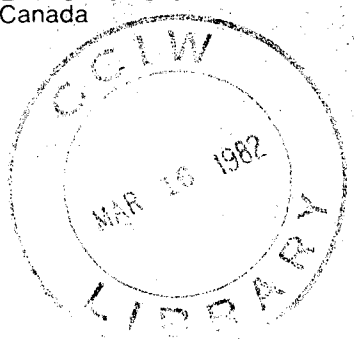Environment
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A Study of Selected Great Lakes Coastal Marshes

A. Mudroch

SCIENTIFIC SERIES NO. 122

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Canada ■✦■

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Abstract

Six marshes adjacent to the Great Lakes were investigated to evaluate their beneficial and/or detrimental effects on the water quality of the lakes. The nutrient (N and P) and trace element (Pb, Cu, Cr, Ni, Cd, As and Hg) concentration changes in marsh water, the geochemistry of sediments, and the nutrient and trace element uptake by marsh plants and their biomass production were investigated. The marsh water retained pH values of between 7.8 and 8.4, and the sediments were submerged mineral soils with pH ranging between 6.9 and 7.2, with more than half of the particles in the silt size (2-63 μm) fraction. Concentrations of nutrients and trace elements in marsh water and sediment were compared with those found in Lakes Ontario and Erie. Large differences were observed between the concentrations of various forms of nitrogen present in marsh, lake and stream water. Most of the nitrogen present in the marsh water was in the form of organic nitrogen. Dissolved oxygen concentration in the marsh water during summer months remained relatively high (4-8 mg L^{-1}). The nutrient input to the marshes affected the aboveground biomass production and the species composition in the marshes. Submerged macrophytes accumulated higher concentrations of Pb, Cr, Ni, Cd, Co and Cu than the emergent macrophytes. All of the marshes studied showed a high capacity to retain nutrients and metals. The degree of this retention depended on the hydrological regime and species composition in the marsh. It was calculated that a complete discharge of the marshes into the adjacent lakes would contribute only negligible quantities of N and P in relation to the loadings from other sources.

Résumé

Les effets positifs et négatifs de six marais attenants aux Grands lacs sur la qualité des eaux de ces derniers ont été étudiés. On a examiné les variations dans les concentrations en matières nutritives (N et P) et en oligo-éléments (Pb, Cu, Cr, Ni, Cd, As et Hg) de l'eau des marais, la géochimie des sédiments et l'assimilation des éléments susmentionnés par les plantes des marais ainsi que la production de leur biomasse. L'eau des marais avait un pH de 7,8 à 8,4, tandis que les sédiments étaient constitués de sols minéraux dont le pH se situait entre 6,9 et 7,2 et dont la granulométrie était surtout du type limoneux (2 à 63 μm). La concentration en matières nutritives et en oligo-éléments des eaux et des sédiments des marais a été comparée à celle des lacs Ontario et Érié. Les concentrations en diverses formes d'azote différaient beaucoup entre les marais et les lacs et les cours d'eau. Dans les marais, on a trouvé surtout de l'azote organique, et la concentration en oxygène dissous est restée relativement élevée durant les mois d'été (4 à 8 mg L^{-1}). L'apport de matières nutritives aux marais a influé sur la production de la biomasse au-dessus du sol et sur la composition des espèces. Les macrophytes submergés ont absorbé plus de Pb, de Cr, de Ni, de Cd, de Co et de Cu que les macrophytes émergés. Tous les marais se sont montrés hautement capables de retenir les matières nutritives et les métaux. Ce filtrage dépendait du régime hydrologique et de la composition des espèces. D'après les calculs, si les marais se vidaient complètement dans les lacs adjacents, leur apport de N et de P serait négligeable comparativement à celui d'autres provenances.

Acknowledgments

Introduction

GENERAL

Due to many variables every marsh in the world is unique. Externally, some of the variables are the climate; the geographical setting, i.e., the geomorphology of an area and the size and type of associated water body (area or length of a lake, pond or reservoir or the depth and flow regime of a river or stream that borders, goes through or is a part of the wetland); and the use of the land bordering the wetland, which may contribute to various vegetative cover and habitat types in the surrounding marsh area. Internally, some of the variables are the morphology and morphometry of the marsh and the vegetative cover-water ratio, which contributes to the variety of different microlandscapes within the marsh and to its size.

The chemical composition of marsh water and the geochemistry of the marsh sediment are both strongly influenced by the bedrock geology, and land use activities in the drainage basin have a major influence on the nutrient supply to the marsh. In support of this, Bjork (1967) proved that even an occasional addition of nutrients, such as a short-term supply of sewage to the surface sub-hydric soil layer, could have a prolonged effect on aquatic macrophyte production by enrichment of the nutrient pool maintained in the perennial plant system. Thus, one may expect that lakeside marshes will have a significant, even profound, influence on the natural flow of nutrients from the terrestrial landscape to an open lake (Prentki et al., 1978). Indeed, nutrient transformation processes such as sorption, coprecipitation, active uptake, nitrification and denitrification remove P and N from the free-flowing water of a wetland and transfer them to the substrate and biota for storage (Sloey et al., 1978). Because of these characteristics wetlands were used for many years in Europe for sewage treatment, and extensive recent research has been carried out in the United States on this subject (Tourbier and Pierson, 1976; Tilton et al., 1976).

Some information is available which characterizes nutrient inputs and outputs and the production and nutrient assimilation by macrophytes in marshes, whereas less information is available which describes microbial assimilation and related nutrient transport in marsh water and sediment.

GREAT LAKES MARSHES

The littoral zone of the Great Lakes, including shallow water and shoreline wetlands, is a valuable wildlife habitat. Owing to the increase in population around the Great Lakes and the demand for rural and industrial land, the marshes have been used as a space for landfill, garbage disposal, dredge spoil disposal and other similar purposes. In confirmation of this, an evaluation of existing marshlands along the northern shore of Lake Ontario has shown that although there were 22 400 acres of marshes at the beginning of the nineteenth century, in 1977 only 13 027 acres remained (McCullough, 1977).

In the past, Great Lakes coastal marshes were mostly studied for management purposes as fish and wildlife habitat and because of their special value to agriculture. The Canadian Wildlife Service (CWS) has identified important waterfowl staging areas and documented waterfowl use of these areas (Dennis, 1974; Dennis and Chandler, 1974; Johnson, 1976).

Since studies of the significance of wetlands with respect to water quality, however, have largely been neglected, this study was initiated to evaluate the beneficial and/or detrimental effects of selected marshes peripheral to the Great Lakes. The investigations included changes in the nutrient and trace element concentrations of marsh water, the geochemistry of sediments, and the nutrient and trace element uptake by marsh plants. The study was designed to characterize each marsh and to help assess its possible effect on the water quality of the lakes. The information obtained will also provide a useful background for any further investigations of sediment-water quality interactions in other Great Lakes (and freshwater) wetland systems.

STUDY AREA

Six marshes adjacent to the Great Lakes were studied with respect to the concentration of nutrients and metals in the water, sediment and aquatic macrophytes: Cootes Paradise on Lake Ontario; Big Creek marsh on Lake Erie; Dover, St. Lukes and Balmoral marshes on the northeastern shore of Lake St. Clair; and part of the marshy area

in the St. Clair River delta. These study areas are shown in Figure 1.
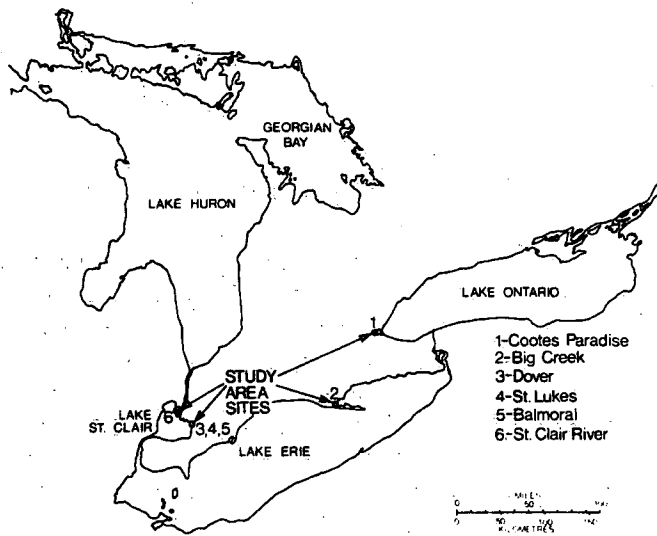
Figure 1. Study area sites.

1-Cootes Paradise
2-Big Creek
3-Dover
4-St. Lukes
5-Balmoral
6-St. Clair River

All six marshes lie at about the same latitude and hence they are influenced by similar climatic conditions. The most important climatological parameters, given by Thomas (1953), are summarized in Table 1.

Table 1. Climatic Conditions of the Study Area

Mean annual temperature	7.2°C
Mean July daily minimum temperature	15.6°C
Mean July daily maximum temperature	26.7°C
Mean January daily minimum temperature	-12.2°C
Mean January daily maximum temperature	-1.1°C
Mean annual snowfall	1016 mm
Mean annual rainfall	635 mm
Mean July total hours of bright sunshine	275
Mean January total hours of bright sunshine	75

The pH values of the marsh waters ranged between 7.8 and 8.4 and reflect the predominant influence of carbonate bedrock.

Ontario soils are also strongly influenced by the properties of the bedrock material. Webber and Hoffman (1967) defined the soil of the Big Creek marsh drainage basin as an undulating sandy loam and the soil of Cootes Paradise drainage basin as an undulating and rolling clayey soil. Both are classified as Gray Brown Podzol. Walpole Island in the St. Clair River delta and Dover, Balmoral and St. Lukes marshes consist of level clayey soils, classified as Humic Gleysols.

Big Creek Marsh — Lake Erie

Big Creek marsh is a Canadian Wildlife Service sanctuary for migratory waterfowl. It is located at the west end of Long Point Bay and occupies an area of about 850 ha. The major water source during the whole year is Big Creek, which runs along the northern border of the marsh. A few channels provide movement of the creek water into the marsh. The marsh has no outlet, and Big Creek discharges into inner Long Point Bay of Lake Erie (Fig. 2).
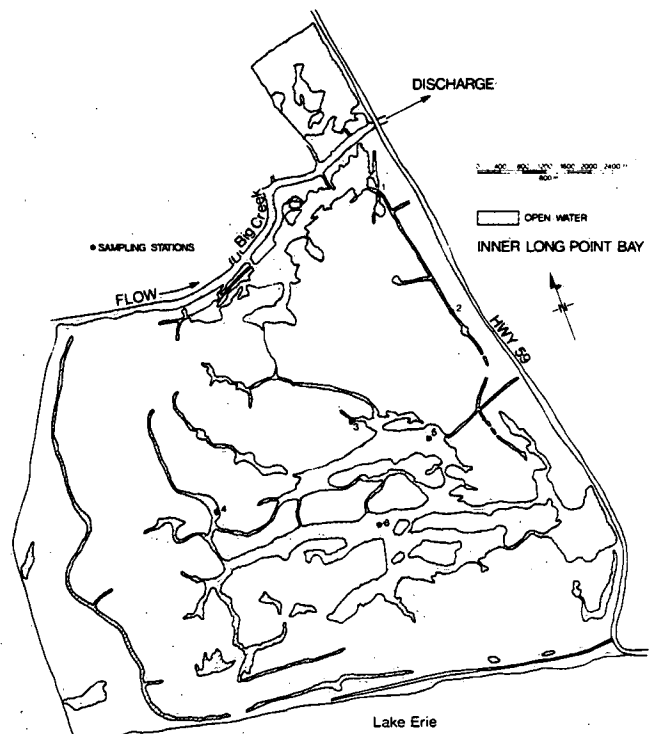
Figure 2. Big Creek marsh sampling stations.

In 1839, Big Creek entered the lake south of Long Point by means of a channel approximately 1.5 km wide at the western end of the Point (Wood, 1951); the channel, however, narrowed and finally filled in. Subsequently, Big Creek returned to an earlier outlet into Long Point Bay.

The bedrock of Big Creek basin consists of Paleozoic sedimentary rocks, mainly limestones, dolomite, chert and sandstone. These are overlain by glacial drift of Pleistocene age and by minor amounts of alluvial, swamp and eolian deposits of Recent age (Yakutchick and Lammers, 1970). About 725 km^2 of the Big Creek drainage basin area is used for farming (tobacco, tomatoes, corn, peppers, etc.).

Lake St. Clair Area Marshes — Dover, Balmoral, St. Lukes and Walpole Island

Dover, Balmoral and St. Lukes marshes are located on the east shore of Lake St. Clair (Fig. 3). All three marshes, which are man-made and adjacent to each other, are important for the spring and fall migration, moulting, feeding and nesting of a variety of waterfowl. In past years, the marshes were used for private hunting. In 1974, Dover marsh was acquired by CWS and serves, at the present time, as a wildlife refuge. The water level in these marshes is regulated by pumps, dikes and channels. Water is supplied to Dover marsh from the nearby municipal drain, to Balmoral marsh from Lake St. Clair, and to St. Lukes marsh partly from the main drain and partly from Lake St. Clair. The water depth in all three marshes ranges from 10 to 50 cm, and they have no outlet.
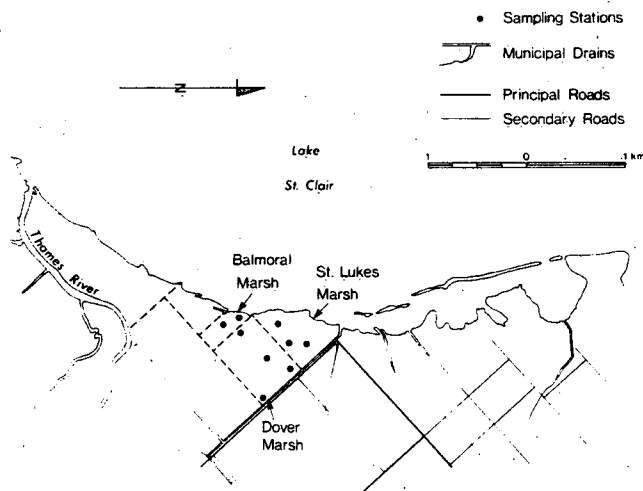
Figure 3. Dover, Balmoral and St. Lukes marsh sampling stations.

The soils of the area are poorly drained sandy loams which overlie clay (Webber and Hoffman, 1967). In the past, most of the area was an elm-ash-maple swamp. Recently, however, artificial drainage has been used to achieve its agricultural potential. The fertility of the soil is increased by the addition of fertilizer. The abundance of fertilizing results in high nutrient levels in the water of the field drainage system, which is also used for water level maintenance in two of the man-made marshes.

Walpole Island, an Indian Reserve, is the largest of the islands in the St. Clair River delta (Fig. 4) (Chapman and Putnam, 1973). The St. Clair delta material is classified as silty sand by Wightman (1961).

A large part of the island, which is now cultivated mainly for corn and soybean, was once a water-saturated marsh. The field drainage is controlled by several miles of drainage ditches and by pumping stations, which maintain water levels below the level of the surrounding tributaries. The uncultivated part of the island is a combination of woodlot, meadow and marsh.

Chenal Écarté is the most important channel within the Walpole Island area carrying the waters of the St. Clair River toward the marshes. The Pottowatamie Island Dredge Cut Channel and Johnston Channel are branches of Chenal Écarté which flow slowly through the Walpole Island area. Two small lakes are formed on part of the waterway: Goose Lake, which is surrounded by a dike and receives water from Pottowatamie Island Dredge Cut Channel, and Johnston Bay, which is partly open along the northeast margin of Lake St. Clair. At high water levels, the part of the Walpole Island that is directly adjacent to Lake St. Clair is flooded by lake water. The meandering Chenal Écarté and Johnston Channel are dredged regularly to a depth of approximately 7 m. The discharge of Johnston Channel is about 8 million cubic metres per day. Goose Lake and Johnston Bay have an almost uniform depth of approximately 1 m. Pottowatamie Island Dredge Cut Channel is about 1-1.5 m deep. There are many other small channels providing access to the marshes where fishing and hunting are the major activities. The water depth of the marshes ranges between 10 and 70 cm.

The bedrock of the Lake St. Clair region is composed of Devonian and Mississippian limestone, sandstones and shales. Pleistocene deposits in the area form a physiographic region known as the St. Clair Plain (Chapman and Putnam, 1973). These deposits consist of uniform, gray glaciolacustrine clay (Soderman et al., 1961).

Cootes Paradise

Cootes Paradise is located west of Hamilton Harbour, Lake Ontario, in the lower part of the Dundas Valley. The area is a wildlife sanctuary with about 1.7 km^2 of open water surrounded by marshy areas and woodland. Secondary sewage effluent from a sewage plant, located less than 1 km west of the marsh, has been discharging into West Pond of Cootes Paradise for a number of years. The main pond of the sanctuary is about 0.5 m deep and is connected to Lake Ontario through Hamilton Harbour by an outflow channel about 3 m deep and 5 m wide below highway No. 403 (Fig. 5). A number of small streams discharge into Cootes Paradise and the largest of them, Spencer Creek, has a mean flow of approximately 2 m^3/s^{-1}. These creeks, including the discharge from the sewage treatment plant, provide a constant flow-through of water into Hamilton Harbour.
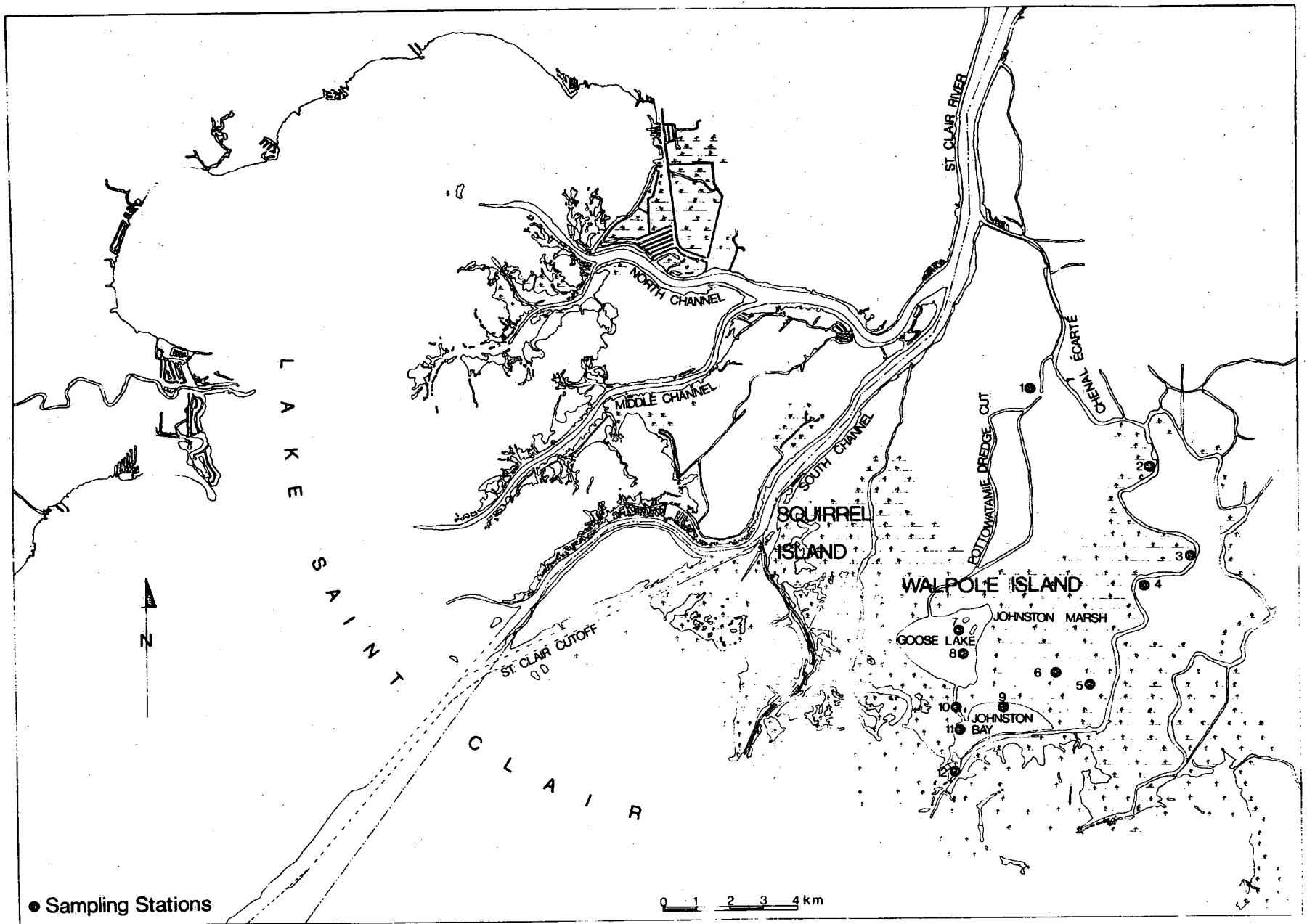
Figure 4. Walpole Island sampling stations.
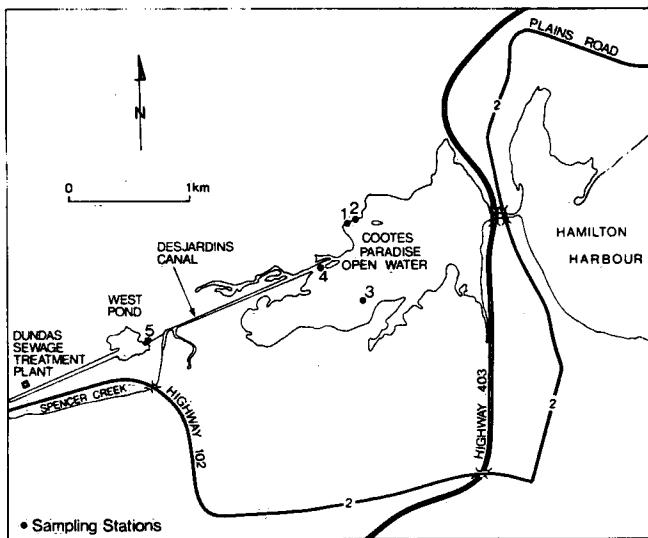
Figure 5. Cootes Paradise sampling stations.

The bedrock of the area is composed of shales, limestone and dolomite of Lower Paleozoic age. The Pleistocene deposits consist of glacial, glaciofluvial and glaciolacustrine deposits associated with the extensive glaciation of Dundas Valley. The geology of the area has been described by Karrow (1959) and Middleton (1971).

VEGETATION COVER OF THE MARSHES

The presence, abundance and distribution of aquatic plants in a marsh are influenced by many factors, such as hydrologic regime, climatic regime, chemical and physical properties of substrate and water. Since at least one of these factors at each of the marshes investigated varied from the others, the species composition and richness were different in each marsh.

In Big Creek marsh, the macrophyte community, occupying the open water, is composed mainly of *Nuphar*, *Nymphaea* and *Chara* spp.; *Elodea* sp. and *Myriophyllum* sp. are also found in some areas. In the southern part of the marsh, the vegetation consists mainly of *Carex aquatilis* with some stands of *Typha* sp. A large population of *Decon verticillatus* is present in the marsh, mainly along the shore. Big Creek marsh vegetation has been studied and described in detail by Bayly (1976).

Dover Marsh vegetation is dominated by *Typha latifolia*, and *Carex lacustris* and *Typha latifolia* are the dominant species in Balmoral and St. Lukes marshes. Large stands of *Pontederia cordata*, *Myriophyllum hetero-phyllum* and *Nymphaea odorata* occur in all three marshes and fill many of the channels. Vegetation in Dover marsh has been extensively studied by Bayly (1975).

The Walpole Island marsh showed the greatest diversity of species. The dominant vegetation types in the marsh area are *Typha* sp. and *Carex* sp. Large stands of *Pontederia cordata*, *Myriophyllum* sp., *Nymphaea odorata*, *Nuphar advena* and *Potamogeton* sp. are present, and other abundant macrophyte species include *Cerato-phyllum* sp., *Elodea* sp., *Chara* sp., *Najas* sp. and *Scirpus* sp. Stands of *Typha* sp. and *Scirpus* sp. occupy the area of Johnston Bay and are abundant along Johnston River shores.

In Cootes Paradise, the formation of an extensive vegetation zone containing many emergent and submergent macrophytes is related to the morphology and high nutrient concentration in water and sediment. The major emergent species in the West Pond is *Glyceria grandis*, which occupies the main vegetation zone. A stand of the same species occurs also in the Long Valley Creek mouth. Abundant submerged macrophytes (*Myriophyllum* sp., *Utricularia* sp., *Ceratophyllum* sp. and *Potamogeton* sp.) and floating-leaved *Lemna* sp. also grow in the West Pond and in bays around the shores of the main water body.

5

Methods

SAMPLING AND SAMPLE PREPARATION

Sampling sites were selected in each of the six marshes based on characteristically different visual parameters. At each marsh, water, sediment and plant samples were taken for comparative purposes and to obtain a representative data set for each marsh. The locations of sampling stations are shown in Figures 2 to 5.

Water

Water was sampled monthly from April or May until November in Cootes Paradise during 1976, in all Lake St. Clair marshes during 1977, and in Big Creek marsh during 1978. Water samples were stored in glass bottles at $4°C$ prior to analysis.

Sediment

Surface sediment (0–8 cm depth) was collected by means of a mini-Shipek grab sampler, transferred to plastic bags, frozen within 6 h, and later freeze-dried in the laboratory. A Brown corer, equipped with a plastic tube, 6.6 cm in diameter, was used for coring. Each core was immediately divided into 5-cm sections, which were transferred to plastic bags, frozen within 6 h and later freeze-dried in the laboratory. About 20 g of dry sediment was used for particle size analysis. The rest of the material was passed through a No. 20 (841 μm) size sieve to remove plant roots, shell fragments and other larger objects, and ground to pass through a No. 100 (149 μm) size sieve. The ground samples were used for geochemical analyses.

Plants

To determine the biomass of dominant emergent macrophytes, *Typha latifolia*, *Carex lacustris* and *Glyceria grandis*, three quadrats, each 1 m^2, were harvested from the uniform portion of each stand. Shoots were cut at soil level, dried in the laboratory at $60°C$ for 72 h and weighed to determine the dry matter content. Above-ground biomass of four plants from each quadrat, randomly chosen, was subsampled and cut into lengths of 0–40 cm, 40–70 cm and 100 cm, which were pulverized in a Wiley mill to pass through a No. 100 (149 μm) size sieve and used for chemical analyses.

To determine the chemical composition of the other most common macrophytes in the marshes, six to ten specimens of each species were collected, washed in the marsh water, frozen within 6 h and later freeze-dried in the laboratory. Dry plants were then pulverized in a Wiley mill to pass through a No. 100 (149 μm) size sieve.

THE pH AND Eh DETERMINATIONS

The pH of water and sediment and the Eh sediment values were determined immediately on collection of the sample. Full details of the procedures have been described by Kemp and Lewis (1968).

DISSOLVED OXYGEN AND TEMPERATURE MEASUREMENT

The temperature and dissolved oxygen readings in water were taken between 14:00 and 15:00 h in most of the marshes every week at each of the sampling stations by means of a YSI–57 oxygen meter.

ANALYTICAL METHODS

Water

The determination of parameters in water samples was carried out by procedures outlined in the *Analytical Methods Manual* (Environment Canada, 1974).

Sediment

The concentration of major elements (Si, Al, Fe, Ca, Mg, Na, K, Ti, Mn, S and P) was determined by X-ray fluorescence spectrometry (Mudroch, 1977) and the concentration of metals (Pb, Ni, Cu, Co, Cr and Zn), by atomic absorption spectrophotometry, using the method described by Mudroch and Capobianco (1978). Arsenic was determined by an X-ray fluorescence spectrometer using bottom sediment spiked with various concentrations of As as a standard. Mercury was determined by the "cold vapor" method described by Capobianco (1975). Organic C and total N concentrations were determined using a Leco carbon analyzer and a Leco nitrogen analyzer, respectively.

Plants

The K, P, Ca and Mg concentrations in plants were determined by an X-ray fluorescence spectrometer (Mudroch and Mudroch, 1977). Total N was determined by a Leco nitrogen analyzer. The Pb, Zn, Cr, Ni, Cd, Co and Cu concentrations were determined by the method used by Mudroch and Capobianco (1978).

Results

SEDIMENT GEOCHEMISTRY

Big Creek Marsh

The major component of the surface sediment (0-8 cm) was silt, which ranged between 57% and 76%.

No large differences were observed in concentrations of Mg, Ca, Na, K, Mn and P in surface sediment, with the exception of sediment samples obtained from the area covered by a dense growth of *Elodea* (Table 2). This sediment contained high concentrations of Ca, which might have been derived from $CaCO_3$ precipitation on the plants. This conclusion is based on observations by Wetzel (1960), who studied deposits of carbonate compounds on the vegetative structures of macrophytes in hard water lakes; he found that the greatest $CaCO_3$ encrustations occurred on submerged plants. Organic C and TN concentrations in sediment were the highest in the same area and were probably due to a greater biomass production than at the other sampling localities. The high organic matter content diluted the concentration of mineral components in the sediment.

The Pb, Cu, Ni, Cr and Zn concentrations in the surface sediments were lower than those found in surficial sediments of Lake Erie by Kemp and Thomas (1976). An exception, however, was the higher concentration of Zn in sediment at station No. 2. Elevated concentrations of As and Hg were found in the part of the marsh that was most affected by inflow from Big Creek. Based on work by Miles (1976), Miles and Harris (1971) and Miles *et al.* (1976), who showed transport of certain insecticides and nutrients by water, suspended and bottom sediment in Big Creek, it is assumed that Hg and As were probably associated with agricultural practices, such as spraying crops with pesticides and herbicides, which were then brought into the marsh by water and the suspended load of Big Creek.

A vertical section and sediment analyses obtained at sampling station No. 5 are shown in Table 3; the stratigraphy is described in Table 4.

The concentration profiles of Fe, Mg, Ca, K and P in the station 5 core were uniform. Organic C, TN and S concentrations were the highest in the surface 20-cm layer, in which the macrophytes were rooted. Throughout the core Ni, Cu, Co and Zn showed uniform concentrations, but Pb, Cr, As and Hg showed enrichment in the surface sediment layer. In Table 5, concentrations of P, organic C, total N, Ca, Pb, Zn, Cu and Hg are compared with those found by Kemp and Thomas (1976) in the profile of fine-grained sediment from the Central and Eastern basins of Lake Erie. Because of high biological activity, Big Creek marsh sediment is enriched in organic C, TN and Ca with respect to Lake Erie sediment. The Zn, Cu and Pb concentrations were similar to the precolonial concentrations of Lake Erie sediments quoted by Kemp and Thomas (1976). Further description and interpretation of the data obtained by analyses of Big Creek marsh sediment were given by Mudroch (1980). The pH values in the sediment profile fell within a narrow range (6.9 to 7.0). Sediment Eh was negative throughout the whole core, with the most negative values (-200 mV) at the depth from 10 to 20 cm.

Dover, Balmoral and St. Lukes Marshes

The major component of the surface sediment was silt, which comprised 45% to 72% of the samples.

The sediment concentration of Mg, Ca, Na, K and Mn was similar in all three marshes (Table 6). Organic C and TN concentrations were the lowest in Dover marsh at the two sampling stations where water depth was about 60 cm and only a few submerged plants were present. Dense stands of *Typha* sp., *Pontederia cordata* and *Nymphaea odorata* were present at the localities where organic C and TN concentrations in the sediment ranged from 10.42% to 18.65% and 1.32% to 2.05%, respectively. Mean values of trace metals concentration in surface sediment of the three marshes were compared with those found by Thomas *et al.* (1975) in surficial sediments of Lake St. Clair (Table 7). Assuming that the lake and marsh sediments are of similar origin, an enrichment of Pb, Zn and Cu existed in the surface marsh sediment. The intensive past hunting activity in Dover marsh, and present and past hunting in Balmoral and St. Lukes marshes could be the source of these metals in the sediment.

Table 2. Major and Trace Element Concentrations in Big Creek Marsh Surface Sediment

Station No.	Percent dry weight												Dry weight (μg g^{-1})								
	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	Org. C	TN	Pb	Ni	Cu	Co	Cr	Zn	S	As	Hg
1	63.0	9.70	2.63	2.87	10.41	1.59	2.04	0.36	0.09	0.24	1.98	0.09	36	20	14	3	67	89	2483	112	0.080
2	63.3	9.97	4.18	2.65	11.73	1.53	2.12	0.45	0.12	0.38	3.48	0.39	86	30	35	6	119	383	1169	0	0.080
3	33.7	6.63	4.20	1.62	20.95	0.45	1.79	0.38	0.12	0.34	14.53	1.83	74	29	26	7	42	126	4659	13	0.930
4	50.3	10.91	5.53	2.61	10.73	0.77	2.59	0.68	0.11	0.28	9.94	1.23	47	48	38	13	64	107	2254	18	0.530
5	54.8	8.17	2.74	2.28	11.03	1.09	1.83	0.36	0.12	0.30	8.85	1.00	47	21	16	3	56	94	4361	64	0.324
6	61.4	9.53	2.68	2.99	11.05	1.35	1.94	0.38	0.10	0.26	3.36	0.39	71	21	12	4	80	88	2531	0	0.334

Table 3. Particle Size Distribution and Geochemistry of Big Creek Marsh Sediment Profile

Depth (cm)	Eh (mV)	pH	Percent dry weight										Dry weight (μg g^{-1})								
			Sand	Silt	Clay	Fe_2O_3	MgO	CaO	K_2O	P_2O_5	Org. C	TN	S	Pb	Ni	Cu	Co	Cr	Zn	As	Hg
0–10	−150	7.0	14.50	76.80	8.70	2.55	2.42	10.05	1.86	0.30	8.50	1.00	4200	43	20	15	3	52	91	65	0.300
10–20	−200	7.1	10.55	69.85	11.60	2.23	2.30	9.70	2.05	0.28	6.20	0.61	3700	33	19	14	3	38	86	38	0.290
20–30	−150	7.0	16.93	70.58	12.49	2.65	2.18	9.76	2.05	0.27	4.25	0.39	3300	25	18	15	3	35	89	25	0.150
30–40	−100	6.9	20.35	75.62	4.03	2.38	2.44	9.40	1.95	0.25	4.50	0.43	3400	25	19	14	3	32	90	22	0.100
40–50	−75	7.0	20.05	79.83	0.12	2.46	2.09	9.68	1.90	0.26	4.60	0.44	3500	27	19	14	3	30	85	18	0.130

Table 4. Big Creek Marsh Sediment Description

Station No.	Depth (cm)	Remarks
5	0–10	Brownish gray silt with some sand and fine roots
	10–25	Gray silt, some sand and small decomposing plant fragments
	25–50	Gray silt with increasing sand content toward the bottom of the core

The concentration of Hg in the three marshes was similar to that found by Kemp and Thomas (1976) in fine-grained precolonial sediments of Lake Erie and Lake Ontario (Table 7). The analytical results (sediment profiles) obtained at each sampling station in each of the three marshes are shown in Tables 8 to 10; the stratigraphy is described in Tables 11 to 13.

The concentration profiles of organic C, TN and S showed an enrichment in the surface sediment layers from 0 to 20 cm at all sampling stations in the three marshes, with the exception of station No. 3 at Dover marsh. The Fe, Mg, Ca, K and P concentrations were uniform throughout the sediment column. The Ni, Cu, Co, Cr and As concentrations were generally similar and uniform in sediment profiles from all three marshes. An enrichment by Zn and Pb was observed in the section from 0 to 20 cm in some of the sediment profiles. As already stated, this enrichment may be due to the more intensive hunting activities in parts of the marshes.

The pH was similar in all sediment profiles, ranging between 6.9 and 7.1. The Eh values were negative in the range of -50 to -300 mV. The most negative values were obtained in the sections from 10 to 20 cm in all of the profiles.

Forty years ago, the three man-made marshes were pasture land. The enrichment of organic C, TN and S in the surface sediment layer reflects the increase of the biomass productivity during the past 40 years.

Walpole Island Marsh

The major type of surface sediment collected at Goose Lake and Pottowatamie Channel was sand. The sediment collected at the other nine stations generally consisted of equal quantities of sand, silt and clay. The high concentration of SiO_2 and low concentration of Al_2O_3 in Goose Lake sediment were due to the presence of large quantities of sandy material with a low content of aluminosilicates, such as clay minerals. This sandy sediment also had the lowest concentration of CaO, MgO, S, P_2O_5, Pb, Ni, Cu, Cr, Co, Zn, As and Hg when compared with the other sediment samples obtained from the Walpole Island area. Organic C and TN concentrations in most of the other ten surface sediment samples were elevated with respect to the concentrations that Kemp (1971) found in the offshore sediments of Lakes Huron, Erie and Ontario (Table 14). This enrichment is obviously due to the deposition of organic material which originates locally in the marshes.

In Table 7, mean values of trace elements in surface sediments sampled from Johnston River, Johnston Bay and Johnston Bay marsh are compared with those found in Lake St. Clair, and in Dover, Balmoral and St. Lukes marshes. The concentration of Zn was similar to that found in the man-made marshes and higher than that of the Lake St. Clair surface sediments. The Pb concentration was elevated with respect to Lake St. Clair sediments; it was, however, lower than that of Dover, Balmoral and St. Lukes marshes. The Cu, Ni, Co and As concentrations in sediments of Lake St. Clair and in all of the marshes investigated were similar, and Cr concentrations in marsh sediments were lower than those of Lake St. Clair sediments. Mean values of Hg concentration in the Walpole Island area sediments were similar to the mean values of Hg concentrations found in Lake St. Clair surface

Table 5. Concentration of Selected Parameters in Lake Erie and Big Creek Marsh Sediments

Location	Depth (cm)	Percent dry weight				Dry weight ($\mu g\ g^{-1}$)			
		P	Org. C	TN	Ca	Pb	Zn	Cu	Hg
Lake Erie Central Basin	0–1	0.19	5.24	0.68	1.64	146	419	66	0.99
	30–40	0.13	1.56	0.20	0.35	22	112	34	0.09
Lake Erie Eastern Basin	0–1	0.14	3.30	0.45	1.51	112	328	57	0.33
	113–120	0.08	1.29	0.16	2.25	25	109	33	0.04
Big Creek marsh	0–10	0.130	8.50	1.00	7.00	43	91	15	0.30
	40–50	0.110	4.60	0.44	6.90	27	85	14	0.13

Table 6. Major and Trace Element Concentrations in the Surface Sediment of Dover, Balmoral and St. Lukes Marshes

Station No.	Marsh	Percent dry weight												Dry weight ($\mu g\ g^{-1}$)								
		SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	Org. C	TN	Pb	Ni	Cu	Co	Cr	Zn	S	As	Hg
1	Dover	52.4	8.7	4.5	1.8	8.2	0.75	2.1	0.40	0.08	0.28	10.42	1.32	45	28	18	6	18	93	3800	10	0.100
2		51.9	8.4	3.8	1.9	10.9	0.91	2.2	0.38	0.09	0.29	16.05	1.92	78	20	20	7	21	118	4100	15	0.120
3		55.8	9.1	2.9	2.1	7.9	0.95	2.0	0.35	0.06	0.23	2.95	0.32	25	14	10	8	10	40	2300	2	0.130
4		56.5	8.9	2.8	2.0	7.6	0.78	2.3	0.42	0.08	0.27	5.05	0.58	20	15	14	6	9	30	2100	10	0.100
1	Balmoral	48.3	7.9	4.5	1.5	6.5	0.56	1.52	0.45	0.07	0.40	18.65	2.05	70	23	35	10	25	105	3900	1	0.150
1	St. Lukes	59.1	8.2	3.1	1.9	6.2	1.20	2.1	0.31	0.05	0.27	13.83	1.62	35	15	12	7	10	65	3100	2	0.210
2		55.3	8.4	4.1	1.7	5.9	0.98	2.2	0.42	0.08	0.35	16.20	2.03	79	25	25	10	20	150	4100	2	0.300

Table 7. Mean Values of Trace Elements in the Surface Sediment of Lake St. Clair and Marshes

Location	Statistics	Dry weight ($\mu g\ g^{-1}$)							
		Pb	Cu	Zn	Ni	Co	Cr	As	Hg
Lake St. Clair	$\bar{x}$	26.7	14.6	46.2	20.8	9.2	58.3	3.4	0.568
	$s_{\bar{x}}$	13.2	9.7	20.2	9.6	3.3	57.1	4.5	0.777
	n	54	54	54	54	54	54	54	54
Dover, Balmoral and St. Lukes marshes	$\bar{x}$	50.3	20.6	85.9	20.0	7.7	16.1	6.0	0.159
	$s_{\bar{x}}$	25.2	11.9	43.2	5.5	1.7	6.4	5.6	0.072
	n	7	7	7	7	7	7	7	7
Walpole Island, Johnston River, Johnston Bay and Johnston Bay marsh	$\bar{x}$	37.7	17.9	85.3	24.8	7.8	24.8	2.5	0.486
	$s_{\bar{x}}$	21.4	10.8	41.2	12.7	4.1	18.8	1.9	0.498
	n	10	10	10	10	10	10	10	10

Table 8. Particle Size Distribution and Geochemistry of Dover Marsh Sediment Profile

Station No.	Depth (cm)	Eh (mV)	pH	Percent dry weight										Dry weight (μg g^{-1})								
				Sand	Silt	Clay	Fe$_2$O$_3$	MgO	CaO	K$_2$O	P$_2$O$_5$	Org. C	TN	S	Pb	Ni	Cu	Co	Cr	Zn	As	Hg
1	0-10	-150	7.1	14.74	60.45	24.81	4.28	1.9	7.9	2.1	0.27	9.95	1.25	3300	42	23	19	6	17	90	8	0.100
	10-20	-250	7.0	13.52	65.28	21.20	4.41	1.8	7.5	2.0	0.26	8.80	0.98	3100	23	30	25	5	14	65	3	0.110
	20-30	-100	7.0	25.42	68.34	6.24	4.25	2.1	7.2	2.1	0.29	4.20	0.51	2700	20	25	20	4	13	50	5	0.090
2	0-10	-175	7.0	14.02	55.83	30.05	3.55	1.9	9.8	1.9	0.28	15.54	1.74	3950	75	75	19	6	20	110	10	0.110
	10-20	-300	7.2	8.43	53.12	38.45	3.15	1.7	8.9	2.0	0.26	9.03	1.06	3150	35	10	18	6	17	75	5	0.100
	20-30	-125	7.0	15.92	56.58	27.50	3.38	2.0	8.6	1.8	0.27	3.89	0.41	2200	19	9	12	7	14	28	5	0.110
3	0-10	-100	7.0	21.90	45.83	34.27	2.64	2.1	7.8	2.0	0.23	2.82	0.31	1900	18	12	17	7	8	34	3	0.120
	10-20	-150	7.2	14.19	56.98	28.83	2.98	1.9	7.5	2.1	0.22	5.35	0.75	2200	25	11	19	9	7	51	2	0.100
	20-30	-75	7.0	26.13	62.30	11.57	2.54	2.0	7.2	2.1	0.23	3.45	0.42	2200	21	14	18	9	9	45	3	0.110
4	0-10	-50	7.0	15.21	58.39	26.40	2.75	1.9	7.4	1.9	0.27	4.91	0.63	2800	19	22	13	6	8	25	<2	0.090
	10-20	-150	7.1	17.18	62.38	20.44	2.84	2.1	7.0	1.8	0.28	3.26	0.45	2200	15	23	12	4	8	22	<2	0.100
	20-30	-75	7.1	23.85	61.53	14.62	2.69	2.2	7.9	2.1	0.25	2.95	0.38	2000	13	20	19	4	9	20	<2	0.100

Table 9. Particle Size Distribution and Geochemistry of Balmoral Marsh Sediment Profile

Station No.	Depth (cm)	Eh (mV)	pH	Percent dry weight										Dry weight (μg g^{-1})								
				Sand	Silt	Clay	Fe$_2$O$_3$	MgO	CaO	K$_2$O	P$_2$O$_5$	Org. C	TN	S	Pb	Ni	Cu	Co	Cr	Zn	As	Hg
1	0-10	-100	6.9	5.35	62.53	32.12	4.15	1.7	6.3	1.6	0.38	17.65	1.98	3700	65	20	32	5	23	120	5	0.120
	10-20	-270	7.0	11.15	55.95	32.90	4.27	1.9	6.5	1.7	0.40	7.63	0.95	3500	38	15	15	10	20	30	3	0.110
	20-30	-200	7.0	20.31	58.22	21.47	4.36	1.8	7.2	1.7	0.32	5.51	0.73	2900	25	15	13	8	19	25	<2	0.110

Table 10. Particle Size Distribution and Geochemistry of St. Lukes Marsh Sediment Profile

Station No.	Depth (cm)	Eh (mV)	pH	Percent dry weight										Dry weight (μg g^{-1})								
				Sand	Silt	Clay	Fe$_2$O$_3$	MgO	CaO	K$_2$O	P$_2$O$_5$	Org. C	TN	S	Pb	Ni	Cu	Co	Cr	Zn	As	Hg
1	0-10	-120	6.9	8.75	64.28	26.97	2.8	1.9	6.1	2.1	0.25	12.5	1.45	3050	38	13	13	7	10	63	5	0.180
	10-20	-180	7.0	9.05	65.82	25.13	2.5	2.0	6.0	2.0	0.23	4.3	0.56	2200	20	10	10	6	8	35	<2	0.130
	20-30	-150	7.0	13.82	58.25	27.93	2.3	2.1	5.9	2.1	0.25	4.5	0.51	2200	19	10	10	7	10	38	<2	0.120
	30-40	-130	7.1	18.52	55.38	26.10	2.4	1.8	6.2	2.0	0.24	3.9	0.45	2000	18	8	10	6	10	35	<2	0.110
2	0-10	-165	6.9	10.25	65.68	24.07	4.5	1.7	5.8	2.2	0.33	14.55	1.78	3900	70	25	25	9	20	100	10	0.300
	10-20	-180	7.0	14.83	62.29	22.88	4.3	1.9	5.9	2.1	0.30	12.38	1.56	3500	55	23	20	11	15	120	8	0.180
	20-30	-100	7.0	20.39	53.81	25.80	4.6	1.8	6.2	2.1	0.28	4.28	0.66	2400	20	20	22	5	20	35	5	0.120

Table 11. Dover Marsh Sediment Description

Station No.	Depth (cm)	Remarks
1	0–20	Very fine, soft, very dark gray silt and clay, with decomposing organic debris
	20–30	Fine silt-clay mixture, dark gray; some sand at the bottom of the core
2	0–20	Very fine, soft, very dark gray silt and clay with many roots and decomposing organic debris
	20–30	Fine firm silt clay mixture, very dark gray with some decomposing roots
3	0–20	Very fine, very dark gray silt-clay mixture with some tiny roots
	20–30	Fine firm silt, some sand at the bottom of the core
4	0–20	Very fine, dark gray silt and clay mixture
	20–30	Fine firm silt-clay mixture, sandy at the bottom of the core

Table 12. Balmoral Marsh Sediment Description

Station No.	Depth (cm)	Remarks
1	0–20	Very fine, very soft, very dark gray silt-clay mixture; large quantities of decomposing organic debris
	20–30	Fine, firm silt and clay mixture, dark gray; some sand at the bottom of the core

Table 13. St. Lukes Marsh Sediment Description

Station No.	Depth (cm)	Remarks
1	0–20	Very fine, soft, very dark gray silt and clay mixture with decomposing organic debris
	20–40	Firm fine dark gray silt and clay mixture; some sand at the bottom of the core
2	0–20	Very fine, very soft, very dark gray silt and clay; many tiny roots, partly decomposed
	20–30	Fine, dark gray silt and clay mixture; some sand at the bottom of the core

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Table 14. Major and Trace Element Concentrations in Walpole Island Surface Sediment

Station No.	Location	Percent dry weight												Dry weight (μg g^{-1})								
		SiO$_2$	Al$_2$O$_3$	Fe$_2$O$_3$	MgO	CaO	Na$_2$O	K$_2$O	TiO$_2$	MnO	P$_2$O$_5$	Org. C	TN	Pb	Ni	Cu	Co	Cr	Zn	S	As	Hg
1	Pottowatamie Channel	60.3	8.2	2.8	3.5	9.5	0.2	2.1	0.47	0.04	0.24	4.7	0.45	38	19	11	5	32	60	2500	<2	0.07
2	Johnston River	60.5	12.3	5.2	3.1	4.1	0.1	3.1	0.80	0.05	0.16	6.8	0.66	54	40	36	9	23	132	3100	<2	1.05
3	Johnston River	60.8	12.1	5.4	3.8	4.5	0.1	3.3	0.80	0.05	0.18	12.5	1.19	69	45	30	11	54	138	4000	5	0.95
4	Johnston River	60.3	12.2	5.3	3.2	5.1	0.1	3.2	0.78	0.05	0.17	8.8	0.83	63	43	32	10	60	145	3500	3	1.50
5	Johnston Bay marsh	61.3	8.4	3.4	3.2	6.1	0.2	2.2	0.50	0.04	0.18	7.6	0.71	14	19	10	4	17	69	3100	5	0.20
6	Johnston Bay marsh	60.5	8.1	3.5	3.1	6.3	0.2	2.1	0.55	0.04	0.19	7.1	0.66	20	18	15	5	19	58	2900	3	0.25
7	Goose Lake	69.7	4.4	0.9	0.8	1.6	0.5	1.8	0.14	0.02	0.05	1.8	0.15	4	3	<1	5	2	17	1500	<2	0.05
8	Goose Lake	75.8	4.6	1.0	0.9	1.4	0.5	1.71	0.13	0.01	0.05	2.1	0.20	3	2	1	2	2	14	1200	<2	0.05
9	Johnston Bay	53.3	9.7	4.6	1.9	3.7	0.1	2.5	0.65	0.07	0.13	7.1	0.68	55	23	19	8	20	110	2500	3	0.10
10	Johnston Bay	67.4	8.3	2.5	2.8	7.1	0.4	2.1	0.42	0.05	0.13	5.8	0.55	34	15	8	1	2	55	1900	3	0.18
11	Johnston Bay	60.6	9.5	3.0	1.8	2.1	0.1	2.5	0.62	0.03	0.14	3.9	0.36	15	13	8	10	8	45	1100	<2	0.16
12	Johnston Bay	57.4	8.3	2.8	5.0	7.9	0.2	2.3	0.51	0.03	0.10	4.1	0.38	15	13	10	15	13	41	1200	3	0.40

sediments in 1974 (Thomas *et al.*, 1975). The vertical section description and results of sediment analyses are shown in Tables 15 and 16.

The concentration profiles of Fe, Mg, Ca, K and P were generally uniform in all sediment cores, except for Ca at station No. 10 (Johnston Bay). At this station a dense growth of submerged macrophytes (*Chara* sp.) was observed. Since these plants accumulate large quantities of calcite on their vegetative structure, the increased Ca concentration at the sediment surface probably originated from the plants. Macrophytes found at most of the sampling stations contributed to the higher organic C and TN concentrations in the sediment layer from 0 to 20 cm. An increase in Pb, Cu and Zn concentrations at the sediment surface was observed in sediment obtained at the three stations in Johnston River (Nos. 2, 3 and 4) and at one station in Johnston Bay (No. 9). Elevated Hg levels were also found in the surface sediment (depth of 0-20 cm) at the three stations in Johnston River and at station No. 12 in Johnston Bay (Fig. 4). All of these localities are in shallow water; they contain more fine-grained material and function as settling areas for fine particles of the suspended load brought by the Johnston River. This river (a branch of Chenal Écarté) is the major channel of the area and carries St. Clair River water with its suspended load into Lake St. Clair. The bottom sediment of Johnston Bay is subject to periodic resuspension by storm activity and flooding, which probably results in a partial re-transportation of suspended solids into Lake St. Clair. Since there is no industrial wastewater input to the Johnston River, the elevated metal concentrations in these sediments probably originated from the suspended load of the St. Clair River.

The pH in all sediment profiles was generally the same (7.0 to 7.1). The Eh in the sandy sediment of Goose Lake had positive values (50 to 200 mV). Positive Eh values are typical of Lake Ontario water-saturated sands (Thomas *et al.*, 1972). The Eh values were negative in the range of -20 to -250 mV in the rest of the sediment, with the exception of the section (20-30 cm) of cores obtained at Pottowatamie Channel and Johnston Bay. The lowest values were found in the section (10-20 cm) of the Johnston Bay marsh sediment profile.

Cootes Paradise

The major component of the sediment collected in Cootes Paradise at stations Nos. 1, 2, 3 and 5 was silt, and at station No. 4, sand. Sediment sampling stations Nos. 1 and 2 were located in an area usually flooded during the spring and during the years of high water level. The concentrations of Al, Ca, Fe and Mn in the surface sediments reflected small changes in the local mineralogy of the Cootes Paradise drainage basin (Table 17). The Fe and

Table 15. Walpole Island Sediment Description

Station No.	Location	Depth (cm)	Remarks
2	Johnston River	0-10	Very fine, soft dark gray silt and clay, with some sand
		10-30	Fine, firm gray silty clay, more sand toward the bottom of the core
3	Johnston River	0-30	Fine, dark gray silt and clay with some sand
4	Johnston River	0-20	Very fine, soft, dark gray silty clay with some sand
		20-30	Fine gray silt and clay mixed with fine sand
5	Johnston Bay marsh	0-10	Fine dark gray silt-clay-sand mixture, with decomposing organic debris
		10-20	Fine, very dark gray silt-clay-sand mixture, many decomposing plant roots
		20-30	Dark gray silt-clay-sand mixture, with few small clam shells
6	Johnston Bay marsh	0-10	Fine, dark gray silt-clay-sand mixture with some decomposing organic debris
		10-20	Fine, very dark gray silt-sand-clay mixture with many decomposing plant roots and leaves
		20-40	Firm, gray, fine sand-silt-clay mixture, more sandy toward the bottom of the core; small clam shells at the bottom
7, 8	Goose Lake	0-20	Firm, fine sand, few small clam shells
9, 10, 11, 12	Johnston Bay	0-10	Fine gray sand-silt-clay mixture
		10-20	Firm, fine, very dark gray sand-silt-clay mixture, some decomposing organic debris
		20-30	Firm, dark gray sand-silt-clay mixture, becomes more sandy toward the bottom of the cores

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Table 16. Particle Size Distribution and Geochemistry of Walpole Island Sediment Profile

Station No.	Location	Depth (cm)	Eh (mV)	pH	Percent dry weight										Dry weight ($\mu g\,g^{-1}$)								
					Sand	Silt	Clay	Fe_2O_3	MgO	CaO	K_2O	P_2O_5	Org. C	TN	S	Pb	Ni	Cu	Co	Cr	Zn	As	Hg
1	Pottowatamie Channel	0–10	−50	7.0	40.25	30.81	28.94	2.7	3.1	9.3	2.1	0.22	4.3	0.39	2100	33	15	10	3	21	46	3	0.07
		10–20	−75	7.1	70.38	19.15	10.47	2.8	2.6	9.3	2.2	0.18	3.4	0.31	1900	25	10	7	2	10	35	2	0.05
		20–30	+50	7.0	68.63	22.49	8.88	2.7	2.7	9.1	2.2	0.19	3.2	0.29	1900	23	10	9	2	9	33	2	0.04
2	Johnston River	0–10	−100	7.0	20.05	61.38	18.57	5.1	2.9	3.6	3.2	0.16	6.9	0.67	2900	50	35	32	9	22	120	3	0.95
		10–20	−175	7.1	23.42	60.29	16.29	5.3	2.4	2.7	3.1	0.12	6.7	0.65	2800	25	28	18	10	17	68	<2	0.25
		20–30	−85	7.1	30.91	55.25	13.84	5.5	2.5	2.9	2.9	0.11	6.8	0.66	2700	28	30	20	8	20	73	2	0.07
3	Johnston River	0–10	−50	7.1	31.86	49.52	18.62	5.5	3.7	4.3	3.3	0.17	10.8	0.98	3900	65	43	25	9	49	120	3	0.90
		10–20	−125	7.0	29.65	50.05	20.30	5.2	3.4	4.2	3.1	0.16	11.2	1.03	3800	40	32	18	10	45	94	2	0.65
		20–30	−75	7.0	26.55	51.82	21.63	5.3	3.2	3.5	3.2	0.17	8.9	0.73	3100	41	28	20	9	36	68	<2	0.20
4	Johnston River	0–10	−70	7.0	26.60	42.95	31.35	5.2	3.1	5.0	3.2	0.16	8.5	0.79	3100	59	40	30	10	55	130	5	1.45
		10–20	−140	7.1	38.05	33.13	28.82	5.3	2.9	4.9	3.1	0.17	7.9	0.74	2900	40	32	25	9	40	95	4	0.32
		20–30	−25	7.0	55.63	22.89	21.48	5.1	2.9	4.7	3.0	0.15	5.6	0.53	1900	38	34	21	10	38	68	4	0.09
5	Johnston Bay marsh	0–10	−100	7.0	35.70	31.42	32.88	3.2	3.2	6.0	2.2	0.17	7.5	0.69	2900	15	19	10	4	14	60	<2	0.20
		10–20	−230	7.1	41.80	38.42	19.78	3.5	3.2	7.9	2.1	0.16	6.2	0.58	2600	17	15	12	5	12	55	2	0.18
		20–30	−150	7.0	33.55	46.18	20.27	3.2	2.7	5.8	2.1	0.13	4.9	0.43	2100	20	16	9	4	10	51	2	0.15
6	Johnston Bay marsh	0–10	−100	7.0	38.72	28.74	32.54	3.4	3.1	6.1	2.1	0.17	6.9	0.64	2800	19	17	13	5	18	55	<2	0.23
		10–20	−250	7.1	37.29	42.58	20.13	3.5	3.2	5.9	2.2	0.16	6.5	0.59	2600	15	16	10	4	15	45	2	0.18
		20–30	−75	7.0	43.24	25.18	31.58	3.4	3.1	6.2	2.1	0.16	4.8	0.43	2000	16	16	12	5	16	50	<2	0.18
		30–40	−20	7.0	51.28	29.15	19.57	3.2	3.1	6.3	2.1	0.17	3.5	0.31	1500	14	15	11	4	17	53	<2	0.15
7	Goose Lake	0–10	+150	7.0	87.25	10.13	2.62	0.7	0.8	1.7	1.7	0.05	1.7	0.10	<500	4	3	<1	2	3	15	<2	<0.05
		10–20	+50	7.0	89.18	9.50	1.32	0.9	0.7	1.9	1.8	0.05	1.1	0.06	<500	5	3	1	3	2	14	<2	<0.05
8	Goose Lake	0–10	+200	7.1	90.04	8.92	1.04	0.9	0.7	1.8	1.9	0.07	1.9	0.11	<500	5	2	1	3	3	16	<2	<0.05
		10–20	+75	7.0	89.25	7.15	3.60	1.1	0.7	2.0	1.7	0.09	1.2	0.06	<500	3	3	1	2	3	17	<2	<0.05
9	Johnston Bay	0–10	−135	7.1	30.64	35.62	33.74	4.7	1.8	3.5	2.5	0.12	6.9	0.62	2300	53	20	18	8	19	100	2	0.10
		10–20	−170	7.0	26.08	39.73	34.19	4.5	1.7	2.9	2.7	0.13	4.2	0.37	1700	25	23	19	9	24	75	<2	0.08
		20–30	−40	7.0	50.28	26.83	22.89	4.6	2.7	2.8	2.5	0.08	3.1	0.26	1100	20	17	10	10	18	46	<2	0.09
10	Johnston Bay	0–10	−55	7.0	37.81	45.23	16.96	2.4	2.7	6.8	2.1	0.13	5.8	0.55	1800	30	14	10	1	2	50	2	0.17
		10–20	−135	7.1	42.56	39.68	17.76	2.5	2.2	3.7	2.3	0.13	4.4	0.40	1600	25	15	12	7	10	55	<2	0.11
		20–30	−20	7.1	48.17	38.29	13.54	2.3	1.7	2.5	2.5	0.11	3.5	0.31	900	20	17	13	7	10	45	2	0.09
11	Johnston Bay	0–10	−95	7.0	33.48	46.59	19.93	2.9	1.8	2.1	2.4	0.13	3.8	0.42	1200	15	14	8	11	9	40	2	0.14
		10–20	−150	7.0	36.92	45.26	17.82	3.0	1.7	2.0	2.3	0.12	3.1	0.34	800	13	13	9	14	8	45	<2	0.11
		20–30	−35	7.0	45.18	39.19	15.63	3.1	1.4	1.9	2.1	0.13	2.1	0.18	<500	10	13	8	13	10	42	<2	0.08
12	Johnston Bay	0–10	−75	7.0	41.52	38.98	19.50	2.7	4.8	7.7	2.3	0.11	3.9	0.44	1600	16	14	10	14	12	40	<2	0.33
		10–20	−125	7.0	38.68	40.15	21.17	2.9	4.5	8.0	2.4	0.10	3.1	0.35	1100	15	13	9	16	13	42	<2	0.18
		20–30	+15	7.0	48.11	35.08	16.81	2.8	4.3	7.9	2.3	0.09	2.3	0.24	600	16	15	10	15	14	40	<2	0.10

Table 17. Major and Trace Element Concentrations in Cootes Paradise Surface Sediment

Station No.	Percent dry weight												Dry weight ($\mu g\ g^{-1}$)								
	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	Org. C	TN	Pb	Ni	Cu	Co	Cr	Zn	S	As	Hg
1	62.5	10.8	7.6	3.0	5.7	0.92	2.93	0.51	0.18	0.09	3.90	0.26	40	33	32	12	19	135	1800	7	0.09
2	67.9	11.2	7.3	2.9	3.9	1.10	2.82	0.50	0.17	0.07	6.75	0.72	42	36	47	11	20	170	2900	5	0.09
3	62.8	8.6	4.8	2.8	11.2	1.20	1.81	0.39	0.09	0.11	1.60	0.17	45	22	36	5	12	190	500	5	0.05
4	65.9	7.3	4.7	3.2	10.9	0.95	1.96	0.35	0.12	0.10	1.70	0.18	44	17	29	4	9	150	500	6	0.06
5	63.8	8.4	5.3	3.4	9.3	1.05	1.82	0.51	0.12	0.70	19.28	2.15	40	32	42	7	75	130	4500	10	0.13

Al concentrations were high, and Ca concentrations, the lowest, in sediment obtained at stations 1 and 2. This was caused by the presence of reddish-brown soil, originating from the Queenston red shale bedrock.

Organic C and TN concentrations were the highest at stations 1 and 2, which was attributed to the occurrence of a dense stand of macrophytes (*Glyceria grandis*) in this area. Only a few submerged macrophytes were present at stations Nos. 3 and 4.

Concentrations of Pb, Zn, Cu and Hg at stations Nos. 1, 2, 3 and 4 were similar and were close to those found by Kemp and Thomas (1976) in precolonial sediments of Lake Ontario.

Table 18. Cootes Paradise Sediment Description

Station No.	Depth (cm)	Remarks
1	0-10	Very fine, brown silty clay, with small roots and larger plant residues beginning to decompose, becomes finer toward 10 cm
	10-30	Firm, dark yellowish-brown silty clay with some small roots
2	0-10	Soft, fine very dark graying brown silt and clay mixture; many old, partly decomposed roots; at 10 cm, black lenses of very fine silty clay
	10-30	Very firm dark gray silty clay with some black specks and lenses of very fine silty clay; many small decomposing roots
3	0-10	Soft, dark olive-gray with some sand
	10-20	Very firm black silty sand mixed with some dark olive-gray silty clay
	20-30	Same as above, few black lenses of very fine silty clay
	30-40	Fine, very firm, very dark gray sand with silt and some clay
	40-50	Firm, very dark gray silt with clay
	50-60	Firm brownish gray silt and clay, spongy consistency; colour more brownish toward the bottom of the core, with many small roots — appearance of an old marsh soil
4	0-10	Fine, dark olive-gray silt-clay-sand mixture; abundant roots and plant parts
	10-50	Firm dark gray silt-clay-sand mixture
	50-90	Medium coarse sand, well sorted
	90-130	Very firm dark olive-gray silty clay with some sand; few tiny roots at the core bottom
5	0-10	Very soft, very fine black silty clay with decomposing organic debris; strong H_2S smell
	10-20	Same as above, firmer
	20-30	Firm, fine, very dark grayish brown silty clay; some sand and few plant residues
	30-40	Firm, very dark gray silt-clay-sand mixture with shell fragments

The concentrations of organic C, TN and TP in sediment from West Pond (station No. 5) exceeded those of the other sediments by many times. This was obviously the effect of the input from the Dundas sewage treatment plant and the high biological activity in this area.

The concentration of Pb in surface sediment at West Pond was similar to that found by Kemp and Thomas (1976) in Lake Ontario surface sediment, and the concentrations of Ni, Ca, Zn, As and Hg were similar to those found at stations 1, 2, 3 and 4. Higher concentrations of Pb and Cr in surface sediment at station No. 5 may have originated from Dundas sewage effluent.

The concentrations of Ca, Mg, K and most of the trace elements were consistent in all of the sediment profiles (Table 19). The concentration profiles of P, Pb and Cr in West Pond sediment showed enrichment in the surface layer. Detailed description and interpretation of the concentration profiles from all stations have been given by Mudroch and Capobianco (1979). A description of cores and the results of sediment analyses are shown in Tables 18 and 19.

Stations 1 and 2 showed the highest positive values of sediment Eh. Since this sediment was above water at the sampling time, it was more oxidized than the sediment collected at other localities. The highest negative Eh values were observed in West Pond sediment. Larger quantities of decomposing plant residues probably affected the sediment Eh values at this station.

WATER CHEMISTRY

Big Creek Marsh

The concentration of N, P, Fe, Mn and Zn in water collected at the six sampling stations during the period May to November 1978 is presented in Table 20, together with a similar data set obtained for Big Creek mouth and Lake Erie (1975 surveillance cruise).

Mean values of total Kjeldahl nitrogen (TKN) concentration in the marsh water were higher than those of Big Creek. Nitrogen in Big Creek was present, mainly as $NO_3 + NO_2$-N. The concentration of NH_4-N in the marsh water was similar to that found in Big Creek. An increase in TKN and NH_4-N in marsh water was observed at stations Nos. 2 to 5 in November. This increase may be caused by decomposition of certain macrophytes. Because the biological activity in the fall is limited by the temperature, the released nitrogen is not utilized completely by phytoplankton and the excess remains for a period of time in the marsh before it is sorbed by

Table 19. Particle Size Distribution and Geochemistry of Cootes Paradise Sediment Profile

Station No.	Depth (cm)	Eh (mV)	pH	Percent dry weight										Dry weight ($\mu g\ g^{-1}$)								
				Sand	Silt	Clay	Fe_2O_3	MgO	CaO	K_2O	P_2O_5	Org. C	TN	S	Pb	Ni	Cu	Co	Cr	Zn	As	Hg
1	0–10	+305	7.0	28.88	55.29	15.83	7.4	3.0	5.5	2.9	0.08	3.70	0.32	1800	35	32	32	12	19	130	7	0.030
	10–20	+120	7.2	41.75	48.13	10.12	7.5	2.9	5.3	2.8	0.09	3.13	0.34	1400	30	33	30	10	19	120	9	0.030
	20–30	+50	7.4	42.53	45.28	12.18	7.3	3.0	5.1	2.9	0.11	2.95	0.28	700	25	32	28	12	20	115	9	0.025
2	0–10	+130	7.1	29.13	50.65	20.22	7.2	2.9	3.8	2.8	0.07	6.50	0.51	2200	40	35	50	10	21	170	6	0.110
	10–20	+35	7.2	25.61	55.21	19.18	7.4	2.8	4.1	2.7	0.08	1.90	0.20	<500	20	30	35	13	20	100	5	0.090
	20–30	+30	7.4	37.25	41.71	21.04	7.3	3.0	3.8	2.9	0.08	2.30	0.25	<500	17	31	29	10	20	90	4	0.040
3	0–10	+15	7.0	29.42	42.43	28.15	4.7	2.8	11.0	1.8	0.11	1.60	0.55	<500	45	23	36	5	12	180	6	0.050
	10–20	+20	7.0	71.24	24.11	4.65	4.6	2.7	10.9	1.7	0.09	1.35	0.08	<500	20	20	25	5	10	105	5	0.030
	20–30	+30	7.1	74.52	23.38	2.1	4.7	2.8	10.5	1.9	0.08	1.40	0.09	<500	25	15	23	3	10	100	6	0.035
	30–40	+10	7.0	80.0	15.63	4.37	4.5	2.9	10.7	1.7	0.07	1.28	0.11	<500	20	12	20	5	11	110	5	0.030
	40–50	+20	7.0	17.65	65.23	17.12	4.4	2.9	11.2	1.7	0.08	4.18	0.44	2200	42	28	46	8	16	230	10	0.09
	50–60	+40	6.9	20.94	63.81	15.25	4.5	2.9	10.9	1.8	0.08	9.56	0.96	4100	46	26	44	8	16	470	7	0.06
4	0–10	−70	7.0	21.51	49.58	28.91	4.5	3.2	10.5	1.8	0.10	1.40	0.14	<500	44	17	28	3	10	150	4	0.06
	10–20	−20	7.0	18.57	51.18	30.25	4.4	3.1	10.8	1.5	0.11	1.55	0.16	<500	45	16	30	4	9	150	5	0.05
	20–30	+5	7.1	25.23	49.62	25.15	4.6	3.0	11.1	1.7	0.09	1.76	0.17	<500	35	15	32	4	10	140	6	0.05
	30–40	+10	7.1	26.03	45.23	28.74	4.7	2.9	10.5	1.6	0.10	1.30	0.14	<500	30	10	31	4	8	120	5	0.05
	40–50	+30	7.1	40.29	48.15	11.56	4.5	2.9	10.3	1.5	0.11	0.90	0.08	<500	20	7	28	3	9	90	6	0.05
	50–60	+90	7.1	75.81	18.19	6.00	4.6	2.2	5.4	0.9	0.09	0.50	0.07	<500	10	5	15	1	5	50	3	0.01
	80–90	+110	7.0	85.13	12.05	2.82	4.9	1.9	5.7	1.0	0.09	0.45	0.05	<500	15	6	10	1	5	55	<2	0.01
	120–130	+10	7.0	40.68	50.06	9.26	4.7	2.9	9.8	1.8	0.11	1.05	0.16	<500	25	16	32	4	11	130	7	0.03
5	0–10	−150	6.8	22.03	45.38	32.59	5.3	3.4	9.2	1.8	0.65	15.38	1.71	5200	205	26	40	6	55	120	13	0.130
	10–20	−235	6.9	4.02	48.82	47.16	5.2	3.2	9.5	1.7	0.35	3.12	0.33	2100	40	13	45	6	10	170	7	0.120
	20–30	−50	7.0	20.11	50.28	29.61	5.1	3.3	9.1	1.9	0.13	2.20	0.23	900	55	18	32	7	13	180	6	0.100
	30–40	−70	7.0	45.41	43.03	11.56	5.3	3.1	9.6	1.8	0.11	2.05	0.21	800	40	22	30	13	12	210	7	0.090

Station No.	Statistics	NH$_4$-N	TKN	NO$_3$+NO$_2$-N	TP	Fe	Mn	Zn
1	Range	0.016–0.035	0.638–0.733	0.028–0.065	0.023–0.043	0.243–0.318	0.095–0.153	0.005–0.011
	$\bar{x}$	0.026	0.685	0.044	0.038	0.284	0.127	0.008
	$s_{\bar{x}}$	0.007	0.045	0.013	0.008	0.027	0.022	0.002
	n	7	7	7	7	7	7	7
2	Range	0.039–0.095	0.658–1.118	0.098–0.180	0.025–0.045	0.390–0.510	0.048–0.070	0.005–0.009
	$\bar{x}$	0.057	0.647	0.132	0.033	0.466	0.059	0.007
	$s_{\bar{x}}$	0.022	0.171	0.030	0.008	0.042	0.008	0.002
	n	7	7	7	7	7	7	7
3	Range	0.045–0.070	0.730–0.950	0.025–0.061	0.043–0.060	0.256–0.365	0.073–0.095	0.005–0.010
	$\bar{x}$	0.055	0.831	0.042	0.050	0.304	0.085	0.008
	$s_{\bar{x}}$	0.009	0.0810	0.015	0.007	0.039	0.008	0.002
	n	7	7	7	7	7	7	7
4	Range	0.043–0.075	0.698–0.910	0.024–0.062	0.021–0.030	0.095–0.135	0.045–0.068	0.005–0.009
	$\bar{x}$	0.058	0.769	0.039	0.026	0.114	0.057	0.007
	$s_{\bar{x}}$	0.010	0.074	0.016	0.004	0.015	0.009	0.002
	n	7	7	7	7	7	7	7
5	Range	0.045–0.082	0.683–0.840	0.010–0.041	0.010–0.028	0.100–0.153	0.020–0.040	0.006–0.010
	$\bar{x}$	0.058	0.754	0.022	0.022	0.126	0.031	0.008
	$s_{\bar{x}}$	0.013	0.058	0.012	0.003	0.018	0.008	0.002
	n	7	7	7	7	7	7	7
6	Range	0.015–0.040	0.390–0.550	0.015–0.060	0.018–0.032	0.145–0.190	0.060–0.100	0.005–0.018
	$\bar{x}$	0.027	0.480	0.033	0.023	0.165	0.082	0.012
	$s_{\bar{x}}$	0.009	0.069	0.017	0.005	0.016	0.016	0.005
	n	7	7	7	7	7	7	7
Big Creek	Range	0.025–0.050	0.290–0.345	0.40–2.21	0.013–0.023	0.115–0.180	0.049–0.061	0.010–0.018
	$\bar{x}$	0.036	0.321	1.23	0.017	0.141	0.055	0.014
	$s_{\bar{x}}$	0.009	0.022	0.593	0.004	0.027	0.005	0.003
	n	7	7	7	7	7	7	7
Lake Erie 1975	Range	N.A.	0.110–0.540	0.005–0.375	0.0097–0.0640	0.060–0.110	N.A.	0.004–0.008
	$\bar{x}$	N.A.	0.277	0.142	0.0229	0.085	N.A.	0.006
	$s_{\bar{x}}$	N.A.	0.087	0.093	0.0109	0.025	N.A.	0.002
	n	N.A.	204	204	205	2	N.A.	2

sediment. Mean values of TP in marsh water were higher (except for water collected at station No. 5) than those of Lake Erie water, and higher than the mean values of TP in Big Creek water. DeMarte and Hartman (1974) found \adsorption of P by the roots of *Myriophyllum* sp. and further transformation to the shoot system, and release to the surrounding water. An additional release of P occurred after physical damage to the shoots. Release of P by certain macrophytes in the marsh could be the reason for higher P concentrations in the marsh water. The mean values of Fe in marsh water exceeded those of Lake Erie.

The concentrations of Pb, Ni, Cu, Cr, Cd and As were <0.001 mg L^{-1} and Hg concentrations remained less than 5 × 10^{-5} mg L^{-1} during the whole study period.

The dissolved oxygen concentration in water decreased occasionally to 5 mg L^{-1} in the afternoon during the summer months; during the night cooling, however, the water was reaerated and the dissolved oxygen concentration increased.

Dover, Balmoral and St. Lukes Marshes

The concentrations of nutrients and trace elements in marsh waters are shown in Table 21. The same parameter values measured in water that had been collected from the municipal drain and Lake St. Clair are included for comparison; as mentioned previously (in the section "Study Area"), the water is pumped into the marshes partly from the municipal drain and partly from Lake St. Clair.

Table 21. Concentrations of Nutrients and Metals in Dover, St. Lukes and Balmoral Marsh Waters (mg L^{-1})

Marsh	Statistics	NH$_4$-N	TKN	NO$_3$ + NO$_2$-N	TP	Fe	Mn	Zn
Dover, all stations	Range	0.055-0.450	1.85-3.70	0.038-0.490	0.087-0.130	0.105-0.358	0.040-0.128	<0.001-0.015
	$\bar{x}$	0.215	2.67	0.280	0.110	0.295	0.074	0.005
	$s_{\bar{x}}$	0.163	0.332	0.187	0.052	0.120	0.021	0.001
	n	28	28	28	28	28	28	28
St. Lukes, all stations	Range	0.045-0.270	1.90-2.60	0.025-0.068	0.027-0.090	0.068-0.169	0.028-0.095	<0.001-0.054
	$\bar{x}$	0.166	2.28	0.040	0.069	0.131	0.048	0.020
	$s_{\bar{x}}$	0.102	0.090	0.010	0.049	0.102	0.019	0.040
	n	14	14	14	14	14	14	14
Balmoral, all stations	Range	0.043-0.210	1.12-2.10	0.017-0.048	0.020-0.087	0.072-0.215	0.035-0.108	<0.001-0.004
	$\bar{x}$	0.135	1.69	0.036	0.043	0.143	0.083	0.003
	$s_{\bar{x}}$	0.076	0.23	0.021	0.020	0.095	0.041	0.002
	n	7	7	7	7	7	7	7
Drain water	Range	0.150-0.200	0.800-0.980	2.70-5.48	0.072-0.145	0.045-0.650	0.040-0.200	<0.001-0.017
	$\bar{x}$	0.179	0.870	4.55	0.114	0.330	0.130	0.010
	$s_{\bar{x}}$	0.010	0.105	2.98	0.092	0.284	0.055	0.011
	n	7	7	7	7	7	7	7
Lake St. Clair water	Range	0.028-0.095	0.390-0.480	0.050-0.075	0.024-0.028	0.035-0.130	0.015-0.066	0.002-0.010
	$\bar{x}$	0.066	0.452	0.069	0.026	0.098	0.041	0.009
	$s_{\bar{x}}$	0.023	0.060	0.010	0.002	0.043	0.010	0.001
	n	7	7	7	7	7	7	7

The highest concentrations of TP and all forms of nitrogen were observed in water collected at Dover marsh. This was obviously the effect of the high nutrient concentration in the municipal drain water, which is pumped regularly into this marsh.

Nutrient concentrations in Balmoral marsh were most likely affected by the lower N and P concentrations of Lake St. Clair water, which is used for water level maintenance in this marsh. No significant increase in the nutrient concentration of marsh water was observed at any of the three marshes during the fall sampling.

The mean values of Fe and Mn concentrations in water were higher in Dover marsh (0.295 and 0.074 mg L^{-1}, respectively) than in Balmoral or St. Lukes. The Zn concentrations of all water samples collected from the three marshes during the sampling period were generally similar and close to those found in Lake St. Clair and the municipal drain water. The concentrations of Cr, Cu, Pb, Ni, As and Cd in all of the water samples collected at the marshes and Lake St. Clair were under detection limits (<0.001 mg L^{-1}), and the Hg concentration was 5 x 10^{-5} mg L^{-1}.

The dissolved oxygen concentration in the marsh water was the lowest in July (6 mg L^{-1}) and was similar in all three marshes.

Walpole Island

The concentrations of nutrients and metals in Johnston River and Johnston Bay (sampling stations 2, 3, 4, 7, 9, 11 and 12) and Johnston Bay marsh (sampling stations 5 and 6) are shown in Table 22.

The NH$_4$-N, NO$_3$ + NO$_2$-N and TP concentrations in water collected in Johnston River, Johnston Bay and Johnston Bay marsh were similar. This similarity is probably due to the periodic flooding of the whole area by Lake St. Clair water. The dike around the marsh partially protects the area from wave action; water level fluctuations in the Great Lakes, however, affect the hydrological regime to a large extent.

The TKN, Fe and Mn concentrations were higher in marsh water (0.730, 0.168 and 0.054 mg L^{-1}, respectively) than in Johnston River and Johnston Bay (0.260, 0.084 and 0.038 mg L^{-1}, respectively).

The dissolved organic matter, produced by the high biological activity in the marsh, was the major contributor to the TKN in the water. Very little is known about the role of macrophytes in cycling Fe and Mn. Osborn and Hem (1962) and DeMarte and Hartman (1974) found indications of Fe translocation from sediments to the leaves of submerged vegetation. No information is available,

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Table 22. Concentrations of Nutrients and Metals in Water at Selected Areas of Walpole Island (mg L^{-1})

Location	Statistics	NH_4-N	TKN	$NO_3 + NO_2$-N	TP	Fe	Mn	Zn
Johnston River	Range	0.055-0.072	0.230-0.310	0.028-0.063	0.021-0.032	0.050-0.110	0.015-0.045	0.005-0.024
and Johnston	$\bar{x}$	0.062	0.260	0.042	0.028	0.084	0.038	0.016
Bay	$s_{\bar{x}}$	0.010	0.042	0.009	0.008	0.022	0.016	0.007
	n	42	42	42	42	42	42	42
Johnston Bay	Range	0.045-0.060	0.500-0.930	0.010-0.060	0.021-0.044	0.070-0.220	0.030-0.095	0.004-0.012
marsh	$\bar{x}$	0.050	0.730	0.050	0.034	0.168	0.054	0.009
	$s_{\bar{x}}$	0.013	0.140	0.032	0.011	0.090	0.028	0.004
	n	14	14	14	14	14	14	14

Table 23. Concentrations of Nutrients and Metals in Cootes Paradise Water (mg L^{-1})

Station	Statistics	NH_4-N	TKN	$NO_3 + NO_2$-N	TP	Fe	Mn	Zn
1, 2, 3, 4	Range	0.010-4.20	0.100-9.000	0.015-2.500	0.010-0.690	0.130-0.450	0.090-2.100	0.005-0.250
	$\bar{x}$	0.924	1.368	0.897	0.120	0.210	0.450	0.098
	$s_{\bar{x}}$	1.030	1.246	0.687	0.101	0.195	1.205	0.156
	n	8	8	8	8	8	8	8
5	Range	8.050-18.000	7.500-20.050	0.050-4.95	1.980-5.54	0.140-0.380	0.100-0.320	0.006-0.059
	$\bar{x}$	10.666	14.000	1.989	3.182	0.250	0.170	0.039
	$s_{\bar{x}}$	4.217	5.109	1.741	1.263	0.180	0.155	0.021
	n	8	8	8	8	8	8	8
Spencer Creek,	$\bar{x}$	0.040	0.680	0.620	0.083	0.095	0.075	0.005
Dundas	$s_{\bar{x}}$	0.010	0.148	0.172	0.026	0.013	0.028	0.001
	n	8	8	8	8	8	8	8

Table 24. Aboveground Biomass Production and Nutrient Content in Most Common Macrophytes Collected from Marshes Studied in July

Species	Location	Biomass dry weight (g/m^2)	K (g/m^2)	P (g/m^2)	N (g/m^2)	Ca (g/m^2)	Mg (g/m^2)
Typha latifolia	Big Creek marsh	1020	10.2	1.6	31.5	12.3	2.5
	Dover marsh	1350	16.2	1.8	37.9	17.8	3.1
	Balmoral marsh	1015	11.3	1.4	31.3	13.0	2.7
	St. Lukes marsh	1170	12.1	1.6	33.5	11.2	2.2
	Johnston Bay marsh (Walpole Island)	995	9.8	1.0	29.1	8.9	2.1
Carex lacustris	Big Creek marsh	730	7.5	0.74	9.5	4.8	1.4
	Balmoral marsh	875	8.9	0.82	10.1	5.2	1.7
	St. Lukes marsh	935	9.5	0.96	10.4	6.5	2.1
	Johnston Bay marsh (Walpole Island)	810	8.3	0.82	10.0	5.6	1.8
Glyceria grandis	Cootes Paradise:						
	West Pond	4800	67.2	6.2	72.0	24.0	8.6
	Desjardins Canal	4000	48.0	5.2	60.0	28.0	8.4
	Long Valley Creek	2700	48.6	6.8	45.9	10.8	6.4

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however, on the release of Fe from plant material after decay.

The concentration of Pb, Cr, Cu, Ni, As and Cd was <0.001 mg L^{-1}, and the concentration of Hg was $<5 \times 10^{-5}$ mg L^{-1} in all water samples. The mean value of Zn concentration was higher in water samples collected at Johnston River and Johnston Bay.

The Johnston Bay area and nearshore zone of Johnston River can be considered a Lake St. Clair littoral zone, which is occupied by various macrophytes. Again, the periodic resuspension of sediment in this area by storm wave activity and flooding has an effect on the partial transportation of suspended solids as well as on the water quality of the area.

Cootes Paradise

The mean values of nutrients and metal concentration in water collected in Cootes Paradise are shown in Table 23. The highest concentrations of total N and P were found at the West Pond outlet sampling station. Semkin et al. (1976) observed that the first reduction in the nutrient concentration of the Dundas sewage treatment effluent, which accounts for 30% to 40% of total P and total N, occurred in the marshy area of the West Pond. This reduction was related to the settling of suspended solids and to the biological activity at West Pond (Mudroch and Capobianco, 1979). The high nutrient content of West Pond sediment is in agreement with this observation.

The major nitrogen species in water at station No. 5 is NH_4-N ($\bar{x} = 10.660$ mg L^{-1}); $NO_3 + NO_2$-N, however, is also present ($\bar{x} = 1.989$ mg L^{-1}). According to Semkin et al. (1976), $NO_3 + NO_2$-N concentration in the sewage treatment plant effluent entering the West Pond is low (approximately 0.2 mg L^{-1}), and at the West Pond where high algal photosynthetic rates result in relatively high dissolved oxygen concentration (up to 10 mg L^{-1}), the bacteria population (Nitrosomonas and Nitrobacter) probably becomes large enough to affect the nitrification. The reduction of nutrient concentration in the main water body of Cootes Paradise is further maintained by the diluting effect of water discharged from Spencer Creek. The major nitrogen species in this creek is $NO_3 + NO_2$-N (Table 23).

The concentrations of Pb, Cr, Cu, Ni, As and Cd in all of the water samples collected at Cootes Paradise were low (<0.001 mg L^{-1}). The Hg concentrations were below detection limit ($<5 \times 10^{-5}$ mg L^{-1}).

PLANT COMPOSITION

The seasonal variations in K, P, N, Ca and Mg in the aboveground biomass of the most abundant marsh plant species sampled are shown in Figures 6 to 11. The aboveground biomass production and nutrient content in the three most common emergent macrophytes in the marshes (Typha latifolia, Carex lacustris and Glyceria grandis) are given in Table 24. Concentrations of N and K in all of the plants were the highest at the beginning of the growing season. The Ca concentration increased in Pontederia cordata, Glyceria grandis, Typha latifolia, Carex lacustris and Myriophyllum heterophyllum during the growing season. The Mg and P concentrations generally remained constant in most species during the growing season. Nutrients were equally distributed in the aboveground biomass of Typha latifolia in June, July and August (Fig. 12). The concentrations of N and Ca in old plants that were sampled in April from a stand of Typha latifolia in Dover marsh exceeded, by many times, those of K, P and Mg. The work of Chamie and Richardson (1978) provides some explanation. These authors studied the decomposition of plants in northern wetlands and found that for most species and their parts, nutrient concentration losses occurred in P, K and Mg, while increases occurred in N and Ca. Davis and Van der Valk (1978) studied decomposition of five emergent macrophyte specimens in prairie glacial marshes, and they found that losses from the standing litter compartment were primarily the result of fragmentation that had occurred during the first winter and spring. Davis and Van der Valk found that K, Na and Mg were released very rapidly from the fallen litter, while N, P and Ca were released very slowly. Fallen litter was submerged only in the spring and early summer. The same authors suggested that leaching from the standing litter may also remove nutrients in the first weeks after shoot death.

Mason and Bryant (1975), in a study of decomposition of Phragmites communis Trin. and Typha angustifolia L., found that Na, K, Mg and P were leached out of plant material during the first month of the experiment and then remained constant. The Ca level showed less change, and the nitrogen level increased, largely due to microbial activity.

These observations support, in general, the results of nutrient concentration of old Typha latifolia sampled in April in Dover marsh.

Glyceria grandis, sampled in Cootes Paradise marsh, produced the highest aboveground biomass (Table 24).

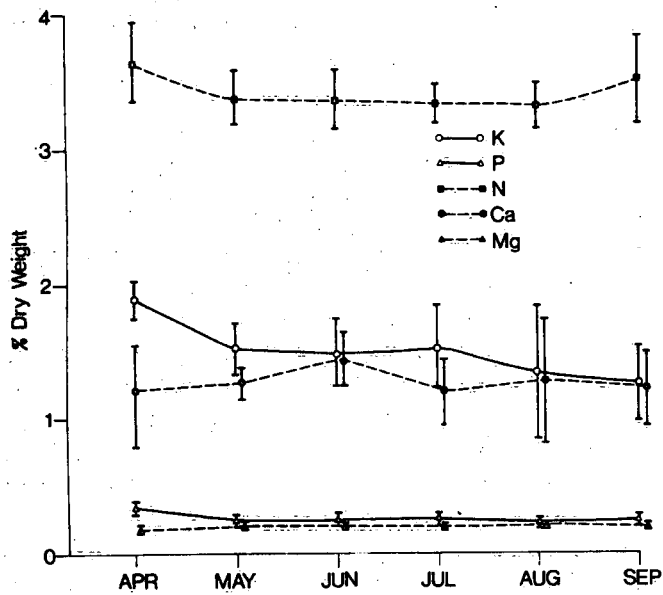The aboveground biomass of Glyceria grandis, growing in the West Pond and Desjardins Canal areas,

Figure 6. Nutrients in *Nymphaea odorata* (Big Creek, Dover, Balmoral, St. Lukes and Johnston Bay marshes).
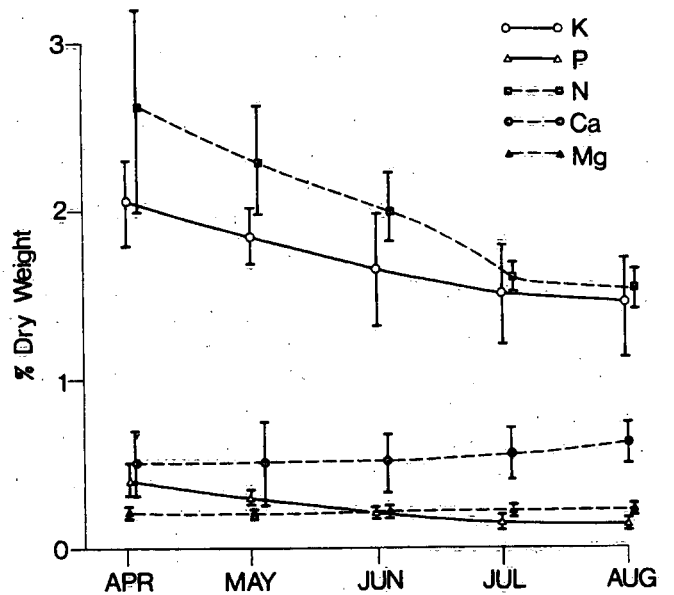

Figure 8. Nutrients in *Glyceria grandis* (Cootes Paradise).
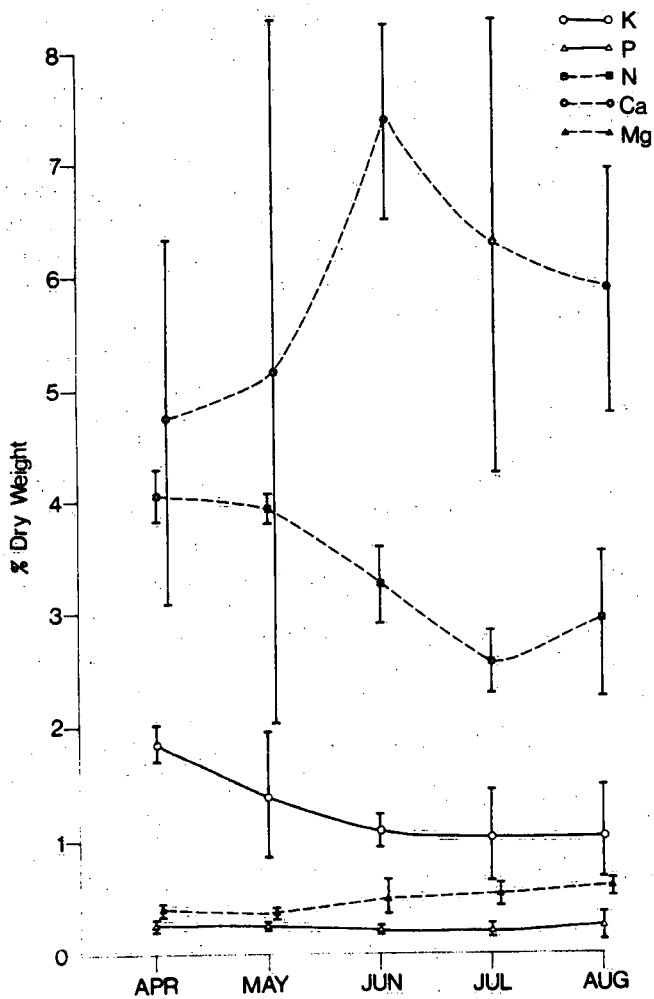

Figure 7. Nutrients in *Myriophyllum heterophyllum* (Big Creek, Dover, Balmoral, St. Lukes and Walpole Island marshes).
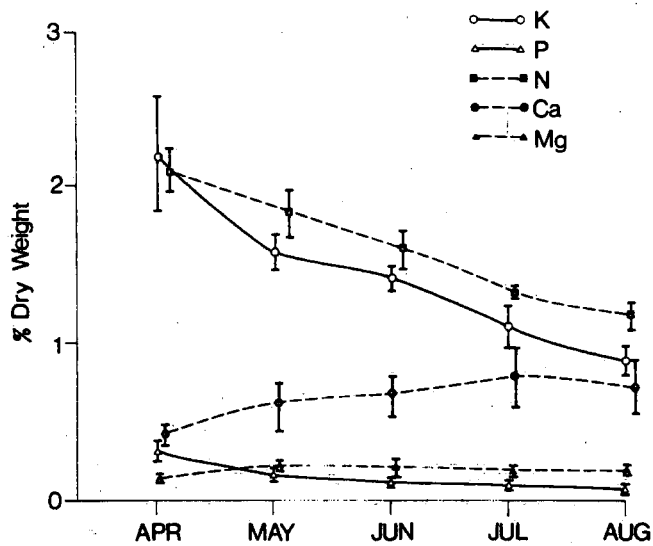
Figure 9. Nutrients in *Carex lacustris* (Big Creek, Balmoral, St. Lukes and Johnston Bay marshes).
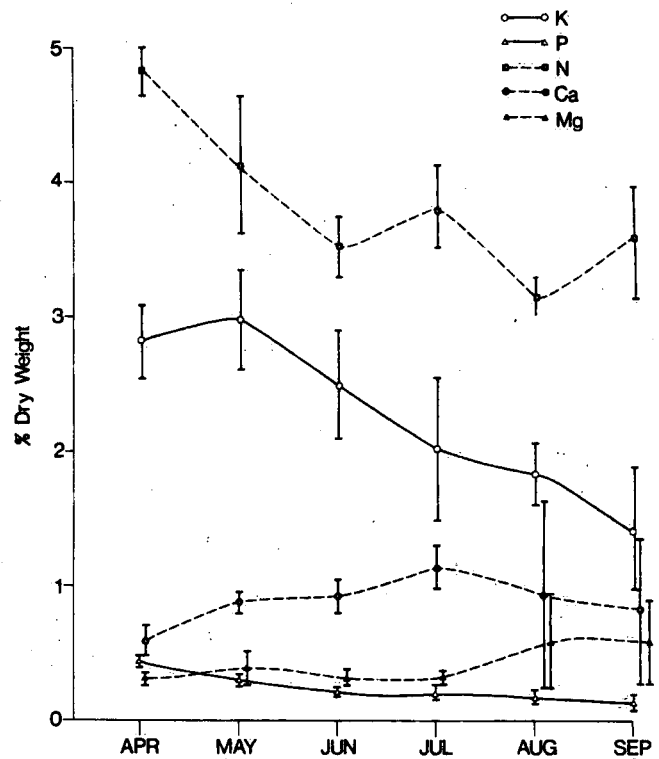

Figure 11. Nutrients in *Pontederia cordata* (Big Creek, Dover, Balmoral and St. Lukes marshes).

increased eight times during the period of April to July and only five and half times in the Long Valley area. The macronutrient uptake per square metre of stand area increased with augmented rates of the net production. The percentage of the macronutrient content per dry weight of plant was higher in the early phase of shoot growth in April than in July (except for Ca in the Long Valley and Desjardins Canal areas), but the total nutrient uptake per square metre was much higher in July than in April for plants from all three localities. The shoot standing crop yield affected the total uptake (grams per square metre) of macronutrients by *Glyceria grandis* at each sampling station (Mudroch and Capobianco, 1979).

Typha latifolia yielded the highest aboveground biomass in Dover marsh, where this plant was the dominant species. In the rest of the marshes, *Typha latifolia* builds stands of variable sizes.

The highest concentration of nutrients in the water pumped into Dover marsh could have fertilizing effects on the biomass production and on species composition. However, the aboveground biomass production of the sampled species was generally in the same range as that shown by other authors (Boyd and Hess, 1970; Dykyjova and Pribil, 1975; Dykyjova, 1978).

Figure 10. Nutrients in *Typha latifolia* (Big Creek, Dover, Balmoral, St. Lukes and Johnston Bay marshes).
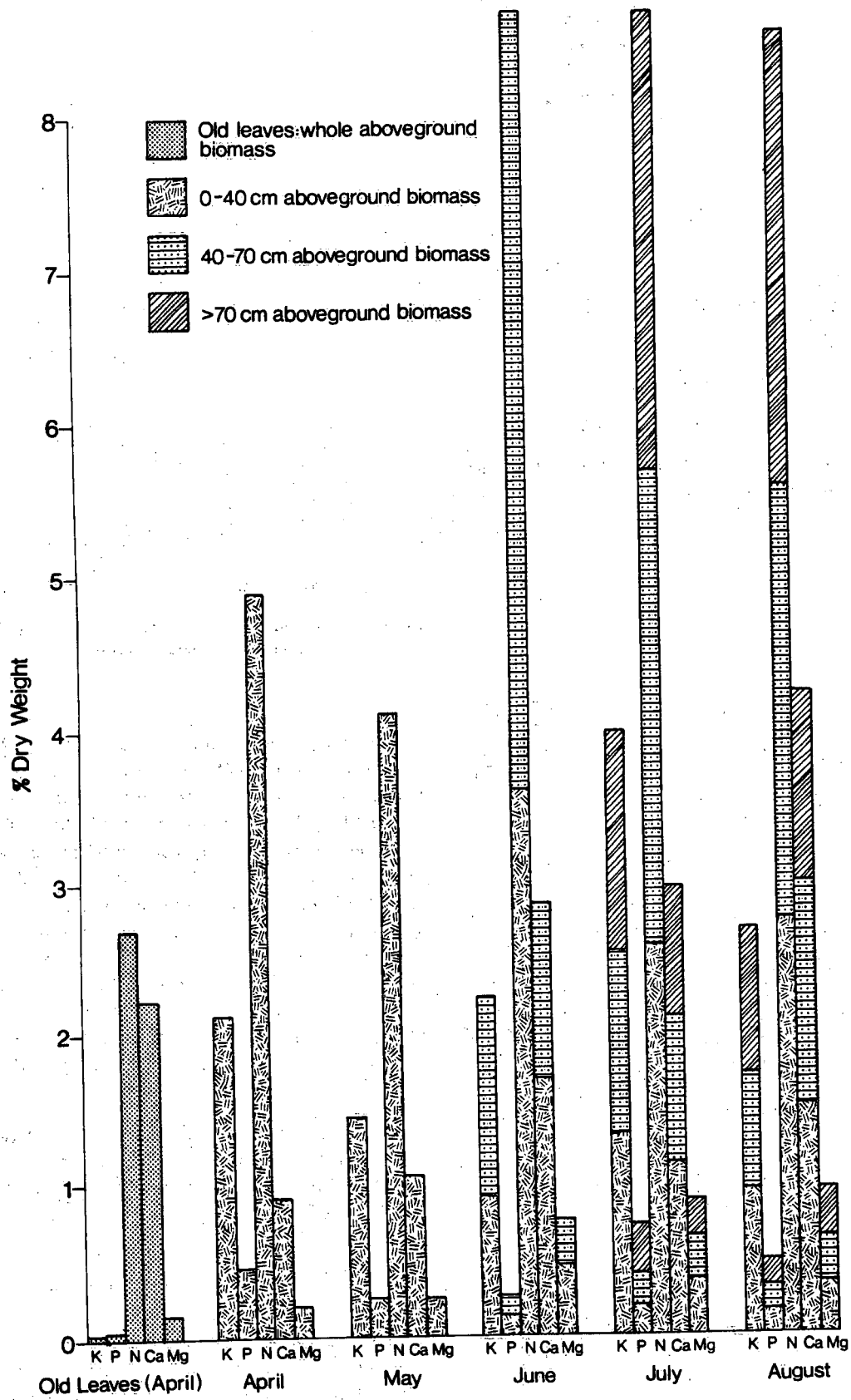
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Figure 12. Nutrients in *Typha latifolia* (Dover marsh).

Metal concentrations in the aboveground biomass of sampled macrophytes in the stage of maximum development are shown in Table 25. The largest amounts of Pb, Cr, Ni, Cd, Co and Cu were accumulated by the submerged macrophyte *Myriophyllum* sp. from all of the marshes investigated, by the submerged macrophyte *Chara* sp. from Dover, St. Lukes and Balmoral marshes and by the floating-leaved macrophyte *Lemna minor* from Cootes Paradise marsh. Generally, the accumulation of metals in plants varied from species to species and showed a complex relationship with the metal concentrations in sediments (Mudroch and Capobianco, 1978). Correlation was found between Ca and Pb, and between Cu, Ni and Cr concentration in macrophytes collected at Big Creek marsh. This finding suggests the possibility of adsorption of these metals by the $CaCO_3$ deposits on the surface of the submerged macrophytes (Mudroch, 1979).

Table 25. Metal Concentrations in Aboveground Biomass of Macrophytes at Maximum Development

Species	Obtained at marsh*	Statistics	Dry weight ($\mu g\ g^{-1}$)						
			Pb	Zn	Cr	Ni	Cd	Co	Cu
Myriophyllum sp.	1,2,3,4,5,6	Range	11-45	11-36	2-40	4-15	<0.5-2.5	<1-10	3-9
		$\bar{x}$	24.8	20.1	9.3	8.5	1.5	6.1	5.5
		$s_{\bar{x}}$	16.5	12.8	8.5	4.9	0.7	3.9	2.1
Chara sp.	2,3,4	Range	20-47	10-19	1-8	8-16	2.5-4.0	7-16	5-6
		$\bar{x}$	35.1	15.0	4.5	10.9	3.2	12.8	5.3
		$s_{\bar{x}}$	13.8	4.1	3.4	4.2	0.8	4.8	0.8
Lemna minor	6	Range	28-190	60-165	23-40	10-16	<0.5-3.0	6-18	9-26
		$\bar{x}$	70.5	90.3	31.4	13.7	2.3	13.2	16.4
		$s_{\bar{x}}$	60.8	72.8	15.9	6.8	0.7	4.1	7.2
Nymphaea odorata	1,2,3,4,5,6	Range	3-6	10-17	—	1-6	—	1-3	1-3
		$\bar{x}$	4.5	13.4	<1	3.2	<0.5	1.8	1.9
		$s_{\bar{x}}$	0.6	2.6	—	2.5	—	0.8	0.9
Pontederia cordata	1,2,3,4,5	Range	4-6	15-22	2-4	1-3	—	<1-2	2-3
		$\bar{x}$	4.8	18.4	2.4	1.6	<0.5	1.3	2.3
		$s_{\bar{x}}$	1.3	2.3	0.8	0.7	—	0.4	0.3
Typha latifolia	1,2,3,4,5	Range	3-6	7-20	<1-6	<1-5	—	<1-3	<1-6
		$\bar{x}$	3.6	13.5	2.4	2.6	<0.5	1.4	2.8
		$s_{\bar{x}}$	0.9	5.4	2.1	1.6	—	0.8	1.1
Lythrum salicaria	2,3,4,5	Range	4-8	17-35	<1-8	2-9	—	1-3	2-4
		$\bar{x}$	4.8	26.8	3.2	3.8	<0.5	1.8	3.6
		$s_{\bar{x}}$	2.3	11.2	2.6	3.1	—	1.9	2.4
Carex lacustris	1,2,3,4,5	Range	3-4	22-31	<1-2	1-2	—	1-2	2-3
		$\bar{x}$	3.6	27.8	1.4	1.4	<0.5	1.6	2.4
		$s_{\bar{x}}$	0.4	5.1	0.5	0.2	—	0.3	0.3
Glyceria grandis	6	Range	3-5	14-17	2-3	2-3	—	1-2	2-6
		$\bar{x}$	4.2	15.3	2.4	2.1	<0.5	1.6	3.8
		$s_{\bar{x}}$	1.1	1.2	0.3	0.2	—	0.2	1.9

*Marsh: 1 — Big Creek
2 — Dover
3 — Balmoral
4 — St. Lukes
5 — Walpole Island
6 — Cootes Paradise

Discussion

SEDIMENTS

As briefly described in the section "Study Area," the soils of the study areas are of similar origin; they are mostly derived from unconsolidated material deposited during glacial times over bedrock. These soils contributed to the geochemical composition of bottom sediments in all of the marshes investigated. Typically, the bottom sediments in the marshes studied are submerged mineral soils, with pH ranging between 6.9 and 7.2 and more than half of the particles of the silt size (2-63 μm). In the sediment from the Walpole Island area, which is influenced by the coarser material of the St. Clair River delta, more than half of the particles are larger than 63 μm (sand size). In Table 26, concentrations of organic matter and some major elements and metals in temperate region mineral surface soils, marsh sediment and Great Lakes sediments are compared. Because of the high biological activity in the marshes these sediments are strongly enriched by organic C and N, and slightly by P, with respect to the Great Lakes bottom sediments and soils. The K and S concentrations are similar to those found in lake sediments, and the S concentrations are higher than in soil. The Ca concentration is higher in marsh

sediments. Wetzel (1960) studied deposits of carbonate compounds on the vegetative structures of macrophytes in four lakes in Michigan. The pH of the water in these lakes ranged between 8.39 and 8.78. He found the greatest $CaCO_3$ encrustation on submerged plants. This $CaCO_3$ encrustation was induced by photosynthetic utilization of CO_2 and bicarbonate from the water by the macrophytes and epiphytic algae (Wetzel, 1975). The high Ca concentration in marsh sediment probably originated from $CaCO_3$ precipitation on the plants.

The most important difference between the terrestrial soil and the marsh sediment is the conversion of the soil to an anaerobic environment with limited oxygen concentration. Chemical compounds present in an oxidized form in terrestrial soil are reduced by bacterial activity under anoxic conditions. In the Great Lakes sediment, a thin oxidized or aerobic surface layer is present at the sediment-water interface (0-2 cm) as well as an underlying reduced or anaerobic layer (Kemp et al., 1977). In marsh sediments, where oxygen may be occasionally depleted at the sediment-water interface, the surface aerobic layer is very thin or nonexistent. The Eh values in all of the sediment profiles collected in the marshes investigated showed reduced

Table 26. Total Amount of Organic Matter and Major Elements in Temperate Region Mineral Surface Soils, Surface Sediment of Marshes Investigated and Great Lakes Surficial Sediment

Parameter	Percent dry weight		
	Temperate region mineral surface soils*	Surface sediment of marshes investigated	Great Lakes surficial sediment
Organic matter	0.40–10.00	2.83–30.17	0.00–9.03†
N	0.02–0.50	0.09–2.15	0.03–0.71†
P	0.01–0.20	0.02–0.30	0.09–0.22‡
K	0.17–3.30	1.40–3.20	1.36–3.04§
Ca	0.07–3.60	1.20–15.00	1.02–5.89‡
Mg	0.12–1.50	0.96–2.61	1.30–2.52§
S	0.01–0.20	<0.05–0.46	0.04–0.46‡

* Buckman and Brady (1969)
† Kemp (1971) for Lakes Huron, Erie and Ontario
‡ Kemp and Thomas (1976), surface sediments (0-1 cm) of Lakes Huron, Erie and Ontario
§ Kemp et al. (1977), surface sediments (0-2 cm) of Lakes Huron, Erie and Ontario

conditions, particularly in the sediment section from 10 to 20 cm. This could be due to the decomposition of organic material and the firmer consistency of this sediment layer. The top sediment from 0 to 10 cm was softer and occasionally aerated by disruption and mixing owing to wind and wave action in the shallow marsh areas. A very thin layer (1-2 mm) of the brown oxidized ooze was observed on top of the sediment at many of the sampling stations. This layer, however, was too thin to permit the measurement of Eh values. The redox potential in the marsh sediment affects the decomposition of organic matter, which is slower under anaerobic conditions and not as complete as under aerated conditions (Isirimah and Keeney, 1973; Patrick and Delaune, 1977). Under low oxygen tension, anaerobic organisms are more active and humification processes prevail; under high oxygen tension, high respiration of aerobic population accompanies the full mineralization of organic substrates (Ulehlova, 1978).

Metals

The characteristics of the organic matter and redox system conditions in soils, and marsh and lake sediment affect not only the difference in chemical forms in which various metals are present but also the difference in their availability to the biota and to the overlying water in aquatic ecosystems.

In Table 27, the concentrations of metals in marsh sediment are compared with those found in soil and Great Lakes surficial sediment. This table shows that Fe concentrations are generally similar in both marsh and soil and that both are lower than that of lake sediment.

Table 27. Metal Concentration Found in Common Soils, Surface Sediments of Marshes Investigated and Great Lakes Surface Sediment

| | Dry weight (μg g^{-1}) | | |
Parameter	Soils*	Surface sediments of marshes investigated	Great Lakes surface sediment
Fe	5000–50 000	6000–51 000	36 500–55 200†
Mn	200–10 000	60–1 200	800–13 400†
Zn	10–250	14–383	154–600†
Cu	5–150	<1–47	43–109†
Co	1–50	1–15	16–46‡

*Buckman and Brady (1969)
† Kemp and Thomas (1976), surface sediments (0-1 cm) of Lakes Huron, Erie and Ontario
‡ Kemp et al. (1977), surface sediments (0-2 cm) of Lakes Huron, Erie and Ontario

The Mn concentration in marsh sediment was about one order of magnitude lower than that shown for the soil and lake sediment. The value for lake sediment given in Table 27 is for the surface section from 0 to 1 cm. In lake sediment, the Mn concentration is the highest because of the upward diagenetic migration and precipitation of this element at the oxidized sediment-water interface (Sozanski and Cronan, 1979). The Mn concentration in the Great Lakes sediment below the 1-cm layer is generally in the range between 500 and 1600 μg/g (Kemp et al., 1977). In the range of Eh values found in marsh sediment, Mn is present in soluble form in sediment interstitial water with generally uniform distribution within the sediment profile.

The Zn, Cu and Co concentrations are lower in the marsh sediment than those in the Great Lakes surficial sediments. This difference is probably due to anthropogenic loading of these elements to the lakes (Kemp and Thomas, 1976) and has less effect on the coastal marshes. The Cu and Co concentrations in the marsh sediments were lower and Zn concentrations slightly higher than those of the soil.

Enrichment of surface sediment by some of the metals investigated was observed in few marshes. The Pb concentration increased toward the surface in most of the sediments. The Zn and Cu increase at the sediment surface was observed in Dover, Balmoral and St. Lukes marshes and was ascribed to past and present intensive hunting activities in the marsh.

Recent discharge of Hg from industrial sources into the St. Clair River system was responsible for the elevated Hg levels in the surface sediment of some stations in the Johnston River area (Mudroch and Capobianco, 1977).

A correlation between concentration of organic C and the trace elements investigated in marsh sediment is shown in Tables 28 and 29. High positive correlations were found between organic C and Pb, and organic C and Cr in vertical profiles and surface sediment of Cootes Paradise and Dover, Balmoral and St. Lukes marshes, and only in vertical sediment profiles of Big Creek marsh. Positive correlation was observed between organic C and Zn in the vertical sediment profile and surface sediments at Dover, Balmoral and St. Lukes marshes, and between organic C and Cu in the surface sediments at Dover, Balmoral and St. Lukes marshes.

Kemp et al. (1976) found high positive correlation between organic C and Pb, Zn, Cd and Cu in sediment cores from Lake Erie. They assumed that this correlation might be indicative of complexing and/or adsorption by organic matter or might be an accidental relationship

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Table 28. Correlation Coefficients Showing Degree of Linear Relationship between Organic C and Selected Parameters in Vertical Sediment Profiles

Marsh	Org. C:TN	Org. C:P	Org. C:S	Org. C:Pb	Org. C:Cr
Cootes Paradise (n = 24)	0.965*	0.705*	0.954*	0.844*	0.868*
Big Creek (n = 6)	0.994*	Insignificant	0.990*	0.997*	0.951†
Dover, Balmoral and St. Lukes (n = 22)	0.993*	Insignificant	Insignificant	0.945*	0.660*
Johnston Bay (n = 7)	0.983	Insignificant	0.968	Insignificant	Insignificant

*Significance level = 0.01
†Significance level = 0.05

Table 29. Correlation Coefficients Showing Degree of Linear Relationship between Organic C and Selected Parameters in Surface Sediments (depth of 0-8 cm)

Marsh	Org. C:TN	Org. C:P	Org. C:S	Org. C:Pb	Org. C:Cr
Cootes Paradise (n = 5)	0.989*	0.942†	0.941†	0.942†	0.987*
Big Creek (n = 6)	0.997*	Insignificant	0.721†	Insignificant	Insignificant
Dover, Balmoral and St. Lukes (n = 7)	0.992*	0.804†	0.879*	0.869†	0.808†

*Significance level = 0.01
†Significance level = 0.05

reflecting increased anthropogenic loading with time paralleled by increased nutrient supply and associated primary productivity in the lakes. Similar processes can be expected to occur in the marsh sediment. The high organic matter content in marsh sediment, however, is associated with the high biological productivity of the marsh and has no relationship to anthropogenic loading of metals to the marsh. Therefore, the complexing and/or adsorption of metals by organic matter in the marsh should be higher than those of lake sediment. Since no investigation of the metal forms in the marsh sediments has yet been undertaken, these suppositions remain unconfirmed.

Nutrients

A high positive correlation between organic C and TN concentrations was observed in the vertical sediment profiles and surface sediments collected in all of the marshes (Tables 28 and 29). This finding is in good agreement with Boyd (1970a) and Klopatek (1975), who have shown that N content of the marsh soil is positively and highly correlated with organic matter content and that N is released only through mineralization. Analysis of bottom sediments from Lakes Ontario, Erie and Huron showed that quantity of N to be directly proportional to the organic C content (Kemp, 1971).

Positive correlation between organic C and TP concentration was observed in vertical profile and surface sediment samples obtained from Cootes Paradise and in surface sediments of Dover, Balmoral and St. Lukes marshes. The sediments, especially those high in organic matter, are known to act as sinks, particularly for overlying waters rich in inorganic P (Kramer et al., 1972; Syers et al., 1973; Patrick and Khalid, 1974). The situation which occurred at Cootes Paradise is typical of this; the site received high P concentration from the sewage treatment plant effluent. A positive correlation existed between organic C and S concentrations in vertical sediment profiles from Cootes Paradise, Big Creek marsh and Johnston Bay marsh, and in surface sediment from Cootes Paradise, Big Creek, Dover, Balmoral and St. Lukes marshes. This observation is supported by the work of Boyd (1970a), who found a correlation between organic matter and reserve sulphur (total sulphur minus sulphate sulphur) by studying the characteristics of aquatic soils. The concentrations of S in various aquatic macrophytes given by Boyd (1970b) and Polisini and Boyd (1972) ranged between 0.11% and 0.59% and those of algae between 0.15% and 1.6% (Healey, 1973). Much of the S in marsh sediment probably originates from decaying macrophytes and algal tissue in which it had been already associated with organic C.

The pH of the marsh sediment was not affected by the organic matter accumulation and was similar to that of the Great Lakes sediment. The presence of the calcium carbonate in the marsh sediments maintains the pH in the neutral range.

WATER

Many complex biological and chemical processes in the marsh ecosystem greatly affect nutrient concentration in water. Very little is known about the microorganisms in a marsh ecosystem. Microbial activities in a marsh, however, control the cycling and availability of mineral nutrients in water, sediment, detritus and plants and are closely related to redox properties of the environment. Complex enumeration and description of microbial populations are impossible because wetlands consist of numerous different microhabitats, each of which forms a peculiar biological-chemical-physical unit that supports a specific microbial community (Day, 1973). During a study of populations of decomposers in the littoral ecosystem of a South Moravian fish pond, Ulehlova (1978) found that various remnant macrophyte species were colonized by microbial populations of different density and species diversity. The microbial populations displayed more or less specific kinds of succession and specific seasonal patterns in each kind of material.

Prentki *et al.* (1978) found that macrophyte translocation of nutrients is an important source of nutrient internal loading and that, in marshes without major surface water inputs, seasonal accumulation and abandonment of nutrients above the soil interface is likely to be the dominant term in nutrient budgets. However, the importance of a macrophyte nutrient pump is difficult to assess because of the lack of information about other non-macrophyte components in the marsh nutrient cycle.

A number of studies have been conducted to determine the effect of leaching and decomposition of dead plant tissue on nutrient concentration in marshes. Davis and Van der Valk (1978) studied standing and fallen litter decomposition in prairie glacial marshes. They discovered that losses from the standing litter are primarily the result of fragmentation that occurs during the first winter and spring. They found that leaching from the standing litter may also remove nutrients in the first few weeks after shoot death. In the fallen litter, K, Na and Mg were released very rapidly, while N, P and Ca were released more slowly, and Al and Fe were accumulated in fallen litter of all species. The release and uptake of nutrients by fallen litter varied from species to species and from site to site, for the same species. Davis and Van der Valk further constructed models of the pattern of nutrient flow through litter of *Typha glauca* and *Scirpus fluviatilis* stands. These models revealed the seasonal patterns in uptake and release of nutrients and the large variability in the patterns of litter decomposition between species.

Godshalk and Wetzel (1978) studied the decomposition of five species of littoral macrophytes and found that temperature was the most important factor influencing the rates of decomposition and the conversion of particulate matter to dissolved organic matter, while O_2 concentration controlled the efficiency of decomposition and the conversion of dissolved organic matter to CO_2. The interaction of these two environmental parameters produced a continuum of decomposition rates, ranging from very slow during cold anaerobic conditions to rapid under warm aereated conditions. Decomposition processes were also affected by the tissue structure and morphology of the plants tested. The same authors pointed out the significance of long-term effects on sedimentation and system morphology as a result of the accumulation and deposition of undecomposed material.

Gallagher (1978) reviewed studies of decomposition in freshwater wetlands and suggested that, as more of the descriptive work becomes complete in the wetland systems, research in those systems will also naturally move in that direction. However, any changes in marsh species composition and vegetation density will bring about changes in the nutrient cycling through the marsh ecosystem.

Despite differences in hydrological regime at each of the marshes, the present study was designed to obtain basic information on concentration status and seasonal changes of nutrient concentration in water of the studied marshes. The study was limited to an investigation of N and P concentrations, since these are two of the major important nutrients in eutrophication of marshes and lakes.

Nutrients

Concentrations of P and N in water at each marsh are compared with those available for marsh inflow or for adjacent water bodies (which may receive the marsh water) or for a water body of the same area (Fig. 13).

Nitrogen

The largest differences were observed between the concentrations of various nitrogen forms present in marsh, lake and stream water. Most of the nitrogen present in the marsh water was in the form of organic nitrogen (with the exception of Cootes Paradise which received high concentrations of NH_4-N from sewage treatment effluent).

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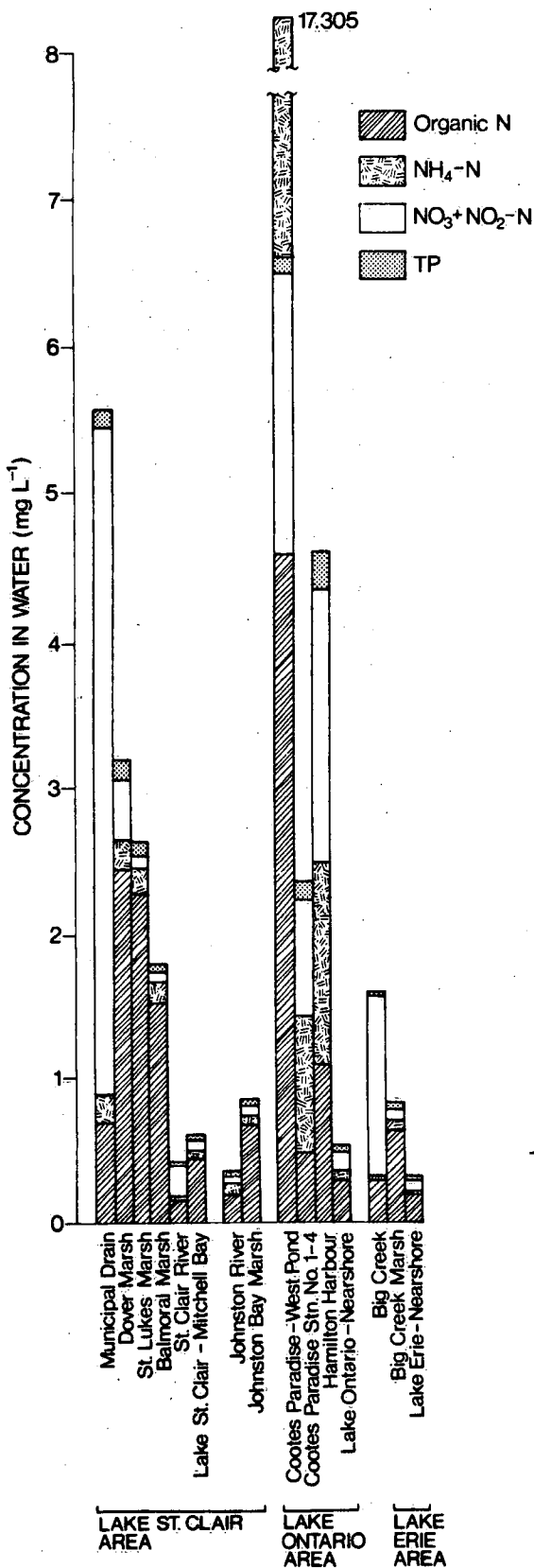
The capacity of a marsh to convert the NO_3-N into organic N seems to be affected by the amounts of NO_3-N received by the marsh via the inflow water and by the marsh area and species composition within the marsh. This observation is in good agreement with that of Engler et al. (1976), who demonstrated that flooded swamps and coastal marsh areas of Louisiana had a high capacity for removal of NO_3^- and that the NO_3^- loss did not take place in the floodwater, but was dependent on the NO_3^- moving downward into the anaerobic soil layer.

Ammonia is a good source of nitrogen for plants, and many plants can use it at alkaline pH values. Most algae and macrophytes, however, grow better with nitrate as their nitrogen source, even though nitrate must be reduced to ammonia (Wetzel, 1975). Wetzel and Manny (1972) found that 95% to 98% of the dissolved organic nitrogen and carbon secreted by some aquatic macrophytes consists of simple and readily decomposable organic material. The capability of suspended carbonate particles to adsorb aminoacids and large proteins and polysaccharides was also demonstrated by Wetzel and Allen (1970), Suess (1968) and Chave (1970). Settling of carbonate particles transports these compounds to the sediments.

The interpretation of changes of various nitrogen species is extremely complex because the rates of N release from various macrophytes present in marshes as well as the rates of mineralization and immobilization of N, and of nitrification and denitrification within the marsh ecosystem are unknown. Organic N is likely the primary form of N which can be transported out of the marshes. Since the composition of organic nitrogen compounds present in marsh water was not investigated, however, conclusions about the utilization of this organic nitrogen, if released to the nearshore zone of Lakes Erie, Ontario and St. Clair, could only be based on information available from literature.

Figure 13. Nitrogen and phosphorus in water. St. Clair River — mean value of depth composite samples at Port Lambton, sampling period from June to September 1972; n = 60 (Ontario Ministry of the Environment, 1972). Hamilton Harbour — mean values of surface samples, sampling period from June to October 1975; n = 40 (Ontario Ministry of the Environment, 1977). Lake Ontario, nearshore — mean values for six stations in vicinity of Hamilton Harbour, sampling period from May to October 1972; n = 60 (Ontario Ministry of the Environment, 1972). Lake Erie, nearshore — mean values for six stations located from Port Dover to the eastern end of Long Point, sampling period from May to October 1972; n = 30 (Ontario Ministry of the Environment, 1972).

The rate of nitrification of organic nitrogen originating in the marshes will depend on the nature of compounds and their resistance to bacterial degradation. Evidence indicates that algae can metabolize dissolved organic matter (Lund, 1965; North and Stephens, 1967; Stephens et al., 1969) and can use either organic or inorganic forms of N (Keeney, 1973). The distribution of the organic nitrogen released from the marshes would further depend on the hydrological regime of the specific nearshore zone.

Phosphorus

The differences between TP concentration and lake water were smaller than those between equivalent nitrogen concentrations (Tables 20 to 23).

The sorption of P by oxidized layer at the sediment-water interface and the role of Fe-components, such as amorphous oxides and hydroxides of Fe, in controlling the levels of dissolved inorganic P in soils and sediments are well documented (Williams et al., 1971; Syers et al., 1973; Patrick and Khalid, 1974). In addition, the positive correlation between organic C and TP concentration in sediment, collected in some of the marshes, suggests adsorption of P on sediment organic matter. Studies by Nichols and Keeney (1973) on N and P release from decaying water milfoil showed that N and P, which were present in the plants, were rapidly released in the absence of sediment-water interactions. However, the presence of sediment altered the decomposition rate of the milfoil by supplying inorganic N, and the sediments studied readily sorbed organic N and inorganic P produced by plant decomposition. Jewell (1971), in a study of aquatic weed decay, found that during the early stages of decomposition, soluble nitrogen and phosphorus concentrations usually remained constant or decreased and that this decrease was probably the result of uptake of nutrients by rapidly growing decomposers. The maximum regeneration rates of N and P were observed five to ten days after the start of decomposition. The same author suggested that the increase of N and P in water after plant decay calculated by his method may not be realized in ponds because of competing reactions such as denitrification and phosphorus speciation.

Input of Nutrients from Marshes to the Lakes

Based on an assumed complete mixing of discharged water and receiving water, it was calculated that a full discharge of Dover marsh into Lake St. Clair would increase the organic N content by about 0.278 mg L^{-1} and the TP by 0.012 mg L^{-1} in Lake St. Clair. A complete discharge of Cootes Paradise water into the Lake Ontario nearshore zone in the vicinity of Hamilton Harbour (surface area of the zone was chosen 3 km × 3 km) would

increase the organic nitrogen by 0.007 mg L^{-1} and TP by 0.002 mg L^{-1}. A complete discharge of Big Creek marsh into inner Long Point Bay of Lake Erie would increase organic N concentration by 0.004 mg L^{-1} and TP concentration by <0.001 mg L^{-1}.

By additional calculations of TP and organic N loading from each marsh to the adjacent water body, assuming that the complete discharge would extend over one year, the following results were obtained: 0.001 g of TN/m^2/yr and <0.001 g of TP/m^2/yr from Dover marsh to Lake St. Clair, <0.001 g of TN/m^2/yr and <0.01 g of TP/m^2/yr from Cootes Paradise marsh to Lake Ontario nearshore zone (in the vicinity of Hamilton Harbour), and 0.017 g of TN/m^2/yr and 0.0008 g of TP/m^2/yr from Big Creek marsh to inner Long Point Bay. These values are much lower than those given for permissible loading levels for TN and TP by Vollenweider (1968). However, any outlet from these marshes into the nearshore zone of the Great Lakes will enrich the lake water with organic N and, to a smaller extent, with TP. The amount of enrichment will depend on the quantity of water discharged, the rate and duration of the discharge, and the amount of mixing and circulation in the receiving nearshore zone.

The contribution of the marshes to the N and P loading to Lakes Ontario and Erie is presented in Tables 30 and 31. The calculation of the contribution from Big Creek marsh is based on the assumption that the residential time of the marsh water is less than four days with a discharge into Lake Erie. Because of the lack of the water quality data for Lake Ontario coastal marshes, the average N and P concentrations obtained during this study were used for the calculation. It is obvious that the marshes contribute very little to the nutrient loading of Lakes Ontario and Erie.

In Table 32, values of organic N and inorganic N and total P, as used by Wetzel (1975) to express the general relationship of lake productivity to average concentration of epilimnetic nitrogen, are compared with values obtained from the study marshes. The marsh values were derived from water quality monitoring data of the Ontario Ministry of the Environment (1972 and 1977). According to this comparison, Dover marsh and the West Pond of Cootes Paradise are hyper-eutrophic; Balmoral and St. Lukes marshes and the rest of Cootes Paradise are eutrophic to hyper-eutrophic; and Big Creek marsh and Johnston Bay marsh are meso-eutrophic to eutrophic. Differentiation of the marshes by this method is affected by the high concentration of organic N in the marsh water. When attempts have been made to determine the composition of dissolved organic nitrogen in marsh water, however, the concentration of biologically useful forms of N represented

Table 30. Sources of N and P to Lake Ontario (1976) (metric tonnes/yr $\times 10^{-3}$)

	Organic N	NH$_4$-N	NO$_3$ + NO$_2$-N	TP
Niagara River	101.72	18.78	47.75	5.56
Municipal	3.25	7.71	1.61	1.17
Industrial	0.50	0.55	0.04	0.12
Tributaries	28.48	7.01	13.61	2.42
Atmospheric	10.69	8.21	4.32	0.44
Total load	144.64	42.26	67.33	9.71
Cootes Paradise*	0.05	0.10	0.09	0.02
Percent of total load of N and P to Lake Ontario	0.03	0.24	0.13	0.21
Lake Ontario coastal marshes*	4.59	0.19	0.11	0.05
Percent of total load of N and P to Lake Ontario	3.17	0.45	0.16	0.51

Data sources: The data for all sources except the Lake Ontario coastal marshes are from Wilson (1978); the data for the Lake Ontario coastal marshes are from Environment Canada (1977)
*Calculated for a complete discharge occurring 100 times per year

Table 31. Sources of N and P to Lake Erie (1976) (metric tonnes/yr $\times 10^{-3}$)

	Organic N	NH$_4$-N	NO$_3$ + NO$_2$-N	TP
Detroit River	60.61	16.67	53.21	7.99
Municipal	1.85	4.10	1.18	1.11
Industrial	0.01	0.10	0.02	0.34
Tributaries	46.13	14.94	68.94	5.92
Atmospheric	9.50	8.50	17.00	0.77
Total load	118.10	44.31	140.35	16.13
Big Creek marsh*	0.20	0.02	0.02	0.01
Percent of total load of N and P to Lake Erie	0.17	0.05	0.01	0.06

Data source: Fraser and Wilson (1980).
*Calculated for a complete discharge occurring 100 times per year.

only a small fraction and it was assumed that the major part of the organic N was refractory and therefore of little use to consumers (Valiela and Teal, 1978).

Since Balmoral, Dover, St. Lukes and Big Creek marshes have no separate outlets, the nutrients from input were accumulated within the marshes over many years. To show the capacity of the marshes to utilize nutrients from water, the input of total N into Dover and Balmoral marshes over 30 years was compared with the present total N concentration in water. Similar calculations were carried out for Big Creek marsh, assuming the time of input to be 50 years and the quantities of total N to be equal every year. Results of the calculations are shown in Table 33. Cootes Paradise data are not included in this comparison, since, as already shown, the flow through the West Pond reduced the total N concentration by about 40%.

Table 32. General Relationship of Lake Productivity to Average Concentration of Epilimnetic N and P

Parameter	Ultra-oligotrophic	Oligo-mesotrophic	Meso-eutrophic	Eutrophic	Hyper-eutrophic
Organic N (mg m^{-3})	<200*	200–400*	400–700*	700–1200*	>1200†
Inorganic N (mg m^{-3})	<200*	200–400* St. Clair River† Lake Ontario† (nearshore zone in Hamilton Harbour vicinity) Lake Erie† (nearshore zone, Port Dover to Long Point end)	300–650* Johnston River Lake St. Clair (Mitchell Bay) Big Creek marsh Johnston Bay marsh	500–1500* Big Creek	>1500* Cootes Paradise Hamilton Harbour‡ Municipal drain Dover, Balmoral and St. Lukes marshes
Total P (μg L^{-1})	<5*	5–10*	10–30* Johnston River Lake Erie† (nearshore zone Port Dover to Long Point end) Lake St. Clair (Mitchell Bay) Lake Ontario† (nearshore zone in Hamilton Harbour vicinity) Big Creek	30–100* Balmoral and St. Lukes marshes Johnston Bay marsh Cootes Paradise (stations 1–4) Big Creek marsh	>100* Dover marsh Municipal drain Cootes Paradise (West Pond) Hamilton Harbour‡

*Wetzel (1975)
†Ontario Ministry of the Environment (1972)
‡Ontario Ministry of the Environment (1977)

DeJong (1976) studied purification of wastewater with the aid of rush and reed ponds and found that the purification of sewage is based on two phenomena: (1) infiltration into the soil and (2) uptake of nutrients by microorganisms and plants in the pond. It was clear that the retention time of water in the pond affected the purification results. Seidel (1976) showed that the relative

Table 33. Total Nitrogen Input to Dover, Balmoral and Big Creek Marshes Compared with Total Nitrogen Concentration in Water

Marsh	Input of TN (kg)	Source of input	Present concentration of TN in marsh water (kg)
Dover (30 yr)	50 400	Municipal drain	2374
Balmoral (30 yr)	3 518	Lake St. Clair	1243
Big Creek (50 yr)	67 400	Big Creek	1685

quantity of inorganic matter absorbed by macrophytes of the same biotype in a given time period varied widely. This was due to various quantities of biomass produced and the ability of a plant to absorb inorganic matter in accordance with the characteristics of its environment.

The results of the present study are in good agreement with the observations of DeJong and Seidel. The degree of nutrient retention depends on the hydrological regime and species composition in each marsh. All of the marshes studied showed a capability of retaining nutrients and metals to varying degrees. A good correlation was observed between all forms of nitrogen in water and total N in sediment, and between TP in sediment and TP in water in Cootes Paradise (Table 34). No relationship between these parameters was observed in the other marshes. The high continuous input of nitrogen and phosphorus compounds from the sewage treatment plant to Cootes Paradise may be the reason for the high positive correlation between these two elements in sediment and water. The settling of suspended particles and the adsorption of nutrients by sediment particles as well as the utilization of plants contribute to the continuous increase of the N and P concentrations in the bottom sediments of Cootes Paradise.

Table 34. Correlation Coefficients Showing Degree of Linear Relationship between Nutrients in Water and Nutrients in Sediment in Cootes Paradise

TP sediment: TP water	TN sediment: $NO_3 + NO_2$-N water	TN sediment: NH_4-N water	TN sediment: TKN water
0.997*	0.877†	0.957†	0.910†

*Significance level = 0.01
†Significance level = 0.05
Note: No. of samples = 40

Metals

The concentration of metals in water samples, with the exception of Fe, Mn and Zn, was mostly under the detection limit or very low in all of the marshes. These three metals are referred to as micronutrients (Wetzel 1975). The average concentration of soluble Fe, Mn and Zn in world surface lakes and rivers is given by Livingstone (1963) as 40 μg L^{-1}, 35 μg L^{-1} and 10 μg L^{-1}, respectively. The mean values of Fe and Mn concentration in marsh water as well as those for Lake Erie, Lake St. Clair, Big Creek and the municipal drain water exceeded to various degrees the concentrations given by Livingstone.

It is well known that the pH and redox potential of surface waters and sediments are important to the regulatory processes affecting the solubility of heavy metals and their distribution among various geochemical forms. The reduction of insoluble Fe and Mn compounds releases certain quantities of these two micronutrients.

Several ferric compounds are reduced under the anaerobic conditions in a water-logged soil by respiring microorganisms (Patrick and Mikkelsen, 1971). Gotoh and Patrick (1974) have shown variations in concentration of readily available Fe over three orders of magnitude as a result of changes in pH and redox potential.

The investigation of the effect of dissolved O_2 on the chemical transformation of metals and nutrients, including Fe, Mn and Zn, by Khalid *et al.* (1978) indicated that changes in redox potential and pH were related to increasing O_2 concentrations. These strongly modified the distribution of trace metals in various chemical fractions as well as the solubility of trace metals in estuarine sediment. Redox potential had a very significant effect on the stability of four Zn and Cu chelates of EDTA (ethylenediaminetetraacetic acid) and DTPA (diethylenetriaminepentaacetic acid) in flooded soils (Reddy and Patrick, 1977).

The variability of Fe and Mn concentrations in the water of the marshes studied was probably controlled by the sediment redox potential and by the fluctuations of dissolved oxygen concentrations at each sampling station.

Local and seasonal variations in DO concentration in the marshes will evidently affect the concentration of metals in water. However other regulatory processes in the marshes that are not understood may influence the solubility and availability of metals to biota. The results of the present investigation showed that Pb, Ni, Cu, Cr, Cd, Zn, As and Hg were present in low concentrations in the marsh water. On the other hand, Fe and Mn concentrations exceeded those of Lake Erie and Lake St. Clair.

Dissolved Oxygen

The average monthly temperature values and dissolved oxygen concentrations in marsh water are shown in Figure 14. Since the marshes are shallow and well mixed by wind, the water temperature is affected directly by the air temperature. Temperature changes during the day were large, especially during summer months. Very often the differences in the temperature were as high as 7°C, with the lowest in the morning and the highest around 14:00. Changes in daily water temperature and wind action together with active photosynthesis of the macrophytes and sessile algae (attached to both macrophytes and sediments) likely assisted in keeping a relatively high dissolved oxygen concentration in the marsh water during the summer months. The high photosynthetic activity at West Pond (Harris and Bacchus, 1974) may be correlated with the relatively high dissolved oxygen concentration in Cootes Paradise No decrease of dissolved oxygen concentration was observed in the fall during decomposition of plants and algae in the marshes.

PLANTS

Large variations were found in concentrations of K, P, N, Ca, Mg and trace metals in the macrophytes collected at the marshes studied. The variations in plant chemical composition are in agreement with those found by Boyd (1978), within-site intraspecific, between-site intraspecific and interspecific. Boyd suggested that actual measurements of chemical composition should be made in studies requiring these data, since no average composition for an individual species or ecological grouping of species based on data from the literature would be reliable. Stake (1967, 1968) and Boyd and Hess (1970) found that correlation of soil and water nutrient concentrations with those found in emergent macrophytes was poor or nonexistent. Klopatek (1975) compared the changes in the amount of N and P in the aboveground and below ground standing crops and the level of nutrients in the soil in monotypic stands of
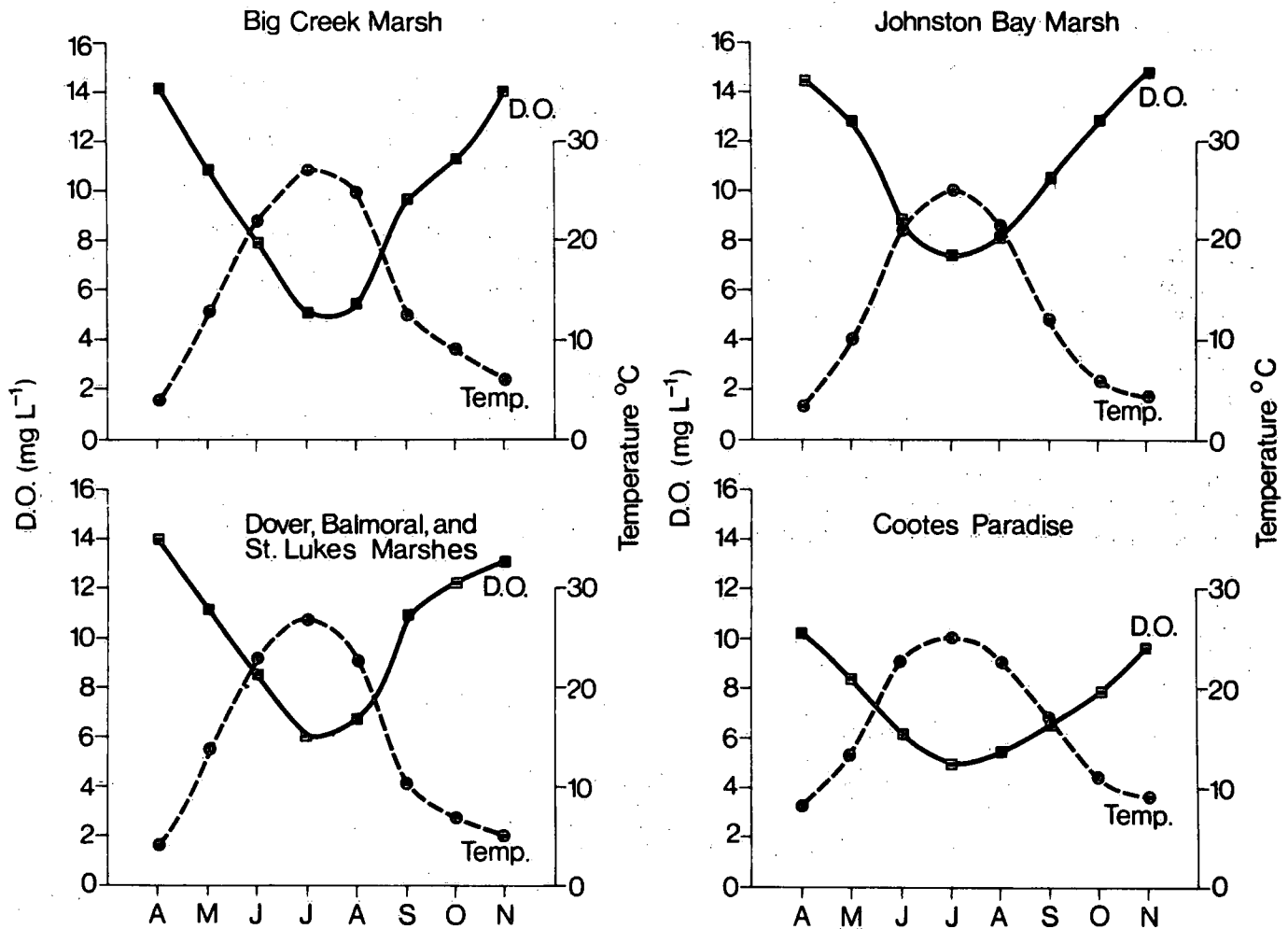
Figure 14. Temperature and dissolved oxygen changes.

Typha latifolia, Scirpus fluviatilis and *Carex lacutris*. He obtained highly significant correlation values for most parameters and concluded that the emergent macrophytes were acquiring their nutrients from the soil. Swindal and Curtis (1957), in studying submerged plants in Wisconsin lakes, found that changes in plant communities are related to changes in substrate.

A positive correlation (correl. coefficient = 0.932, no. of pairs = 6) was observed between the annual loading of total N to the marshes studied and the aboveground biomass production of *Typha latifolia*, sampled from stands at Dover, Balmoral, St. Lukes and Big Creek marshes, as well as of *Glyceria grandis*, sampled at Cootes Paradise. Sculthorpe (1967) stated that numerous aquatic plants, which tend to form extensive pure stands, ascend to their status early and attain a seasonal or permanent predominance. At a favourable site, one species may gain an early initiative and increase much faster than any competitor.

Species composition may have changed in Cootes Paradise, since, according to the vegetation map prepared by Kay (1949), this area was occupied by a mixed stand of *Typha* sp. and *Glyceria grandis*. At present, the area is completely occupied by *Glyceria grandis*.

The calculated input of N to each marsh, expressed in kilograms of total N per hectare per year, demonstrates the variation of nitrogen loading to each of the marshes studied (Table 35). In many examples, Jacobs (1975) showed that the increase of eutrophication not only increases the biomass productivity but also decreases the diversity. Very high nutrient loading to Cootes Paradise affected the macrophyte species composition in this area. In a study of chlorophyll and production in West Pond area, Harris and Bacchus (1974) correlated the biomass production of the algae *Scenedesmus quadricauda* to a perpetual supply of phosphorus and nitrate. This algae was also the dominant species throughout the season.

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Table 35. Loading of Total N to the Marshes	
Marsh	Kilograms of total N ha^{-1} yr^{-1}
Balmoral	0.6
Big Creek	1.7
St. Lukes	3.1
Dover	5.6
Cootes Paradise, West Pond	64 000
Cootes Paradise, rest of marsh	4 320

Among the three diked marshes investigated on Lake St. Clair, Dover marsh receives the highest amount of total N, which may be the reason for the dominance of *Typha* sp. in this area.

Submerged macrophyte samples at the marshes investigated accumulated more Pb, Cr, Ni, Cd, Co and Cu than the emergent plants. However, the concentration of these metals in submerged plants varied widely. The uptake mechanism of elements by submerged plants from water and sediment was studied by a number of investigators (Steeman Nielsen, 1951; Olsen, 1953; Lowenhaupt, 1956; Sutcliffe, 1962; Spence, 1967; Denny, 1972; Mayes *et al.*, 1977).

The correlation between Ca and the Pb, Cu, Ni and Cr concentrations in submerged macrophytes that were collected at Big Creek marsh suggests coprecipitation or adsorption of these metals by calcite deposited on the surface of the plants, but this area needs further investigation.

Summary and Conclusions

This study was initiated to evaluate the beneficial and/or detrimental effects of selected marshes peripheral to the Great Lakes in relation to water quality. Nutrient and trace element concentration changes in marsh water, the geochemistry of sediments, and nutrient and trace element uptake by marsh plants and their biomass production were investigated to characterize each marsh, to help assess the possible effect of the marsh on the water quality of the lakes, and to provide background information for further studies of the specific marshes.

Six marshes adjacent to the Great Lakes were selected for the study: Cootes Paradise on Lake Ontario; Big Creek marsh on Lake Erie; Dover, Balmoral and St. Lukes marshes on the northeast shore of Lake St. Clair; and the marshy area of the St. Clair River delta.

The water of the marshes investigated is under the influence of carbonate rocks and retains pH values of between 7.8 and 8.4. The sediments in all of the marshes studied were submerged mineral soils with pH ranging between 6.9 and 7.2 with more than half of the particles in the silt size (2-63 μm) fraction. The pH was not affected by the accumulation of organic matter, and a differentiation of the material into the soil horizons or layers was not observed.

Organic C, TN, TP and Ca concentrations in marsh sediment were higher than those found in the Great Lakes sediments. Products of the high biological activity contributed to the elevated organic C, TN and TP concentrations, and calcite deposits on the surface of macrophytes produced the enrichment of sediment by Ca.

The low redox potential of the bottom sediment, particularly of the layer from 10 to 20 cm, slowed down the organic matter decomposition and affected solubility of Mn and Fe.

The Zn, Cu and Co concentrations in marsh sediment were lower than those of the Great Lakes fine-grained surficial sediments, which are affected by the anthropogenic loading to the lakes. An enrichment by Pb, Zn and Cu observed at the surface sediment layer in some of the marshes may be the effect of hunting activities. Discharge of Hg from industrial sources into the St. Clair River system (during the early 1970's) was responsible for the elevated Hg levels found in surface sediments of the Walpole Island area. The positive correlation between organic C and a few of the metals investigated (Pb, Cr, Zn and Cu) in some of the marshes was ascribed to a possible complexing and/or adsorption of metals by organic matter.

A high positive correlation between organic C and TN was found in all of the marsh sediment samples. The positive correlation between organic C and TP observed in some of the sampled sediments was probably due to the adsorption of P onto the organic rich sediment, and the positive correlation between organic C and S was ascribed to the decomposition of algae and macrophytes, which contain relatively high quantities of S in their tissues.

Large differences were observed between the concentrations of various forms of N present in marsh, lake and stream water. Most of the nitrogen present in the marsh water was in the form of organic nitrogen. The sorption capacity of the sediment produced only slightly elevated TP concentrations in marsh water in comparison with adjacent lake water.

Concentrations of Pb, Cu, Cr, Ni, Cd, As and Hg in marsh water were generally very low (<0.001 mg L^{-1} for Pb, Cu, Cr, Ni, Cd and As; <5 x 10^{-5} mg L^{-1} for Hg). In some cases, the Fe and Mn concentrations exceeded those found in the Great Lakes. The low redox potential of sediment affected the availability of these two elements to the overlying marsh water.

Changes in daily water temperature and wind action, together with active photosynthesis of the macrophytes and sessile algae (attached to both macrophytes and sediments), likely assisted in keeping a relatively high dissolved oxygen concentration in the marsh water during summer months. No decrease of dissolved oxygen concentration was observed in the fall during decomposition of plants and algae. This was ascribed to the fast cooling of the shallow marshes during the fall months.

The nutrient input to the marshes affected the aboveground biomass production and the species composition in the marshes. Submerged macrophytes accumulated higher concentrations of Pb, Cr, Ni, Cd, Co and Cu than

the emergent macrophytes. However, the concentration of these metals in submerged plants varied widely. Positive correlation between Ca and the Pb, Cu, Ni and Cr concentrations found in the macrophytes suggested coprecipitation or adsorption of these metals by calcite deposited on plant surfaces.

All of the marshes studied showed a high capacity to retain nutrients and metals. The degree of this retention depends on the hydrological regime and species composition in the marsh. Generally, a marsh on a tributary stream to a lake would be beneficial by reducing the amount of nutrients transported into the lake and therefore minimizing the algal bloom. Various chemicals (metals, etc.) adsorbed on the fine particles suspended in the stream water settle in the marsh. For example, a 30% to 40% reduction of the TN and TP concentrations originating from a sewage treatment plant effluent was observed in Cootes Paradise marsh The reduction was related to the settling of suspended solids and to the biological activity in the marsh.

According to calculations, a complete discharge of the marshes into the adjacent lakes would contribute only negligible quantities of N and P in relation to the loadings from other sources. It was estimated that the discharge of Lake Ontario coastal marshes would contribute 3.17% of organic N, 0.45% of NH_4-N, 0.16% of NO_3 + NO_2-N, and 0.51% of TP to the total N and P loadings to Lake Ontario. However, local effects in the nearshore zone, into which each marsh would discharge, would be controlled by the hydrological regime of the receiving zone and would be site-specific.

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