Macrophytes and Water Quality of the Nkoup River System (Foumbot, Cameroon)

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ABSTRACT

The floristic characteristics of three river segments of the Nkoup river basin were monitored from January to June 2004 and in the same period in 2005 and the dominant macrophytes together with water samples were analysed for their heavy metal contents. *Potamogeton* spp, *Ceratophyllum demersum* L., *Pistia stratiotes* L. and *Ipomoea aquatica* Forsk. were found to be the dominant macrophytes in the Nkoup river system. They take up substantial amounts of Fe, Mn, Zn, Cu, Ni and Cr which were found in fairly high concentrations in the river water. Samples of *Potamogeton pectinatus* L., *Pistia stratiotes* L. and *Ipomoea aquatica* Forsk. collected from different river segments had different levels of heavy metals that showed some correlations with the levels of metals in solution. The macrophyte roots accumulated significantly higher amounts of metals than the shoots. *Potamogeton pectinatus* L. was the best accumulator for Mn and Ni, *Pistia stratiotes* L. for Zn and Cu and *I. aquatica* Forsk. for Fe and Cr. Integrated propagation of these macrophytes in river channels in the Nkoup river system is recommended for maximum removal of the heavy metals detected in the system.

Key words: heavy metals, macrophytes, nutrients, phytoremediation, river pollution.

RÉSUMÉ

Les caractéristiques floristiques de trois cours d'eau du basin versant de la rivière Nkoup ont été suivies du mois de janvier à juin 2004 et à la même période en 2005, et le contenu en métaux lourds des macrophytes dominants ainsi que des échantillons d'eau déterminé. *Potamogeton* spp, *Ceratophyllum demersum* L., *Pistia stratiotes* L. et *Ipomoea aquatica* Forsk. sont dominants dans ces cours d'eau, et ils absorbent des quantités importantes de Fe, Mn, Zn, Cu, Ni et Cr qui s'y trouvent. L'analyse de *Potamogeton pectinatus* L., *Pistia stratiotes* L. et de *Ipomoea Aquatica* Forsk. a montrée que les taux des métaux lourds dans ces macrophytes varient en fonction du cours d'eau, et quelques corrélations significatives ont été observées entre les taux dans les macrophytes et dans l'eau. En outre, les racines accumulent beaucoup plus de métal que les feuilles. *Potamogeton pectinatus* L. absorbe mieux le Mn et le Ni tandis que *Pistia stratiotes* L. est plus indiqué pour le Zn et le Cu, et *Ipomoea Aquatica* Forsk. pour le Fe et le Cr. Une propagation intégrée des trois macrophytes est recommandée pour une meilleure épuration des cours d'eau du bassin versant du Nkoup.

Mots clés : métaux lourds, macrophytes, nutriments, pollution hydrique, phytoépuration

INTRODUCTION

Macrophytes constitute one of the essential ecological components of a river system. Through their photosynthetic activity, they use up CO_2 and release O_2 into the medium, thus contributing to the oxygen budget and autochthonous carbon pool. Submerged macrophytes and other structural features may act as sediment traps because of their effectiveness in reducing flow velocity (Jackson and Kalff, 1993), while enhancing spatial diversity in the aquatic ecosystem. They also serve to stabilise river banks and consolidate the building blocks. Besides, they remove nutrients from the water and sediments that would otherwise be used by algae that form problematic blooms (Sarnell *et al*, 1998).

Some plants have the natural ability to absorb and accumulate trace elements in their tissues and this ability is being harnessed to remove toxic heavy metals from contaminated soils and waters (Baker *et al*, 1994). In particular, wetland plants have been grown in polluted waters for environmental remediation. *Lemna minor* L. and *Azolla pinnata* R. have been shown to bio-concentrate Fe and Cu (Jain *et al*, 1989). *Eichhornia crassipes* Mart. has been used successfully in waste treatment systems to improve water quality by reducing the levels of organic and inorganic nutrients (Delgado *et al*, 1995), while the accumulation of Zn, Cu, Pb and Cd by several species of wetland plants has been demonstrated by Larsen and Schierup (1981) and Dunbabin and Bowmer (1992). However, because plant species differ in their abilities to take up and accumulate various heavy metals in their tissues, there is need for a judicious selection of plant species for use in constructed wetlands in order to maximise their capacity to remove potentially toxic elements (Qian *et al*, 1999). Based on metal concentration in plant tissues and/or rate of element accumulation in harvestable tissues, *Lemna polyrrhiza* L., *Lemna minor* L. and *Eichhornia crassipes* (Mart.) have been identified as excellent accumulators of Pb, Cd and Se and Cu, respectively (Zayed *et al*, 1998; Zhu *et al*, 1999). *Polygonum hydropiperoides* L. was shown to have a high efficiency to accumulate several trace elements in its roots and shoots (Qian *et al*, 1999), and the water fern *Azolla caroliniana* Willd. has been described as the greatest accumulator of Ni (Sela and Garty, 1989).

Increasing demands on water resources and contamination from industrial wastes and human activities have raised the nutrient and heavy metal loads of aquatic ecosystems. The deterioration of water quality that ensues impinges on the abundance and composition of aquatic vegetation. Agami (1984) found that species richness decreased considerably with increasing pollution in the Amal river (Israel), while Caffrey (1985) demonstrated that alteration of the composition of water due to organic pollution may affect both macrophyte species composition and abundance in rivers. In the Nile (Egypt), the growth and distribution of macrophyte communities were affected by both sediment and water pollutant factors (Ali and Soltan, 1996). Literature on water pollution in Cameroon is rather scarce and mainly limited to streams in the national capital Yaoundé and its environs. Tsala *et al* (1993) investigated the role of *Pistia stratiotes* L. in the uptake of heavy metals from domestic sewage before discharge into the river Biyeme, while Fonkou *et al* (2005) studied the accumulation of heavy metals in a number of macrophytes found in the Olezoa wetland complex, but the general emphasis has been on the physico-chemical and bacteriological aspects of river pollution (Nguematcha, 1977; Njine *et al*, 2002).

The Nkoup river is located in a major agricultural area where both subsistence and medium-scale commercial farming is practiced in a semi-rural/semi-urban setting. The proximity of the Nkoup river to both farmlands and residential areas, coupled with the scarcity of potable water supplies, makes it subject to multiple uses: domestic chores, irrigation, recreation, abstraction for distribution to the population after treatment. This anthropogenic pressure on the river generates a pollution problem that needs to be redressed. Nutrients and heavy metals such as Fe, Mn, Cu, Ni and Cr from diffuse sources have been identified as major pollutants in the Nkoup drainage basin (Tita M.A., unpubl. data). Metal pollutants in water may be acutely toxic (Hg, Pb, Cd), or bioaccumulate and magnify in aquatic food chains (Ni, Cr, Cu), eventually attaining toxic/lethal thresholds in primary, secondary and tertiary consumers (Campbell, 1995). Aquatic biota have a moderate to high potential to bioconcentrate Cu, and in fish, it effectively interferes with bronchial ion transport, plasma ion concentration, haematological parameters and enzyme activities (Hall *et al.*, 1998). Ni constitutes the most common skin allergen in the general population followed by Cr (Adriano, 2001). This study investigates the potential impact of heavy metal accumulation by aquatic macrophytes under field conditions. An understanding of the macrophyte composition and distribution in the Nkoup river system together with their uptake functions is essential for the development of any restoration and management program, since the riparian zones have been cleared and replaced by ridged crops or simply turned into open landfills.

The floristic characteristics of the Nkoup river system and the role of dominant macrophytes in maintaining water quality through heavy metal accumulation were assessed, and the uptake of heavy metals by dominant macrophytes from various river segments compared in relation to water metal contents. The feasibility of using these macrophytes in constructed wetlands for the abatement of metal pollutants in the river system is discussed.

1 EXPERIMENTAL

1.1 Location of study site

The Nkoup river is located in Foumbot sub-division in the Western Province of Cameroon. It is fed by several small streams principal among which is the Ngouongouo river, as well as a multitude of springs, many of which are diverted for irrigation before being drained back into the river-bed. Three river segments in the river basin, each representing more or less homogenous conditions of water quality, were explored: (1) the Nkoup river at Baïgom (05°34'25"N; 010°40'43"E), (2) the Ngouongouo river behind the hospital (0.5°30'20"N; 010°38'04"E), (3) the Nkoup river behind the coffee factory (05°30'03'N; 010°37'59"E) (Fig. 1). The Baïgom segment (BGS) extends for 1km up and downstream of the Baïgom bridge, and the water drains in from the Baïgom plain which is an intensive agricultural area in the basin. The Ngouongouo segment (NGS) extends from the bridge on the way to Fousset passing through the south eastern and most densely populated part of the town, to its confluence with the Nkoup river as the latter flows out of the town. The Nkoup-Factory segment (NFS) is at the outlet of the Nkoup river from Foumbot town. It stretches from the confluence of the Mgbekoun stream that drains the daily market, passing by the town slaughter house, the coffee factory and down to the Nkoup falls.

1.2 Water sampling and analysis

Water samples were collected monthly from each river segment from January to June in 2004 and 2005 using 1L acid-washed polyethylene bottles and transported to the laboratory in an ice bucket. Once there, one aliquot sample was acidified to pH 2 with pure grade HNO_3 and stored in the refrigerator at 4° C until analysis, while the second was used to determine total suspended solids (TSS) by filtration on cellulose acetate filter (0.45 µm, Millipore) using a vacuum pump. The other aliquot sample was analysed for total nitrogen (TN) after oxidation by the Zambelli reagent method (AFNOR, 1975) and total phosphorus (TP) by the molybdovanadate colorimetric method after digestion

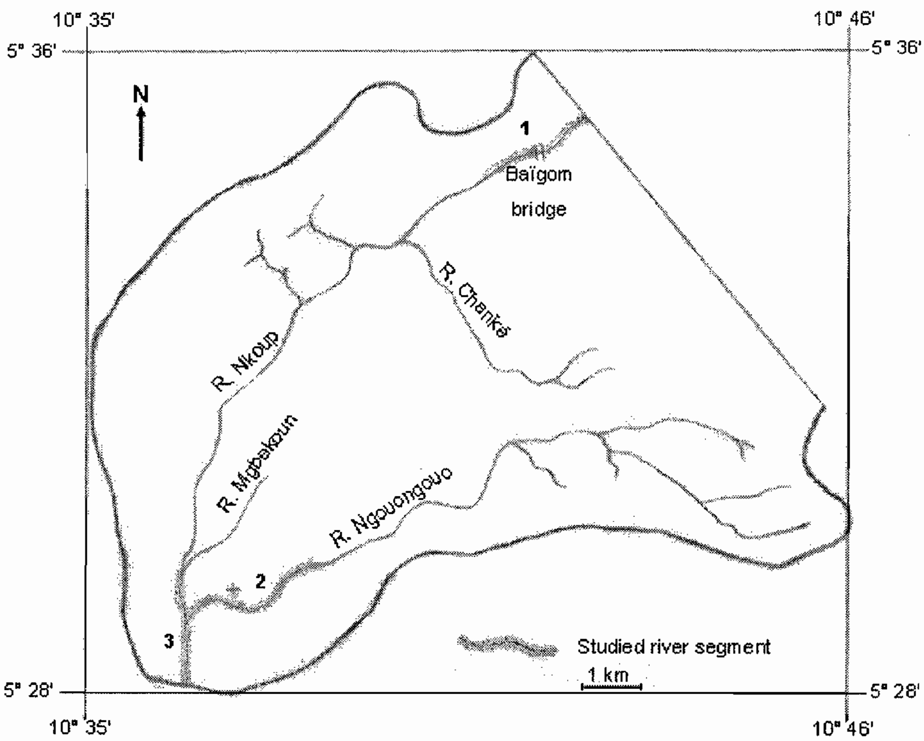

Fig. 1: Nkoup river basin showing sampling sites (1: Baïgom segment; 2: Ngouongouo segment; 3: Nkoup-Factory segment).

(AFNOR, 1978). Heavy metals were determined by atomic absorption spectrophotometry (AAS) after acid digestion and filtration following standard procedures for water analysis (APHA, 1985). Meanwhile, electrical conductivity (EC) and temperature (T), pH and dissolved oxygen (DO) were determined *in situ* using a portable conductivity meter (WTW, Cond 330i model), pH meter (WTW, pH 330i model) and oxygen meter (Oxi 196) respectively.

1.3 Macrophyte sampling

Aquatic vegetation was sampled monthly in each river segment from January to June in 2004 and in 2005, to determine the composition, distribution and abundance of the macrophyte community. Transects were made at various points along the river segment and 50 x 50 cm quadrats demarcated along each transect. The distribution of species along each transect was noted with respect to its distance from the water line, and for each quadrat, the frequency and relative frequency were calculated for each species sampled. Percent surface area covered by each species was estimated based on the Daubenmire (1968) cover class. The percent cover and relative percent cover were calculated using the mid-point of the cover classes. Most of the species were identified on the spot while the rest were pressed and identified later in the National Herbarium in Yaoundé, Cameroon.

In February and March of each year, the aboveground macrophyte biomass was collected from 3 to 5 locations at each river segment using the 50 x 50 cm quadrats, sorted into growth forms, rinsed of debris and the fresh and dry weights determined after oven-drying at 105°C for 24 h.

1.4 Macrophyte metal content

Dominant macrophytes were harvested at the end of each growing season (May/June) for heavy metal analysis. Many individuals of each macrophyte were collected from several sites along the explored segment to constitute a composite sample. Samples were washed thoroughly in tap water to remove debris and sediments, oven-dried at 80°C for 24-48 h and digested in HNO_3:$HClO_4$ (3:1,v/v) mixture. Fe, Mn, Zn, Cu, Ni, Cr were determined by AAS according to standard methods (APHA, 1985). Particular attention was paid to *Potamogeton pectinatus* L., *Pistia stratiotes* L. and *Ipomoea aquatica* Forsk. as representatives of different life forms with a history of phytoremediation.

1.5 Statistical analysis

To determine differences between sites and between macrophytes, results were analysed using one-way analysis of variance (ANOVA) followed by Duncan's multiple range test and probability for significance was set at $p \leq 0.05$ (SPSS 10.0). Linear regression analysis was used to determine the relationship between heavy metal concentration in water and macrophytes using the Microsoft EXCEL statistical package.

2 RESULTS

2.1 Water quality

Table 1 shows the mean and standard deviation of physico-chemical variables measured in the Nkoup river system during the study period. Temperature ranged from 23.1 to 23.9°C; pH was slightly acidic at BGS and neutral at NGS and NFS. Electrical conductivity and suspended solids were significantly ($p < 0.05$) higher at NGS and NFS. Dissolved oxygen was generally low but lowest (<4 mg/l) at NGS. Total nitrogen was most concentrated at NGS whereas total phosphorus concentrated at BGS. Of the several heavy metals analysed, only Fe, Mn, Zn, Cu, Ni, and Cr were detected (Table 1). The major heavy metal in all the river segments was Fe (0.971-1.411 mgL^{-1}) followed by Mn (0.091- 0.11 mgL^{-1}). The least concentrated

Table 1: Mean of Physico-chemical variables of the Nkoup river segments studied.

	T (°C)	pH	EC (µScm^{-1})	TSS	DO	TN	TP	Fe	Mn	Zn	Cu	Ni	Cr
				....	....	....	....	mgL^{-1}	....	....	....	....	
BGS	23.7^{ab}	6.57^{a}	61.41^{a}	18.41^{a}	5.85^{b}	3.23^{a}	1.23^{c}	1.018^{a}	0.134^{a}	0.030^{a}	0.021^{a}	0.018a	0.010^{ab}
	(2.2)	(0.22)	(5.74)	(7.23)	(0.44)	(2.12)	(0.54)	(0.217)	(0.06)	(0.013)	(0.010)	(0.011)	(0.011)
NGS	23.9^{b}	7.07^{b}	200.2^{b}	51.1^{c}	3.91^{a}	4.86^{b}	0.98^{ab}	1.168^{a}	0.210^{b}	0.056^{b}	0.041^{b}	0.054^{b}	0.013^{b}
	(1.37)	(0.15)	(25.24)	(12.6)	(1.22)	(1.95)	(0.18)	(0.26)	(0.05)	(0.041)	(0.050)	(.026)	(0.006)
CFS	23.1^{a}	7.32b	240.3^{b}	37.2^{b}	6.13^{b}	3.94^{ab}	0.733^{a}	0.971^{a}	0.140^{a}	0.035^{a}	0.028^{a}	0.021^{a}	0.006^{a}
	(2.07)	(0.23)	(49.49)	(7.6)	(0.67)	(2.35)	(0.37)	(0.51)	(0.02)	(0.023)	(0.009)	(0.009)	(0.005)

Values are means of 15 entries each with standard deviation in parenthesis. Values in the same column followed by different letters are significantly different at $p \leq 0.05$ (Duncan test). BGS: Baïgom segment; NGS: Ngouongouo segment; NFS: Nkoup-Factory segment.

Table 2: Abundance of different macrophytes observed in river segments in the Nkoup river basin.

Species	*BGS		NGS		NFS	
	Rel freq (%)	Rel cover (%)	Rel freq (%)	Rel cover (%)	Rel freq (%)	Rel cover (%)
Free floating						
Azolla pinnata R. Br.	5.2	6.8	0	0	0	0
Lemna spp.	0	0	0	0	13.2	10.6
Pistia stratiotes L.	1.2	2.7	0	0	29.1	30.7
Floating-leaved						
Crinium thaianum Schultze	5.1	6.1	0	0	0	0
Nymphaea sp.	2.4	2.1	0	0	0	0
Ottelia ulvifolia Walp.	0	0	2.5	0.9	0	0
Sudmerged						
Ceratophyllum demersum L.	13.9	17.9	0	0	0	0
Potamogeton nodosus Poir.	19.1	23.3	0	0	0	0
Potamogeton octandrus Poir.	17.3	21.7	16.8	14.4	0	0
Potamogeton pectinatus L.	18.5	12.6	14.3	7.5	0	0
Emergent						
Aneilema beniniense Kunth	5.2	1.8	0	0	0	0
Commelina benghalensis L.	0	0	28.8	30.7	19.3	15.4
Leersia hexandra Sw.	7.3	3.3	22.8	24.5	20.4	19.3
Ipomoea aquatica Forsk.	5.1	2.4	15	21.8	18.2	24.1

*BGS: Baïgom segment; NGS: Ngouongouo segment; NFS: Nkoup-Factory segment.
Rel. freq: Relative frequency (number of occurrences of species / total occurrence of all species x 100%).
Rel. cover: Relative cover (species cover / total macrophyte cover x 100%).

metal was Cr (≤0.013 mgL^{-1}). Zn and Cu levels were low (<0.06 mgL^{-1}) whereas Fe, Mn, Ni and Cr were higher than background levels (usually non-detectable) for the region.

2.2 Macrophyte composition, distribution and abundance

A total of 14 macrophytes belonging to 9 families were identified in the Nkoup river system. The Baïgom segment was most floristically rich with a total of 11 species covering 45% of the water surface compared to NGS and NFS with 6 and 5 species that covered only 6 and 15% of the surface, respectively (Table 2). Five of the macrophytes at BGS were unique to this segment while two of them (*Potamogeton octandrus* Poir. and *Potamogeton pectinatus* L.) were also present at NGS. None of the submerged macrophytes found at BGS was present at NFS which comprised only floating and emergent species.

The BGS segment was dominated by the pondweeds (*Potamogeton nodosus* Poir., *P. pectinatus* L. and *P. octandrus* Poir.) in an overlapping and mosaic distribution with *Ceratophyllum demersus* L. that accounted for 85% of the total vegetation cover. In NGS, the emergent species *Commelina beghalensis* L., *Leersia hexandra* Sw. and *Ipomoea*

Table 3: Heavy metal contents ($mgkg^{-1}$) of dominant macrophytes harvested from river segments in the Nkoup river basin.

Macrophyte	Fe	Mn	Zn	Cu	Ni	Cr
Ceratophyllum demersum L.	602.90	258.25	104.12	67.90	63.62	61.84
Potamogeton nodosus Poir.	696.50	361.10	90.30	182.26	116.50	76.75
Potamogeton octandrus Poir.	863.75	402.20	147.21	154.30	55.46	61.05
Potamogeton pectinatus L.	1182.00	376.69	303.32	60.60	206.27	45.96
Pistia stratiotes L.	427.20	187.51	251.45	197.31	165.80	24.84
Ipomoea aquatica Forsk.	1379.00	138.65	139.90	42.75	104.35	49.15

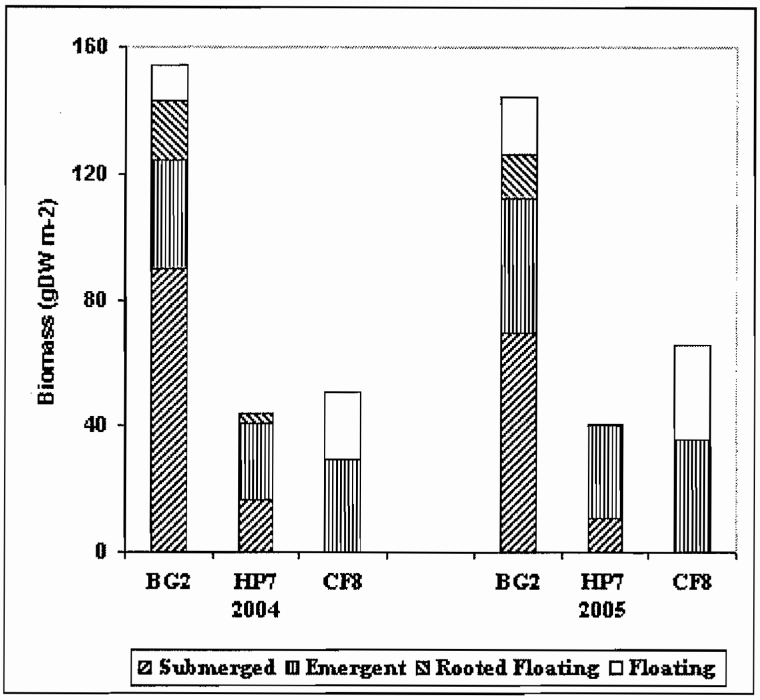

Fig. 2: Aboveground dry biomass harvested from river segments in the Nkoup river basin in 2004 and in 2005 (BGS: Baïgom segment; NGS: Ngouongouo segment; CFS: Nkoup-Factory segment).

aquatica Forsk. were most abundant but the submerged species, *Potamogeton octandrus* and *Potamogeton Pectinatus* occurred extensively at one locality, representing 21.9% cover. At NFS the most frequently occurring species was the free floating *Pistia stratiotes* (29.1%) followed by the emergent species *Ipomoea aquatica*, *Leersia hexandra* and *Commelina beghalensis* with relative cover of 24.1, 19.3 and 15.4%, respectively.

Total aboveground biomass was significantly higher at BGS than either of NGS and CFS (Fig. 2). The submerged component was absent at CFS while that of BGS was much higher than NGS for 2004 and 2005. Rooted floating biomass was absent at CFS in both years and at NGS in 2005. No floating biomass accumulated at NGS during the study period.

2.3 Macrophyte metal contents

Potamogeton pectinatus and *Ipomoea aquatica* accumulated the highest Fe concentrations while all the *Potamogeton* species contained more Mn (Table 3). The concentration of Zn in macrophytes ranged between 90 and 147 $mgkg^{-1}DW$ except in *Pistia stratiotes* and *Potamogeton pectinatus* where the values were much higher. Cu concentrations in *Ceratophyllum demersum*, *Potamogeton pectinatus* and *Ipomoea aquatica* were relatively low compared to the others with values of 154.3 $mgkg^{-1}DW$ and above. The concentration of Ni was highest in *Potamogeton pectinatus* and lowest in *Potamogeton octandrus*. Cr accumulation was highest in *Potamogeton nodosus*, *Ceratophyllum demersum* and *Potamogeton octandrus* (>60 $mgkg^{-1}DW$). The lowest content was in *Pistia stratiotes*.

Further analysis of *Potamogeton pectinatus*, *Pistia stratiotes* and *Ipomoea aquatica* showed that significant differences existed between the concentration of heavy metals in the roots and shoots ($p < 0.001$), with the root concentrations being consistently higher than shoot concentrations across all the metals analysed (Fig. 3). Apart from Fe in *Ipomoea aquatica*, shoot metal concentrations were higher in *Potamogeton pectinatus* than in *Pistia stratiotes* and *Ipomoea aquatica*. *Potamogeton pectinatus* growing at NGS accumulated more Mn, Zn, Cu and Ni than those growing at BGS, but significant differences ($p < 0.05$) were observed only for Zn ($p = 0.010$) and Ni ($p = 0.012$) (Table 4). Conversely, *Potamogeton pectinatus* growing at BGS accumulated more Fe and Cr that were not however, significantly different from those at NGS. Except for Zn ($p = 0.041$), there were no significant differences ($p > 0.05$) in metal contents of *Pistia stratiotes* growing at BGS and those at NFS. Similarly, no significant differences existed in *Ipomoea aquatica* Fe and Mn contents among segments. However, significant differences were recorded for Zn, Cu and Ni with lower contents in plants from BGS (Table 5).

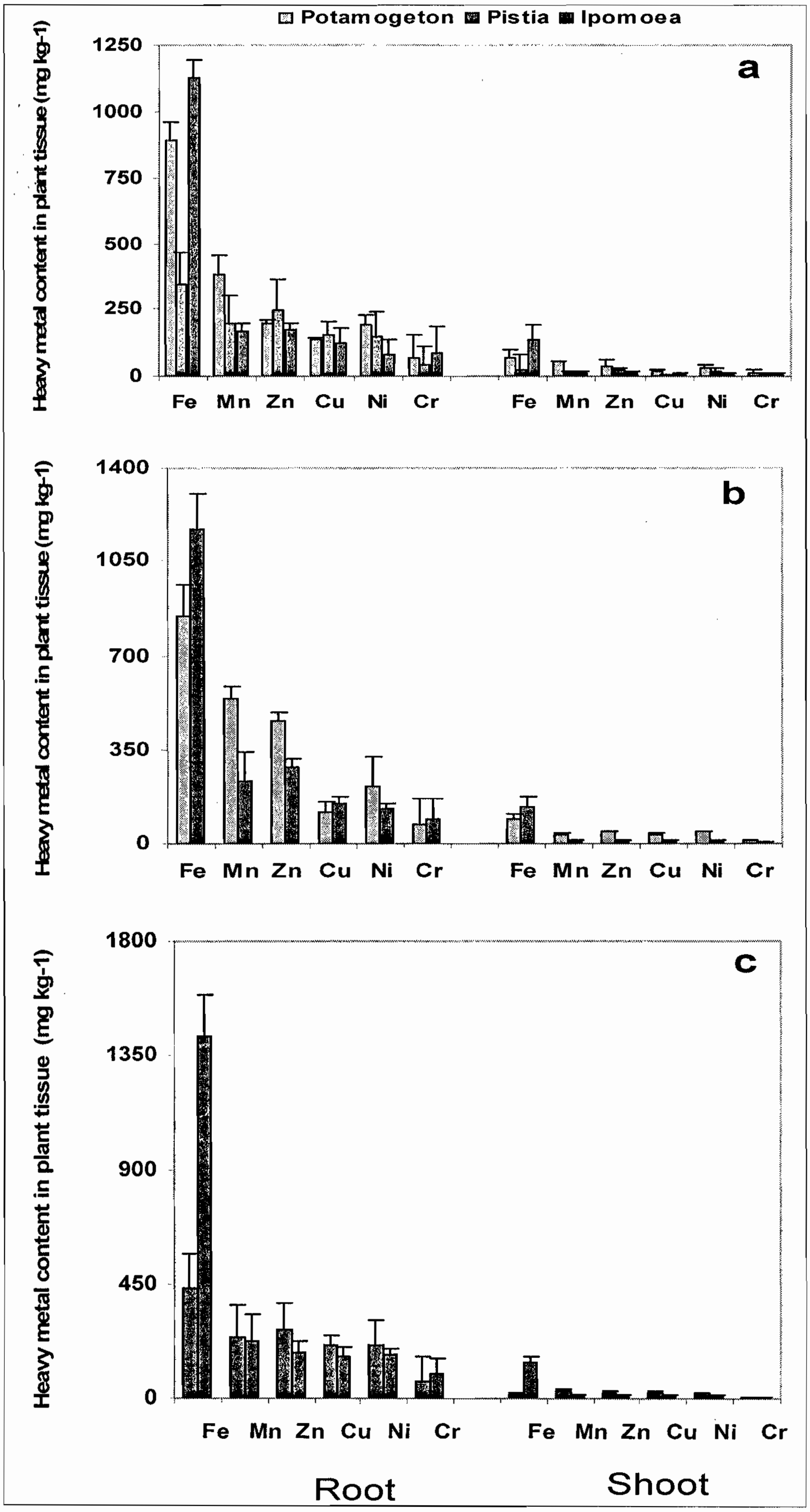

Fig. 3: Heavy metal content of tissues of macrophytes harvested from Baïgom segment (a), Ngouongouo segment (b) and Nkoup-Factory segment (c) (n = 6, mean ± standard deviation).

Table 4: T-tests on mean macrophyte metal concentrations between pairs of river segments in the Nkoup river

	Potamogeton pectinatus L.			*Pistia stratiotes L.*		
Variable	Direction of Difference	t-value	p	Direction of Difference	t-value	p
Fe	BGS > NGS	0.370	0.724	BGS < NFS	-0.265	0.800
Mn	BGS < NGS	-0.687	0.505	BGS < NFS	-0.205	0.845
Zn	BGS < NGS	-3.698	0.010**	BGS < NFS	-2.966	0.041*
Cu	BGS < NGS	-1.196	0.258	BGS < NFS	-2.206	0.070
Ni	BGS < NGS	-4.665	0.012*	BGS < NFS	-0.642	0.548
Cr	BGS > NGS	0.895	0.405	BGS < NFS	-0.239	0.819

*significant difference at p = 0.05;
**significant difference at p = 0.01. BGS: Baïgom segment; NGS: Ngouongouo segment;
NFS: Nkoup-Factory segment

Linear regression analyses showed positive correlations between heavy metal concentrations in water samples and macrophytes and significant correlations ($p < 0.05$) were observed for Zn and Ni in *Pistia stratiotes* (R^2 = 0.787; and 0.647, respectively) and Mn in *Potamogeton pectinatus* (R^2 = 0.625) (Fig. 4). Among heavy metals, significant correlation in accumulation only existed between Fe and Cr in *Ipomoea aquatica* (R^2 = 0.727).

3 DISCUSSION

The macrophyte community in the Nkoup river system differed both in species richness and diversity among the segments studied. All the different life forms of aquatic macrophytes were present in the BGS segment, which also contained the highest number of species, whereas no floating species were found at NGS, and at NFS only floating and emergent species were present. High species diversity is characteristic of unimpacted or unpolluted conditions while lower species diversity often signifies environmental stress (Nilsson et al, 1989). The high concentration of suspended solids and substandard levels of dissolved oxygen in the lower reaches of the Nkoup river could constrain the flora to turbidity tolerant species and life forms. Thus, at NFS the vegetation is biased towards emergent and floating species while submerged flora abounds at BGS where the depth and low turbidity are attenuating. Besides, this segment is characterised by significantly higher phosphorus levels which, together with nitrogen, constitute major ecological determinants of the floristic composition in aquatic systems (Muller, 1990). Under such conditions, eutrophic species such as *Ceratophyllum demersum*, *Elodea nuttallii* H. and *Potamogeton pectinatus* may form relatively large widespread vegetations that account for the bulk of the productivity of the open water (Nurminen, 2003). Eutrophy may also explain, at least in part, the presence of the two *Potamogeton* species at NGS where relatively high levels of nutrients were also registered. Many species of the *Potamogeton* family (*Potamogeton coloratus* Vahl, *Potamogeton obtusifolia* Desv. *and Potamogeton berchtoldii* Fieber) have been described by several authors as indicators for the first stages of eutrophication (Agami *et al*, 1976; Schneider and Melzer, 2004).

At BGS and NGS, combined aboveground biomass was significantly higher in 2004 than in 2005 whereas at NFS, more biomass was measured in 2005. When analysed according to life forms, much more emergent and floating vegetation seemed to have been produced in the latter year, which could explain the concurrent increase in biomass at NFS whose vegetation is predominantly emergent and floating. The proliferation of these life forms might have been responsible for

Table 5: Analysis of variance for heavy metal contents of *Ipomoea aquatica* Forsk. from different segments in the Nkoup River segment

	Fe	Mn	Zn	Cu	Ni	Cr
BGS	1262.50[a]	179.00[a]	183.88[a]	132.67[a]	85.25[a]	90.09[b]
	(86.92)	(77.98)	(17.48)	(10.14)	(37.55)	(23.63)
NGS	1305[a]	245.50[a]	295.85[b]	344.60[c]	242.88[b]	75.36[ab]
	(204.73)	(158.45)	(19.34)	(14.44)	(27.77)	(19.67)
NFS	1570.25[a]	337.13[a]	290.50[b]	273.95[b]	260.38[b]	53.19[a]
	(399)	(143.15)	(46.99)	(40.76)	(24.89)	(10.53)

Values are means of 6 entries each with standard deviation in parenthesis. Values in the same column followed by different letters are significantly different at p = 0.05 (Duncan test). BGS: Baïgom segment; NGS: Ngouongouo segment; NFS: Nkoup-Factory segment.

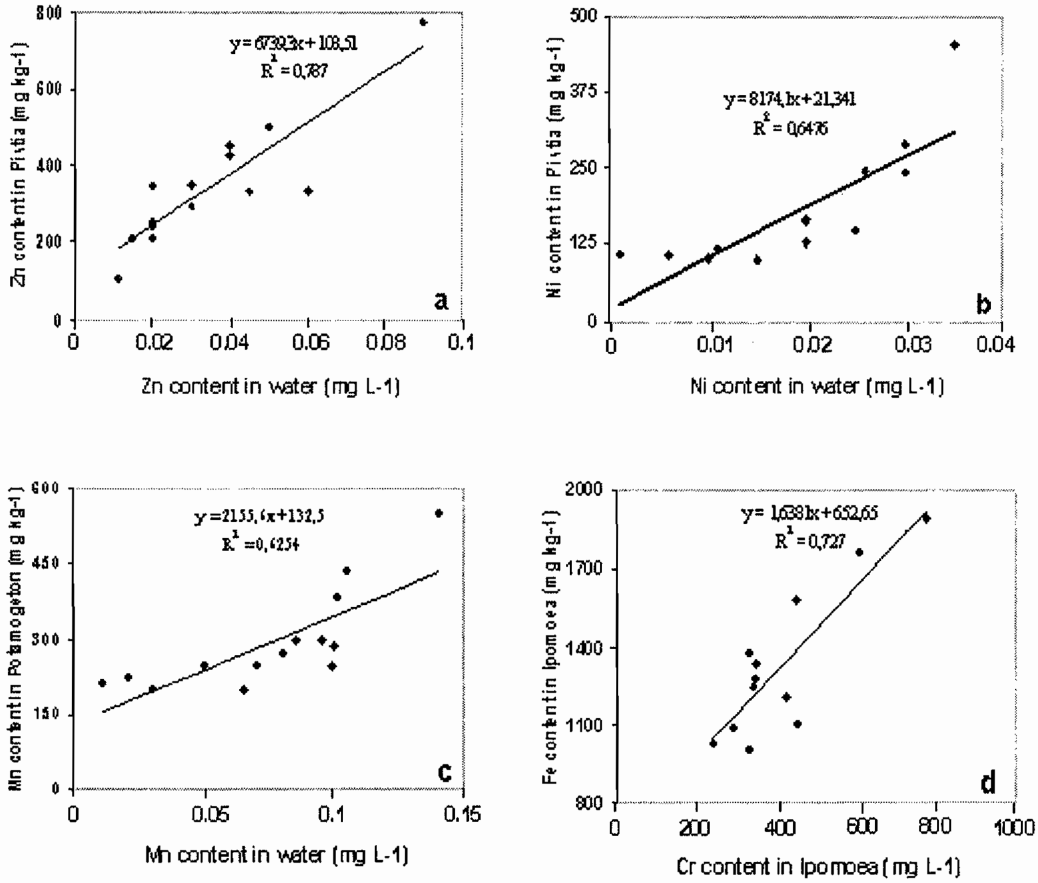

Fig. 4: Relationship between heavy metal concentrations in macrophytes and in water samples (a, b, c) and between heavy metals in macrophytes (d) from river segments in the Nkoup river basin.

the reduction in submerged biomass as a result of shading and perhaps competition for nutrients (Greenway and Woolley, 1999). Although macrophyte biomass occasionally peaked at high values, submerged biomass was for the most part below nuisance level, estimated by Chambers et al (1999) to be about 100 $gDWm^{-2}$.

The concentration of heavy metals was above the background levels (usually non-detectable) for the region, and generally exceeded the recommended limits of WHO (1998) for metals in water for domestic use and normal aquatic life. Moreover, all investigated metals were consistently greater in NGS than in the other segments, suggesting that they are largely anthropogenic in origin. In effect, this segment drains the urban centre where population cluster is highest in the river basin. Heavy metal input in the river probably derives from non-point sources that include leachates from mixed wastes, surface runoff and car washing, as well as eroded soil from market gardens where fertilizers and pesticides are used indiscriminately.

Substantial differences in the accumulation of heavy metals were observed among the species. At BGS, the submerged species generally accumulated more Mn and Cr than *Ipomoea aquatica* and *Pistia stratiotes* whereas *Ipomoea aquatica* accumulated more Fe. Further analysis of *Potamogeton pectinatus*, *Pistia stratiotes* and *Ipomoea aquatica.* established the latter as a good accumulator of Fe and Cr, and *Potamogeton pectinatus* of Mn and Ni. Many authors have reported higher levels of metals in submerged macrophytes than in emergent and floating species (Jackson and Kalff, 1993; Harris and Davidson, 2002). They suggest that because particulate matter and sediments are reservoirs for heavy metals, submerged macrophytes that trap these particles have increased amount of exposure to such metals, hence increasing the level of accumulation. Similarly, emergent species could accumulate more metals than their floating counterparts as a result of greater contact with heavy metal-enriched substrates. *Pistia stratiotes* accumulated more Zn and Cu with the Zn contents significantly correlated to water column levels. However, only a few significant correlations existed between heavy metal content in plants and the content in water, a possible indication that other environmental factors have an important role in regulating macrophyte metal uptake in the river. In nutrient-enriched environments for example, the bioavailable fraction of metals may be reduced as a result of binding to nutrient anions while uptake may also be affected by metal-metal interactions and/or competition for uptake sites (Campbell, 1995).

For all the metals measured in the present study, metal concentrations in the roots were significantly greater than in the leaves ($p < 0.001$). The tendency for wetland plants to accumulate metals mainly in roots is well documented (Peverly *et al*, 1995; Cardwell *et al*, 2002; Göthberg *et al*, 2004). The greater accumulation of metals in root tissues may imply that roots are the primary site of metal uptake, although high metal concentrations in the roots may also result from a mechanism within the plant which favours this location for deposition (Miller et al, 1983), or from the adsorption of metals on the Fe plaque (which plaque was observed on plants at BGS and NGS). Where shoot accumulation was significant (Fe, Zn and Mn), *Potamogeton pectinatus* generally performed better than *Pistia stratiotes* and *Ipomoea aquatica*. It is likely that with its vegetative tissues bathed in the nutrient medium, *Potamogeton pectinatus* may have additional access to mineral ions by foliar absorption. Its thin membranous leaf morphology would then be a facilitating element, serving to increase the surface area to volume ratio (Wu and Guo, 2000).

The concentrations of metals in the macrophytes greatly exceeded the respective concentrations in water, indicating their ability to take up and accumulate metal ions from the water. In fact, bioconcentration factors ranged from 115 for Fe in *Pistia stratiotes* to 7951 for Cr in *Ipomoea aquatica*. Working under laboratory conditions, Zayed et al. (1998) and Zhu et al. (1999) proposed that a good metal accumulator wetland plant should have the ability to bioconcentrate the element in its tissues to 1000 fold the initial supply. Based on the bioconcentration factor, *Ipomoea aquatica* qualifies as a good accumulator of Fe (1617) in the Nkoup river system, while *Pistia stratiotes* would be more effective in accumulating Zn and Cu (2351 and 1257, respectively). *Potamogeton pectinatus* on its part exhibited an overall better performance than the other species in the bioconcentration of Mn (2833) and Ni (4807).

The capacity to accumulate heavy metals in the aboveground plant tissues constitutes a key point for the suitability of plants for remediation through regular harvesting (Salt and Kramer, 2000), and on this score, *Potamogeton pectinatus* could present additional advantages over *Pistia stratiotes* and *Ipomoea aquatica* for the accumulation of Mn, Zn, Ni and Cr. Nevertheless, *Pistia stratiotes*, a floating macrophyte that can be harvested wholly, seems more suitable for the removal of Zn and Cu. Combining *Pistia stratiotes* and *Potamogeton pectinatus* in an in-channel constructed wetland is likely to yield good results for Zn, Cu and Mn removal but harvesting must be well regulated and synchronised to avoid suffocation of *Potamogeton pectinatus* by the more prolific *Pistia stratiotes*. *Pistia stratiotes* could also be associated with *Ipomoea aquatica* especially at NGS where the extensive branching shoots of the latter could help retain the floating *Pistia stratiotes* to ensure removal of Cr both from solution and from the sediments at all seasons. Above all, the three species could be introduced and propagated in the Mgbekoun river, another river segment in the same basin with similar physico-chemical properties to NGS, but completely devoid of in-stream vegetation.

CONCLUSION

The Nkoup river system is dominated by several submerged species of the *Potamogeton* family upstream at BGS whereas its lower reaches (NFS) are dominated by the floating *Pistia stratiotes* that may disappear completely during high discharge, leaving emergent species like *Ipomoea aquatica* as the permanent macrophyte in this segment. NGS that drains the urban area harbours some *Potamogeton pectinatus* and *Potamogeton octandrus*, but it is both qualitatively and quantitatively poor in vegetation. These macrophytes accumulate varying amounts of Fe, Mn, Zn, Cu, Ni and Cr detected in high concentrations in the river water. The bioconcentration factors for these metals in *Potamogeton pectinatus*, *Pistia stratiotes* and *Ipomoea Aquatica* are sufficiently high to warrant their conservation and propagation in the river channels for metal removal and improved water quality.

ACKNOWLEDGEMENTS

The authors are grateful to the Département Soutien et Formation des Communautés Scientifiques du Sud (DSF-IRD) for their financial support.

REFERENCES

Adriano D.C., 2001. Trace Elements in the Terrestrial Environment: Biogeochemistry, Bioavailability and Risks of Metals. 2nd ed., Springer-Verlag, New York, 841 p.

AFNOR, 1975. Dosage des nitrites. *Norme AFNOR* NF T 90 - 013.

AFNOR, 1978. Dosage des orthophosphates, des phosphates hydrolysables et du phosphore total. *Norme AFNOR* NF T 90 - 023.

Agami M., 1984. Effects of water pollution on plant species composition along the Amal River, Israel. *Arch Hydrobiol.* 100 (4): 445-454.

Agami M., Litav M., Waisel Y., 1976. The effect of various components of water pollution on the behaviour of some aquatic macrophytes of the coastal rivers of Israel. *Aquatic Botany* 2: 203-213.

Ali M. M., Soltan M., 1996. The impact of three industrial effluents on submerged aquatic plants in the River Nile, Egypt. *Hydrobiologia* 340: 77-83.

APHA (American Public Health Association), 1985. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington, DC.

Baker A., McGrath S. P., Sidoli C. M., Reeves R. D., 1994. The possibility of *in situ* heavy metal decontamination of polluted soils using crops of metal-accumulating plants. *Resour. Conserv. Recycle* 11: 41-49.

Caffrey J., 1985. A scheme for the assessment of water quality using aquatic macrophytes as indicators. *J. Life Sci. Dubl. Soc.* 5: 105-111.

Campbell P. G. C., 1995. Interactions between trace metals and aquatic organisms, p 45-105. *In*: Tessier A., D.R. Turner (ed.). Metal Speciation and Bioavailability in Aquatic Systems. John Wiley and Sons, New York.

Cardwell A. J., Hawkee D. W., Greenway M., 2002. Metal accumulation in aquatic macrophytes from southeast Queensland, Australia. *Chemosphere* 48, 653-663.

Chambers P. A., Dewreede R. E., Irlandi E. A., Vandermeulen H., 1999. Management issues in aquatic ecology: a Canadian perspective. *Can. J. Bot.* 77: 471 – 487.

Daubenmire R. F., 1968. Plant Communities: A Textbook of Plant Synecology. Harper and Row, New York, 300 pp.

Delgado M., Guardiola E., Bigeriego M., 1995. Organic and inorganic nutrients removal from pig slurry by water hyacinths. *J. Environ. Sci. Health* 30: 1423-1434.

Dunbabin J. S., Bowmer K. H., 1992. Potential use of constructed wetlands for treatment of industrial wastewaters containing metals. *Sci. Total Environ.* 111: 151-168.

Fonkou T., Agendia P., Kengne I., Amougou A., Focho D., Nya J., Dongmo F., 2005. Heavy metal concentrations in some biotic and abiotic components of the Olezoa wetland complex (Yaoundé - Cameroon, West Africa). *Wat. Qual. Res. J. Can.* 40(4): 457 - 461.

Göthberg A., Greger M., Holm K., Bengtsson B. E., 2004. Influence of nutrient level on uptake and effects of mercury, cadmium and lead in water spinach. *J. Environ. Qual.* 33: 1247-1255.

Greenway M., Woolley T., 1999. Constructed wetlands in Queensland: Performance efficiency and nutrient bioaccumulation. *Ecol. Eng.* 12: 39 – 45.

Hall L.W., C.Scott M., Killen W.D., 1998. Ligand model predicting chronic copper toxicity to *Daphnia magna*. *Environ. Toxicol. Chem.*, 17: 1172 - 1189.

Haris C. J., Davidson I. J., 2002. Heavy metal concentrations in macrophytes from the Manly Lagoon Catchment. *In*: UTS Freshwater Ecology Report of 2002, Department of Environmental Sciences, University of Technology, Sydney.

Jackson L. J., Kalff J., 1993. Patterns in metal content of submerged aquatic macrophytes: role of plant growth form. *Freshwater Biol.* 29: 351-359.

Jain S. K., Vasudevan P., Jha N. K., 1989. Removal of some heavy metals fom polluted water by aquatic plants: studies on duckweed and water velvet. *Biol. Wastes* 28: 115 – 126.

Larsen V. J., Schierup H. H., 1981. Macrophyte cycling of Zn, Cu, Pb and Cd in the littoral zone of polluted and non-polluted lake: II. Seasonal changes in heavy metal content of aboveground biomass and decomposing leaves of *Phragmites australis* (Cav.). *Trin. Aquat. Bot.* 11: 211-230.

Miller G. E., Wile I., Hitchin G. G., 1983. Patterns of accumulation of selected metals in members of the softwater macrophytes flora of central Ontario lakes. *Aquat. Bot.* 15: 53 – 64.

Muller S., 1990. Une séquence de groupements végétaux bioindicateurs d'eutrophisation croissante des cours d'eau faiblement minéralisés des Basses-Vosges gréseuses du Nord. *C. R. Acad. Sci. Paris* 310 (III), 509-514.

Nguematcha J. M., 1977. Démonstration bactériologique de la pollution fécale de quelques étangs et lacs à usage domestique dans la ville de Yaoundé (Cameroun). *Med. Afr. Noire* 24 (3): 199-203.

Nilsson C., Grelsson G., Johansson M., Sperens U., 1989. Patterns of plant species richness along river banks. *Ecology* 70(1): 77-84.

Njiné N., Kemka S. H., Zebaze T. D., Niyitegeka M., Nola T., Ayissi A., Monkiedje, Foto M., 2002. Apports d'eaux usées non traitées dans le lac municipal de Yaoundé (Cameroun) et effets sur la capacité d'assimilation de l'écosystème. Proceedings of the Int. Symposium on Environmental Pollution Control and Waste Management, 1-10 Jan 2002, Tunis.

Nurminen L., 2003. Macrophyte species composition reflecting water quality changes in adjacent water bodies of Lake Hiidenvesi, SW Finland. *Ann. Bot. Fennici* 40: 199-208.

Peverly J. H., Surface J. M., Wang T., 1995. Growth and trace metal absorption by *Phragmites australis* in wetland constructed for landfill leachate treatment. *Eco. Eng.* 5: 21-35.

Qian J. H., Zayed A., Zhu Y. L., Yu M., Terry N., 1999. Phytoaccumulation of trace elements by wetland plants: III. Uptake and accumulation of ten elements by twelve plant species. *J. Environ. Qual.* 28: 1448-1455.

Salt D. E., Kramer U., 2000. Concentrations of heavy metals and plant nutrients in water, sediment and aquatic macrophytes of anthropogenic lakes (former open cut brown coal mines) differing in stage of acidification. *Sci. Total Environ.* 281: 87-98.

Sarnelle O., Cooper S. D., Wiseman S., Mavuti K. M., 1998. The relationship between nutrients and trophic-level biomass in turbid tropical ponds. *Freshwat. Biol.* 40: 65-75.

Schneider S., Melzer A., 2004. Sediment and water nutrient characteristics in patches of submerged macrophytes in running waters. *Hydrobiologia* 527: 195-207.

Sela M., Garty J., 1989. The accumulation and the effect of heavy metals on the water fern *Azolla filiculoides*. *New Phytol.* 112(1): 7-12.

Tsala N. G., Omokolo N. D., Tita M. A., 1993. Effect of some heavy metals on photosynthetic activity and chlorophyll content in *Pistia stratiotes*. *J. Zhejiang Agric. University* 19 (1): 110-116.

WHO, 1998. Guidelines for Drinking Water Quality 2nd ed. Vol. 2. Health Criteria and Other Supporting Information, 1996 (pp. 940-949) and Addendum to vol. 2, 1998 (pp. 281-283) Geneva, World Health Organisation.

Wu L., Guo X., 2002. Selenium accumulation in submerged aquatic macrophytes, *Potamogeton pectinatus* L. and *Ruppia maritime* L. from water with elevated chloride and sulphate salinity. *Ecotoxicol. Environ. Safety* 51: 22 – 27.

Zayed A., Gowthaman S., Terry N., 1998. Phytoaccumulation of trace elements by wetland plants: I. Duckweed. *J. Environ. Qual.* 27: 715 – 721.

Zhu Y. L., Zayed A. M., Qian J. H., De Souza M., Terry N., 1999. Phytoaccumulation of trace elements by wetland plants: II. Water Hyacinth (*Eichhornia crassipes*). *J. Environ. Qual.* 28: 339-344.

Received: 02/05/2007
Accepted: 28/10/2007