A TWO YEAR STUDY OF THE HIGHER AQUATIC PLANT COMMUNITY IN A SECTION OF THE OTTAWA RIVER, CANADA, WITH EMPHASIS ON ITS ROLE IN MERCURY UPTAKE

by

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To

Mike and Dee

Sven and Timmy

Abstract

The higher aquatic plant composition, distribution, biomass, and standing crop were investigated during two consecutive summers, in a polluted section of the Ottawa River, Canada. In addition inorganic mercury uptake from soil, Ottawa River sediment and Ottawa River water, was studied in two rooted aquatic plant species, *Sagittaria latifolia*, found in the study section of the Ottawa River, and *Scirpus cyperinus*, found in a nearby tributary of the Ottawa, the Rideau River.

A total of 42 species was recorded in 1972 and 1973. Seventeen of these species were common to abundant in both summers. *Sagittaria latifolia*, *Polygonum amphibium*, *Nymphaea tuberosa*, *Vallisneria americana* and *Sparganium angustifolium* were the most common and most widespread species. The distribution pattern of most species was characterized by pure stands or stands dominated by one species. Dense growth was found in sheltered areas, at the entrance to bays, and sand bars along the islands. *Nymphaea tuberosa*, generally found in sheltered habitats, occurred in areas open to strong winds and currents. Only three species, *Sagittaria latifolia*, *Sparganium eurycarpum* and *Polygonum amphibium* (forma terrestris) were found to be tolerant of heavy pollution.

In the 504 ha study area, 9.0 ha were covered by aquatic vegetation in 1972 and 24.0 ha in 1973. The increase was due largely to a greater quantity of submersed species occurring in 1973. Mean biomass of emergent vegetation was 1.94 kg fresh wt./m^2

in 1972 and 3.24 kg fresh wt./m^2 in 1973. For submersed and floating leaf vegetation together it was 0.30 kg fresh wt./m^2 and 0.63 kg fresh wt./m^2 in 1972 and 1973 respectively. Dry weights were about 10% of the fresh weight. Underground parts accounted for about 24% of the total plant weight in emergent species and 10% in submersed species. In two species, Scirpus validus and Nymphaea tuberosa, the roots and rhizomes accounted for about 33% of the plant biomass.

In laboratory experiments low concentrations (<1-24 ppb) of radioactive mercuric chloride were added to water. Higher concentrations (up to 60 ppb fresh wt.) were added to river sediments. Both Sagittaria latifolia and Scirpus cyperinus were found to accumulate mercury from these sources. When Hg was taken up from the water by submersed shoots, it was found in the emersed shoots, tubers and to a lesser extent in roots. Roots also took up and stored mercury, when such was present in the surrounding medium. For this reason, it was concluded that underground parts should not be ignored when dealing with emergent forms of aquatic plants. In submersed plants the underground parts account for a fairly small part of total biomass, and may be of minor importance in the total mercury uptake.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

Page

Section I

COMPOSITION, DISTRIBUTION, BIOMASS AND STANDING CROP OF HIGHER AQUATIC PLANTS IN A SECTION OF THE OTTAWA RIVER, ONTARIO AND QUEBEC.

1. INTRODUCTION

In 1972 a five year comprehensive study on distribution and transport of persistent chemicals in a flowing water ecosystem, was initiated by the National Research Council of Canada (NRC) and the University of Ottawa. The chemical compounds, being released to the environment as a result of natural processes (weathering and draining of bedrocks) and human activities (pesticides used in forestry and agriculture and mercury compounds used as bactericides in pulp mills) are transported within rivers and cycled in the environment (Gavis and Ferguson, 1972; Hartung and Dinman, 1972).

The study area selected by NRC is located in a 5 km section of the Ottawa River about 10 km below Ottawa, Canada where the water is polluted by both municipal sewage effluents and industrial wastes, mainly from pulp and paper mills.

The scope of the NRC and the Ottawa University project in this 5 km section of a flowing water ecosystem included the investigation of the physicochemical characteristics of the water, the distribution and composition of suspended solids, the bed sediments and the description of the biota, i.e. all primary producers, consumers and decomposers in the trophic levels typical of aquatic ecosystems. This information provided a basis for further laboratory work with persistent chemicals and proved useful in the field sampling program in assisting analyses of the composition and distribution of these chemical compounds within the study area.

The present study deals with the macrophytes, which comprise a significant part of the primary producers in the study area. It has long been known that aquatic vegetation reacts to changes in the surrounding environment. In 1933 Butcher published an interesting overview on composition and distribution of higher aquatic plants and their relation to moving water in small rivers of England. This general picture has since been followed by more specific work on different ecological aspects of aquatic plants in running waters. Edwards and Owens (1960), Owens and Edwards (1961, 1965 and 1967) and Westlake (1966) were dealing with macrophyte biomass and productivity also on small rivers and streams. While Sirjola (1969) in Finland looked at cover and frequency of aquatic vegetation and its relation to water velocity in the field, Peltier and Welch (1969) combined plant growth studies with nutrient content of the water, light availability and temperature in a river in Alabama, U.S.. Recently several important studies on the effect of pollution by sulphite paper mills on aquatic plants have been carried out in large lake systems in Finland (Suominen 1968; Eloranta 1970 and Kurimo 1971). Other aspects of pollution were studied by Kohler, Wonnenberger and

Zeltner (1973) in the Moosach River system in Germany. They were looking at the possibility of using aquatic plants as indicators for pollution, based on certain chemical data. In Canada, Dansereau (1958), Gillet and Dore (1974) and Gentner (1973) have looked at the species composition in the Ottawa River district as well as in other areas. As a whole, however, no major investigations on the ecological significance, the distribution or the biomass of higher aquatic plants in very wide rivers such as the Ottawa have been previously conducted. The importance of the aquatic vegetation in the two running water systems of small rivers and large rivers can be expected to be quite different. Therefore, it was considered necessary to carry out a special investigation on this type of vegetation, its species composition, distribution, biomass and standing crop in the Ottawa River.

2. DESCRIPTION OF AREA

2.1 River Origin and Location of Study Area

The Ottawa River* is situated in eastern Canada in the provinces of Ontario and Quebec (Fig. 1). It is 1160 km long, and originates in Lake Capimichigama about 250 km north-west of Ottawa. For 480 km it flows westward through forested country. Upon reaching the head of Lake Timiskaming, the river turns south easterly and continues in this direction until it finally drains into the St. Lawrence River. Throughout its journey it forms several lakes and rapids, descending a total of 366 m from headwater to mouth. The total drainage area of the Ottawa River is 145,000 sq. km (OWRC-QWB, 1971).

The bedrock in the region consists of two major forms: precambrian rock of the Canadian Shield in the Upper Ottawa valley and the east side of the river, sandstone and limestone deposited during the Ordovician period in the west side. The mean annual precipitation over the whole basin is 876 mm with a runoff of 444 mm. The largest part of the drainage area is covered by coniferous forests interspersed with swamps and peat bogs. The contribution of farmland to the surroundings is comparatively minor.

In 1972 a 6.4 km long section of the Ottawa River, including the 5 km long NRC and Ottawa University study area,

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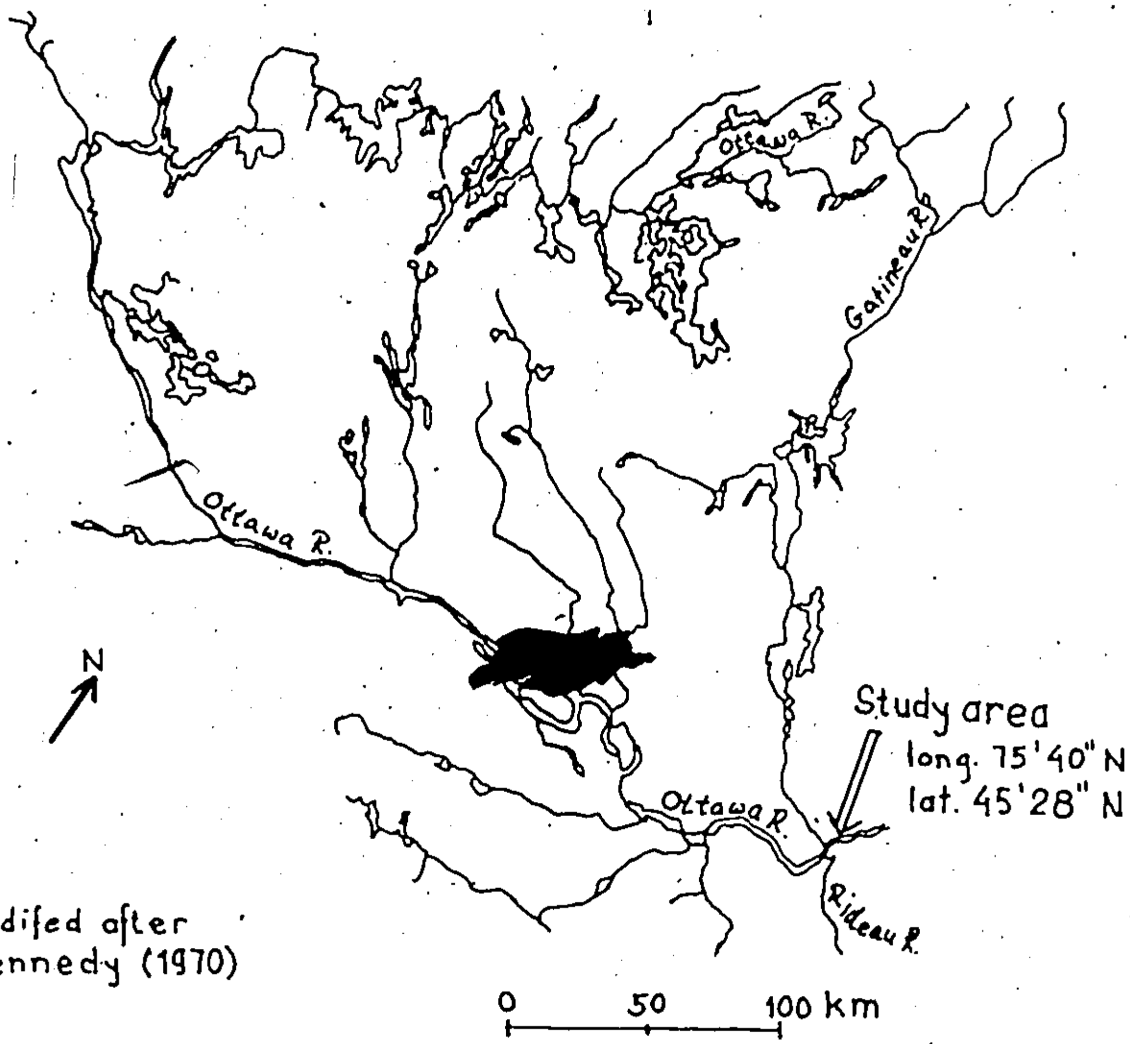
* The information on the Ottawa River is taken from Ontario Water Resources Commission - Quebec Water Board (OWRC-QWB) report on water quality and its control in the Ottawa River basin 1971 and 1972 and from C. C. Kennedy (1970).

Fig. 1 The Ottawa River drainage area and location of study section.



modifed after
Kennedy (1970)

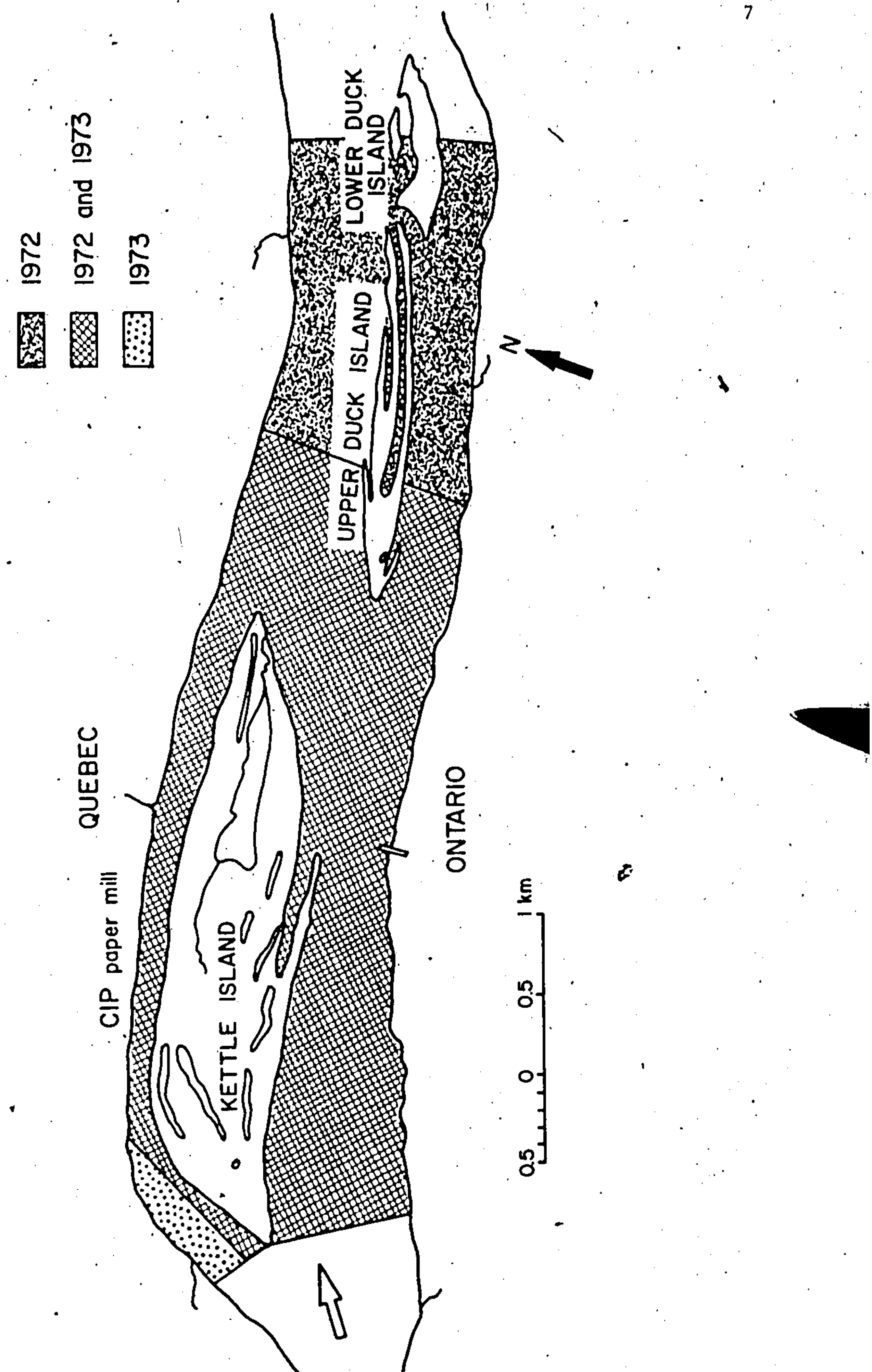
was mapped (Figs. 2 and 3). The section was reduced in 1973 to the 5 km long stretch by truncating 1.4 km from the downstream end of the section, to conform with the limits adopted for the study area by the NRC and Ottawa University. In addition, all of Upper Duck Island was included in the 1973 survey even though it extended beyond the 5 km limit. Three large islands, Kettle Island, Upper Duck Island and Lower Duck Island divide the river into two channels throughout the whole 6.4 km long section.

Upstream, in the immediate vicinity of the study area two major tributaries, the Rideau and Gatineau Rivers, flow into the Ottawa River (Fig. 1). The Rideau River flows through areas of cultivated lowlands and through the city of Ottawa. The Gatineau River has its headwaters close to those of the Ottawa River and descends directly south from the forested highlands.

2.2 Bottom Morphometry and Shoreline Characteristics in Study Area

The width of the river in the study area ranges from 1.2 km to 1.6 km and depth never exceeds 12 m (Fig. 4). Only very few areas along the shore drop off suddenly. Usually there is a gradual decline to deeper parts. The bottom sediments vary in composition throughout the area. Where the current is comparatively fast the bottom material is composed of coarse sand. Finer particles are found closer to shore. Nearly the whole length of the south (Ontario) shore is composed of heavy clay

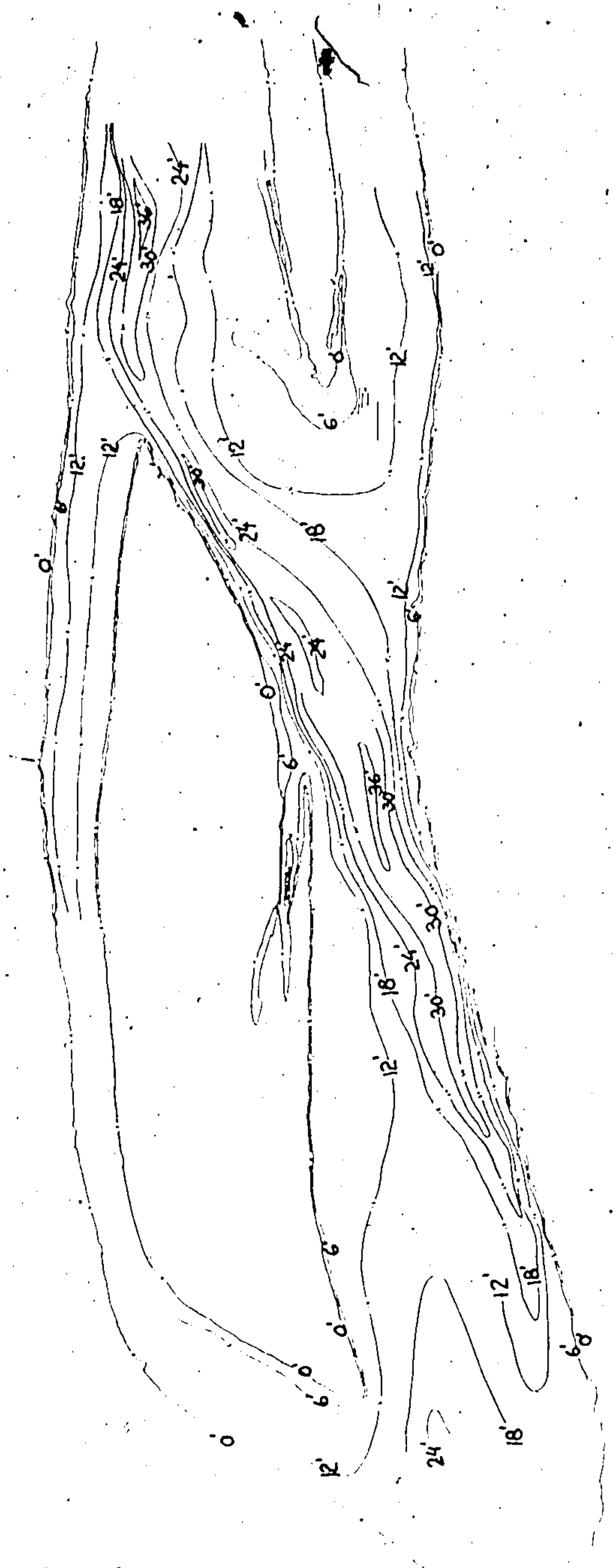
Fig. 2 The study area (white arrow indicates direction of flow).



1972
1972 and 1973
1973
LOWER DUCK ISLAND
UPPER DUCK ISLAND
N
QUEBEC
CIP paper mill
KETTLE ISLAND
ONTARIO
0.5
0
0.5
1 km

Fig. 3 Looking downstream from above the study area. (April, 1974)

Fig. 4 Depth profile in the study area (as modified from Stryde and Glazebrook (1974)).


0'
6'
12'
18'
24'
30'
36'

interspersed with a few small, sandy beaches. The steep clay banks are subject to severe erosion from wave and current action. Runoff from the slopes also carry a lot of clay material into the river. In 1972 rockfill was added to approximately 1,200 m along this Ontario shoreline to prevent erosion (Fig. 5). However, a large part of the shoreline is still not protected and many trees on the bank become uprooted sliding or falling into the river (Fig. 6).

The bottom of the channel between the Quebec shore and Kettle Island, downstream from the CIP paper mill (Fig. 2) is covered with wood chips. Stumps and logs are common in the shallow water. The bank on the Quebec side is not as steep as that on the Ontario side. It includes a fair amount of developed land and the paper mill.

The trees on the islands often grow close to the water, their branches reaching out over the river. The tips of these islands are long shallow sand banks, where the banks sometimes extend for a short distance downstream along the island to form a sand bar and a shallow bay (Figs. 7a and b). In some places shallow sand bars containing old stumps parallel the shoreline. Logs are commonly found in the shallow water around these islands.

2.3 Physical and Chemical Characteristics of the Water

In 1972 and 1973 a mean spring-autumn (April-September)

Fig. 5 Rockfill along the Ontario shore; an erosion control measure. (April, 1974)

Fig. 6 Eroded river bank on Ontario shore resulting in trees being uprooted and sliding into the river. Logs are frequently stranded on the shore. (August, 1972)

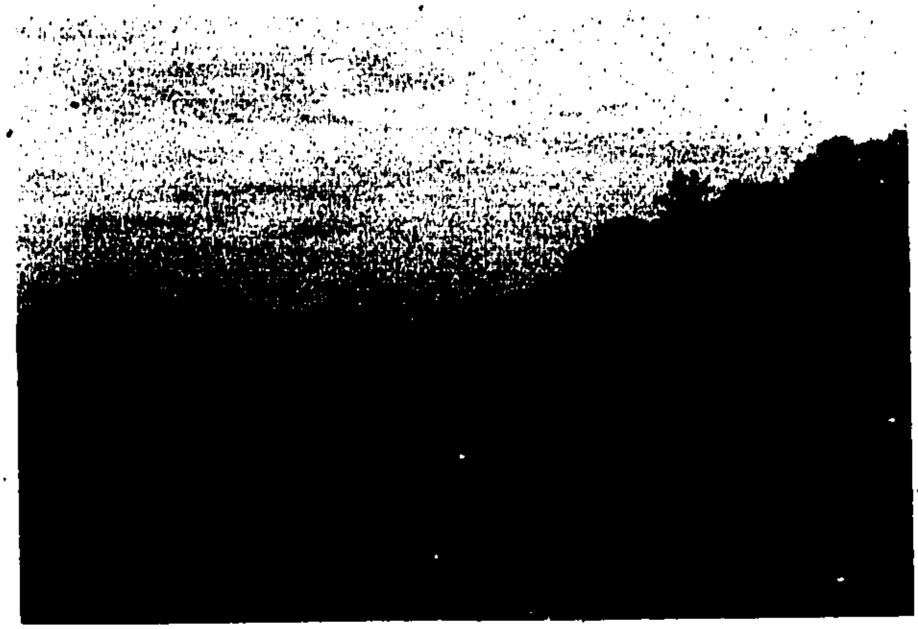
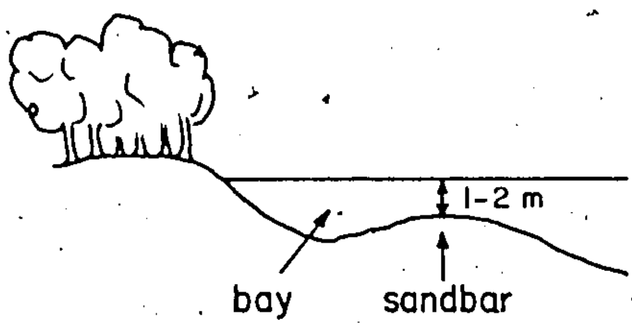


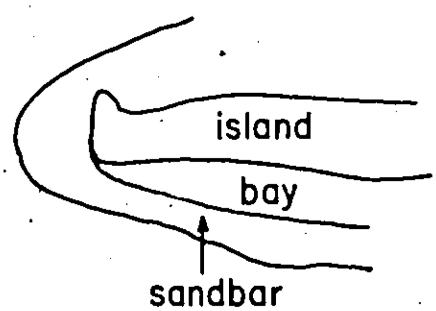
Fig. 7 Shore and bottom profiles in the study area.

(Fig. 7b is an aerial view of Fig. 7a)

a)



b)



flow of 2355 m^3/sec. and 1900 m^3/sec. respectively was estimated* for the study area. The river is regulated for hydro-electric power production, and fluctuations in water level in the study area throughout the year do not follow natural discharge patterns. Dams reduce the volume of water in spring and enhance the water flow considerably during the summer season. Sudden changes in water level resulting from changes in discharge rates at the dams were observed several times during the study period.

A survey of water velocity in the 6.4 km section was conducted in July and September 1972 (Warnock 1972). He has shown that the velocities are higher in the midchannels than closer to shore as would be expected. During the time of the study, values averaging around 0.40 m/sec. were obtained. In the shallow regions the flow was slower and ranged from 0.01 to 0.24 m/sec. A more detailed study on current velocities in the littoral zone was performed in July and August 1973 (Stryde and Glazebrook, 1973). Readings were taken between 6 and 10 m from shoreline. Velocities ranged between 0.00 to 0.53 m/sec. (Fig. 8).

The quality of the Ottawa River water that reaches the upstream urban areas of Ottawa and Hull is, according to the OWRC-QWB report (1971), satisfactory for most urban and recreational uses, although its nutrient content is high enough to support a large production of aquatic plants and phytoplankton. Heavily populated areas do not appear until the river reaches the cities

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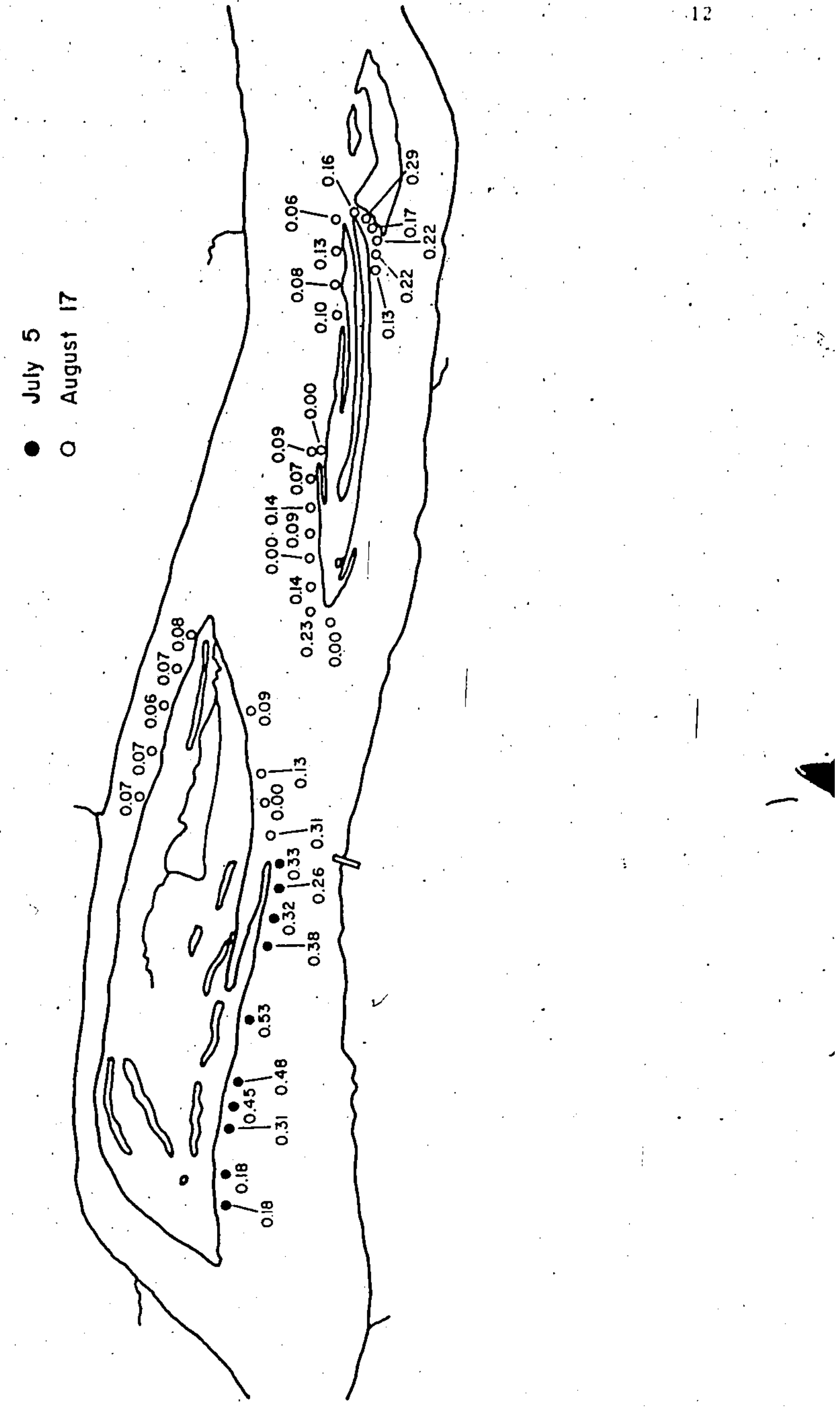
* Calculated from Warnock (1972 and 1974)

Fig. 8 Current velocities (m/sec) in the littoral zone of the study area (summer 1973). (Data from Stryde and Glazebrook (1973)).


● July 5
○ August 17
0.16
0.29
0.06
0.17
0.22
0.13
0.22
0.08
0.13
0.10
0.00
0.09
0.07
0.14
0.09
0.00
0.14
0.23
0.00
0.08
0.07
0.06
0.07
0.07
0.09
0.13
0.00
0.31
0.33
0.26
0.32
0.38
0.53
0.48
0.45
0.31
0.18
0.18

of Ottawa and Hull with a combined regional population of more than 500,000. By the time the Ottawa River water flows through Ottawa and Hull prior to reaching the study area, its composition changes considerably due to industrial and municipal wastes. Hull and most of the smaller municipalities, within 50 km of Hull along the river as well as industries had no treatment up until 1973 and contributed heavily to the pollution of the river. In addition, the CIP paper mill at Tempelton, Quebec (Fig. 2) has a profound impact on the water within the study area (Figs. 9 and 10).

The data on physical and chemical parameters for the south channel opposite Kettle Island in Table 1 (OWRC-QWB 1971, Fig. 11), indicates the quality of the water entering the study area.

The effluents that enter the river from the paper mills consist of wood chips, bark, fiber and other biodegradable matter. The impact of the CIP paper mill is shown by the high BOD (biochemical oxygen demand) levels in the area (Table 1, Mackie 1971), and the bottom sediments contain a large amount of N_2 and H_2S gas. Mackie (Ibid) also shows that concentrations of phenols are higher below the pollution source than above. The OWRC-QWB report points to changes in transparency of the water as seen in Secchi disk readings. Immediately below the CIP paper mill a low reading of 0.6 m is reported while further downstream along the shore the average reading increases to 1.0 m. On the other side of Kettle

Fig. 9 The channel below the CIP paper mill between Quebec shore and Kettle Island is wide enough that the north east shore of Kettle Island is not always exposed to the paper mill effluents. (July, 1972)

Fig. 10 The CIP paper mill is responsible for the heaviest pollution loading to the study area. (July, 1972)

TABLE 1.

Physical and chemical characteristics of the water in the study area after OWRC-QWB (1971) and Mackie (1971). Stations are marked in Fig. 11. The OWRC-QWB report did not state time of sampling. Mackie made weekly determinations at each station, and data from summers 1968 and 1969 with bottom and surface samples were averaged. Units are in mg/l unless otherwise indicated. For each parameter, the range is followed by the mean and number of samples.

Table 1

Parameter	OWRC-QWB		Mackie (1971)				
	Channel S Kettle Island (1970)	Channel S Kettle Island (1969)	Gatineau River	Canoe Club	Above CIP	Below CIP Quebec	Below CIP Kettle Island
Dissolved oxygen	8-10	5.0-10.5	6.0-10.0	6.0-12.0	6.0-12.0	6.0-10.0	7.0-11.0
	9.1	8.3	8.4	8.3	8.0	7.7	8.4
	4	9	40	36	33	21	14
BOD	.6-1.2	.5-1.8	0.5-2.5	0.5-2.3	0.5-4.0	0.4-29.4	0.5-3.0
	.8	1.1	1.6	1.3	1.6	6.8	1.2
	4	9	10	13	13	8	5
Phosphates total	.02-.04	.02-.04	0.04-0.30	0.02-0.38	0.07-0.26	0.02-0.27	0.06-0.30
	.03	.03	0.11	0.15	0.14	0.14	0.16
	4	7	17	18	17	11	6
PO_4 soluble	.0-.0	.0-0.2	-	-	-	-	-
	.0	.01					
	3	7					
Nitrogen NH_3 (as N)	.07-.09	.02-.13	-	-	-	-	-
	.08	.04					
	3	5					
NO_2 (as N)		.0-.01	.004-.017	0.003-0.014	0.004-0.026	0.004-0.045	0.004-0.017
	.0	.0	.010	0.008	0.013	0.018	0.008
	3	7	17	18	17	11	6
NO_3 (as N)	.09-.11	.01-.18	0.2-.24	0.01-0.24	0.02-0.24	0.01-0.24	0.04-0.07
	.08	.07	.21	0.10	0.09	0.10	0.06
	3	7	9	10	9	5	4
Total Kjeldahl (as N)	.49-1.0	.29-1.1	-	-	-	-	-
	.7	.52					
	4	7					

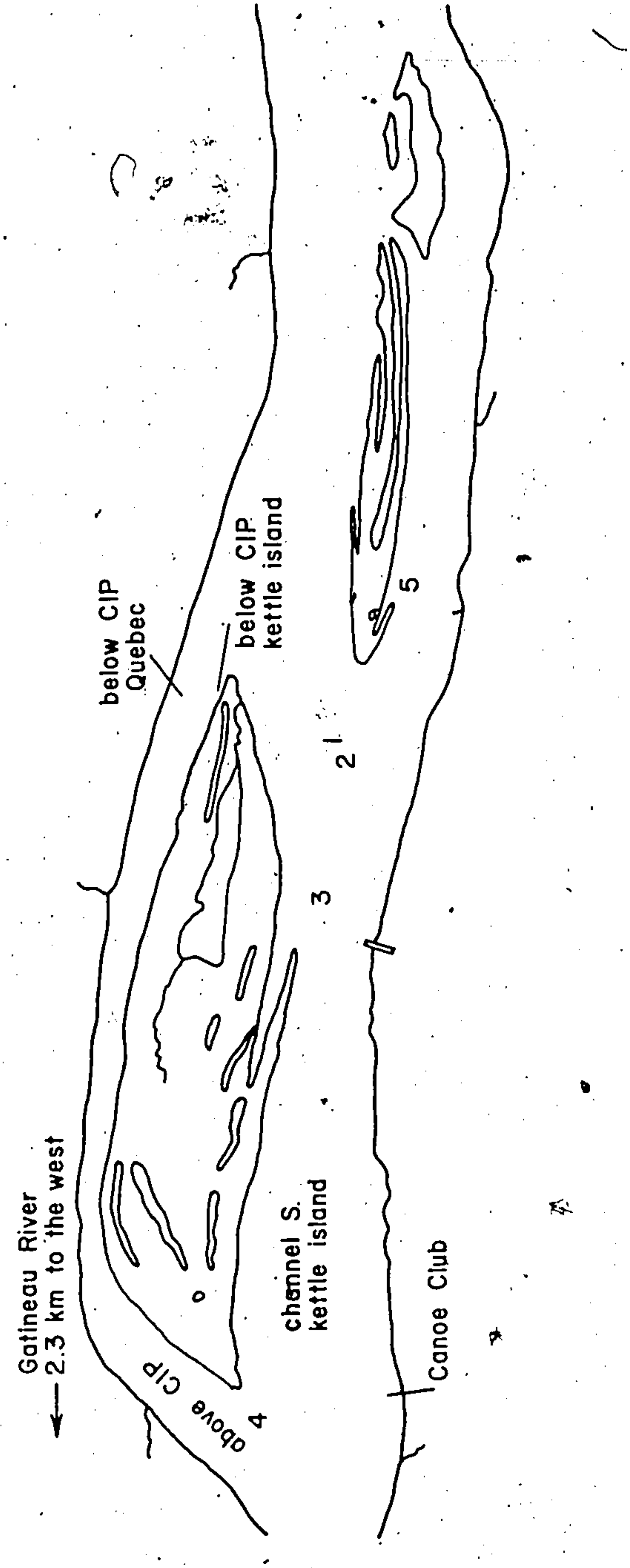
Table ... (cont...)

	OWRC - QWB						
	Channel S Kettle Island (1970)	Channel S Kettle Island (1969)	Gatineau River	Canoe Club	Above CIP	Below CIP Quebec	Below CIP Kettle Island
Total Solids	40-90 62 4	- 60 1	-	-	-	-	-
Suspended Solids	5-15 8 4	- 5 1	-	-	-	-	-
Turbidity (Standard Jackson units)	4.5-8.0 6.8 3	- 8.0 1	5.0-21.0 15.0 17	10.0-28.0 18.3 18	5.0-26.0 18.6 17	34.0-115.0 45.5 11	20.0-22.0 21.0 6
Conductivity (micromhos)	53-79 64 4	- 80 1	36.0-50.0 41.6 20	58.0-104.0 71.8 22	45.2-83.0 64.3 20	31.0-76.0 54.4 14	35.0-86.0 59.0 6
Chloride	2-4 2 4	- 3 1	1.0-5.0 2.3 17	1.0-5.0 3.0 18	1.0-5.0 2.8 17	1.0-9.0 4.0 11	2.0-2.5 2.3 6
Hardness (as $CaCO_3$)	- 28 1	- 30 1	10.0-20.0 16.9 10	20.0-35.0 27.5 10	20.0-32.0 27.7 10	20.0-55.0 38.5 8	20.0-20.0 20.0 2
Alkalinity (as $CaCO_3$)	- 17 1	- 23 1	10.0-26.0 16.4 16	17.0-37.0 25.5 18	17.5-30.0 24.1 17	18.0-30.0 24.1 11	18.0-30.0 23.5 6
Iron	- .25 1	- .4 1	0.10-0.70 0.33 17	0.00-0.90 0.31 18	0.00-0.80 0.28 17	0.18-0.74 0.33 11	0.14-0.50 0.33 6

Table 1 (cont'd.)

	OWRC-QWB		Mackie (1971)				
	Channel S Kettle Island (1970)	Channel S Kettle Island (1969)	Gatineau River	Canoe Club	Above CIP	Below CIP Quebec	Below CIP Kettle Island
pH (Standard pH units)	-	-	6.5-7.5	6.6-7.5	6.7-7.0	6.3-7.0	6.7-7.0
	7.3	7.7	6.8	6.9	6.9	6.8	6.8
	1	1	40	38	36	20	16
Sulfates	-	-	8.0-14.0	11.0-17.0	12.0-20.0	12.0-40.0	11.0-17.0
	14	10	10.3	14.3	15.1	21.8	14.0
	1	2	11	12	11	9	2
Phenols	-	-	0.0-10.0	0.0-10.0	0.0-10.0	8.0-10.0	0.0-20.0
			3.9	5.7	5.6	9.2	10.5
			9	10	7	5	4

Fig. 11 Sampling stations for water chemistry and light penetration. Stations 1-5 were used for Secchi transparency measurements (1973).


Gatineau River
2.3 km to the west
above CIP
4
channel S.
kettle island
Canoe Club
3
2
below CIP
Quebec
below CIP
kettle island
5

Island my own measurements (sampling stations indicated in Fig. 11) in August 1973 showed a low of 1.7 m Secchi transparency after heavy rain storms and a high of 2.3 m under normal summer conditions in the midchannel. The OWRC-QWB report gives an average Secchi depth value of 1.5 m along the Ontario shoreline.

Bacterial growth consisting largely of the slime bacterium Sphaerotilus covers the bottom as well as the logs and stumps in the shallow water from the CIP outlets to the end of the study section on the Quebec side. Apart from the high BOD and phenol values, other chemical characters (e.g. sulfite) of the water in this section may also differ significantly from the area upstream of the paper mill but these are not evident from Table 1.

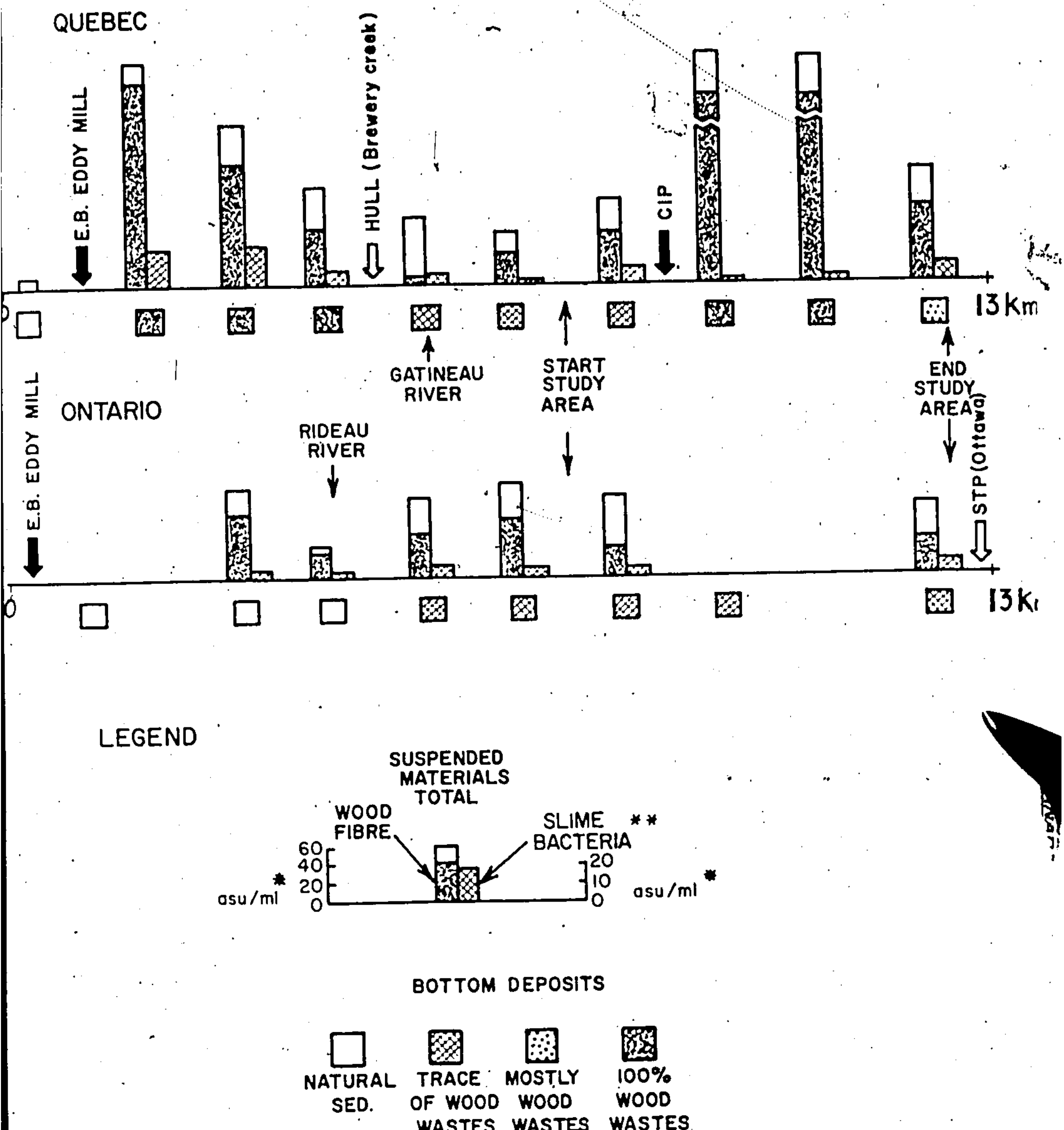
The northeast shore of Kettle Island does not appear to be affected by the wastes from CIP as much as the Quebec shore. This is reflected in the chemical results of Mackie's (1971) study (Table 1). The CIP effluents apparently do not always reach Kettle Island as observed in the field, where on occasion, a border line for the wastes could be seen with the naked eye.

Upstream from the CIP mill outlets, the river is covered by logs, with the exception of a narrow channel along Kettle Island, which is left open for small boat traffic (Fig. 15). There is also a cleared open space of roughly 800 m in length and 100 m in width along the Quebec shore. The water in this section of the river is likely to be affected by the Gatineau River (Warnock, 1973). According to Mackie's (1971) study, the Gatineau River has lower alkalinity, calcium, hardness, phenols, sulfates and conductivity than the Ottawa River, while nitrates are higher (Table 1). However, any influence of the Gatineau River water cannot be proved with the chemical and physical data obtained by Mackie. His results show instead more similarity between the water in the channel on the Quebec side and that from the upstream Ottawa. The Rideau River effluents appear to run parallel with the Ottawa River water along the Ontario shore throughout most of the study area. This could explain the difference in phosphates in the littoral zone of the Ottawa River on the Ontario shore, from that of the Ottawa River on the Quebec shore, where the Gatineau River has its major influence. Any other changes in this region caused by the Rideau River are not indicated in the chemical data of Table 1.

The river has also recovered considerably from the discharges from the E.B. Eddy Co., by the time it reaches the study area (OWRC-QWB, 1971). BOD levels at the entrance of the study area are similar to those found above Ottawa (Mackie, 1971 and OWRC-QWB, 1972). However, there are still excessive amounts of suspended wood fibers. Wood chips in the sediments in the Ontario section of the study area (Fig. 12) are also likely to originate with the E.B. Eddy Co..

During the summer of 1972, oil films were frequently

Fig. 12 Suspended solids and bottom sediment composition in the study area (as modified from OWRC-QWB (1971)).



* asu/ml = an areal measure of particles in the water; one areal standard unit is equivalent to 400 square microns.

** mainly *Sphaerotilus*.

observed on the water surface in the channel on the Quebec side. Thin layers of oil built up on the emergent aquatic plants throughout the season.

The average water temperature during winter under the ice ranges between $0^{o}C$ and $0.1^{o}C$. The whole river freezes over apart from a channel below the CIP paper mill and a few spots in the midstream on the Ontario side in December or January and the ice clears in March or April. Where current speeds are high ice generally fails to form. In the summer, water temperature reaches a high of $25^{0}C$.

3. MATERIALS AND METHODS

3.1 Mapping of Higher Aquatic Plant Distribution, Summers 1972 and 1973

3.1.1 Field Studies

An aquatic plant was defined by Fasset (1968) as "one which may, under normal conditions, germinate and grow with at least its base in the water and is large enough to be seen with the naked eye".

The Ottawa River program, of which this study is a part, is concerned with the flowing water ecosystem. Therefore, only vegetation related to the open river water was studied intensively. Bays and ponds on the islands were left unsurveyed.

Field studies were carried out in late summer, when the number of aquatic plant species were in full development and flower at its maximum (Westlake, 1969). This made plant identification possible.

The mapping, including estimation of total coverage by aquatic plants, was done from a boat and by wading in shallow sections of the study area. A glass bottom box was held over the side of the boat to assist in observations of the submersed* vegetation. In the summer of 1972 aqua lung-assisted divers were also used to check on submersed vegetation in 1.5 to 6 meters of water. Deep water specimens were collected by the divers and by using a garden rake over the edge of the boat, and by dragging an anchor over the bottom of the river. Collected plants were stored in plastic bags in a 5°C cold room until they could be preserved or processed. Coarse

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* submersed adopted from Sculthorpe (1971) for plants with their shoots totally in the water face.

plants were placed directly into a plant press and delicate plants were washed of debris and floated onto specimen mounting sheets before being pressed. Identifications were confirmed by Mrs. Susan Aiken and members of the Plant Research Institute of Ottawa.

The occurrence of the species was recorded on maps* (scale of 1:5,000). The shorelines were divided into 100 m intervals 240 in all by using a 100 m rope in the process of mapping. The area covered by aquatic plants within 100 m intervals was estimated visually. This was easily done with emergent vegetation, since in most areas this type of plant growth extended to no more than about 30 m from shore. The submersed vegetation was marked off with the help of the 100 m rope. The frequency of each species within the interval was marked on a subjective scale of 1 to 5, in which 1 was sparse and 5 indicated very dense grwoth. The grouping pattern was also marked on a subjective scale of 1 to 5, where 1 indicated whether species were growing singly or in very small groups and 5 indicated that large unispecific carpets of the plants were observed. This grouping pattern scale is a variation of Phillips' method (1959).

Distribution maps were compiled from the above records both for 1972 and 1973. In order to obtain a very general indication of the distribution of water plants and to simplify the detail on the map the plants were grouped into four morphological

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* The distribution maps are stored at the Biological Sciences Division, National Research Council.

types with the following symbols (cf. Table 4):

- ● Emergent plants, e.g. Sagittaria latifolia Sparganium eurycarpum. (1)
- o Floating leaf vegetation, e.g. Water lilies (2) Nymphaea tuberosa, Nuphar variegatum.
- ɸ Pond weeds with both submersed and floating leaves, e.g. Potamogeton epihydrus. (3)
- / Submersed plants, e.g. Vallisneria americana. (4)

Distribution maps (Figs. 16-30) were also composed from the above records for every species of aquatic plant found to be common in the study area.

3.1.2 Remote Sensing

Air photos were taken by the Remote Sensing Branch of Environment Canada over parts of the study area during the time of the field study in 1972. On August 14th pictures were taken from an altitude of 2000 m. On the 5th and the 9th of September they were taken from 150 m. Both Infra Red film and conventional colour film were used. Films are on file at the National Air Photo Library in Ottawa.

The photos were used in aiding in the estimation of the total coverage by aquatic plants. The aquatic vegetation was traced from the photo negatives onto transparent paper. The areas were then adjusted to the 1:5,000 scale used in the field work and checked against the field observations.

3.2 Biomass and Standing Crop* Estimates, Summers of 1972 and 1973

The collection sites for higher aquatic plants were selected differently in the two summers of the survey. In 1972 the sampling was essentially random, based on a system of transects prepared for the Ottawa River Project, by the Ottawa University and the National Research Council. In 1973, the distribution patterns and the density of the aquatic plants were considered before the actual selection of sampling sites was done. Sampling techniques were kept the same as far as possible in both surveys.

Growth area, biomass and standing crop of aquatic vegetation were cataloged for each of the separate cells in the revised grid system designed by NRC in 1973 (Eriksson, 1974). Data for both summers 1972 and 1973, were converted to this base.

3.2.1 Sampling Program for 1972

All samples except two were collected where the Ottawa River program transects intersected the shoreline of Quebec, Ontario, Kettle Island and Upper Duck Island (Fig. 13). At two sites, A and B, no vegetation was found. With the knowledge from earlier field observations, stations close to the transect, with more or less typical vegetation were chosen for sampling. There-

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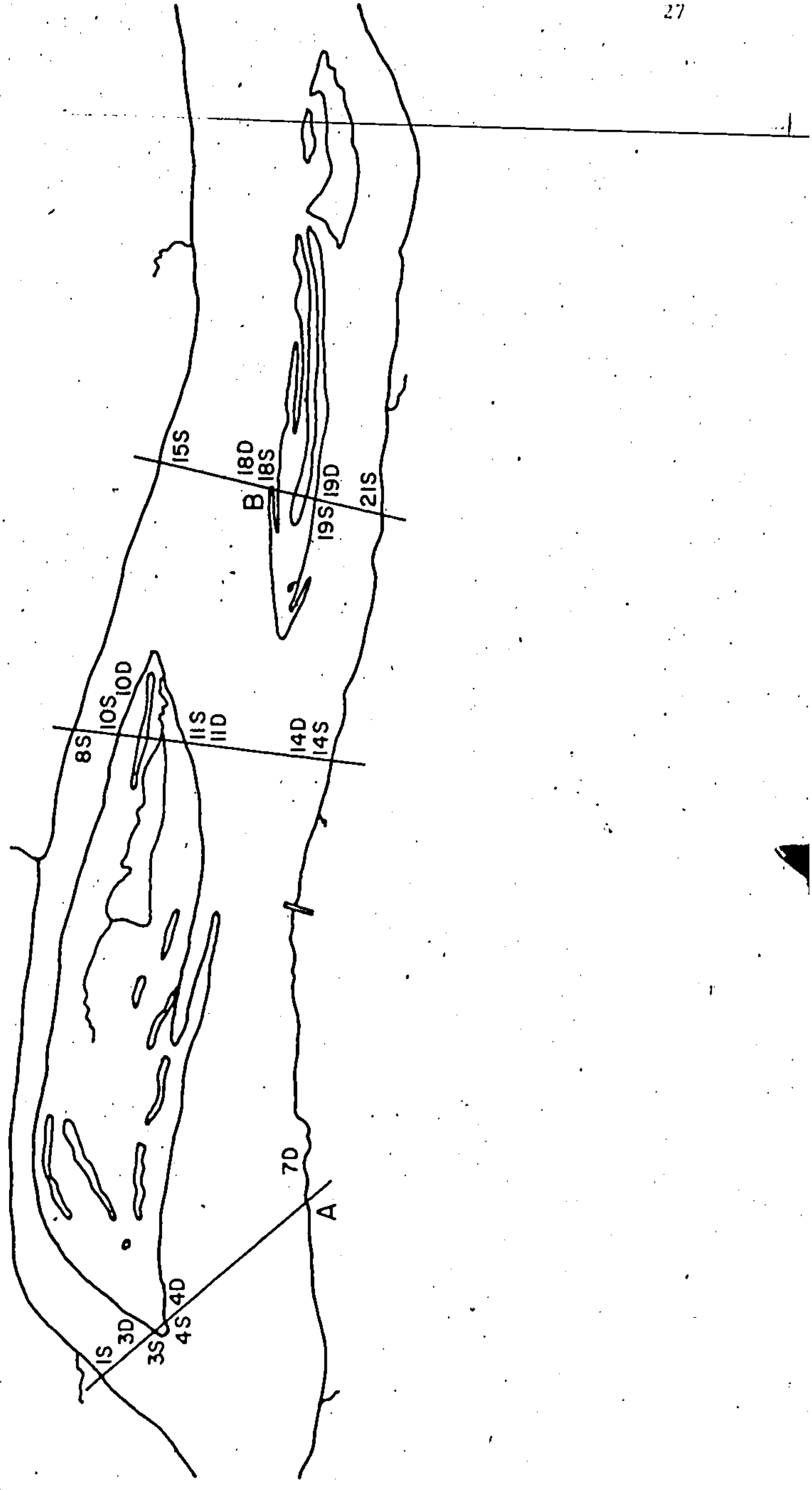
* Biomass is defined here as all recovered plant material, including underground parts. Standing crop refers only to the shoot.

Fig. 13 Sampling stations chosen for estimating macrophyte biomass and standing crop in 1972. Transects are indicated by straight lines.


1S
3D
3S
4S
4D
A
7D
8S
10S
10D
11S
11D
14D
14S
15S
18D
18S
B
19D
19S
21S

fore station 7D was 250 m downstream from the transect point and station 18S was 25 m upstream from the transect point.

A total of 19 plant samples was taken in July, August and September (Table 5). The first series of three samples was made in the middle of July and the remaining ones in August and the first week in September. Two kinds of samples were collected: (1) aquatic plants in shallow water and (2) aquatic plants in deep water. The shallow water samples were taken among emergent vegetation close to the shorelines. The deep water samples were taken in water 60 to 100 cm deep. This refers to areas occupied by floating leaf vegetation, pond weeds with both submersed and floating leaves or submersed forms. The sampling was done within a metal frame, which was randomly placed at each station mentioned above. In the first series of three samples a 1/2 m x 1/2 m quadrat was used. All aquatic plant material was collected within this area. For the remaining series a 1 m x 1 m metal quadrat was used. This increased size reduced variability in the sampling results (Westlake 1969).

All aquatic plant material including underground parts was collected within the quadrat for later analysis. The plants were placed in plastic bags and brought to the lab, where they were stored at 5°C for not more than 24 hours. Prior to determining fresh weight the plants were hung on suspended lines for 10 to 30 min. to allow excess water to drip off (Westlake 1966a). The species were sorted and grouped into eight different units: green parts of the shoot, white base of the shoot, wilted material, roots, rhizomes, tubers, stolons and runners. The plant weight was obtained in grams with two decimal accuracy. After weighing, plants were stored in a freezer at -10°C. Parts of the first three samples and the total of the remaining samples were sent to the NRC laboratories for dry weight and ash free dry weight determination. These determinations were done on combined samples where the units were grouped into: 1) "green" (all above ground parts of the plant) and 2) "root" (all underground parts of the plant). The results were given in percent water and percent ash free dry weight. The former values were then used to calculate dry weight.

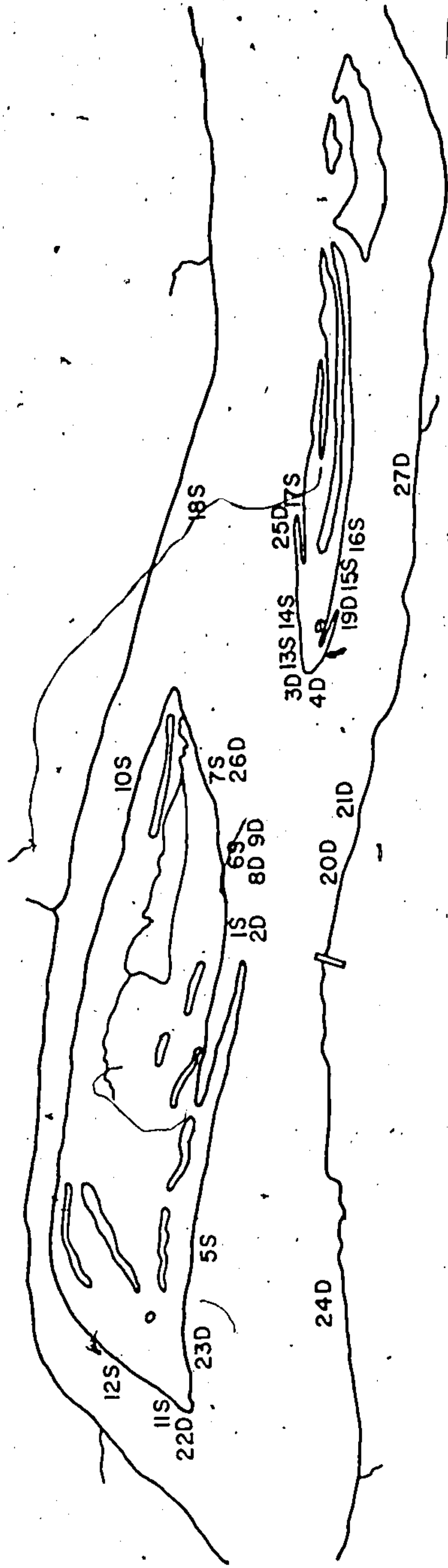
Samples taken in similar types of vegetation were grouped together and mean values of fresh weight and dry weight were used in estimating biomass and standing crop for all sampling areas within the study section. As there was only a maximum of two samples taken for each group, maximum and minimum values are given whenever possible. In the assessment of biomass and standing crop the distribution patterns of plant species were taken into consideration before samples were applied to the different vegetation areas. The calculated biomass and standing crop were finally grouped into seven areas: 1. Quebec west (above the CIP paper mill), 2. Quebec east (below the CIP paper mill), 3. Kettle Island north west and 4. Kettle Island north east (above and below the CIP paper mill), 5. Kettle Island south, 6. Upper Duck Island

and 7. Ontario shore.

3.2.2 Sampling Program for 1973

Sampling was conducted throughout the month of August and in the beginning of September. The same two kinds of samples were collected as in 1972, i.e. (1) "Shallow water" and (2) "Deep water" samples. However, the deep water samples were collected in 50 to 150 cm deep water, instead of the 60 to 100 cm of 1972. A total of 27 plant samples was removed at stations indicated in Fig. 14. In each location all material was collected with a metal quadrat of one square meter in area. This was placed in areas with more or less homogeneous and typical vegetation. The boat was rowed straight into a known area and the metal frame was lowered over one side. The border between open water and vegetation was avoided in the sampling because of changes in plant morphology, species composition and density that can be expected in a transition zone (Odum, 1971; Daubenmire, 1968). Two samples were taken in areas where the coverage by plants was dense and one sample was taken where plants were sparse. The plants were transported to the lab and stored in the same way as previously described for the summer of 1972. The method used for fresh weight determinations was also the same. To record dry weight all the plant material was chopped, mixed well, and if large, subsampled before drying in an oven maintained at 105°C for 24 hours. Individual species and plant

Fig. 14 Sampling stations for biomass and standing crop estimates (1973).


18S
25D
17S
16S
15S
19D
14S
13S
3D
4D
27D
10S
7S
26D
21D
6S
8D
9D
20D
1S
2D
5S
24D
23D
12S
11S
22D

parts were kept separated through this process. Ash free dry weight was determined on the same units by grinding the samples, then taking two subsamples in each case and ashing at 550°C for 24 hours. Weights were obtained on an analytical balance with 0.1 mg sensitivity. In the calculation of biomass and standing crop, the values recorded from the quadrat samples were compiled (Table 12) according to the following criteria: seven different plant associations dominated the vegetation pattern in the study area. Association 1 had mainly Sagittaria latifolia in the stands. Association 2 consisted of the main part of the rest of the shallow water vegetation, which was dominated by mixed stands of S. latifolia and Sparganium eurycarpum. Association 3 was found only in station 17S and contained mainly Sparganium eurycarpum. Association 4 contained pure Nymphaea tuberosa stands. Association 5 was recognized as densely populated stands with mainly Vallisneria americana and Sparganium angustifolium, which could be readily seen from the boat. Association 6 was similar to no. 5 in composition of species but vegetation was sparse. However there were large areas of deep and turbid water where the vegetation could not be seen from the boat. These were surveyed blindly with an anchor. Thus no distinction could be made between dense and sparse vegetation. Since large patches of dense vegetation were found to be as common as areas with very sparse or no vegetation, estimates are therefore based on biomass values in Association 5 in half this area and Association 6 in the other half.

Association 7 consisted of mixed stands of <u>Sparganium angustifolium</u>, <u>Nymphaea tuberosa</u> and <u>Polygonum amphibium</u>.

4. RESULTS

4.1 Macrophyte Species Distribution and Biology, 1972 and 1973

A total of 42 species was recorded in the 6.4 km long stretch in summer 1972 (Tables 2 and 3), and 35 species were found in the summer of 1973 (Table 2). All the species found in 1973 were included in the species list of the summer before. The five species Acorus calamus, Butomus umbellatus, Myriophyllum spicatum, Potamogeton spirillus and Scirpus fluviatilis, found only in 1972 occurred as single plants in one or two places within the 1973 region and were not found elsewhere in the 6.4 km stretch of 1972. The species Sparganium chlorocarpum, found only in 1972, was observed both within the 1973 study region and on Lower Duck Island. Chara sp. was recorded in a few patches only on Kettle Island in 1972.

The distribution of the aquatic plants is shown in Fig. 15 where species are arranged according to 4 life-forms and Figs. 16 to 30 where 15 of the most common species are recorded separately. Similar distribution patterns were found for most species in the two summers, and the same stands could often be recognized. The only striking difference between 1972 and 1973 was the change in the submersed vegetation. Although the stands of 1972 reappeared in 1973, the submersed vegetation had extended over a considerably larger area in certain parts of the river. In 1973 Vallisneria americana had extended further out (to distances of about 200 m from the shoreline) in some areas, while along one shore of Kettle Island (north east) it had almost completely disappeared.

TABLE 2. Macrophyte species listed in alphabetical order and the species occurrence on different shores of the study area during 1972-73.

Species	Quebec shore west* (1)	Quebec shore east (2)	Kettle Island north west (3)	Kettle Island north east (4)	Upper Duck Island north (5)	Kettle Island south (6)	Upper Duck Island south (7)	Ontario shore (8)	Lower Duck Island north** (9)	Lower Duck Island south** (10)	Lower Duck Island west** (11)
	Shores†										
Acorus calamus L.					X	X					
Butomus umbellatus L.								X			
Ceratophyllum demersum L.					Xx		X	x	X		
Chara sp.						X					
Eleocharis sp. (50-90 cm high)						Xx	Xx	x	X		
E. sp. ($\sim$20 cm high)						X	X		X		
Elodea canadensis (Michx.) Planchon	x		Xx	Xx	Xx	Xx	Xx	Xx	X		X
Equisetum sp.								X			
Fontinalis antipyretica			x		Xx		x			X	
Hydrocharis morsus ranae L.						Xx	X				

TABLE 2 (cont'd)

Juncus filiformis L.						Xx					
Lemna minor L.	x		X		X	X	X		X		
Myriophyllum humile (Raf.) Morong			x		X	X	Xx				
M. spicatum Fernald.						X					
Najas flexilis (Willd.) Rostk. & Schmidt					Xx	Xx			X	X	
Nitella sp.			X[a]		X[a]X[a]			X			
Nuphar variegatum Engelm.						Xx					
Nymphaea tuberosa Paine	x		Xx		Xx	Xx	Xx	Xx	X		
Polygonum amphibium (floating form) L.	x		Xx		Xx	Xx	Xx	Xx	X	X	
P. amphibium (terrestrial form) L.		Xx									
Pontederia cordata L.			Xx		Xx	Xx	Xx		X		
Potamogeton berchtoldii Fieber.			Xx			X					
R. epihydrus Raf.			x	Xx	X[a]x[a]			X			
P. natans L.						X					
P. richardsonii (Benn.) Rydb.			x	Xx	X[a]x[a]	X	Xx	Xx			X
P. spirillus Tuckerman						X					
P. sp. (branched narrow leaves)								Xx	X		
P. sp. (branched very fine leaves)					x[a]						
Sagittaria latifolia Willd. Wapato	x	Xx	Xx	Xx	Xx	Xx	Xx		X	X	
Scirpus atrosinctus Fernald.			Xx		Xx	Xx	Xx		X		
S. fluviatilis (Torr.) Gray							Xx				
S. validus Vahl.	x		Xx		Xx	Xx	Xx		X		
Sparganium angustifolium Michx.	x		Xx		Xx	Xx	Xx	Xx	X	X	X
S. chlorocarpum Rydb.							X		X		
S. eurycarpum Engelm.	x	X	Xx		Xx	Xx	Xx	X	X	X	
Typha latifolia L.		Xx				Xx	Xx	x	X	X	
Vallisneria americana Michx.	x		Xx	Xx	Xx	Xx	Xx	Xx	X	X	X

X = 1972, x = 1973
* = Investigated only in 1973
** = Investigated only in 1972
a = Found only on upstream tip of island
† = cf. p. 60

Table 3. Macrophyte species occurring in the study area during 1972-73*, not mentioned in Table 2.

Calamogrostis canadensis (Michx.) Beauv.

Carex sp.

Eupatorium borealis (Nash) Batchelder

Phalaris arundinacea L.

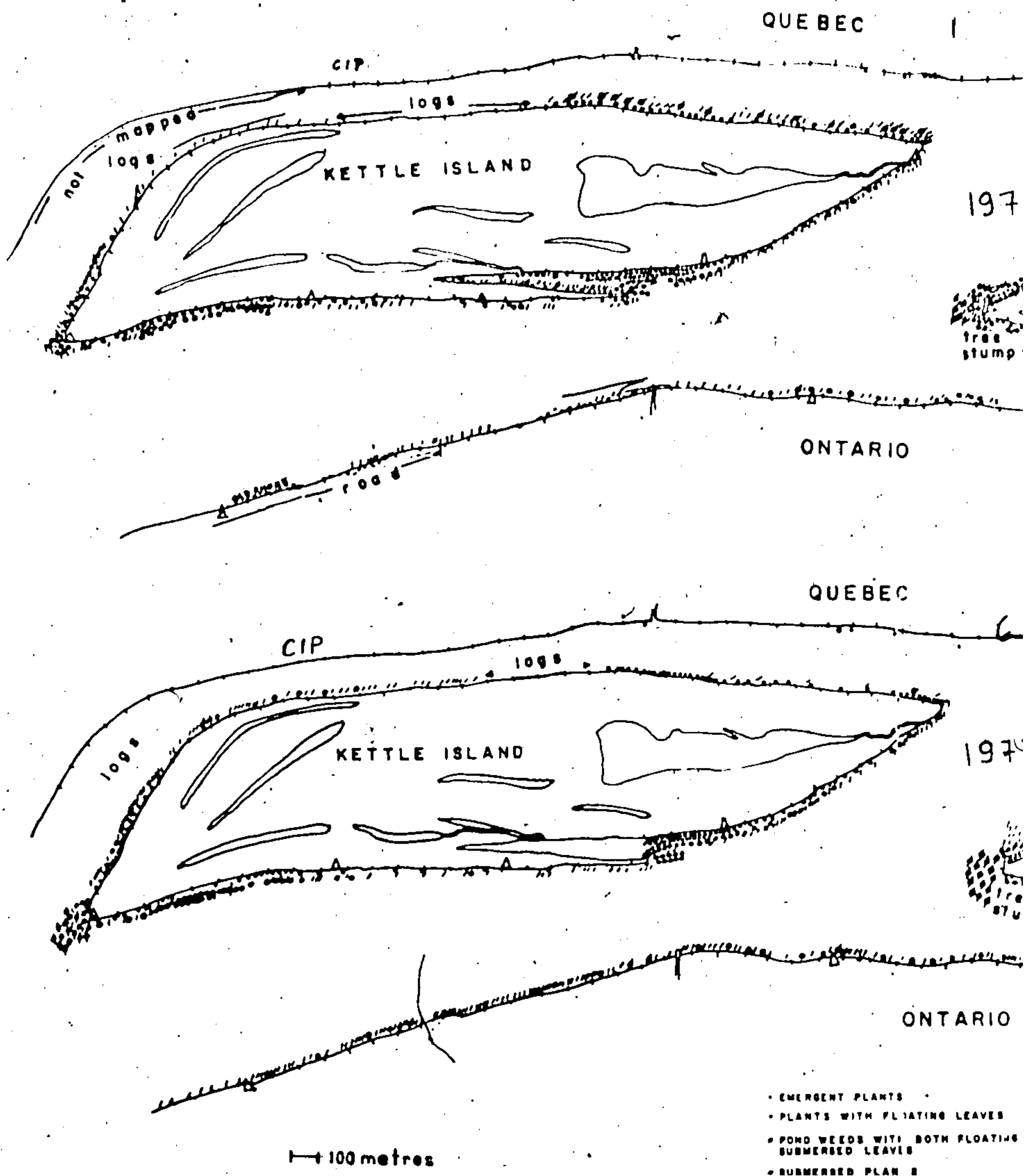
Solidago sp.

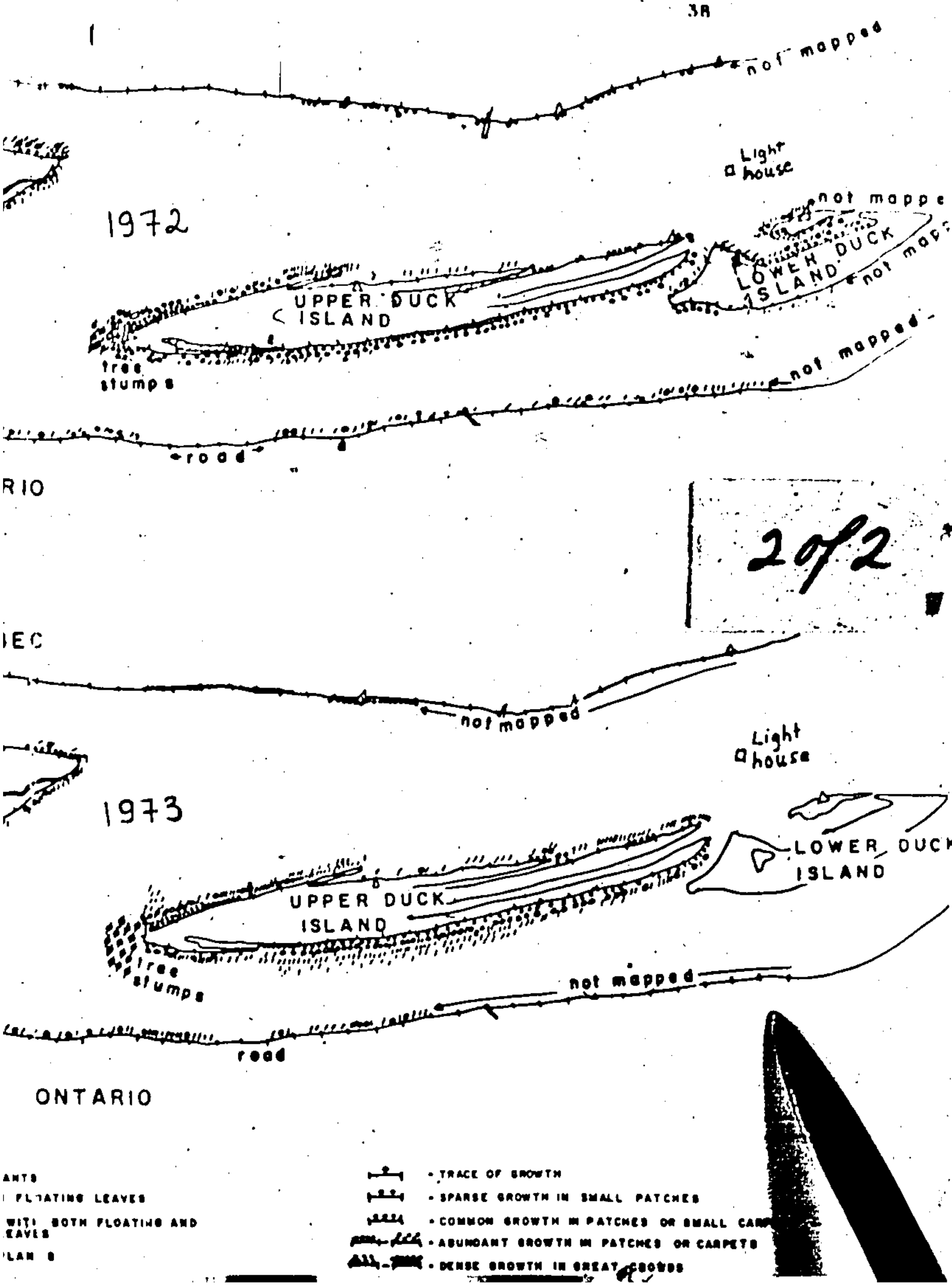
Spartina pectinata Link.

* These are species that were recorded during August in both summers 1972 and 1973, but were not considered true aquatic species and therefore not well mapped. Later it was found that they are taken up in Fasset's manual (1968). The species were found only on the islands.

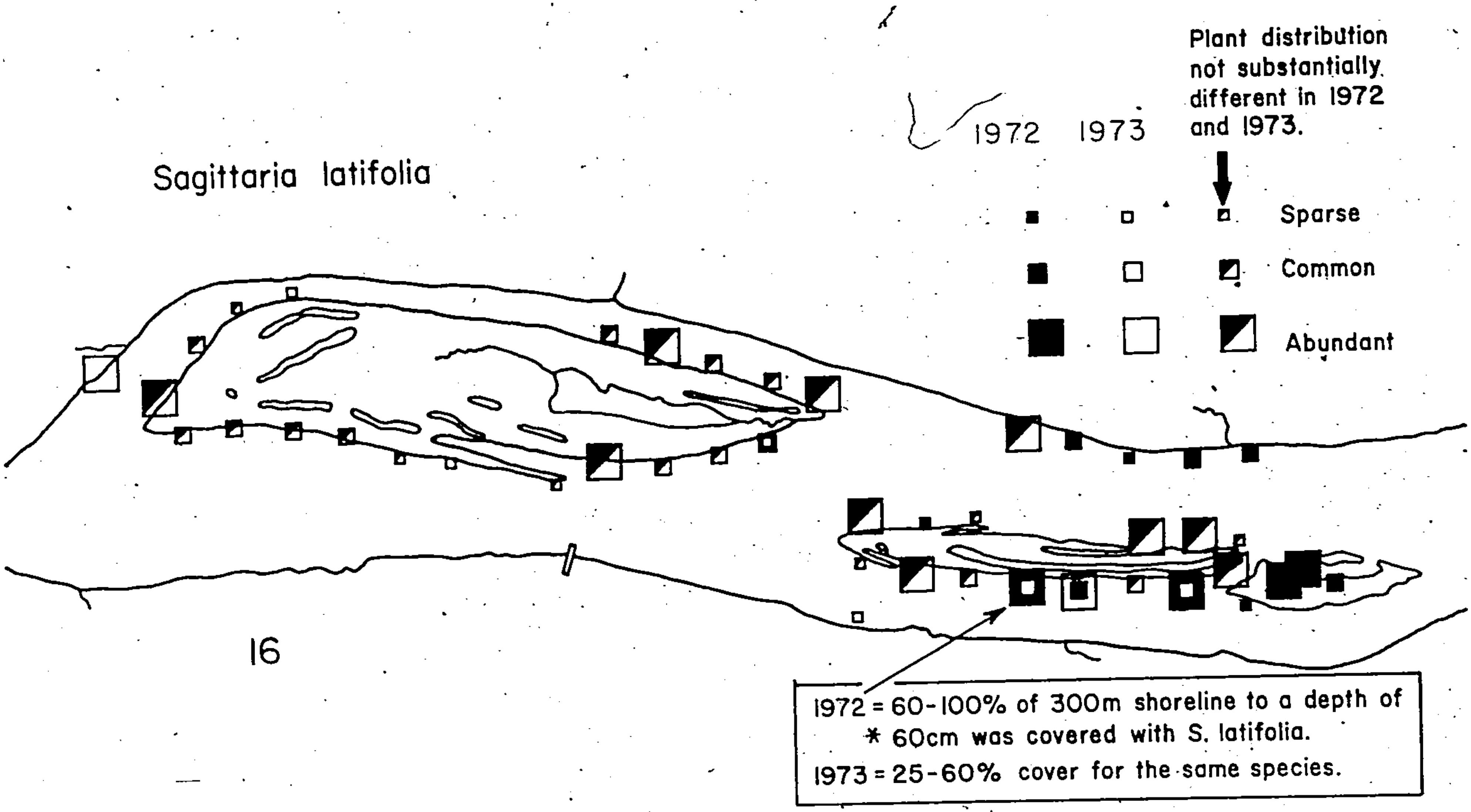
Fig. 15 Macrophyte distribution in the study area (1972-73).

1 of


QUEBEC
CIP
logs
not mapped
logs
KETTLE ISLAND
197
tree stump
road
ONTARIO
QUEBEC
CIP
logs
logs
KETTLE ISLAND
ONTARIO
EMERGENT PLANTS
PLANTS WITH FLOATING LEAVES
POND WEEDS WITH BOTH FLOATING SUBMERSED LEAVES
100 metres

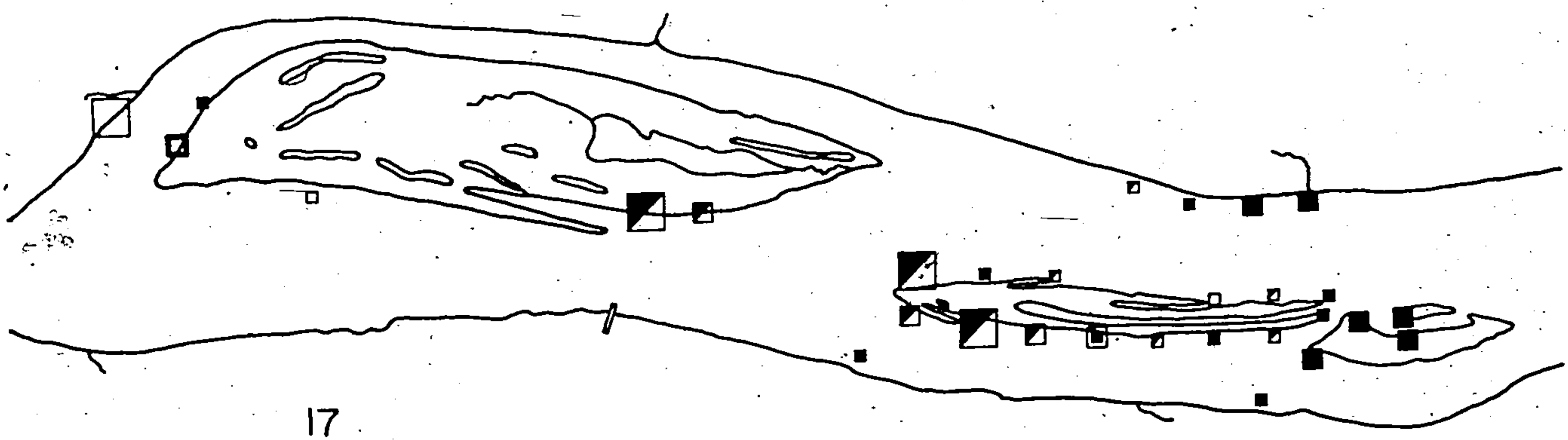

not mapped
Light house
1972
not mappe
LOWER DUCK ISLAND
not map
UPPER DUCK ISLAND
tree stumps
not mapped
road
RIO
2 of 2
EC
not mapped
Light house
1973
LOWER DUCK ISLAND
UPPER DUCK ISLAND
tree stumps
not mapped
road
ONTARIO
ANTS
FLOATING LEAVES
WITH BOTH FLOATING AND LEAVES
LAN S
TRACE OF GROWTH
SPARSE GROWTH IN SMALL PATCHES
COMMON GROWTH IN PATCHES OR SMALL CAR
ABUNDANT GROWTH IN PATCHES OR CARPETS
DENSE GROWTH IN GREAT GROWS

Figs. 16-30 Distribution maps of aquatic plant species in 1972 and 1973. Explanation of symbols given in Fig. 16.



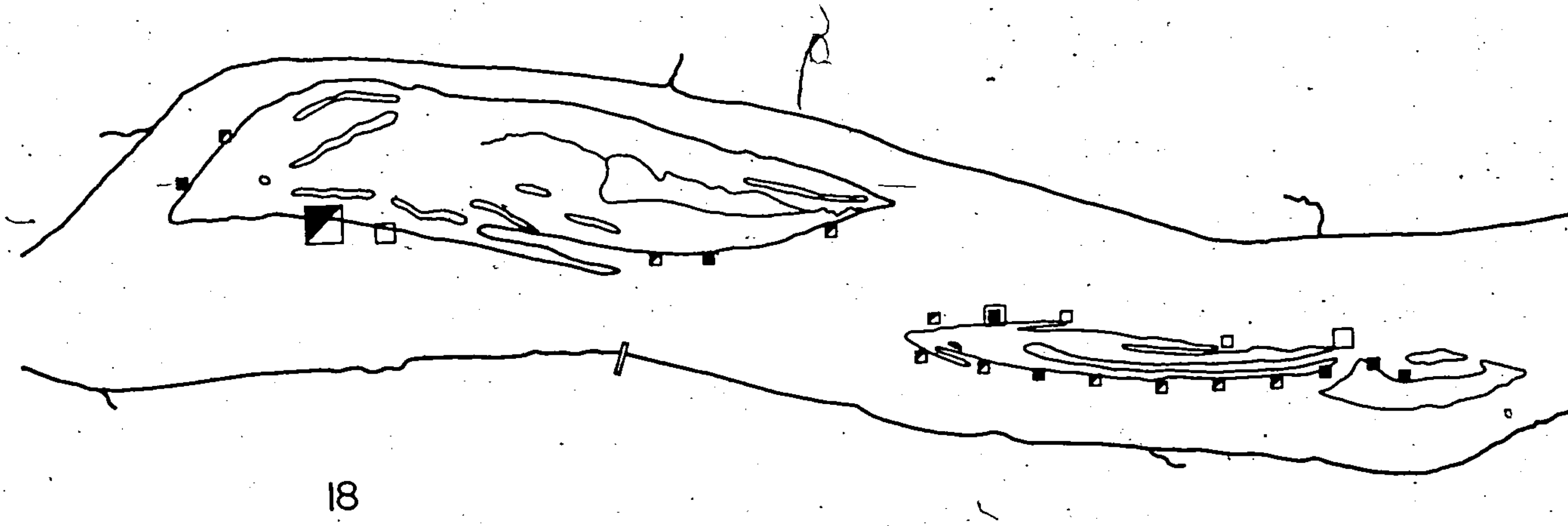
* This depth applies to all the other emergent species in figs. 16–30. Deep water species were found at a depth of 60–300 cm.

Sparganium eurycarpum



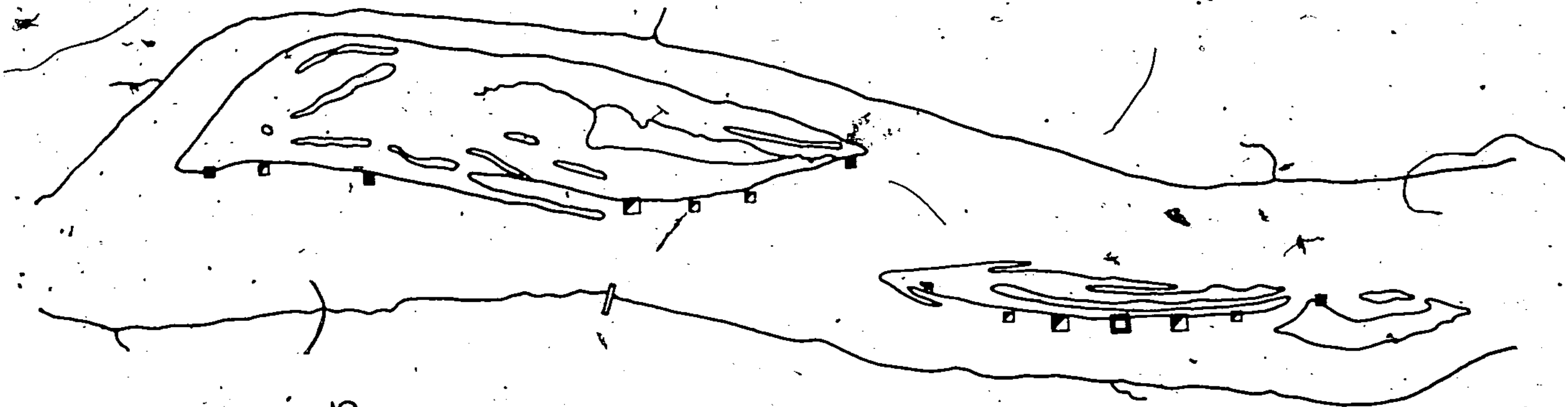
17

Scirpus validus

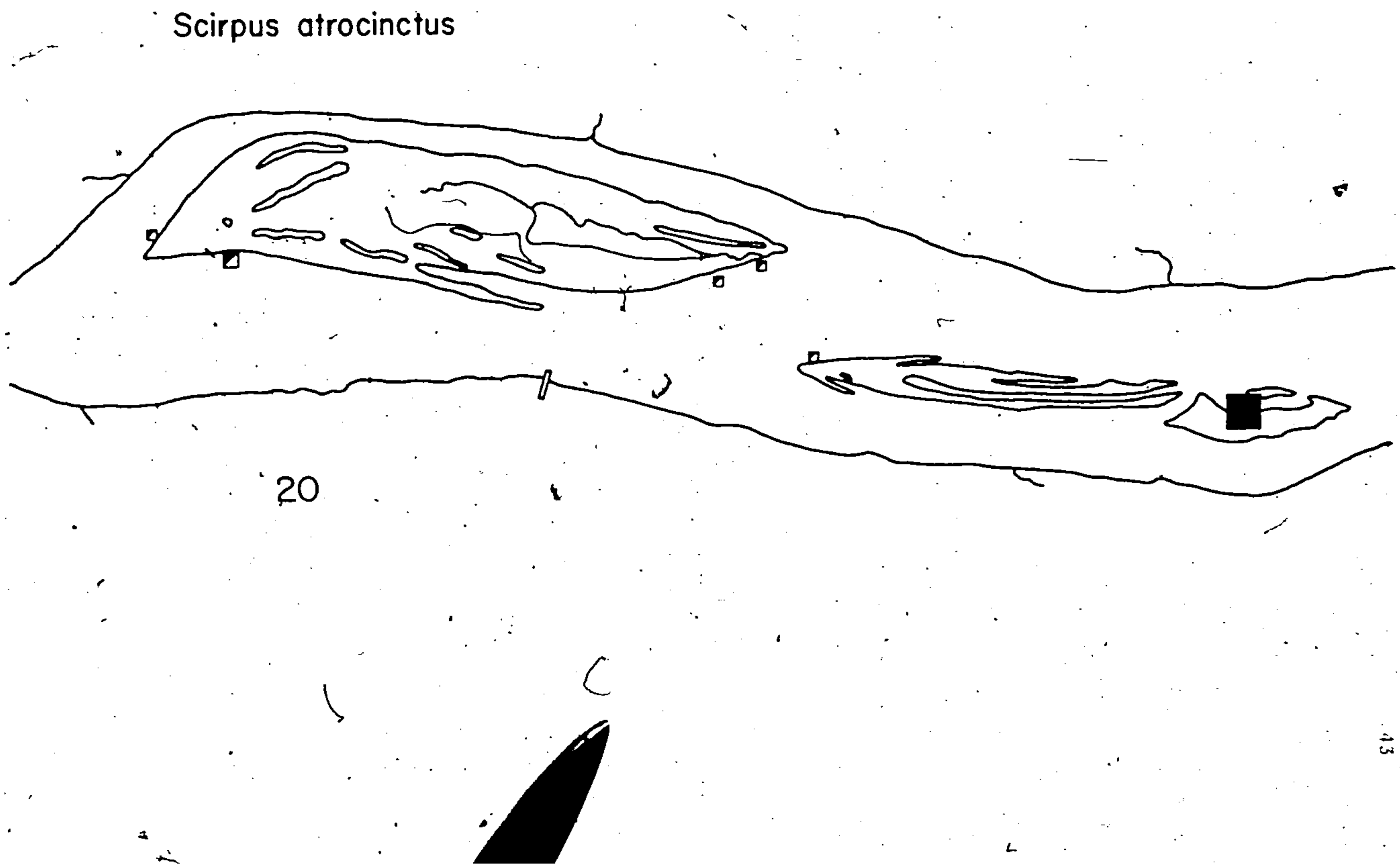


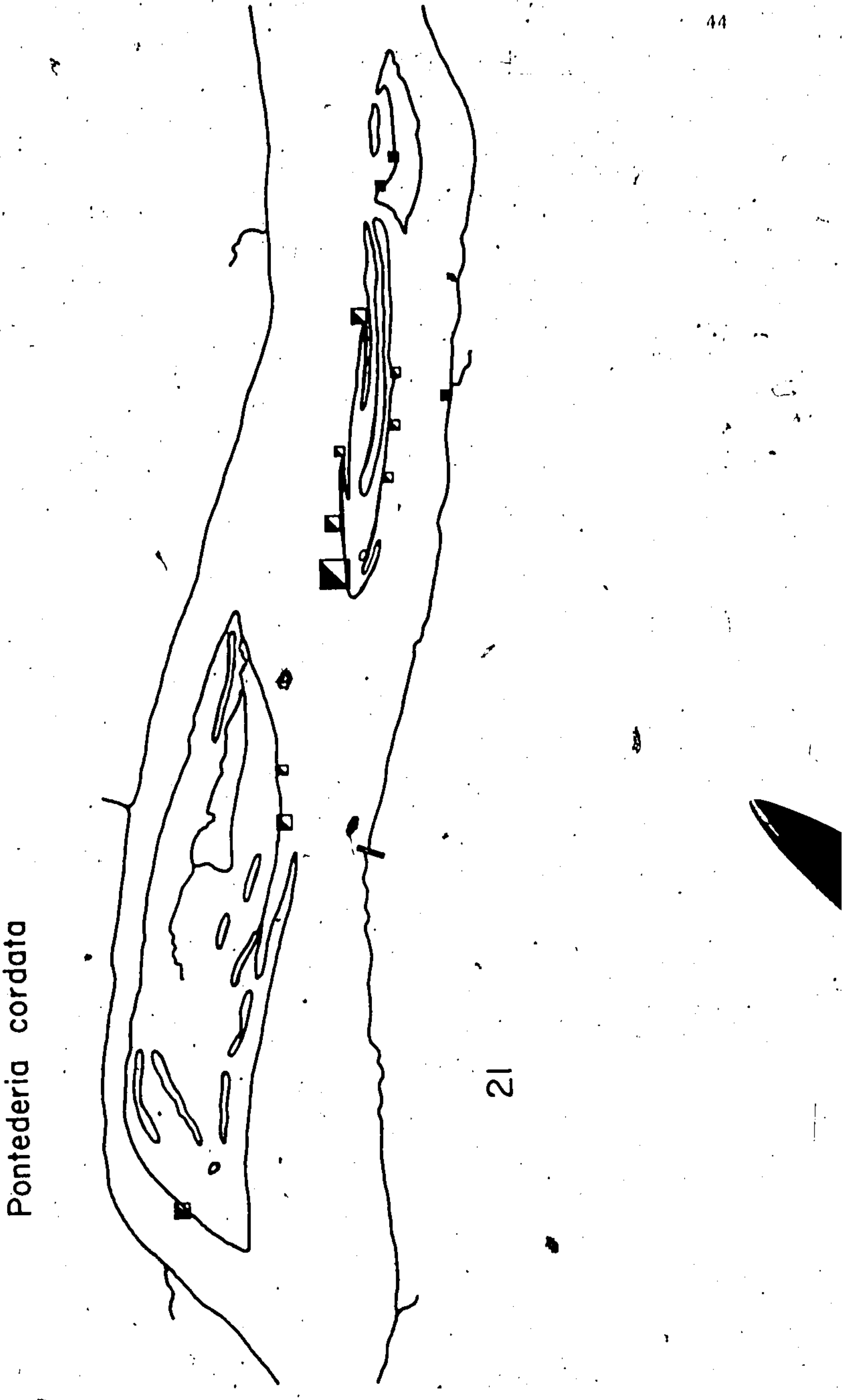
18

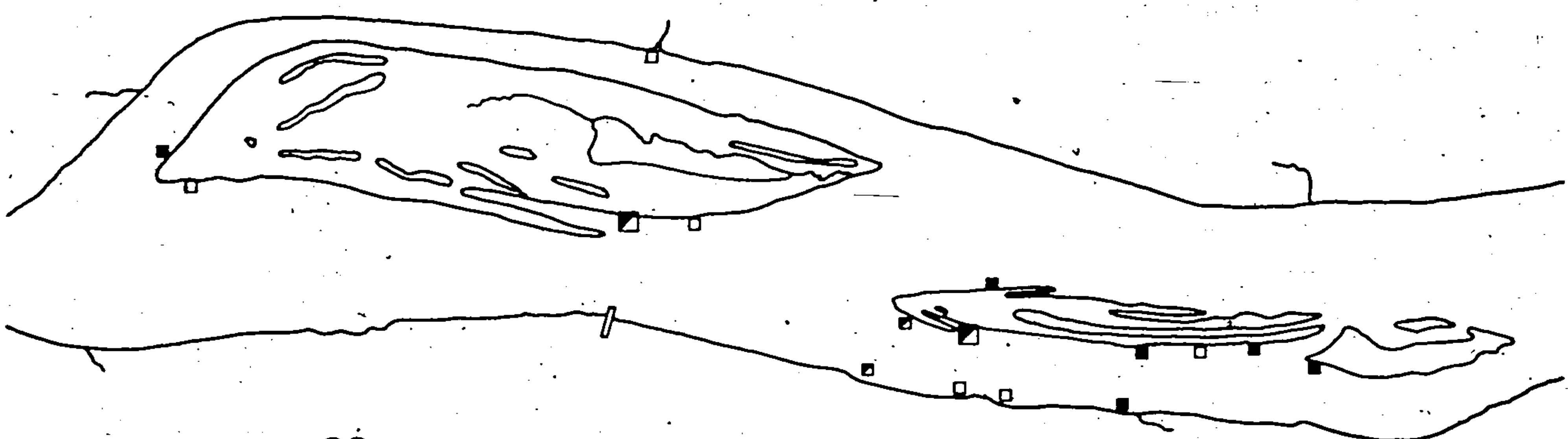
Eleocharis sp.



19

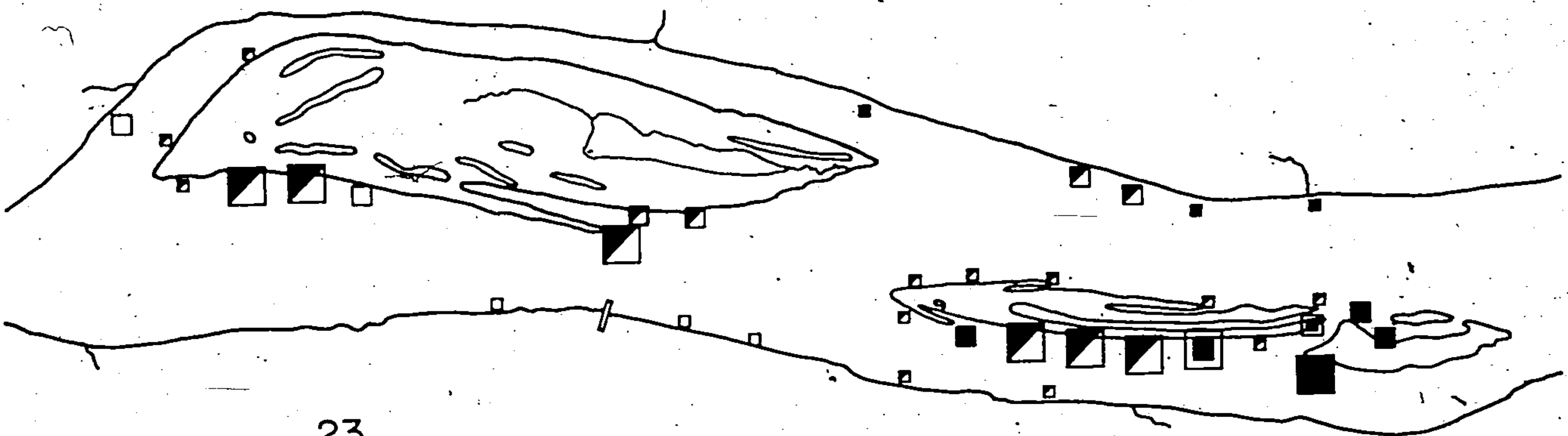

Scirpus atrocinctus
20


Pontederia cordata
21



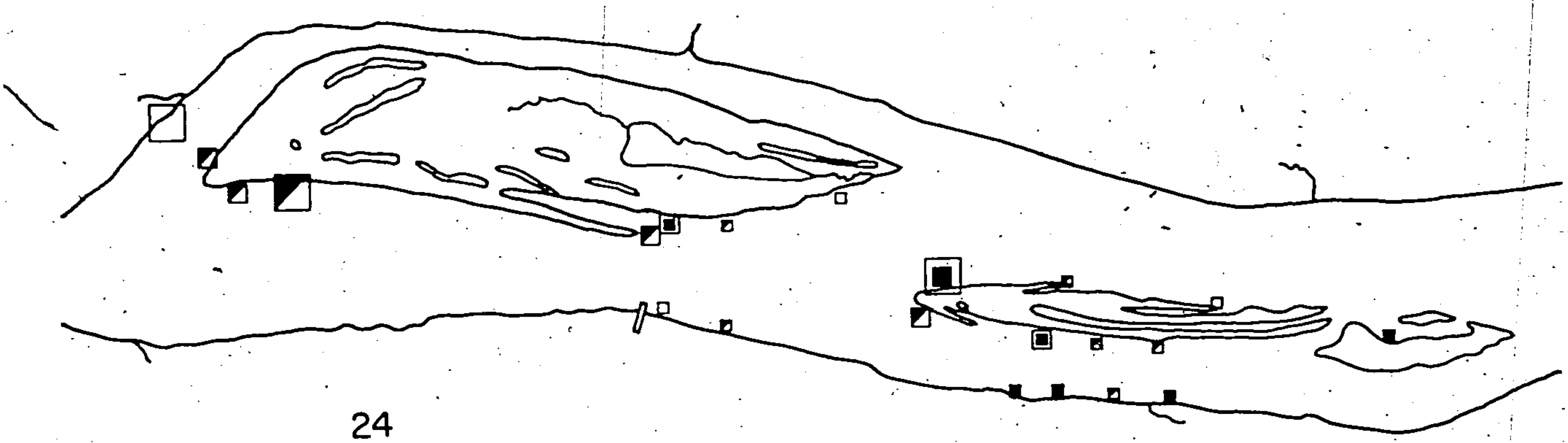
22

Polygonum amphibium



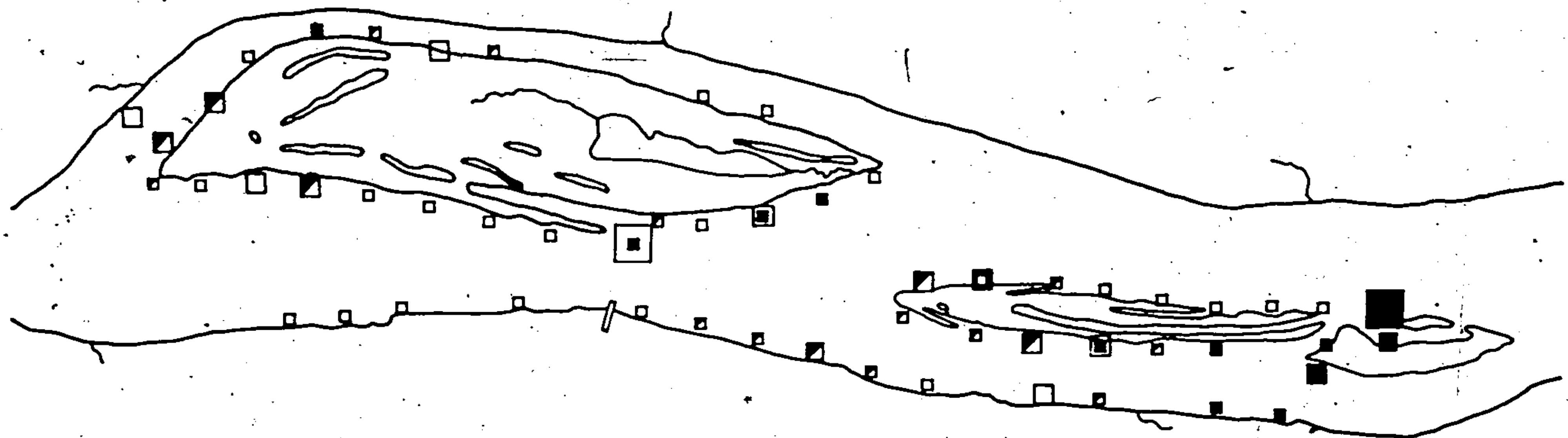
23

Nymphaea tuberosa



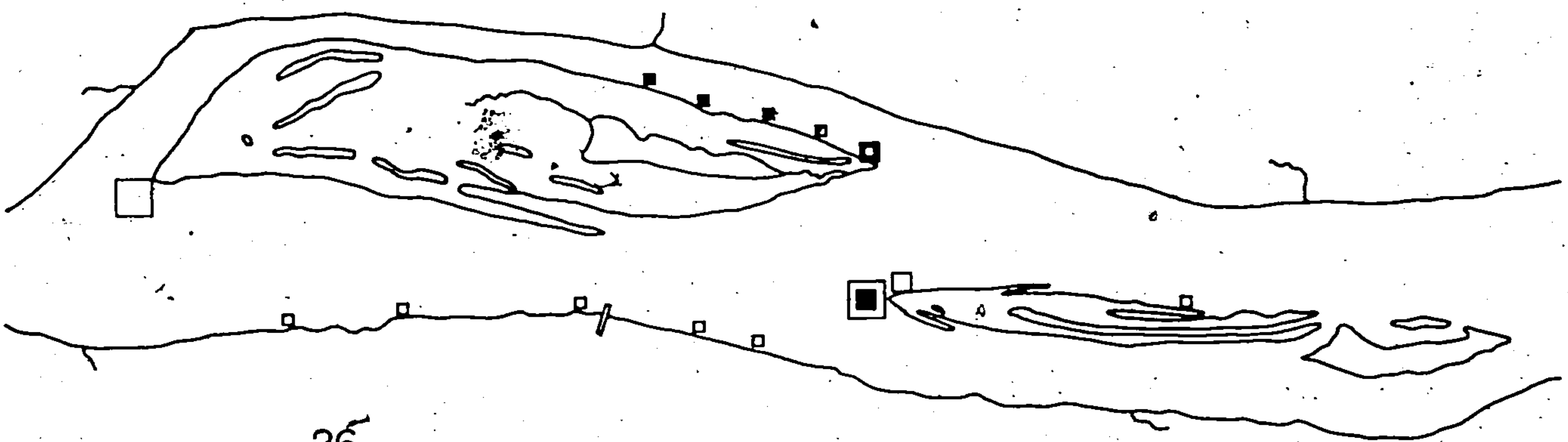
24

Sparganium angustifolium



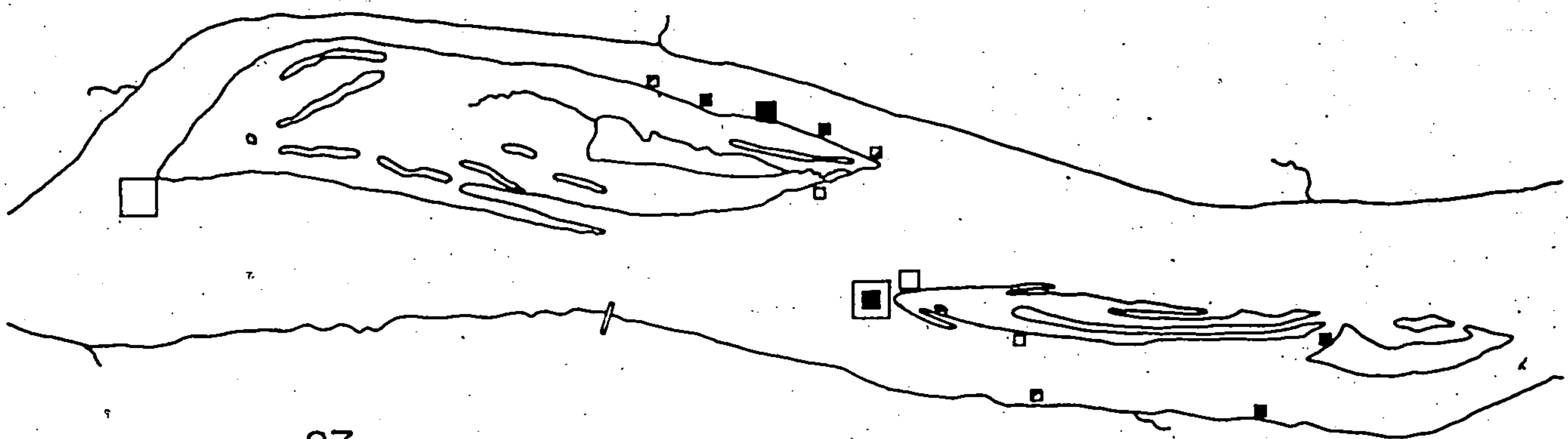
25

Potamogeton epihydrus



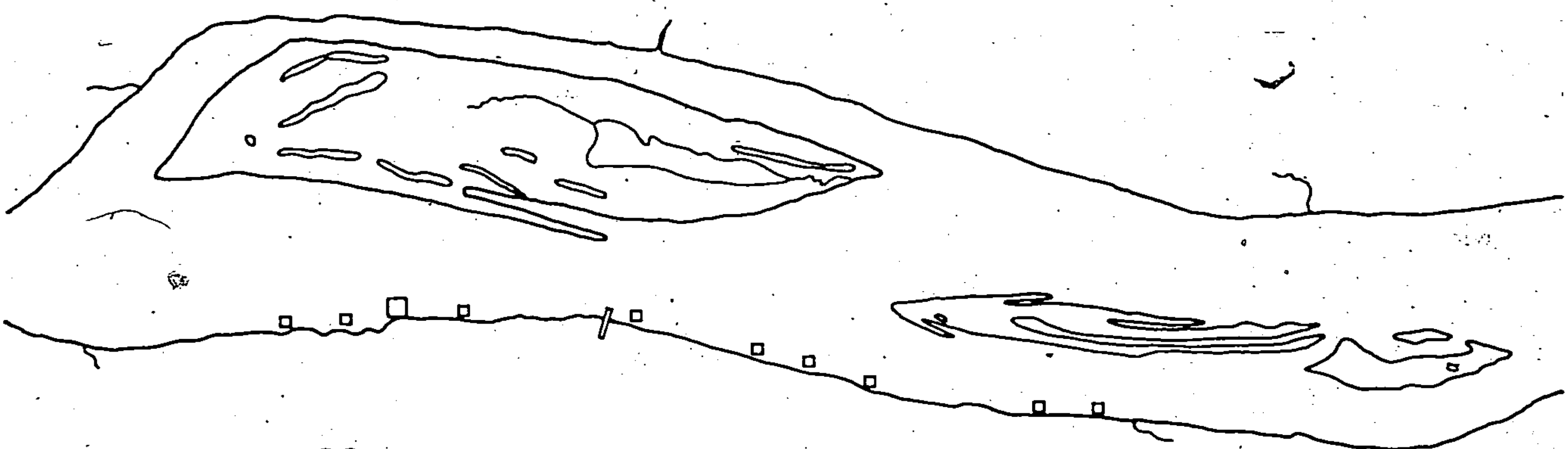
26

Potamogeton Richardsonii



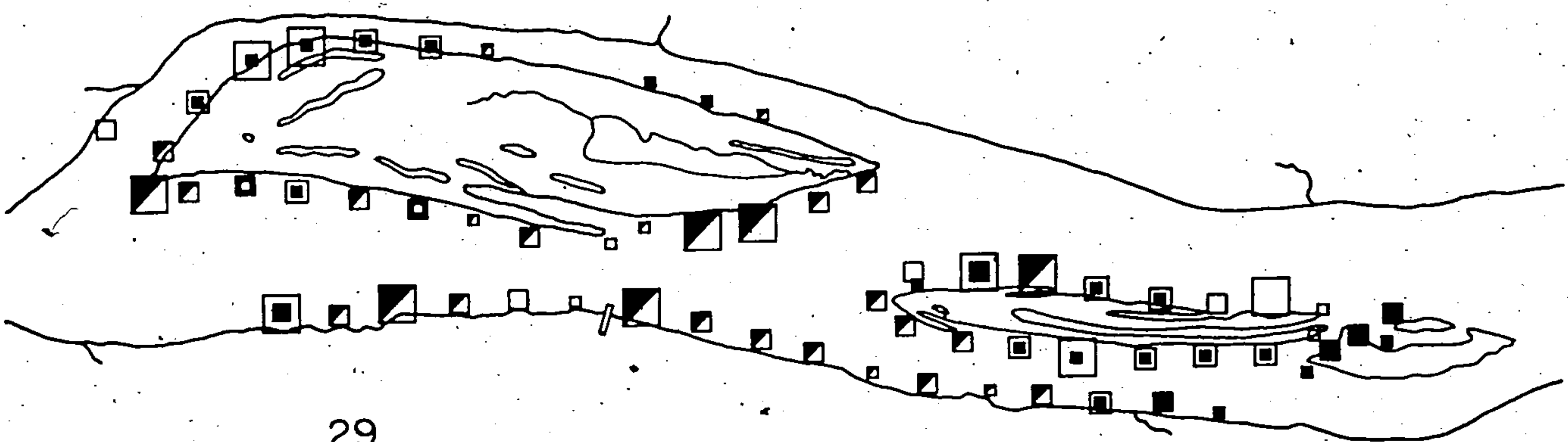
27

Potamogeton sp.



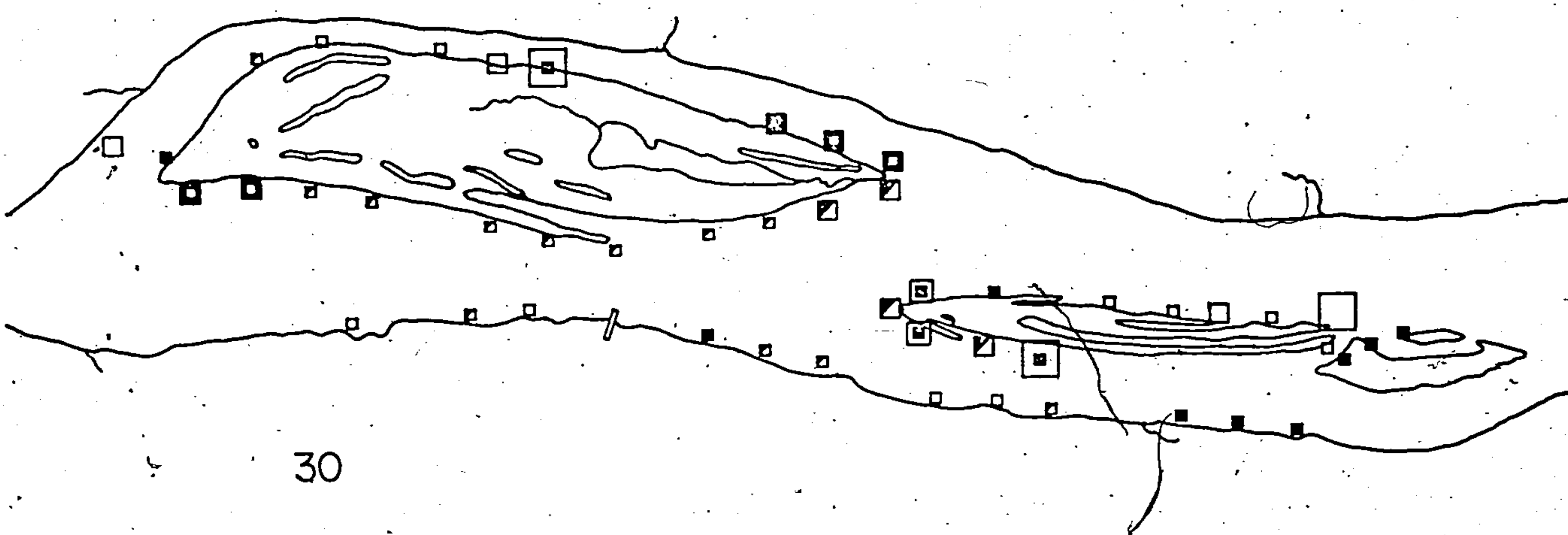
28

Vallisneria americana



29

Elodea canadensis



30

Sagittaria latifolia (Fig. 16) was the most widespread species in the area. It often occurred as the dominant species in mixed stands, where it was interspersed with either single plants or small stands of *Scirpus validus* or *Eleocharis* sp. or single plants to large carpets of *Sparganium eurycarpum*. In some areas separate stands of *Sagittaria latifolia* would alternate with patches of either *Scirpus validus*, *Eleocharis* sp., *Sparganium eurycarpum* or the terrestrial form of *Polygonum amphibium*, but it was also found as the only emergent species. It grew in both fast running water on shores exposed to wind and wave action and in calmer reaches. It was supported by a variety of substrates, even by thick layers of wood chips. The heavy clay was the only substrate which did not support growth of *S. latifolia*.

The size of the species varied considerably. Where the height was the same, the breadth of the leaves ranged from narrow (total area 25 cm^2) to broad (total area 300 cm^2). The different sizes were not confined to any specific areas but the specimens with the largest leaves were mostly found close to shore. Flowers were very abundant. In 1973 shoots were observed to start developing from the old tubers in the first week of June. New tubers started to develop in late August and leaves started to wilt at the same time.

In areas with extensive aquatic vegetation *Sparganium* eurycarpum (Fig. 17) was as common as Sagittaria latifolia. S. eurycarpum covered large parts as a single species or mixed with S. latifolia or Scirpus validus. Although occurring in other areas along the shores it was not as frequent as S. latifolia. It appeared mostly shielded by carpets of floating leaf vegetation such as Polygonum amphibium and/or Sparganium angustifolium. The substrate was the same as for S. latifolia, except it did not grow where wood chips made up the major part of the sediments. Shoots were observed in early June. Flowers were not very common, and the species seemed to develop mainly from rhizomes.

Scirpus validus (Fig. 18) appeared frequently in the study area. Mostly it grew singly or in very small groups of a few plants. It was interspersed with Sagittaria latifolia and or Sparganium eurycarpum. When alternating, along the shoreline, with either of these species, S. validus grew in stands up to 50 m^2 in area. It often reached a height of 140 cm.

One of the Eleocharis sp. (Fig. 19) found in the area had the same growing pattern as S. validus but was not found as frequently. The other Eleocharis sp. was very sparse. The latter occurred in small clumps close to shore or on stumps in water about 10 cm deep.

Scirpus atrocinctus (Fig. 20) was fairly common in some areas. It usually grew in thin stands up on the shore and behind other emergent species. Flowering specimens were frequently found.

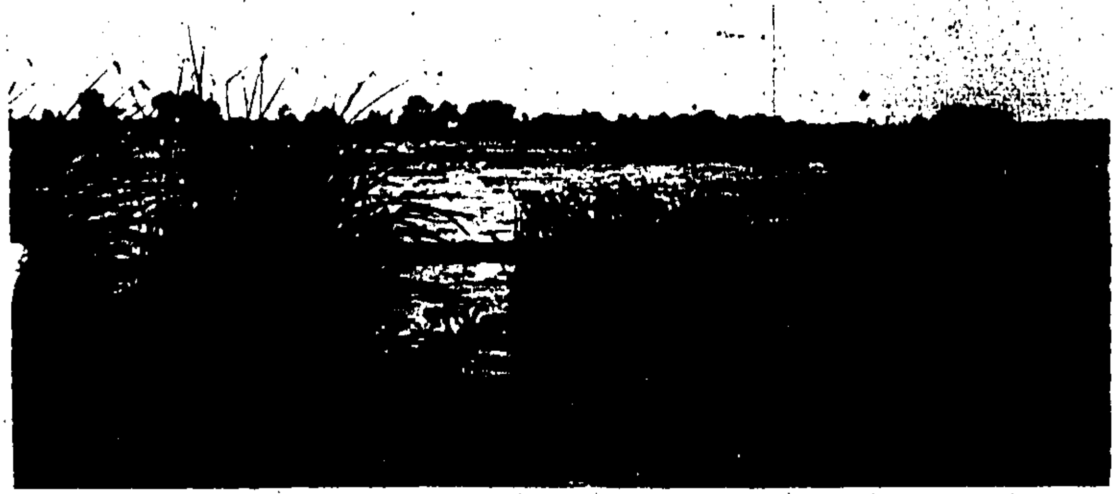
The same stands of Pontederia cordata (Fig. 21) were identified in 1972 and 1973. Small patches of the species could be found inside a S. latifolia stand, but it was more common to find P. cordata separated from and outside other emergent vegetation (Fig. 31). In all areas flowering plants were recorded.

Only two large, pure stands of Typha latifolia (Fig. 22) were recorded in the study area. In late summer of 1973 these were found to be cut down completely, presumably to use for the duck blinds built in the area.

Among the floating leaf plants Polygonum amphibium (Figs. 23 and 32) was the most widespread throughout the study area. It is noteworthy that on the Quebec shore, below the paper mill, there was a terrestrial form of this plant, which was not found elsewhere. The aquatic form did not occur on this side. Elsewhere both forms grew in large carpets and were never interspersed with other species. The terrestrial form alternated with stands of Sagittaria latifolia and Sparganium eurycarpum. The aquatic form often grew submersed in bays described earlier on page 9 or on the sand bars that formed these bays (Fig. 7a and b). Downstream from bay openings, large areas were covered with the species. Here old stumps were frequently found and the substrate consisted of a soft organic mud. Both forms were flowering frequently late in August and long into

Fig. 31 Emergent vegetation (in foreground a stand of *Pontederia cordata*; in background *Scirpus validus* and *Sagittaria latifolia*) on sandy substrate behind a "shielding point" (p. 92) on the north shore of Upper Duck Island. (August, 1973)

Fig. 32 A stand of *Polygonum amphibium* showing typical epiphytic growth of filamentous algae on submersed stems. (August, 1973)



September.

Nymphaea tuberosa (Fig. 24) covered large areas in a few places. It grew in separate stands but close to the aquatic form of Polygonum amphibium. It was one of the earlier species to flower as it was found to bloom in late July. The rhizomes, found while sampling to estimate biomass, were about 3 cm in diameter and had numerous new "rhizome buds" on them.

Nuphar variegatum was very sparse in the area. When it occurred it was always together with Nymphaea tuberosa. A few flowers of the species were found.

Sparganium angustifolium (Fig. 25) was fairly common, and occuppied the same areas in both summers. Separate stands of this species were common on sand bars at the tip or along the islands. It also occurred in smaller patches along the clay shore on the Ontario side. In all areas it was exposed to fairly strong currents and to wave action. Flowers were never observed and the species probably spread only through vegetative reproduction.

Potamogeton epihydrus (Fig. 26) often appeared in two forms mixed in the same stand, a floating and submersed leaf form and a completely submersed leaf form. In 1973 the species had expanded into larger areas than 1972 and had become the dominant species where Vallisneria americana and Sparganium angustifolium had been the most common the summer before. In other areas it had disappeared completely. Sandy bottom supported the dense growth while smaller patches were found on wood chips. Flowers and fruits occurred frequently. According to Mrs. Aiken, some specimens thought to be this plant, were much more branched than is usual for this species, which might have been the result of water chemistry (Aiken, Personal Communication).

Potamogeton Richardsonii (Fig. 27) grew in the same areas as P. epihydrus, but also occurred as single plants among Vallisneria americana.

A Potamogeton sp. with branched narrow leaves (Fig. 28) frequently occurred among Vallisneria americana or Sparganium angustifolium along one shore in 1973. Only a few specimens were found growing together. The plant was never observed to flower. In 1972 a similar Potamogeton sp., possibly the same, occurred along the same shore.

Vallisneria americana (Fig. 29) was the most widespread submersed species. Dense, fairly large carpets were found in both sheltered and open areas, but smaller patches which were spread over large shallow areas were more common. The substrate varied from heavy clay to coarse sand. It was found to be abundant and most common in water 0.6 to 2 meters deep, and it did not grow below 3 meters. In 1973 the species had spread to distances of 125 m from shore. In 1972 it was not found more than 75 m away from the shoreline in these areas. Flowers were found to be abundant in some sheltered areas but also occurred in fast flowing water,

Elodea canadensis (Fig. 30) was found more frequently in 1972 than 1973. In both summers it appeared in small patches often on sandy substrates. In 1972 it also occurred on portions of the river bottom covered with wood chips. Flowers were not observed in the study area. In the sheltered bay on Kettle Island, however, flowers were found in great numbers.

Two species of macro algae were found in the area. These were a Nitella sp. and a Chara sp.. Nitella sp. occurred on sandy bottoms in deep water outside other vegetation or in very shallow water where wave action presumably hindered other growth. The Chara sp. was found only in 1972. This species was found in the same type of habitat as Nitella sp.

The moss Fontinalis antipyretica was found in small quantities in the summer of 1973. It grew on sandy bottom in water about 1.5 m deep. It was observed both in the winters of 1972 and 1973 in a few areas on the south side of Kettle Island. Either it had been overlooked in the summers or it could grow more abundantly in the winter season when competition from other species was minimal (Daubenmire 1968).

4.2 Macrophyte Associations in 1972 and 1973

In order to get an idea how the physical and chemical characteristics of the water as well as the type of shorelines and bottom sediments have affected the plant communities, it is convenient to divide the study area into ten areas in all. The areas are A. the Quebec shore (in Tables 2 and 4 divided into west and east sides), B. Quebec side of Kettle Island, C. Quebec side of Upper Duck Island, D. Quebec side of Lower Duck Island, E. Ontario side of Kettle Island, F. Ontario side of Upper Duck Island, G. West side of Lower Duck Island, H. Ontario side of Lower Duck Island, I. Ontario shore and J. Western Points of Kettle Island and Upper Duck Island.

The number of species on each shore is recorded in Figs. 33 and 34 for summer 1972 and 1973 respectively. In the same figures the number of species commonly found on the shore is added (Table 4). Only 17 of the 42 species were found to be common in the area and the records were very similar in the two summers. Six species appeared to be widespread in the 5 km long study section in both years, while 3 were confined to only one shore.

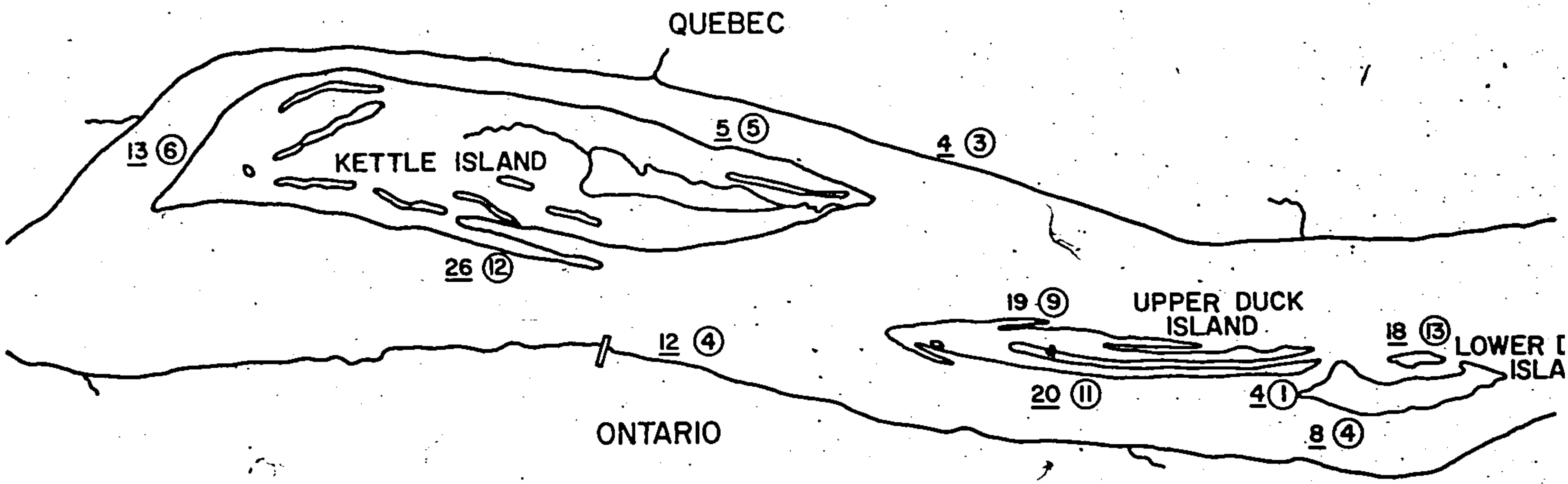
Observations on the Ten Shores (Fig. 15)

A. Quebec shore

A striking contrast in vegetation was observed above and below the CIP paper mill during both summers of the survey. In the study area above the paper mill where there were large numbers of floating logs, it was not practical to survey the area for plants.

Fig. 33 Total number of species (underlined) and number of common species (circled) on each shore of the study area (1972).

Fig. 34 Total number of species (underlined) and number of common species (circled) on each shore of the study area (1973).


QUEBEC
13 (6)
5 (5)
4 (3)
KETTLE ISLAND
26 (12)
12 (4)
19 (9)
UPPER DUCK ISLAND
18 (13)
LOWER D ISLA
20 (11)
4 (1)
8 (4)
ONTARIO

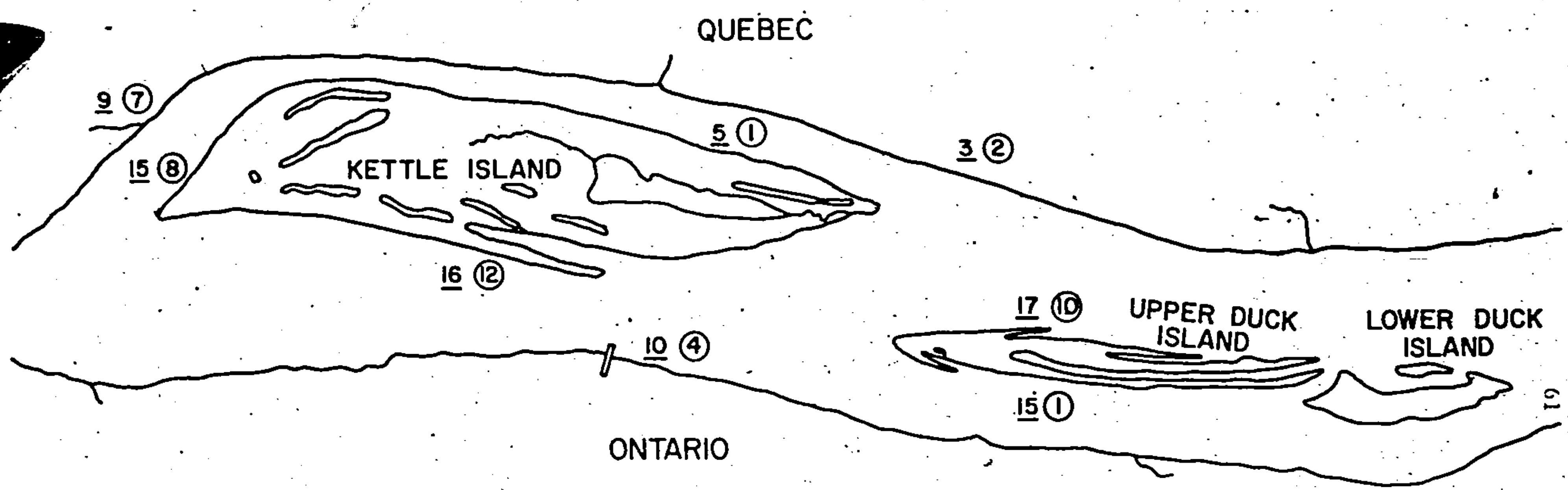

QUEBEC
9 (7)
15 (8)
5 (1)
3 (2)
KETTLE ISLAND
16 (12)
10 (4)
17 (10)
UPPER DUCK ISLAND
LOWER DUCK ISLAND
15 (1)
ONTARIO

TABLE 4. Common species in the study area and the shore location where they were dominant. Species divided into the four morphological groups: 1. emergent plants, 2. floating leaf plants, 3. plants with floating and submersed leaves and 4. submersed plants.

Species	Quebec shore west* (1)	Quebec shore east (2)	Kettle Island north west (3)	Kettle Island north east (4)	Upper Duck Island north (5)	Kettle Island south (6)	Upper Duck Island south (7)	Ontario shore (8)	Lower Duck Island north** (9)	Lower Duck Island south** (10)	Lower Duck Island west** (11)
1. Eleocharis sp. (50-90 cm high)						Xx	Xx		X		
Polygonum amphibium (terrestrial form)		Xx									
Pontederia cordata					Xx	Xx	Xx		X		
Sagittaria latifolia	x	Xx	Xx	Xx	Xx	Xx	Xx		X	X	
Scirpus atrosinctus						Xx			X		
S. validus			Xx		Xx	Xx	Xx		X		
Sparganium eurycarpum	x	X†	X		Xx	Xx	Xx		X	X	
Typha latifolia					X	Xx	Xx		X		
2. Nymphaea tuberosa	x		Xx		Xx	Xx	Xx		X		
Polygonum amphibium (floating form)	x					Xx	Xx		X	X	
Sparganium angustifolium	x		Xx		Xx	Xx	Xx	Xx	X	X	

TABLE 4 (cont'd)

3. Potamogeton epihydrus		x	X	x[a]					
4. Elodea canadensis	x	x	X	Xx	Xx	Xx	Xx	X	
Najas flexilis								X	
Potamogeton Richardsonii		x	X	x[a]					
P. sp. (branched narrow leaves)							Xx		
Vallisneria americana	x	Xx	X	Xx	Xx	Xx	Xx	X	X

* only mapped in 1973

** only mapped in 1972

† occurred in the same area also 1973, but this was outside the 5 km study section both summers.

Further upstream (area 1, Tables 2 and 4) both shoreline vegetation and rooted aquatics in deeper water were abundant. Downstream from the CIP paper mill (area 2, Tables 2 and 4) the bottom was covered with wood chips and fine silt. The quantities of microbiological growth consisting mainly of Sphaerotilus, that occurred on stumps and logs in the shallow water as well as on any emergent vegetation, decreased as the distance from the mill increased. The shoreline below CIP was characterized by sparse aquatic plant growth (Fig. 35). The first 2700 m had only a few patches of emergent plants covering about 0.5% of the area in this distance. A few shorter stretches had also been disturbed by private developments. Downstream the plants became more frequent. There was no submersed vegetation along the whole shore, however Sagittaria latifolia was one of the three species found on this shore. The second species Polygonum amphibium, as described earlier in the text, below the CIP paper mill had a tendency to climb up on the shoreline. Sparganium eurycarpum has not been recorded as pollution tolerant, but it certainly appeared to be in this location, as it started to appear where the water was still severely affected by pulp mill effluent.

B. Quebec Side of Kettle Island

Shoreline trees often overhang the water (Fig. 36). In the approximate center of this shore (areas 2 and 3, Tables 2 and 4), across from the CIP paper mill, there was a storage area for

Fig. 35 Quebec shore below CIP. For 2700 m there is no aquatic vegetation. (August, 1972)

Fig. 36 Sagittaria latifolia among overhanging tree branches on the north shore of Kettle Island below the paper mill. (September, 1973)

logs in both summers. The western end of this shore had quantities of both submersed and emergent vegetation (Figs. 37, 38 and 39). Several of the most common species in the study area were found here, Vallisneria americana being the most abundant species.

On the eastern end, where the paper mill effluent water reached across the channel to the island, the bottom was covered with the characteristic wood chips and silt as previously described. A difference was found in this area between the two summers. In 1972 five species were recorded, all being common, down to the last 100 m before the tip of the island. In 1973 only one species was found in any abundance and the other four species recorded here appeared as either a few scattered specimens (Vallisneria americana, Elodea canadensis and Potamogeton Richardsonii) or in a single patch as in the case of P. epihydrus. In both summers Sagittaria latifolia was the only plant in shallow water (Figs. 40, 41 and 42), and the same stands were found in 1972 and 1973. In 1972, the four deep water species grew in a narrow band at a depth of 60 to 100 m. The most interesting of these was Potamogeton epihydrus, as this was the only area in the study section where it occurred over a substantial distance.

C. Quebec Side of Upper Duck Island

The effluent water from the paper mill would sometimes be distinguished from the Ottawa River water because of its light brown colour and was not observed to reach this shore (area 5, Figs. 37 and 38 Sagittaria latifolia and Nymphaea tuberosa behind "shielding point" (p. 92) on Kettle Island. Sparganium angustifolium in the background. (Patric Pang is holding the one square meter metal frame used in biomass sampling). (August, 1972)

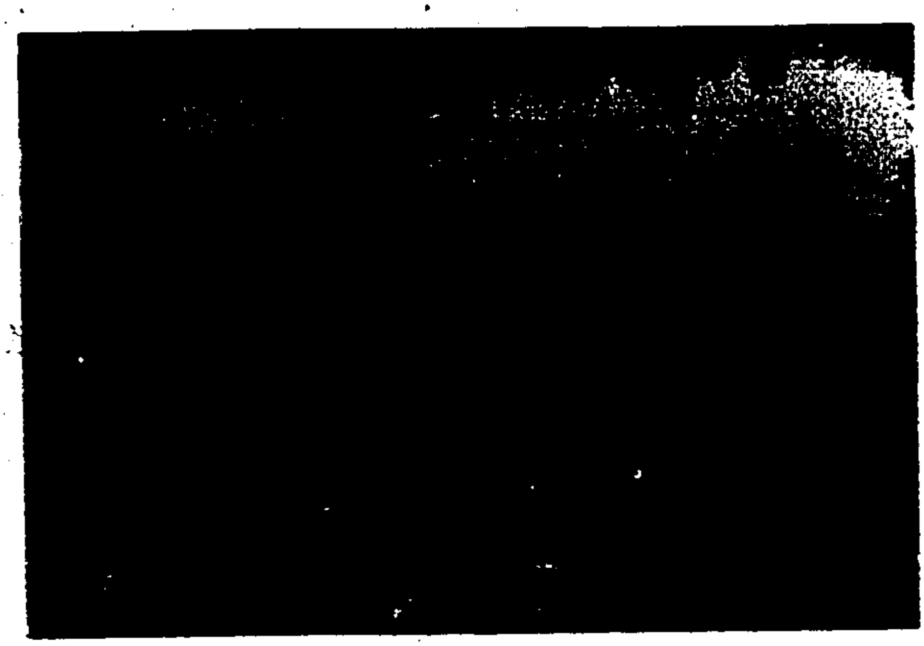
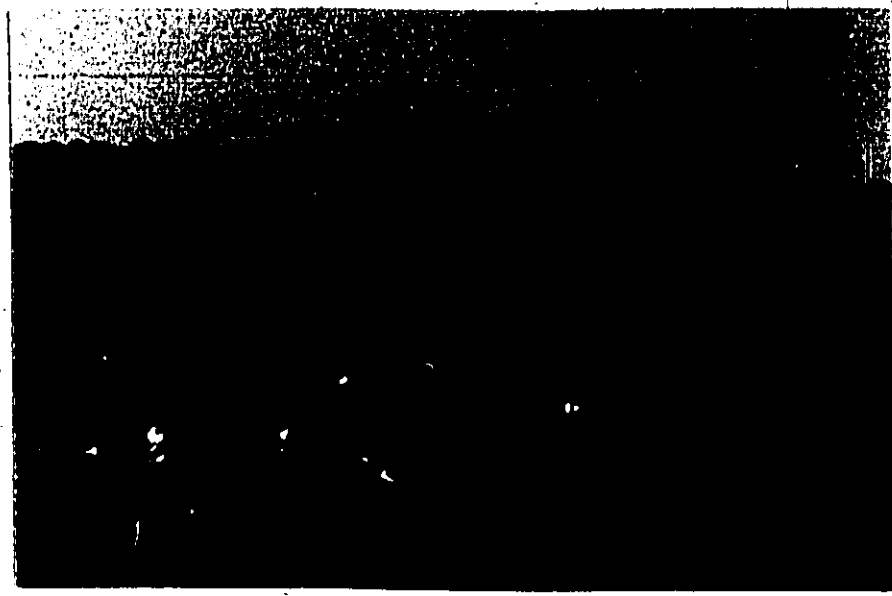
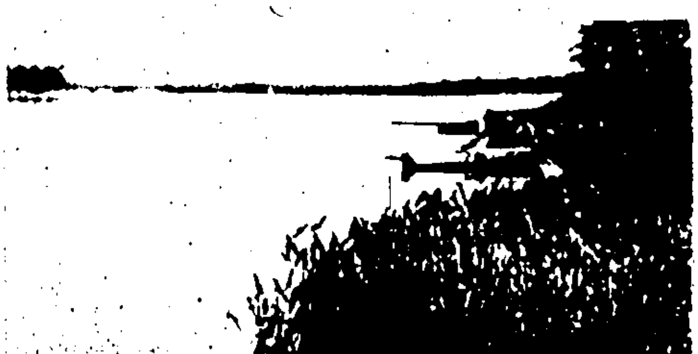


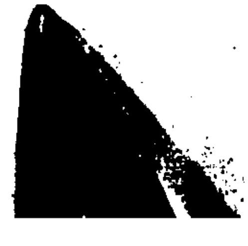
Fig. 39 Picture taken from the same area as Figs. 37 and 38 in the summer of 1973. The species <u>Nymphaea tuberosa</u> reappeared in 1973 in the same numbers while <u>Sagittaria latifolia</u> had disappeared in some places. Submersed and floating leaf plants appeared on the shallow sandbanks tapering off upstream (<u>Sparganium angustifolium</u> can be seen in the background). (August, 1973)

Fig. 40 <u>Sagittaria latifolia</u>, first aquatic plant to be capable of colonizing the shoreline below the CIP paper mill. (September, 1973)





Figs. 41 and 42 *Sagittaria latifolia* appearing to be healthy in the polluted water along the north shore of Kettle Island below the paper mill. Logs, wood chips and an oil film is floating on the water. (August, 1972)



Tables 2 and 4). Rather, it seems, through investigations done in the area in 1973 (Warnock), that the water flowing between the Ontario shore and Kettle Island splits at the upstream tip of Upper Duck Island and similar water therefore follows both the north and south shore of the island. Summer cottages and docks were frequent on the north shore. Outside these there was very sparse growth in water surveyed at a depth of 0 to 1.5 m. Towards the western end of the island the growth became much more dense behind the point. Most of the common species occurred here. Further downstream the shore had the appearance of having been washed away and there was almost no emergent vegetation. In 1972 Najas flexilis was found on this shore in a large carpet mixed with dense Vallisneria americana.

D. Quebec Side of Lower Duck Island (Surveyed only in 1972)

This shore (area 9, Tables 2 and 4) was also protected from the CIP effluent by the same flow that protected Upper Duck Island. A strait was formed here because of a small island situated north of the main island. Where this strait opens upstream, it was sheltered from the full impact of the current partly because of the position of the main island, and partly by a large shallow sand bar stretching out from the strait between Upper Duck Island and Lower Duck Island toward the lighthouse indicated in Fig. 15. As terrestrial vegetation was low along the shore, there was little shielding from the sun over the strait.

All the common species of 1972 were found here. Sagittaria latifolia interspersed with some Sparganium eurycarpum formed an enormous carpet of about 5000 m^2. Pontederia cordata formed larger patches than in any other surveyed area. The north shoreline of the small island was steep. As a result only submersed vegetation was found here.

E. Ontario Side of Kettle Island

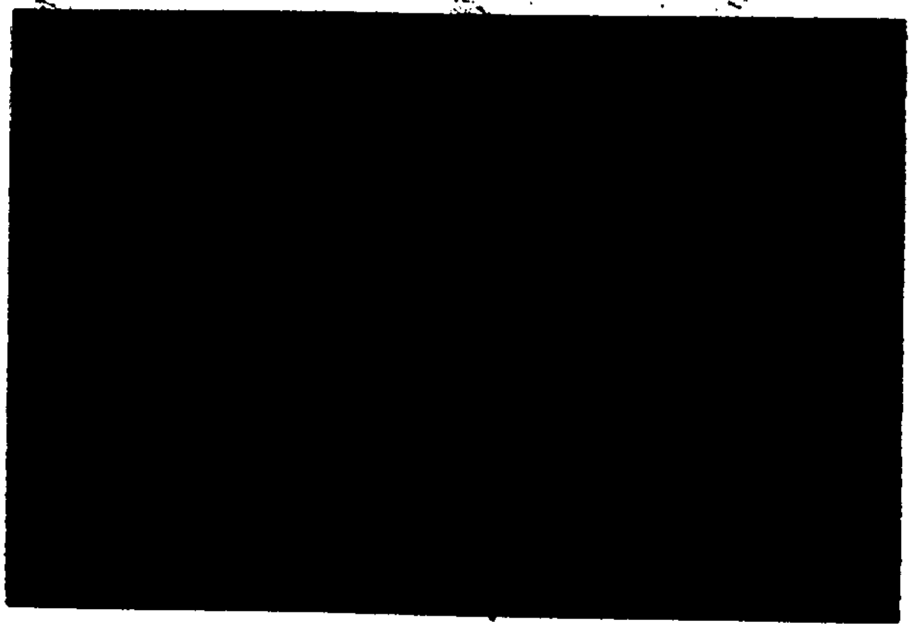
At the western end, where this shore (area 6, Tables 2 and 4) had an area with a sand bar going from the shore towards the east, fairly dense growth occurred in the two summers both on and inside the sand bar (Fig. 43). In 1972 all the common species were found except Typha latifolia. In 1973 the same species reappeared and a few T. latifolia plants occurred.

The densest vegetation of the whole area was found at the entrance to the bay near the midpoint of the shoreline (Figs. 44-47). All the common species appeared in large carpets. Further downstream the shore often dropped away suddenly and the emergent vegetation diminished as shown in Figs. 48 and 49. Submersed vegetation was abundant, Vallisneria americana being the dominant species. Tree stumps and a number of shallow sandy beaches appeared along the middle of this side of the island (Figs. 50-53). Very sparse or no emergent vegetation was found here. Sometimes Elodea canadensis and a few small patches of Vallisneria americana would be found in this kind of habitat but mostly the bottom was covered with carpets of periphyton.

Fig. 43 South shore of Kettle Island. Patches of Polygonum amphibium colonizing the outer margin of a sandbar. Emergent vegetation along the shore consists mainly of Sagittaria latifolia and Scirpus validus with the floating leaf species Sparganium angustifolium colonizing slightly deeper water (60-90 cm). (August, 1973)

Fig. 44 Very dense aquatic vegetation (Sagittaria latifolia mixed with small stands of Scirpus validus) at opening of the bay on the south shore of Kettle Island. (One square meter has been sampled for estimates of biomass and standing crop.) (August, 1973)

Fig. 45 Carpet of Sparganium angustifolium at opening of bay on the south shore of Kettle Island (Polygonum amphibium and Nymphaea tuberosa in background). (August, 1973)



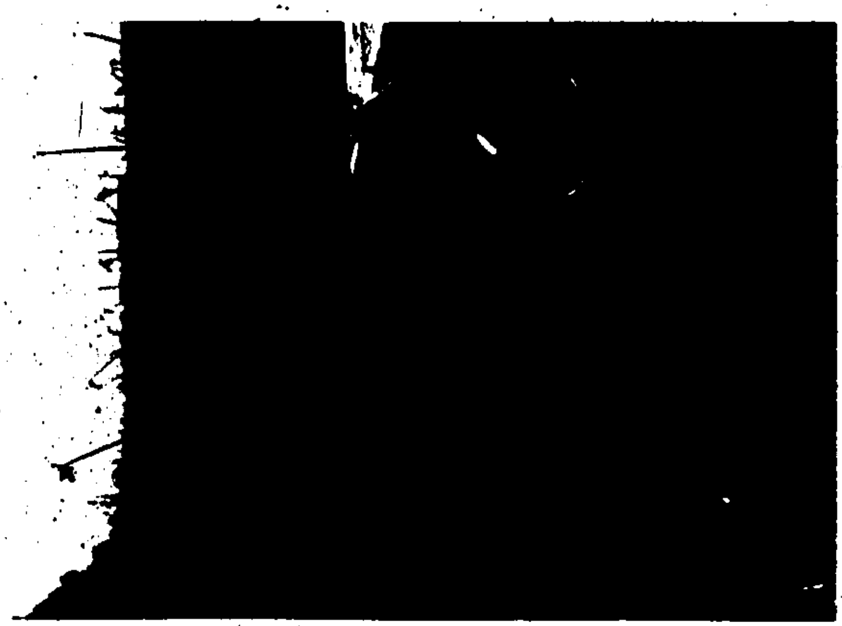
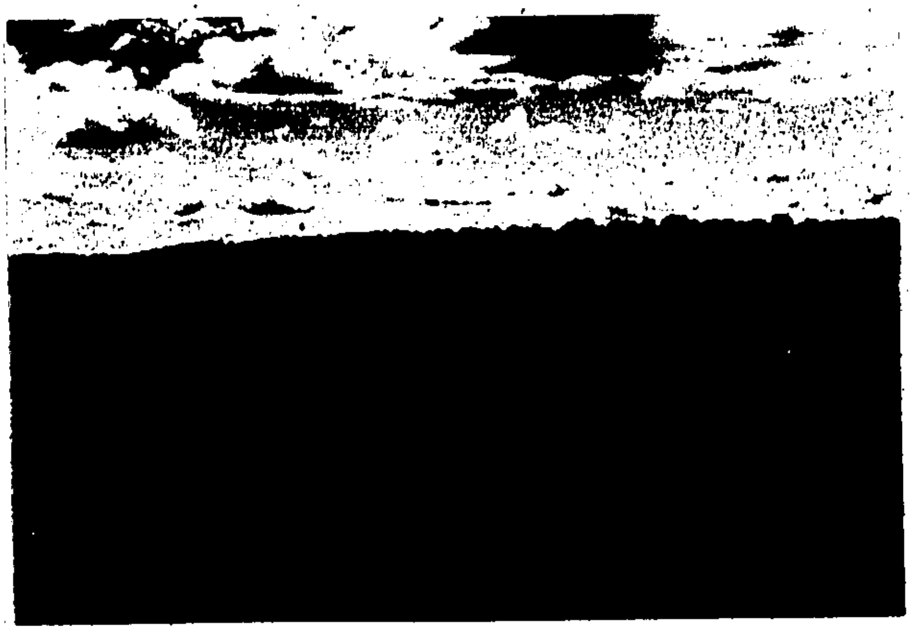
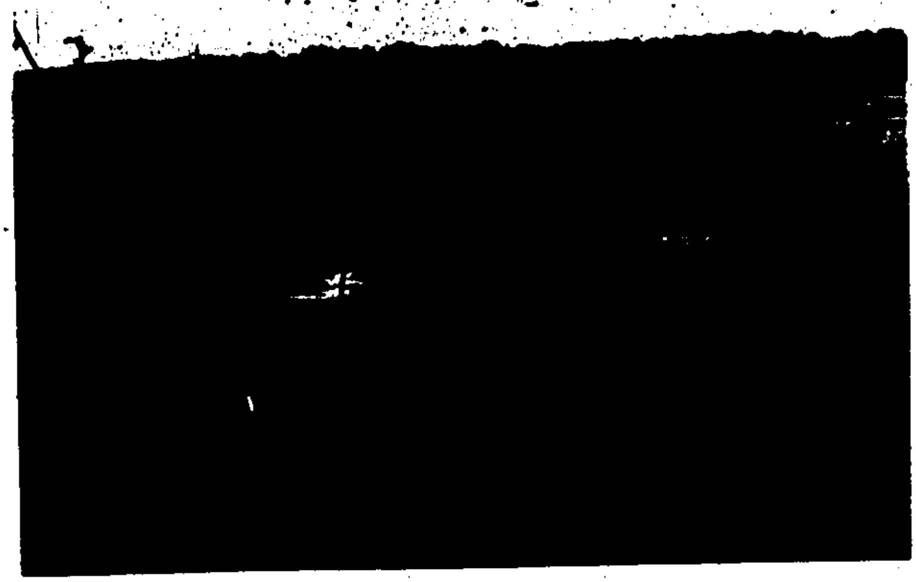


Fig. 46. Small stands of *Pontederia cordata* emerge earlier than *Scirpus validus* and *Sagittaria latifolia* in the month of July. This stand of *P. cordata* was later surrounded by other plant growth as in Fig. 47. (July, 1972)

Fig. 47 Dense growth of the emergent plants *Scirpus validus* mixed with *Sagittaria latifolia* and *Pontederia cordata* at the opening of the bay on the south shore of Kettle Island. The latter species bears purple flowers (above oar in the boat). Further out in shallow water (60-90 cm) large stands of the floating leaf species *Sparganium angustifolium*, *Polygonum amphibium* and *Nymphaea tuberosa* are growing. (August, 1972)





Figs. 48 and 49 Thin stands of Sagittaria latifolia appear on the south sides of Kettle Island, Fig. 48 and Lower Duck Island, Fig. 49, where shores are exposed to wind and current. (Mary Secord is sampling the vegetation for estimates of biomass.) (July, 1972)

Fig. 50 Large tree stumps appear frequently along the island shores. (July, 1972)

Fig. 51 Tree stumps and tufts of Graminea dominated the shoreline, middle of Kettle Island South shore. Note the absence of emergent vegetation which presumably results from intense wave action. (August, 1973)

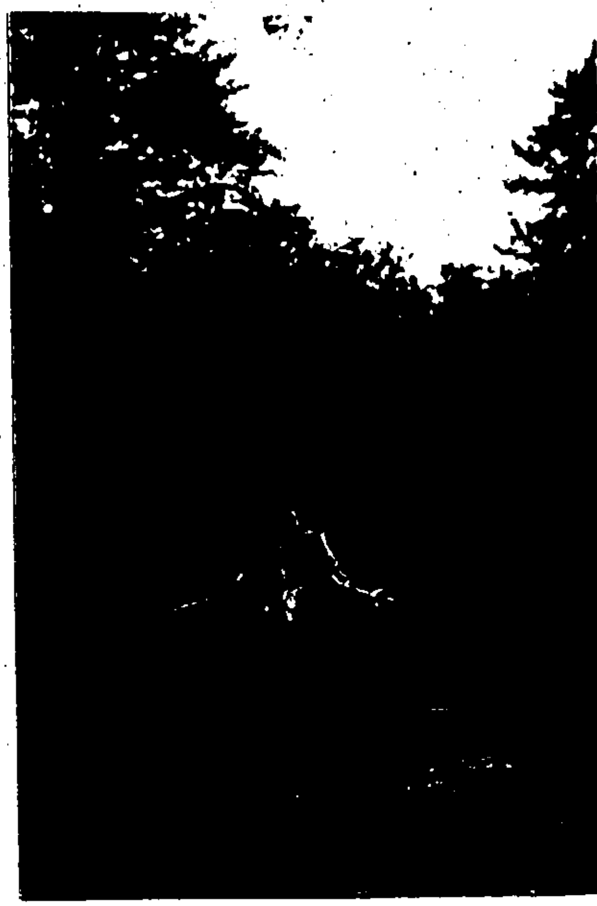


Fig. 52 Some sandy beaches appear on the south shore of Kettle Island. Macrophytes are sparse, but thick carpets of epipelic periphyton are common. (August, 1973)

Fig. 53 Sparse emergent vegetation along the middle of the south shore of Kettle Island. Scirpus validus dominates the foreground. (August, 1973)

F. Ontario Side of Upper Duck Island

At the western end of this island (area 7, Tables 2 and 4), there was an area of tree stumps under water and many dead tree branches emerging from the water (position marked in Fig. 15). In this area *Polygonum amphibium* and many submersed species grew at high densities. The vegetation diminished from west to east along the island. Broad and dense vegetation occurred again at the bay opening and continued over a longer distance than on the other two islands. This was probably a consequence of the shallow bank of old stumps following the shorelines (Figs. 54 and 55). Patches of *Eleocharis* sp. alternating with patches of *Sagittaria latifolia* were characteristic of the emergent vegetation of this area.

G. West Side of Lower Duck Island (Surveyed only in 1972)

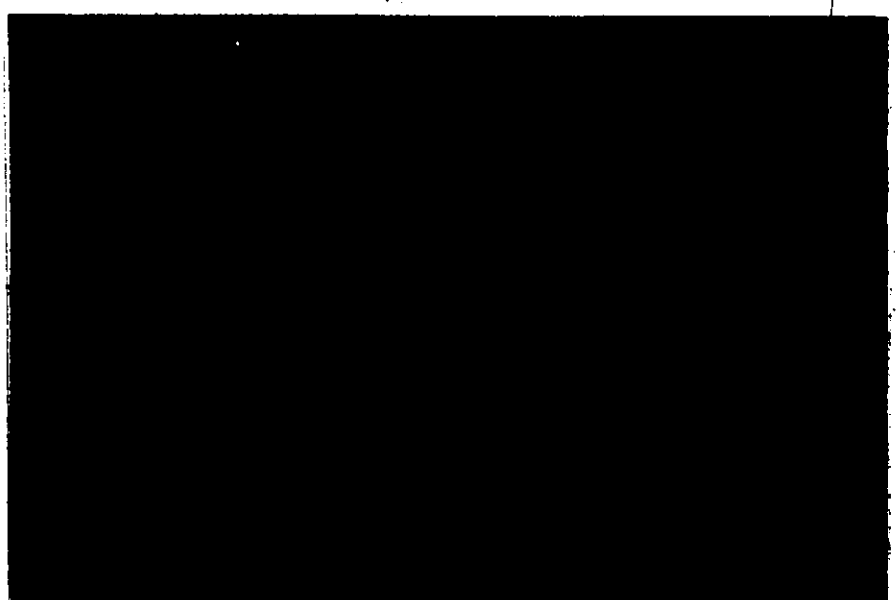
The shore (area 11, Tables 2 and 4) was open to current, parts of it were steep and the region closest to the Quebec side was rocky. Almost the whole area was shaded by high trees. Submersed vegetation was common with *Vallisneria americana* as dominant species. Emergent plants were only found in the area closest to the Ontario side which was exposed to light.

H. Ontario Side of Lower Duck Island

Emergent vegetation was sparse along the whole shore (area 10, Tables 2 and 4; Fig. 49). Submersed plants were common.

Fig. 54 Emergent and floating leaf vegetation are common behind the "shielding points" (p. 92) and among the tree stumps on the south shore of Upper Duck Island. (August, 1973)

Fig. 55 The emergent vegetation is almost completely wilted in October. Picture taken over the same area as Fig. 54. (October, 1972)



Off the shore Polygonum amphibium and Sparganium angustifolium formed a large carpet. Nearer the shore quantities of Najas flexilis were found.

I. Ontario Shore

As described above this shore (area 8, Tables 2 and 4) had been disturbed in many areas by man and by erosion from the steep clay bank. The steep bank is often densely populated with trees which shade the near shoreline and the littoral zone (Figs. 56 and 6). Emergent vegetation in this area was sparse and only a few patches of floating leaf vegetation were found. The only abundant aquatic plant in this area was Vallisneria americana. This was again found to be abundant and most common in water 0.6 to 2 meters deep, and did not grow below 3 meters. It was rare in the water closest to the shore between zero and 0.6 m in depth. Presumably this shallow region was disturbed by wave action. This is similar to what was found on the Ontario side of Kettle Island along the eastern part of the island. Vallisneria americana was frequently associated with Potamogeton sp., a plant with branched narrow leaves.

J. Western Points of Kettle Island and Upper Duck Island

The shores of the western or upstream ends of these islands (included in areas 3 and 5, Tables 2 and 4) were very similar, with their shallow sand banks tapering off the shore upstream. Only submersed and floating leaf plants were found there

Fig. 56 Eroded river bank on Ontario shore in which trees become uprooted and/or slide into the water. (August, 1972)

(Fig. 39). In 1972 Vallisneria americana and Sparganium angustifolium were dominant species. Potamogeton epihydrus and P. Richardsonii occurred in smaller amounts. In 1973 the same stands of V. americana and S. angustifolium were found but P. epihydrus and P. Richardsonii had covered considerably larger areas. At Kettle Island in 1972 Nitella sp. occurred only at the western point.

4.3 Biomass and Standing Crop

In 1972 the total growth area was 9.0 ha while it extended to 24.0 ha in 1973 (Table 17). This was 1.8% and 4.6% respectively of the total river area* within the study-section. In both years the shallow water vegetation, consisting mainly of emergent species, occupied a smaller area than the deep water vegetation, which consisted of floating leaf, floating and submersed leaf and submersed forms. The emergent vegetation reappeared in the summer of 1973 within the same areas where it was found the previous year. In 1972 the growth area of the emergent vegetation was estimated to be 2.0 ha (23% of the total plant coverage) and in 1973 the growth area had increased to 2.4 ha, which, because of the large increase in total growth area, was only 10% of total plant coverage. In the second year of surveying, the deep water vegetation had spread out over an area which was about 3 times larger than in the first year. Its coverage had extended from 7.0 ha in 1972 to 21.6 ha in 1973. The largest vegetation areas were found around the islands and above the CIP paper mill in both summers. Very little aquatic growth appeared on the Quebec shore below the CIP paper mill. Practically no emergent forms were found along the Ontario shore, but submersed forms covered fairly large areas in this region.

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* Total river area (503.6 ha) was calculated from Warnock and co-workers (1974).

Total fresh weight, percent dry weight and percent ash free dry weight (the two latter based on whole biomass of the sample) of standing crop and underground parts of all samples, taken in 1972 and 1973, are recorded in Tables 5 and 6. Dry weights are given in Tables 7 and 8. The species composition of each sample is shown in Tables 9 and 10.

It can be noted from Tables 9 and 10 that in both years the most important emergent species was Sagittaria latifolia. This species occurred in most of the shallow water sampling stations. In samples with the highest biomass, S. latifolia was the dominant species and the vegetation could be very dense. As an example it can be mentioned that sample 16S of 1973, with the highest weight recorded, contained 250 stems per m^2. Among the deep water plants, Vallisneria americana was the species most frequently occurring in the samples.

The groups that were compiled from sampling stations with similar types of vegetation for total biomass and standing crop estimates in 1972 and 1973 are indicated in Tables 11 and 12. The mean, maximum and minimum values of fresh weight and dry weight of the 1972 groups are listed in Tables 13 and 14. Mean values and standard deviation of each mean for groups collected in 1973 are included in Table 12.

TABLE 5 Fresh weight, percent dry weight and percent ash free dry weight based on total fresh weight of samples for biomass and standing crop estimates in 1972

Station	Date	total sample (g fresh wt./m^2)	% root of total	SHOOT* fresh wt. (g/m^2)	SHOOT* % dry wt.	SHOOT* % ash free dry wt.	ROOT* fresh wt. (g/m^2)	ROOT* % dry wt.	ROOT* % ash free dry wt.
11S[a]	July 11	1238	50	624	12	10	614	11	6.9
4S[a]	July 14	1908	18	1558	15	12	350	4.0	2.9
14S[a]	July 17	172	36	110	8.1	4.6	62	4.6	-
3S	Aug. 16	1514	46	812	8.0	7.0	702	5.0	4.1
1S	Aug. 17	375	40	229	11	9.8	146	5.3	4.8
10S	Aug. 21	974	9	887	7.2	6.3	87	1.0	0.6
19S	Aug. 22	4180	14	3574	8.5	7.7	606	2.0	1.4
15S	Aug. 25	3779	19	3072	7.3	6.5	707	1.5	1.1
18S	Aug. 25	1604	57	697	6.9	6.1	907	12	10.7
21S	Aug. 26	30	43	17	10	6.6	13	6.6	6.6
8S	Aug. 28	1043	19	846	7.2	5.6	197	1.9	1.3
3D	Aug. 29	711	16	599	6.7	5.9	112	1.5	1.2
4D	Aug. 29	387	19	315	14	9.8	72	2.3	2.0
7D	Aug. 21	496	13	431	12	8.6	65	1.8	1.4
10D	Aug. 31	327	11	292	11	7.9	35	1.2	0.9
11D	Aug. 31	176	1	175	15	13	1.2	0.1	0.1
19D	Aug. 31	272	6	257	11	9.5	15	0.7	0.4
14D	Sept. 1	224	12	197	13	9.8	27	1.3	0.9
18D	Sept. 1	45	36	29	11	6.6	16	4.4	4.0

a) Samples taken with a ¼ m^2, all other samples taken with a 1 m^2

* Shoot and Root refer to plant material above and below sediment surface respectively
S Samples taken in shallow water (0 to 60 cm)
D Samples taken in deep water (60 to 100 cm)

TABLE 6 Fresh weight, percent dry weight and percent ash free dry weight based on total fresh weight of samples for biomass and standing crop estimates in 1973

				SHOOT*			ROOT*		
Station	Date	total sample (g fresh wt./m^2)	% root of total	fresh wt. (g/m^2)	% dry wt.	% ash free dry wt.	fresh wt. (g/m^2)	% dry wt.	% ash free dry wt.
1S	Aug. 6	2569	19	2076	8	7	493	2	2
5S	Aug. 9	1429	14	1232	7	6	197	2	1
6S	Aug. 14	4116	6	3874	7	6	242	0.5	0.3
7S	Aug. 14	1602	7	1493	8	6	109	0.5	0.4
10S	Aug. 15	2543	13	2222	7	6	321	1	0.8
12S	Aug. 16	2994	7	2780	9	8	214	1	0.5
13S	Aug. 21	2770	17	2312	11	10	458	2	2
14S	Aug. 21	1727	19	1402	6	5	325	1	1
15S	Aug. 24	3090	19	2514	9	7	576	2	2
16S	Aug. 24	6007	18	4947	8	6	1060	1	1
17S	Aug. 27	1378	18	1134	8	7	244	2	2
18S	Aug. 27	4442	16	3715	7	6	727	1	1
2D	Aug. 6	393	4	376	12	11	17	1	0.5
3D	Aug. 7	191	20	152	7	5	39	2	0.1
4D	Aug. 7	92	0	92	8	7	0	-	-
8D	Aug. 15	628	0	628	17	14	0	-	-
9D	Aug. 15	1880	40	1137	8	7	743	5	5
11D	Aug. 16	2382	38	1467	6	6	915	5	4
19D	Aug. 29	292	3	284	4	3	8	0.3	0.2
20D	Aug. 29	299	3	289	7	5	10	0.3	0.2
21D	Aug. 29	972	2	949	5	4	23	0.2	0.1
22D	Aug. 30	961	1	948	6	5	13	0.2	0.1
23D	Aug. 30	2344	3	2277	5	4	67	0.3	0.2
24D	Sept. 4	1054	1	1047	6	4	7	0.1	0.0

TABLE 6 (cont'd)

Station	Date	total sample (g fresh wt./m^2)	% root of total	SHOOT* fresh wt. (g/m^2)	SHOOT* % dry wt.	SHOOT* % ash free dry wt.	ROOT* fresh wt. (g/m^2)	ROOT* % dry wt.	ROOT* % ash free dry wt.
26D	Sept. 5	922	5	876	6	4	46	0.4	0.3
27D	Sept. 5	946	1	940	5	4	6	0.1	0.1

All samples were taken using a one m^2 quadrat
* Shoot and Root refer to plant material above and below sediment surface
S Samples taken in shallow water (0 to 60 cm)
D Samples taken in deep water (60 to 150 cm)

TABLE 7 Dry Weight of Samples for Biomass Estimates 1972

Station	Date	Shoot Dry wt. (g/m²)	Root Dry wt. (g/m²)	Total Dry wt. (g/m²)
11S[a]	July 11	150	135	287
4S[a]	July 14	280	77	357
14S[a]	July 17	14	8	22
3S	Aug. 16	122	77	199
1S	Aug. 17	41	20	61
10S	Aug. 21	71	10	81
19S	Aug. 22	357	85	442
15S	Aug. 25	276	57	333
18S	Aug. 25	112	192	304
21S	Aug. 26	3	2	5
8S	Aug. 28	76	20	96
3D	Aug. 29	48	11	59
4D	Aug. 29	54	9	63
7D	Aug. 21	60	9	69
10D	Aug. 31	35	4	39
11D	Aug. 31	26	0.3	26
19D	Aug. 31	31	2	33
14D	Sept. 1	28	3	31
18D	Sept. 1	5	2	7

S shallow water vegetation

D deep water vegetation

a) samples were taken with a ¼ m^2 quadrat

TABLE 8 Dry weight of samples for biomass estimates 1973

Station	Date	Shoot Dry wt. (g/m^2)	Root Dry wt. (g/m^2)	Total Dry wt. (g/m^2)
1S	Aug. 6	198	56	254
5S	Aug. 9	98	26	124
6S	Aug. 14	301	20	321
7S	Aug. 14	127	8	135
10S	Aug. 15	189	28	217
12S	Aug. 16	260	20	280
13S	Aug. 21	299	55	354
14S	Aug. 21	110	21	131
15S	Aug. 24	268	56	324
16S	Aug. 24	456	76	532
17S	Aug. 27	116	29	145
18S	Aug. 27	304	50	354
2D	Aug. 6	48	2	50
3D	Aug. 7	14	3	17
4D	Aug. 7	7	0	7
8D	Aug. 15	104	0	104
9D	Aug. 15	144	101	245
11D	Aug. 16	148	111	259
19D	Aug. 29	13	.8	14
20D	Aug. 29	20	1	21
21D	Aug. 29	53	2	55
22D	Aug. 30	55	2	57
23D	Aug. 30	111	6	117
24D	Sept. 4	59	.6	60
26D	Sept. 5	51	4	59
27D	Sept. 5	49	.5	50

TABLE 9 Main species in samples used for biomass estimates in 1972

Station	Species
11S	species unknown
4S	species unknown
14S	species unknown
3S	Sagittaria latifolia
1S	Nymphaea tuberosa
10S	Sagittaria latifolia
19S	Sagittaria latifolia
15S	Sagittaria latifolia
18S	Sparganium eurycarpum (60%) (Eleocharis sp.) (40%)
21S	Equisetum sp.
8S	Sagittaria latifolia
3D	Sparganium angustifolium
4D	Vallisneria americana
7D	Vallisneria americana
10D	Elodea canadensis
11D	Elodea canadensis
19D	Elodea canadensis, Vallisneria americana
14D	Vallisneria americana
18D	Vallisneria americana

TABLE 10 Main species in samples used for biomass estimates in 1973

Station	Species
1S	Sagittaria latifolia, Scirpus validus[a]
5S	Sagittaria latifolia, Scirpus validus[a]
6S	Sagittaria latifolia[a]
7S	Sagittaria latifolia[a]
10S	Sagittaria latifolia[a]
12S	Sagittaria latifolia[a]
13S	Sagittaria latifolia, Sparganium eurycarpum[a]
14S	Sagittaria latifolia[a]
15S	Sagittaria latifolia, Sparganium eurycarpum[a]
16S	Sagittaria latifolia[a]
17S	Sparganium eurycarpum[b]
18S	Sagittaria latifolia[a]
2D	Sparganium angustifolium, Polygonum amphibium[a]
3D	Vallisneria americana[b]
4D	Potamogeton epihydrus[b]
8D	Polygonum amphibium[a]
9D	Polygonum amphibium, Nymphaea tuberosa[a]
11D	Nymphaea tuberosa[a]
19D	Vallisneria americana[a]
20D	Vallisneria americana[b]
21D	Vallisneria americana[a]
22D	Sparganium angustifolium[a]
23D	Vallisneria americana[a] (picked by hand)
24D	Vallisneria americana[a]
26D	Vallisneria americana, Sparganium angustifolium[a]
27D	Vallisneria americana[a]

a) sampled in dense vegetation

b) sampled in sparse vegetation

TABLE 11 Sample stations with the same vegetation associations grouped together for biomass and standing crop estimates 1972 and shores where these associations were applied

Sample stations		Shores
4S	11S	Quebec west, Kettle Island south
4D	11D	Quebec west, Kettle Island south
8S	15S	Quebec east
3S		Kettle Island north west
3D		Kettle Island north west
10S		Kettle Island north east
10D		Kettle Island north east
18S	19S	Upper Duck Island
18D	19D	Upper Duck Island
7D	14D	Ontario

TABLE 12 Sample stations with the same vegetation associations grouped together for biomass and standing crop estimates 1973 and their fresh weight and dry weight (means are followed by standard deviations).

Sample Stations		Biomass (kg fresh wt./m^2)		Biomass (kg dry wt./m^2)		Standing crop (kg fresh wt./m^2)		Standing crop (kg dry wt./m^2)	
No.	Stations	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1.	7S 10S 12S 18S	2.895	1.183	0.247	0.093	2.485	1.026	0.220	0.078
2.	1S 5S 6S 13S 14S 15S 16S	3.330	1.572	0.291	0.141	2.622	1.342	0.247	0.125
3.	17S	1.378	-	0.145	-	1.134	-	0.116	-
4.	11D	2.382	-	0.259	-	1.467	-	0.148	-
5.	19D 20D 21D 22D 23D 24D 26D 27D	0.974	0.633	0.054	0.031	0.951	0.616	0.051	0.030
6.	3D 4D	0.142	0.070	0.012	0.007	0.122	0.042	0.011	0.005
7.	2D 8D 9D	0.967	0.799	0.133	0.101	0.714	0.388	0.099	0.048

* Representative plant species for each group are given on page 35.

TABLE 13 Fresh weight, mean, maximum and minimum values for biomass and standing crop of sample stations with the same vegetation associations grouped together in biomass and standing crop estimates 1972*.

Sample Stations		Biomass (kg fresh wt./m^2) Mean	Max	Min	Standing crop (kg fresh wt./m^2) Mean	Max	Min
4S	11S	1.550	1.910	1.240	1.091	1.558	0.624
4D	11D	0.280	0.390	0.180	0.245	0.315	0.175
8S	15S	2.400	3.780	1.040	1.959	3.072	0.846
3S		1.500	-	-	0.812	-	-
3D		0.710	-	-	0.599	-	-
10S		0.974	-	-	0.887	-	-
10D		0.327	-	-	0.292	-	-
18S	19S	2.892	4.180	1.604	2.136	3.574	0.697
18D	19D	0.159	0.272	0.045	0.143	0.257	0.029
7D	14D	0.360	0.496	0.224	0.314	0.431	0.197

S and D Shallow and Deep Water

* This table is derived from Tables 5 and 7.

TABLE 14 Dry weight, mean, maximum and minimum values for biomass and standing crop of sample stations with the same vegetation associations grouped together in biomass and standing crop estimates 1972*.

Sample Stations		Biomass (kg dry wt./m^2) Mean	Max	Min	Standing crop (kg dry wt./m^2) Mean	Max	Min
4S	11S	0.322	0.357	0.287	0.215	0.280	0.150
4D	11D	0.045	0.063	0.026	0.040	0.054	0.026
8S	15S	0.215	0.333	0.096	0.176	0.276	0.076
3S		0.199	-	-	0.122	-	-
3D		0.059	-	-	0.048	-	-
10S		0.081	-	-	0.071	-	-
10D		0.039	-	-	0.035	-	-
18S	19S	0.373	0.442	0.304	0.235	0.357	0.122
18D	19D	0.020	0.033	0.007	0.018	0.031	0.005
7D	14D	0.050	0.069	0.031	0.044	0.060	0.028

S and D Shallow and Deep Water

* This table is derived from Tables 5 and 7.

Biomass estimates in the whole study area (Tables 15, 16 and 17) show that in 1972 the mean fresh weight of shallow water plants was 1.94 kg/m^2. In 1973 for the same type of vegetation it was 3.24 kg/m^2. The mean fresh weights for deep water vegetation were 0.30 and 0.63 kg/m^2 for the two years, respectively. In shallow water plants, underground parts made up 28% of the biomass in 1972 and 20% in 1973 based on fresh weights. This gave a standing crop of 1.41 kg/m^2 in 1972 and 2.60 kg/m^2 in 1973. In deep water plants the underground bulk was less important, being 13% in 1972 and 7% in 1973, giving a standing crop of 0.26 and 0.59 kg/m^2 respectively.

Mean dry weights of biomass in 1972 were for shallow water plants 0.30 kg/m^2 and for deep water vegetation 0.04 kg/m^2. The values obtained in 1973 were 0.29 and 0.05 kg/m^2 respectively. The standing crop of emergent vegetation expressed in dry weight for 1972 was 0.20 kg/m^2 and in 1973, 0.25 kg/m^2, while the values for the deep water vegetation were 0.04 kg/m^2 in both years.

Fresh weight of plant parts as percentage of total fresh weight of the plant is given in Table 18. The loss in weight through drying and ashing, is shown in Tables 19 and 20.

TABLE 15 Estimate of total biomass and standing crop for each shore of study area (1972)*

		Growth Area (m^2)	Biomass (kg fresh wt.)	Standing crop (kg fresh wt.)	Biomass (kg dry wt.)	Standing crop (kg dry wt.)
Quebec west	S	1300	2000	1400	400	300
	D	6500	1800	1600	300	300
Quebec east	S	100	200	200	20	20
	D	0	0	0	0	0
Kettle Island north west	S	1200	1800	1000	200	100
	D	6700	4800	4000	400	300
Kettle Island north east	S	2000	1900	1800	200	100
	D	900	300	300	40	30
Kettle Island south	S	9000	14000	9800	2900	1900
	D	26500	7400	6500	1200	1100
Upper Duck Island	S	6800	19700	14500	2500	1600
	D	20000	3200	2900	400	400
Ontario	S	0	0	0	0	0
	D	8900	3200	2800	400	400

S = shallow water vegetation D = deep water vegetation

* mean values from Tables 13 and 14 were used in this estimate

Growth area was estimated visually as described in Methods

TABLE 16 Estimate of total biomass and standing crop for each shore of the study area (1973)*

		Growth Area (m^2)	Biomass (kg fresh wt.)	Standing crop (kg fresh wt.)	Biomass (kg dry wt.)	Standing crop (kg dry wt.)
Quebec west	S	400	1200	1000	100	100
	D	5000	4800	3600	700	500
Quebec east	S	1200	3500	3100	300	300
	D	0	0	0	0	0
Kettle Island north west	S	1400	4000	3500	300	300
	D	8500	7000	6700	400	400
Kettle Island north east	S	600	1700	1500	100	100
	D	0	0	0	0	0
Kettle Island south	S	12000	39600	31300	3500	3000
	D	11200	10800	8600	1300	1000
Upper Duck Island	S	8600	28500	22500	2800	2300
	D	181600	104800	99100	7000	6200
Ontario	S	0	0	0	0	0
	D	9100	8900	8600	500	500

* mean values from Table 12 were used in this estimate. Growth area was estimated visually as described in Methods

S = shallow water vegetation D = deep water vegetation

TABLE 17 Biomass and standing crop in 5 km section of the Ottawa River*

Vegetation type	Area (m^2)	Biomass Total (kg) fresh wt.	Biomass Total (kg) dry wt.	Biomass kg/m^2 fresh wt.	Biomass kg/m^2 dry wt.	Standing crop Total (kg) fresh wt.	Standing crop Total (kg) dry wt.	Standing crop kg/m^2 fresh wt.	Standing crop kg/m^2 dry wt.
1972									
Shallow water	20400	39600	6200	1.941	0.303	28700	2530	1.406	0.200
Deep water	69500	20700	2700	0.297	0.040	18100	4000	0.260	0.040
Shallow and Deep water	89900	60300	8960	0.670	0.100	46800	6600	0.520	0.070
1973									
Shallow water	24200	78500	7100	3.240	0.290	62900	6100	2.600	0.250
Deep water	216000	136300	9900	0.630	0.050	126700	8600	0.590	0.040
Shallow and Deep water	239600	214800	17000	0.900	0.070	189600	14500	0.790	0.060

* This table is derived from Tables 15 and 16.

TABLE 18 Percent fresh weight of plant parts 1973 and 1972 (mean is followed by standard deviation, and number of samples is given in parenthesis; range is given when results were obtained from 2 samples).

Species		Shoot	White Base	Wilted Shoot	Root	Tuber	Stolon	Rhizome	Runners
1973									
Sagittaria latifolia		67 ±8 (11)	12 ± 3 (11)	7.5 ± 4.1 (11)	9.7 ± 3.4 (11)	-	5.3 ± 2.2 (7)	-	-
Scirpus validus		58 47-69	5.3 4.4-6.2	3.7 0-7.4	-	-	-	33* 25-41	
Sparganium angustifolium		86 ± 11 (3)	4.7 ± 4.4 (3)	-	4.9 ± 3.2 (3)	-	-	-	3.8 ± 3.0 (3)
Polygonum amphibium		100	-	-	-	-	-	-	-
Nymphaea tuberosa	leaves stem	25 (23-27) 28 (25-31)	-	4.7 3.3-6.0	5.9 4.8-7.0	-	-	37 31-42	-
Vallisneria americana		82 ± 11 (8)	5.2 ± 2.8 (8)	-	4.4 ± 6.00 (8)	-	-	-	7.1 ± 4.3 (8)
Sparganium eurycarpum		49 ± 4 (3)	18 ± 0.6 (3)	16.3 ± 5 (3)	9.8 ± 1.3 (3)	-	-	7.3 ± 1.8 (3)	-

* roots were not separated from the rhizomes, as roots made up a very small proportion.
n = number of samples

Species	Shoot	White Base	Wilted Shoot	Root	Tuber	Stolon	Rhizome	Runners
1972								
Sagittaria latifolia	74 ± 4 (5)	6 ± 2 (5)	4 ± 3 (5)	9 ± 6 (5)	stolon + tuber 6 ± 5		-	-
Elodea canadensis	99 ± 0.6 (3)	-	-	1 ± 0.6 (3)	-		-	-
Vallisneria americana	75 ± 9 (7)	7 ± 4 (7)	-	6 ± 2 (7)	-		-	runners + tuber 12 ± 8

TABLE 19 Mean values of dry weight (percent fresh weight) for different plant parts 1973. Means are followed by standard deviations and number of samples (n) is indicated in parenthesis.

Species		Shoot	White Base	Wilted Shoot	Root	Tuber	Stolon	Rhizome	Runners
Sagittaria latifolia		8.2 ± 1.0 (11)	7.2 ± 1.2 (11)	7.3 ± 1.6 (11)	9.4 ± 1.5 (11)	14.3* 14.4-14.2	6.2 ± 0.8 (7)	-	-
Scirpus validus		13.3 11.7-14.9	-	-	-	-	-	14.1 13.0-15.2	-
Sparganium eurycarpum		15.1 ± 2.3 (3)	9.7 ± 2.4 (3)	4.8 ± 1.0 (3)	9.5 ± 0.7 (3)	-	-	13.8 ± 2.8 (3)	-
Nymphaea tuberosa*	leaf	14.9 (14.9-15.8)		7.2	5.5			14.1	
	stem	8.4 (7.0-9.7)	-	(7.0-7.4)	(5.2-5.9)	-	-	(13.5-14.6)	-
Polygonum amphibium		15.9 ± 1.2 (3)	-	-	-	-	-	-	-
Sparganium angustifolium		7.5 ± 2.6 (3)	6.6 ± 2.7 (3)	-	10.8 ± 1.7 (3)	-	-	-	7.5 ± 0.8 (3)
Vallisneria americana		5.9 ± 1.7 (8)	6.8 ± 1.8 (9)	-	9.5 ± 1.3 (9)	-	-	-	6.1 ± 1.0 (9)

* based on two samples

TABLE 20 Mean values of ash free dry weight (percent fresh weight/part) for different plant parts 1973. Means are followed by standard deviations and number of samples (n) is indicated in parenthesis.

Species	Shoot	White Base	Wilted Shoot	Root	Tuber	Stolon	Rhizome	Runners
Sagittaria latifolia	7.8 ±1.0 (11)	5.3 ±0.8 (11)	5.8 ±1.3 (11)	6.8 ±1.3 (11)	13.2* (12.9-13.2)	5.3 ±0.8 (7)	-	-
Scirpus validus	12.4 10.8-13.9	-	-	-	-	-	11.3 11.2-11.4	-
Sparganium eurycarpum	13.9 ±2.3 (3)	8.6 ±2.4 (3)	4.1 ±0.9 (3)	7.2 ±0.8 (3)	-	-	12.6 ±2.7 (3)	
Nymphaea tuberosa*	leaf 13.6 (12.9-14.3) (2) stem 7.2 (5.9-8.5) (2)	-	6.2 (5.9-6.3) (2)	4.6 (4.4-4.8) (2)	-	-	12.9 (12.3-13.3) (2)	-
Polygonum amphibium	14.1 ±1.0 (3)	-	-	-	-	-	-	-
Sparganium angustifolium	6.2 2.1 (3)	5.5 ±2.3 (3)	-	8.1 ±1.7 (3)	-	-	-	6.5 ±0. (3)
Vallisneria americana	4.3 ±0.9 (8)	4.6 ±1.1 (9)	-	6.3 ±0.9 (9)	-	-	-	4.9 ±1. (9)

* based on only two samples

5. DISCUSSION

5.1 Macrophyte Species Distribution and Biology for 1972 and 1973 and Comparison with Other Available Data on the Ottawa River and Other Rivers

During the two summers of the survey, no important changes in species composition were observed in the study area. Very few investigations seem to have been published on the ecology of aquatic plants in wide rivers like the Ottawa. For this reason comparisons were made with smaller rivers such as those described by Butcher (1933) on small streams in England and those of Hynes (1971 and 1972). In an interpretation of Butcher, Hynes (Ibid) divides the higher aquatic plants to be found in running water into three categories, which he bases on ecological behaviour. The first group is designated as plants attached to rocks and other solid objects including the mosses, which are usually confined to smaller head water streams. Fontinalis antipyretica was recorded in the Ottawa River during my survey. It is common in other large rivers as well, where it is tolerant of a wide range of environmental conditions including organically polluted water (Hynes, Ibid).

The free floating plants, the second group in Hynes' categorization, were very sparse throughout the study area. With the high floods and wind and wave action, they easily get washed away. Lemna minor was found, sometimes growing among floating leaf species such as Potamogeton epihydrus, P. Berchtoldii, and Sparganium angustifolium.

The rooted aquatic plants were the most common forms found in the study area and are included in Hynes' third group. The Charales which have rhizoids instead of roots, are also included in this group. Chara sp. and Nitella sp. appeared at very low densities in the study section.

Most of the species found in my survey seem to be common in the Ottawa district, up and down the Ottawa River, in nearby lakes and other tributaries of the Ottawa (Gillet and Dore, 1974).

Sagittaria latifolia, occurred frequently in the study section as well as in the whole Ottawa valley. It has also been reported by Stuckey and Wentz (1969) as an abundant species in polluted areas of another Ottawa River in Ohio, U.S.A. It occurred in fewer numbers in waters not affected by industrial pollution. They also list several Polygonum species in the polluted areas, although P. amphibium is never mentioned by Stuckey and Wentz. A few Finnish studies (Eloranta 1970; Kurimo 1971) show that this species can grow in fairly dense patches in contaminated waters. This was also observed in the Ottawa River. Kurimo (Ibid) found it to be indifferent to the quality of the bottom, growing equally well on organic and mineral substrates, and it was independent of wave and wind action.

Other genera of aquatic plants, which I found, that were also characteristic of running waters, were Potamogeton, Sparganium, *Elodea*, *Scirpus* and *Typha*.

The submersed species *Vallisneria americana* was abundant and *Elodea canadensis* was common in the study area. Both of them have been observed by Aiken (1972), Gillet and Dore (1974) and myself in dense masses in shallow areas up the Ottawa River.

The growth pattern of all the species found in the Ottawa River section was mainly characterized by numerous pure stands of aquatic plants. According to Sculthorpe (1971) several rooted aquatic plants tend to form vast pure stands as a result of their particular mode of vegetative reproduction.

5.2 Macrophyte Species Associations for 1972 and 1973

Certain observations can be made for the whole study area in both years (1972 and 1973). Dense growth with a vegetation typical to lakes was found in sheltered areas (behind "shielding points") and at the entrance to bays, where there was shelter from wind and current. Butcher (1933) names this kind of habitat with a substrate of mud the 'littoral'. He also mentions that a wide variety of aquatic plants can grow here where their underground parts will be either fibrous roots or thick rhizomes. This proved to be true for the Ottawa River study as well. *Sagittaria latifolia* and *Sparganium eurycarpum*, with well developed underground parts, were dominant species, and other species with fibrous root systems were found, such as *Typha latifolia* and *Scirpus validus*.

Dense growths of floating leaf and submersed species were found on shallow sand banks formed along the islands and in the bays between the sand banks and the island shore (Figs. 7a and b). Nymphaea tuberosa made up large stands in these bays exposed to both wind and current action (Figs. 7a and b). It was somewhat peculiar to find N. tuberosa here as this species is normally confined to sheltered bays (Gillet and Dore, 1974). A possible reason for the species' existence in this habitat could be that plants became established soon after the area was flooded through the construction of dams, and when there were still tree stumps exposed to the water. The stumps may have provided good "traps" for seeds coming downstream from other areas. By the time a more unstable substrate, such as sand had deposited in these areas, the plants would already have had well developed rhizomes for anchoring.

The species composition and numbers of commonly found species on all three islands in 1972, and on the two islands in 1973, were fairly similar in areas not affected by heavy pollution. All had emergent forms, floating leaf forms and submersed forms. The localized distribution of Potamogeton epihydrus on the upstream tip of Upper Duck Island and on the north east shore of Kettle Island in 1972, was the only exception. As the species was found in smaller numbers during 1972 than the following year, it is possible that this species had just started to invade the areas around the upstream tip of the islands. These tips being long shallow sand banks, also exposed to current and winds, seemed to be a suitable habitat for P. epihydrus and also P. Richardsonii. According to Hynes (1971) a partly silted substrate on gravel, i.e. where current is fairly strong, is a common support for growth of Potamogeton species.

The north east shore of Kettle Island, which is sometimes exposed to the wastes from the CIP paper mill, showed an interesting difference in species composition when compared with the rest of the island shores. During both years only one emergent species, Sagittaria latifolia, considered by Stuckey and Wentz (1969) to be highly pollutant tolerant, was found in this area. In 1972 a few species of the submersed and floating leaf forms (Vallisneria americana, Elodea canadensis, Potamogeton epihydrus and P. Richardsonii) were fairly common. However in 1973 the difference from other shores was even more pronounced, as no submersed forms occurred, and the only floating leaf form was represented by a small patch of Potamogeton epihydrus. The difference between shores is very probably due to the sulfite mill pollution. However the change between years is more difficult to explain. A possible explanation could be that generally, conditions on the north east shore of Kettle Island in 1972 were slightly better than 1973 and happened to be favourable to a few species. Effluents from the paper mill may have more effectively stopped photosynthesis by decreased light penetration in 1973. This would agree with Kurimo (1970) who in her study on a Finnish Lake system, showed that Elodea canadensis derives only slight benefit from domestic sewage but, as was also found by Eloranta (1970), the species is absent from heavily polluted areas. Also, in other areas in the study section, conditions seemed to have been more favourable for its growth. This was seen in the increased coverage by Vallisneria americana, Potamogeton epihydrus and P. Richardsonii, around Upper Duck Island and Kettle Island. The occasionally very low water levels observed in 1973 may have permitted enough light to penetrate so that growth could establish further out from shore.

Another striking contrast was noted during both summers, between the Quebec and Ontario shores. The Quebec shore had only emergent vegetation and only three species were found that were capable of growing under the prevailing conditions. The Ontario side had only four common species, which were all submersed forms. As the water chemistry has been shown to be fairly similar over the whole study area, apart from the B.O.D. levels (OWRC-QWB 1970 and Mackie 1971, 2.3 this section), it is believed that the lack of plants in the deeper water on the Quebec side was due to the lack of light caused by higher turbidity along this shore. Light penetration decreased rapidly with increased suspended solids. Bacterial growth (e.g. Sphaerotilus) was so intense below CIP that plants would not be able to establish themselves before becoming completely blanketed with these slime bacteria. Two of the emergent species, Sagittaria latifolia and Polygonum amphibium, occurred only on the shore above the water, which was unusual in the rest of the study area as previously mentioned (4.1). This ability may class them as pollutant tolerant species. Sparganium eurycarpum was also considered to be a pollution tolerant form as it grew well in polluted conditions on the Quebec shore. On the Ontario side erosion would probably be the main factor controlling emergent vegetation. Both the unstable substrate and the dense clay in this area probably hindered root development, although the submersed species Vallisneria americana and the floating leaf form Sparganium angustifolium were able to establish in great numbers on this substrate.

In respect to the whole study area, the water entering it was already polluted from upstream sources and therefore there were species over the whole area that were tolerant to pollution. But, on the Quebec side the water was heavily polluted below the CIP paper mill, and only about 0.5% of the first 3 km of shoreline below the mill was covered by any plants. Emergent forms could apparently tolerate these conditions and colonize the area before submersed forms could establish themselves.

5.3 Biomass and Standing Crop

5.3.1 Biomass and Standing Crop Estimates in 1972 and 1973 and a Comparison with Other Studies

The fresh weight biomass was smaller in the summer of 1972 than in the summer of 1973 (Table 17): 1,940 g fresh wt./m^2 as opposed to 3,240 g/m^2 for the shallow water plants and 300 as opposed to 630 g/m^2 for deep water plants. Standing crop based on fresh weight differed in the same way as biomass: 1,406 g/m^2 in 1972 and 2,600 in 1973 for shallow water vegetation and 260 and 590 g/m^2 for the deep water vegetation in each respective years.

Based on the calculations presented in Table 17, the conclusion that fresh weight of biomass and standing crop was larger in 1973 than in 1972 is unescapable. Not only was a larger area covered by aquatic plants in 1973, but the density of plant material per unit area was also greater. Total dry weight of plant material produced in 1973 was also greater, but in a unit area dry weight showed no significant difference from one year to the other (Table 17), i.e. the plants growing in 1973 also appeared to be more succulent than those found in 1972. In the two summers the percent underground parts was almost equivalent in the shallow water plants and fairly similar in the deep water vegetation (Tables 5 and 6). The type of vegetation generally observed in a running water system has well developed fibrous root systems which could be expected to influence the biomass values considerably (Butcher 1933). However, it was interesting to find that the underground parts* in the shallow water vegetation survey in the Ottawa River did not represent more than about 24% of the total

* Westlake's (1963) impression is that the method used in sampling the underground parts underestimates the proportion of these parts.

plant biomass. This low proportion may be related to the dominance of Sagittaria latifolia, which does not have an extensive root development. In the deep water vegetation underground parts were even less important (about 10% of the total biomass). The weight ratios between shoots and the rest of the plant may vary with season and the state of growth (Sculthorpe 1971) thus the sampling time should be standardized. Sagittaria latifolia, one of the most important species in the area was observed to develop it's tubers late in September, and this might be true also for rhizomes in species such as Sparganium eurycarpum and Nymphaea tuberosa. Sculthorpe (1971) mentions that among other plants Nymphaea species has relatively slow growing rhizomes. In his study of macrophytes in an oligotrophic lake, F. Eriksson (1973) found that the root proportion in Sparganium angustifolium (a fairly abundant species in the Ottawa River), was low in August (9%) and higher both in July (12%) and September (11%). No exact information on the species Vallisneria americana, common in the Ottawa River study area, has been found. However, both Sculthorpe and Westlake mention that roots, not including other underground parts, probably represent less than 10% of the biomass in submersed fresh water species. They base their conclusions mainly on work done by Edwards and Owens (1960) and Forsberg (1959) neither of whom included species of Vallisneria americana.

It is difficult to find published estimates on biomass or standing crop in which the habitats for aquatic plants are similar to those found in the Ottawa River. Usually studies have been performed on much smaller rivers or streams (Owens and Edwards 1961a, 1961b; Westlake 1961). The standing crop of the submersed vegetation found in the Ottawa River is more comparable to that observed in the eutrophic Lake Sniardwy (Bernatowicz et al, 1968), where wave action was considered to have an important influence on the development of the plants, than to estimates for small rivers. The standing crop was found to be much smaller in this lake than in others of the same area with calmer waters. The emergent vegetation had a smaller biomass in Lake Sniardwy than in the Ottawa River, probably due to the fact that the habitat for the emergent plants in the latter case resembles more sheltered areas in a lake. The closest estimate found, concerning biomass, is that of a polluted stream studied by Westlake (1961) where he considers the maximum biomass to be low (0.12 kg dry wt./m^2) compared to many other clean rivers with 0.11 to 0.52 kg dry wt./m^2 (Westlake 1963).

5.3.2 Ratios of Fresh Weight, Dry Weight and Ash Free Dry Weight

The loss in weight through drying was very similar for underground parts and shoots (Tables 19 and 20). The results obtained in 1973 show that all subunits (shoot, white base, wilted shoot, root, rhizome, tuber and runner) of all the species sampled had dry weights of less than 16% of their fresh weight. The species

Polygonum amphibium had the highest dry matter content, which was 15.9% (the whole plant was treated as a shoot). Values approaching this level were also found in leaves and rhizomes of Nymphaea tuberosa, Scirpus validus and Sparganium eurycarpum while other parts had dry weights ranging between 4 and 9% of their fresh weights. Higher dry weight content in the leaves, compared to other shoot parts were also observed by F. Eriksson (1973) in his studies of Nuphar luteum in an oligotrophic lake. In the other species investigated in the Ottawa River, i.e. Sagittaria latifolia, Sparganium eurycarpum and Vallisneria americana, all the parts except the tubers of S. latifolia had similar dry weight content (varying between 6 and 11%). In the tuber, dry weight matter was higher (14.3%).

In the literature submersed species are considered to have lower dry weight content than emergent hydrophytes, and the floating leaf plants are usually found somewhere in between in terms of their dry matter (Straškraba, 1966). This pattern was not observed in the Ottawa River survey, but dry weight content was normally very similar between the three life forms when comparing plants as a whole (Tables 5 and 6). In 1972 the total dry weight content varied between 6 and 22%, while in 1973 the variation was within the same range but slightly smaller (4 to 14%).

Very little information has been found on ash content in aquatic plants, but 15 to 25% of the dry weight is common for submersed species, and 10 to 20% in the softer emergent plants (Westlake 1965a). This seems to correspond well with the results obtained in this study. Westlake also mentions that rhizomes have higher ash content than other parts. This was found only in Scirpus validus, while in Sagittaria latifolia, Sparganium angustifolium and Sparganium eurycarpum the roots had a slightly higher ash content.

5.3.3 Contribution of Different Plant Parts to Total Plant Biomass

Westlake (1965a) states that many perennial emergent plants have a large proportion of their biomass buried in the sediments. This was found in Scirpus validus, as well as in the floating leaf form of Nymphaea tuberosa, where rhizomes with the roots made up 33 and 34% respectively of the whole plant (Table 18). Here the root percentage was very small compared to rhizomes.

As Westlake also says, the base of the green shoot may be a significant part of the plant. Sagittaria latifolia and Sparganium eurycarpum were found to have 12 and 18% respectively of their biomass associated with the base of the shoots. However, in S. latifolia as well as in Sparganium angustifolium, Polygonum amphibium and Vallisneria americana, the green portion of the shoot was by far the most important part of the plant in terms of biomass. The root content was in all species less than 10% and especially small in Elodea canadensis, Sparganium angustifolium, Nymphaea tuberosa and Vallisneria americana. In Sparganium eurycarpum, the wilted portion of the shoot made up about 16% of the total biomass in August, while it was not more than 7.5% in other species. During winter the root and tuber and rhizome component usually dominates the total biomass, while in summer the green parts are the dominant biomass component (Sculthorpe, 1971). This seasonal influence of the ratios between different parts on the biomass is discussed in more detail in 5.3.1.

6. CONCLUSIONS

1. The macrophyte composition, distribution and biomass were investigated during two consecutive summers in a polluted section of the Ottawa River, Ontario and Quebec, below the cities of Ottawa and Hull.

2. A total of 42 species were recorded in 1972 and 35 species were found in the summer of 1973. Seventeen of these species were common to abundant in both years. Sagittaria latifolia, Sparganium eurycarpum, Polygonum amphibium, Nymphaea tuberosa, Vallisneria americana and Sparganium angustifolium were found to be the most common and the most widespread species in the area. Emergent and submersed plant forms were abundant, while floating forms were very sparse.

3. Similar distribution patterns were found in most species in the two summers. They were characterized by pure stands or stands dominated by one single species and sparsely interspersed with one or two others.

4. Most plant species found in the study area have also been observed up and down the Ottawa River, in nearby lakes and/or in other tributaries of the Ottawa.

5. Dense growth approaching that found in lakes, was observed behind shielding points and at the entrance to bays, where there was shelter from wind and current. Downstream from these areas the vegetation became gradually more sparse as current and wave action became more severe.

6. Dense growths of floating leaf species and submersed species

were found on shallow sand banks formed along the islands and between the sand banks and the island shore. *Nymphaea tuberosa*, usually found in sheltered areas, was here exposed to both strong winds and currents.

7. The species composition and numbers of common species found on all three islands were fairly similar. All had emergent forms, floating and submersed leaf forms and submersed forms. The localized distribution of *Potamogeton epihydrus* on the upstream tip of Upper Duck Island and on the north east shore of Kettle Island in 1972, was the only exception.

8. In certain parts of the study area all the submersed species found in 1972, i.e. *Vallisneria americana*, *Elodea canadensis*, *Potamogeton epihydrus* and *P. Richardsonii*, had disappeared in 1973. This was probably due to decreased light penetration caused by effluents from the paper mill, as in other parts, *V. americana*, *P. epihydrus* and *P. Richardsonii* had extended over considerably larger areas during 1973 than in the previous year. The occasional very low water levels in 1973 are suggested as the reason for the latter changes.

9. Another striking contrast was noted during both summers, between the Quebec and Ontario shores. The Quebec shore had only emergent vegetation and only three species were found that were capable of growing under the prevailing conditions. The Ontario side had only four common species, which were all submersed forms. *Sparganium eurycarpum* was considered to be a pollutant tolerant

species as it grew well in polluted conditions on the Quebec shore.

10. The water entering the study area was already polluted from upstream sources, and therefore there were species over the whole area that were tolerant to pollution. On the Quebec side where the water was even more heavily polluted below the CIP paper mill there was no vegetation for nearly 3 km below the factory. Further downstream, emergent forms were able to tolerate the conditions and colonized the area. Still further downstream, submersed forms were found as well.

11. The total growth area in the study section, which had a 21 km long shoreline, was 9.0 ha (1.8% of the total river area) in 1972 and 24.0 ha (4.6%) in 1973. Submersed vegetation comprised the most significant proportion of total aquatic plant cover (7.0 ha in 1972 and 21.6 ha in 1973). The areas around the shorelines of the islands and above the CIP paper mill had the most extensive plant covers.

12. Mean biomass was significantly higher on a fresh weight basis in the summer of 1973 than in 1972. Dry weight per unit area showed no large difference from one year to the other. In 1972 the mean biomass was 1.94 kg fresh wt./m^2 and 0.30 kg dry wt./m^2 for the emergent plants and 0.30 kg fresh wt./m^2 and 0.04 kg dry wt./m^2 for the floating leaf and submersed species together. In 1973 the mean biomass was 3.24 kg fresh wt./m^2 and 0.29 kg dry wt./m^2 and 0.63 kg fresh wt./m^2 and 0.05 kg dry wt./m^2 for the respective vegetation types. Results indicate that plants were more succulent

in 1973 than in the previous year.

13. In the two summers the percent underground parts of total plant biomass was almost equivalent in the shallow water plants (about 24%) and fairly similar in the deep water vegetation (about 10%). The low proportion of 24% in the emergent vegetation may be related to the dominance of Sagittaria latifolia in the study area.

14. Total dry weight percentage in emergent, floating leaf and submersed forms varied between 6 and 22% in 1972, while in 1973 the variation was slightly smaller (4 to 14%).

15. In most species that were collected, the green part of the shoot, made up the largest proportion by weight of the plant. In Scirpus validus and Nymphaea tuberosa, rhizomes with roots represented 33 and 34% of the whole plant respectively. In Sagittaria latifolia and Sparganium eurycarpum, the white base of the shoot was found to be important, with 12 and 18% of their biomass in this part. In Sparganium eurycarpum wilted leaves were 16% of the plant, as early as August.

Section II

MERCURY UPTAKE IN ROOTED HIGHER AQUATIC PLANTS; LABORATORY STUDIES.

1. INTRODUCTION

Despite the fact that the greatest amount of mercury transported in a river system is associated with the river sediments, most studies of aquatic plants have been made in aqueous media only. This includes both emergent, rooted aquatic plants (Carbonneau and Tremblay, 1972) and submersed species (Mortimer and Umoessin, 1972). In experiments where sediment is taken into consideration (Dolar et al, 1971 and Hannerz, 1968) or in field work (Dietz, 1972) little or no attention has been paid to roots, rhizomes, tubers or stolons of plants that grow in sediment.

To understand the role that rooted higher aquatic plants play in the recycling of mercury through the environment, and to obtain useful information for future field sampling, it was felt that a more detailed knowledge of mercury kinetics in rooted aquatic plants growing in sediments was needed.

The present study considers three aspects of this general problem:

1. The movement of mercury from water to plants and sediments.
2. The movement of mercury from particulates and fine sediments into plants, water and deeper sediments.

3. The movement of mercury from deeper sediments into water or directly into plants.

2. MATERIALS AND METHODS

2.1 Materials

Plants: Specimens were collected from the Ottawa River (Section I) shortly before the experiments or from greenhouse cultures of the same plant material.

Soil: The plants were potted in Ottawa River sediments of the wood chip type (a heavy organic clay), or in a greenhouse soil plus sand mixture as detailed below.

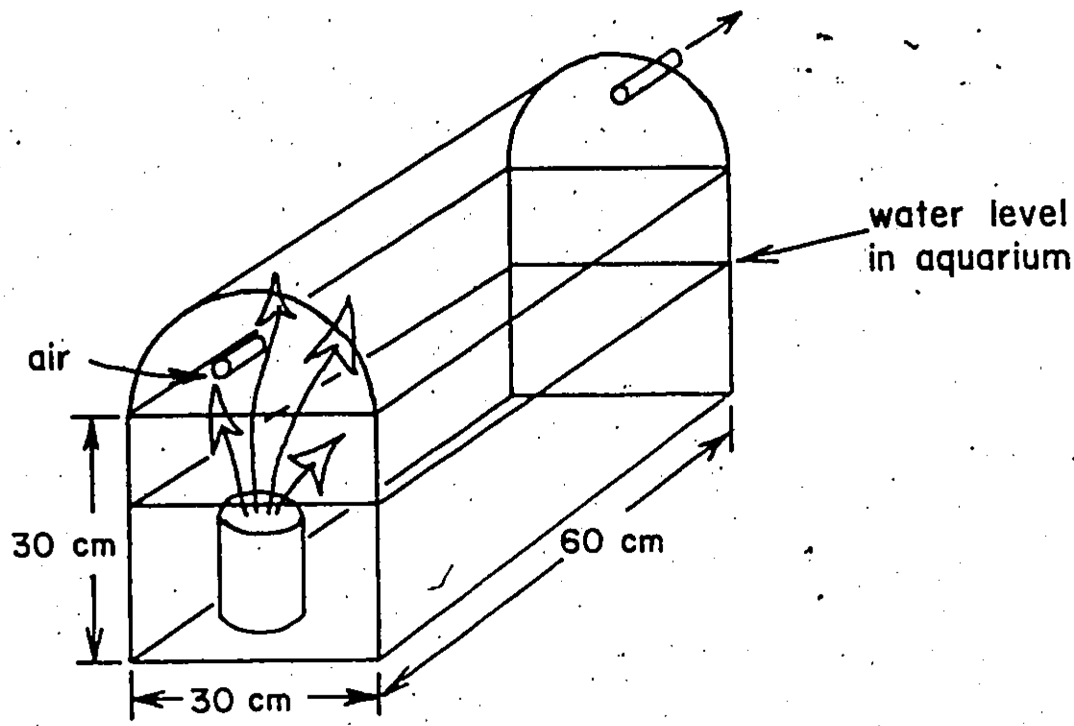
Water: The aquaria were filled with water taken from the Ottawa River.

Mercury compound: Mercuric chloride labelled with ^{203}Hg ($^{203}HgCl_2$) was added to the water or the sediments at pre-determined levels. The quantity of mercury added was calculated to approximate known values for Ottawa River water and Ottawa River sediments.

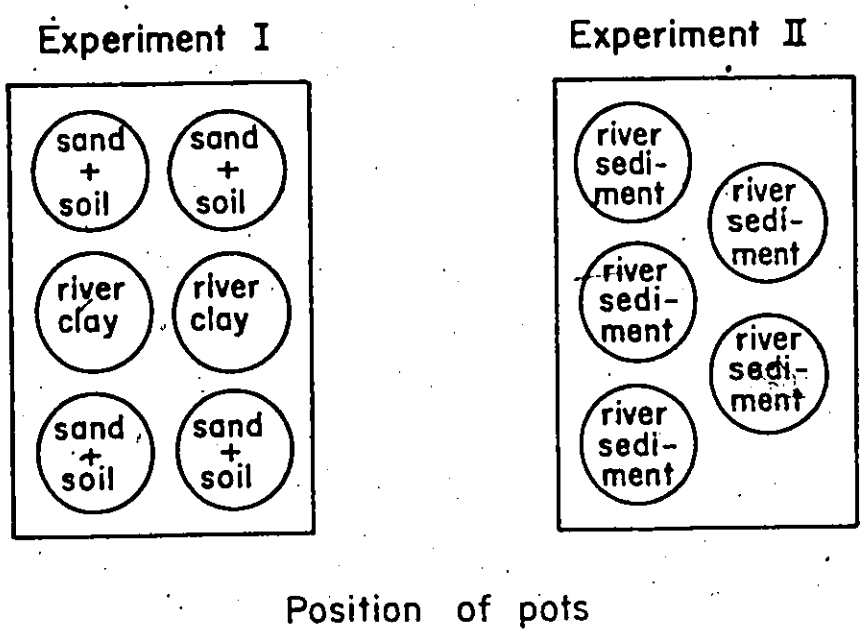
2.2 Experimental Technique

All experiments were run in a greenhouse. River sediments were spread out on large trays, dried and aerated. Tap water was then added until the sediment had reached the same consistency as when collected. Groups of young aquatic plants were potted in the greenhouse soil or river sediment. Each species was kept in a separate pot and placed in standard aquaria (dimensions 30 x 30 x 60 cm^3) (Figs. 57, 58 and 59) filled above soil surfaces with Ottawa River water (20 and 30L). A plexiglass-hood was placed over each aquarium so that the plants could grow

Fig. 57 Experimental design of ^{203}mercury incorporation study.

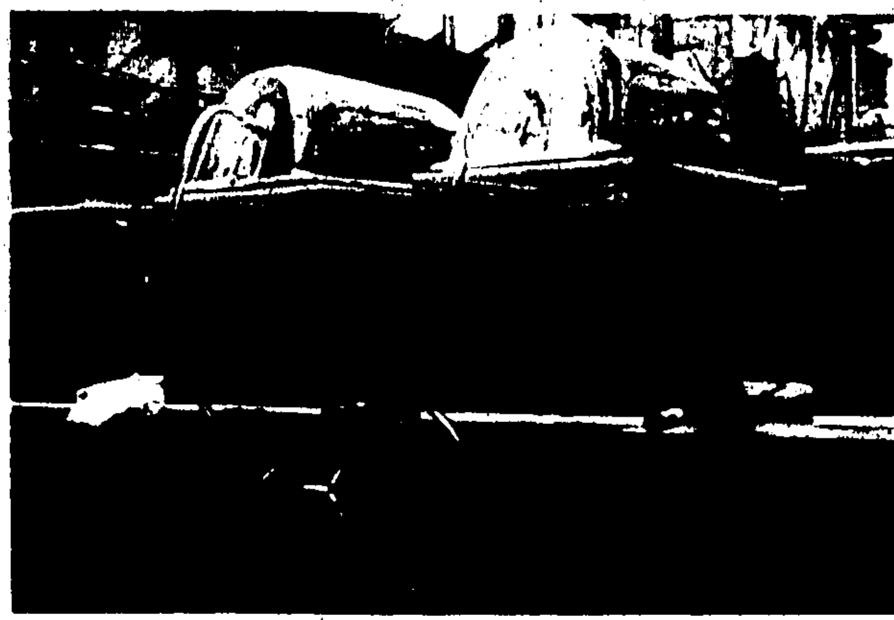

water level
in aquarium
air
30 cm
60 cm
30 cm

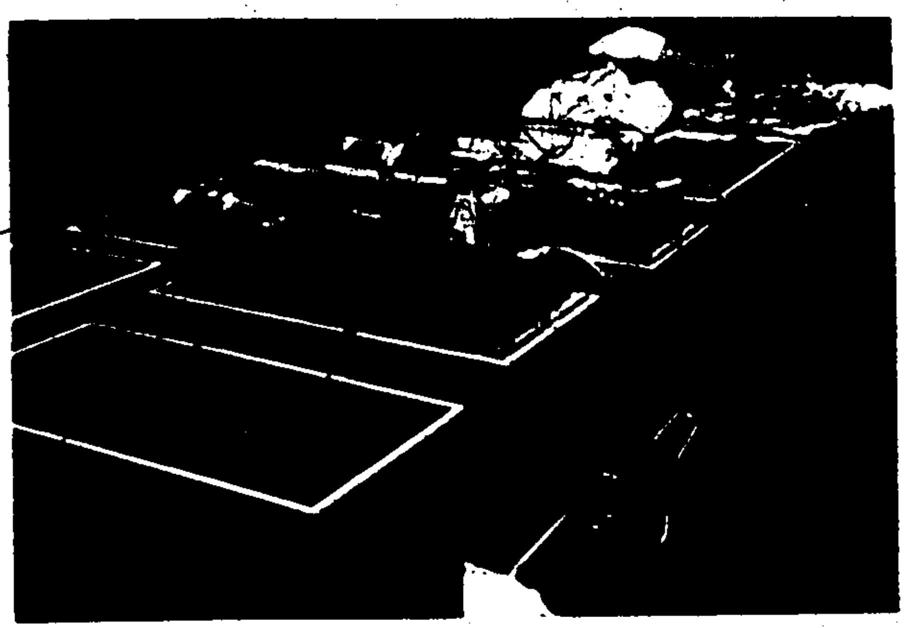
a


Experiment I
sand + soil
sand + soil
river clay
river clay
sand + soil
sand + soil
Experiment II
river sediment
river sediment
river sediment
river sediment
river sediment
Position of pots

b

Figs. 58 and 59 Experimental set up for ^{203}mercury uptake enclosed aquarium studies.





straight up unimpeded and still be contained within the aquarium (Figs. 58 and 59). A gentle stream of air was blown over the water across the aquaria. The air was filtered through charcoal at an outlet in the far end of the hood. The plants were allowed to stabilize for two to three weeks prior to the addition of the mercury. Mercuric chloride was then added in a single dose at the beginning of the experiment.

In order to control insect invasions (white fly), which on previous occasions had destroyed similar plants, the emergent plant parts were brushed with Malathion 50. Attached algal (periphyton) growth was reduced only slightly by the addition of a few snails which were introduced for this purpose.

2.3 Sampling, Sample Preparation and Analysis

Ten ml water samples were taken frequently throughout the experiments. Charcoal filters were analysed once during and once at the end of the experiment. Each plant, its soil and associated invertebrates were removed for examination at the end of the experiment to minimize the possible disturbance to the system. The plants were rinsed carefully with tapwater to wash away any water that could contain mercury compounds. They were then divided into as many as eleven parts: fresh leaves, wilted leaves, shoots above water, shoots in water, roots, fresh tubers, decaying tubers, stolons and inside parts of emersed and submersed shoots and tubers. The soil was separated into three layers: a thin top layer comprised of a 2 to 3 mm thick ooze or floc formed during the experiment, a 1 cm thick layer under the ooze and thirdly the remaining soil, 13 cm of soil. Water, charcoal filters representative parts of plants, aliquots of homogenized sediments, snails and material from the sides of the aquaria were placed in glass vials. Samples were analysed directly on a Nuclear Chicago γ-counter with a 3 inch, deep well sodium iodide crystal. Finally, all of these samples were weighed.

In one of the experiments pH was measured using pH paper. This was done simultaneously with water sampling. Initially pH was measured with a pH meter (Portomatic model 175) to give parallel readings with a more accurate method. This was dropped later because the pH indicator paper proved to be satisfactory for the purposes of this study, and contamination of the electrode was avoided.

Daily temperature recordings were taken for each room in the greenhouse.

2.4 Experimental Design

Experiment I

Two aquaria (I_1 "water treated" and I_2 "water treated") with the following design were used:

Plants: 1. Two pots of Sagittaria latifolia (originally from the Ottawa River, taken from greenhouse cultures) were in each aquarium. 2. Four pots of Scirpus cyperinus (also taken from the greenhouse, originally from the Rideau River) were in each aquarium.

Soil: Pots containing river clay or greenhouse soil were distributed in the aquaria as diagrammed in Fig. 57b.

A variety of containers: Plastic plant pots with holes in the bottom, 1 liter plastic beakers and 1 liter glass beakers were used. Each aquarium had two pots of each kind.

With a water level of 6 cm over the surface of the soil, aquarium I_1 contained 20 liters and aquarium I_2, 21 liters.

Mercury was added to the water in both aquaria (Fig. 60a). The concentrations in the water of aquarium I_1 was initially 0.022 μg/g and in aquarium I_2, 0.028 μg/g. At the end of the experiment these concentrations had fallen to 0.010 μg/g and 0.008 μg/g respectively.

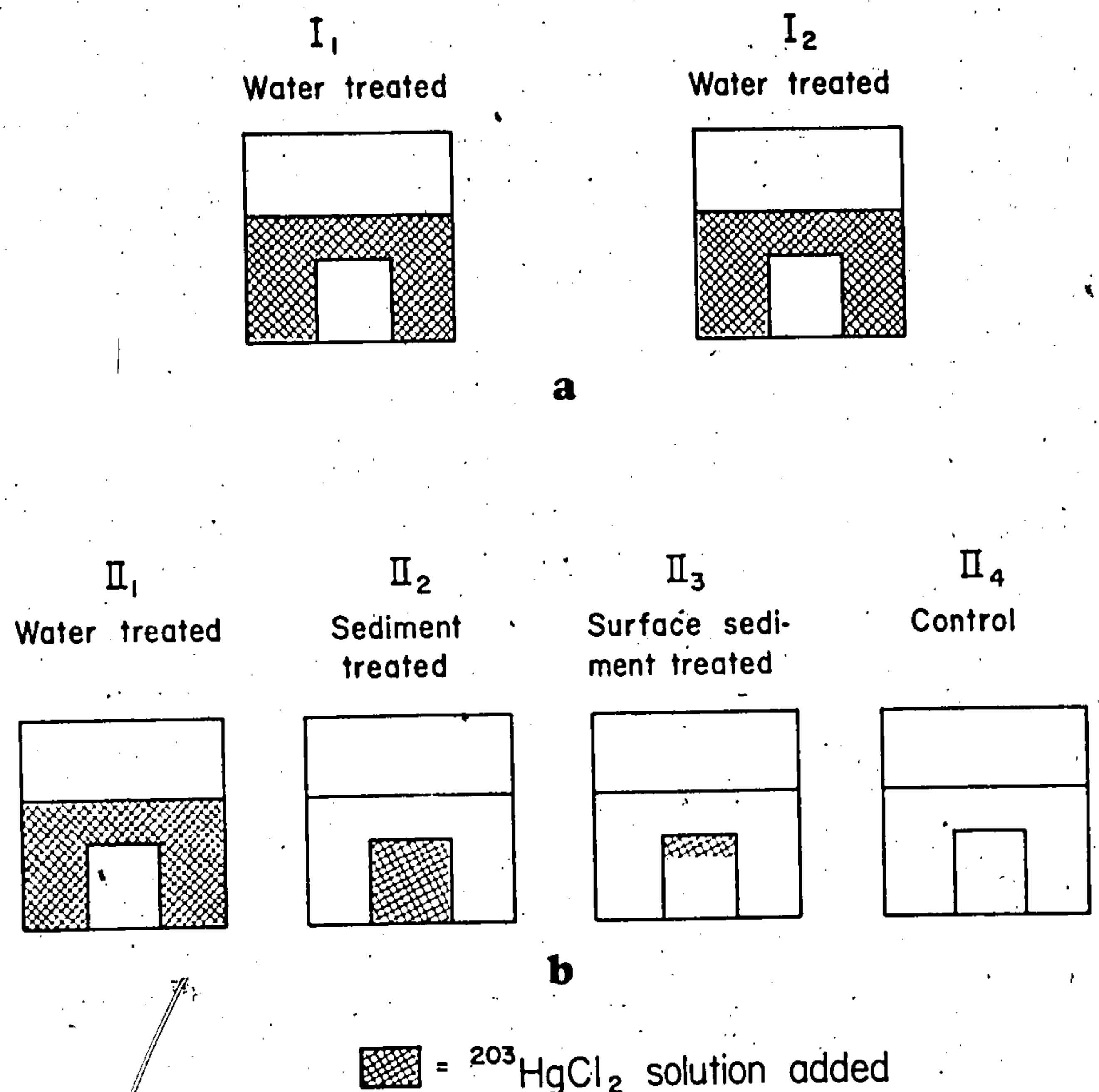
The experiment was conducted during 10 days in May, 1973.

The recovery of ^{203}mercury was 83% in aquarium I_1 and 56% in aquarium I_2.

Experiment II

Four aquaria (II_1 "water treated", II_2 "all sediment treated", II_3 "surface sediment treated" and II_4 "control") with the following design were used:

Fig. 60 Experimental design for ^{203}mercury additions to aquaria I_1, I_2 and II_1 to II_4.


I₁
Water treated
I₂
Water treated
a
II₁
Water treated
II₂
Sediment treated
II₃
Surface sediment treated
II₄
Control
b
= 203HgCl2 solution added

Plants: 1. three pots with <u>Sagittaria latifolia</u> (from the Ottawa River), 2. two pots with <u>Scirpus cyperinus</u> (from greenhouse cultures) and 3. approximately 200 plants of <u>Lemna minor</u> (from greenhouse cultures) were used.

Soil (Fig. 57): sediment with high organic content, wood chips and decomposing plant material was collected from a stand of <u>Sagittaria latifolia</u> in the Ottawa River.

Pots: 1 liter glass beakers.

Water volume: all aquaria were filled with 31 liters of river water. Three liters were added on the eighth day to compensate for loss of water through uptake and evaporation.

Mercury (Fig. 60): in aquarium II_1 Hg was added to the water as $HgCl_2$. Initially the concentration in the water was 0.014 μg/g and at the end of the study it was 0.004 μg/g. Mercuric chloride was added to all the soil in aquarium II_2 by pipet. The concentration in the soil was approximately 0.06 μg/g fresh wt. at the start. The concentration in the water after filling was extremely low $<$ 0.001 μg/g. The counts however were still higher than those from the background and control samples (see aquarium II_4 below). The final concentration was also $<$ 0.001 μg/g. Mercuric chloride was added to a 1 cm thick top layer of soil in aquarium II_3 by removing the soil, adding the mercury solution, mixing thoroughly and replacing the mixture on top of the pot. The initial concentration in this soil was 0.34 μg/g. Again the mercury concentration in the water was extremely low, but slightly higher than background and control. This was also the case at the end of the experiment.

Aquarium II_4 which was designated as the Control had the same set up except for mercury addition as all the other aquaria in Experiment II.

The experiment was conducted during 12 days in June to July, 1973.

Note: five snails were introduced into each aquarium.

In the calculations to obtain ^{203}mercury concentrations, all counts were corrected for background, decay and counting efficiency, by reference to the known standard, then extrapolated to day 0 (first day of experiment) and expressed in µg/g fresh weight.

3. RESULTS

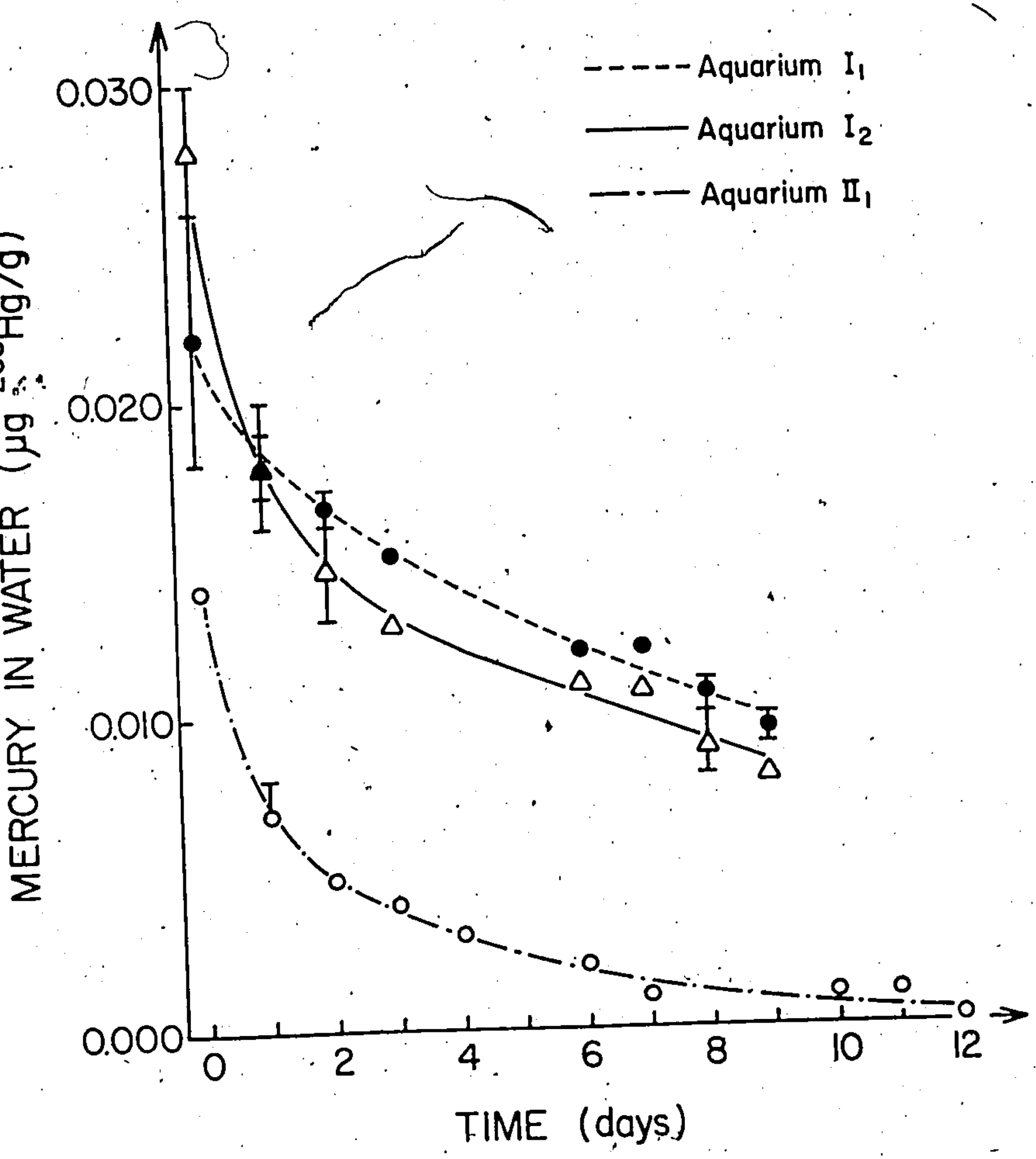
3.1 Condition of Plants During Experiment

Plants did not grow well in the clay. Those grown in mud and river sediment grew normally compared to others kept in tubs in the greenhouse. Sagittaria latifolia developed tubers in the first experiment. Lemna minor known to be mercury sensitive (Mortimer and Umoessin, 1972) grew well and reproduced in the control doubling its biomass. In aquaria II_2 and II_3, with extremely low mercury concentration in the water, the L. minor biomass did not increase. In aquarium II_1 (water treated), with high mercury concentration in the water, L. minor was dying off by the end of the study. Planktonic algae became abundant in all the aquaria and an ooze layer settled on the soil surface and on the bottom of the aquaria in all cases. A number of very small invertebrates were observed living in the top layer of this ooze during the entire experiment.

3.2 Changes in Mercury Concentrations During the Experiment

Mercury concentrations in the water decreased rapidly (Fig. 61) in the beginning of the experiments in cases where mercury was added directly to the water. After two days the decrease slowed down. In all other aquaria the mercury concentration in the water was low from the beginning. It stayed fairly constant being slightly higher than the control during the first three days and close to or equal to the control during the following days of study.

Fig. 61 Loss of ^{203}mercury from water over a 12 day period. Aquaria I_1 and I_2 are represented by the mean of two samples; aquarium II_1 is represented by the mean of four samples (vertical lines indicate ranges).



Aquarium I_1
Aquarium I_2
Aquarium II_1
MERCURY IN WATER (μg ^{203}Hg/g)
0.030
0.020
0.010
0.000
0
2
4
6
8
10
12
TIME (days)

Charcoal filters showed very little uptake of mercury (included in "other" Fig. 62). Where such uptake was found, it was concentrated at the intake part of the filter with a negligible amount, if any at all, being found at the other end. In the first experiment (I_1 and I_2, both water treated) the main uptake was during the first six days. In the second study the only aquarium to show any accumulation in the filters, was number II_1 with similar mercury addition as in experiment I. Here the absorption was higher during the last five days.

3.3 Mercury Distribution within the Aquaria (Fig. 62)

Of the introduced ^{203}mercury, 83% was recovered in aquarium I_1 (water treated) and 56% in aquarium I_2 (water treated). Nearly half of the recovered mercury was found in the water in both aquaria at the conclusion of the first study. The ooze layer of the soil (Table 21 and Fig. 63) had the highest concentration of ^{203}Hg with values of 0.61 µg/g fresh wt.. Further down, in the 1 cm layer, mercury was found at a level of 0.10 µg/g. The rest of the sediments, which were mixed before sampling had very low concentrations (up to 0.02 µg/g). The clay showed a similar pattern, however nothing was found below 1 cm.

Plants took up a fairly large amount of mercury (Table 21 and Fig. 63). Concentrations in submersed parts of these plants were higher than those in emersed portions. There was also a difference between the two plant species. The underwater parts of

Fig. 62 Percent distribution of recovered ^{203}mercury at the end of the experiments as the percentage of total recovered ^{203}mercury (numbers above bars represent percent ^{203}mercury recovered of total ^{203}mercury added; vertical lines indicate ranges and (n) represents number of samples for each component).

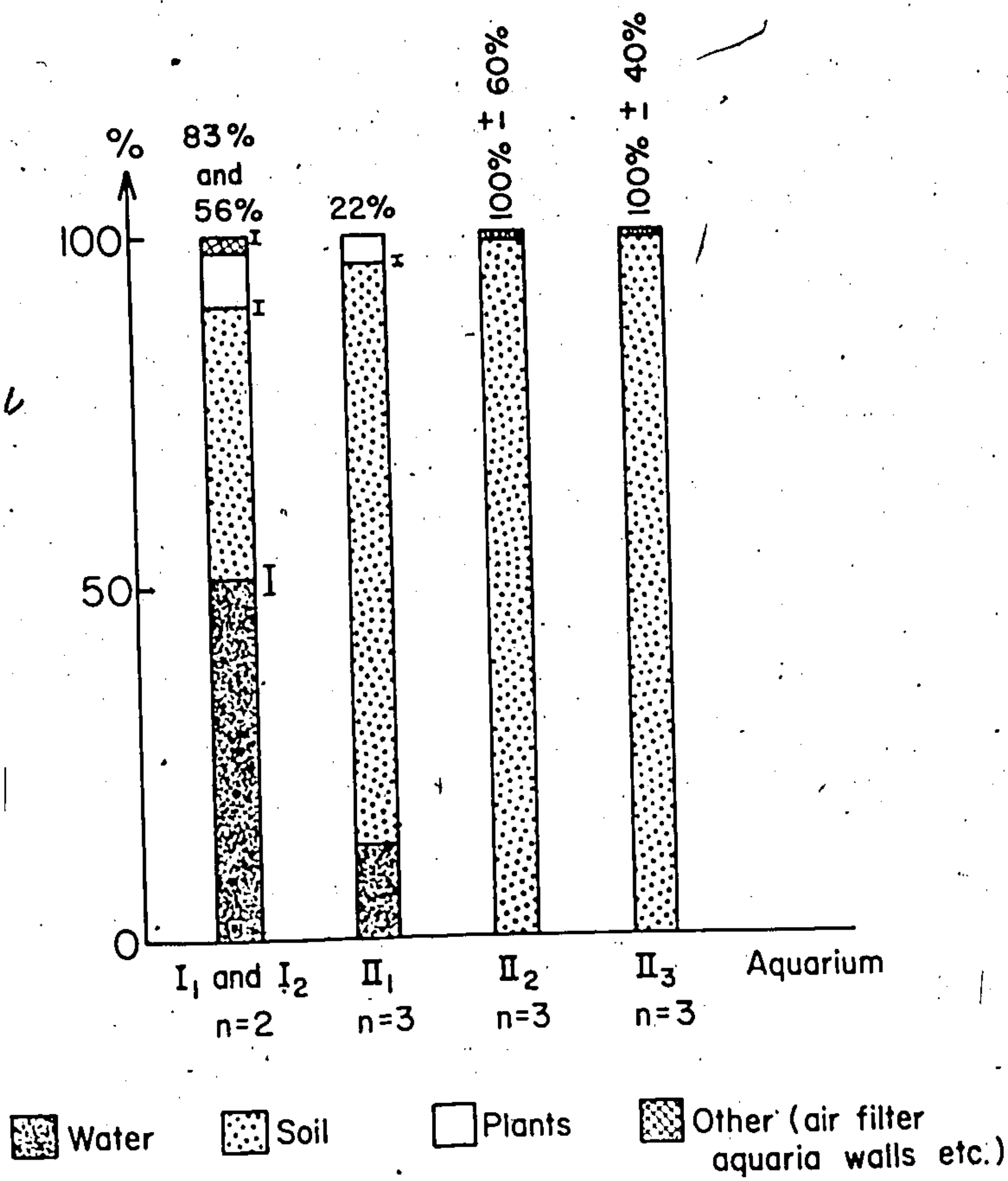
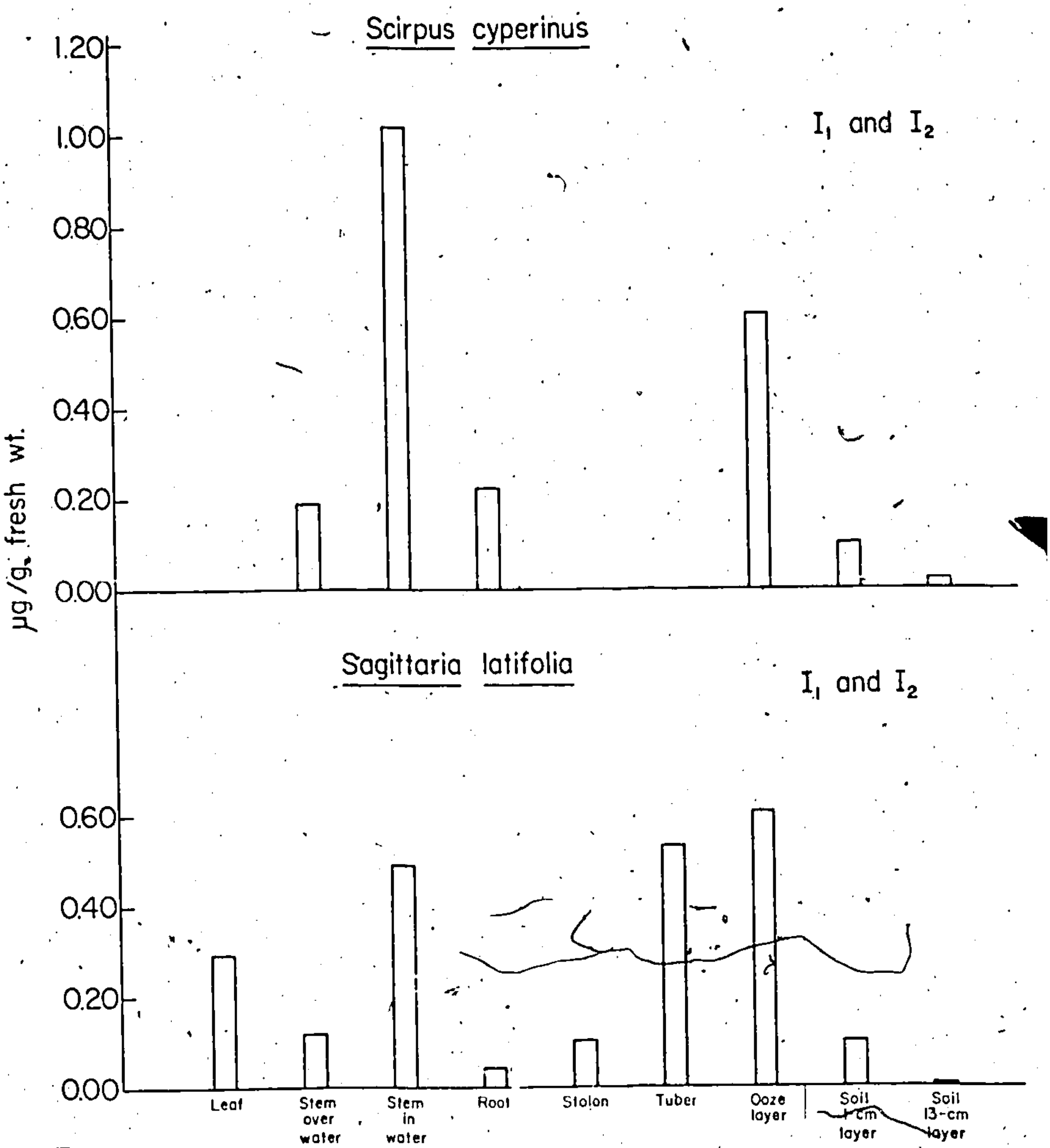

%
83%
and
56%
22%
100% ± 60%
100% ± 40%
100
50
0
I₁ and I₂
n=2
II₁
n=3
II₂
n=3
II₃
n=3
Aquarium
Water
Soil
Plants
Other (air filter
aquaria walls etc.)

TABLE 21 ^{203}mercury concentration (μg ^{203}Hg/g fresh wt.) in plants at the end of experiments I_1 and I_2 combined (mean of two samples is followed by the range).

Sample	Scirpus cyperinus mean	range	Sagittaria latifolia mean	range
Leaf	-		0.30	(0.23 - 0.36)
Stem over water	0.19	(0.15 - 0.23)	0.12	(0.09 - 0.14)
Stem in water	1.02	(0.94 - 1.10)	0.49	(0.40 - 0.57)
Root	0.23	(0.12 - 0.33)	0.04	(0.03 - 0.05)
Stolon	-		0.10	
Tuber	-		0.53	(0.52 - 0.54)
Ooze layer	0.61	(0.60 - 0.61)	0.61	(0.60 - 0.61)
Soil 1-cm layer	0.10	(0.09 - 0.11)	0.10	(0.09 - 0.11)
Soil 13-cm layer	0.02		0.01	(0.00 - 0.01)

Fig. 63. Distribution of ^{203}mercury in plants and soil at the end of the experiments I_1 and I_2 combined. Bars represent mean of two samples.


Scirpus cyperinus
I₁ and I₂
1.20
1.00
0.80
0.60
0.40
0.20
0.00
μg/g. fresh wt.
Sagittaria latifolia
I₁ and I₂
0.60
0.40
0.20
0.00
Leaf
Stem over water
Stem in water
Root
Stolon
Tuber
Ooze layer
Soil 1-cm layer
Soil 13-cm layer

S. latifolia, had absorbed up to 0.49 μg/g fresh wt. and *Scirpus cyperinus* significantly higher amounts. Roots took up a small amount of mercury. The concentrations were 0.03 to 0.05 μg/g fresh wt. in *S. latifolia* and 0.12 to 0.33 μg/g in *S. cyperinus*. The elevated values of the latter could be due to some roots in the samples having higher concentrations by growing through the holes in the bottom of the pots and out into the water. Comparatively high mercury levels (ca 0.53 μg/g) were also found in tubers of *S. latifolia* that had developed during the experiment. The center of these tubers had the same concentration as the whole tuber indicating that the mercury was present throughout and not just in the surface layers.

In the second experiment recovery of mercury in aquarium II_1 (water treated) was unexplicably low, only 22%. In aquaria II_2 (all sediment treated) and II_3 (surface sediment treated) recoveries were 100 ± 60% and 100 ± 40% respectively. The variability in the data illustrate the difficulties in sediment sampling. In the experiments where mercury was added to the water (II_1, water treated), as much as 83% of the recovered ^{203}mercury was found in the soil (Fig. 62). The main part of this mercury was distributed in the surface layers (0-1 cm in depth). Very little was found in the deeper sediment layers. Mercury concentrations varied a lot in the soil surface samples (Tables 22 and 23; Figs. 64 and 65). They were mainly between 0.18 μg/g fresh wt. and 0.28 μg/g but one sample

TABLE 22 ^{203}mercury concentrations(μg ^{203}Hg/g fresh wt.) in Sagittaria latifolia and water at the end of experiments II_1, II_2 and II_3 (mean of three samples is followed by range unless otherwise noted).

	AQUARIUM					
	II_1		II_2		II_3	
Sample	mean	range	mean	range	mean	range
Leaf	0.020	(0.015-0.026)	0.001		0.001	
Stem over water	0.026	(0.020-0.035)	0.001		0.000	
Stem in water	0.032	(0.020-0.044)	0.001		0.001	
Root	0.010	(0.005-0.015)	0.015	(0.010-0.020)	0.004	
Ooze layer	0.229	(0.074-0.409)	0.083	(0.065-0.105)	0.187	(0.137-0.235)
Sediment 1-cm layer	0.132	(0.110-0.167)	0.123	(0.060-0.194)	0.282	(0.225-0.345)
Sediment 13-cm layer	0.005		0.107	(0.069-0.155)	0.013	(0.002-0.021)
Water at start (n = 2)	0.014		<0.001		<0.001	
Water at end	<0.001		<0.001		<0.001	

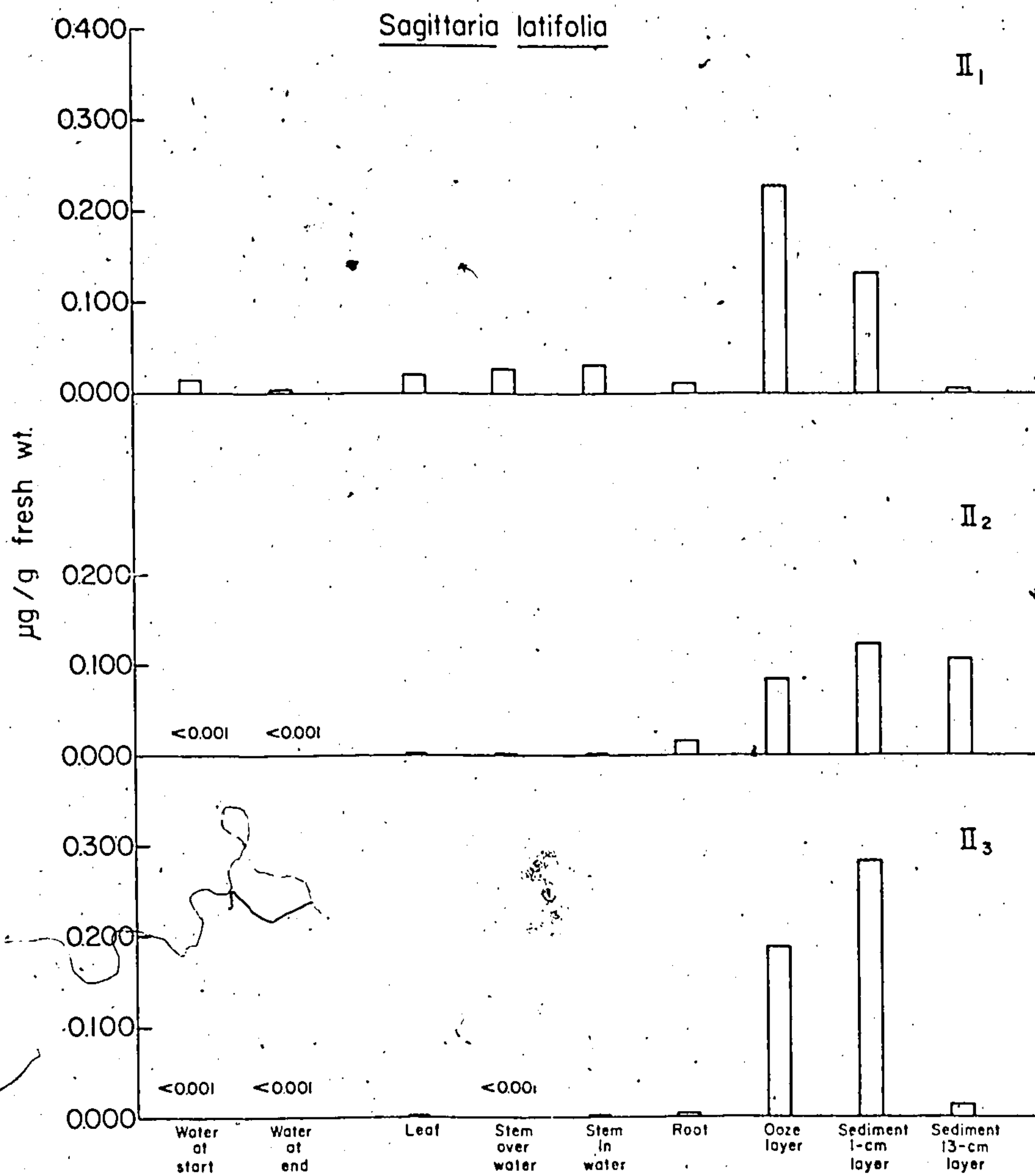
n = number of samples

TABLE 23 ^{203}mercury concentrations (μg ^{203}Hg/g fresh wt.) in <u>Scirpus cyperinus</u> and water at the end of experiments II_1, II_2 and II_3 (mean of three samples is followed by range unless otherwise noted).

	AQUARIUM					
	II_1		II_2		II_3	
Sample	mean	range	mean	range	mean	range
Stem over water	0.061	(0.034-0.095)	0.001		0.000	
Stem in water	0.177	(0.105-0.258)	0.004	(0.002-0.008)	0.001	
Root	0.010	(0.005-0.015)	0.045	(0.022-0.080)	0.002	
Ooze layer	0.245	(0.177-0.285)	0.065	(0.055-0.084)	0.133	(0.096-0.157)
Sediment 1-cm layer	0.092	(0.055-0.140)	0.074	(0.034-0.140)	0.262	(0.242-0.295)
Sediment 13-cm layer	0.005		0.070	(0.045-0.092)	0.004	
Water at start (n = 2)	0.014		<0.001		<0.001	
Water at end	<0.001		<0.001		<0.001	

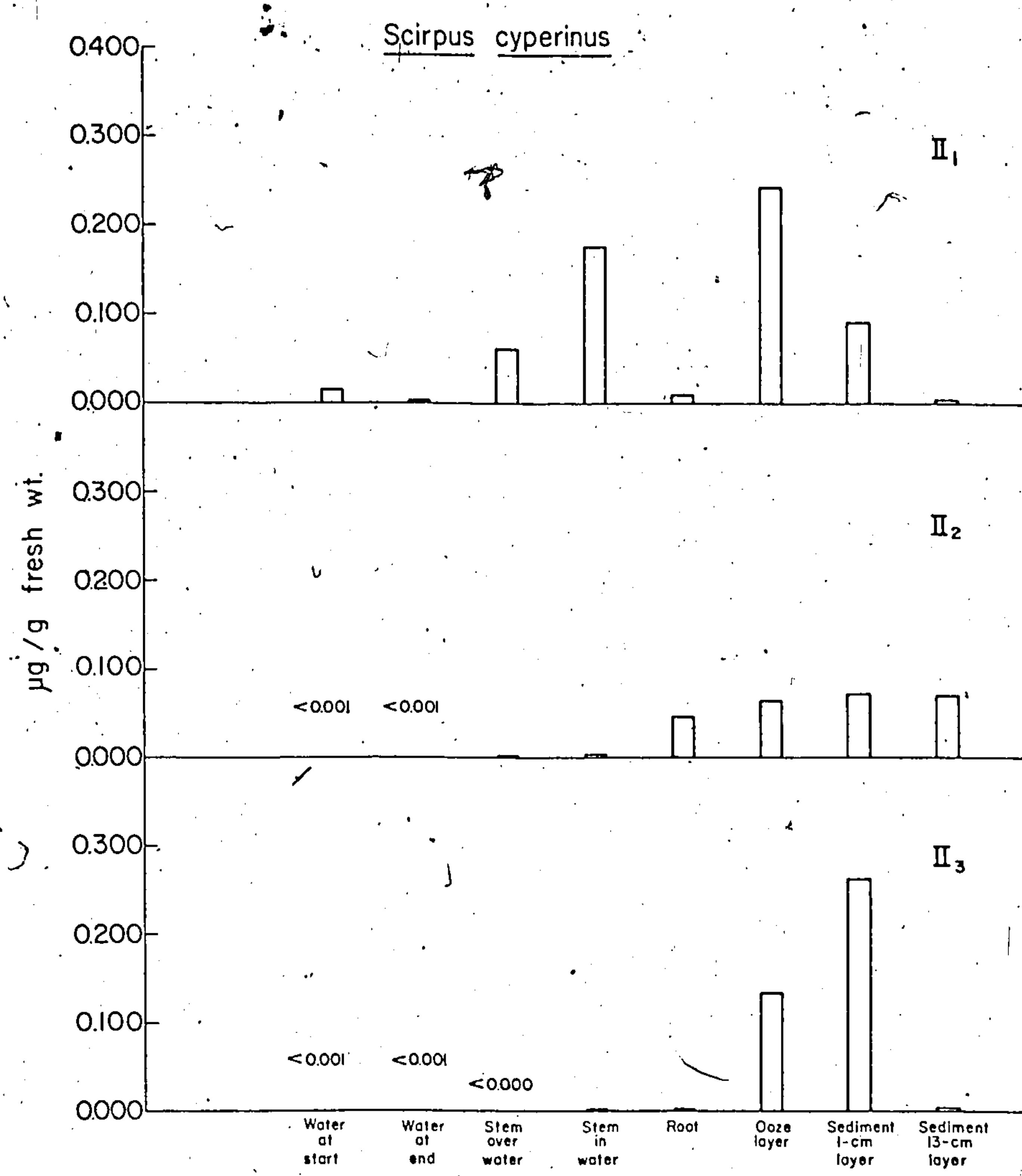
n = number of samples

Fig. 64 Distribution of ^{203}mercury in water, plants and sediment at the end of experiments II_1, II_2 and II_3 with <u>Sagittaria latifolia</u>. Bars represent mean of three samples. ^{203}mercury concentrations in water at the start of the experiments are included.



Sagittaria latifolia
II1
II2
II3
μg / g fresh wt.
0.400
0.300
0.200
0.100
0.000
<0.001
<0.001
<0.001
<0.001
<0.001
Water at start
Water at end
Leaf
Stem over water
Stem in water
Root
Ooze layer
Sediment 1-cm layer
Sediment 13-cm layer

Fig. 65 Distribution of ^{203}mercury in water, plants and sediment at the end of the experiments II_1, II_2 and II_3 with <u>Scirpus cyperinus</u>. Bars represent mean of three samples. ^{203}mercury concentrations in water at the start of the experiments are included.



Scirpus cyperinus
μg/g fresh wt.
0.400
0.300
0.200
0.100
0.000
II1
II2
<0.001
<0.001
II3
<0.001
<0.001
<0.000
Water at start
Water at end
Stem over water
Stem in water
Root
Ooze layer
Sediment 1-cm layer
Sediment 13-cm layer

had 0.41 μg/g. In the 1 cm layer there was less variation with an average value of 0.11 μg/g. The ooze layer on the bottom of the aquaria outside the pots, had a mercury concentration between 0.2 to 0.4 μg/g fresh wt..

Mercury introduced into the deeper soil (1 to 14 cm) remained there to the end of the experiment. In aquarium II_2 where all the sediment was treated with mercury, concentrations were very similar through all three layers varying around 0.09 μg/g (Tables 22 and 23; Figs. 64 and 65). In aquarium II_3 (surface sediment treated) they were highest in the 1 cm layer, with an average value for all pots of 0.27 μg/g. Concentrations were slightly lower in the surface ooze and very low (0.01 μg/g and less) in the rest of the sediment (1 to 14 cm).

The plants in the sediment treated experiments took up very little mercury in proportion to the other compartments (Tables 22 and 23; Figs. 64 and 65). In aquaria II_2 (all sediment treated) and II_3 (surface sediment treated), which had very low mercury concentrations in the water during the whole experiment, all shoot parts of both species were found to have less than 0.01 μg mercury/g fresh wt.. The roots of S. latifolia in aquarium II_2 contained larger amounts of mercury (average 0.02 μg/g) than in II_3 (0.004 μg/g). S. cyperinus showed the same pattern but values were 0.05 μg/g and 0.002 μg/g respectively.

The plants in the water treated aquarium (II_1) absorbed a higher proportion of mercury than those in sediment treated aquaria (Fig. 62). The increase was confined to the stem and leaf parts of both species (Tables 22 and 23). The roots of both species showed a modest decrease in mercury relative to those grown in mercury treated sediment. For example, Scirpus cyperinus roots in water treated aquaria were 0.01 μg/g and in sediment treated 0.045 μg/g.

When the epidermal layer of plant samples was removed, there was still about 10% of accumulated mercury remaining in the inner parts. For Sagittaria latifolia the numbers were: for emergent tissues, 0.002 μg/g, and for submersed 0.006 μg/g. For Scirpus cyperinus the values were 0.016 and 0.010 μg/g respectively.

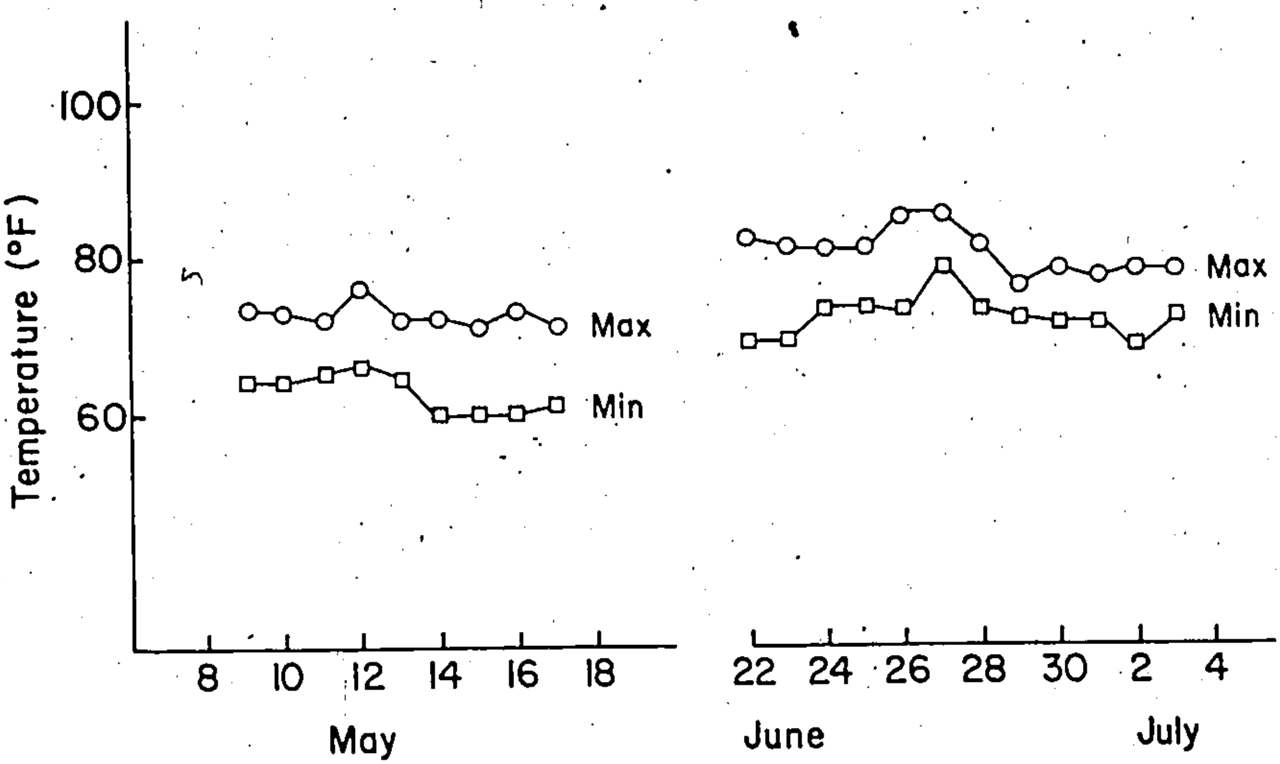
Also some decayed tubers were analysed but showed low uptakes around 0.001 μg/g.

Snails and the floating leaf plant Lemna minor, in all three aquaria, accumulated mercury, more so in aquarium II_1 (water treated) than II_2 (all sediment treated) and II_3 (surface sediment treated). The total amount absorbed by these organisms was too small to contribute to the distribution pattern.

pH was recorded in experiment II. Measured in the daytime, it was stable at roughly 7.5 during the whole study in all four aquaria.

The temperature was different during the two study periods I and II as shown in Fig. 66.

Fig. 66 Temperature readings in greenhouse during experiments.



Temperature (°F)
100
80
60
Max
Min
Max
Min
8
10
12
14
16
18
22
24
26
28
30
2
4
May
June
July

4. DISCUSSION

The mercury did not seem to affect the growth of either *Sagittaria latifolia* or *Scirpus cyperinus*. The same has already been shown with other emergent species (Hannerz, 1968; Carbonneau and Tremblay, 1972). Plants grew well except in clay, which was so dense that it was difficult for their roots to penetrate. In the Ottawa River study area (Section I) there were no emergent plants found in this kind of clay. Only submersed species, whose roots do not penetrate very deep were found.

The plants were quite effective in the uptake of mercury. It appears that the higher the concentration in the water the more mercury was accumulated by the shoot (Figs. 63, 64 and 65). This pattern was independent of the concentration levels in the soil. When looking at the shoot parts, similar results to what has been presented before in Hannerz' study (1968) were obtained. In general submersed parts retained more mercury than emersed parts (Figs. 63, 64 and 65). Also, the internal tissues were found to contain lower concentrations than the rest of the plant parts. This may indicate that mercury adsorption is more important than Hg absorption. The question here arises whether the mercury would be absorbed to the plant surface or is bound to micro flora and fauna ("periphyton") attached to the plant surface. This microgrowth is probably difficult to wash away completely in the cleaning process, without also taking off plant material. However it was found that similar algae and debris which accumulated on the sides of the aquaria during the experiments, had very low concentrations of mercury. Therefore it is more probable that there is a physiological uptake mechanism in the outer layers of the plant tissues.

An indication of the importance of mercury translocation in S. latifolia was noted in the water treated aquaria of experiment I. During the experiment, the mercury concentration in the soil increased up to 0.01 μg/g. Tubers which developed during the experiment in this soil accumulated high concentrations of mercury. As shown in Table 21 and Fig. 63 the mercury ratio in tubers to that in soil was about 500 to 1. This accumulation was not a surface phenomenon, since the innter parts of the tubers were just as radio active as the outer, and since the roots and stolons growing in the same soil showed very little mercury uptake. If tubers show the same pattern in situ after the mother plant has been exposed to high concentrations of mercury this could have a deleterious effect on animals that may feed on them. Sculthorpe (1971) describes the importance of this plant part as a food source.

The important link in mercury accumulation in these plants seems to be the uptake from water to submersed shoots. Where roots were surrounded by sediment with high mercury levels (0.07 to 0.11 μg/g fresh wt.), and the concentration in water was extremely low (less than 0.001 μg/g) (Tables 22 and 23; Figs. 64 and 65) accumulation in the shoots was also extremely low. The traces of mercury found in these shoots could as well originate from the water as from the soil. Upward translocation from the roots to the shoots does not appear to be a significant source of mercury in the shoots of these plants.

The roots appear able to take up and store mercury when it is present in the surrounding medium. In experiment I_1 (Table 21, Fig. 63) roots of the species S. cyperinus probably accumulated mercury from water, as some of the roots had spread out over the holes exposed to the water compartment at the bottom of the plant pots. In aquarium II_2 roots were surrounded by soil containing mercury. At the end of this experiment, concentrations were almost the same in the roots as in the soil they grew in. Whether translocation of mercury from shoots to roots is a significant vector in accumulation has not been resolved in these experiments. The relative concentration between mercury levels in shoot and root varies considerably depending on species and growth conditions.

As indicated in the above text, a difference in uptake between species was found. In S. cyperinus mercury was found at higher levels than in S. latifolia. If, as believed, mercury is mainly taken up by and translocated from the surface layers in the submersed shoot, the morphology of the plant surface could be an important factor in the concentration levels of mercury. In S. cyperinus, which has a bristly surface, the proportion of surface layer to the internal tissues is larger than in S. latifolia with a smooth surface. However, the difference in uptake could be a physiological phenomenon. In recent experiments (Mortimer, 1974) on two species of Elodea (a submersed aquatic plant form) with similar surface morphology, mercury uptake differed between the two species and he explained this in terms of different physiological reactions to Hg.

The pattern of mercury uptake by Ottawa River sediments, which was studied by Kudo and Hart (1972) is followed in these experiments. The sediments form the largest accumulating compartment when mercury is added to the water, and the sediments retain almost all of the mercury added to them.

Although the two experiments were run at different ambient temperatures, there is no way to correlate differences to this parameter. The temperature change accompanied the more complex seasonal parameters, such as photoperiod, total light and temperature differentials, which were not measured. However, I am convinced that the seasonal performance of the plant has a bearing on mercury uptake, particularly for tuber forming plants like the Sagittaria.

Alghouth there are still unanswered questions about mercury uptake in higher aquatic plants and the above laboratory answers might not apply when it comes to plant behaviour in the field, this study showed that more work has to be put into field sampling for mercury analyses and possibly also for other minerals. In works presented lately on enrichment of heavy metals in aquatic plants, underground parts have been neglected, as in the case of Dietz (1972) and Reay (1972) both collected only shoots for their analyses. This exclusion of parts growing in the sediment may not be an important factor when it comes to submersed species of aquatic plants, as they often have a very low biomass proportion in underground parts (Section I). However it is very important in emergent species, where parts in the sediment, as in the case of the findings in the Ottawa River (Section I) accounted for about 24% of the total plant biomass. Westlake (1965a) reported that underground parts made up 50% or more of his total biomass. For this reason, the root uptake component, was included in the laboratory experiments which I performed.

5. CONCLUSIONS

Mercury uptake from soil, river sediment and water by two rooted aquatic plant species, Sagittaria latifolia and Scirpus cyperinus, was measured after 10 days exposure to radioactive mercuric chloride. The density of vegetation was close to what has been found in some parts of the Ottawa River. Both species were found to be active in their uptake of mercury. Mercury uptake by the plants was proportional to the concentration of mercury in the water. Submersed parts and tubers accounted for the largest accumulation of mercury and little was detected in the roots. Submersed parts also appeared to be the important link in the translocation of mercury from water to the remainder of the plant. Evidence was presented for a physiological mechanism in the mercury uptake process by plants.

Even though plants accumulated mercury, the soil, river sediment and the ooze formed during the study were more important in binding the mercury. The plants accounted for a maximum of only 7% of the recovered mercury (in plants with tuber growth).

In surveys concerned with total enrichment of heavy metals in aquatic plants, the exclusion of underground parts may be an important mistake. In emergent species, parts growing in the sediment sometimes account for 50% or more of the total plant biomass, and the mercury accumulation in these parts cannot be ignored.

Section III

MERCURY ACCUMULATION IN OTTAWA RIVER MACROPHYTES.

1. INTRODUCTION

As an extension of the in vitro experiments on mercury uptake by rooted higher aquatic plants (Section II of this thesis), one emergent plant form (Sagittaria latifolia) and two submersed forms (Vallisneria americana and Elodea canadensis) were sampled in the summer of 1973 in the Ottawa River study area for mercury analysis. In the previous year a preliminary investigation on mercury accumulation by higher aquatic plants in the same section of the river was performed. Only one other survey on mercury enrichment by aquatic plants in a field situation (Dietz, 1972) is known by the author. Dietz's study does not take the underground parts (roots, tubers, etc.) into consideration, however. Dietz's paper discusses some unresolved questions on the role of roots in mercury accumulation from water and sediments. These questions served as the impetus for the following investigations. The emphasis was laid on assessing mercury concentrations in different parts of higher aquatic plants in order to estimate the levels of mercury found in macrophytes in this section of the Ottawa River. These data were also compared with the laboratory mercury uptake results.

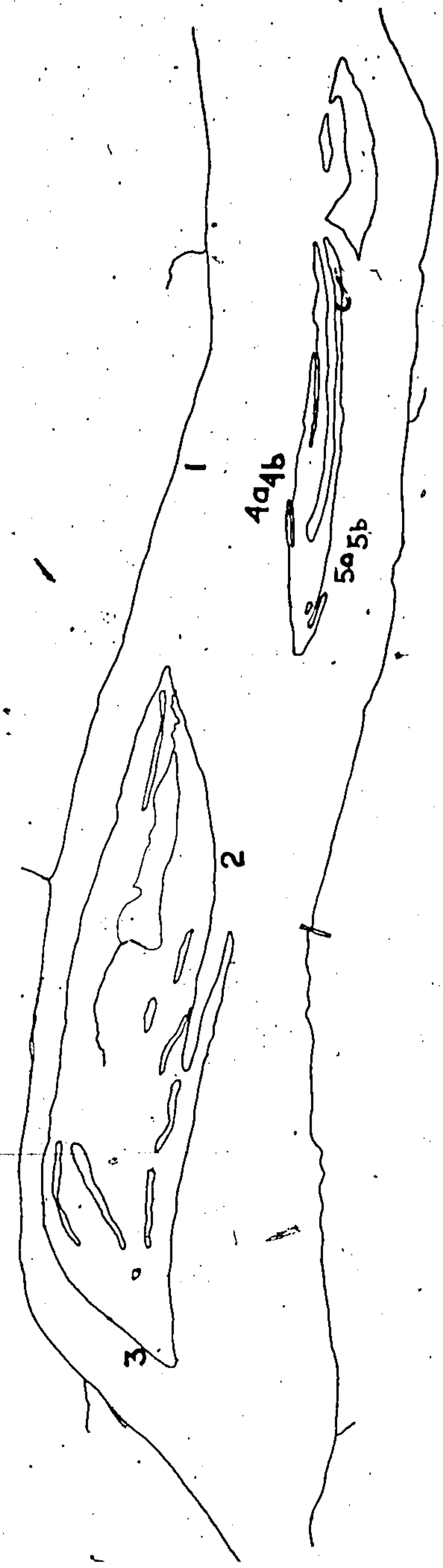
2. MATERIALS AND METHODS

Water samples for mercury analyses were taken from May to November in 1972 and February to August as well as in October and November in 1973 (Norstrom and Peter, 1972; Norstrom and Brownstein, 1974).

In 1972, plant material for mercury analysis was taken from total and mixed samples of aquatic vegetation collected for the estimate of biomass and standing crop (Section I, Materials and Methods). Sediment samples were taken with a plastic core 18.0 cm^2 in cross sectional area to a depth of 13 cm. At three stations samples were taken randomly within the transects selected by the University of Ottawa and the National Research Council of Canada (Section I, Materials and Methods). The rest were taken in the center of the same quadrat from which plant material was collected. Samples were placed in glass vials and stored in the freezer for one month before being sent to the NRC laboratories for analysis.

In 1973, samples of emergent vegetation were collected on the 24th of September and submersed vegetation on the 15th of October. The emergent plants were collected close to the Quebec shore and at two locations on Kettle Island near the shore (Fig. 67). The submersed plants were sampled at a water depth of 150-200 cm on the north and south sides of Upper Duck Island (Fig. 67). The plants were collected at each station over a fairly large area in which the vegetation was relatively homogenous. The plants were placed in plastic bags and stored at 5°C for up to four hours

Fig. 67 Sampling stations for aquatic plants.


1
4a
4b
5a
5b
2
3

after sampling. Plants were cleaned very carefully with tapwater, and spread out on paper which would absorb any adhereing water. After fresh weight was determined, the plants were stored in plastic bags at $5^{o}C$. Within the next 12 hours, they were placed in an oven at $30^{o}C$ and dried for 24 hours. The dry weight was recorded and the material was milled into fine particles. Three subsamples of each of the emersed shoots, submersed shoots, roots, stolons and tubers of Sagittaria latifolia, and submersed shoots of Vallisneria americana and Elodea canadensis, were prepared. All dry samples were frozen in preparation for mercury analysis at the NRC laboratories. Analyses of plant material and sediments were done by flameless absorption spectrophotometry following modifications of Magos' methods (Norstrom and Peter, 1972; Norstrom and Brownstein, 1974). These analyses were performed by M. Brownstein.

3. RESULTS AND DISCUSSION

3.1 Mercury in water

The mercury concentrations in water were fairly low in the two years of investigations, with the highest value in May 1972 (0.050 µg/l). There may have been a general trend towards lower concentrations with time (October 1973, 0.005 µg/l).

3.2 Mercury in sediments

The sediment samples taken directly in connection with the plant samples generally had mercury concentrations ranging from 0.05 to 0.14 µg/g dry wt. (Table 24). The highest value (0.79 µg/g) was from below CIP where the sediment was associated mainly with wood fibres (which are characteristic of the bottom sediments along the Quebec shore). A fairly high value (0.31 µg/g) occurred in fine clay on the Ontario shore. Samples from the latter site have shown high concentrations of many other pollutants such as DDE, DDD and DDT (Norstrom and Brownstein, 1974). I observed a localized effluent of untreated sewage once after a heavy rainstorm in this area. Also a marina and sea plane base are situated immediately upstream. These factors could contribute to these higher mercury levels. Earth taken from around airports has been reported to contain unnaturally high concentrations of mercury (Klein, 1972).

In 1973 no analyses of sediments directly associated with the aquatic plants were done, since only a limited number of samples could be analysed within the Ottawa River project. However a certain number of sediment analyses were carried out on samples from other

Table 24. Density, fraction dry material and mercury concentration in sediment associated with aquatic plants (Norstrom and Peter, 1972). (All analyses were in duplicate. With 17 other sediment samples from the same 'study area' (Section I, Description of Study Area) the mean variation between duplicates was 19 ppb or 9.2%).

Station	Density (g/ml)	Dry Weight (%)	Total Hg (µg/g dry wt.)
1S	2.08	77.8	0.09
3S	1.85	67.8	0.11
4S	1.52	69.8	0.14
8S	1.67	60	0.07
10S	1.82	68.2	0.10
11S	2.04	75.9	0.06
14S	1.39	50.3	0.31
15S	1.08	32.6	0.79
18S	1.26	79.6	0.05
19S	1.60	60.5	0.26
21S	1.54	65	0.07
3D	1.56	70.9	0.09
4D	1.38	72.7	0.12
7D	1.67	60.8	0.09
10D	1.48	67	0.12

S = Shallow water

D = Deep water

sites in the study area (Norstrom and Brownstein, 1974). The highest mercury concentrations (up to 1 μg/g dry wt.) were again obtained in sediments below CIP. The main channel sediments (sand) had the lowest mercury levels (around 0.03 μg/g dry wt.). Therefore sediments around the aquatic plants in 1973, could be expected to have had mercury levels around 1 μg/g dry wt. and below, but not less than 0.03 μg/g dry wt..

3.3 Mercury in plants

According to Norstrom and Peter (1972) the results from analyses of the mercury content in plants, were somewhat questionable in the 1972 samples due to a miscalculation in the size of subsamples needed for analysis. However, results show that mercury concentrations in samples of mixed plant species were generally less than 0.13 μg/g dry wt. in both shoots ("greens") and underground parts ("roots") (Table 25). A few very high values were obtained in the roots (1.17 μg/g dry wt.) in station 14S and (0.87 μg/g) at station 10S. However no correlation was found between "roots" and "greens", "roots" and sediments or "greens" and sediments (Ibid). High mercury concentrations in "roots" could therefore not be explained from high concentrations in the surrounding sediments, nor from the mercury level in the water, which was only an average of 0.04 μg/l during May to September 1972.

The results in summer 1973 show that concentrations in plants of 1973 were similar to those of the previous year (Table 26).

Table 25. Mercury concentrations and species composition in plant samples 1972. (Mean concentration and the variation from the mean for all 'green' (shoot) were 0.07 ± 0.02 µg/g dry wt. and for all 'roots' (underground parts) 0.18 ± 0.07 µg/g). Species name is followed by percent shoot of total shoot weight and percent underground parts of total underground parts weight in paranthesis.)

Station	Date	Species	Total Hg (µg/g dry wt.) 'Shoots'	Total Hg (µg/g dry wt.) 'Roots'
1S	Aug. 17	Unknown (48; 79), Nymphaea tuberosa (48; 79), Hydrocharis morsus ranae (14; 6)	< 0.01*	0.03
3S	Aug. 16	Sagittaria latifolia (87; 28), Nymphaea tuberosa (13; 22)	0.06	0.10
4S	July 14	Unknown (100; 100)	0.09	0.10
7D	Aug. 21	Vallisneria americana (100; 100)	< 0.01*	0.13
10S	Aug. 21	Sagittaria latifolia (96; 94), Vallisneria americana (3; 6)	< 0.01*	0.87
11S	July 11	Unknown (100; 100)	0.11	0.08
14S	July 14	Unknown, (100; 100)	0.11	1.17
19S	Aug. 22	Sagittaria latifolia (99; 96), Vallisneria americana (2; 3)	0.05	0.28
3D	Aug. 29	Sparganium angustifolium (100; 100)	< 0.01*	0.13
8S	Aug. 28	Sagittaria latifolia (100; 100)	0.34	0.09
14D	Sep. 1	Vallisneria americana (96; 100), Elodea canadensis (4; 0)	0.24	0.02
10D	Aug. 31	Elodea canadensis (63; 11), Potamogeton epihydrus (37; 89)	< 0.01*	0.08
11D	Aug. 31	Elodea canadensis (98; 100), Vallisneria americana (2; 0)	0.01	0.08
4D	Aug. 29	Vallisneria americana (100; 100)	< 0.01*	0.06
19D	Aug. 31	Elodea canadensis (66; 13), Vallisneria americana (30; 80)	0.21	< 0.01
		Myriophyllum sp. (4; 7)		
15S	Aug. 25	Sagittaria latifolia (100; 100)	0.01	0.09
18D	Sep. 1	Vallisneria americana (100; 100)	< 0.04	0.06
21S	Aug. 26	Equisetum sp. (100; 100)	< 0.01*	0.08
18S	Aug. 25	Sparganium eurycarpum (60; 53), Eleocharis sp. (39; 46)	0.12	< 0.01

S = Shallow water vegetation; D = Deep water vegetation; * = See Section I of this thesis;

* = Samples contain small amount of mercury, larger samples required

Table 26. Concentration of mercury in plant material (µg/kg dry wt.) in 1973. (Mean of three samples is followed by range unless otherwise indicated.)

Species	Station	Mercury (µg/kg dry wt.)				
		Emersed Shoot	Submersed Shoot	Root	Stolon	Tuber
Sagittaria latifolia	1	95*(90-99)	84(81-88)	127*(126-128)	76(73-80)	43(40-45)
	2	90*(88-98)	75(70-83)	114*(113-116)	71(66-73)	46(36-53)
	3	99(97-100)	93(92-95)	290(281-306)	124(118-128)	60(56-65)
Vallisneria americana	4a	-	105(103-107)	-	-	-
	5a	-	96(93-98)	-	-	-
	4b	-	104(100-108)	-	-	-
	5b	-	109(100-116)	-	-	-

* Mean of two samples

Therefore the decrease of mercury in the river water from 1972 to 1973 did not seem to affect the accumulation of mercury in the plants. To compare results from the analyses with the experiments in Section VI of this thesis, and with other work and surveys done in the same field, mercury concentrations based on fresh weight have to be considered (Table 27). This presents a somewhat different picture than shown in Table 26. Emersed shoots of Sagittaria latifolia had a slightly higher dry weight than submersed shoots, roots and stolons of the same species (Table 28). The tubers of S. latifolia had considerably higher dry weight content at the low drying temperature used ($30^{o}C$). In this way the tubers had among the highest concentrations on a fresh weight basis (0.012 to 0.015 μg/g fresh wt.) (Table 27) while they had the lowest mercury levels on a dry weight basis (Table 28).

Because of the higher mercury concentrations in some of the underground parts compared to shoot parts, the possibility of contamination of samples from the surrounding media (sediment and water) is considered below. Sediments may be difficult to wash away completely (leaving very small amounts on the plant). However the amount of sediment needed to give concentrations high enough to be reflected in the results certainly could not remain on the washed roots. Secondly, the roots with a smaller diameter giving a larger surface area/unit weight than in tubers or stolons should have had the highest mercury concentrations of the three plant parts on a

Table 27. Concentration of mercury in plant material (μg/kg fresh wt.). -(Mean of three samples is followed by range unless otherwise indicated.)

Species	Station	Mercury (ug/kg fresh wt.) Emersed Shoot	Submersed Shoot	Root	Stolon	Tuber
Sagittaria latifolia	1	10*(10-11)	4.9(4.7.5-1)	7.0*(7.0-7.1)	5.0(4.6-5.2)	13(12-13)
	2	9.4*(8.7-10)	3.4(3.2-3.8)	6.9*(6.9-7.0)	4.8(4.4-4.9)	12(9.1-14)
	3	8.7(8.6-8.8)	4.6(4.7-4.9)	14.0(13.5-14.7)	7.58(7.21-7.82)	15(14-16)
Vallisneria americana	4a	-	5.71(5.59-5.82)	-	-	-
	5a	-	5.3(6.2-6.5)	-	-	-
Elodea canadensis	4b	-	8.86(8.52-9.20)	-	-	-
	5b	-	12.1(11.1-12.9)	-	-	-

* Mean of two samples

Table 28. Percent dry weight at 30^{o}C. (Values are based on total samples.)

Species	Station	Percent dry wt.				
		Emersed Shoot	Submersed Shoot	Root	Stolon	Tuber
Sagittaria latifolia	1	10.83	5.81	5.53	6.53	29.30
	2	10.49	4.57	6.06	6.70	26.65
	3	8.82	5.11	4.82	6.11	24.92
Vallisneria americana	4a	-	5.54	-	-	-
	5a	-	6.61	-	-	-
Elodea canadensis	4b	-	8.52	-	-	-
	5b	-	11.12	-	-	-

fresh weight basis if sediment contamination was critical. This was not the case. Instead the results indicated that different plant parts are ablo to accumulate mercury from water and/or sediment to different degrees, as was seen in Section II of this thesis.

4. CONCLUSIONS

Plants in the Ottawa River, below Ottawa, Canada clearly absorb mercury from the water and/or the sediment. Concentrations in the plant tissues (on dry weight basis) are about 10000 times that in the water and about the same as that in the sediments.

The decrease in mercury concentration in river water between 1972 and 1973 were not reflected in the plant analyses.

Where comparable analyses were available there was no correlation between mercury concentrations in underground parts and shoots, underground parts and sediments or shoots and sediments.

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