Effects of surrounding land use on metal accumulation in environments and submerged plants in subtropical ponds

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Abstract Ponds are widely used as stormwater treatment facilities to retain contaminants, including metals, and to improve water quality throughout the world. However, there is still a limited understanding of the effects of surrounding land use on metal accumulation in pond environments and organisms. To address this gap, we measured the concentrations of nine metals (i.e., Al, Ba, Ca, K, Li, Mg, Na, Se, and Sr) in water, sediments, and submerged plants collected from 37 ponds with different surrounding land uses in southwestern China and assessed the metal accumulation capacity of four dominant submerged plant species. Our results showed that Al, Ca, and K concentrations in the water were above drinking water standards. In the sediments, the average concentrations of Ca and Sr were higher than the corresponding soil background values. *Ceratophyllum demersum* L. could accumulate more K in aboveground biomass than *Myriophyllum spicatum* L. and *Potamogeton maackianus* A. Benn. The K concentration in submerged plants was positively influenced by the corresponding metal concentration in the water and negatively

influenced by water temperature. Among the nine studied metals, only the water K concentration in ponds receiving agricultural runoff was significantly higher than that for ponds receiving urban and forested runoff. This result suggests that surrounding land use types have no significant effect on metal accumulation in sediments and submerged plants in the studied ponds. A large percentage of the metals in these ponds may be derived from natural sources such as the weathering of rocks.

Keywords Aquatic plants · Bioaccumulation · Heavy metals · Light metals · Sediments

Introduction

Ponds are important freshwater habitats for conserving aquatic biodiversity throughout many regions of the world (Oertli et al. 2002; Akasaka et al. 2010). However, many ponds have been drained and filled for agricultural or urban uses (Brönmark and Hansson 2002). Approximately 40–90 % of the ponds in northwestern European countries have been lost during the last century (Oertli et al. 2002). In many regions, such as southern China, ponds are often used as stormwater treatment facilities to reduce runoff peaks and improve water quality by physical, chemical, and biological processes (Campbell 1994; Yin and Shan 2001). However, such ponds may retain a large amount of contaminants, including metals, in the water and sediments, and these contaminants can act as a pollution source for adjacent aquatic ecosystems (Mermillod-Blondin et al. 2008).

Many ponds receive water mainly from direct precipitation and surface runoff discharged from surrounding landscapes (Wang et al. 2014). It has been reported that runoff from urban and agricultural lands contains elevated metal concentrations

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compared to runoff from natural vegetation areas (Helsel et al. 1979; Xiao et al. 2013). To date, only a few studies have addressed the relationships between metal concentrations in ponds and the surrounding land use characteristics, and their results are not consistent (e.g., Karouna-Renier and Sparling 2001; Liebens 2001). Liebens (2001) found that pond sediments had consistently lower levels of heavy metals in residential areas than in commercial areas. However, Karouna-Renier and Sparling (2001) reported that the water and sediment metal concentrations in ponds did not differ significantly among land uses.

Some organisms in ponds, such as aquatic plants, fish, and invertebrates, are sensitive to metal contamination and can accumulate metals in their tissues (Gundersen and Steinnes 2001; Weber et al. 2013; Harguinteguy et al. 2014). In the past two decades, submerged plants have been extensively used to stabilize and remove metals from polluted water and sediments in freshwater habitats (Outridge and Noller 1991; Rai et al. 1995; Mishra and Tripathi 2008; Kara 2010; Wang et al. 2014). Submerged plants possess significant potential to accumulate metals partly due to their greater surface area in contact with the water as compared to non-submerged (e.g., emergent and floating-leaved) plants (Xing et al. 2013). Such phytoremediation technology is a low-cost and environmentally friendly remediation method that utilizes the capacity of submerged plants to extract heavy metals either from the water via the leaves or from the sediments through the roots (Outridge and Noller 1991; Rai et al. 1995; Peng et al. 2008; Olguín and Sánchez-Galván 2012).

Highly toxic heavy metals, such as Cd, Cr, Hg, and Pb, have been frequently studied due to their severe toxic effects on the environment and aquatic organisms (Singh et al. 2003; Bai et al. 2009; Huang et al. 2012; Zeng and Wu 2013). In recent years, less toxic heavy metals (e.g., Sr and Se) and light metals (e.g., Al, K, Mg, and Na) have gained increasing attention by researchers because they are essential or beneficial elements for living organisms but can also cause adverse effects on organisms and human health when their concentrations exceed a certain threshold (Gensemer and Playle 1999; Mechora et al. 2011; Xing et al. 2013). For instance, excess Al in soils can result in a reduced and damaged plant root system which may limit mineral nutrient and water uptake (Jansen et al. 2002).

In this study, we measured the concentrations of nine metals (i.e., Al, Ba, Ca, K, Li, Mg, Na, Se, and Sr) in water, sediments, and submerged plants collected from 37 subtropical ponds around Lake Dianchi in southwestern China. Based on previous reports of the effect of adjacent land use on metal concentrations in ponds (e.g., Liebens 2001), we hypothesized that the concentrations of the measured metals in ponds receiving urban or agricultural runoff would be significantly higher than those in ponds receiving forested runoff. The aims of this study were as follows: (1) to examine the spatial

variation of the metals in the water and sediments, (2) to determine the accumulation of metals in the submerged plants, and (3) to analyze the influences of environmental factors on the metal accumulation capacity of submerged plants.

Materials and methods

Study areas

Lake Dianchi (24° 40′–25° 02′ N, 102° 36′–102° 47′ E) is a large, shallow, eutrophic lake located in southwestern China (Fig. 1). The lake is characterized by a surface area of 297.9 km², an average water depth of 4.4 m, and a water retention time of 11.69 months. The average air temperature of Lake Dianchi is 7.4 °C in January and 19.6 °C in July. The mean annual rainfall is approximately 1036 mm, and over 85 % of the total rainfall is concentrated in the rainy season from May to October (Wang and Dou 1998). The predominant land uses in the catchment of Lake Dianchi are forests (51.1 %), croplands (26.5 %), and urban areas (9.0 %).

There are over 200 ponds around Lake Dianchi (Wang et al. 2014). These ponds receive water directly from precipitation and surrounding surface runoff. All ponds contain standing water throughout the year. In the present study, we selected 37 ponds non-randomly based on the ease of access (Fig. 1). The 37 ponds had surface areas ranging from less than 20 m² to over 500 m² and mean depths ranging from 0.3 m to 2.1 m. Adjacent land use within about 250 m of each pond was visually assessed and roughly assigned to one of three categories (i.e., cropland, forest, and urban). The 37 ponds were then separated into agricultural ponds ($N=19$), forested ponds ($N=11$), and urban ponds ($N=7$) according to their adjacent land use.

Field sampling

A sampling campaign was conducted from 26 May to 5 June 2011. In each pond, three sites were selected randomly to sample the water, surface sediments, and submerged plants from a small boat. At each sampling site, water depth and Secchi depth were recorded, and water temperature, pH, dissolved oxygen, conductivity, and oxidation–reduction potential were measured on-site using a YSI Professional Plus multi-parameter water quality meter (YSI Inc., Yellow Springs, Ohio, USA). A 500 mL water sample was collected at a depth of approximately 0.5 m and was immediately acidified with HNO₃ to a pH below 2.0. Then, approximately 1 kg of surface sediment was collected at the same site using a Peterson dredge and was placed in a sealed plastic bag. Submerged plants were collected using a pronged plant grab (25 cm×35 cm). Aboveground parts of submerged plants (i.e., stems, leaves, and reproductive structures) were rinsed

Fig. 1 Locations of the sampled ponds around Lake Dianchi in southwestern China

to remove all sediments, algae, and invertebrates and were put into cloth bags after species identification. The Flora of China (<http://www.efloras.org/>) was used as the authority for identifying the submerged species.

Determination of metal concentrations

In the laboratory, water samples were filtered through a 0.45- μm cellulose acetate membrane before measurement. Sediment samples were dried in an oven at 80 °C for 48 h; coarse debris was removed, and then, the sediment was passed through a 100-mesh nylon sieve (Zorer et al. 2009). Samples

of submerged plants were dried in an oven at 105 °C for 24 h and then ground using a hand mortar. The plant and sediment samples were then accurately weighed and microwave-digested with a mixture of HNO_3 , HCl , HF , and H_2O_2 before testing (Zeng and Wu 2013; Xing et al. 2013).

Nine metal concentrations (i.e., Al, Ba, Ca, K, Li, Mg, Na, Se, and Sr) in the water, sediments, and submerged plants were measured using inductively coupled plasma atomic emission spectrometry (ICP-AES, IRIS Intrepid II XSP, Thermo Elemental, USA). Reagent blanks and standard reference materials were also prepared to detect potential contamination during the analytical procedure. The relative error for all

Table 1 Summary statistics of metal concentrations in water (mg L^{-1}) and sediments (mg kg^{-1} dry weight) collected from ponds

Water ($N=37$)						Sediments ($N=37$)				
	Minimum	Maximum	Average	S.E.	WHO (2008) limit	Minimum	Maximum	Average	S.E.	Soil background value ^a
Al	ND	0.738	0.237	0.043	≤ 0.2	1962.54	39,311.78	17,226.65	1945.55	88,100
Ba	0.021	0.106	0.050	0.004	≤ 0.7	126.37	591.05	281.21	19.18	346
Ca	97.927	182.915	137.861	3.061	100	3082.26	126,387.64	38,024.43	4960.50	1600
K	0.389	27.601	15.019	1.051	≤ 12	1782.04	8786.82	3634.89	273.32	16,100
Li	0.000	0.042	0.006	0.001	–	9.48	56.16	30.80	1.93	38.2
Mg	19.729	51.363	27.017	1.452	50	450.44	39,034.27	4045.77	1158.43	6100
Na	8.450	69.597	37.659	2.127	200	359.92	2581.02	1080.90	103.73	1600
Se	ND	0.004	0.002	0.000	0.01	ND	ND	ND	ND	0.487
Sr	0.144	0.490	0.266	0.012	–	24.97	241.08	90.22	8.63	85

ND not detected

^a Metal background values of soils in the Yunnan Province (SEPAC 1990)

metals was less than 10 %, and the recovery rates ranged from 90 to 110 %.

Statistical analyses

Metal concentrations in water and sediments were analyzed at the pond level, while metal concentrations in submerged plants were analyzed at both the pond and species levels. Before the statistical analyses, the raw data were tested with the Shapiro–Wilk test for normality. Because most of the data in the present study were not normally distributed, non-parametric statistics were applied. We conducted a Kruskal–Wallis test to determine the differences in the metal concentrations of the water, sediments, and submerged plants among agricultural, forested, and urban ponds. Multiple comparisons were conducted with a Mann–Whitney test when the Kruskal–Wallis test indicated significant differences. The Spearman correlation test was used to examine the relationships among the metal concentrations in the water, sediments, and submerged plants. All statistical analyses were performed using PASW Statistics 18.0 software (IBM SPSS Inc., Chicago, USA).

Results

Metal concentrations in water and sediments

The Al and Se concentrations in more than half of the water samples were below the detection limit (Table 1). Among the nine metals measured in the water, Al, Ca, and K were present in higher concentrations than the permissible levels of these elements set by the WHO (Table 1). Only the water K concentration in agricultural ponds (17.358 mg L^{-1}) was significantly higher than that in forested ponds (13.817 mg L^{-1}) and urban ponds (10.559 mg L^{-1} ; Fig. 2).

The Se concentrations in the sediments were below the detection limit at all sampling sites (Table 1). The mean concentrations of Ba ($281.21 \text{ mg kg}^{-1}$), Li (30.80 mg kg^{-1}), and Sr (90.22 mg kg^{-1}) were similar to the soil background values in the Yunnan Province, whereas the average concentration of Ca ($38,024.43 \text{ mg kg}^{-1}$) exceeded the corresponding soil background value (Table 1). There was no significant difference in sediment metal concentrations among the agricultural, urban, and forested ponds (Fig. 3).

Metal concentrations in submerged plants

Submerged plants were only found in 21 ponds. Seven submerged species were encountered in the sampling campaign including *Myriophyllum spicatum* L. (8 designates the appearance in 8 out of 21 ponds), *Ceratophyllum demersum* L. (6), *Stuckenia pectinata* (L.) Börner (5), *Potamogeton maackianus*

Fig. 2 Metal concentrations (mean $\pm$ SE) in water collected from 37 ponds with different surrounding land uses. Different letters indicate significant differences at $p < 0.05$

A. Benn. (3), *Hydrilla verticillata* (L.f.) Royle (2), *Potamogeton crispus* L. (1), and *Potamogeton malaianus* Miq. (1). There was no significant difference in metal concentrations in submerged plants among the agricultural, urban, and forested ponds (Fig. 4).

Significant differences were found in K and Na concentrations among the four dominant species (i.e., *M. spicatum* L., *C. demersum* L., *S. pectinata* (L.) Börner, and *P. maackianus* A. Benn.). The K concentration in *C. demersum* L. was significantly higher than that in *M. spicatum* L. and *P. maackianus* A. Benn. but not significantly higher than that in *S. pectinata* (L.) Börner (Table 2). The Na concentrations in *M. spicatum* L. and *C. demersum* L. were significantly higher than that in *S. pectinata* (L.) Börner (Table 2). The maximum values of Ba, Na, and Se were 272.99 , 8928.53 , and 2.62 mg kg^{-1} in *M. spicatum* L. (Table 2).

Fig. 3 Metal concentrations (mean $\pm$ SE) in sediments collected from 37 ponds with different surrounding land uses

Fig. 4 Metal concentrations (mean $\pm$ SE) in submerged plants collected from 21 of the 37 ponds with different surrounding land uses

Correlations of metal concentrations among submerged plants, water, and sediments

Water temperature correlated strongly with the Ca ($r=0.49$, $p<0.05$), K ($r=-0.56$, $p<0.01$), and Sr ($r=0.54$, $p<0.05$) concentrations in submerged plants (Table 3). In addition, dissolved oxygen in the water was positively related to plant Ca ($r=0.52$, $p<0.05$) and Mg ($r=0.61$, $p<0.01$) concentrations.

Only the K concentration in submerged plants had a positive relationship with its corresponding concentration in water (Table 4). The water Se concentration showed a significant relationship with plant Na ($r=-0.89$, $p<0.05$; Table 4). Except for Mg and Se, the plant metal concentrations had no significant correlations with the metal concentrations in the sediments (Table 5).

Discussion

Effects of surrounding land uses on metal pollution in aquatic systems

Land use types are closely related to the characteristics of human activities, which may, in turn, indicate the anthropogenic contaminants carried into aquatic ecosystems through runoff processes (Liu et al. 2012). It has been reported that surface runoff from croplands and urban areas has elevated concentrations of contaminants (e.g., nitrogen, phosphorus, persistent organic pollutants, and metals) when compared to runoff from forests or grasslands (Karouna-Renier and Sparling 2001; Akasaka et al. 2010; Liu et al. 2011; Xiao et al. 2013). Some studies have found that nitrogen and phosphorus concentrations in freshwater systems receiving urban or agricultural runoff are significantly higher than those

Table 2 Minimum, maximum, and mean concentrations of metals in the four dominant submerged plant species (mg kg⁻¹ dry weight) collected from ponds

	<i>C. demersum</i> L. (N=6)			<i>M. spicatum</i> L. (N=8)			<i>S. pectinata</i> (L.) Börner (N=5)			<i>P. macckianus</i> A. Benn. (N=3)		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Al	2452.99	14,994.59	6685.27	820.36	15,006.13	3729.53	1827.51	18,076.77	6595.69	1860.59	3968.31	3063.98
Ba	80.59	181.15	114.64	98.88	272.99	151.75	73.02	198.24	122.81	80.47	188.54	149.29
Ca	15,360.83	11,8337.12	42,167.54	24,357.58	12,8113.62	77,348.9	17,200.71	14,3495.61	56,735.79	22,700.16	17,4839.93	110,673.50
K	9671.66	21,684.80	15,692.44a	2540.67	13,731.30	8038.76b	5613.76	18,528.50	10,573.00ab	2908.14	5288.86	4460.28b
Li	5.17	20.54	11.60	4.05	16.34	8.12	5.18	22.62	10.57	2.45	9.04	6.38
Mg	6997.67	18,742.98	10,741.72	4969.72	11,841.37	8626.20	6291.82	9878.49	7578.82	4231.75	9616.84	6791.35
Na	3987.06	7608.78	6414.69a	3233.71	8928.53	6752.73a	1862.80	5797.06	3258.35b	3404.15	6448.29	4683.99ab
Se	0.46	2.40	1.17	0.48	2.62	1.79	0.52	1.95	1.04	1.32	2.01	1.76
Sr	59.80	243.14	130.92	73.42	259.77	162.12	87.12	265.66	153.75	105.02	556.32	404.33

Within a row, mean values followed by different letter are significantly different ($p<0.05$)

Table 3 Spearman correlations between water quality and metal concentrations in submerged plants

Submerged plants (mg kg ⁻¹ dry weight)		Al	Ba	Ca	K	Li	Mg	Na	Se	Sr
Water quality	Water depth (m)	-0.09	-0.09	0.03	0.08	-0.04	0.20	0.19	0.03	0.14
	Secchi depth (m)	0.05	0.03	-0.15	0.16	0.16	0.04	-0.05	-0.20	-0.10
	pH	-0.09	0.29	0.44	-0.29	0.17	0.54*	0.03	0.11	0.37
	Temperature (°C)	-0.15	0.25	0.49*	-0.56**	0.16	0.27	-0.30	0.01	0.54*
	Dissolved oxygen (mg L ⁻¹)	-0.11	0.28	0.52*	-0.31	0.35	0.61**	-0.01	0.10	0.41
	Conductivity (μS cm ⁻¹)	0.09	-0.18	-0.25	0.30	-0.08	-0.20	0.28	0.00	-0.20
	Oxidation–reduction potential (mv)	0.23	0.00	-0.20	-0.08	0.29	-0.08	-0.30	0.00	-0.25

*Significant at the 0.05 level; **Significant at the 0.01 level

receiving forested runoff (e.g., Fitzpatrick et al. 2007). However, consistent with previous reports (Karouna-Renier and Sparling 2001; Casey et al. 2006), we found only a significant difference in water K concentration in ponds among land use types.

Metals enter into ponds from a variety of sources including natural or anthropogenic sources. The main anthropogenic sources of metals are mining, disposal of untreated effluents, industrial facilities, and traffic as well as heavy metal-containing fertilizers and pesticides in agricultural areas (Reza and Singh 2010). For K, the metal level in the water in agricultural ponds was significantly higher than that in urban and forested ponds. This result suggests that K fertilizers used on agricultural lands may be the dominant source of K in the studied ponds. For other metals (e.g., Al and Mg), the metal concentrations in forested ponds were similar in magnitude to ponds in other land use categories, suggesting that natural sources (e.g., the weathering of underlying soil and rock) other than the surrounding land use types may be responsible for a substantial percentage of the measured metal concentrations in the studied region (Casey et al. 2006). In addition, the

accumulation and distribution of metals in a pond are affected by flow velocity, residence time, and sediment properties such as particle size and organic matter content (Karouna-Renier and Sparling 2001).

Metal accumulation capacity of submerged plants

Many studies have assessed the ability of submerged plants for metal removal; the majority of them have been conducted under strict laboratory conditions (e.g., Fritioff et al. 2005). However, these metal accumulation capacities may be entirely different when plants are under field conditions, because metals may be at lower concentrations and some environmental factors (e.g., water pH and temperature) may be less favorable (Olguín and Sánchez-Galván 2012). Metal hyperaccumulation is a rare phenomenon that occurs in both terrestrial and aquatic plants. Over 450 higher plant species have been identified as metal hyperaccumulators, representing less than 0.2 % of all angiosperms in the world (McGrath and Zhao 2003). Al is the most abundant metal and the third most common element in the Earth's crust. There are many species

Table 4 Spearman correlations between metal concentrations in submerged plants and in water

Submerged plants (mg kg ⁻¹ dry weight)		Al	Ba	Ca	K	Li	Mg	Na	Se	Sr
Water (mg L ⁻¹)	Al	0.16	0.02	0.17	0.15	0.09	-0.05	-0.38	-0.34	0.35
	Ba	-0.02	0.15	-0.28	-0.09	0.07	-0.28	-0.05	-0.17	-0.14
	Ca	-0.04	-0.27	-0.09	0.03	-0.16	-0.15	0.07	-0.12	-0.03
	K	0.22	-0.28	-0.37	0.49*	-0.03	-0.20	0.16	-0.11	-0.29
	Li	-0.13	-0.03	-0.26	0.08	0.13	0.29	0.38	0.00	-0.12
	Mg	-0.21	0.04	-0.13	0.12	0.11	0.32	0.11	0.05	-0.20
	Na	0.01	-0.36	-0.33	0.22	-0.16	-0.31	0.32	0.23	-0.27
	Se	0.60	0.54	0.26	-0.03	0.60	0.14	-0.89*	-0.70	0.37
	Sr	0.28	-0.29	-0.26	0.25	-0.17	-0.68**	0.08	-0.16	-0.17

*Significant at the 0.05 level; **Significant at the 0.01 level

Table 5 Spearman correlations between metal concentrations in submerged plants and in sediments

		Submerged plants (mg kg ⁻¹ dry weight)							
		Al	Ba	Ca	K	Li	Mg	Na	Sr
Sediments (mg kg ⁻¹ dry weight)	Al	-0.20	-0.29	0.03	-0.26	-0.38	-0.14	0.16	0.27
	Ba	0.15	0.07	-0.13	0.02	0.18	0.13	-0.08	0.09
	Ca	-0.29	-0.16	0.03	-0.32	-0.29	0.09	0.12	0.34
	K	-0.14	-0.06	-0.21	-0.03	-0.16	0.13	0.11	0.46*
	Li	-0.23	0.35	0.10	-0.38	0.18	0.53*	-0.02	0.36
	Mg	-0.07	-0.01	-0.02	-0.04	-0.25	-0.12	0.17	0.14
	Na	-0.20	0.11	0.17	-0.18	-0.23	-0.16	0.05	0.18
	Se	–	–	–	–	–	–	–	–
	Sr	-0.12	-0.04	-0.16	-0.09	0.04	0.18	0.04	0.17

*Significant at the 0.05 level

that have been identified as Al hyperaccumulators in the world (Jansen et al. 2002). In the present study, the concentration of Al in *M. spicatum* L., *C. demersum* L., *S. pectinata* (L.) Börner, and *P. maackianus* A. Benn. was much higher than the respective threshold (1000 mg kg⁻¹ or 0.1 %) used to define hyperaccumulators (Branquinho et al. 2007). Therefore, the four submerged plants listed above are considered to be hyperaccumulators of Al. Xing et al. (2013) also reported that *C. demersum* L. in eutrophic lakes along the middle and lower reaches of the Yangtze River in China could accumulate up to 7685 mg kg⁻¹ of Al in aboveground tissues.

Na and K have been studied more for their negative effects at excess levels (i.e., salt stress) than as essential and beneficial metals for plant growth (Pilon-Smits et al. 2009). In the present study, the average concentrations of Na in *M. spicatum* L. and *C. demersum* L. were 6752.73 and 6414.69 mg kg⁻¹, respectively. The threshold for characterization as a halophyte is 2500 mg kg⁻¹ of Na in plant tissues (Pilon-Smits et al. 2009). Therefore, the above two submerged plants can tolerate salt stress and accumulate high levels of Na in their stems and leaves. In the studied ponds, the mean values of K and Na in submerged plants were 10,214.12 and 5584.26 mg kg⁻¹, respectively. In addition, Rawlence and Whitton (1977) showed that the ranges of the K and Na concentrations in submerged plants in three New Zealand lakes were 20,000–30,000 and 5000–5800 mg kg⁻¹, respectively. However, Xing et al. (2013) reported maximum average K and Na values of 7121 and 16,843 mg kg⁻¹ in *Najas marina* collected from eutrophic lakes in the Yangtze River basin. We can conclude that submerged plants in ponds in southwestern China had relatively high K and low Na concentrations in aboveground biomass.

Metal accumulation in submerged plants depends on a number of factors including the total amount and bioavailability of each metal as well as the temperature, pH, salinity, redox potential, and other environmental variables in the ambient water and sediments (Jackson 1998). Fritioff et al. (2005)

demonstrated that the concentrations of some metals in the tissues of *Elodea canadensis* Michx. and *Potamogeton natans* L. increased with increasing water temperature. We also found positive correlations between plant Ca and Sr concentrations and the pond water temperatures. In the present study, we found significantly positive correlation only between water pH and Mg accumulation in plants. One likely explanation for this result is that the competition between hydrogen ions and metal ions for surface sorption sites can be responsible for reduced Mg bioaccumulation at lower pH levels (Heijerick et al. 2005).

Conclusions

This study shows that sampled ponds in southwestern China had high Al, Ca, K, and Sr concentrations in the water or sediments. Surrounding land use types appear to have little effect on metal accumulation in water, sediments, and submerged plants. The four dominant submerged plants (*M. spicatum* L., *C. demersum* L., *S. pectinata* (L.) Börner, and *P. maackianus* A. Benn.) can accumulate high levels of Al and Na in aboveground biomass. In addition, the accumulation of K and Mg in submerged plants is influenced by both the metal concentration in water and the water temperature or pH. Further studies are needed to determine the distribution of the metals in the different parts of submerged plants and the possible toxic effects on the different tissues.

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