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## Spatial patterns of submerged macrophytes and heavy metals in the hypertrophic, contaminated, shallow reservoir Lake Qattieneh/Syria

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### ABSTRACT

Our investigation on macrophytes in Lake Qattieneh, a large, shallow reservoir in western Syria, is a first assessment of ecological status of this lake. We studied spatial distribution patterns of aquatic macrophyte vegetation and heavy metal concentrations to determine if they can be used as indicators of point sources of pollution. Industrial and municipal point sources at the lake shore increase nutrient load and contamination by heavy metals. Water analyses revealed high concentrations of some heavy metals at some littoral sites: Ni 88.7  $\mu\text{g L}^{-1}$ , Cr 49.99  $\mu\text{g L}^{-1}$ , Co 14.38  $\mu\text{g L}^{-1}$ , and Cu 11.65  $\mu\text{g L}^{-1}$ . Despite hypertrophic conditions and high heavy metal contamination, we recorded several submerged macrophyte species with heterogeneous spatial distribution patterns. Whereas *Potamogeton pectinatus* L. dominates in the eastern part of the lake, near industrial point sources, both *Myriophyllum spicatum* L. and *Potamogeton lucens* L. form extended patches in the western part of the lake. The shallow, littoral areas near villages are dominated by *Ranunculus trichophyllus* Chaix in Villars and *Ceratophyllum demersum* L. The west–east gradient in nutrient and heavy metal concentrations in waters and sediments are reflected by the spatial distribution of submersed species. While the heavy metal concentrations of the water body vary considerably in different seasons, the contents in submersed macrophytes integrate seasonal variations of longer time periods. Spatial distribution and tissue accumulation of littoral macrophyte species reflect the environmental conditions at respective sites such as heavy metal contents in water and sediment.

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### Introduction

Changes in composition and the decline of submerged macrophyte communities in lakes due to increased nutrient inputs have been reported by many ecologists in different countries (e.g., Best et al. 1984; Lachavanne 1985; Melzer et al. 1986). Increasing nutrient loading may also result in a shift from a macrophyte-dominated clear water state to a turbid, phytoplankton-dominated state (Scheffer et al. 1993; Scheffer 1998). On the other hand, oligotrophication exerts a marked influence on species composition and distribution of submerged macrophytes (Lachavanne et al. 1991; Schmieder 1997).

Furthermore, the immobile nature of macrophytes combined with their selective absorption of certain ions and ability to accumulate heavy metals makes them a particularly effective bioindicator of metal pollution, since they represent real levels present at that site (Atri 1983; Greger and Kautsky 1993; Guilizzoni 1975). Hutchinson et al. (1975) found that metal

uptake and accumulation of submerged macrophytes is species specific. According to Crowder et al. (1989) submerged species accumulate much more metal in their tissues than floating and emergent species, and *Myriophyllum spicatum* accumulates much more Pb than *Vallisneria americana*. Moreover, sources of different metals taken up by submerged plants are different. Campbell and Stokes (1985), who studied the relationship between the partitioning of Cu and Zn in lake sediments found that Zn accumulated in the plant tissues seemed to come directly from the water column, whereas the source of Cu seemed to be the sediment. However, bio-indicative systems based on macrophytes are mainly developed for small regions and portability to other regions without proof is not assured.

Lake Qattieneh, the largest lake in Syria, receives different kinds of pollutants due to human activities, which add excessive amounts of plant nutrients, primarily phosphorus and nitrogen to the lake, resulting in hypertrophic conditions (Anonymus 2001). Different studies have been carried out in order to define the pollution level and effects of these pollutants on human health in the area studied (Anonymus 2001). However, until now, no research has been carried out addressing Lake Qattieneh macrophytes and their ecology. This study focuses on distribution of macrophytes of Lake Qattieneh in relation to limnological and

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sedimentological factors as indicators of water quality. The aim was to analyse the distribution patterns in relation to the patterns of pollution factors to determine indicative species for heavy metals as a base for development of a bio-indicator system in Syria.

## Materials and methods

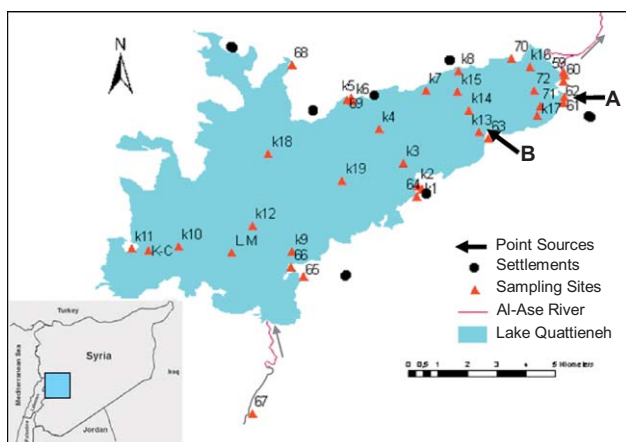
### Study area

Lake Qattieneh is a large, shallow, calcareous lake located in northwestern Syria with a mean surface area of 57.3 km<sup>2</sup> (Fig. 1). The total amount of water in Lake Qattieneh is estimated as 200 million m<sup>3</sup>, with a maximum depth of 10 m in winter and 7 m in summer. The geological formation in the west and northwest of the lake reservoir is mainly metamorphic (basaltic), with many large blocks spread on the land mostly used as pasture. Limestone rocks and marl-like deposits dominate in the east, northeast and south of the reservoir. The Al-Ase River which is the main source of water input of Lake Qattieneh enters the lake from southwest and leaves it in the north east. Lake Qattieneh receives high nutrient input from the catchment area, particularly in the eastern part of the lake, due to human activities, i.e. disposal from a phosphorus fertilizer (Fig. 1, A) and a battery factory (Fig. 1, B). Furthermore, the untreated sewage water from villages on the lakeshore, as point sources, and leaching from irrigation of agricultural fields in the southern shore area as non-point sources enter the lake. Soil erosion in the watershed of Lake Qattieneh is sometimes extensive due to severe rainstorms associated with the hot mediterranean climate, where these mobilize uncovered soil in the barely vegetated catchment.

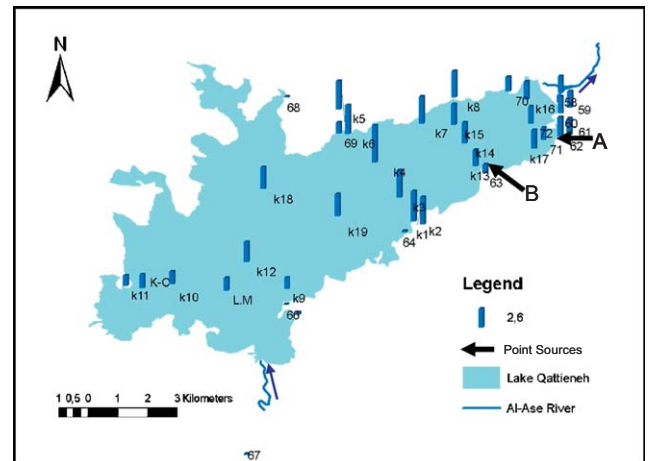
The dominant wind direction of the study area is west with an annual mean of 3.4 m s<sup>-1</sup> and a maximum speed of 23.0 m s<sup>-1</sup> recorded in July (Anonymus 2001). Due to a terrain depletion between the Lebanon mountain range and the Coastal mountain range, the wind system of Lake Qattieneh is closely related to the diurnal mediterranean land–water wind system with strong westerly winds in spring and summer blowing from morning to late afternoon, causing diurnal mixing of the lake water and sediment relocation.

### Sampling and field analyses

To carry out this research we got two official permissions for sampling of water, sediment and plants in September 2003



**Fig. 1.** Study area of Lake Qattieneh indicating locations of the sampling sites, settlements and point sources (A: Phosphorus fertilizer factory, B: Battery factory).



**Fig. 2.** Spatial patterns of soluble PO<sub>4</sub><sup>3-</sup> concentrations (mg L<sup>-1</sup>) in surface water layer of Lake Qattieneh indicating locations of point sources (A: Phosphorus fertilizer factory, B: Battery factory).

(sites 60–72) and April 2004 (sites K2–K19) (Fig. 1). In September 2003 samples were collected from shore by foot in shallow water areas except samples of sites 71 and 72 taken by a small boat. Samples of sites 65 and 68 were taken from temporarily flooded nearshore wetlands. Sampling in April 2004 was accompanied by the motor boat of fishery supervision for offshore samples, which were collected along 6 transects. Sampling by boat was mainly done in the morning due to strong winds during daytimes (Fig. 2).

Submerged plants were collected from the sample sites by hand (September 2003) and at offshore sites using a rake (April 2004). Depending on the species both submerged and floating leaves were sampled, whereas for emergent species also roots were sampled. We collected five plant samples for each present species and site, which were merged for analyses. All plant samples were carefully washed with lake water to remove debris, put in plastic sample bags and transported to the laboratory. Here they were again washed with distilled water, sorted, dried at 80 °C to determine dry weight and afterwards ground to a fine powder using a pestle and mortar for analyses.

Some physical and chemical variables of the water were registered during the two field campaigns in summer 2003 and spring 2004 (e.g., pH, water temperature, turbidity and electric conductivity (EC)). Turbidity was measured by Secchi disk transparency (SDT). pH was measured with a pH meter (WTW ph 320) calibrated to 7 and 10 pH. Electric conductivity (EC) was measured with WTW LF 318.

Water samples were taken from surface layer and at offshore sites also from near sediment layer using a Ruttner's sampler. Water samples were filtered immediately after sampling using glass fiber filters (Whatman GF/A) and stored cool for analyses. Sediment samples were collected using an Ekman grab. Two samples were taken per site and merged together for analyses. Field water sampling and measurements followed standard methods (APA 1985).

Cartographic representation and distribution mapping of sampling sites were done during the field surveys on a georeferenced Ikonos image (2001) of the study area using a field notebook (ITRONIX, Eschborn, Germany) with Arc-Pad software (ESRI, Redlands, USA) combined with a GPS (Garmin, Olathe, USA).

### Chemical analyses of water, sediment and plant samples

Alkalinity was measured in the laboratory using titration with sulphuric acid after addition of phenolphthalein and bromocresol

**Table 1**

List of species presence at the different sampling sites (see Fig. 1 for the locations of the sampling sites).

| Species/sites                                      | K2 | K5 | K6 | K7 | K8 | K9 | K10 | K11 | K-C | LM | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 |
|--|----|----|----|----|----|----|-----|-----|-----|----|----|----|----|----|----|----|----|----|----|
| <i>Alisma plantago lanceolata</i> Withering        |    |    |    |    |    |    |     |     |     |    |    |    |    |    | *  |    |    |    | *  |
| <i>Bidens tripartita</i> L.                        |    |    |    |    |    |    |     |     |     |    | *  |    |    |    |    |    |    |    | *  |
| <i>Bolboschoenus maritimus</i> (L.) Palla in Koch  |    |    |    |    |    |    |     |     |     |    | *  |    |    |    |    |    |    |    | *  |
| <i>Butomus umbellatus</i> L.                       |    |    |    |    |    |    |     |     |     |    |    |    |    |    | *  |    |    |    | *  |
| <i>Ceratophyllum demersum</i> L.                   |    |    |    |    |    |    |     |     |     |    | *  |    |    |    | *  |    | *  |    | *  |
| <i>Chara</i> sp.                                   |    |    |    |    |    | *  |     |     |     |    |    |    |    |    |    |    |    |    |    |
| <i>Cladium mariscus</i> (L.) Pohl                  |    |    |    |    |    |    |     |     |     |    |    |    |    |    |    |    | *  |    |    |
| <i>Cladophora</i> sp.                              | *  |    |    |    |    |    |     |     |     |    |    |    |    |    |    |    |    |    |    |
| <i>Cyprus</i> sp.                                  |    | *  |    |    |    |    |     | *   | *   |    |    |    |    |    |    |    |    |    |    |
| <i>Epilobium hirsutum</i> L.                       |    |    |    |    |    |    |     |     |     |    |    |    |    |    |    |    | *  |    |    |
| <i>Euphorbia</i> sp.                               |    |    |    |    |    |    |     |     |     |    | *  |    |    | *  |    |    |    |    |    |
| <i>Myriophyllum spicatum</i> L.                    |    | *  |    |    | *  | *  | *   | *   | *   | *  | *  |    |    | *  |    |    |    |    |    |
| <i>Persicaria amphibia</i> (L.) Gray               |    | *  |    |    | *  |    |     |     | *   |    |    |    |    |    |    |    |    |    | *  |
| <i>Phalaris arundinacea</i> L.                     |    |    |    |    |    |    |     |     |     |    | *  |    |    |    |    |    |    |    | *  |
| <i>Phragmites australis</i> (Cav.) Trin. ex Steud. |    |    |    |    |    |    |     |     |     |    | *  | *  |    |    |    |    | *  |    | *  |
| <i>Polygonum lapathifolium</i> L.                  |    |    |    |    |    |    |     |     |     |    |    |    |    |    | *  |    |    |    | *  |
| <i>Potamogeton pectinatus</i> L.                   |    |    |    |    |    | *  |     |     | *   |    |    | *  | *  |    |    |    |    |    |    |
| <i>Potamogeton lucens</i> L.                       |    |    |    |    |    | *  | *   | *   | *   | *  | *  | *  | *  |    | *  |    |    |    |    |
| <i>Potamogeton pusillus</i> L.                     |    |    |    |    |    | *  |     |     | *   |    |    |    |    |    |    |    |    |    |    |
| <i>Ranunculus trichophyllus</i> Chaix              | *  | *  |    |    |    | *  |     |     | *   |    |    |    |    |    |    |    |    |    |    |
| <i>Rumex aquaticus</i> L.                          | *  |    |    |    |    |    |     |     | *   |    |    |    |    |    |    |    |    |    |    |
| <i>Schoenoplectus lacustris</i> (L.) Palla         |    |    |    |    |    | *  |     |     | *   |    |    |    |    |    |    |    |    |    | *  |
| <i>Typha angustifolia</i> L.                       |    |    |    |    |    |    |     |     |     |    | *  | *  |    |    |    |    |    |    |    |
| <i>Typha latifolia</i> L.                          |    |    |    |    |    |    |     |     |     |    | *  |    |    |    |    |    | *  |    |    |

methyl red. Analyses of nutrients  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ ,  $\text{NO}_2^-$ ,  $\text{NH}_4^+$ ,  $\text{PO}_4^{3-}$  were performed according to USEPA method 365.2 and Standard Method 4500-P-E for wastewater (APA 1985) using HACH DR/4000 spectrophotometer. Soluble reactive phosphorus was measured using the ascorbic acid method; nitrate was analyzed using the cadmium reduction method. Ammonium was measured with the salicylate method for low-range ammonium and nitrite was analyzed with the diazotization method for low range also.

For chlorophyll (a), the samples were stored in the dark at sub-freezing ( $-20^\circ\text{C}$ ) temperatures for 2 days before we could analyse it. The extraction and analysis was done by using acetone, then the sample was centrifuged at 4000 rpm then measured at 647, 664, and 652 nm in spectral photometer (APA 1985).

Plant samples were dried at  $60^\circ\text{C}$  in an oven and grinded in a mortar mill for analyses. The analysis of plant samples were performed after pressure digestion for 20 min with 5 ml  $\text{HNO}_3$  and 1 ml  $\text{H}_2\text{O}_2$  (VDLUF 1996). Soils were digested with aqua regia (DIN ISO 11466 1997).

The concentration of Fe, Ni and Zn in water, plant, and sediment samples were determined by ICP-OES (inductively coupled plasma–optical emission spectrometry) (EN ISO 11885 1997), and Cd, Cr, Co, Pb and Cu by ICP-MS (inductively coupled plasma mass spectrometry) (DIN 38406-29 1998). Pearson correlation coefficients were calculated (Parker 1983) to examine the relationships between the concentrations of elements in water, surface sediments and in plant tissues.

GIS techniques (Arc GIS software, ESRI, Redlands, USA) were used to set up a lake specific GIS from the field mappings and to display spatial distribution maps of the nutrient contents and macrophyte species of Lake Qattienh.

## Results

### Macrophyte species composition and spatial distribution

The identification of water plants in Lake Qattienh revealed 21 species including submerged, emergent, and swamp plants (Table 1, Fig. 1). The species composition of submerged macrophytes at different sites revealed obvious spatial patterns.

The eastern part near the point sources was dominated by *Potamogeton pectinatus*, whereas in the western part large patches of *P. lucens* and *Myriophyllum spicatum* dominated. The very shallow areas near the municipalities were mainly settled by *Ranunculus trichophyllus*, *Ceratophyllum demersum* and *Persicaria amphibia*. Reeds were restricted to only small shore sections.

### Physical and chemical characteristics of lake water

Physical characteristics of lakes water body revealed marked seasonal differences. Mean temperature of samples taken in September 2003 and April were  $27.4$  and  $16.2^\circ\text{C}$ , respectively (Table 2, Table 3). Mean pH was 7.58 in September 2003 compared to 8.96 in April 2004. Secchi depth measurements revealed high turbidity of water in both seasons. Analyses of basic nutrient concentrations in lake water showed high concentrations for soluble  $\text{PO}_4^{3-}$  compared to moderate concentrations of Nitrate-N. Again, considerable seasonal variations occurred. Spatial patterns indicate Al-Ase River as source of Nitrogen (site 67, Fig. 1) and industrial point sources in eastern part of the lake as sources of phosphorous (Fig. 1A, phosphorus fertilizer factory). High concentrations in reduced nitrogen components indicate highly active reduction processes even in surface water layers. Chlorophyll a content of a pooled sample from three sites across Lake Qattienh in September 2003 was  $0.44 \mu\text{g L}^{-1}$ .

### Heavy metals in water, sediments and plants

Analysis of heavy metals in the lake water (Table 4) revealed high concentrations of Cr and Ni with a mean value of  $27.3$  and  $27.0 \mu\text{g L}^{-1}$ , respectively. Ni concentrations in the lake water ranged from  $9.0$  to  $88.7 \mu\text{g L}^{-1}$ . The highest values in the lake were registered at sites 68, 69 and 70 near the northern shore (Fig. 1), which also contained high values of Cr and Co. These sites showed a clear indication of high Cr, Co and Ni concentration in the water (Table 4), sediment (Table 5), and in floating leaves of *P. amphibia* (Table 6, data for sites 68 and 70 only). In addition to the spatial patterns of heavy metal concentrations in lake water (Table 4) forming a clear west–east gradient, considerable

**Table 2**

Physical and chemical characteristics of Lake's Qattienah nearshore surface water layer in September 2003 (location of site numbers see Fig. 1).

|          | pH   | EC ( $\mu\text{S cm}^{-1}$ ) | Secchi depth (m) | Temperature ( $^{\circ}\text{C}$ ) | $\text{PO}_4^{3-}$ ( $\text{mg L}^{-1}$ ) | $\text{SO}_4^{2-}$ ( $\text{mg L}^{-1}$ ) | N- $\text{NO}_3^-$ ( $\text{mg L}^{-1}$ ) | N- $\text{NO}_2^-$ ( $\text{mg L}^{-1}$ ) | N- $\text{NH}_4^+$ ( $\text{mg L}^{-1}$ ) |
|----------|------|------------------------------|------------------|------------------------------------|---|---|---|---|---|
| 60       | 7.62 | 390                          | 0.5              | 26.3                               | 2.28                                      | 20.7                                      | 0.5                                       | 0.01                                      | 0.18                                      |
| 61       | 7    | 410                          | 0.6              | 34.1                               | 2.35                                      | 17.6                                      | 0.6                                       | 0   | 0.26                                      |
| 62       | 7.7  | 410                          | 0.3              | 27.7                               | 2.74                                      | 28.4                                      | 0   | 0.02                                      | 0.15                                      |
| 63       | 7.78 | 340                          | 0.6              | 26.6                               | 1.19                                      | 13.0                                      | 0   | 0.01                                      | 0.38                                      |
| 64       | 7.77 | 390                          | 0.6              | 25.6                               | 0.28                                      | 3.9                                       | 0   | 0.01                                      | 0.38                                      |
| 67       | 7.09 | 410                          | 0.7              | 22.9                               | 0.19                                      | 3.9                                       | 2.1                                       | 0.003                                     | 0.14                                      |
| 68       | 7.71 | 400                          | 0.7              | 29                                 | 0.17                                      | 2.5                                       | 0   | 0.004                                     | 0.4                                       |
| 69       | 7.7  | 440                          | 0.8              | 27                                 | 1.54                                      | 15  | 0   | 0   | 0.30                                      |
| 70       | 7.85 | 410                          | 0.1              | 26.3                               | 1.99                                      | 15.6                                      | 0   | 0.002                                     | 0.25                                      |
| 71       | 7.5  | 440                          | 0.6              | 24.1                               | 1.75                                      | 14.2                                      | 0.1                                       | 0.001                                     | 0.21                                      |
| 72       | 7.66 | 410                          | 0.5              | 32.8                               | 2.45                                      | 17.1                                      | 0   | 0   | 0.17                                      |
| Mean     | 7.58 | 398                          | 0.55             | 27.4                               | 1.48                                      | 13.51                                     | 0.33                                      | 0.006                                     | 0.25                                      |
| Standard | 0.26 | 36                           | 0.20             | 3.19                               | 0.99                                      | 8.73                                      | 0.61                                      | 0.008                                     | 0.09                                      |
| Maximum  | 7.85 | 440                          | 0.8              | 34.1                               | 2.74                                      | 28.4                                      | 2.1                                       | 0.032                                     | 0.4                                       |
| Minimum  | 7    | 340                          | 0.1              | 22.9                               | 0.08                                      | 0.6                                       | 0   | 0   | 0.14                                      |

**Table 3**

Physical and chemical characteristics of Lake's Qattienah water.

|                    | Depth (m) | pH   | EC ( $\mu\text{S cm}^{-1}$ ) | Secchi depth (m) | Temperature ( $^{\circ}\text{C}$ ) | $\text{PO}_4^{3-}$ ( $\text{mg L}^{-1}$ ) | $\text{SO}_4^{2-}$ ( $\text{mg L}^{-1}$ ) | N- $\text{NO}_3^-$ ( $\text{mg L}^{-1}$ ) | N- $\text{NO}_2^-$ ( $\text{mg L}^{-1}$ ) | N- $\text{NH}_4^+$ ( $\text{mg L}^{-1}$ ) |
|--------------------|-----------|------|------------------------------|------------------|------------------------------------|---|---|---|---|---|
| K2                 | 0         | 8.7  | 370                          | 0.7              | 17.5                               | 4.3                                       | 25.9                                      | 0.3                                       | 0.1                                       | 0.26                                      |
| K3                 | 0         | 8.65 | 368                          | 0.6              | 19.3                               | 3.8                                       | 27.2                                      | 0.4                                       | 0.01                                      | 0.28                                      |
| K3                 | 4.5       | 9.43 | 372                          | -                | 16.6                               | 3.4                                       | 25  | 0.3                                       | 0.01                                      | 0.14                                      |
| K4                 | 0         | 9.2  | 372                          | 0.9              | 19.1                               | 5.3                                       | 28.2                                      | 0.4                                       | 0.1                                       | 0.14                                      |
| K4                 | 4.5       | 9.19 | 372                          | -                | 17.4                               | 3.8                                       | 26.5                                      | 0.4                                       | 0.008                                     | 0.2                                       |
| K6                 | 0         | 8.7  | 371                          | 0.8              | 18.9                               | 0.4                                       | 29.1                                      | 0.4                                       | 0.008                                     | 0.2                                       |
| K7                 | 0         | 8.83 | 371                          | 0.5              | 15.5                               | 0.4                                       | 28.6                                      | 0.4                                       | 0.007                                     | 0.17                                      |
| K8                 | 0         | 8.9  | 369                          | 0.5              | 15.8                               | 3.6                                       | 28.8                                      | 0.5                                       | 0.008                                     | 0.19                                      |
| K9                 | 0         | 9.02 | 357                          | 0.4              | 15.5                               | 1.2                                       | 25.1                                      | 0.3                                       | 0.005                                     | 0.23                                      |
| K9                 | 2         | 8.99 | 354                          | -                | 15.2                               | 1.6                                       | 25.8                                      | 0.3                                       | 0.006                                     | 0.17                                      |
| K10                | 0         | 9.09 | 345                          | 0.5              | 15.6                               | 1.8                                       | 13.9                                      | 0.3                                       | 0.007                                     | 0.27                                      |
| K10                | 2.5       | 9.04 | 357                          | -                | 15.6                               | 2.3                                       | 26.6                                      | 0.4                                       | 0.08                                      | -   |
| K11                | 0         | 9.15 | 346                          | 0.3              | 16.2                               | 1.5                                       | 22.5                                      | 0.3                                       | 0.006                                     | 0.18                                      |
| K12                | 0         | 8.81 | 366                          | -                | 15.8                               | 2.8                                       | 21.7                                      | 0.5                                       | 0.008                                     | 0.22                                      |
| K13                | 0         | 9.05 | 367                          | 0.5              | 15.1                               | 2.3                                       | 26.7                                      | 0.4                                       | 0.009                                     | 0.25                                      |
| K13                | 5         | 8.96 | 365                          | -                | 14.2                               | 3   | 26.9                                      | 0.5                                       | 0.009                                     | 0.14                                      |
| K14                | 0         | 9.10 | 369                          | 0.6              | 15.0                               | 2.9                                       | 27.3                                      | 0.5                                       | 0.011                                     | 0.23                                      |
| K14                | 5         | 9.05 | 362                          | -                | 15.3                               | 2.9                                       | 23.8                                      | 0.3                                       | 0.01                                      | 0.2                                       |
| K17                | 0         | 8.30 | 368                          | 0.7              | 15.4                               | 2.7                                       | 26.8                                      | 0.4                                       | 0.01                                      | 0.11                                      |
| K18                | 0         | 9.01 | 371                          | 0.7              | 15.6                               | 3.1                                       | 27.6                                      | 0.5                                       | 0.009                                     | 0.18                                      |
| Mean               | -         | 8.96 | 365                          | 0.57             | 16.2                               | 2.7                                       | 25.7                                      | 0.38                                      | 0.019                                     | 0.197                                     |
| Standard deviation | -         | 0.3  | 8.3                          | 0.16             | 1.43                               | 1.3                                       | 3.39                                      | 0.08                                      | 0.029                                     | 0.047                                     |
| Maximum            | -         | 9.2  | 372                          | 0.9              | 19.3                               | 5.3                                       | 29.1                                      | 0.5                                       | 0.1                                       | 0.28                                      |
| Minimum            | -         | 8.3  | 345                          | 0.3              | 15                                 | 0.4                                       | 13.9                                      | 0.3                                       | 0.005                                     | 0.11                                      |

Data April 2004, location of site numbers see Fig. 1.

seasonal changes occur. Samples taken in September 2003 from nearshore areas revealed clearly higher concentrations than those taken mainly from offshore areas in April 2004.

The concentrations of different metals in the sediments and plants were much higher than in the water (compare Tables 4–6). In general, sediment samples taken in the littoral zone as well as the wetlands of most studied locations were characterized by high concentrations of Cr (maximum  $147 \text{ mg kg}^{-1}$ ), Cu (maximum  $64 \text{ mg kg}^{-1}$ ), and Ni (maximum  $97 \text{ mg kg}^{-1}$ ).

The concentrations of the elements in submerged and emergent plants from Lake Qattienah differed depending on the sampling site and on the species (Table 6). Site 61 located in the eastern part of the lake directly in front of the effluent of the phosphate fertilizer factory, showed much higher and very variable heavy metal concentrations in *P. lucens*. The highest concentrations of Ni, Zn, Cd, Pb, and Cu in the sediments were also registered at this site (Table 5). Furthermore, *P. pectinatus* sampled

from site 62 had higher concentrations of Cu, Cr, Co and Pb than from site 63, located near a battery factory, which had higher contents of Ni. The concentrations of these elements were not only high in the sediments but also in the water column (see Tables 4–6). Concentrations of Ni, Cr, Cu and Pb in *M. spicatum* from site K8 in the western part of the lake were also higher than for this species sampled from other sites, i.e. k5, k9, 62 and 63. The concentrations of most heavy metals were higher in the roots of the plants than in shoots. *P. australis* showed the highest capacity for accumulating trace elements and deposited them mainly in the roots (Table 6).

The west–east gradient in nutrient and heavy metal concentrations in waters and sediments are reflected by the spatial distribution of submersed species. While the heavy metal concentrations of the water body vary considerably in different seasons, the contents in sediments and submersed macrophytes integrate seasonal variations of longer time periods.

Coefficients of correlation (Pearson), calculated between metal contents in plant tissues, water and surficial sediments, showed a positive significant correlation between sediments and submerged plants *Potamogeton* spp. and *M. spicatum*, respectively, for Ni, Cu and Co (Table 7). Furthermore, correlations between Zn

in water and Co and Cu, respectively, as well as between Ca and Cr and Pb, respectively, in the investigated plants were positive and significant.

## Discussion

Submerged vegetation of Lake Qattienah reveals low species richness mainly restricted to rather a few tolerant species, i.e. *M. spicatum*, *P. pectinatus* and *P. lucens*, reflecting the highly eutrophic conditions of the lake. All plants seem to be well adapted to highly turbid conditions caused by phytoplankton blooms and sediment stirring by wave action. The water pondweed is adapted to low-light conditions (Blindow 1992; Hough and Forwall 1988) and can survive adverse conditions due to underground tubers. In particular, the wind-induced wave action and mixing seem to maintain the system well oxygenated preventing anaerobic conditions. Fish deaths have been observed occasionally, during spells of calm periods (Anonymus 2001). However, co-occurrence of submerged plants and high densities of phytoplankton in a shallow lake is inconsistent with the theory of alternative stable states (Scheffer et al. 1993; Scheffer 1998). For the growth of submerged macrophytes there must be at least spells of higher light availability in the surface water. However, we do not have seasonal data on turbidity or phytoplankton biomass to clarify this discrepancy.

The study has revealed that the lake is contaminated by certain heavy metals according to US-EPA (1986) criteria. Cr and Ni levels exceed water quality norms of US-EPA (1986), particularly in the eastern part of the lake where highest values of these metals were registered due to industrial discharge. Sediment samples taken in the littoral zone and from the wetlands of most studied locations were characterized by relatively high concentrations of Cr, Cu and Ni, which partly exceeded the criteria of NY-SDEC (1998). Both the emergent and submerged species of Lake Qattienah contained increased levels of Cr, Co, Cu, Ni and Fe, whereas Pb and Zn

**Table 4**

Concentration of elements in Lake Qattienah surface water layer ( $\mu\text{g L}^{-1}$ ) (sites 60–72 represent data of September 2003 and sites K2–K18 data of April 2004, location of site numbers see Fig. 1, \*values below detection limit not included).

| Site No. | Cd  | Cr    | Co   | Cu   | Pb   | Ni   | Zn    |
|----------|-----|-------|------|------|------|------|-------|
| 58       | <2  | 46.2  | 2.4  | 2.1  | –    | 48.8 | 20.9  |
| 61       | <2  | 47.5  | 3.2  | 1.8  | –    | 37.3 | 5.74  |
| 62       | <2  | 69.1  | 2.1  | –    | –    | 20.8 | 10.9  |
| 63       | <2  | 17.3  | 3.3  | –    | –    | 35.7 | 13.2  |
| 64       | <2  | 18    | 2.2  | –    | –    | 30.4 | <2    |
| 66       | <2  | 12    | 0.89 | –    | –    | 12.2 | 9.33  |
| 67       | <2  | 6.66  | 5.4  | 7.7  | –    | 78.8 | <2    |
| 68       | <2  | 50    | 6.2  | 0.86 | –    | 59.3 | 2.03  |
| 69       | <2  | 45.6  | 14   | 12   | –    | 88.7 | 12.2  |
| 70       | <2  | 47.1  | 4.4  | 3.6  | –    | 56.1 | 9.09  |
| 71       | <2  | 50.1  | 2.2  | 0.77 | –    | 45.1 | 6.1   |
| 72       | <2  | 42.7  | 2.8  | –    | –    | 46.2 | 4.78  |
| K2       | <1  | 29    | <1   | 9.0  | 4.2  | 10   | 15    |
| K3       | <1  | 17    | <1   | 3.2  | <1   | 9.4  | 12    |
| K4       | <1  | 17    | <1   | 4.4  | <1   | 9    | <5    |
| K6       | <1  | 16    | <1   | 2.3  | 1.6  | 9.4  | 27    |
| K7       | <1  | 25    | <1   | 2.8  | <1   | 9.7  | 7.7   |
| K8       | <1  | 15    | <1   | 4.5  | 2.5  | 9.8  | 10    |
| K9       | <1  | 15    | <1   | 2.9  | 4.3  | 9.4  | 6     |
| K10      | <1  | 19    | <1   | 3.0  | 10   | 11   | 6.1   |
| K11      | <1  | 18    | <1   | 4.3  | <1   | 11   | 24    |
| K12      | 1.1 | 17    | <1   | 4.4  | 2    | 12   | 6.6   |
| K13      | <1  | 18    | <1   | 3.2  | 1    | 9.6  | 5.4   |
| K14      | <1  | 19    | <1   | 4.0  | <1   | 10   | 59    |
| K17      | <1  | 16    | <1   | 4.1  | <1   | 12   | 17    |
| K18      | <1  | 16    | <1   | 5.7  | 4.2  | 11   | 14    |
| Mean     |     | 27.3* | 4.1* | 4.1* | 3.7* | 27   | 13.2* |
| Std      |     | 16.4  | 3.57 | 2.6  | 3    | 23.6 | 11.8  |

**Table 5**

Concentration of elements ( $\mu\text{g g}^{-1}$  dry weight) in sediments of Lake Qattienah (data of September 2003 (sites 60–72) and April 2004 (sites K3–K19), location of site numbers see Fig. 1).

| Site no.                                 | Cd       | Co       | Cr       | Cu      | Ni       | Pb      | Fe    | Zn  |
|--|----------|----------|----------|---------|----------|---------|-------|-----|
| 60                                       | 0.3      | 12       | 40       | 15      | 32       | 7.1     | 16153 | 41  |
| 61                                       | 1.4      | 13       | 55       | 64      | 74       | 22      | 15606 | 94  |
| 62                                       | 0.5      | 12       | 59       | 27      | 49       | 12      | 20977 | 86  |
| 63                                       | 0.4      | 12       | 45       | 20      | 41       | 8.1     | 20738 | 39  |
| 64                                       | 0.5      | 6.3      | 33       | 7.6     | 29       | 3       | 8198  | 19  |
| 66                                       | 0.3      | 10       | 58       | 20      | 48       | 9.9     | 18933 | 59  |
| 68                                       | 0.3      | 98       | 147      | 59      | 97       | 9.4     | 92871 | 90  |
| 69                                       | 0.3      | 66       | 104      | 47      | 75       | 8.7     | 69634 | 82  |
| 70                                       | 0.4      | 94       | 106      | 53      | 78       | 11      | 82907 | 90  |
| 71                                       | 0.3      | 10       | 49       | 16      | 38       | 7.5     | 15020 | 42  |
| 72                                       | 0.4      | 12       | 62       | 21      | 48       | 9.2     | 19646 | 54  |
| K3                                       | 0.33     | 13       | 47       | 15      | 41       | 6.0     | 19400 | 73  |
| K4                                       | 0.37     | 13       | 55       | 14      | 47       | 7.3     | 2430  | 105 |
| K7                                       | 0.39     | 15       | 56       | 16      | 46       | 7.9     | 24800 | 96  |
| K9                                       | 0.34     | 10       | 52       | 15      | 42       | 5.1     | 18700 | 73  |
| K10                                      | 0.62     | 35       | 132      | 41      | 109      | 16      | 65100 | 111 |
| K12                                      | 0.29     | 9.7      | 46       | 17      | 36       | 5.7     | 16300 | 44  |
| K13                                      | 0.25     | 9.7      | 36       | 14      | 27       | 4.1     | 12600 | 32  |
| K14                                      | 0.42     | 14       | 59       | 23      | 45       | 6.2     | 23500 | 53  |
| K15                                      | 0.34     | 12       | 50       | 18      | 39       | 4.7     | 19700 | 46  |
| K16                                      | 0.31     | 14       | 46       | 17      | 35       | 4.6     | 17600 | 45  |
| K17                                      | 0.31     | 11       | 39       | 15      | 32       | 4.9     | 14000 | 42  |
| K18                                      | 0.37     | 14       | 52       | 18      | 46       | 6.8     | 24700 | 61  |
| K19                                      | 0.37     | 14       | 46       | 15      | 39       | 5.5     | 19800 | 52  |
| Mean                                     | 0.46     | 22       | 61       | 24      | 50       | 8.0     | 27471 | 64  |
| Std                                      | 0.31     | 26       | 30       | 15      | 21       | 4.1     | 23870 | 25  |
| Limits of detection $\mu\text{g g}^{-1}$ | 0.05–0.1 | 0.05–0.1 | 0.25–0.5 | 0.1–0.2 | 0.25–0.5 | 0.1–0.2 | 1–2   | –   |



**Table 6**

Mean concentration of elements ( $n = 3$ ) in some aquatic species sampled from Lake Qattieneh from different sites ( $\mu\text{g g}^{-1}$  dry weight) (data of September 2003 (sites 60–72) and April 2004 (sites K5–K9 and K-C), location of site numbers see Fig. 1.

| Plant species                                | Sites | Cd       | Co       | Cr       | Cu      | Ni       | Pb      | Zn       | Fe    |
|--|-------|----------|----------|----------|---------|----------|---------|----------|-------|
| <i>P. lucens</i> –Shoots                     | 61    | 0.24     | 66       | 50       | 30      | 53       | 4       | 75       | 38500 |
| <i>P. lucens</i> –Shoots                     | 62    | 0.11     | 2.5      | 3.9      | 3.3     | 5.4      | 1.2     | 18       | –     |
| <i>P. lucens</i> –Shoots                     | 60    | 0.069    | 0.93     | 1.7      | 3.2     | 2.8      | 0.34    | 8.7      | 330   |
| <i>P. lucens</i> –Shoots                     | K10   | 0.15     | 2        | 3.3      | 10      | 5.6      | 0.65    | 26       | 627   |
| <i>P. pectinatus</i> –Shoots                 | 63    | 0.18     | 0.93     | 3.7      | 4.6     | 4.9      | 1       | 21       | 940   |
| <i>P. pectinatus</i> –Shoots                 | 62    | 0.19     | 1.3      | 8.24     | 8.37    | 3.78     | 1.2     | 49       | 881   |
| <i>P. pectinatus</i> –Shoots+Periphyton      | 62    | 0.4      | 5.42     | 22       | 11      | 17       | 4.35    | 51       | 6975  |
| <i>P. pectinatus</i> –Shoots                 | K-C   | 1.3      | 3.5      | 3.4      | 7.8     | 5.5      | 0.46    | 24       | 695   |
| <i>C. demersum</i> –Shoots                   | 67    | 0.37     | 9.9      | 4.4      | 3.7     | 17       | 0.9     | 47       | 1250  |
| <i>M. spicatum</i> –Shoots                   | K5    | 0.21     | 6.6      | 4.9      | 9.1     | 6        | 1.1     | 57       | 2700  |
| <i>M. spicatum</i> –Shoots                   | K8    | 0.42     | 9.3      | 23       | 14      | 19       | 5.4     | 30       | 1030  |
| <i>M. spicatum</i> –Shoots                   | K9    | 0.63     | 10       | 7        | 10      | 10       | 1.3     | 30       | 2800  |
| <i>M. spicatum</i> –Shoots                   | 62    | 0.14     | 2.57     | 8.73     | 9.61    | 12       | 1.2     | 48       | 1345  |
| <i>M. spicatum</i> –Roots                    | 62    | 0.1      | 2.25     | 4        | 6.83    | 2.93     | 0.82    | 31       | 1038  |
| <i>M. spicatum</i> –Roots                    | 63    | 0.12     | 2.56     | 4.2      | 5.61    | 3.45     | 0.9     | 27       | 1271  |
| <i>M. spicatum</i> –Shoots                   | 63    | 0.16     | 3.1      | 6.94     | 9.2     | 13.2     | 1.3     | 45       | 1356  |
| <i>P. amphibia</i> –Leaves                   | K-C   | 0.18     | 5.3      | 1.7      | 13      | 4.7      | 0.51    | 37       | 616   |
| <i>P. amphibia</i> –Roots                    | K-C   | 0.023    | 9.56     | 1.92     | 10.3    | 4.1      | 0.05    | 13.8     | 3178  |
| <i>P. amphibia</i> –Leaves                   | 68    | 2.63     | 7.4      | 27       | 21      | 36       | 108     | 161      | 1620  |
| <i>P. amphibia</i> –Roots                    | 68    | 0.32     | 13       | 31       | 16      | 34       | 7       | 53       | 8360  |
| <i>P. amphibian</i> –Leaves                  | K5    | 0.17     | 5        | 2.5      | 12      | 5        | 0.12    | 47       | 681   |
| <i>P. amphibian</i> –Roots                   | K5    | 0.016    | 8.35     | 3.1      | 9.23    | 3.31     | 0.04    | 17.6     | –     |
| <i>P. amphibian</i> –Leaves                  | 70    | 3.23     | 8.2      | 26       | 23      | 37       | 106     | 162      | 1670  |
| <i>P. amphibian</i> –Roots                   | 70    | 0.42     | 14       | 31       | 16.5    | 36       | 7.7     | 55       | –     |
| <i>S. lacustris</i> –Shoots                  | 68    | 0.04     | 0.61     | 3.5      | 6.6     | 4        | 1.1     | 23       | 410   |
| <i>S. lacustris</i> –Shoots                  | K9    | 0.04     | 0.61     | 3.1      | 5.6     | 4        | 1.1     | 23       | 410   |
| <i>S. lacustris</i> –Shoots                  | 61    | 0.036    | 0.66     | 3.8      | 7.1     | 4.3      | 1.6     | 27       | 503   |
| <i>P. australis</i> –Shoots                  | 61    | 0.1      | 0.22     | 1.4      | 2.3     | 1.6      | 0.3     | 25       | 380   |
| <i>P. australis</i> –Roots                   | 61    | 0.45     | 8.3      | 40       | 17      | 38       | 6.7     | 96       | 13400 |
| <i>P. australis</i> –Shoots                  | 62    | 0.13     | 0.26     | 1.67     | 2.98    | 1.73     | 0.36    | 29.6     | 385   |
| <i>P. australis</i> –Roots                   | 62    | 0.48     | 8.65     | 42.3     | 18.6    | 36.4     | 6.3     | 101      | 13560 |
| <i>A. lanceolata</i> –Roots                  | 68    | 0.33     | 8.6      | 21       | 19      | 23       | 4.9     | 79       | 13400 |
| <i>A. lanceolata</i> –Leaves                 | 68    | 0.11     | 0.9      | 3.1      | 6.8     | 3.1      | 0.8     | 26       | 930   |
| <i>B. umbellatus</i> –Roots                  | 68    | 0.13     | 9.4      | 4.6      | 7.5     | 7.1      | 0.72    | 15       | 2750  |
| <i>B. umbellatus</i> –Leaves                 | 68    | 0.1      | 3        | 3.7      | 3.8     | 4.3      | 0.7     | 28       | 1620  |
| Limits of detection ( $\mu\text{g g}^{-1}$ ) |       | 0.05–0.1 | 0.05–0.1 | 0.25–0.5 | 0.1–0.2 | 0.25–0.5 | 0.1–0.2 | 0.25–0.5 | 1–2   |

**Table 7**

Correlation coefficients (Pearson) between heavy metal contents in sediments and plants of Lake Qattieneh.

| Relations                                      | R     | P-Value |
|--|-------|---------|
| Ni in <i>M. spicatum</i> and Ni in sediments   | 1     | 0.018   |
| Cu in <i>M. spicatum</i> and Cu in sediments   | 0.951 | 0.049   |
| Co in <i>M. spicatum</i> and Co in sediments   | 0.901 | 0.036   |
| Cu in <i>M. spicatum</i> and Co in sediments   | 0.888 | 0.044   |
| Ni in <i>P. pectinatus</i> and Ni in sediments | 0.95  | 0.05    |
| Cu in <i>P. pectinatus</i> and Cu in sediments | 0.999 | 0.016   |
| Zn in water and Co in the investigated species | 0.44  | 0.008   |
| Zn in water and Cu in the investigated species | 0.6   | 0.002   |
| Ca and Cr in the investigated species          | 0.524 | 0.03    |
| Ca and Pb in the investigated species          | 0.69  | 0.002   |

concentrations were comparable with background values in plants growing in uncontaminated environments (Kabata-Pendias and Pendias 1984).

The data for heavy metal analysis in water, sediment and aquatic macrophytes showed medium to high variations in concentrations. Spatial patterns correspond to locations and input from different point sources, creating gradients of respective elements. However, despite a strong wind system, the mixing of lake water is incomplete so that gradients caused by the continuous high input from point sources are not dissipated. The eastern part of the lake, which is more affected by industrial effluents, revealed also the highest values in sediments and in submerged and emergent plants. This is confirmed by a significant

positive correlation between Co, Ni and Cu in sediments and submerged species. Such positive correlations have also been reported by other workers (Hutchinson et al. 1975; Mudroch and Capobianco 1979; Crowder et al. 1989). Thus, a significant portion of Cu, Co and Ni in the plants are most probably derived from the sediments (Demirezen and Aksoy 2004; Aulio 1980; Mudroch and Capobianco 1979).

Statistical analyses reveal that metal concentrations were significantly higher in the roots than in the leaves or shoots of most emergent plants, the former may be associated with an external ion oxide coating known to absorb metals. Also Cardwell et al. (2002) and Hutchinson et al. (1975) reported higher metal concentrations in roots than shoots. However, Behan et al. (1979) and Welsh and Denny (1976) suggested that this difference may, in part, be due to adherence of some sediment particles to roots.

A species may accumulate different heavy metals differently. The significant positive correlation between Co, Ni and Cu in sediments and submerged species (*M. spicatum*, *P. pectinatus* and *P. lucens*) indicates that these species may be used in the chemical qualification of the environment in Lake Qattieneh, and seem to be good biomonitors for Ni, Cu and Co, whereas *P. amphibia* seems to be a better biomonitor for Pb and Cd in Lake Qattieneh. The positive correlations between different metals in sediment and plant tissue confirm the conclusion that the accumulation ability of various species is different for different heavy metals. Franzin and McFarlane (1980), as well as Samecka and Kempers (1996) suggested from a reasonable correlation between Zn in water and Co and Cu in the investigated plants, that these plants may qualitatively indicate the degree of Zn contamination of aquatic

environments if the contamination is severe. Similar conclusions were reached by Louise et al. (1997) and Campbell and Stokes (1985).

Since Lake Qattienah water is very calcareous, temperature increase and photosynthesis activity produce a deposit of the precipitated calcium carbonate on submerged plants. Heavy metals may adsorb onto this thick layer of calcium carbonate, and despite careful cleaning of the samples some traces may be found in sample analyses, as described by Mickle and Wetzel (1978). On the other hand, the high concentration of Ca in the lake waters may play a modifying role on plant uptake of all elements whether essential or non-essential for survival and growth (Franzin and McFarlane 1980).

The west–east gradient in nutrient and heavy metal concentrations in waters and sediments are reflected by the spatial distribution of submersed species. While the heavy metal concentrations of the water body vary considerably in different seasons, the contents in submersed macrophytes integrate seasonal variations of longer time periods. Spatial distribution and tissue accumulation of littoral macrophyte species reflect the environmental conditions at respective sites such as heavy metal contents in water and sediment.

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### References

- Anonymus, 2001. Scientific report about Lake Qattienah 2001. Directorate of Alase basin/Homs, Syria.
- APA, 1985. Standard Methods for the Examination of Water and Wastewater, 16th ed. American Public Association, Washington, D.C.
- Atri, F.R., 1983. Schwermetalle und Wasserpflanzen. Aufnahme und Akkumulation von Schwermetallen und anderen anorganischen Schadstoffen bei höheren aquatischen Makrophyten. Gustav Fischer Verlag, Stuttgart, New York.
- Aulio, K., 1980. Accumulation of copper in fluvial sediments and yellow water lilies (*Nuphar lutea*) at varying distances from a metal processing plant. *Bull. Environ. Contam. Toxicol.* 25, 713–717.
- Best, E.P.H., de Vries, D., Reins, A., 1984. The macrophytes in the Loosdrecht Lakes: a story of their decline in the course of eutrophication. *Verh. Internat. Verein. Limnol.* 22, 868–875.
- Behan, M.J., Kinraid, T.B., Selsler, W.I., 1979. Lead accumulation in aquatic plants from metallic sources including shot. *J. Wildl. Manage.* 43, 240–244.
- Blindow, I., 1992. Decline of charophytes during eutrophication: comparison with angiosperms. *Freshwater Biol.* 28, 9–14.
- Campbell, P.G.C., Stokes, P.M., 1985. Acidification and toxicity of metals to aquatic biota. *Can. J. Fish. Aquat. Sci.* 42, 2034–2049.
- Cardwell, A.J., Hawker, D.W., Greenway, M., 2002. Metal accumulation in aquatic macrophytes from southeast Queensland, Australia. *Chemosphere* 48, 653–663.
- Crowder, A., Dushenko, W.T., Greig, J., Poland, J.S., 1989. Metal contamination in sediments and biota of the Bay of Quinte, Lake Ontario, Canada. *Hydrobiologia* 188/189, 337–343.
- Demirezen, D., Aksoy, A., 2004. Accumulation of heavy metals in *Typha angustifolia* (L.) and *Potamogeton pectinatus* (L.) living in Sultan Marsh (Kayseri, Turkey). *Chemosphere* 56 (7), 685–696.
- DIN 38406-29, 1998. Determination of 61 elements by inductively coupled plasma mass spectrometry (ICP-MS).
- DIN ISO 11466, 1997. Bodenbeschaffenheit – Extraktion in Königswasser löslicher Spurenelemente.
- EN ISO 11885, 1997. Determination of 33 elements by inductively coupled plasma atomic emission spectroscopy.
- Franzin, W.G., McFarlane, A., 1980. An analysis of the aquatic macrophyte, *Myriophyllum exalbescens*, as an indicator of metal contamination of aquatic ecosystems near a base metal smelter. *Bull. Environ. Contam. Toxicol.* 24, 597–605.
- Greger, M., Kautsky, L., 1993. Use of macrophytes for mapping bioavailable heavy metals in shallow coastal areas, Stockholm, Sweden. *Appl. Geochem. Suppl.* 2, 37–43.
- Guilizzoni, P., 1975. Manganese, copper and chromium content in macrophytes of Lake Endine, northern Italy. *Mem. Ist. Idrobiol.* 32, 313–332.
- Hough, R.A., Forwall, M.D., 1988. Interactions of inorganic carbon and light availability as controlling factors in aquatic macrophyte distribution and productivity. *Limnol. Oceanogr.* 33, 1202–1208.
- Hutchinson, T.C., Fedorenko, A., Fitchko, J., Kuja, A., Van Loon, J., Lichwa, J., 1975. Movement and compartmentation of nickel and copper in an aquatic ecosystem. In: Hemphill, D.D. (Ed.), *Trace Substances in Environmental Health*, vol. 9. Univ. of Missouri Press, Columbia, pp. 89–105.
- Kabata-Pendias, A., Pendias, H., 1984. *Trace Elements in Soils and Plants*. CRC Press, Boca Raton, FL, USA.
- Lachavanne, J.B., 1985. The influence of accelerated eutrophication on the macrophytes of Swiss Lakes: abundance and distribution. *Verh. Internat. Verein. Limnol.* 22, 2950–2955.
- Lachavanne, J.B., Juge, R., Perfetta, J., 1991. The consequences of water oligotrophication on macrophytic vegetation of Swiss Lakes. *Verh. Internat. Verein. Limnol.* 24, 943–948.
- Louise, S.C., Cattaneo, A., Chassé, R., Fraikin, C.G.J., 1997. Technical evaluation of monitoring methods using macrophytes, phytoplankton and periphyton to assess the impacts of mine effluents on the aquatic environment. Report presented to Canada Centre for Mineral and Energy Technology, Ottawa, Ontario.
- Melzer, A., Harlacher, R., Held, K., Sirch, R., Vogt, S., 1986. Die Makrophytenvegetation des Chiemsees. *Informationsberichte Bayer. Landesamt f. Wasserwirtschaft* 4/86, 204 pp.
- Mickle, A.M., Wetzel, R.G., 1978. Effectiveness of submersed angiosperm–epiphyte complexes on exchange of nutrients and organic carbon in littoral systems. II. Dissolved organic carbon. *Aquat. Bot.* 4, 317–329.
- Mudroch, A., Capobianco, J.A., 1979. Effects of mine effluent on uptake of Co, Ni, Cu, As, Zn, Cd, Cr and Pb by aquatic macrophytes. *Hydrobiologia* 64, 223–231.
- NY-SDEC (New York State Department of Environmental Conservation), 1998. *Technical Guidance for Screening Contaminated Sediments*. Division of Fish, Wildlife and Marine Resources, March.
- Parker, R.E., 1983. *Introductory Statistics for Biology*. Edward Arnold Publishers, Ltd., London.
- Samecka, C.A., Kempers, A.J., 1996. Bioaccumulation of heavy metals by aquatic macrophytes around Wroclaw, Poland. *Ecotoxicol. Environ. Saf.* 35 (3), 242–247.
- Scheffer, M., Hosper, S.H., Meijer, M.L., Moss, B., Jeppesen, E., 1993. Alternative equilibria in shallow lakes. *Tree* 8, 275–279.
- Scheffer, M., 1998. *Ecology of Shallow Lakes*. Chapman and Hall, London.
- Schmieder, K., 1997. Littoral zone – GIS of Lake Constance a useful tool in lake monitoring and autecological studies with submersed macrophytes. *Aquat. Bot.* 58, 333–346.
- US-EPA, 1986. Quality criteria for water EPA 440/5-8-001 US environmental protection agency, Office of Water, Regulations and Standards, Washington, D.C.
- VDLUFA (Ed.), 1996. *Methodenbuch Band VII*, 2nd edition. Methode 2.1.1, Nassaufschluss unter Druck.
- Welsh, R.P.H., Denny, P., 1976. Water plants and recycling of heavy metals in an English Lake. In: Hemphill, D.D. (Ed.), *Trace Substances in Environmental Health*, Vol. 10. Univ. of Missouri Press, Columbia, pp. 217–223.