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Neutron Activation Analyses Used to Study Elemental Accumulation in Some Marine Macrophytes (Mediterranean Sea Coast of Egypt)

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Abstract

The concentrations of Na, Mg, Al, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Zn, As, Se Br, Rb, Sr, Zr, Mo, Ag, Sb, I, Cs, Ba, La, Sm, Eu, Tb, Yb, Hf, Ta, W, Au, Th and U in 6 types of marine macrophytes (algae and seagrass): *Gelidium pusillum* (Stackhouse) Le Jolis, *Ulva intestinalis* Linnaeus, *Amphiroa rigida* J.V. Lamouroux, *Hypnea* sp., *Cystoseira* sp. and *Posidonia oceanica* (L.) Delile (seagrass) collected from 3 stations along the Mediterranean Sea coast of Egypt were determined using instrumental neutron activation analysis. The contents of elements in marine macrophytes indicated that they accumulated elements at different levels depending on their type of species (brown, red, green and seagrass) and the ambient water conditions. However, the concentrations of Cr, Co, Ni, Se, Zr, Mo, Ag, Cs, La, Sm, Eu, Yb, Hf, Ta, Au and U were very similar in all samples. In general the levels of classically investigated elements, particularly Mn, Fe, Co, Ni and Zn determined in the macrophytes in the present study are lower or within the wide range of values previously reported for species of these genera sampled along the Egyptian Mediterranean coast.

Keywords

Algae and Seagrass, Elemental Analysis Mediterranean Sea, Neutron Activation Analysis

1. Introduction

With an estimated population of 132 million inhabitants that increases sharply during the summer tourist season, the Mediterranean coast, including its Egyptian part, is particularly subject to strong human pressure [1]. The western part of the Nile Delta Coast (Abu Qir Bay), which is polluted by industrial wastes from 22 different factories including food processing and canning, paper industry, fertilizer industry and textile manufacturing, is considered as hot spot area [2] [3]. Pollution of the marine environment with trace elements (TEs) remains a topical subject because some of these elements, not frequently monitored up to now (e.g. Sb, Mo, etc.) can be considered as environmental pollutants of "emerging concern" [4]. The monitoring of marine pollution using different bioindicator species provides several advantages [5] [6] when compared with chemical analysis of environmental matrices (*i.e.* water and sediments). A wide variety of species have been shown to be relevant indicators to assess the contamination status of marine ecosystems, where different species of seagrass and macroalgae are among the most used in the Mediterranean [4] [7].

During the last decades numerous studies have been carried out concerning trace element accumulation in marine macrophytes sampled along the Mediterranean coast of Egypt. However, data are mostly available for species of a few genera such as Ulva, and only a small number of elements, mainly Cd, Cu, Cr, Mn, Co, Ni, Pb and [2] [3] [8] [9] [10]. References concerning widespread macroalgae that could potentially be used as biomonitors and levels of the majority of elements are scarce. To extend the list of potential biomonitors in the study area and add data about accumulation of a wide range of elements, including major and rare earth elements, the aim of this work was to evaluate the concentrations of up to 39 elements in 6 species of macrophytes sampled in the coastal waters of Egypt (Mediterranean Sea) using neutron activation analysis (NAA).

2. Materials and Methods

2.1. Study Area

The samples were collected during summer 2015 in the coastal waters of the city of Alexandria and Marsa Matrouh city which are both situated on the Mediterranean coast of Egypt and are considered the main two cities and industrial zones on the north coast of Egypt. The sampling sites are presented in **Figure 1**. The first sampling site is located at Cleopatra beach, Marsa Matrouh city (31˚22'29.0"N, 27˚11'23.0"E). It is characterized by big anthropogenic loading during summer period when the number of visitors to Marsa Matrouh may reach more than one million [10]. The second and third sampling sites are adjacent to Alexandria, the second largest city in Egypt and a major economic center, extending about 32 km to the north west of Nile Delta stretching over 70 km along the coast [11]. Alexandria's environmental problems have grown in severity as its population and associated urban and industrial development have increased since the beginning of the 20th century [12]. The second sampling site is located at Citadel beach (31˚12'49.6"N, 29˚53'01.1"E), about 4 km from Alexandria port, which is considered the main port in Egypt. Alexandria Port receives many types of containers (e.g., cement, coal, fertilizers, grain and flour, oil and oil

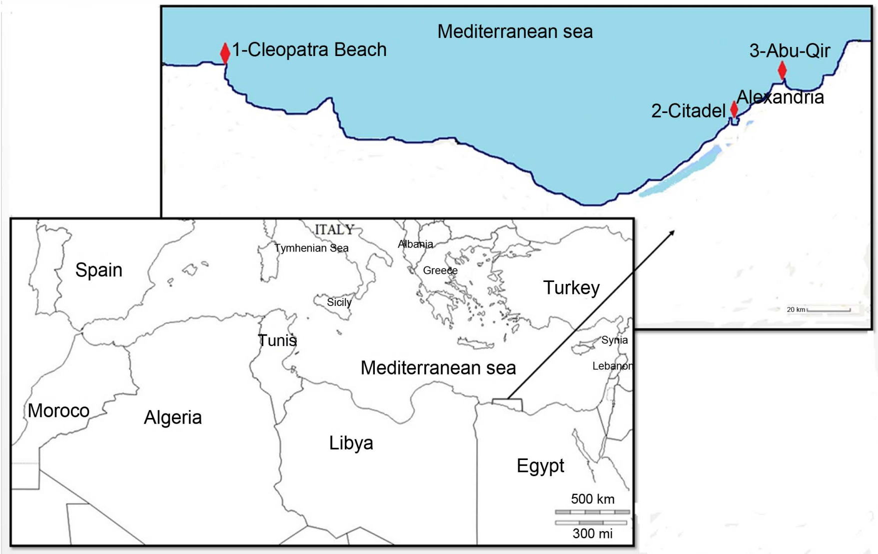

Figure 1. Sampling locations on the Mediterranean Sea in the north coast of Egypt.

products) *(http://www.apa.gov.eg/)* and it is affected by fishing and hatching activities [9]. The third sampling site is located at Abu-Qir bay (31˚19'40.4"N, 30˚03'45.0"E) Abu Qir Bay is situated along the southeastern coast of Alexandria and is considered as a strongly contaminated area. It is subjected to several land-based sources, such as freshwater from the Rosetta mouth of the Nile River loaded by nutrients, Lake Edku effluent carrying heavy metals, pesticides, humic acids, and nutrients; and El-Tabia Pumping Station (TPS) contributing industrial and domestic wastes. The estimated amount of untreated sewage and industrial wastes from 22 different factories pumped to Abu-Qir Bay through TPS is of about 2 million m^3/day. The bay is also exposed to oil pollution from fishing boats, the activities of gas production liquefying and export field [3] [13] [14].

2.2. Sampling and Sample Preparation

The samples that were found attached to rocks were collected at 3 station (1-st – *Cystoseira* sp. and *Posidonia oceanica*; 2-nd-*Gelidium pusillum;* 3-d-*Hypnea* sp., *Ulva intestinalis*, *Amphiroa rigida)* by hand on the depth 0.5 to 1.5 m, rinsed with ambient water and cleaned from epiphytes, then kept in a polyethylene bags and transferred to the laboratory in an ice-box. In the laboratory samples were rinsed with distilled water [7] and dried till constant weight at 40˚C during 24 hours then manually homogenized in agate mortar [15].

2.3. Analysis

Neutron activation analysis was performed in the radioanalytical laboratory at the pulsed fast reactor IBR-2 of the Frank Laboratory of Neutron Physics, JINR, Dubna, Russia [16]. For short irradiation samples of about 0.3 g were heat-sealed in polyethylene bags. For long irradiation samples of the same weight (about 0.3 g) were packed in aluminium cups. To determine the short lived isotopes (Al, S, Cl, Ca, Ti, V, Mn, Mg, and I) conventional irradiation channel was used. Samples were irradiated for 3 min and measured twice after 2 - 3 min and the second one for 20 min after 9 - 10 min of decay. Long-lived isotopes were determined using epithermal neutrons in cadmium-screened irradiation channel with neutron flux density Φepi. = 3.6×10^{12} n/(cm^2·s). Samples were irradiated for 5 d, repacked and then measured twice after 4 - 6 and 20 d of decay, respectively. Measuring time varied from 1 to 5 h. To process gamma spectra and to calculate concentrations of elements in the samples, software was used that was developed at FLNP JINR [17]. The errors in the determined concentrations were in the range of 5% - 15% and 30% or greater for those elements (e.g. Zr, Mo, Ag, Au) which concentrations in the samples were at the level of detection. Quality control was ensured by simultaneous analysis of the examined samples and standard reference materials SRM 1632c (trace elements in coal, National Institute of Standard and Technology (NIST)), SRM 1633b (constituent elements in coal fly ash, NIST), 1547 (peach leaves, NIST), 690CC (calcareous soil, Food and Agriculture Organization of the United Nations), 1573a (tomato leaves, NIST), SRM 433 (marine sediments, International Atomic Energy Agency) and BCR 667 (estuarine sediment, Institute for Reference Materials and Measurements) irradiated in the same conditions together with the samples under investigation. The NAA data and certfied values of reference materials are given in **Table 1**.

3. Results and Discussion

For all collected samples the concentrations of Na, Mg, Al, S, Cl, K, Ca, Sc, V, Mn, Fe, Co, Ni, Zn, As, Se Br, Rb, Sr, Ag, Sb, I, Cs, Ba, Ta, Th, and U were determined while the content of Ti, Cr, Zr, Mo, La, Sm, Eu, Tb, Yb, Hf, W and Au in some species was below the level of detection (**Table 2**).

The concentration of major elements varied in a wide range depending on the species of macrophytes (from 1635 mg/kg for K in *Posidonia oceanica* to 246,500 mg/kg for Ca in *Amphiroa rigida*). The highest concentration of Na and S were found in *Hypnea* sp., while the maximum values of Cl and Ca were determined in *Ulva intestinalis* and *Amphiroa rigida*, respectively. The concentration of Mg varied in a more narrow range, and their minimum and maximum contents differ in the samples by up to eight times. The results obtained for some trace elements varied in a wide range depending on the species of analyzed macrophyte (from 0.002 mg/kg for Tb in *Hypnea* sp. to 2100 mg/kg for Sr in *Amphiroa rigida* while the concentrations of Cr, Co, Ni, Se, Zr, Mo, Ag, Cs, La, Sm, Eu, Yb, Hf, Ta, Au and U were very similar in all samples (**Figure 2**).

The concentration of elements in the samples collected at the same station (Abo-Qir bay) are varied greatly too. Thus the content of Na, S, Cl, Ca and Sr in *Hypnea* sp., *Ulva intestinalis* and *Amphiroa rigida* differ by more than 10 times, Mg, Ba, Tb and Th differ by up to 10 times. Nevertheless, the levels of such elements as Sc, Ti, V, Cr, Fe, Co, Ni, Zn, Se, Zr, Mo, Ag, Sb, I, Cs, La, Sm, Hf, Ta, Au and U are very similar in *Hypnea* sp., *Ulva intestinalis* and *Amphiroa rigida* and differ by up to 3 times. The accumulation rate of major and trace elements

Table 1. Analysis of certified reference materials: certified and determined values, standard deviation.

Element	Determined concentration, μg × g^{-1} dry weight	Certified concentration, μg × g^{-1} dry weight	Standard deviation, %	SRM
Na	300	298.8	0.4	1632c
Mg	4326	4320	0.1	1547
Al	9143	9150	0.1	1632c
S	13498	14620	7.7	1632c
Cl	590	600	1.67	1573a
K	27045	27000	0.2	1573a
Ca	15637	15600	0.2	1547
Sc	14.64	14.6	0.2	433
Ti	518	517	0.3	1632c
V	23.7	23.72	0.1	1632c
Cr	154	136	14	433
Mn	132	131.8	0.2	1633b
Fe	74492	77800	4.3	1633b
Co	12.8	12.9	0.1	433
Ni	39.3	39.4	0.1	433
Zn	202	210	3.7	1633b
As	18.92	18.9	0.1	433
Se	10.3	10.26	0.4	1633b
Br	17.1	18.7	8.5	1632c
Rb	98.9	99.9	1.0	433
Sr	301.6	302	0.1	433
Zr	140	148	5.4	433
Mo	0.43	0.46	6.5	1573a
Ag	0.131	0.133	0.7	433
Sb	1.95	1.96	0.1	433
I	0.29	0.3	3.2	1547
Cs	10.2	11	6.8	1633b
Ba	67.56	67.5	0.1	1632c
La	30.6	33.6	9.2	433
Ce	168	190	11.5	1633b
Sm	1.082	1.078	0.4	1632c
Eu	1.34	1.18	13.7	433
Tb	0.65	0.7	6	433
Yb	1.56	1.57	0.6	690cc
Hf	3.82	3.66	4.6	433
Ta	1.79	1.8	0.1	1633b
W	0.481	0.480	0.2	1632c
Au	0.015	0.016	6.3	667
Th	9.77	9.78	0.1	433
U	0.512	0.513	0.1	1632c

Table 2. Concentrations of elements (mean ± standard error, in $\mu g \cdot g^{-1}$ dry weight) in marine macrophytes (the Mediterranean coast of Egypt).

Type of algae	Phylum	Na mg/kg	Mg mg/kg	Al mg/kg	S mg/kg	Cl mg/kg	K mg/kg	Ca mg/kg	Sc mg/kg	Ti mg/kg	V mg/kg	Cr mg/kg
Gelidium pusillum	Rhodophyta	30,400 ± 600	9000 ± 200	72.7 ± 7.0	82,600 ± 21,200	58,300 ± 4400	42,300 ± 3900	5000 ± 400	0.010 ± 0.003	73 ± 37	3.7 ± 0.3	3.28 ± 0.94
Hypnea	Rhodophyta	81,800 ± 1700	5700 ± 200	157.0 ± 9.0	125,000 ± 32,300	87,100 ± 6500	23,300 ± 2300	5800 ± 450	0.040 ± 0.010	100 ± 54	2.0 ± 0.3	0.99 ± 0.56
Ulva Intestinalis	Chlorophyta	50,000 ± 1000	28,400 ± 700	483.0 ± 14.0	66,500 ± 17,400	118,000 ± 8900	28,200 ± 2600	8400 ± 600	0.090 ± 0.010		3.6 ± 0.3	
Amphiroa rigida	Rhodophyta	5400 ± 100	42,000 ± 1000	678.0 ± 17.0	7000 ± 3300	7900 ± 600	6200 ± 600	246,500 ± 16,300	0.100 ± 0.010	110 ± 21	3.7 ± 0.2	1.52 ± 0.66
Cystoseira sp.	Ochrophyta	10,500 ± 200	10,200 ± 200	83.2 ± 3.0	28,700 ± 7600	29,500 ± 2200	46,700 ± 3700	19,000 ± 1300	0.030 ± 0.010		13.2 ± 0.5	1.59 ± 0.50
Posidonia oceanica	Tracheophyta	16,400 ± 300	5700 ± 150	431.0 ± 11.0	11,900 ± 4100	36,400 ± 2700	1600 ± 900	14,250 ± 1000	0.140 ± 0.020	40 ± 24	1.4 ± 0.1	3.34 ± 0.39

Type of algae	Phylum	Mn mg/kg	Fe mg/kg	Co mg/kg	Ni mg/kg	Zn mg/kg	As mg/kg	Se mg/kg	Br mg/kg	Rb mg/kg	Sr mg/kg	Zr mg/kg
Gelidium pusillum	Rhodophyta	18.5 ± 1.4	203 ± 15	0.23 ± 0.01	2.31 ± 0.24	18.30 ± 0.60	8.09 ± 0.22	0.47 ± 0.03	980 ± 117	17.8 ± 3.3	146 ± 9	
Hypnea	Rhodophyta	13.2 ± 1.6	165 ± 13	0.20 ± 0.01	0.89 ± 0.19	9.87 ± 0.37	5.75 ± 0.19	0.13 ± 0.08	906 ± 108	11.4 ± 2.1	43 ± 3	
Ulva intestinalis	Chlorophyta	24.5 ± 1.0	533 ± 32	0.22 ± 0.01	1.74 ± 0.21	11.80 ± 0.40	8.58 ± 0.45	0.19 ± 0.03	890 ± 106	8.5 ± 1.6	11 ± 7	2.74 ± 1.09
Amphiroa rigida	Chlorophyta	48.6 ± 2.3	292 ± 18	0.28 ± 0.01	0.85 ± 0.13	19.70 ± 0.60	2.09 ± 0.06	0.11 ± 0.04	200 ± 24	2.7 ± 0.5	2100 ± 129	3.90 ± 1.28
Cystoseira sp.	Ochrophyta	5.4 ± 0.7	72 ± 9	0.19 ± 0.01	1.26 ± 0.19	65.00 ± 1.70	45.90 ± 0.90	0.10 ± 0.03	455 ± 54	16.9 ± 3.1	1505 ± 93	3.53 ± 1.27
Posidonia oceanica	Tracheophyta	11.3 ± 1.0	437 ± 23	0.27 ± 0.01	2.22 ± 0.18	2.07 ± 0.17	3.22 ± 0.13	0.56 ± 0.03	412 ± 50	0.7 ± 0.1	345 ± 21	3.27 ± 1.13

Type of algae	Phylum	Mo mg/kg	Ag mg/kg	Sb mg/kg	I mg/kg	Cs mg/kg	Ba mg/kg	La mg/kg	Ce mg/kg	Sm mg/kg	Eu mg/kg	Tb mg/kg
Gelidium pusillum	Rhodophyta		0.140 ± 0.000	0.050 ± 0.003	112 ± 16	0.020 ± 0.002	4.20 ± 0.52					
Hypnea	Rhodophyta		0.020 ± 0.010	0.030 ± 0.002	88 ± 13	0.010 ± 0.002	1.85 ± 0.42	0.13 ± 0.10		0.05 ± 0.03		0.002 ± 0.001
Ulva intestinalis	Chlorophyta	1.04 ± 0.49	0.010 ± 0.002	0.030 ± 0.002	41 ± 6	0.030 ± 0.002	5.04 ± 0.63					
Amphiroa rigida	Chlorophyta	0.60 ± 0.20	0.050 ± 0.002	0.010 ± 0.002	68 ± 10	0.020 ± 0.002	13.20 ± 0.70	0.37 ± 0.04	5.72 ± 0.69	0.09 ± 0.01	0.03 ± 0.02	0.010 ± 0.002
Cystoseira sp.	Ochrophyta	1.48 ± 0.94	0.010 ± 0.003	0.090 ± 0.010	140 ± 21	0.020 ± 0.002	29.50 ± 2.00	0.17 ± 0.06				
Posidonia oceanica	Tracheophyta	0.63 ± 0.39	0.013 ± 0.004	0.552 ± 0.0164	819 ± 120	0.020 ± 0.002	2.42 ± 0.28	0.27 ± 0.13	4.13 ± 0.61	0.05 ± 0.02	0.03 ± 0.02	0.010 ± 0.020

Type of algae	Phylum	Yb mg/kg	Hf mg/kg	Ta mg/kg	W mg/kg	Au mg/kg	Th mg/kg	U mg/kg
Gelidium pusillum	Rhodophyta			0.010 ± 0.002	3.68 ± 1.25	0.010 ± 0.004	0.010 ± 0.002	0.31 ± 0.10
Hypnea	Rhodophyta			0.003 ± 0.001		0.010 ± 0.003	0.010 ± 0.004	0.23 ± 0.07
Ulva intestinalis	Chlorophyta		0.05 ± 0.02	0.010 ± 0.002		0.010 ± 0.004	0.030 ± 0.002	0.25 ± 0.06
Amphiroa rigida	Chlorophyta	0.04 ± 0.01	0.05 ± 0.01	0.010 ± 0.002			0.050 ± 0.004	0.28 ± 0.02
Cystoseira sp.	Ochrophyta		0.04 ± 0.01	0.010 ± 0.002			0.020 ± 0.002	0.76 ± 0.05
Posidonia oceanica	Tracheophyta	0.08 ± 0.05	0.07 ± 0.02	0.010 ± 0.002	1.68 ± 0.63		0.080 ± 0.004	0.82 ± 0.05

by marine macrophytes depends on many factors, where the taxonomic identity of the plant and concentration of elements in the ambient environment are among the most important ones. The collected marine macrophytes represent three algal classes and seagrass species: Chlorophyceae (*Ulva intestinalis*), Rhodophyceae (*Gelidium pussilum*, *Amphiroa rigida*, *Hypnea* sp.), Phaeophyceae (*Cystoseira* sp.) and Tracheophyta (*Posidonia oceanica*).

The maximum values of Cl and Fe and the lowest content of I are found in *Ulva intestinalis.* Our levels of Na, K and Ca are 2 - 3 higher than the data reported by El-Said (2013) for *Ulva lactuca* collected from Abo-Qir bay, Egypt.

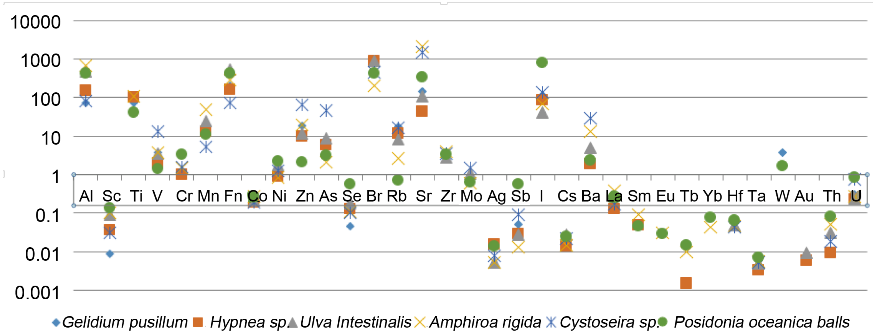

Figure 2. Concentration of trace elements in mg/kg dry weight in marine algae and seagrass collected from the Mediterranean coast of Egypt.

Our levels of Mn in *Ulva intestinalis* are 2 - 2.5 times higher than the data of other authors, while the content of Fe, Co, Ni and Zn is up to 10 times lower than the concentrations reported for the species of *Ulva* collected along the Mediterranean coast of Egypt (**Table 3**).

Gelidium pussilum is characterized by the highest levels of Ni, Br and Rb and the lowest values of Al, Ca and Sc. The contents of Na (21,000 μg/g), Ni, and Zn (**Table 3**) reported by Shams El Din and El-Sherif (2012) [18] for *Gelidium corneum* sampled along the western coast of Alexandria are similar to our data, while the concentrations of K (2700 μg/g) and Ca (26,000 μg/g) are an order of magnitude lower and higher, respectively, than our results.

Hypnea sp. is characterized by the highest contents of Na and S and the lowest levels of Cr, Sr, La, Ta, and Tb. Our results obtained for major elements (except for Ca) are 2 - 3 times higher than the data reported by El-Said (2013) [9] for *Hypnea musciformis* collected from Abo-Quir bay, Egypt. The determined concentrations of Fe and As in *Hypnea* sp. are in agreement with the reported data for species of Mediterranean *Hypnea*, while in most cases our contents of Co, Ni, and Zn are one order of magnitude lower than the results of other authors (**Table 3**).

Amphiroa rigida is characterized by the highest levels of Mg, Al, Ca, Ti, Mn, Sr, La and Sm and the lowest values of Na, S, Cl, Ni, As, Br, Mo and Sb. The results obtained for Na and K are in agreement with the data reported by El-Said (2013) [9] for the species of the same family Corallinaceae (*Jania rubens*) collected from Abo-Quir bay, while our levels of Mg and Ca are 10 and 100 times higher, respectively, than the data of the same author. The content of Mn, Fe and Zn are similar to the values reported by other authors for *Jania rubens* sampled along the Mediterranean coast of Egypt. Our levels of Co and Ni are up to one order of magnitude lower than the literature data (**Table 3**).

The maximum values of K, V, Zn, As, Mo and Ba and the lowest contents of Mn and Fe are found in *Cystoseira* sp. our concentrations of Na and Ca are in agreement with the data reported by Shams El Din and El-Sherif (2012) [18] for *Cystoseira spinosa* sampled along the western coast of Alexandria, Egypt, while our value for K is 23 times higher. Also our levels of major elements (Na, Mg, Cl, K, Ca, Sr) and halogens (Br, I) are similar to the published results for *Cystoseira*

Table 3. Concentration of some trace elements (in μg × g^{-1} dry weight) in marine macrophytes (the Mediterranean Sea).

Element	*Gelidium sp.*	*Hypnea sp.*	*Ulva sp.*	*Corallinales*	*Cystoseira sp.*	*Posidonia sp.*	Location and date of sampling	Reference
Cr	-	-	-	-	1.59	3.34	Marsa Matruh, Mediterranean Sea, 2014	This study
	-	-	-	-	11.9	33.3	Tartous, Syria, Mediterranean Sea, 1999	[7]
	-	-	-	-	0.32	-	Sicily, Italy, Mediterranean Sea, 2004	[19]
	-	-	-	-	-	0.184	Calvi, Corsica, France, Mediterranean Sea, 2010	[4]
Fe	203	165	533	292	-	-	Alexandria, Mediterranean Sea, 2014	This study
	-	-	-	-	72	437	Marsa Matruh, Cleopatra beach 2014	This study
	410	-	-	222	73	396	Marsa Matruh,Mediterranean Sea, 2009-2010	[10]
	-	-	525	467	-	-	Alexandria, Mediterranean Sea, 2005	[8]
Co	-	0.20	0.22	0.28	-	-	Alexandria Mediterranean Sea, 2014	This study
	-	-	-	-	0.19	-	Marsa Matrouh, Mediterranean Sea, 2014	This study
	-	-	7.08	16.6	-	-	Eastern harbor, Mediterranean Sea, 2005	[8]
	-	-	3.60	2.95	-	-	Abu-Qir, Alexandria, Mediterranean Sea, 2008	[2]
	-	2.07	1.12	8.52	-	-	Abu-Qir, Alexandria, Mediterranean Sea, 2008-2010	[3]
	-	-	0.93	-	3.43	-	Tartous, Syrian coast, Mediterranean Sea, 1999	[7]
Ni	2.31	0.89	1.74	0.85	-	-	Alexandria, Mediterranean Sea, 2014	This study
	-	-	-	-	1.27	2.22	Marsa Matruh, Mediterranean Sea, 2014	This study
	4.07	-	17	3.94	5.41	4.9	Marsa Matruh, Mediterranean Sea, 2009-2010	[10]
	-	5.85	3.64	12	-	-	Abu-Qir, Alex.,2008-2010	[3]
	7.46	-	-	-	6.56	-	Alexandria, Mediterranean Sea, 2006	[18]
Zn	18	9.87	11.8	19.65	-	-	Alexandria, Mediterranean Sea, 2014	This study
	-	-	-	-	65	2.065	Marsa Matruh, Mediterranean Sea, 2014	This study
	42	-	-	-	-	12.34	Marsa Matruh, Mediterranean Sea, 2009-2010	[10]
	-	-	57.4	-	-	-	Abu-Qir, Alexandria, Mediterranean Sea, 2006	[2]
	-	-	97.5	2.37	-	-	Abu-Qir, Alexandria, Mediterranean Sea, 2007	[2]
	-	-	13.93	13.46	-	-	Abu-Qir, Alexandria, Mediterranean Sea, 2008	[2]
	-	-	10.0	12.54	-	-	Abu-Qir, Alexandria, Mediterranean Sea, 2009	[2]
	-	15.04	-	-	-	-	Abu-Qir, Alex., 2008-2010	[3]
	19.64	-	-	-	18.01	-	Western coast, Alexandria, Mediterranean Sea, 2006	[18]
	-	-	-	-	26.2	-	Sicily, Italy, Mediterranean Sea, 2004	[19]
	-	-	-	-	-	107	Calvi, Corsica, France, 2010	[4]
	-	95.1	108.7	-	101.7	-	Thessaloniki, Greece, 2007	[21]
	-	-	35.92	17.17	11.17	-	Tartous and Ras sharma, Sryia, 1998-1999	[7]
As	-	5.75	8.58	-	-	-	Alexandria, Mediterranean Sea, 2014	This study
	-	-	-	-	46	3.13	Marsa Matruh, Mediterranean Sea, 2014	This study
	-	-	-	-	-	0.92	Calvi, Corsica, France, 2010	[4]
	-	2.59	2.05	-	46	-	Thessaloniki, Greece, 2007	[20]
	-	-	-	-	5.95	29	Tartous, Syria, 2000	[7]

sp. collected along the Syrian coast of the Mediterranean Sea [7] differing only by a factor of 1.5 - 2.0 Level of Fe detected in this survey is in good agreement with the data reported for the species of *Cystoseira* sampled along the Mediterranean coast of Egypt, while our content of Ni is about 5 times lower.

Posidonia oceanica is characterized by the highest level of Sc, Cr, Se, Sb, I, Hf, Th and U and the lowest values of K, Ti, V, Zn and Rb. Our concentration of Na, K and Ca are 2 - 3 times lower than the data reported by Shams El Din and El-Sherif (2012) [18] for *Posidonia oceanica* collected along the western Egyptian Mediterranean coast. The levels of Fe and Ni determined in this survey are in agreement with the results of Khaled (2014) [10] published for *Posidonia oceanica* collected near Marsa Matruh, Egypt, Mediterranean Sea.

In general the levels of Mn, Fe, Co, Ni and Zn observed in *Ulva intestinalis*, *Gelidium pussilum*, *Amphiroa rigida*, *Hypnea* sp., *Cystoseira* sp. and *Posidonia oceanica* in the present study are within the wide range of those previously reported for species of these genera sampled along the Egyptian Mediterranean coast (see **Table 3**). References concerning other trace and major elements in studied seaweeds are too scarce to establish comparisons.

The present results indicate that the accumulation of several elements in seaweeds is largely related to the phylogenetic origin of the species, which determines the biochemical composition of macroalgae. Thus, brown algae (in our study-*Cystoseira* sp.) usually accumulate more As, Sr and U than other taxonomic groups. High levels of as in brown algae are due to high phosphate concentrations in these macroalgae [21], as seaweeds take up and bioaccumulate arsenate from seawater as a phosphorus analogue [22]. High Sr concentrations in brown macroalgae are related to the cell wall polysaccharide alginate (constitute about 10% - 40% of brown algae dry weight), as the main accumulation mechanism for Sr in brown algae is an ion exchange between seawater and alginate [20]. High concentration of Ca (about 25% of dry weight) in *Amphiroa rigida* could be explained by calcareous deposits contained within the cell walls which are typical for all algae of the order Corallinales. Elevated levels of Sr in *Amphiroa rigida* when compared to other studied macrophytes are related to high content of Ca which geochemical and biochemical characteristics are similar to those of Sr [23].

However, high concentrations of some trace elements in macrophytes may also be explained by their elevated level in the water area of sampling. Thus the maximum contents of V, Zn, Mo in *Cystoseira* sp. and Cr and Ni in *Gelidium pussilum* are likely due to relatively high level of pollution of sampling sites.

4. Conclusion

The concentrations of more than 30 elements that were rarely or never studied as well as the levels of classically investigated Mn, Fe, Co, Ni and Zn in 6 species of marine macrophytes sampled along the Egyptian coast of the Mediterranean Sea were determined using neutron activation analysis. The results obtained for major and some trace elements varied within a wide range depending on the species of analyzed macrophyte, while the concentrations of Cr, Co, Ni, Se, Zr, Mo, Ag, Cs, La, Sm, Eu, Yb, Hf, Ta, Au and U were very similar in all samples. The contents of Na, S, Cl, Ca and Sr in *Hypnea sp.*, *Ulva intestinalis* and *Amphiroa rigida* sampled at the same station (Abo-Qir bay) differ by more than 10 times; Mg, Ba, Tb and Th differ by up to 10 times indicating that the accumulation of these elements is closely related to species biochemical composition, thallus morphology, or growth strategy. Our results indicate that *Cystoseira* sp. is a strong accumulator of As, Sr and U, and *Amphiroa rigida* of Ca and Sr. The studied species of macrophytes might be regarded as potential biomonitors for the elements concerned along the Egyptian coast of the Mediterranean Sea. Nevertheless, future investigations should be conducted in water areas with different levels of anthropogenic pollution, including relatively pristine areas, to reveal other accumulation properties of the macrophytes studied.

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