

CHEMICAL COMPOSITION OF AQUATIC MACROPHYTES.
III. MINERAL COMPOSITION OF FRESHWATER MACROPHYTES
AND THEIR POTENTIAL FOR MINERAL NUTRIENT REMOVAL
FROM LAKE WATER

A. JABBAR MUZTAR, S. J. SLINGER, and J. H. BURTON¹

Department of Nutrition, College of Biological Science, University of Guelph, Guelph, Ontario
N1G 2W1. Received 21 Apr. 1977, accepted 14 Mar. 1978.

MUZTAR, A. JABBAR, SLINGER, S. J. AND BURTON, J. H. 1978. Chemical composition of aquatic macrophytes. III. Mineral composition of freshwater macrophytes and their potential for mineral nutrient removal from lake water. Can. J. Plant Sci. 58: 851-862.

Mineral composition of aquatic plants from Chemung Lake and Lake Ontario was investigated. The four species harvested at progressive dates in 1974 showed no trend of variation in their individual mineral contents. This was probably because some dates did not correspond with a specific growth stage. All the four species harvested at three dates, except *Myriophyllum spicatum* and *Vallisneria spiralis* collected in September, were extremely high in ash. *Myriophyllum* and *Vallisneria* harvested in September represented immature plants, since these were obtained from sites harvested previously and consequently were much lower in ash. Calcium and phosphorus levels varied with the ash content, with the former being the major cation in all species. Analyses of washed and unwashed samples of several macrophytes harvested in 1975 showed that extremely high ash was the result of surface calcification with CaCO_3 . Silica, Co, Cu and Se were present at safe levels for feeding to animals. Results indicated that harvesting aquatic plants has the potential to remove large quantities of mineral nutrients from the aquatic environment, and feeding good quality plants to herbivore and poultry could meet their requirements for many of the mineral elements.

Nous avons étudié la composition minérale des plantes aquatiques du lac Chemung et du lac Ontario. Les quatre espèces récoltées à des dates successives en 1974 n'ont pas révélé d'évolution particulière de la teneur en minéraux, ce qui, probablement, tient au fait que certaines des dates ne correspondaient pas à un stade de croissance spécifique. Les quatre espèces récoltées aux trois dates, sauf les collectes de *Myriophyllum spicatum* et *Vallisneria spiralis* en septembre, étaient extrêmement riches en cendres. Les échantillons de ces deux dernières espèces en septembre consistaient en plantes immatures puis qu'ils provenaient de plantes déjà récoltées auparavant, ce qui explique leur teneur en cendres beaucoup plus basse. Les teneurs en Ca et en P ont varié parallèlement à la teneur en cendres, Ca étant le principal cation dans toutes les espèces. Les analyses des échantillons lavés et non lavés de plusieurs espèces aquatiques supérieures récoltées en 1975 montrent que la teneur très élevée en cendres est le résultat d'une calcification en surface par CaCO_3 . Les concentrations de silice, de Co, de Cu et de Se étaient sans danger pour l'alimentation des animaux. Les résultats indiquent que la récolte des plantes aquatiques offre un moyen d'exporter de grandes quantités de nutriments minéraux des milieux aquatiques et que l'emploi d'espèces végétales de bonne qualité dans l'alimentation des herbivores et de la volaille pourrait combler leurs besoins pour beaucoup de ces éléments minéraux.

¹Present address (J.H.B.): Department of Animal and Poultry Science, Ontario Agricultural College, University of Guelph, Guelph, Ontario N1G 2W1.

Can. J. Plant Sci. 58: 851-862 (July 1978)

The mineral content of aquatic plants has been reported to vary with the fertility of the aqueous environment (Boyd 1970a,b; Culley and Epps 1973; Denton 1967; Lawrence and Mixon 1970; Shirley and Esley 1970). The fertility of a water body depends on the industrial and municipal effluents as well as on the runoff and drainage from agricultural operations entering it. These inflows carry large amounts of nitrogen and phosphorus which are frequently regarded as the limiting nutrients for aquatic vegetation. The geomorphological character of the water body is also important in furnishing nutrients which would support plant growth. For instance, lakes and rivers flowing over rocky lands and through areas covered with foliage trees will receive considerable quantities of nutrients from allochthonous sources. The plant species growing in saline waters (Anderson et al. 1965) and those in hard water lakes (Wetzel 1960) differ considerably in the content of some of the mineral elements. It therefore appears that the same species growing in different water bodies will show considerable variation in mineral composition. Furthermore, some of the elements such as N, S, P and K have been reported to be absorbed mostly during the early part of the growth cycle (Boyd 1969). Thus the stage of growth also affects the mineral level of these plants.

Aquatic macrophytes have been reported to possess great potential for mineral absorption from the aqueous environment (Boyd 1969, 1970a; Boyd and Hess 1970; Howard-Williams et al. 1972). This mineral-absorbing potential could possibly be harnessed to reduce the nutrient content of eutrophic waters and thus circumvent the potential for excessive plant growth. The mechanical harvesting of macrophytes could remove mineral matter from the aqueous medium. Harvested plants may have potential use for composting, as mulches or as animal feedstuffs and thus defray part of the cost of harvesting operations.

In the past few years, eutrophication of freshwater lakes in Ontario has been aug-

mented considerably, with a resultant increase in macrophyte growth. There is an immediate need, therefore, to develop an economically feasible management program to contain the growth of these plants. A knowledge of the mineral composition of the species and lake water would be very useful in the development of any kind of plant management program. This study was undertaken to investigate the variations and differences in mineral content of aquatic macrophytes with species and harvesting time as well as to examine their mineral-stripping potential.

MATERIALS AND METHODS

The plant materials for mineral analyses included samples of four species harvested three times during the summer of 1974 and washed and unwashed samples of several aquatic plants obtained in 1975 from Chemung Lake and Lake Ontario. All plant samples were obtained from Chemung Lake with the exception of *C. glomerata* and duckweed (*Lemna minor*). *Cladophora glomerata* was collected from Lake Ontario and duckweed was obtained from a marsh in the vicinity of Guelph. Harvested plant materials were placed in polythene bags and transported to the laboratory under cool conditions. Each sample from 1975 was divided into two portions. One portion was washed with tap water to remove adhering matter. The washed and unwashed samples from 1975 and plant samples from 1974 (which were not washed) were freeze-dried and ground to pass a 1-mm screen using a Wiley mill. Samples for mineral analysis were prepared in the following ways. A 1-g sample of whole dried, ground plant was digested with 27 ml of concentrated HNO_3 and 5 ml of HClO_4 . The digest was made up to 50 ml with deionized water. Aliquots were then used to determine the individual mineral elements Ca, Mg, K, Na, Fe, Mn, Cu, Zn and Co using a Techtron Model AA-4 Atomic Absorption Spectrophotometer. Insoluble silica (sand) and soluble silica were determined by the methods of the Association of Official Analytical Chemists (AOAC 1970). Selenium was determined by the method of Hoffman et al. (1968). Of the anionic groups determined, chloride was measured by the method of AOAC (1970), sulfate by the method of Dunk et al. (1969), and carbonate was

Table 1. Mineral composition of the surface waters of Chemung Lake†

Chemical parameters	Nature of sampling area		
	Moderate to heavy weed growth	Scattered weed cover on bottom	Weed-free
	<i>n</i> =144‡	<i>n</i> =105	<i>n</i> =176
Ca	44.13±1.79	44.00±2.08	49.00±1.29
Na	4.16±0.09	4.13±0.20	3.97±0.18
Mg	5.06±0.22	4.42±0.26	4.33±0.31
K	1.11±0.08	1.23±0.08	1.18±0.08
Fe	0.06±0.007	0.05±0.01	0.062±0.009
Mn	0.043±0.002	0.042±0.005	0.038±0.005
SiO ₂	1.53±0.21	1.83±0.58	1.90±0.37
Inorganic carbon	23.59±0.83	23.03±0.60	25.60±0.49
Organic carbon	12.25±1.05	10.80±0.69	11.00±0.68
Total Kjeldahl N	0.67±0.04	0.56±0.02	0.57±0.01
Total P (μg/l)	29.63±1.86	21.50±1.41	23.50±1.29

†All values are expressed as mg/l unless otherwise stated. All values are means with standard errors. Data summarized from Wile and Hitchin (1977).

‡*n*=number of samples of water taken for mineral analysis over a period of 6 yr from 1971 to 1976.

determined as carbon dioxide according to the method outlined in the text by Kolthoff and Sandell (1946). Phosphorus was determined by the method of King (1932) using 1-amino-2-naphthol-4-sulfonic acid as the reducing agent.

RESULTS AND DISCUSSION

The mineral composition of surface waters of Chemung Lake from the different sites shown in Table 1 is summarized from Wile and Hitchin (1977). Calcium and orthosilicate levels were relatively low in the weed-growing waters while levels of Na, Mg and Mn were relatively high. There was essentially no difference in K and Fe content of waters in areas with or without macrophytes. The inorganic carbon content of weed-infested waters was lower than those with no weed growth, which indicated that inorganic carbon was being utilized for

bio-production. This was supported by the organic carbon content, which was relatively high in the weed-infested waters. Nitrogen and phosphorus levels also were higher in waters of weed-growing sites compared with weed-free waters.

The total N, P, and Fe content in sediment from different sites of Chemung Lake are shown in Table 2 (Wile and Hitchin 1977). Both N and P levels were substantially higher in sediment with macrophyte infestation.

The relatively high N and P levels both in the surface waters and in the hydrosol of the shallow, weed-infested areas reflect a highly productive environment. Nitrogen (Gerloff and Skoog 1957; Prowse and Talling 1958; Nye and Greenland 1960; Talling 1965, 1966; Moss 1969; Mitchell

Table 2. Total nitrogen, phosphorus and iron (mg/g dry wt) in sediment samples collected in 1971 from Chemung Lake†

Nature of sampling area	Nitrogen	Phosphorus	Iron
Area with macrophyte growth	27	1.9	11
Area with scattered weed cover on bottom	13	1.2	15
Area without macrophyte growth	20	1.2	12

†Data from Wile and Hitchin (1977).

UNIVERSITY OF WATERLOO LIBRARY

Table 3. Mineral composition of aquatic plants harvested during the summer of 1974, dry weight

Species	Date of cutting	Ash (%)	Ca (%)	P (%)	Mg (%)	Na (%)	K (%)	Mn (%)	Se (ppm)
<i>Cladophora glomerata</i>	1 July	38.8	5.2	0.20	0.26	0.07	4.30	0.05	-
	1 Aug.	45.5	8.2	0.13	0.37	0.08	2.10	0.03	1.10
	1 Sept.	43.9	7.0	0.17	0.45	0.18	1.40	0.03	-
Mean \pm SE		42.7 \pm 2.0	6.8 \pm 0.9	0.17 \pm 0.02	0.36 \pm 0.06	0.11 \pm 0.04	2.60 \pm 0.87	0.04 \pm 0.01	
<i>Myriophyllum spicatum</i>	1 July	63.7	23.7	0.09	0.23	0.27	0.56	0.06	0.22
	1 Aug.	60.6	20.7	0.11	0.24	0.36	0.76	0.05	0.24
	1 Sept.	26.2	6.4	0.26	0.35	1.13	1.21	0.02	-
Mean \pm SE		50.2 \pm 12.0	16.9 \pm 5.3	0.15 \pm 0.05	0.27 \pm 0.04	0.59 \pm 0.27	0.84 \pm 0.19	0.04 \pm 0.01	
<i>Potamogeton</i> spp.	1 July	16.0	5.0	0.27	0.52	0.53	3.90	0.04	0.10
	1 Aug.	19.2	5.1	0.21	0.50	0.64	0.79	0.01	0.10
	1 Sept.	29.4	7.4	0.17	0.32	1.14	1.10	0.03	-
Mean \pm SE		21.5 \pm 4.0	5.8 \pm 0.8	0.22 \pm 0.03	0.45 \pm 0.06	0.77 \pm 0.19	1.93 \pm 0.99	0.03 \pm 0.01	
<i>Vallisneria americana</i>	1 July	32.2	5.1	0.30	0.43	1.69	1.13	0.01	-
	1 Aug.	47.0	11.6	0.17	0.43	2.62	3.10	0.03	0.34
	1 Sept.	24.7	5.0	0.27	0.43	4.96	2.19	0.04	-
Mean \pm SE		34.6 \pm 6.6	7.2 \pm 2.2	0.25 \pm 0.04	0.43 \pm 0.00	3.09 \pm 0.97	2.14 \pm 0.57	0.03 \pm 0.01	

and phosphorus (Hasler and Einsele 1948; Sawyer 1947; Edmonson 1970) have been regarded as the essential and frequently limiting elements for growth of aquatic plants. Hutchinson (1957) has indicated that phosphorus may limit production when the N/P ratio of the aqueous environment is high (total Kjeldahl plus nitrate to total phosphorus) whereas nitrogen would be expected to limit production when the ratio is less than 9. Nitrogen:phosphorus ratios in waters from either weed-infested or weed-free sites of Chemung Lake were high (>20). This indicated that phosphorus may be the key nutrient controlling production in this lake.

The mineral composition of aquatic plants harvested at progressive dates in the summer of 1974 is shown in Table 3. The calcium content ranged from 5% for *V. americana* harvested in early September to 23.7% for *M. spicatum* cut in early July. High Ca levels have been partially accounted for by the deposition of CaCO_3 on the surface of aquatic plants (Welch 1952). A direct relationship between total alkalinity in the water and CaCO_3 deposited on the surfaces and in the tissues of *Chara* has been reported by Boyd and Lawrence (1966).

The levels of phosphorus were, in general, relatively low and fluctuated in all the species over the three harvesting times. Magnesium and manganese levels varied with harvesting time and species in most instances. Interestingly, the levels of sodium increased considerably with progress in harvesting time from July onwards in all the species in spite of the fact that the *M. spicatum* and *V. americana* harvested in September was the second cutting. A similar increase in the K level was also observed in *M. spicatum*, while marked fluctuations occurred in the K content of the remaining species. Selenium analysis could not be completed on all the four species at three harvesting dates because of a shortage of sample material. Selenium levels did not appear to change at the different harvesting

times as observed from the available figures in Table 3. However, some species did appear to accumulate more Se than others.

The results of mineral analyses for plants harvested in the summer of 1975 are shown in Tables 4 and 5. The unwashed materials of all plant species contained 2–6 times more calcium than the washed, with the exception of *M. spicatum*, *Chara* sp. and duckweed; this element constituted 30% or more of the total ash in both the washed and unwashed samples of most species.

The amount of carbonate was in several cases as high as calcium; in general, CO_3 level was positively correlated with Ca level. It is of interest that in samples of all plant species, either washed or unwashed, levels of Ca and CO_3 varied almost directly with the ash content, which supports the concept that a large proportion of the ash in aquatic plants is present as CaCO_3 . In addition, a reduction in the ash content of most samples upon washing was accompanied by a corresponding decrease in both the calcium and CO_3 levels. These results indicate that the high levels of ash encountered in most aquatics is largely extraneous and much of it is CaCO_3 ; however, wide variations are evident both within and between species in this regard. On the other hand, there was a slight increase in phosphorus content of most plant species after washing, with most values ranging from 0.15 to 0.2% for the unwashed samples and from 0.2 to 0.25% for the washed samples. This indicates that phosphorus is mainly a constituent of the plant tissue.

Most species did not deposit high levels of either insoluble or soluble silica. Levels of insoluble silica were less than 0.8% in the unwashed samples of most species and less than 0.6% in the washed samples. *Chara* sp., duckweed and *C. glomerata* were the only species with high levels of insoluble silica. Soluble silica levels were, in general, lower in the washed than in the unwashed samples. *Najas flexilis*, the mixture of macrophytes, and duckweed con-

Table 4. Mineral composition of aquatic plants harvested in the summer of 1975 on a washed and unwashed basis†

Chemical parameter	Treatment‡	Potamogeton species§			Myriophyllum spicatum			Vallisneria americana¶		
		Range	Mean±SE		Range	Mean±SE		Range	Mean±SE	
Ash (%)	W	12.2-17.2	14.6±1.07		12.9-62.6	38.9±14.4		23.3-43.1	33.2±9.9	
	U	27.5-55.4	41.9±4.61		13.5-67.6	46.2±16.6		25.2-66.2	45.7±20.5	
Insoluble silica (%)	W	0.00-0.38	0.25±0.12		0.03-0.77	0.31±0.23		-	0.55	
	U	0.04-0.92	0.29±0.17		0.01-4.46	1.75±1.37		-	0.70	
Soluble silica (%)	W	0.05-0.64	0.24±0.11		0.34-0.68	0.46±0.11		-	0.42	
	U	0.16-0.28	0.23±0.02		0.21-0.85	0.49±0.19		-	0.42	
Ca (%)	W	2.50-5.11	3.26±0.49		2.38-20.81	11.91±5.33		1.86-9.95	5.91±4.05	
	U	7.37-30.2	15.62±3.86		2.60-24.07	15.03±6.43		2.75-19.10	10.93±8.18	
P (%)	W	0.22-0.34	0.27±0.02		0.10-0.23	0.15±0.04		0.19-0.22	0.21±0.02	
	U	0.12-0.28	0.19±0.03		0.11-0.21	0.14±0.03		0.12-0.22	0.17±0.05	
Na (%)	W	0.30-0.98	0.55±0.14		0.29-1.84	1.00±0.45		1.53-2.27	1.90±0.37	
	U	0.17-1.54	0.68±0.24		0.33-1.35	0.71±0.32		0.76-4.67	2.72±1.96	
K (%)	W	1.21-1.64	1.43±0.09		0.70-0.95	0.81±0.07		0.82-1.27	1.05±0.23	
	U	0.15-2.12	1.24±0.33		0.71-1.17	0.88±0.14		0.76-0.97	0.87±0.11	
Mg (%)	W	0.16-0.48	0.29±0.06		0.20-0.48	0.33±0.08		0.24-0.27	0.26±0.02	
	U	0.17-0.61	0.36±0.07		0.18-0.38	0.27±0.06		0.21-0.55	0.38±0.17	

Fe (%)	W	0.003-0.02	0.011±0.003	0.014-0.03	0.021±0.005	0.02-0.49	0.26±0.24
	U	0.01-0.05	0.023±0.007	0.03-0.04	0.033±0.003	0.03-0.64	0.34±0.31
Cl (%)	W	0.04-0.71	0.38±0.11	0.16-2.48	1.08±0.71	-	0.01
	U	0.33-0.92	0.58±0.12	0.64-2.26	1.20±0.53	-	1.27
SO ₄ (%)	W	0.61-0.94	0.72±0.08	0.57-1.20	0.83±0.19	-	0.83
	U	0.53-1.54	0.79±0.19	0.71-1.20	0.90±0.15	-	0.60
CO ₃ (%)	W	2.9-8.5	4.70±0.98	0.10-16.60	9.53±4.91	-	16.1
	U	11.1-28.4	18.08±3.46	1.4-32.1	18.73±9.08	-	26.8
Cu (ppm)	W	1.4-21.1	11.3±3.5	5.4-13.7	8.7±2.5	4.7-16.9	10.8±6.1
	U	4.1-20.6	8.8±3.0	4.6-13.2	9.3±2.5	8.1-10.6	9.4±1.3
Zn (ppm)	W	18.5-33.7	26.2±2.6	17.3-22.0	20.2±1.5	34.4-41.7	38.1±3.7
	U	16.3-26.5	20.6±1.7	14.5-17.8	16.1±1.0	29.0-47.6	38.3±9.3
Mn (ppm)	W	34-292	124.8±44.2	141-709	337.7±185.8	315-653	484±169
	U	59-401	182.6±58.2	132-706	376±171	370-633	502±132
Se (ppm)	W	0.07-0.11	0.09±0.01	0.09-0.16	0.12±0.02	-	0.34
	U	0.08-0.16	0.11±0.01	0.08-0.27	0.17±0.06	0.132-0.14	0.14±0.004

†All values are on a dry matter basis.

‡W, washed in the laboratory to remove extraneous matter; U, unwashed.

§Range and mean values with standard errors are based on a single sample of each of five species — *P. amplifolius*, *P. zosteriformis*, *P. crispus*, *P. pectinatus* and *P. richardsonii*.

||Range and mean values with standard errors are based on three samples of the same species.

§§Range and mean values with standard errors are based on two samples of the same species. Values without the standard error are for a single sample.

tained slightly more than 1% soluble silica in the unwashed sample while others contained relatively smaller amounts. Within species, variation in both soluble and insoluble silica contents was large, as evidenced by the values for *M. spicatum* and *Potamogeton* species.

Levels of Na, K and Mg varied both within and between species of plant but did

not show any particular trend with washing. Some contained more Na, K or Mg as a result of washing while others contained less. There was also no consistent trend in the relative concentrations of the Na and K cations in aquatic macrophytes. On the other hand, Fe levels were higher in the unwashed than in the washed samples of all species.

Table 5. Mineral composition of aquatic plants harvested in the summer of 1975 on a washed and unwashed basis†

	Treatment‡	Alfalfa (<i>Medicago sativa</i>)§	<i>Elodea canadensis</i>	<i>Chara sp.</i>	<i>Cladophora glomerata</i>	<i>Najas flexilis</i>	Mixture of species//	Duckweed (<i>Lemna minor</i>)
Ash (%)	W	-	14.9	76.5	26.2	19.0	17.3	16.6
	U	-	50.2	78.7	38.8	51.5	33.6	27.0
Insoluble silica (%)	W	-	0.01	8.23	0.68	-	0.07	0.68
	U	-	0.05	10.31	2.45	0.27	0.12	4.87
Soluble silica (%)	W	-	0.07	0.20	0.18	-	0.09	0.60
	U	-	0.37	0.27	0.72	1.09	1.09	1.06
Ca (%)	W	-	2.60	27.48	4.57	5.04	3.16	4.77
	U	1.63	14.17	27.21	9.91	13.30	8.89	4.86
P (%)	W	-	0.25	0.06	0.19	0.16	0.22	0.50
	U	0.29	0.15	0.06	0.26	0.10	0.19	0.67
Na (%)	W	-	0.70	0.26	0.13	1.19	1.65	0.34
	U	0.10	0.49	0.42	0.09	0.79	1.16	0.34
K (%)	W	-	1.50	0.28	2.78	1.01	1.57	0.94
	U	2.71	1.95	0.51	2.54	0.51	1.39	2.17
Mg (%)	W	-	0.15	0.23	0.22	0.55	0.58	0.45
	U	0.38	0.36	0.28	0.24	0.53	0.53	0.68
Fe (%)	W	-	0.02	0.011	0.08	0.114	0.03	0.41
	U	0.04	0.02	0.024	0.17	0.110	0.11	0.70
Cl (%)	W	-	0.17	0.44	0.45	0.77	2.20	0.33
	U	0.62	0.48	0.88	0.56	0.52	1.65	0.91
SO ₄ (%)	W	-	0.71	0.56	-	-	1.11	-
	U	0.46	0.61	0.93	-	0.53	0.89	-
CO ₃ (%)	W	-	2.5	30.8	8.6	11.0	2.8	2.8
	U	-	21.8	39.1	10.5	-	4.4	3.2
Cu (ppm)	W	-	8.3	6.0	31.4	6.3	13.9	20.9
	U	11.4	6.0	6.4	32.1	4.3	6.4	15.6
Zn (ppm)	W	-	17.6	14.7	20.5	15.2	27.3	51.9
	U	19.3	15.3	15.8	34.9	8.7	25.0	61.1
Mn (ppm)	W	-	46	490	150	135	368	1,998
	U	37	146	519	313	134	477	1,324
Se (ppm)	W	-	ND¶	0.084	0.58	0.142	0.104	0.352
	U	0.54	ND	0.124	0.88	0.074	0.203	0.480

†All values are on dry matter basis.

‡W: Washed in the laboratory to remove extraneous matter. U: Unwashed.

§Values reported by National Academy of Sciences-National Research Council (1971).

//*Myriophyllum* sp., *Vallisneria* sp., *Elodea* sp., *Ceratophyllum* sp. and *Najas* sp. were mixed in the ratio of 40:30:10:10:10 by wet weight, respectively.

¶ND = non-detectable.

chloride content was, in general, reduced on washing while sulfate values showed no distinct trend of any kind.

Levels of Cu, Zn, and Mn were variable, with the range being particularly large for Cu (1–31 ppm) and Mn (34–1998 ppm). There was no substantial change in Cu content on washing; the effect was variable for Zn while Mn was reduced in most species.

Selenium levels generally decreased upon washing. Most species contained less than 0.2 ppm of selenium, with *C. glomerata* and duckweed being the only species with substantially higher levels, going up to 0.9 and 0.5 ppm, respectively. Selenium determination in the unwashed sample of *N. flexilis* was made difficult by the presence of large amounts of sediment.

The unwashed sample of *Chara* sp. and duckweed contained approximately 10 and 8 ppm of Co, respectively, while the unwashed sample of *V. americana* contained about 13 ppm of cobalt. In the remainder of the species, Co was not found within the sensitivity range of the instrument (<3 ppm).

Alfalfa is a terrestrial legume and because of its widespread use is a logical reference material with which to compare the aquatic macrophytes. Compared with terrestrial grasses, alfalfa contains relatively high levels of Ca, Mg and S and frequently Cu. Legumes in general tend to be lower in Mn and Zn than grasses.

Compared with alfalfa, aquatic macrophytes contained much higher levels of Ca, Na and Mn but slightly lower levels of K and Se. Phosphorus content was generally lower in aquatic species, with Mg being present at similar levels. *Vallisneria americana*, *N. flexilis*, *C. glomerata* and duckweed, on the average, contained more Fe, while Cu and Zn were present in comparable quantities to alfalfa.

The levels of Na, K, Mg, Fe and Mn in aquatic macrophytes were similar to those reported for several species by Linn et al. (1975). Compared with algae (Boyd and

Lawrence 1966), Ca was much higher in the macrophytes, with Na and SO_4 also being relatively high, while algae contained generally higher amounts of K. Aquatic macrophytes contained P levels similar to the nonplankton algae but much lesser amounts compared with the phytoplankton. Levels of Mg and SO_4 were more consistent in macrophytes while these were more variable in algae species. The microelements Fe, Mn, Zn and Cu were generally higher in nonplankton and phytoplankton algae, with only Mn being somewhat lower in the latter class when compared with some of the macrophyte species.

Silica in grasses has been reported to cause a major nutritional problem in range cattle in the Northern Great Plains of North America (Connell et al. 1959; Parker 1957). The mixed grasses in these areas contained more than 2% of soluble silica (Bezeau et al. 1966). The only macrophyte species with high total silica content was *Chara* sp. Aquatic macrophytes contained low levels of Co and Se, and Cu of less than 30 ppm. Levels of harmful chemicals such as nitrate, oxalate and cyanide in water hyacinth have been reported to be below the toxic range for animals (Shirley and Easley 1970). These data suggest that most aquatics could be safely used as animal feedingstuffs.

Estimates of the potential removal of 11 mineral elements from Chemung Lake have been presented in Table 6. These data are based on a harvest yield of 11 tonnes/ha/yr which was the average obtained for the years 1974 through 1976 and the respective species data for unwashed plants shown in Table 4. *Potamogeton* and *Myriophyllum* species will remove much greater quantities of most elements than will *Vallisneria*; consequently, in any determination of the rate of removal of nutrients, it is important to estimate the species composition of the plant matter being harvested.

Results of the mineral analyses have shown that dried aquatic macrophytes can provide certain of the minerals required in livestock diets. Compared with conven-

Table 6. Quantities of minerals (kg/ha) removed from waters of Chemung Lake by aquatic macrophytes†

	<i>Potamogeton</i> species†	<i>Myriophyllum</i> <i>spicatum</i>	<i>Vallisneria</i> <i>americana</i>	Mean \pm SD
Ca	295.5	268.1	121.8	228.5 \pm 93.4
P	3.6	2.5	1.9	2.7 \pm 0.86
N	33.3	29.9	24.4	29.2 \pm 4.49
SO ₄	15.0	16.1	6.7	12.6 \pm 5.14
Na	12.9	12.7	30.3	18.6 \pm 10.10
K	23.5	15.7	9.7	16.3 \pm 6.92
Mg	6.8	4.8	4.2	5.3 \pm 1.36
Fe	0.44	0.59	3.8	1.6 \pm 1.90
Cu	0.02	0.02	0.01	0.02 \pm 0.01
Zn	0.04	0.03	0.04	0.04 \pm 0.01
Mn	0.35	0.67	0.56	0.53 \pm 0.16

†Data calculated from mineral values of unwashed samples in Table 4 and harvest yield of 11 tonnes/ha.

tional forage crops, however, large variations occur in mineral composition both within and among species. Time of harvesting may also affect content. Although a part of the variation is due to a difference in the morphological structure and the physiological needs of these plants, stage of growth and fertility of water play a critical role in the nutrient composition of aquatic macrophytes. The capacity for depositing ash in the surface tissue and leaves by most aquatic plants appears to be extremely high. This capacity is governed by the richness of water in certain minerals as well as plant population densities. Plants growing in soft waters will have lower surface mineral deposition than those growing in hard waters.

Chemung Lake is a hard water lake with high levels of dissolved Ca. It also contains, both in water and hydrosol, sufficient levels of N and P to produce high plant growth rates. The inorganic carbon content of surface water is also high. There is thus a great latent potential for macrophyte growth in the lake. Surface calcification, in the form of CaCO₃, is the primary cause of the high ash in macrophytes in this lake, with deposition increasing as the plants age.

On the other hand, mineral analyses of the harvested plant materials indicated that significant quantities of mineral matter could be removed from the lake by

mechanical harvesting. The mineral removal estimates in Table 6 are somewhat low compared with the theoretical values reported by Boyd (1970b) where a much higher rate of production per unit area was assumed. Certainly mineral removal per unit area of Chemung Lake could be substantially increased by judicious harvesting of designated sites with higher biomass. The mature plants would, however, have low nutritive value as animal feedstuffs because of the high ash content. Washing has been shown to considerably reduce the ash content and thus improve the concentration of organic nutrients but this process would increase the cost and does not appear to be feasible at the present time. Under the conditions of plant growth reported here, careful selection of plant material to be used for animal feeds would be absolutely necessary in order to obtain a product with acceptable levels of certain of the minerals. The products obtained when harvesting heavy infestations of mature plants would be useful only as mulch or compost material.

ACKNOWLEDGMENTS

The authors thank John Neil, Limnos Ltd., the Ontario Ministry of the Environment, the Ontario Ministry of Agriculture and Food and the National Research Council of Canada for financial assistance. We appreciate the assistance of Ken Bush with a number of the analyses.

- Thank Professor David Arthur for the selenium determinations. The duckweed was kindly provided by Professor W. G. Barker of the Department of Botany and Genetics.
- ANDERSON, R. R., BROWN, R. G. and RAPPLEYE, R. D. 1965. Mineral composition of Eurasian watermilfoil, *Myriophyllum picatum*. L. Chesapeake Sci. 6: 68-72.
- ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS. 1970. Methods of analysis. AOAC, Washington, D.C.
- BEZEAU, L. M., JOHNSTON, A. and SMOLIAK, S. 1966. Silica and protein content of mixed prairie and fescue grassland vegetation and its relationship to the incidence of silica urolithiasis. Can. J. Plant. Sci. 46: 625-631.
- BOYD, C. E. 1969. Production, mineral nutrient absorption, and biochemical assimilation by *Justicia americana* and *Alternanthera philoxeroides*. Arch. Hydrobiol. 66: 139-160.
- BOYD, C. E. 1970a. Production, mineral accumulation and pigment concentrations in *Typha latifolia* and *Scirpus americanus*. Ecology 51: 285-290.
- BOYD, C. E. 1970b. Vascular aquatic plants for mineral nutrient removal from polluted waters. Econ. Bot. 24: 95-103.
- BOYD, C. E. and HESS, L. W. 1970. Factors influencing shoot production and mineral nutrient levels in *Typha latifolia*. Ecology 51: 296-300.
- BOYD, C. E. and LAWRENCE, J. M. 1966. The mineral composition of several freshwater algae. Proc. Annu. Conf. S.E. Assoc. Game Fish Comm. 20: 413-424.
- CONNELL, R. F., WHITING, F. and FORMAN, S. A. 1959. Silica urolithiasis in beef cattle. I. Observation on its occurrence. Can. J. Comp. Med. Vet. Sci. 23: 41-46.
- CULLEY, D. D., Jr. and EPPS, E. A. 1973. Use of duckweed for waste treatment and animal feed. Water Pollut. Contr. Fed. J. 45: 337-347.
- DENTON, J. B. 1967. Certain relationships between the chemical composition of aquatic plants and water quality. Proc. 29th Annu. Meeting. So. Weed Sci. Soc.
- DUNK, R., MOSTYN, R. A. and HOARE, H. C. 1969. The determination of sulfate by indirect atomic absorption spectroscopy. At. Absorp. Newsl. 8: 79-81.
- EDMONSON, W. T. 1970. Phosphorus, nitrogen and algae in Lake Washington after diversion of sewage. Science 169: 690-691.
- GERLOFF, G. C. and SKOOG, F. 1957. Nitrogen as a limiting factor for the growth of *Microcystis aeruginosa* in southern Wisconsin lakes. Ecology 38: 556-561.
- HASLER, A. D. and EINSELE, W. G. 1948. Fertilization for increasing productivity of natural inland waters. Trans. 13th N. Amer. Wildl. Conf. pp. 527-555.
- HOFFMAN, I., WESTERBY, R. J. and HIDIROGLOU, M. 1968. Precise fluorometric microdetermination of selenium in agricultural materials. J. Assoc. Off. Anal. Chem. 50: 50-55.
- HOWARD-WILLIAMS, C., FURSE, M., SCHULTEN-SENDEN, C., BOURN, D. and LENTON, G. 1972. Lake Chilwa, Malawi. Studies on a tropical freshwater ecosystem. Report to IBP/UNESCO Symposium, Reading, England.
- HUTCHINSON, G. E. 1957. A treatise on limnology. Vol. I. John Wiley and Sons Inc., New York, N.Y. pp. 1015.
- KING, E. J. 1932. The colorimetric determination of phosphorus. Biochem. J. 26: 292-297.
- KOLTHOFF, I. M. and SANDELL, E. B. 1946. Textbook of quantitative inorganic analysis. The Macmillan Co., New York, N.Y. pp. 385-389.
- LAWRENCE, J. M. and MIXON, W. W. 1970. Comparative nutrient content of aquatic plants from different habitats. Proc. 23rd Annu. Meeting So. Weed Sci. Soc.
- LINN, J. G., STABA, E. J., GOODRICH, R. D., MEISKE, J. C. and OTTERBY, I. E. 1975. Nutritive value of dried or ensiled aquatic plants. I. Chemical composition. J. Anim. Sci. 41: 601-609.
- MITCHELL, D. S. 1970. Autecological studies of *Salvinia auriculata*. Ph.D. Thesis, University of London.
- MOSS, B. 1969. Limitation of algal growth in some Central African waters. Limnol. Oceanog. 14: 591-601.
- NATIONAL ACADEMY OF SCIENCES-NATIONAL RESEARCH COUNCIL 1971. Nutrient requirements of poultry. NAC-NRC, Washington, D.C.
- NYE, P. H. and GREENLAND, D. J. 1960. The soil under shifting cultivation. Farnham Royal, Bucks. (England). Commonw. Bur. Soils. Commonw. Agric. Bur. (Tech. Comm. 51).
- PARKER, K. G. 1957. "Water-belly" (Urolithiasis) in range steers in relation to some characteristics of rangeland. J. Range Manage. 10: 105-111.

- PROWSE, G. A. and TALLING, J. F. 1958. The seasonal growth and succession of plankton algae in the White Nile. *Limnol. Oceanog.* **3**: 222-238.
- SAWYER, C. N. 1947. Fertilization of lakes by agricultural and urban drainage. *N. England Water Works Assoc.* **61**: 109-127.
- SHIRLEY, R. L. and EASLEY, J. F. 1970. Chemical composition of aquatic plants in lakes and rivers of Florida throughout-year progress report. *Proc. Aquat. Plant Res. Conf.*
- TALLING, J. F. 1965. Productivity of phytoplankton in Lake Victoria. *J. Appl. Ecol.* **2**: 415 (Abstr.).
- TALLING, J. F. 1966. Comparative problems of phytoplankton production and photosynthetic productivity in a tropical and a temperate lake. Pages 399-424 in C. Goldman, ed. *Primary productivity in aquatic environments*. University of California Press, Berkeley. (Mem. 1st. Ital. Idrobiol. (Suppl.) **18**).
- WELCH, P. S. 1952. *Limnology*, 2nd ed., McGraw-Hill, New York, N.Y.
- WETZEL, R. G. 1960. Marl encrustations on hydrophytes in several Michigan lakes. *Oikos* **11**: 223-236.
- WILE, I. and HITCHIN, G. 1977. The physical-chemical limnology of Chemung Lake. Pages 37-55 in *An assessment of the practical and environmental implications of mechanical harvesting of aquatic vegetation in southern Chemung Lake*. The Ontario Ministry of the Environment report. Toronto, Ont.