the 3 sites of study.

Table 1: General characteristics of the 3 studied sites along Al-Hanyaa coastline, Libya.

Site	Distance from S1 (km)	Pollution status	Source of pollution	Substratum composition
S1	–	Clean site	Non	80% rock + 20% sand
S2	1.2≅	Semi-polluted	Affected by S3	100% sand
S3	1.5≅	Polluted	Sewer pipes	90% rock + 10 sand

Sample collection:

Water was sampled from the sites of study in plastic containers and the predominant algal species were sampled during low tide during winter 2014. Seaweeds were thoroughly cleaned in the field, immersed in sea water of the sampling sites and transported immediately to the laboratory.

Determination of metal content of water and algae:

In the laboratory, the seaweeds were further cleaned by washing under a jet of tap water and rinsed with distilled and de-ionized water. Extraction of mineral content of seaweeds was carried out according to [9]. The sampled algae were dried at 80 ˚C for 48 hours and then grinded into a fine powder prior to analysis. A known weight (0.05-0.1 g) of the powdered material was digested by adding 5 ml of concentrated H_2SO_4 and heated for 15 min at 70–80 °C, cooled to room temperature and 2 ml of concentrated nitric acid was added slowly. The mixture was heated for further 30 minutes, cooled to room temperature where 15 ml of hydrogen peroxide was added and the mixture was heated for two hours at 150 °C. The clear extract was diluted to 100 ml with 2% HNO_3 in a volumetric flask. Concentrations of Zn, Cu, Mn, Cd and Pb in the water samples and in the algal extract were determined using an Analyst 800 graphite furnace Perkin-Elmer atomic absorption spectrophotometer (GF AAS).

Indices of pollution:

Bioaccumulation factor (BAF):

BAF of the studied metals was calculated according to the following formula of [10].

$$\mathrm{BAF} = \frac{\text{Metal concentration } (\mu g\ g^{-1}\ \text{FW}) \text{ in algal biomass}}{\text{Metal concentration } (\mu g\ l^{-1}) \text{ in sea water}}$$

Metal pollution index (MPI):

It was used to compare the total content of heavy metals in algal biomass at different sites [11].

$MPI = (Cf_1 \times Cf_2 \times Cf_3 \ \ldots \times Cf_n)^{1/n}$

Where Cf_1, Cf_2, Cf_3, … Cf_n are the concentrations of metal 1, metal 2 and metal (n) in the sample respectively.

Statistical analysis:

Analysis of variance (ANOVA) and correlation analysis were performed by using the statistical package, SPSS 22 (SPSS, USA). Data were subjected to one-way ANOVA and mean separation was done according to the Duncan's multiple range test at $p \leq 0.05$. The similarity between the studied sites was estimated by performing cluster analysis (Bray-Curtis similarity index).

Results:

Sea water temperature was non-significantly different at the three sites of study and ranged between 20.3°C at S1 and 21.7 °C at S2. The heavy metals concentrations in sea water were low at site 1, moderate at site 2 and relatively high at site 3 (Table 2). Zn was the most abundant metal and also the least variable among the three sites where its concentration varied within a narrow range (5.4–7.4 µg l^{-1}) with a coefficient of variation (CV) of 16%; whereas Cd was the least abundant and the most variable metal (0.02–0.07 µg l^{-1}) with a CV of 66%. The other metals exhibited intermediate concentrations and variability among the three sites with CV of 42%, 29% and 31% for Cu, Mn and Pb respectively.

Pollution specificity of macroalgal species:

The present investigation shows radical diversity in algal species between the three studied sites; where each site exhibited its distinct flora. Four macroalgal species were encountered at the clean site (S1); and these were sorted into 2 phaeophytes (*Cystoseira compressa* and *C. corniculata*) and 2 rhodophytes (*Laurencia papillosa* and *Polysiphonia opaca*). At the semipolluted site (S2), two species dominated, the phaeophyte *Dictyota dichotoma* and the rhodophyte *Corallina elongata*. At the polluted site (S3), 4 macroalgal species prospered: 2 chlorophytes (*Enteromorpha intestinalis* and *Ulva lactuca*), the rhodophyte *Jania adhaerens* and the phaeophyte *Ectocarpus siliculosus* (Table 3). It is worthy to state that *Corallina elongata* formed noticeable blooms and dominated the sandy shallow intertidal zone but grew hardly on the rocky substrate at the semipolluted site (S2).

Table 2: Temperature and heavy metals concentrations (µg l^{-1}) of sea water at the 3 sites of study at Al-Hanyaa, Libya. Each value in the mean of 3 replicates ± SE. Means with common letters are not significantly different at $P \leq 0.05$.

Site	Temp. (°C)	Cu	Zn	Mn	Pb	Cd
S1	20.3 ± 0.06^{a}	0.24 ± 0.01^{a}	5.40 ± 0.12^{a}	0.11 ± 0.01^{a}	0.21 ± 0.01^{a}	0.02 ± 0.006^{ab}
S2	21.7 ± 0.67^{abc}	0.46 ± 0.01^{b}	6.90 ± 0.46^{ab}	0.17 ± 0.02^{ab}	0.33 ± 0.01^{ab}	0.03 ± 0.005^{a}
S3	20.4 ± 0.78^{ab}	0.60 ± 0.06^{c}	7.40 ± 0.17^{bc}	0.20 ± 00.05^{abc}	0.40 ± 0.15^{abc}	0.07 ± 0.008^{c}

Heavy metals concentrations in the macroalgal species:

Table 3 shows that heavy metals were accumulated in the different algal species to different extents. At site 1, *Cyst. compressa* exhibited preferential accumulation of Zn; both of *Cyst. corniculata* and *L. papillosa* showed preferential accumulation of Zn and Cu; while *P. opaca* exhibited preference for Pb and Zn. At site 2, *D. dichotoma* exhibited an outstanding preferential accumulation of Mn while *C. elongata* accumulated Cu preferentially. At site 3, a pattern of particular accumulation of Pb was shared by *E. intestinalis* and *U. lactuca*; but another trend of substantial accumulation of Mn was shared by *J. adhaerens* and *Ect. siliculosus*. In general, Cd was the least accumulated heavy metal irrespective of site and algal species.

Despite of the different patterns of heavy metal accumulation in the different algal species, yet the 4 species of S1 as well as the 2 species of S2 exhibited limited genotypic variability in the total heavy metal load in their tissues; this in contrast to the marked genotypic variability at S3, at which *J. adhaerens* exhibited an accumulation capacity about 4 times that of the three accompanying species. The total heavy metal content was lowest in the four species of the clean site (S1), unexpectedly intermediate in the 4 species of the polluted site (S3) - with the exception of *J. adhaerens* - and highest in the 2 species of the semipolluted site (S2). The genotypic variability in heavy metal accumulation among the species of each site differed according to the heavy metal investigated. Copper, Zn and Pb were accumulated to comparable extents in the 4 algal species of S1 with coefficient of variation (CV) of 13%, 20% and 23% respectively and average concentrations of 18.1, 23.5 and 20.4 µg g^{-1} FW respectively. A relatively greater genotypic variability was found for Mn and Cd with CV of 42% and 84% respectively; where the concentration of Mn in *Cyst. compressa* (19.28 µg g^{-1} FW) was about 2.5 times its concentration in *P. opaca* and the concentration of Cd in *Cyst. corniculata* (5.02 µg g^{-1} FW) was 10 times that of *P. opaca*. At site 2, the concentrations of Cu, Zn and Cd in *C. elongata* were about 2.5 times their concentrations in *D. dichotoma*; while Mn concentration in *D. dichotoma* was about 3 times its concentration in *C. elongate*, with a limited variability (CV of 18.6%) for Pb among the two species.

Table 3: Heavy metals concentrations (µg g^{-1} FW) in the macroalgal species collected from the different sites at Al- Hanyaa, Libya. Each value is the mean of three replicates ± SE. Means with common letters are not significantly different at $P \leq 0.05$.

Site and Species	Cu	Zn	Mn	Pb	Cd
S1 (Clean)					
Cyst. compressa	18.39 ± 5.28^{ab}	30.22 ± 4.13^{a}	19.28 ± 7.03^{a}	23.18 ± 3.97^{ab}	1.03 ± 0.42^{c}
Cyst. corniculata	20.39 ± 1.94^{a}	21.21 ± 2.81^{bc}	10.68 ± 3.35^{b}	17.40 ± 2.81^{bc}	5.02 ± 0.93^{a}
L. papillosa	18.85 ± 3.66^{ab}	19.42 ± 1.99^{bcd}	10.64 ± 2.06^{b}	15.40 ± 3.65^{cd}	4.71 ± 0.74^{ab}
P. opaca	14.60 ± 0.87^{abc}	23.10 ± 0.58^{b}	7.41 ± 2.51^{bc}	25.74 ± 5.71^{a}	0.51 ± 0.20^{cd}
S2 (Semi-polluted)					
D. dichotoma	26.73 ± 2.47^{b}	19.52 ± 0.42^{b}	136.2 ± 11.4^{a}	35.74 ± 12.8^{ab}	3.46 ± 0.58^{a}
C. elongata	72.71 ± 3.90^{a}	47.63 ± 1.65^{a}	47.37 ± 6.78^{b}	46.57 ± 6.87^{a}	1.51 ± 0.54^{b}
S3 (Polluted)					
E. intestinalis	27.29 ± 3.47^{b}	25.12 ± 2.10^{b}	6.40 ± 1.44^{cd}	31.54 ± 5.97^{ab}	1.34 ± 0.39^{c}
U. lactuca	25.73 ± 2.34^{bc}	19.58 ± 0.59^{c}	15.03 ± 4.40^{c}	33.03 ± 2.55^{a}	3.92 ± 1.13^{ab}
J. adhaerens	56.88 ± 3.22^{a}	36.10 ± 2.48^{a}	282.5 ± 13.2^{a}	18.53 ± 0.86^{cd}	4.63 ± 1.36^{a}
Ect. siliculosus	17.85 ± 2.14^{d}	8.320 ± 0.09^{d}	46.16 ± 11.4^{b}	20.02 ± 4.39^{c}	0.77 ± 0.21^{cd}

The genotypic variability in heavy metal accumulation was outmost at the polluted site (3), with a CV of 50% for Cu, Zn and Cd and maximum concentration of the 3 metals in *J. adhaerens* but minimum concentration in *Ect. siliculosus.* Mn exhibited the greatest variability (CV of 150%) with the highest concentration (282.5 µg g^{-1} FW) in *J. adhaerens* and the lowest concentration (6.4 µg g^{-1} FW) in *E. intestinalis* and fairly low levels in *U. lactuca* and *Ect. siliculosus*.

BAF of the different heavy metals - except Mn - showed a common pattern of peaking at site 2, with moderate reduction at S1 and a relatively great reduction at S3. The average BAF of the two species of S2 attained peaks of 108, 124, 124 and 4.26 for Cu, Pb, Cd and Zn respectively and were reduced by 30%, 22%, 24% and 11% respectively below these maxima in the four species of S1 but by 51%, 48%, 68% and 38% respectively below the maxima in the four species of S3. A somewhat different pattern was exhibited by Mn where its BAF at S2 was about 5 times its value at S1 and was slightly further increased at S3. The BAF was lowest for Zn - the most abundant metal in sea water - and averaged around 4.35, 4.86 and 3.01 at S1, S2 and S3 respectively but was highest for the least abundant metals: Mn and Cd and averaged around 110, 543 and 574 at S1, S2 and S3 respectively for Mn and around 94, 124 and 39 at S1, S2 and S3 respectively for Cd.

Table 4: BAFs of the different heavy metals by macroalgal species at the 3 studied sites of Al-Hanyaa rocky shore, Libya.

Site	Species	Cu	Zn	Mn	Pb	Cd
S1	*Cyst. compressa*	76.61	5.60	176.87	110.37	34.44
	Cyst. corniculata	84.98	3.93	97.97	82.84	167.25
	L. papillosa	78.56	3.60	97.59	73.32	156.91
	P. opaca	60.97	4.28	67.96	122.58	17.09
S2	*D. dichotoma*	58.11	2.83	805.75	108.30	172.79
	C. elongata	158.06	6.90	280.30	141.11	75.73
S3	*E. intestinalis*	45.48	3.39	32.65	78.86	19.08
	U. lactuca	42.88	2.65	76.67	82.57	56.02
	J. adhaerens	94.81	4.88	1951.57	46.34	70.88
	Ect. siliculosus	29.76	1.12	235.53	50.04	11.01

Nevertheless, despite the common pattern of low BAF for Zn and the high BAF for Mn there was genotypic variability in metal uptake preference. For example, at S1 preferential accumulation of the xenobiotic heavy metals: Cd by both *Cyst. corniculata* and *L. papillosa* and Pb by *P. opaca* was observed where their BAF exceeded that of Mn. Similarly, at S3 *E. intestinalis* and *U. lactuca* showed higher BAF for Pb than for Cu and Mn. At S3, *J. adhaerens* showed the highest ability to accumulate Cu, Zn, Mn and Cd compared with the 3 species associating it but the least ability to accumulate Pb which was accumulated to the greatest extent by *U. lactuca*. At S2, *C. elongata* accumulated Cu, Zn and Pb to a greater extent than its associate species *D. dichotoma* while the reverse was turn for Mn and Cd.

The average MPI was highest (25.1) for the two species inhabiting S2, intermediate (17.9) for the 4 species of S3 and least (11.4) for the 4 species of S1 (Fig. 2). The average MPI was highest (25.1) for the two species inhabiting S2 with a limited genotypic variability (CV = 3.7%), lowest (11.4) for the four species of S1 with moderate genotypic variability (CV = 20%) and intermediate (17.9) for the four species of S3 with the greatest genotypic variability (CV = 64%); where *J. adhaerens* showed the highest MPI (34.62) and *Ect. siliculocus* the second smallest MPI (10) among all the investigated species.

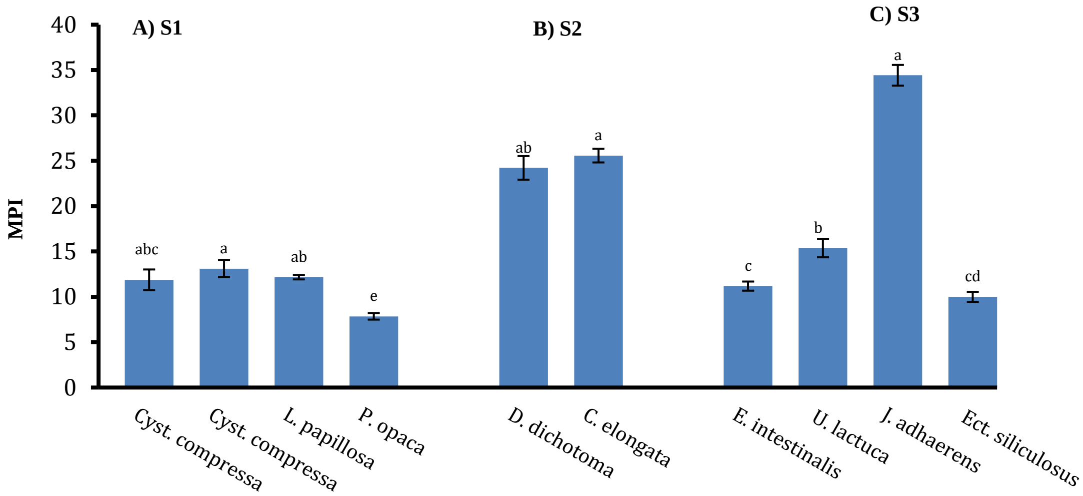

Fig. 2: MPI of macroalgal species in the 3 studied sites of Al-Hanyaa rocky shore, Libya.

Based on the Bray-Curtis similarity index (SI), the encountered algal species can be classified into six groups: A- F (Fig. 3). At S1, *Cyst. corniculata* and *L. papillosa* formed a homogenous group (C) with the closest similarity (≅ 95%), followed by *E. intestinalis* and *U. lactuca* (group B) with a fairly high SI of ≅ 88 % and *Cyst. compressa* and *P. opaca* (group A) with an SI of 83 %. At S2, *D. dichotoma* and *C. elongata* (group D) exhibited a moderate similarity index of 53%. Despite *J. adhaerens* and *Ect. siliculosus* inhabited the same site (S3), they had the lowest similarity with each other as well as with the other algal groups in accumulating heavy metals; therefore they were separated into distinct groups (E and F respectively). However, *Ect. siliculosus* had a similarity index of 65% with groups A, B and C. Group E is clearly distinct from the other groups by dissimilarity of ≅ 68 %. Generally, groups A, B and C had the highest similarity irrespective of pollution status of water in their habitats, followed by groups F, D and E.

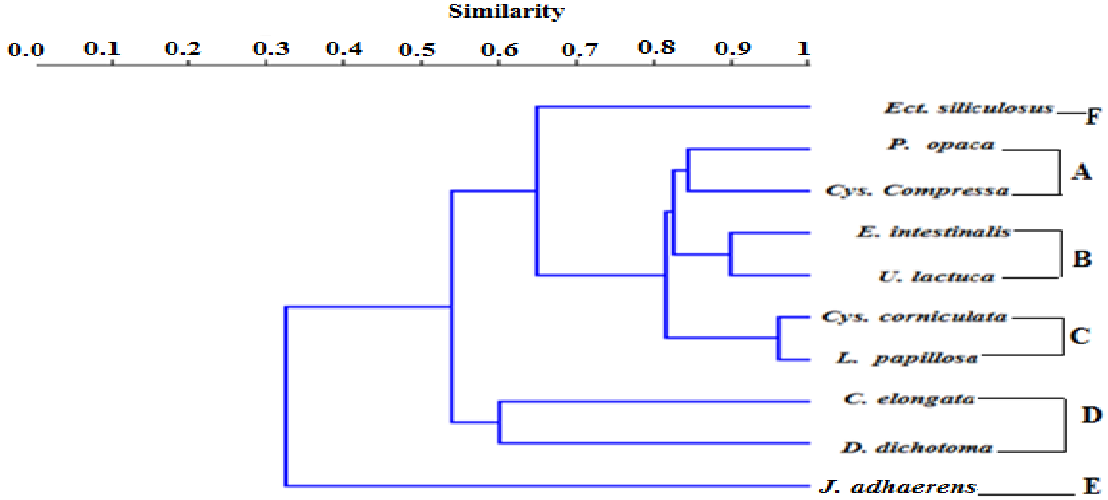

Fig. 3: Cluster analysis showing similarity in heavy metal accumulation between different algal species.

Discussion:

In recent years marine water pollution by untreated sewage discharge impacts water quality and the coastal community [12]. Despite of the discharge of wastes in sea water, the heavy metal levels in sea water recorded in the present work were in general lower than those reported by [13] in the northern delta lakes of Egypt as well as the standard limits of [14]. This might point to the rural nature of the study area and could be further attributed to transfer of heavy metals from the water column to the underlying substratum through adsorption onto suspended particles which are subsequently deposited in the form of fine-granulated sediment [15]. Despite the overall low heavy metal concentration in sea water, Zn was the most abundant metal and the least variable among sites whereas Cd was the least abundant and the most variable metal. In this regard, [14] reported that Zn was the dominant heavy metal in sea water but Cd was the second rare element after Cu.

The radical differences in floristic composition among the three sites of the present study is in agreement with [16] and [4] who reported differences in algal composition of sea water according to pollution status and suggested that the correlation between the macroalgae flourishing at a specific site and the pollution status of water may point to their specificity in pollution tolerance/preference. The floristic composition of the polluted site (S3) is in partial agreement with the findings of [17] who recorded that organic pollution increases density and number of tolerant species but reduces certain species. Therefore, the biodiversity of aquatic ecosystems and the presence or absence of specific macroalgal species can be used as a reliable indicator for assessment of the quality of sea water. Furthermore, the radical variation in algal species among the studied sites along with the relatively limited variation in chemical composition of sea water is in agreement with the conclusion of [3] that biological indices are more reliable than chemical indices for the assessment of environmental pollution.

Thriving of C. *elongata* at S2, a site characterized with sandy sediment and relatively calm shallow sewage-polluted water means that this species can tolerate high levels of organic pollution and agrees with the findings of [18] that C. *elongata* can inhibit the growth of coliform bacteria such as *Escherichia coli* and *Enterococcus faecalis.* The probability exists also that *C. elongata* benefits from microbial growth in the sewage-contaminated water. The association between algae and their surface-bound bacteria can contribute potentially to heavy metal accumulation and tolerance by algae [19]. The suitability of *C. elongata*, as a prospective sentinel for heavy metal pollution, evaluates it as a promising bioindicator and as a phyto-bioremediation agent for sea water [20].

The present results reveal dominance of brown and red algae at the sites of study. The unique accumulation efficiency and tolerance to heavy metals can be attributed to the high content of alginate and fucoidan in the cell walls of brown algae and of sulfated polysaccharides in red algae, for which heavy metals show a strong affinity [21]. The high content of these matrix-imbedded amorphous polysaccharides contribute to the ability of these algae to bind heavy metals and evaluates them as potentially excellent heavy metal bio-sorbents [22].

The radical differences in floristic composition of the different sites points to substantial genotypic variability in pollution tolerance. The dominance of two *Cystoseira* species at the clean site (S1) and of *Ulva lactuca* at the polluted site (S3) is in agreement with [23] who reported that some species of *Cystoseira* are very sensitive to urban pollution; while *Ulva* spp. are pollution-tolerant. The overall lower content of Cd in algal biomass may be attributed to the lower input of Cd in sea water at the studied sites and to lower algal affinity for Cd uptake. The interaction between Cd and the chemical groups in algal cells can be accomplished through several processes such as ion exchange, surface complex formation, micro precipitation, chelation, and coordination, which may be related to the nature and content of sulfated polysaccharide or carboxyl groups and represent the selection criteria for determining the extent of accumulation of heavy metals [16]. The preferential accumulation of Mn by *J. adhaerens*, *Ect. siliculosus* and *D. dichotoma* is in agreement with the findings of [6] who claimed that red algae exhibit a preferential uptake of Mn relative to other heavy metals.

According to [24], the state of conservation of an ecosystem or the choice to monitor its state can be evaluated using the bioaccumulation factors (BAFs) of the living organisms for heavy metals. BAFs for algal species are meaningful to compare their capability for metal accumulation regardless of the differences in metal concentration between the different sites. BAF of the investigated metals -except Mn- showed a common pattern of peaking at site 2, with moderate reduction at S1 and relatively great reduction at S3. This pattern of relationship between BAF and site (in fact, the heavy metal concentration of water) suggests that uptake of the investigated heavy metals is performed via saturation kinetics where the increase in metal concentration of water from S1 to S2 lies within the linear phase of uptake and is, therefore, corresponded by an increase in uptake efficiency; but the further rise in metal concentration at S3 seems to lie within the saturation phase and therefore did not yield proportional increase in uptake efficiency. By contrast, the progressive rise in BAF of Mn form S1 through S2 up to S3 suggests that the levels of Mn in sea water at the sites of study involving the polluted site (S3) are within the linear phase of uptake. In support to this postulation, the levels of heavy metals at the sites of study are lower than those reported by [13] in the northern delta lakes of Egypt as well as the standard limits of EPA [14]. These low levels of heavy metals in water necessitate selective high affinity transport (saturable) uptake systems [25]. Furthermore, the overall low BAF for Zn and the overall high BAF for Mn irrespective of site and algal species along with the high levels of Zn and low levels of Mn in sea water might mean that the high and less variable post-optimal levels of Zn yield low BAF while the suboptimal and increasing levels of Mn through the three sites can lead to proportional increase in BAF.

The genotypic variability in accumulation of heavy metals emerges more clearly when considering BAF. BAFs for algal species inhabiting the clean site (S1) show that *Cyst. compressa* is particularly efficient in accumulating Mn, *L. papillosa* in accumulating Cd, *P. opaca* in accumulating Pb and *Cyst. corniculata* in accumulating Cu. At the semipolluted site (S2), *D. dichotoma* showed preferential accumulation for Mn and Cd while *C. elongata* accumulated Cu, Pb and Zn preferentially. At the polluted site (S3), *J. adhaerens* exhibited distinctly high BAF (the highest BAF for Mn, Cu, Cd and Zn) whereas *U. lactuca* showed the highest BAF for Pb. The potentiality of organisms to accumulate heavy metals has been claimed to be significant when BAF exceeds 100 or more but non-significant when it is less than unity [26]. BAF of Mn, Cd and Pb were higher than 100 for most algal species of the present study which point to the high aptitude of the investigated species as bioaccumulators.

Metal pollution index (MPI) can be used to compare the average heavy metal content of different algal species within the same site or among different sites. The ability to accumulate heavy metals was highest in *J. adhaerens* which was substantially higher than those of the accompanying species at S3 and slightly higher than those of the two species at S2 (*D. dichotoma* and *C. elongata*). This points to a marked genotypic variability in heavy metal accumulation and agrees with the findings of [5] who reported that some macroalgae can concentrate heavy metals in their tissues to several times higher than those in the ambient water.

The variation in the capacity of algal species to accumulate heavy metals may be expressed also in terms of the similarity index. This genotypic variability may be attributed to the difference among algal species in morphology and physiology which are largely related to their taxonomical groups [6]. Generally, metal affinity can be related to the nature of the parietal polysaccharides and their content of sulphate and carboxyl groups which are involved in ionic exchange and metal sequestration [16].

Although *E. intestinalis* and *U. lactuca* (group B) inhabited S3, they showed close (80%) similarity to the members of group A (*Cyst. compressa* and *P. opaca*) and group C (*Cyst. corniculata* and *L. papillosa*) inhabiting S1. Also, *Ect. siliculosus* (group F) inhabiting S3 showed 65% similarity to the species of the groups A and C inhabiting S1. This may suggest that the similar nature of substratum at S1 and S3 (both are rocky) rather than the status of water pollution is the controlling factor in determination of algal distribution. This is in agreement with the findings of [27] who concluded that the nature of substrate along with the extent of pollution may be major modifiers of algal diversity and distribution.

Conclusion:

Despite of the generally low levels of the heavy metals: Cu, Zn, Mn, Pb and Cd in sea water and the rural nature of the study area, Zn was the most abundant metal whereas Cd was the least abundant one. The radical variation in floristic composition among the studied sites along with the limited variation in heavy metal composition of sea water justifies the use of biological indices rather than chemical indices as criteria for assessment of environmental pollution. The dominance of brown and red algae at the sites of study points to their ability to tolerate heavy metal pollution. Among the investigated algal species *J. adhaerens* expressed the greatest capability to accumulate heavy metals. The substratum nature as well as the pollution status of water are important factors affecting the diversity of macroalgae.

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