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Seasonal courses of nutrients and heavy metals in water, sediment and above- and below-ground *Typha domingensis* biomass in Lake Burullus (Egypt): Perspectives for phytoremediation

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ABSTRACT

The present study was carried out in natural stands of *Typha domingensis* in Lake Burullus, Egypt, to investigate (1) nutrient dynamics and heavy metals accumulation in its organs, (2) the phytoextractive potential of its organs and (3) the amount of nutrients and heavy metals released back into the water after decomposition of the dead tissues. Nitrogen concentrations were higher in the shoot than in the root and rhizome, while P, Ca, Cu, Fe, Zn and ash concentrations were higher in the root than in the rhizome and shoot. Significant differences in the concentrations of Mg, Cd, Cu and ash were assessed during the growing season of *T. domingensis*. The content of most nutrients and heavy metals in the shoot increased rapidly during the early growing season in February, reached maximal values in July and then decreased again. The nutrient and heavy metal contents in the below-ground portion of the plant showed an opposite trend compared to the shoot; they decreased sharply during the spring, when they were translocated, supporting the heterotrophic phase of shoot growth. However, they increased slightly from July to September and then decreased again. The transfer factors of all nutrients and heavy metals from the sediment to the below-ground organs were greater than unity. The higher translocation ratio of N in *T. domingensis* shoots makes it suitable for N phytoextraction from water and sediment, while the lower translocation ratios for Cd, Cu, Fe, Pb and Zn make it suitable for metal ion phytostabilisation. The dead shoot biomass of the stands at the end of 2010 amounted to 1950 g DM m^{-2}, when the seasonal decomposition process began. With a decay rate of 0.0049 day^{-1}, 1624 g DM m^{-2} is decomposed in the lake in a year. This is equivalent to releasing the following nutrient and heavy metals into the surrounding water (in g m^{-2}): 23.4 N, 0.8 P, 19.2 Ca, 1.8 Mg, 5.6 Na, 32.8 K, 0.01 Cd, 0.01 Cu, 0.84 Fe, 0.12 Pb and 0.03 Zn.

Introduction

Plants play an important role in nutrient cycling in wetlands through uptake, storage, and release processes (Eid et al., 2010a). In particular, plants with a high annual production, such as *Typha* species, can extract large amounts of nutrients from their environment. Consequently, wetland plants have been used to reduce the nutrient content of domestic, industrial, and agricultural wastewater (e.g., Vymazal, 2008). The recycling of nutrients is an important function in aquatic ecosystems; for this reason, the dynamics of nutrient cycling should be understood to properly manage wetland ecosystems that are used for biomass production or wastewater treatment (Bose et al., 2008; Calheiros et al., 2009; Lorenzen et al., 2001; Sasmaz et al., 2008). *Typha* species generally act as nutrient pumps (Sharma, 2007), absorbing large amounts of nutrients from the sediment and accumulating them in their above-ground tissues. However, the contribution of plants to removing nutrients is often temporary as they release nutrients through leaching and microbial decomposition of their litter (Eid et al., 2010a; Sharma et al., 2006).

Heavy metals, such as Cd, Cu, Fe, Pb and Zn, are elements that cannot be degraded by microbial or chemical process; therefore, they tend to accumulate in soils and aquatic sediment. The problem is not restricted to soils with high metal levels, such as those of mining areas, but also includes those with moderate to low metal contamination (Ali et al., 2004). Thus, the contamination of

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the aquatic and soil environments with these metals is a serious problem that threatens aquatic ecosystems, agriculture and human health (Gupta et al., 2010; Hegazy et al., 2011). These toxic elements come from many human activities, such as corrosion, smelting, refining of non-ferrous metals, electroplating, agricultural practices and industrial and municipal wastes (Kabata-Pendias, 2011; Ross, 2004). Recently, there has been increasing interest in the study of metal-accumulating plants as phytoremediators (Peng et al., 2008). One method of phytoremediation is phytostabilisation, where plants are used to immobilise metals and store them in their below-ground organs and/or soil. In contrast, during phytoextraction, hyperaccumulators may be used to remove metals from the soil and concentrate them in above-ground organs (Bose et al., 2008; Weis and Weis, 2004).

Lake Burullus is a lagoon extending along the Deltaic Mediterranean coast of Egypt (Long. 31°22′–31°35′N, Lat. 30°31′–31°08′E). It is characterised by an arid climate with warm summers (20–30 °C) and mild winters (10–20 °C). In 1998, the lake was registered as a Ramsar site because of its importance for wintering, foraging, refuge and breeding of birds (Kassas, 2002), and in particular, as a suitable habitat for fry and juveniles (Khalil and El-Dawy, 2002). It is connected with the Mediterranean Sea through a natural outlet, called Al-Bughaz. The area of Lake Burullus is approximately 410 km^2, with an oblong shape bordered by agricultural lands in the south and a sand bar that separates it from the Mediterranean Sea in the north. The depth of this lake varies between 20 cm close to the shore of the eastern basin and 200 cm in the middle basin and near the sea outlet. Lake Burullus, one of the Mediterranean eutrophic lakes, is one of the major disposal areas for agricultural drainage water in Egypt. It receives approximately 4 billion m^3 of drainage water per year from the Nile Delta agricultural lands (El-Shinnawy, 2002), which accounts for 97% of the water inflow (Eid, 2012; Shaltout and Khalil, 2005).

Typha domingensis (Pers.) Poir. ex Steud. is a plant that grows throughout the warm-temperate and tropical regions. In Egypt, it spreads in water bodies such as lakes, ditches and marshy places (Boulos, 2005; Täckholm, 1974), and it is one of the major components of the vegetation stands along the shores of Lake Burullus (Shaltout and Al-Sodany, 2008). *T. domingensis* is an emergent plant that is commonly used in constructing wetlands for enhancement of water quality in water treatment systems (Eid et al., 2012a; El-Sheikh et al., 2010; Hegazy et al., 2011) due to its high growth rate and great capacity for accumulating nutrients in its tissues (Lorenzen et al., 2001; Newman et al., 1996). As the role of *T. domingensis* in nutrient cycling is not yet clearly understood in Lake Burullus, the present study aims to investigate (1) nutrient dynamics and heavy metals accumulation in the organs of *T. domingensis*, (2) the phytoextractive potential of its organs and (3) the amount of nutrients and heavy metals released back into the water after decomposition of dead tissues. These studies are important to understand the effect of *T. domingensis* on the aquatic ecosystem and could help to find suitable strategies for its management in Egyptian wetlands.

Materials and methods

Field and laboratory

Biomass data for *T. domingensis* in Lake Burullus, which are used in the present study, are presented in Fig. 1 as in Eid et al. (2012b). Sampling was carried out at three sites (Fig. 2). Above-ground organs were sampled monthly from February 2010 to October 2010, each time from three randomly distributed quadrats (0.5 × 0.5 m) at each sampling site. Care was taken to randomly select these quadrats and to ensure that sampling was not conducted in quadrats that were <2 m from the shoreline or from previously sampled quadrats. Below-ground organs were excavated from the same quadrats at a depth of 0.5 m (90–100% of all roots and rhizomes are located between 0 and 20 cm depth; Miao and Sklar, 1998), washed with lake water until free from sediment, and then sorted into rhizomes and roots.

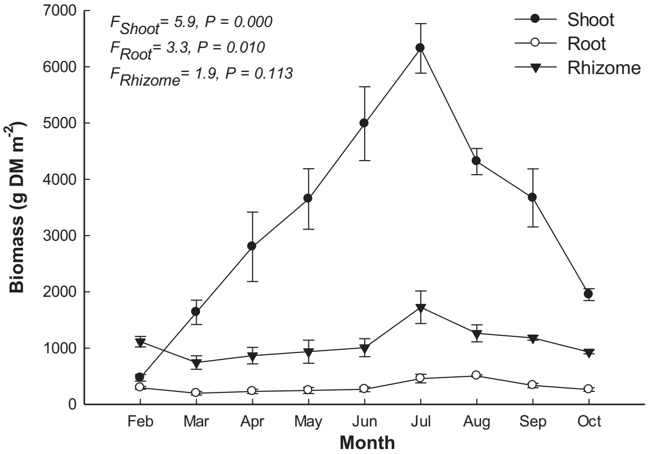

Fig. 1. Monthly variation in the above- and below-ground biomass of *Typha domingensis* in Lake Burullus during one growing season (February–October 2010). Vertical bars indicate the standard errors of the means (N = 9). F-values represent the one-way ANOVA, degree of freedom (df) = 8.
Data from Eid et al. (2012b).

In the laboratory, samples were carefully washed with tap water over a 4 mm mesh sieve to minimise material loss, oven dried at 85 °C to a constant weight and ground using a metal-free plastic mill. All biomass values were determined as gram dry matter per square metre (g DM m^{-2}).

Water sampling

At each sampling site, three water samples were collected monthly from the same sampling quadrats. The water samples were taken as integrated composite samples from the top of the water surface down to 50 cm. The samples were collected in plastic bottles and brought to the laboratory where filtered. EC, pH, N and P were measured directly after collection. After that, samples were deep-frozen for further analysis of dissolved Ca, Mg, Na, K, Cd, Cu, Fe, Pb and Zn.

Sediment sampling

At each sampling site, three sediment samples were collected monthly from the same sampling quadrats wherefrom the plant biomass samples were taken, as a profile down to a depth of 50 cm. The sediments were air dried and passed through a 2 mm sieve to remove gravel and debris.

Chemical analysis

For sediment samples, soil–water extracts at 1:5 were prepared for the determination of pH and EC, while 2.5% (v/v) glacial acetic acid was used for the extraction of Ca, Mg, Na and K. Diethylenetriaminepentaacetic acid solution (DTPA) was used for the extraction of available heavy metals (Cd, Cu, Fe, Pb and Zn). Sodium bicarbonate solution was used for the extraction of available P, and potassium sulphate solution was used for the extraction of available N.

For plant samples, nutrients (except N) and heavy metals were extracted from 0.5 to 1 g of plant organs (shoot, root and rhizome)

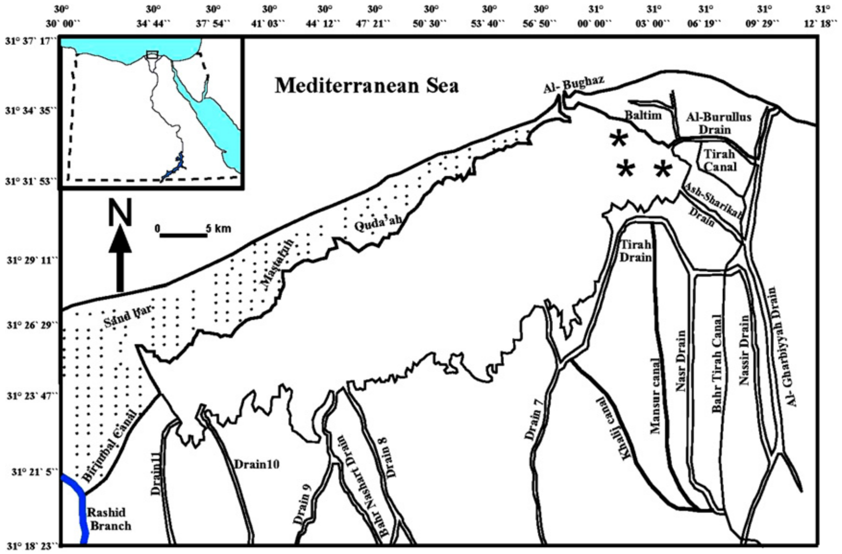

Fig. 2. Map of Lake Burullus (Egypt) indicating the locations of the three sampling sites (*).

using a mixed-acid digestion method. For plant, water and sediment samples, Ca, Mg, Na, K, Cd, Cu, Fe, Pb and Zn were determined by atomic absorption spectroscopy (Shimadzu AA-6300), and P was determined spectrophotometrically (CECIL CE 1021) using the ammonium–molybdate method. EC and pH of water and sediment samples were measured using conductivity and pH-meters (Myron L Model DA-1 and ICM Model 41150, respectively). Amount of ash ($mg\,g^{-1}$) was estimated in plant samples by ignition at 550 °C for 2 h. Total N was determined in plant samples using a CHN Elemental Analyzer (Yanako CHN Corder MT-5 and Auto Sampler MTA-3, manufactured by Yanako Co., Ltd., Japan).

The indo-phenol blue method was used for determination of N in water and sediment samples using a spectrophotometer (CECIL CE 1021). All of these procedures are outlined in detail in Allen (1989) and APHA (1998). The data of N, P, Ca, Mg, Na and K concentrations are presented in $mg\,g^{-1}$, while Cd, Cu, Fe, Pb and Zn concentrations are presented in $mg\,kg^{-1}$. Chemical concentrations are expressed based on dried matter. Finally, the nutrient and heavy metal contents of the above- and below-ground biomasses ($g\,m^{-2}$) were calculated by multiplying the nutrient and heavy metal concentrations with the biomass of the respective parts ($g\,DM\,m^{-2}$).

Estimation of transfers of substances

A transfer factor (TF) was calculated to determine the relative uptake of nutrients and heavy metals from the sediment by the plant (Chamberlin, 1983): TF = concentration of an element in the plant body ($mg\,kg^{-1}$)/concentration of the same element in the sediment at the same site ($mg\,kg^{-1}$).

A translocation ratio (TR) was calculated to depict the ability of the plant to translocate nutrients and heavy metals from the root to the shoot (Kim et al., 2003): TR = concentration of an element in the shoot ($mg\,kg^{-1}$)/concentration of the same element in the root ($mg\,kg^{-1}$).

Statistical analysis

Nutrient and heavy metal data for *T. domingensis* tissues were subjected to a two-way analysis of variance to test the differences between tissues over time. The significance of variation in water and sediment quality parameters over time was assessed using one-way analysis of variance (ANOVA-1). Correlations between the concentrations of nutrients and heavy metals in the plant organs and water or sediment samples were evaluated using the Pearson's *r* coefficient. We used regression procedures to evaluate the statistical relationships between biomass and nutrient and heavy metal contents in *T. domingensis* ($g\,m^{-2}$). Statistical analyses were carried out using STATISTICA (Statsoft, 2007).

Results

Many water parameters of Lake Burullus had their highest values during the summer months (Fig. 3), such as Cu and Zn in June, N, Mg, Na and K in July and Cd and Pb in August. However, EC and Ca were highest in April, pH in September and P and Fe in February. In addition, many sediment parameters had their highest values during the summer months (Fig. 4), such as Pb in June, Ca, Mg and EC in July and P, Cd and Cu in August. However, N and K were highest in March, Na in April, pH in September and Fe and Zn in February.

Shoots started to grow in early spring (February), reached their maximum biomass of 6327 $g\,DM\,m^{-2}$ in mid-summer (July), and then rapidly decreased growing in fall when they entered the senescence stage. Growth ceased completely already before fully dying off in the winter (Fig. 1). The total below-ground biomass decreased to 941 $g\,DM\,m^{-2}$ in spring (March) due to the upward translocation of rhizome reserves fueling the initial growth of shoots, then gradually increased to a maximum biomass of 2184 $g\,DM\,m^{-2}$ in mid-summer (July), when downward translocation of assimilates occurred from shoots, and decreased afterwards to reach finally 1193 $g\,DM\,m^{-2}$ in autumn (October).

The mean N concentration was higher in the shoot than in the root or rhizome, while the concentrations of P, Ca, Cu, Fe, Zn and ash were higher in the root than in the rhizome or shoot (Figs. 5 and 6). Significant seasonal differences were recorded for Mg, Cd, Cu and ash amounts during the growing season of *T. domingensis*, while such differences were no significant for N, P, Ca, Na, K, Fe, Pb and Zn (Figs. 5 and 6). Maximum concentrations of all nutrients in the shoot were recorded at the beginning of the growing season, after which they gradually decreased (Fig. 5). In addition, N, P, Ca, Na and K concentrations decreased in the rhizome from February to July and began to increase thereafter. However, Fe, Zn and ash concentrations increased in the rhizome from February to March and then decreased to minimum values in July and increased thereafter (Fig. 6).

The nutrient and heavy metal contents in the shoot increased rapidly from the early growing season (February) until

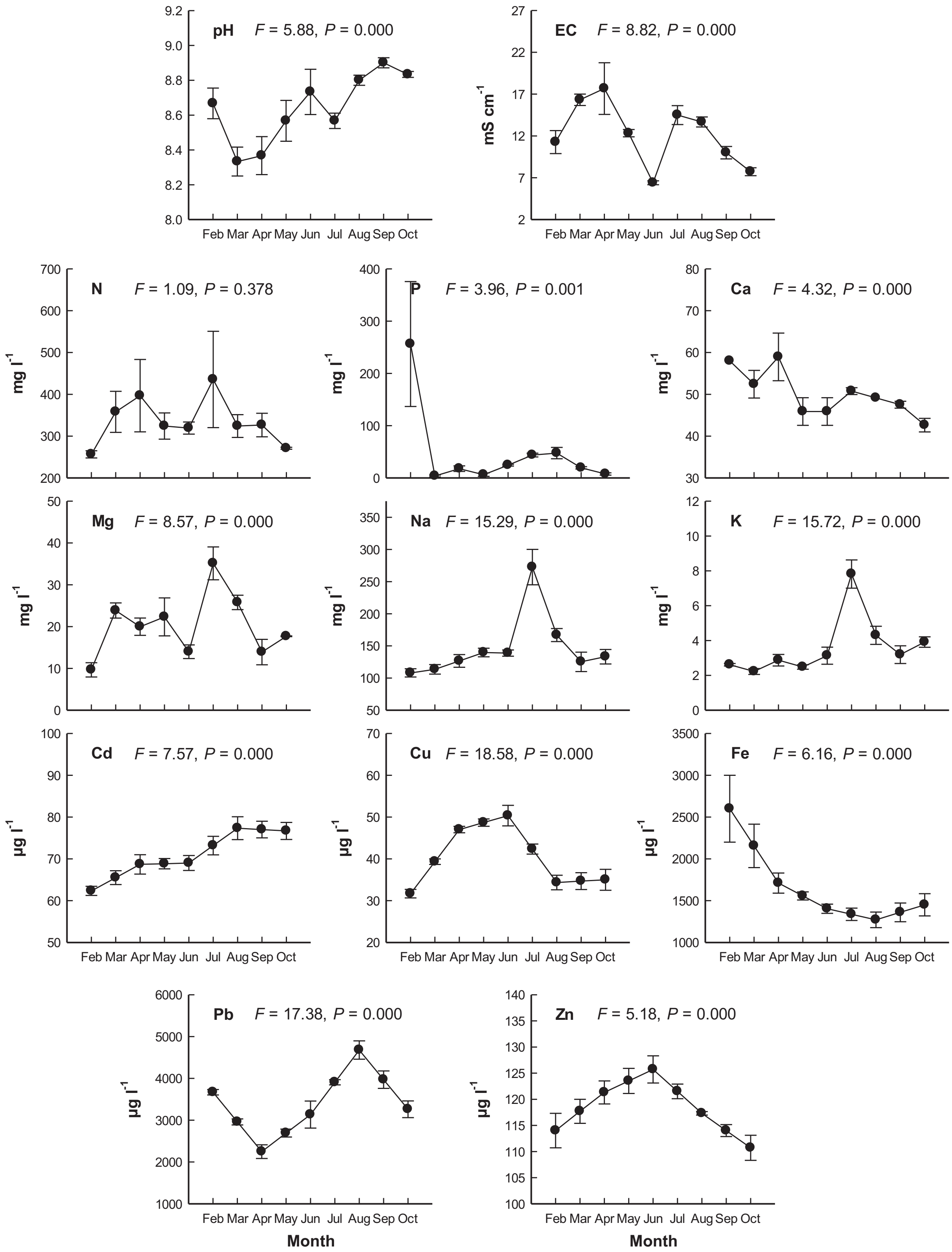

Fig. 3. Monthly variation in the water characteristics in stands supporting *Typha domingensis* in Lake Burullus. Water characteristics were measured monthly from February to October 2010. Vertical bars indicate the standard errors of the means ($N = 9$). *F*-values represent the one-way ANOVA, degree of freedom (df) = 8.

reaching their maxima in July and then decreased (Figs. 7 and 8). The contents of nutrients and heavy metals in the below-ground biomass decreased sharply during the spring, when they became translocated to support the heterotrophic phase of shoot growth, increased slightly from July to September, and continued to decrease thereafter (Figs. 7 and 8).

The transfer factor (TF) of all nutrients and heavy metals from the sediment to the below-ground organs

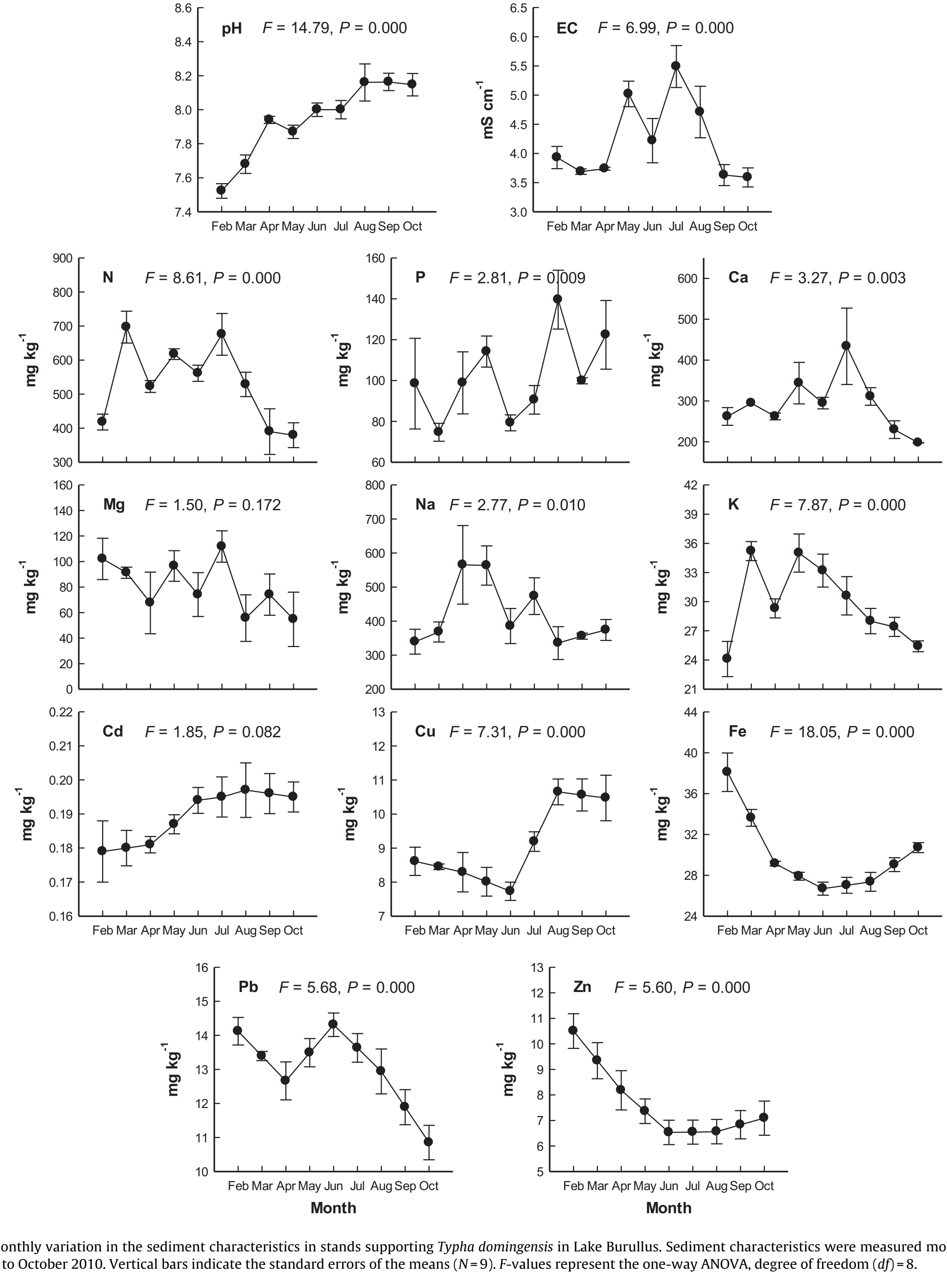

Fig. 4. Monthly variation in the sediment characteristics in stands supporting *Typha domingensis* in Lake Burullus. Sediment characteristics were measured monthly from February to October 2010. Vertical bars indicate the standard errors of the means ($N = 9$). *F*-values represent the one-way ANOVA, degree of freedom (df) = 8.

was greater than unity and had the following sequence: K > Fe > Ca > Cd > N > Mg > P > Na > Pb > Zn > Cu (Table 1). N had the maximum translocation ratio from the below-ground to the above-ground organs, while Fe had the minimum. For all heavy metals, translocation ratios were less than unity, indicating that heavy metal concentrations in the below-ground organs were higher than in the above-ground organs.

In many cases, the concentrations of the same elements in the different organs of *T. domingensis* were positively correlated (Table 2). Only P in the rhizome and root was negatively

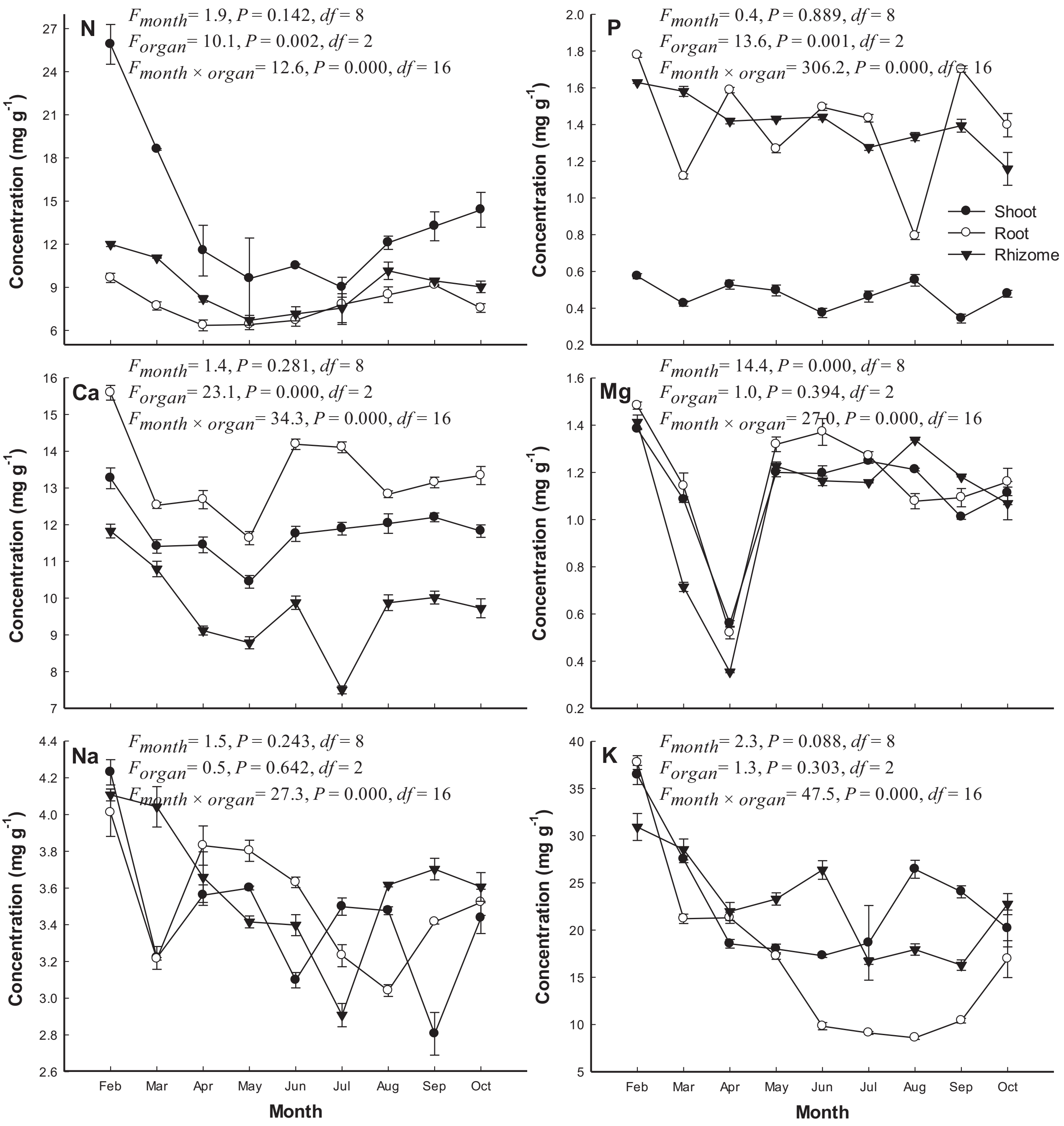

Fig. 5. Monthly variation in the nutrient concentrations in *Typha domingensis* in Lake Burullus during one growing season (February–October 2010). Vertical bars indicate the standard errors of the means (N = 9). F-values represent the two-way ANOVA. *df*: degree of freedom.

correlated. However, P in the sediment and Cd in the root, rhizome and shoot were positively correlated with P and Cd in the water. Regression equations between the biomass and nutrient and heavy metal contents indicated that all correlations were significantly positive (Table 3).

Discussion

The nature of bottom sediment of lakes and similar water bodies reflects, to a great extent, the conditions resulting from water inputs and the type of pollutants (Radwan, 2001). In Lake Burullus, the concentrations of nutrients and heavy metals are due to the input of domestic, industrial and agricultural drainage from human settlements, factories and reclaimed lands in the catchment area of this lake (Eid et al., 2010b; Okbah, 2005; Okbah and Hussein, 2006; Shaltout and Khalil, 2005). Many of the estimated water and sediment parameters in the present study had high values during the summer, which may be due to an excessive inflow of drainage discharge into the lake during the rice cultivation season (June–September) – cf. Eid et al. (2010b).

With concern to uptake of chemical elements in *T. domingensis*, no significant differences were found between the shoot and rhizome concentrations of Mg, Na, K, Cd, Cu and Pb; similar findings were reported also in *Phragmites australis* (Eid, 2012; Engloner et al., 2004). Seasonal variation in N, P, Ca, Mg, Na and K were

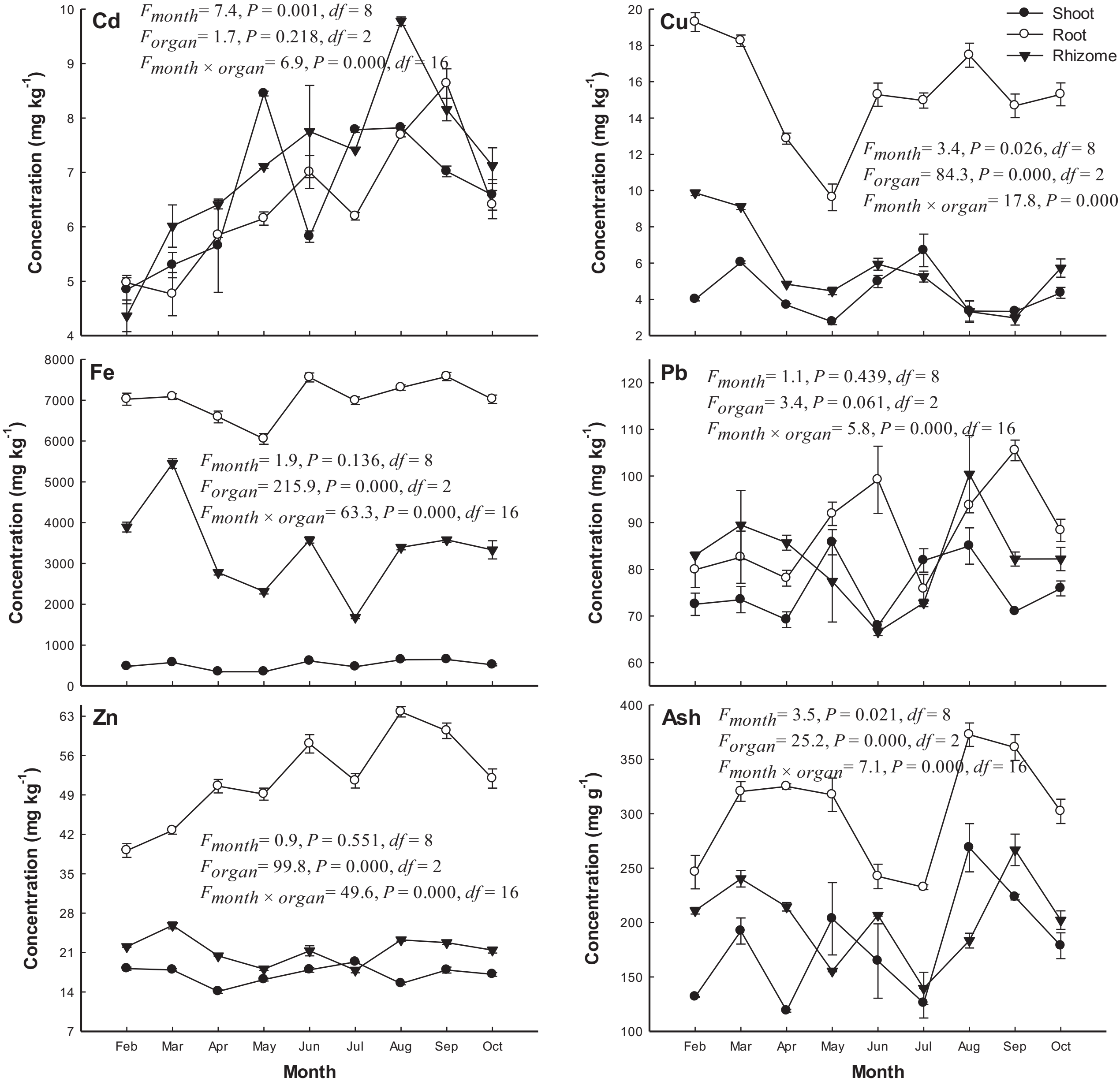

Fig. 6. Monthly variation in the heavy metal and ash concentrations of *Typha domingensis* in Lake Burullus during one growing season (February–October 2010). Vertical bars indicate the standard errors of the means (N = 9). F-values represent the two-way ANOVA. df: degree of freedom.

Table 1
Mean and standard error (SE) of the transfer factors from sediment to below-ground organs and translocation ratios from below- to above-ground organs of the nutrients and heavy metals in *Typha domingensis* in Lake Burullus.

	Transfer factor		Translocation ratio	
	Mean	SE	Mean	SE
N	15.8	1.9	1.8	0.2
P	13.4	1.8	0.4	0.1
Ca	39.4	3.3	1.1	0.1
Mg	13.7	1.7	1.1	0.1
Na	8.8	0.8	1.0	0.1
K	671.1	116.2	1.2	0.3
Cd	35.7	2.3	0.9	0.1
Cu	1.2	0.1	0.6	0.1
Fe	174.7	11.6	0.1	0.0
Pb	6.5	0.4	0.9	0.1
Zn	5.0	0.5	0.6	0.0

similar to the patterns reported in previous studies (Bernard and Fitz, 1979; Garver et al., 1988; Sharma et al., 2006). The concentration of mineral elements in the shoot of *T. domingensis* depends on its growth stage (Sharma et al., 2006). In the present study, maximum nutrient concentrations in the shoot were recorded in

Table 2
Positive (above diagonal) and negative (below diagonal) correlations (P < 0.05) between the nutrients and heavy metals in the sediment, water and *Typha domingensis* organs in Lake Burullus.

	Water	Sediment	Root	Rhizome	Shoot
Water	–	P	Cd	Cd	Cd
Sediment	Cu	–		Fe	
Root	K, Cu	Zn	–	Mg, K, Cd, Cu, Fe	Ca, Mg, Cd, Fe
Rhizome	Na, K, Zn		P	–	N, Mg, Cd, Cu, Fe
Shoot		K			–

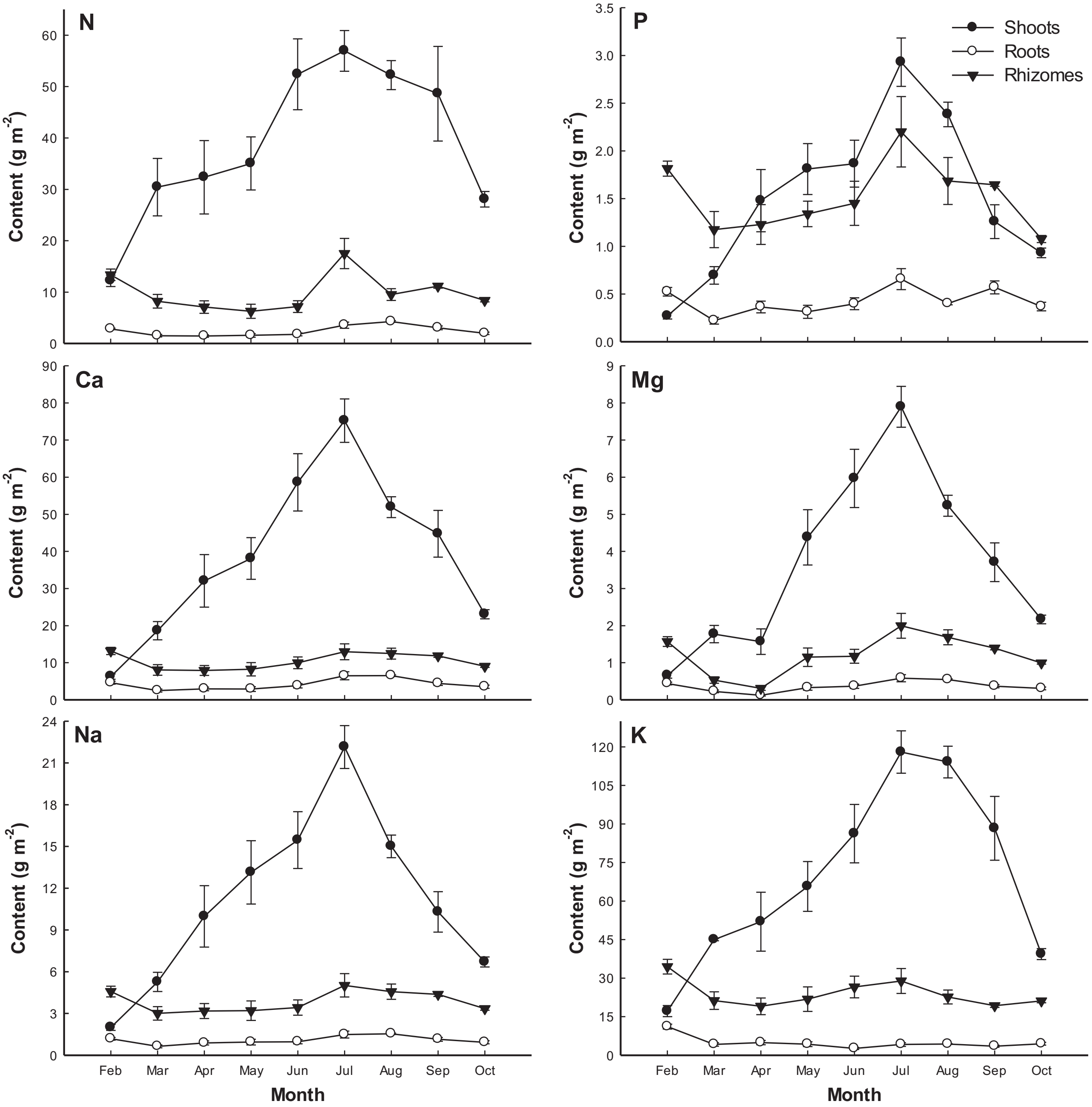

Fig. 7. Monthly variation in the nutrient content of *Typha domingensis* in Lake Burullus during one growing season (February–October 2010). Vertical bars indicate the standard errors of the means ($N = 9$).

February at the beginning of the growing season, and then they gradually decreased due to dilution in the above-ground biomass. Although nutrient concentrations in the shoot declined throughout the growing season, the nutrient content increased and reached its maxima in July, which means that biomass was the decisive factor in determining the quantity of nutrients per unit area of stand (Boyd and Hess, 1970). Nitrogen concentration was greater in the shoot than in the below-ground organs. Similar finding were obtained by Ruiz and Velasco (2010) and Eid (2012) in *P. australis*. The decrease in N, P, Ca, Na and K concentrations in the rhizome during the growth period from February to July indicates an upward translocation of reserves to support the heterotrophic phase of shoot growth. From July onwards, N, P, Ca, Na and K concentrations began to increase in rhizomes due to downward translocation, which recycles and withdraws nutrients from the senesced parts of the plant for reuse (Vitousek, 1982), in parallel with carbohydrate allocation to the rhizomes (Tursun et al., 2011).

In Lake Burullus during the growing season, shoots of *T. domingensis* accumulate a larger quantity of nutrients than the below-ground organs, thus constituting a significant pool of absorbed nutrients. However, the below-ground organs accumulate a larger quantity of heavy metals and ash than the shoot, which contributes a significant pool of absorbed heavy metals and ash. In addition, the ash values in roots reached 37% of the dry matter, which could be the result of excessive surface soil contamination (Cherney, 2006) and/or carbon mineralisation there. As 0.01–39.3 g m^{-2} of the nutrients and heavy metals remained in the dead biomass at the end of the growing season (Figs. 7 and 8), other parts of these elements taken up into the plants must have been released back into the ecosystem either through leaching or during

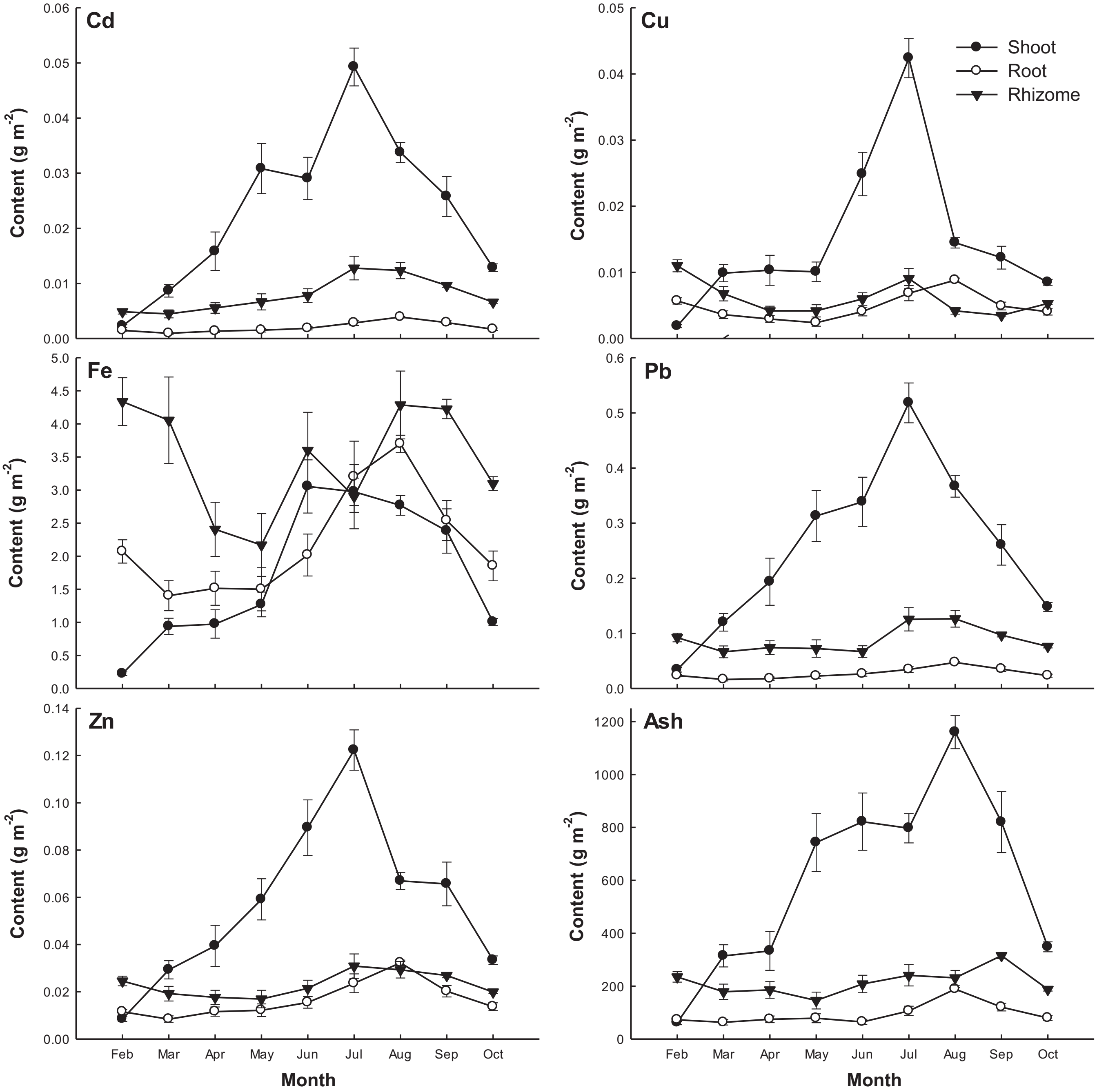

Fig. 8. Monthly variation in the heavy metals and ash content of *Typha domingensis* in Lake Burullus during one growing season (February–October 2010). Vertical bars indicate the standard errors of the means ($N = 9$).

decay of shoots. The dead shoot biomass entering the decomposition process at the end of 2010 amounted to 1950 g DM m^{-2} (Fig. 1). Using a decay rate of 0.0049 day^{-1} (Cunha-Santino and Bianchini, 2006), we calculate that 1624 g DM m^{-2} is decomposed in a year. This is equivalent to releasing the following amounts into the surrounding water (in g m^{-2}): 23.4 N, 0.8 P, 19.2 Ca, 1.8 Mg, 5.6 Na, 32.8 K, 0.01 Cd, 0.01 Cu, 0.84 Fe, 0.12 Pb and 0.03 Zn.

In the present study, the Fe concentration in the rhizome was positively correlated with that in the sediment, while the Cd concentration in the water was positively correlated with Cd concentrations in all of the organs (Table 2). Such correlations indicate that *T. domingensis* reflects the cumulative effects of environmental pollution from water and sediment. The nutrient and heavy metal compositions of aquatic plants have been reported to increase with increasing levels of environmental nutrients and heavy metals (Bonanno and Lo Giudice, 2010; Eid et al., 2012a; Peng et al., 2008; Ruiz and Velasco, 2010), but this relationship is not simple and probably differs with both species and element (Boyd and Hess, 1970). A linear relationship between Cd in the plant material and its concentration in the growth media was reported by Kabata-Pendias (2011). Herawati et al. (2000) reported a significant positive correlation between the Cd in rice and its level in many soil types.

Budget calculations of nutrients and heavy metals in aquatic ecosystems need information on biomass and chemical compositions of species. Equations based on biomass would be helpful for calculating nutrient and heavy metal quantities per unit area for a particular species (Table 3). In our study, biomass accounted for 78% of the variation in grams per square metre of N, P, Ca, Mg, Na, K,

Table 3
Regression equations between the biomass of *Typha domingensis* in Lake Burullus as the *x* variable (g DM m^{-2}) and the respective nutrient and heavy metal contents as the *y* variable (g m^{-2}).

Constituent (*y*)	Regression equation	*r*	*P*
Shoot			
N	$y = 16.624 + 0.008\,x$	0.780	0.013
P	$y = -0.136 + 0.001\,x$	0.938	0.000
Ca	$y = -3.048 + 0.013\,x$	0.991	0.000
Mg	$y = -0.506 + 0.001\,x$	0.960	0.000
Na	$y = 0.089 + 0.003\,x$	0.973	0.000
K	$y = -2.766 + 0.020\,x$	0.911	0.001
Cd	$y = -0.003 + 7.805 \times 10^{-6}\,x$	0.968	0.000
Cu	$y = -0.004 + 5.851 \times 10^{-6}\,x$	0.886	0.001
Fe	$y = -0.049 + 0.0005\,x$	0.917	0.001
Pb	$y = -0.011 + 8.024 \times 10^{-5}\,x$	0.983	0.000
Zn	$y = -0.005 + 1.875 \times 10^{-5}\,x$	0.985	0.000
Ash	$y = 27.358 + 0.113\,x$	0.928	0.000
Rhizome			
N	$y = -1.830 + 0.011\,x$	0.859	0.003
Ca	$y = 4.117 + 0.006\,x$	0.844	0.004
Mg	$y = -0.571 + 0.002\,x$	0.873	0.002
Na	$y = 1.272 + 0.002\,x$	0.897	0.001
Cd	$y = -0.002 + 9.080 \times 10^{-6}\,x$	0.850	0.004
Pb	$y = 0.011 + 7.183 \times 10^{-5}\,x$	0.878	0.002
Zn	$y = 0.006 + 1.575 \times 10^{-5}\,x$	0.887	0.001
Root			
N	$y = -0.943 + 0.011\,x$	0.967	0.000
Ca	$y = -0.107 + 0.014\,x$	0.974	0.000
Mg	$y = -0.014 + 0.001\,x$	0.874	0.002
Na	$y = 0.247 + 0.003\,x$	0.964	0.000
Cd	$y = 8.462 \times 10^{-6}\,x$	0.934	0.000
Cu	$y = 1.797 \times 10^{-5}\,x$	0.927	0.000
Fe	$y = -0.147 + 0.0075\,x$	0.988	0.000
Pb	$y = 6.367 \times 10^{-5} + 8.832 \times 10^{-5}\,x$	0.937	0.000
Zn	$y = -0.005 + 6.867 \times 10^{-5}\,x$	0.956	0.000
Ash	$y = -8.038 + 0.402\,x$	0.860	0.003

Cd, Cu, Fe, Pb, Zn and ash (Table 3). In Lake Burullus, the estimates of these twelve constituents in *T. domingensis* stands from biomass data should be sufficient for most nutrient and heavy metal budget studies.

Factors affecting nutrient and metal accumulation by aquatic plants could be of biological (e.g., species, plant age, generation time) or non-biological nature (e.g., temperature, season, salinity, pH – Bonanno and Lo Giudice, 2010; Sharma et al., 2006). Nutrient and metal accumulation by macrophytes is in particular affected by their concentrations in the water and sediment (Lin and Zhang, 1990; Ruiz and Velasco, 2010), but even more by nutrient and metal speciation, such as availability of free ions and the effect of humic complexes (Bonanno and Lo Giudice, 2010). With concern to overall element budgets, in the present study, N, P, Na, K and Pb levels in *T. domingensis* were comparable to those of some other studies (Table 4).

The calculated transfer factors (TFs) generally indicate movements of nutrients and heavy metals from soil to the roots, while the translocation ratios (TRs) generally indicate transport of nutrients and heavy metals from cattail roots to shoots. They characterise the uptake efficiency with respect to the available nutrients and metals from the environment and give an idea of whether the plant is an accumulator or excluder (Bose et al., 2008). Zu et al. (2005) reported that TFs > 1 were found in nutrient- and metal-accumulating plants, whereas they are typically <1 in nutrient- and metal-excluding plants. TRs > 1 indicate that the plant is effective in the translocation of nutrients and metals from root to shoot tissue (Ma et al., 2001). In *T. domingensis* growing in Lake Burullus for all heavy metals the mean TRs from the below- to the above-ground tissues were lower than one, which means that *T. domingensis* does not effectively transfer heavy metals from the below- to above-ground tissues, i.e., the plant accumulates metals in the below-ground organs

Table 4
Examples of average *Typha* species nutrient and heavy metal concentrations in natural stands worldwide.

Species	N (mg g^{-1})	P (mg g^{-1})	Ca (mg g^{-1})	Mg (mg g^{-1})	Na (mg g^{-1})	K (mg g^{-1})	Cd (mg kg^{-1})	Cu (mg kg^{-1})	Pb (mg kg^{-1})	Zn (mg kg^{-1})	Reference
T. domingensis (Pers.) Poir. ex Steud.											
	10.3	1.0	11.6	1.1	3.5	19.9	6.71	8.46	82.1	30.2	Present study
	16.0	1.1	–	–	–	–	–	–	–	–	Miao and Sklar (1998)
	16.8	–	–	–	–	–	–	–	–	–	Esteves et al. (2008)
T. angustifolia L.											
	13.2	1.9	6.1	1.5	7.3	20.1	–	–	–	–	Mason and Bryant (1975)
	16.0–31.0	1.7–3.6	–	–	–	–	–	–	–	–	Sharma et al. (2006)
T. angustata Bory & Chaub.											
	39.3	0.6	–	–	–	–	–	19.8	19.3	59.1	Bose et al. (2008)
T. elephantina Roxb.											
	11.7	1.4	–	–	–	–	–	–	–	–	Gopal and Sharma (1984)
T. glauca Godr.											
	30.6	3.4	9.1	1.8	–	21.1	–	–	–	–	Bernard and Fitz (1979)
	7.0–30.2	0.9–4.8	–	–	–	–	–	–	–	–	Davis and van der Valk (1983)
T. latifolia L.											
	13.7	2.1	8.9	1.6	3.8	23.8	–	–	–	–	Boyd and Hess (1970)
	–	–	–	–	–	–	0.3	40.0	10.5	278.0	Sasmaz et al. (2008)
	–	–	–	–	–	–	2.4	–	475.1	237.0	Ye et al. (1997)

better than in the above-ground organs. This is in agreement with results reported by other researchers (e.g., Bose et al., 2008; Eid et al., 2012a; Hegazy et al., 2011; Sasmaz et al., 2008). The higher translocation ratio of N in *T. domingensis* shoots makes it suitable for N phytoextraction from water and sediment of the eutrophic lake, while the lower translocation ratios for Cd, Cu, Fe, Pb and Zn could make the species suitable for metal phytostabilisation (Ali et al., 2004; Sasmaz et al., 2008). Differences in TR values in detail may be related to differences in the solubility and availability of each heavy metal ion (Kim et al., 2003) and may also be due to compartmentalisation and translocation in the vascular system (Kim et al., 2003). The high concentration of Fe in the root of *T. domingensis* is probably due to the presence of iron plaques remains at the roots, although root samples were carefully washed with tap water after sampling. To remove the roots' iron coating completely, probably it would have been necessary to use the dithionite-citrate-carbonate (DCB) modified method of Taylor and Crowder (1983). Iron plaques are commonly observed on the roots of wetland plants and may play a key role in constructed wetlands detoxifying the water from pollutants (Wang and Peverly, 1996). The plaques, resulting from oxidation of iron ions by oxygen release from roots, may protect the root from heavy metal toxicity by co-precipitation or adsorption of toxic metals (Ali et al., 2002).

In conclusion, *T. domingensis* in Lake Burullus could be a suitable green filter to reduce the pollution load reaching the lake, if the above-ground biomass is harvested when they contain the maximum amounts of nutrients and heavy metals. In Lake Burullus, the above-ground biomass reaches its maximum value in July, as did as the maximum content of N, P, Ca, Mg, Na, K, Cd, Cu, Pb and Zn. Thus, we recommend harvesting and removing leaves and upper shoot parts in July to avoid leaching of nutrients from the plant materials to the sediment and water. Harvested materials could be used as roof or fencing materials, green manure or as substrate for biogas production. The annual production of this plant approximates 35.8 ton ha^{-1}; thus, the sustainable annual utilisation of this species should not exceed its annual production. However, over the long term, annual harvesting may lead to deterioration of the primary productivity of *T. domingensis*. Thus, for the sustainable use of *T. domingensis* stands, harvests should not be conducted annually; perhaps harvest rotation could be used (similar to crop rotation in farming).

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