Comparative trace element trends in Posidonia oceanica and its sediments along the Turkish-Mediterranean coast

Rafet Cagri OZTURK (rafetcagriozturk@gmail.com)
Karadeniz Teknik Universitesi https://orcid.org/0000-0003-1785-4056
Kenan Gedik
Recep Tayyip Erdoğan University: Recep Tayyip Erdogan Universitesi
Ahmet Şahin
Karadeniz Technical University: Karadeniz Teknik Universitesi
Yaşar Özvarol
Akdeniz University: Akdeniz Universitesi
Erhan Mutlu
Akdeniz University: Akdeniz Universitesi

Research Article

Keywords: Trace elements, The Mediterranean Sea, sea grass, Posidonia oceanica, sediment, bioaccumulation

Posted Date: April 19th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-353031/v1

Abstract

Concentrations of eight trace elements (V, Cr, Ni, Cu, Zn, As, Cd, and Pb) were investigated in *Posidonia oceanica* blades and in the sediments sampled from 23 stations along the Turkish-Mediterranean Sea coast. Trace element (TE) concentration in both sediment and *P. oceanica* showed a statistically significant distribution among sampling stations. Most of the TE concentration in samples varied remarkably among stations without a consistent trend. Concentrations of Zn, Cd, Cu, and Pb in sediment of all of the sampling stations were determined as non-polluted based on the comparison with the sediment quality guideline index. More than quarter of the sampling stations were found as moderately or heavily polluted for Cr, Ni, and As. The mean TE concentrations found in the sediment sample in the present study were similar to the concentrations reported from the different parts of the eastern Mediterranean Sea. TE concentrations in *P. oceanica* were generally lower compared to the concentrations in the sediment except for Cd, Zn, and Cu. While positive correlation was found for Ni concentrations between sediment and *P. oceanica* samples, negative correlation was detected for V, Cr, Zn, Cu, As, and Cd concentrations between sediment and *P. oceanica*. The highest bioaccumulation factor in P. oceanica was calculated for Cd. The study area of the present study, especially the western sites (provinces of Antalya and Muğla) hosts millions of tourists annually and under the influence of intensive human activities in summer. Thus, coastal waters are heavily exposed to TEs and significantly positive correlations were detected between the anthropogenic TE pollutants (As, Cd, Cu, Zn, Pb, and V) and natural sourced TE (Ni and Cr).

Introduction

Posidonia oceanica (L.) Delile is an endemic flowering seagrass species of the Mediterranean Sea inhabiting coastal waters between 0–40 m depth. They attach to the sedimentary seabed with their roots, from which they take up nutrients, and forms a habitat called meadow which extends over wide areas. These large underwater meadows are an important part of the ecosystem providing habitat for breeding, shelter, feeding, shore protection, nutrient cycling, and several other benefits (Barbier et al. 2011; Short et al. 2011; Romero et al. 2015). *Posidonia oceanica* is sensitive to environmental deteriorations caused by human activities (Ruiz and Romero 2003; Holmer et al. 2008). The local decline in *P. oceanica* meadows has been reported from different parts of the Mediterranean sea due to anthropogenic disturbances (Montefalcone et al. 2009; Guillén et al. 2013).

Trace element contamination in the marine ecosystem is major concern due to their environmental persistence, biogeochemical recycling, bioaccumulation, and potential ecological risks. The Mediterranean Sea coast of Turkey is densely populated and most of the towns discharge their wastewater directly to the sea. Industries and agriculture in major cities of the region such as Muğla, Antalya, and Mersin also lead to trace element contamination through waste discharges. Tourism on the other hand also cause the similar form of pollution as any other industry. The Mediterranean Sea coast of Turkey is one of the leading tourist destinations that welcomes millions of tourists every year in summer and tourism is mainly concentrated in the coastal areas. Most of the coastline is urbanized and their population multiply during the holiday seasons and so the adverse effects on the marine environment multiplies.

Posidonia oceanica is suggested as an ideal biological indicator for biomonitoring (Debono and Borg 2006; Romero et al. 2015; El Zrelli et al. 2017) because of their wide distribution across the Mediterranean Sea, sensitivity to the environmental changes, abundance, and easy collection. (Pergent-Martini et al. 2005). Previous studies have shown the ability of *P. oceanica* up taking trace elements (TE) by its roots and leaves from the marine environment (Lafabrie et al. 2009) and its ability to reflect the former and current presence of the TEs in the environment (Pergent-Martini 1998). *Posidonia oceanica* has been extensively used as a bio-indicator for TE pollution (Pergent-Martini

1998; Lafabrie et al. 2007; Zhou et al. 2008; Zakhama-Sraieb et al. 2014). Perennial tissues of the species store TEs for long-term periods (Romeo et al. 1995; Lafabrie et al. 2009) and reflects the environmental status of TEs (Tovar-Sanchez et al. 2010). Sediment on the other hand, serves as a sink and source of trace metals. The accumulation of heavy metals in sediment affects the benthic organisms (Huang et al. 2020).

To best of our knowledge there is only a single study heavy metal contamination in the Turkish Mediterranean coast which is a local study performend in beach sediment in Mersin, Turkey (Yalcin 2009). A study is lacking to associate the trace element contamination in sediment with bioindicator species in the region. In the present study, we collected sediment and *P. oceanica* samples in order to define the current risk status of TE concentrations both in the sediment and *P. oceanica* throughout the Mediterranean Sea coast of Turkey. The main objectives of this study were i) to compare TE concentrations between the sediments and *P. oceanica* and ii) to compare TE status across the Mediterranean coast of Turkey.

Material And Method

Sample Collection and Preparation

Sample collection was performed in 2019 (June-July) during acoustic field survey for estimation of *P. oceanica* biomass. *Posidonia oceanica* and surface sediments were collected from 23 sites along the Mediterranean Sea coast of Turkey (Figure 1). *P. oceanica* samples were collected by scuba diving between 10-40 meters and sediment samples were collected by a van Veen grab. Samples were placed in the sterile zip-locked bags and transported to the laboratory without breaking the cold chain and stored at -80°C until analyses.

In the laboratory, leaf blades (the highest accumulation has been reported in this part based on the works of Lafabrie et al. 2008; Zakhama-Sraieb et al. 2016) of the *P. oceanica* were separated, rinsed with ultrapure water to remove exogenous substances, and dried at 45 ºC for 24 hours. Dried blades were powdered in a mortar. Sediment samples (100-150 g) were placed in the glass petri dishes and dried at 4 ºC until constant weight. Dried sediment was homogenized in a mortar and then sieved through a 2 mm sieve. Each sample was digested using HNO_3 (Suprapur, Merck) and H_2O_2 (Suprapur, Merck) according to US EPA 3050B method (EPA 1999). Briefly, 0.3 g of samples (dried sediment and blades) were placed into the extraction tubes containing 5 ml of HNO_3 (65% Suprapur, Merck) and heated on the block heater at 95±3ºC for 2.5 hours. After cooling, 2.5 ml of H_2O_2 (30% Suprapur, Merck) was added, and tubes were heated on the block heater at 95±3ºC for another 2 hours. Next, the tube caps were removed, and samples were evaporated until having 2 ml of the mixture (leftover). Digested samples were diluted with ultrapure water and filtered through PTFE filter (0.45 µm pore size) and stored at 4ºC until analyses.

Trace Element Analysis

Concentrations of Vanadium (V), Chromium (Cr), Nickel (Ni), Copper (Cu), Zinc (Zn), Arsenic (As), Cadmium (Cd), and Lead (Pb) in the sediment and *P. oceanica* blades were measured by inductively coupled plasma mass spectrometry (ICP-MS) (Agilent, 7800). The accuracy of the analytical method was checked by using certified reference materials of estuarine sediment (BCR 277R) and seaweed (ERM-CD200) (Table 1). Analytical measurements were performed in triplicate. Internal standards were used for quality control and quality assurance. The measured values were the mean±standard error (SE) and expressed as mg kg^{-1} (dry weight).

Table 1. Analysis of the certified reference material (BCR 277R Estuarine sediment, and ERM CD200 seaweed): standard material values versus measured values

	*DL	$_a$Reference values mg kg^{-1}	$_b$Reference values mg kg^{-1}	$_a$Analyzed values mg kg^{-1}	$_b$Analyzed values mg kg^{-1}	$_a$Recovery (%)	$_a$Recovery (%)
As	0.0390	18.3	55	17.1	52.4	93.4	95.3
Cd	0.0003	0.61	0.95	0.58	0.89	95.1	93.7
Cr	0.0554	188		175.8		93.5	
Cu	0.0588	63	1.71	65.1	1.66	103.3	97.1
Ni	0.0236	130		122.4		94.2	
Pb	0.0391		0.51		0.50		98.0
Zn	0.0757	178	25.3	172.9	23.4	97.1	92.5

$_a$BCR 277R Estuarine sediment, $_b$ERM CD200 seaweed, *detection limit (ppb), N=5.

Statistical Analysis

The normality of the variables was tested using Shapiro-Wilk test. Homogeneity of variance was checked with the Levene test. Differences between the metal concentrations among stations were evaluated by one-way analysis of variance (ANOVA). Significantly different concentrations were determined by a post hoc test of Tukey HSD. Pearson correlation analysis was implemented to test for significant relationships among measured TEs. Parametric (Pearson) correlation coefficient was calculated to evaluate the relationship between the TE concentrations in the sediment and *P. oceanica*. Factor analysis (FA) was further implemented to to assess the major sources of the TEs in the sediment samples. The ability of *P. oceanica* to accumulate the TEs that present in the sediment (bioaccumulation factor) was also calculated with the following formula:

Where C_{blades} is the TE concentration in the *P. oceanica* blades and $C_{sediment}$ is the TE concentration in the sediment.

The data analyses were conducted by using R (ver. 4.0.3) (R Core Team 2020) and the visualizations were prepared by using ggplot2 (Wickham 2016) and cowplot (Wilke 2020) packages.

Results And Discussion

Trace elements in Sediment

Sediment is vital, particularly for the coastal ecosystem, yet is under pressure from several anthropogenic pollutants due to the increasing population in the coastal regions. TEs, one of the most important pollutants, will go under cyclic sedimentation and accumulate in the surface sediment after a certain period following entering the coastal waters in various ways. Hence, there are generally high amounts of TEs in the sediments of the coastal zones where industrialization activities and population density are high (Sañudo-Wilhelmy and Flegal 1991; Worakhunpiset 2018). In the present study, the trace element concentrations in sediment collected along the Mediterranean Sea coast of Turkey were detected between a minimum and a maximum concentration as follows (mg kg^{-1}): Ni, 1.68-354.55; Cr, 1.74-132.54; V, 0.98–77.28; Zn, 1.33–62.05; As, 0.44–34.41; Cu, 0.59–20.47; Pb, 0.29–13.46; Cd, ND-0.34 (Table S1). The distribution of TEs in the sediments sampled from different locations was given in Fig. 2. Although

most of the TE concentrations in the sediments varied significantly ($p < 0.05$, ANOVA, post-hoc: Tukey) among stations, not a consistent trend was observed in these variations (Fig. 3, Table S1). TE concentrations in the sediments were listed as follows: Ni > Cr > V > Zn > As > Cu > Pb > Cd. Factor analysis was used to assess the major sources of the TEs in the sediments collected along the Mediterranean Sea coast of Turkey. Two components (eigenvalues values > 1) were extracted (Table 2) according to the factor analysis. While the variance of the first component 54.93%, the second one was 25.19%. The total variance was calculated as 80.12%. TEs of V, Zn, Cu, Pb, Cd, and As were presented in the first component, while Ni and Cr were presented in the second component. The elements grouped in the first component might be of an anthropogenic origin. In detail, while Pb and V might be associated with the motor vehicle emissions (El-Moselhy 2006; Shui et al. 2020), Zn, Cu, Cd, and As may result from the input of sewage, industrial discharges, and the surface water coming from the excessive usage of the agricultural pesticides and/or fertilizers (Tang 2008; Shi et al. 2018). The Ni and Cr which were classified in the second component after FA, are naturally occurring elements in the earth's crust (Salomons and Förstner 1988). Additionally, Amorosi (2012) determined that Ni and Cr, are caused by terrestrial transport especially in the coastal sediments, and it even has been reported that Ni and Cr go above the threshold limits with these transfers (Amorosi and Sammartino 2007).

Pearson's correlation test was applied to determine the relationship between the TEs detected in the sediments and the data were given in Table 3. There was a statistically significant ($p < 0.01$) relationship between Ni and Cr which are thought to have a similar contamination source ($r = 0.88$) based on the FA results (second component) (Table 2). On the other hand, V, Cu, Zn, As, Cd, and Pb, which are thought to have anthropogenic contamination based on the FA data (first component) given in Table 2, were found to have significant relationships among the listed TEs (Table 3).

Table 2
Results of the factor analysis

	C1	**C2**
V	0.962	
Zn	0.938	
Cu	0.924	
Pb	0.899	
Cd	0.763	
As	0.560	
Ni		0.953
Cr		0.952
Eigenvalues	4.394	2.016
Variance (%)	54.929	54.929
Cumulative of variance (%)	25.194	80.123

*Varimax with Kaiser Normalization rotation method was performed. 2 components (C) were extracted with Eigenvalues > 1.

The researchers try to evaluate the sediment quality by comparing the TE values obtained from sampling with the indexes specified by various legal organizations. One of these indexes is the Sediment Quality Guideline (SQG) specified by the US EPA. According to the SQG sediments are classified under 3 categories as non-polluted, moderately polluted, and heavily polluted (Perin et al. 1997). TE concentration values obtained in this study were compared with the SQG values (Table S1). Zn, Cd, Cu, and Pb were determined as non-polluted TEs in all stations. Cr was found non-polluted in 39% of the stations, moderately polluted in 39%, and heavily polluted in the remaining stations while Ni was found to be non-polluted in 48%, heavily polluted in 39%, and moderately polluted in the remaining stations. For As, 65% of the stations were heavily polluted, while 17% of the remaining stations were non-polluted and the other half of the stations (17%) was moderately polluted (Table S1).

Table 3
Correlation coefficients between the trace element concentrations

	V	**Cr**	**Ni**	**Cu**	**Zn**	**As**	**Cd**	**Pb**
V		0.213	-0.040	**0.833	**0.906	**0.725	**0.733	**0.816
Cr	***0.260**		**0.877	*0.296	0.167	0.087	0.152	**0.478
Ni	****0.341**	****0.451**		0.047	-0.075	-0.067	-0.041	*0.240
Cu	****0.422**	****0.394**	****0.669**		**0.906	**0.365	**0.690	**0.926
Zn	****0.690**	****0.389**	****0.515**	****0.747**		**0.611	**0.571	**0.827
As	****0.605**	****0.672**	****0.596**	****0.706**	****0.665**		0.165	**0.472
Cd	****0.729**	****0.400**	****0.549**	****0.575**	****0.865**	****0.578**		**0.679
Pb	****0.577**	**0.240**	****0.446**	***0.318**	****0.462**	****0.429**	****0.539**	

*Correlation is significant at the 0.05 level. ** Correlation is significant at the 0.01 level. Bold data indicates the correlation among detected TEs in the *Posidonia oceanica*.

Trace element concentrations of the surface sediment reported in the other coastal areas of the Mediterranean Sea were listed in Table 4. The mean TE concentrations found in the Mediterranean Sea coast of Turkey in this study were generally similar to the concentrations reported in the other areas (Table 4). Indeed, in a study conducted in the coastal area of Morocco (El-Sorogy and Attiah 2015) the Ni, Zn, As, and Pb values were obtained higher than the values determined in our study (Table S1 and Fig. 3). The values were found to be similar or lower than the literature in terms of Pb data obtained in our work (Roussiez et al. 2005; Zohra and Habib 2016; Amor et al. 2019; Abdallah and Badr-ElDin 2020). A trend similar to Pb was detected for Cd concentrations, and the values obtained in the study were found to be lower than that of the Cd values specified in the following literature (Yalcin 2009; Zohra and Habib 2016; Chifflet et al. 2019; Abdallah and Badr-ElDin 2020).

Table 4

The comparison of trace element concentrations (mg kg^{-1}) in the surface sediments of different coastal areas of the Mediterranean Sea

Location	V	Cr	Ni	Cu	Zn	As	Cd	Pb	Reference
Mediterranean Sea Coast of Turkey	0.98–77.28	1.74-132.54	1.68-354.55	0.59–20.47	1.33–62.05	0.44–34.41	ND-0.34	0.29–13.46	This study
Mediterranean Sea Coast of Turkey	22.5–55.4	134–711	93.2–258	4.4–32.1	15.4–20.9	15.7–24.2	3.6–5.5	3.5–7.7	(Yalcin 2009)
Mediterranean Sea Coast of Morocco	NA	14.35–500	ND-40.00	ND-25.00	7.78–480.00	NA	0.04–1.20	2.43–75.80	(Saddik et al. 2019)
Mediterranean Sea Coast of Tunisia	NA	NA	9.13–30.51	8.23–28.56	47–546	13.11-36.00	4.42–7.92	65.06–151.50	(Zohra and Habib 2016)
Mediterranean Sea Coast of Morocco	NA	0.23–0.29	706.91-894.17	NA	298.50-394.11	227.96-394.11	NA	333.47-476.45	(El-Sorogy and Attiah 2015)
Mediterranean Sea Coast of Lebanese	28.3–75.4	16.9–94.3	12.6–49.3	NA	26.9-956.6	ND-14.6	2.54–13.47	ND-53.8	(Merhaby et al. 2018)
Mediterranean Sea Coast of France	NA	106.8	99.2	39.3	172.3	NA	NA	23.2	(Roussiez et al. 2005)
Mediterranean Sea Coast of Tunisia	NA	15.55–55.44	13.98–39.11	1.53-128.82	34.42-450.68	NA	0.25–1.37	16.14–55.14	(Amor et al. 2019)
Mediterranean Sea Coast of Tunisia	5.47–43.56	1.17–13.87	1.97–13.80	1.71–13.87	9.34–73.06	1.12–6.79	1.43–3.51	2.12–15.17	(Chifflet et al. 2019)
Mediterranean Sea Coast of Egypt	NA	2.18–28.18	NA	NA	NA	52.71–132.90	0.52–5.23	29.87-192.94	(Abdallah and Badr-ElDin 2020)
Mediterranean Sea Coast of Egypt	NA	4.08-297.95	1.65–60.25	0.46–26.26	2.05–62.21	NA	0.04–0.47	3.34–53.67	(Soliman et al. 2015)
Mediterranean Sea Coast of Spain	NA	2.4–37.5	1.3–18.3	1.1–7.9	6.8–66.7	1.8–47.1	0.10–0.36	1.7–12.6	(Martínez-Guijarro et al. 2019)
Mediterranean Sea Coast of TRNC	NA	1.49–92.7	11.5–36.9	11.3–48.9	31.6–72.5	NA	NA	10.8–21.8	(Abbasi and Mirekhtiary 2020)

ND- Non detectable level, NA-Not available

Table 5

The comparison of trace element concentrations (mg kg^{-1}) in blades of *Posidonia oceanica* from different coastal areas of the Mediterranean Sea

Location	V	Cr	Ni	Cu	Zn	As	Cd	Pb	Reference
Mediterranean Sea Coast of Turkey	0.37–69.61	0.03–64.21	0.99–36.37	0.23–25.99	1.71-121.89	0.01–5.07	0.03–3.07	0.01–5.32	This study
Mediterranean Sea Coast of Algeria	NA	0.20-25.95	15.02–43.39	0.76–6.54	10.67–87.53	NA	NA	NA	(Saliha et al. 2016)
Mediterranean Sea Coast of Tunusia	NA	NA	NA	4.33 ± 0.25	157.67 ± 15.50	Na	0.58 ± 0.10	1.27 ± 0.20	(El Zrelli et al. 2017)
Mediterranean Sea Coast of Sardinia	NA	NA	NA	6.0 ± 2.5	Na	NA	0.6 ± 0.1	5.2 ± 8	(Baroli et al. 2001)
Mediterranean Sea Coast of Algeria	NA	15.2–68.1	NA	6.07–52.44	8.52–40.17	NA	0.53–2.33	7.73–71.25	(Zeghdoudi et al. 2019)
Mediterranean Sea Coast of France	NA	1.53 ± 1.07	NA	12.1 ± 2.6	179 ± 69	NA	2.4 ± 0.5	7.76 ± 2.74	(Warnau et al. 1995)
Mediterranean Sea Coast of Corsica	NA	0.15–1.07	15.93–48.73	NA	NA	NA	1.47–3.97	1.27–3.37	(Lafabrie et al. 2008)
Mediterranean Sea Coast of Italy	NA	1	55	14	100	4	2	1	(Ferrat et al. 2012)
Mediterranean Sea Coast of France	NA	7.7–21.6	7.2–26.3	6.6–30.6	10.7–95.1	3.3–228	0.2–0.7	5.7–47.3	(Serrano et al. 2011)
Mediterranean Sea Coast of Italy	NA	NA	NA	2.21–6.95	129–193	NA	0.43–0.57	1.26–1.71	(Di Leo et al. 2013)
Mediterranean Sea Coast of Tunusia	NA	NA	1.86–2.56	4.81–11.56	21.58–31.59	NA	0.51–0.85	0.15–1.37	(Zakhama-Sraieb et al. 2016)
Mediterranean Sea Coast of Italy	NA	2.47 ± 0.32	20.1 ± 2.56	11.6 ± 1.88	115 ± 17.8	2.73 ± 0.18	1.34 ± 0.10	3.22 ± 0.42	(Bonanno and Di Martino 2017)
NA-Not available									

Trace elements in Posidonia oceanica

Trace elements are divided into two groups as essential (As, Cr, Cu, Ni, V, and Zn) and non-essential (Cd and Pb) elements in the biological system (Tacon 1987; WHO 2004). Besides, non-essentials can be toxic even at very low concentrations, while essential ones can only be toxic to marine life above a certain concentration (EPA 1999; Nordberg et al. 2007). Also, these TEs are among the elements frequently monitored by the researchers in the coastal pollution studies as they have vital effects on the coastal ecosystem (Tovar-Sanchez et al. 2010; Richir 2016; Bertini et al. 2019; Chifflet et al. 2019; Martínez-Guijarro et al. 2019). Thus, these elements were preferred in our study and their accumulation in the *P. oceanica* was examined. The distribution of the TE concentrations in *P. oceanica* sampled along the Mediterranean Sea coast of Turkey was presented in Fig. 2. With a widely varying range,

minimum and maximum TE concentrations were detected as follows (mg kg^{-1}): As, 0.01–5.07; Cd, 0.03–3.07; Cr, 0.03–64.21; Cu, 0.23–25.99; Ni, 0.99–36.37; Pb, 0.01–5.32; V, 0.37–69.61; Zn, 1.71-121.89. On the other hand, TE concentrations in blades of *P. oceanica* were as follows: Zn > V > Cr > Ni > Cu > Pb > As > Cd. Trace element concentrations in the blades showed a statistically significant distribution among sampling stations (Fig. 3 and Table S2). Although most of the TE concentrations in *P. oceanica* blades varied remarkably among stations, no consistent trend was observed in these variations. Lafabrie et al. (2007) stated that the source of these elements in the coastal meadows is mostly anthropogenic and originating from the coastal settlements and heavy industrialization or harbors and rivers. The region in which the study was conducted, especially the provinces of Antalya and Muğla, stands out for their summer tourism and these provinces both host nearly 20 million tourists annually. Furthermore, these areas are under the influence of intensive human activities such as hotel stayings, beaches, private travels, and sightseeing boat traffics (Mutlu et al. 2020). Due to these activities, it is mainly considered that the coastal waters are heavily exposed to TEs, especially owing to untreated wastewater and excessive sea traffic resulting from these activities along the coastal line. Therefore, the FA results overlap the data showing the TEs mostly derived from the anthropogenic activities except for Ni and Cr (Table 2). Besides, when the correlation of the TEs was examined with each other, a significant positive correlation was detected between the elements that are determined to be anthropogenic (As, Cd, Cu, Zn, Pb, V) and naturally sourced (Ni and Cr) (Table 3). Similar correlations were reported in the previous studies (Lafabrie et al. 2008; Zakhama-Sraieb et al. 2016; Bravo et al. 2016).

When we compare the trace element concentrations detected in the sampled sediments and *P. oceanica* TE concentrations in the blades were mostly lower compared to the concentrations in the sediments except for Zn, Cu, and Cd. A good bio-indicator is expected to have a good correlation between its TE concentration of the surrounding water column or sediment and the concentration in its tissues (Bonanno and Orlando-Bonaca 2018). In accordance, several other studies have revealed that *P. oceanica* reflects the TE status in the environment (Lafabrie et al. 2007; Bravo et al. 2016). Therefore, the relationship between the concentrations found in the sediments and the blades of *P. oceanica* were analyzed by linear regression analysis (Fig. 4). Different sampling locations showed a positive relationship (Fig. 4; $R^2 = 0.43$) in terms of sediments and the *P. oceanica* for Ni concentrations, (this element was also found as the highest element in terms of average abundance detected in the sediment samples), however, a negative relation for the V, Cr, Zn, Cu, As, and Cd was recorded (Fig. 4). Besides, there was no relationship between Pb concentrations in the sediment samples and the *P. oceanica* (R^2:0.0004) (Fig. 4). Furthermore, as in our study, Bonanno and Martino (2017) reported that Ni and Zn have a positive relationship with the sediments and *P. oceanica*. Bonanno and Martino (2017) also stated that there was no relationship between their sediments and *P. oceanica* in terms of Pb concentrations. On the contrary, some other researchers reported a positive relationship between the sediment and *P. oceanica* metal accumulations (Bravo et al. 2016; Bonanno et al. 2020).

The calculated bioaccumulation factors (BAF) were ranged as follows: As, 0.01–4.30; Cd, 0.48-255.31; Cr, 0.01–36.88; Cu, 0.01–14.15; Ni, 0.01–33.17; Pb, 0.01–5.25; V, 0.01–17.75; Zn, 0.03–46.14 (Fig. 5). According to the average BAF values, the Cd was determined to have the highest BAF value among all elements (37.77), and this value was 6 times higher than the value of Zn (6.95) which was having the closest BAF value to Cd. Afterwards BAF value list was as follows: Cu (3,37), Ni (2,56), V (2,45), Cr (1,64), Pb (0,72) and As (0,47). While the BAF values obtained by Bravo et al (2016), were in accordance with the results of our current study, only our Ni and Cd values were found to be higher from another study conducted by Bonanno and Martino (2017)

Trace element concentrations in the *P. oceanica* reported in the other coastal areas of the Mediterranean Sea were listed in Table 5. Trace element concentrations in our study were mainly within the range of the values reported for *P.*

oceanica in previous research (Warnau et al. 1995; Baroli et al. 2001; Lafabrie et al. 2008; Serrano et al. 2011; Ferrat et al. 2012; Di Leo et al. 2013; Zakhama-Sraieb et al. 2016; Saliha et al. 2016; Bonanno and Di Martino 2017; El Zrelli et al. 2017; Zeghdoudi et al. 2019). However, Cr and Pb were the only elements that concentrations were generally found higher compared to previously reported data (Table 4).

Conclusion

In the present study, trace element concentrations were evaluated in Posidonia oceanica and sediment collected from 23 sampling sites in the Turkish-Mediterranean Sea coast. Results have shown that some of the sampling stations are significantly contaminated by Cr, Ni, and As. Trace element concentrations in *P. oceanica* and in sediment were within the range of the values that reported from the different parts of Eastern Mediterranean Sea. It is worth mentioning that the *P. oceanica* blades show different patterns of metal contamination than sediment. The range of values for these trace elements provide useful information regarding the presence of anthropogenic contamination and possible sources.

Declarations

Acknowledgement

Sampling of the study was carried out during an acoustic survey study within the framework of the project funded by the Scientific and Technological Research Council of Turkey (TUBITAK: 117Y133). Experimental procedures of the study were funded by the Scientific Research Projects Coordination Unit of Karadeniz Technical University (Project No. FHD-2020-9100). The authors would like to thank the crew of the R/V “Akdeniz Su”.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests

Funding

Sampling of the study was carried out during an acoustic survey study within the framework of the project funded by the Scientific and Technological Research Council of Turkey (TUBITAK: 117Y133). Experimental procedures of the study were funded by the Scientific Research Projects Coordination Unit of Karadeniz Technical University (Project No. FHD-2020-9100).

Authors’ contributions

RÇÖ and EM acquired the financial support for the project leading to this publication. KG, RÇÖ, and AŞ contributed to the study conception and design. Sampling was performed by YÖ, AŞ and RÇÖ. KG performed trace element analysis. The first draft of the manuscript was written by RÇÖ and KG. All authors read and approved the final manuscript.

References

Abbasi A, Mirekhtiary F (2020) Heavy metals and natural radioactivity concentration in sediments of the Mediterranean Sea coast. Mar. Pollut. Bull. 154:111041

Abdallah MAM, Badr-ElDin AM (2020) Ecological risk assessment of surficial sediment by heavy metals from a submerged archaeology harbor, South Mediterranean Sea, Egypt. Acta Geochim 39:226–235. https://doi.org/10.1007/s11631-019-00340-2

Amor R Ben, Yahyaoui A, Abidi M, et al (2019) Bioavailability and Assessment of Metal Contamination in Surface Sediments of Rades-Hamam Lif Coast, around Meliane River (Gulf of Tunis, Tunisia, Mediterranean Sea). J. Chem. 2019:1–11

Amorosi A (2012) Chromium and nickel as indicators of source-to-sink sediment transfer in a Holocene alluvial and coastal system (Po Plain, Italy). Sediment Geol 280:260–269. https://doi.org/10.1016/j.sedgeo.2012.04.011

Amorosi A, Sammartino I (2007) Influence of sediment provenance on background values of potentially toxic metals from near-surface sediments of Po coastal plain (Italy). Int J Earth Sci 96:389–396. https://doi.org/10.1007/s00531-006-0104-8

Barbier EB, Hacker SD, Kennedy C, et al (2011) The value of estuarine and coastal ecosystem services. Ecol Monogr 81:169–193. https://doi.org/10.1890/10-1510.1

Baroli M, Cristini A, Cossu A, et al (2001) Concentrations of Trace Metals (Cd, Cu, Fe, Pb) in Posidonia oceanica Seagrass of Liscia Bay, Sardinia (Italy). In: Faranda FM, Guglielmo L, Spezie G (eds) Mediterranean Ecosystems: Structures and Processes. Springer-Verlag, Italia, p 489

Bertini L, Focaracci F, Proietti S, et al (2019) Physiological response of Posidonia oceanica to heavy metal pollution along the Tyrrhenian coast. Funct. Plant Biol. 46:933–941

Bonanno G, Di Martino V (2017) Trace element compartmentation in the seagrass Posidonia oceanica and biomonitoring applications. Mar. Pollut. Bull. 116:196–203

Bonanno G, Orlando-Bonaca M (2018) Chemical elements in Mediterranean macroalgae. A review. Ecotoxicol Environ Saf 148:44–71. https://doi.org/10.1016/j.ecoenv.2017.10.013

Bonanno G, Veneziano V, Orlando-Bonaca M (2020) Comparative assessment of trace element accumulation and biomonitoring in seaweed Ulva lactuca and seagrass Posidonia oceanica. Sci Total Environ 718:137413. https://doi.org/10.1016/j.scitotenv.2020.137413

Bravo I, Focaracci F, Cerfolli F, Papetti P (2016) Relationships between trace elements in Posidonia oceanica shoots and in sediment fractions along Latium coasts (northwestern Mediterranean Sea). Environ Monit Assess 188:157. https://doi.org/10.1007/s10661-016-5122-9

Chifflet S, Tedetti M, Zouch H, et al (2019) Dynamics of trace metals in a shallow coastal ecosystem: Insights from the Gulf of Gabès (Southern Mediterranean Sea). AIMS Environ. Sci. 6:277–297

Debono S, Borg JA (2006) Use of Posidonia oceanica as a bioindicator of ecological status for Maltese coastal waters. Biol Mar Mediterr 13:206–209

Di Leo A, Annicchiarico C, Cardellicchio N, et al (2013) Trace metal distributions in Posidonia oceanica and sediments from Taranto Gulf (Ionian Sea, Southern Italy). Mediterr Mar Sci 14:204. https://doi.org/10.12681/mms.316

El-Moselhy KM (2006) Distribution Of Vanadium In Bottom Sediments From The Marine Coastal Area Of The Egyptian Seas. Egypt J Aquat Res 32:12–21

El-Sorogy AS, Attiah A (2015) Assessment of metal contamination in coastal sediments, seawaters and bivalves of the Mediterranean Sea coast, Egypt. Mar Pollut Bull 101:867–871. https://doi.org/10.1016/j.marpolbul.2015.11.017

El Zrelli R, Courjault-Radé P, Rabaoui L, et al (2017) Biomonitoring of coastal pollution in the Gulf of Gabes (SE, Tunisia): use of Posidonia oceanica seagrass as a bioindicator and its mat as an archive of coastal metallic contamination. Environ Sci Pollut Res 24:22214–22225. https://doi.org/10.1007/s11356-017-9856-x

EPA U (1999) SW-846 reference methodology: method 3050B. Standard operating procedure for the digestion of. Soil/Sediment Samples Using a hotplate/beaker digestion technique. Chicago, Illinois

Ferrat L, Wyllie-Echeverria S, Cates G, et al (2012) Posidonia oceanica and Zostera marina as Potential Biomarkers of Heavy Metal Contamination in Coastal Systems. In: Ecological Water Quality - Water Treatment and Reuse. InTech

Guillén JE, Sánchez Lizaso JL, Jiménez S, et al (2013) Evolution of Posidonia oceanica seagrass meadows and its implications for management. J Sea Res 83:65–71. https://doi.org/10.1016/j.seares.2013.04.012

Holmer M, Argyrou M, Dalsgaard T, et al (2008) Effects of fish farm waste on Posidonia oceanica meadows: Synthesis and provision of monitoring and management tools. Mar Pollut Bull 56:1618–1629. https://doi.org/10.1016/j.marpolbul.2008.05.020

Huang Z, Liu C, Zhao X, et al (2020) Risk assessment of heavy metals in the surface sediment at the drinking water source of the Xiangjiang River in South China. Environ Sci Eur 32:23. https://doi.org/10.1186/s12302-020-00305-w

Lafabrie C, Pergent-Martini C, Pergent G (2008) Metal contamination of Posidonia oceanica meadows along the Corsican coastline (Mediterranean). Environ Pollut 151:262–268. https://doi.org/10.1016/j.envpol.2007.01.047

Lafabrie C, Pergent G, Pergent-Martini C (2009) Utilization of the seagrass Posidonia oceanica to evaluate the spatial dispersion of metal contamination. Sci Total Environ 407:2440–2446. https://doi.org/10.1016/j.scitotenv.2008.11.001

Lafabrie C, Pergent G, Pergent-Martini C, Capiomont A (2007) Posidonia oceanica: A tracer of past mercury contamination. Environ Pollut 148:688–692. https://doi.org/10.1016/j.envpol.2006.11.015

Martínez-Guijarro R, Paches M, Romero I, Aguado D (2019) Enrichment and contamination level of trace metals in the Mediterranean marine sediments of Spain. Sci. Total Environ. 693:133566

Merhaby D, Ouddane B, Net S, Halwani J (2018) Assessment of trace metals contamination in surficial sediments along Lebanese Coastal Zone. Mar. Pollut. Bull. 133:881–890

Montefalcone M, Albertelli G, Morri C, et al (2009) Legal protection is not enough: Posidonia oceanica meadows in marine protected areas are not healthier than those in unprotected areas of the northwest Mediterranean Sea. Mar Pollut Bull 58:515–519. https://doi.org/10.1016/j.marpolbul.2008.12.001

Mutlu E, Özvarol Y, Şahin A, et al (2020) Macro litter distribution of the Turkish Mediterranean coasts dominated by pleasure crafts. Mar Pollut Bull 151:110833. https://doi.org/10.1016/j.marpolbul.2019.110833

Nordberg GF, Fowler BA, Nordberg M, Friberg LT (2007) Handbook on the Toxicology of Metals

Pergent-Martini C (1998) Posidonia oceanica: A biological indicator of past and present mercury contamination in the Mediterranean Sea. Mar Environ Res 45:101–111. https://doi.org/10.1016/S0141-1136(97)00023-8

Pergent-Martini C, Leoni V, Pasqualini V, et al (2005) Descriptors of Posidonia oceanica meadows: Use and application. Ecol Indic 5:213–230. https://doi.org/10.1016/j.ecolind.2005.02.004

Perin G, Rebello Wagener A, Hamacher C, et al (1997) A five-year study on the heavy-metal pollution of Guanabara Bay sediments (Rio de Janeiro, Brazil) and evaluation of the metal bioavailability by means of geochemical speciation. Water Res 31:3017–3028

R Core Team (2020) R: A Language and Environment for Statistical Computing

Richir J (2016) Trace Elements in Marine Environments: Occurrence, Threats and Monitoring with Special Focus on the Coastal Mediterranean. J Environ Anal Toxicol 6:1000349. https://doi.org/10.4172/2161-0525.1000349

Romeo M, Gnassia Barelli M, Juhel T, Meinesz A (1995) Memorization of heavy metals by scales of the seagrass Posidonia oceanica, collected in the NW Mediterranean. Mar Ecol Prog Ser 120:211–218. https://doi.org/10.3354/meps120211

Romero J, Alcoverro T, Roca G, Pérez M (2015) Bioindicators, Monitoring, and Management Using Mediterranean Seagrasses: What Have We Learned from the Implementation of the EU Water Framework Directive? In: The Handbook of Environmental Chemistry. Springer, pp 161–182

Roussiez V, Ludwig W, Probst J-L, Monaco A (2005) Background levels of heavy metals in surficial sediments of the Gulf of Lions (NW Mediterranean): An approach based on 133Cs normalization and lead isotope measurements. Environ Pollut 138:167–177. https://doi.org/10.1016/j.envpol.2005.02.004

Ruiz JM, Romero J (2003) Effects of disturbances caused by coastal constructions on spatial structure, growth dynamics and photosynthesis of the seagrass Posidonia oceanica. Mar Pollut Bull 46:1523–1533. https://doi.org/10.1016/j.marpolbul.2003.08.021

Saddik M, Fadili A, Makan A (2019) Assessment of heavy metal contamination in surface sediments along the Mediterranean coast of Morocco. Environ. Monit. Assess. 191:197

Saliha B-T, Waffa H, Mourad B (2016) Assessment of Metallic Trace Elements Using the Seagrass Posidonia oceanica and the Surface Sediment from North Eastern of Algeria. Asian J Biol Sci 10:17–26. https://doi.org/10.3923/ajbs.2017.17.26

Salomons W, Förstner U (1988) Environmental Management of Solid Waste. Springer Berlin Heidelberg, Berlin, Heidelberg

Sañudo-Wilhelmy SA, Flegal AR (1991) Trace element distributions in coastal waters along the US-Mexican boundary: relative contributions of natural processes vs. anthropogenic inputs. Mar Chem 33:371–392. https://doi.org/10.1016/0304-4203(91)90078-B

Serrano O, Mateo MA, Dueñas-Bohórquez A, et al (2011) The Posidonia oceanica marine sedimentary record: A Holocene archive of heavy metal pollution. Sci Total Environ 409:4831–4840. https://doi.org/10.1016/j.scitotenv.2011.08.001

Shi T, Ma J, Wu X, et al (2018) Inventories of heavy metal inputs and outputs to and from agricultural soils: A review. Ecotoxicol Environ Saf 164:118–124. https://doi.org/10.1016/j.ecoenv.2018.08.016

Short FT, Polidoro B, Livingstone SR, et al (2011) Extinction risk assessment of the world’s seagrass species. Biol Conserv 144:1961–1971. https://doi.org/10.1016/j.biocon.2011.04.010

Shui L, Pan X, Chen X, et al (2020) Pollution Characteristics and Ecological Risk Assessment of Heavy Metals in Sediments of the Three Gorges Reservoir. Water 12:1798. https://doi.org/10.3390/w12061798

Soliman NF, Nasr SM, Okbah MA (2015) Potential ecological risk of heavy metals in sediments from the Mediterranean coast, Egypt. J Environ Heal Sci Eng 13:70. https://doi.org/10.1186/s40201-015-0223-x

Tacon A (1987) The Nutrition and Feeding of Farmed Fish and Shrimp- A Training Manual. 2. Nutrient sources and Composition. In: Food Agric. Organ. United Nations

Tang J (2008) Background value of soil heavy metal in the Three Gorges Reservoir District. CHINESE J ECO-AGRICULTURE 16:848–852. https://doi.org/10.3724/SP.J.1011.2008.00848

Tovar-Sanchez A, Seron J, Marba N, et al (2010) Long-term records of trace metal content of western Mediterranean seagrass (Posidonia oceanica) meadows: Natural and anthropogenic contributions. J Geophys Res G Biogeosciences 115:G02006. https://doi.org/10.1029/2009JG001076

Warnau M, Ledent G, Temara A, et al (1995) Heavy metals in Posidonia oceanica and Paracentrotus lividus from seagrass beds of the north-western Mediterranean. Sci. Total Environ. 171:95–99

WHO (2004) Vitamin and mineral requirements in human nutrition, 2. edition

Wickham H (2016) ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York

Wilke CO (2020) cowplot: Streamlined Plot Theme and Plot Annotations for “ggplot2”

Worakhunpiset S (2018) Trace Elements in Marine Sediment and Organisms in the Gulf of Thailand. Int J Environ Res Public Health 15:810. https://doi.org/10.3390/ijerph15040810

Yalcin MG (2009) Heavy mineral distribution as related to environmental conditions for modern beach sediments from the Susanoglu (Atakent, Mersin, Turkey). Environ Geol 58:119–129. https://doi.org/10.1007/s00254-008-1499-2

Zakhama-Sraieb R, Sghaier Y, Ben Hmida A, Xharfi-Cheikhrouha F (2014) Mercury Contamination in Posidonia Oceanica in a Harbour Area of the Eastern Coast of Tunisia. In: 5ème Symposium Médoterranéen sur la Végétation Marine. pp 184–187

Zakhama-Sraieb R, Sghaier YR, Hmida A Ben, et al (2016) Variation along the year of trace metal levels in the compartments of the seagrass Posidonia oceanica in Port El Kantaoui, Tunisia. Environ. Sci. Pollut. Res. 23:1681–1690

Zeghdoudi F, Tanjir LM, Ouali N, et al (2019) Concentrations of trace-metal elements in the superficial sediment and the marine magnophyte, Posidonia oceanica (L) Delile, 1813 from the Gulf of Skikda (Mediterranean coast, East of Algeria). Cah Biol Mar 60:223–233. https://doi.org/10.21411/CBM.A.BBC0ABC8

Zhou Q, Zhang J, Fu J, et al (2008) Biomonitoring: An appealing tool for assessment of metal pollution in the aquatic ecosystem. Anal Chim Acta 606:135–150. https://doi.org/10.1016/j.aca.2007.11.018

Zohra BS, Habib A (2016) Assessment of heavy metal contamination levels and toxicity in sediments and fishes from the Mediterranean Sea (southern coast of Sfax, Tunisia). Env Sci Pollut Res 23:13954–13963

Figures

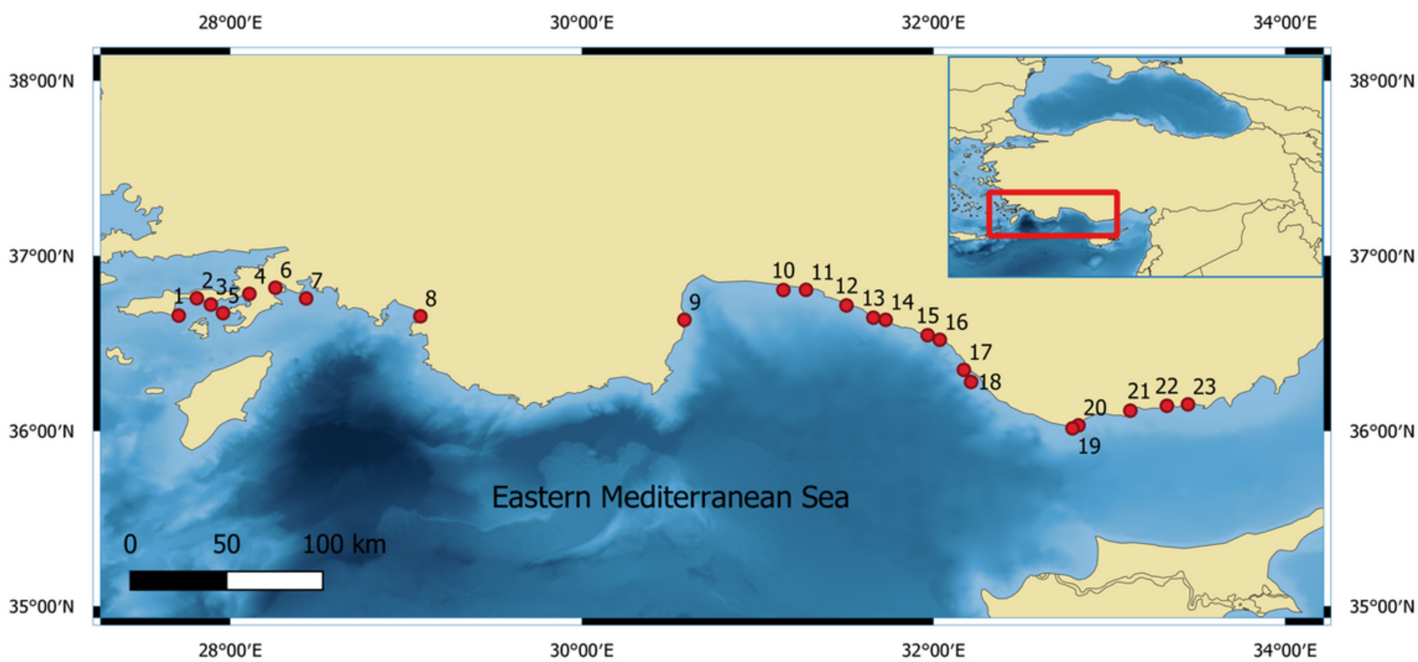

Figure 1

Sampling area. Posidonia oceanica and sediment samples were collected from 23 different stations along the Mediterranean Sea coast of Turkey

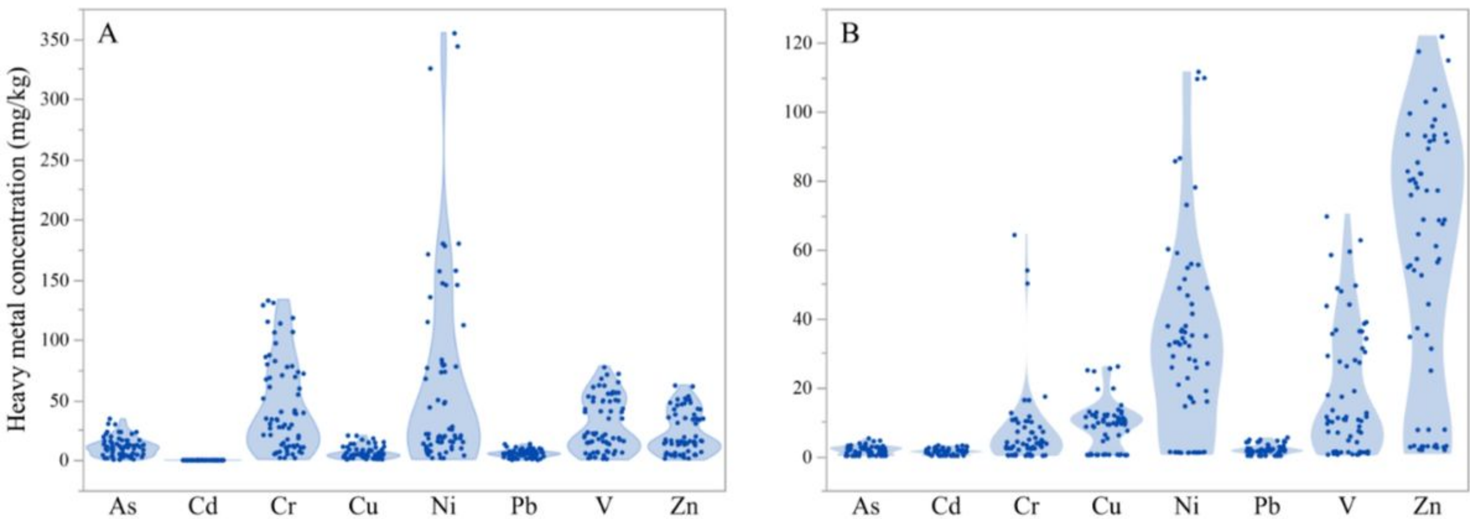

Figure 2

Violin plots showing the distribution of trace elements (mg kg-1 dry weight) in sediment (A) and Posidonia oceanica (B) collected from 23 different stations along the Mediterranean Sea coast of Turkey. Each dot shows the result of different samples.

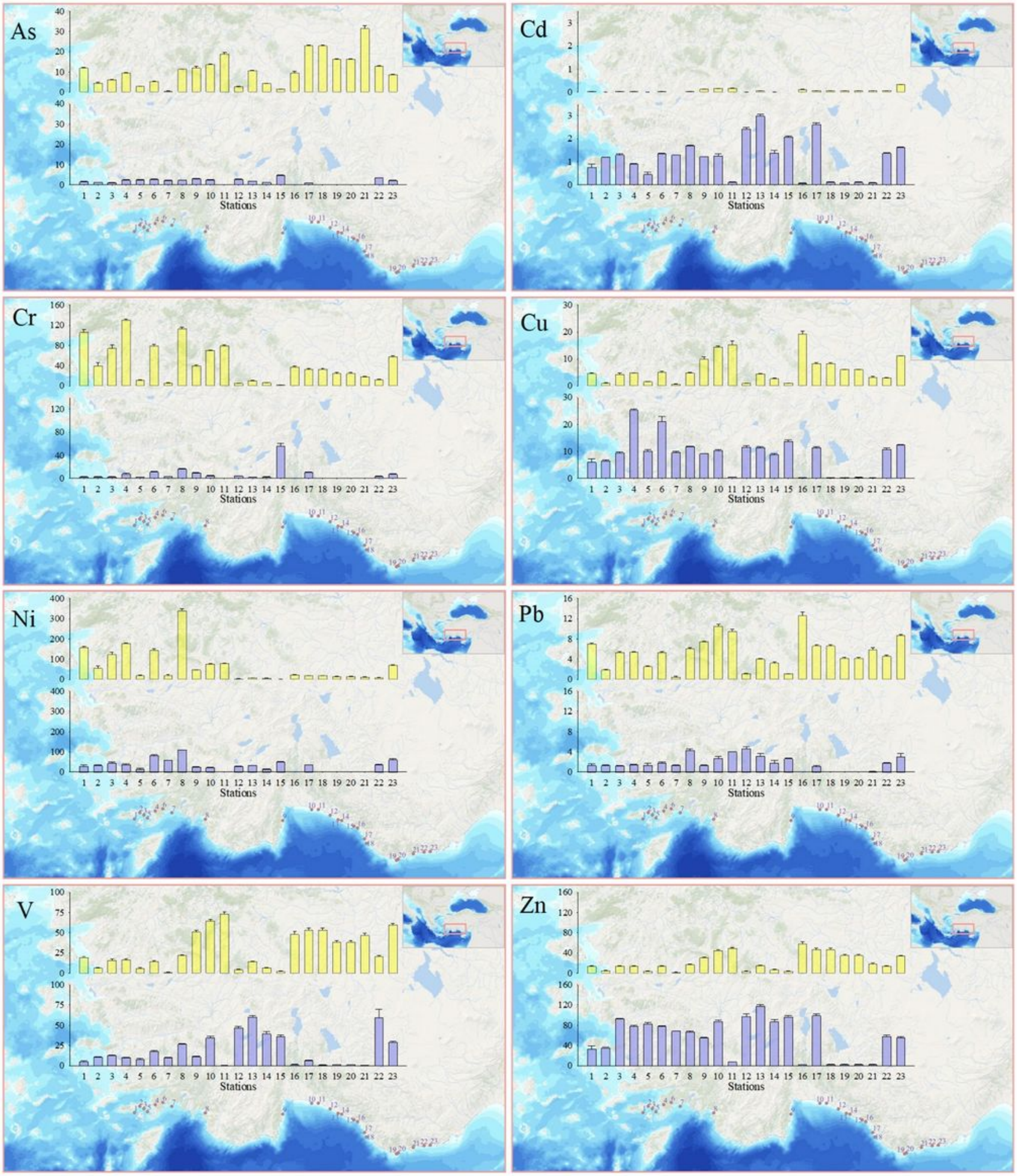

Figure 3

Trace element concentrations (average ± standard error; dry weight, mg kg-1) in the sediments (yellow bars) and the Posidonia oceanica (purple bars) collected from 23 different stations along the Mediterranean Sea coast of Turkey.

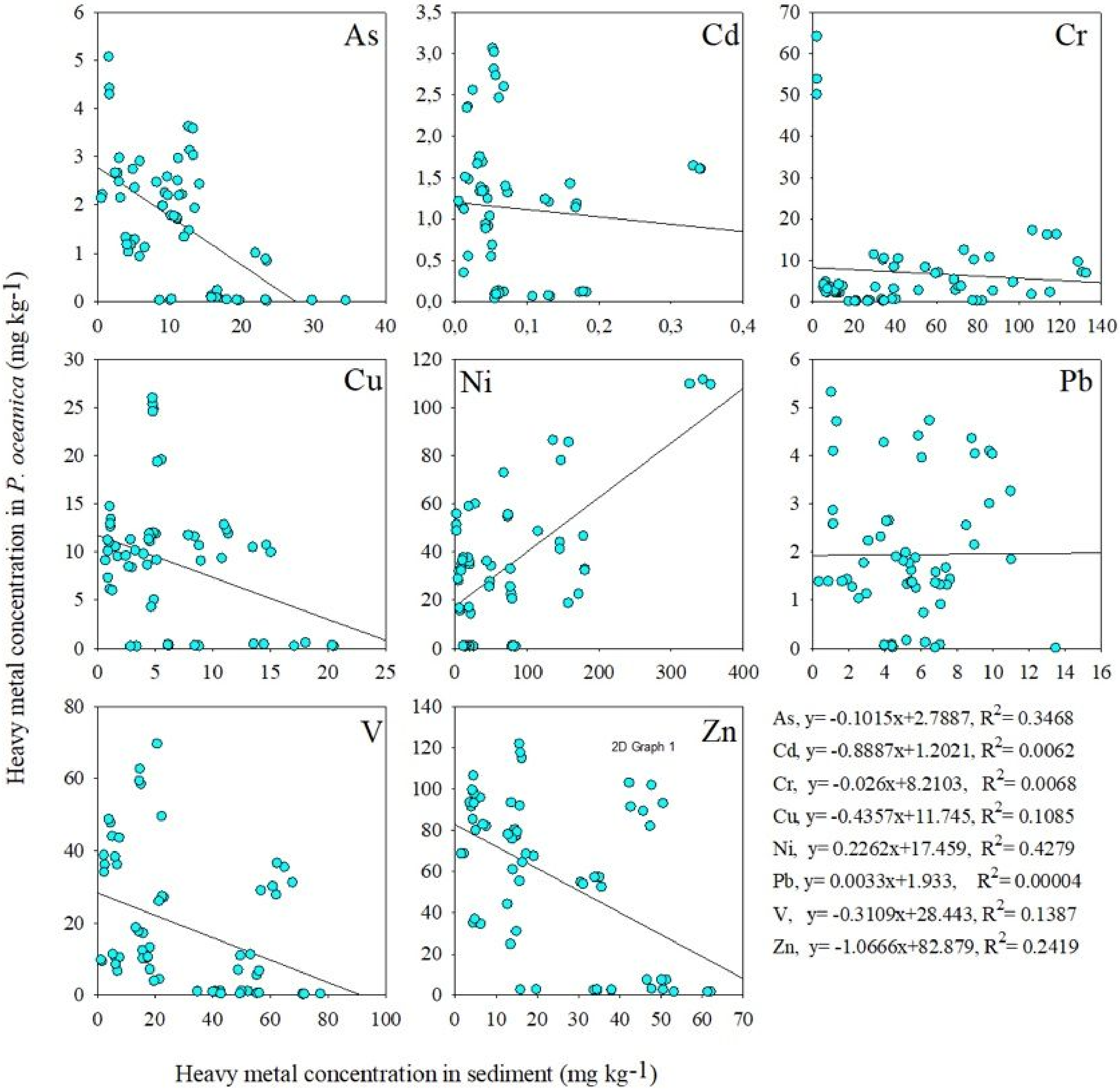

Figure 4

The relationship between trace element concentration in sediment and Posidonia oceanica sampled along the Mediterranean Sea coast of Turkey. Each dot shows the result of different samples.

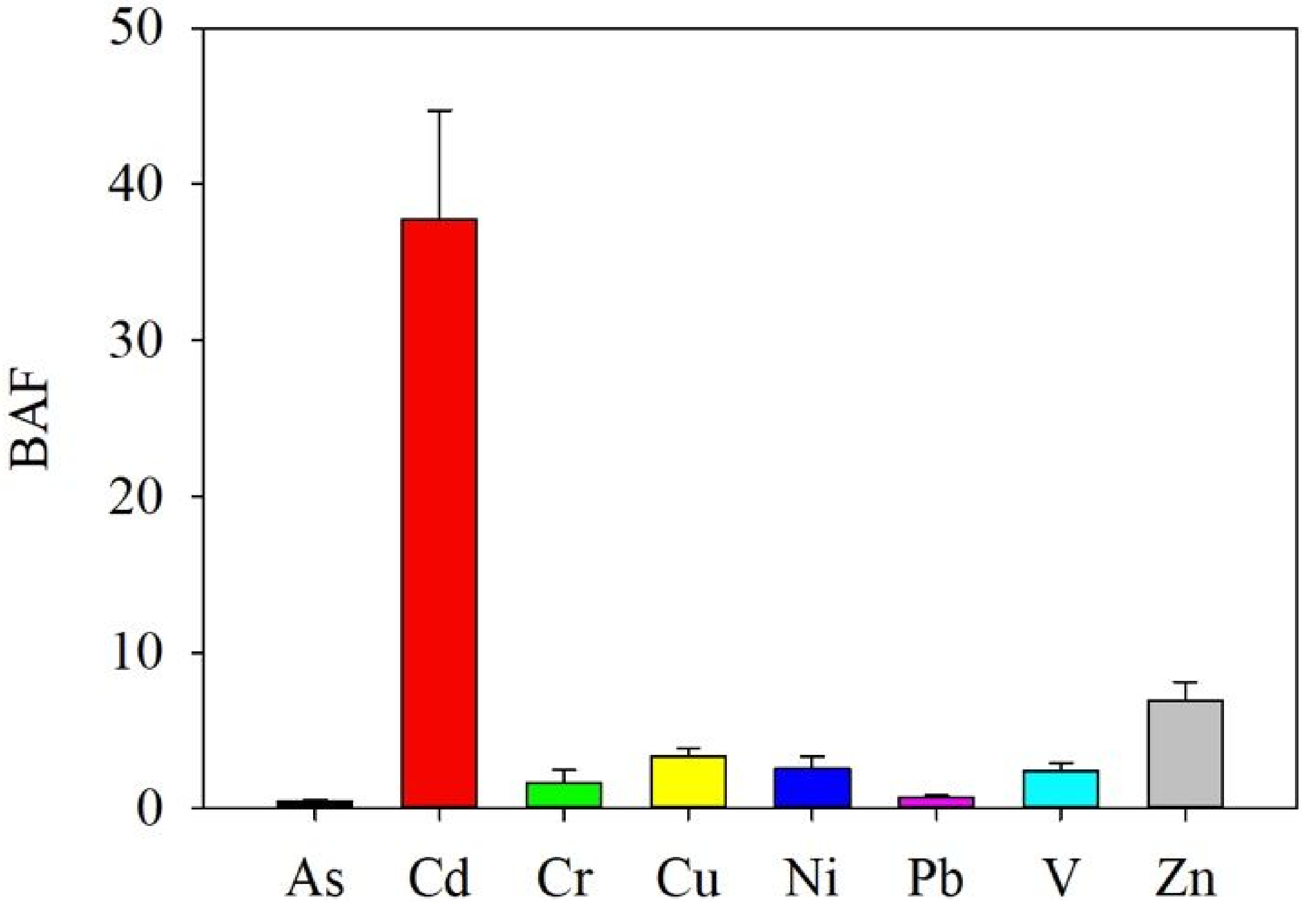

Figure 5

Bioaccumulation factor in Posidonia oceanica