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

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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 (Debano 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 performed 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 °C 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 °C until constant weight. Dried sediment was homogenized in a mortar and then sieved through a 2 mm sieve. Each sample was digested using HNO₃ (Suprapur, Merck) and H₂O₂ (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 HNO₃ (65% Suprapur, Merck) and heated on the block heater at 95±3°C for 2.5 hours. After cooling, 2.5 ml of H₂O₂ (30% Suprapur, Merck) was added, and tubes were heated on the block heater at 95±3°C 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 4°C 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
### 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 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:

\[
\text{Bioaccumulation factor} = \frac{C_{\text{blades}}}{C_{\text{sediment}}}
\]

Where \( C_{\text{blades}} \) is the TE concentration in the *P. oceanica* blades and \( C_{\text{sediment}} \) 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

| Reference | Analyzed | Recovery |
|-----------|----------|----------|
| Reference | Analyzed | Recovery |
| Reference | Analyzed | Recovery |

|   | Reference | Analyzed | 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.
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).

|       | 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).

|     | V    | Cr  | Ni  | Cu  | Zn  | As  | Cd  | Pb  |
|-----|------|-----|-----|-----|-----|-----|-----|-----|
| V   |      |     |     |     |     |     |     |     |
| Cr  | 0.260|     |     |     |     |     |     |     |
| Ni  | **0.341** | **0.451** |       |     |     |     |     |     |
| Cu  | **0.422** | **0.394** | **0.669** |     | **0.906** |     |     |     |
| 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** |     |     | **0.472** |
| Cd  | **0.729** | **0.400** | **0.549** | **0.578** | **0.578** | **0.462** | **0.429** | **0.539** |
| 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 Morocco | NA          | NA           | 9.13–30.51    | 8.23–28.56   | ND–476.00    | 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 Lebanon | 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 | NA | 0.6±0.1 | 5.2±8 | (Baroli et al. 2001)        |
| Mediterranean Sea Coast of Sardinia | NA | NA | NA | 6.0±2.5 | Na | Na | Na | 6.0±2.5 | 5.2±0.1 | (Zeghdoudi et al. 2019)      |
| Mediterranean Sea Coast of France | NA | 15.2–68.1 | NA | 6.07–52.44 | 8.52–40.17 | NA | 0.53–2.33 | 7.73–71.25 | (Warnau et al. 1995)         |
| Mediterranean Sea Coast of Corsica | NA | 1.53±1.07 | NA | 12.1±2.6 | 179±69 | NA | 2.4±0.5 | 7.76±2.74 | (Lafabrie et al. 2008)       |
| Mediterranean Sea Coast of Italy | NA | 0.15–1.07 | 15.93–48.73 | NA | NA | NA | 1.47–3.97 | 1.27–3.37 | (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 | 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 (337), Ni (256), V (245), Cr (164), Pb (072) and As (047). 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

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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

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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.

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**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