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EFFECT OF MUNICIPAL SEWAGE ON THE SUBMERGED MACROPHYTES OF A LAKE LITTORAL*

ABSTRACT: The effect was determined of municipal sewage on the littoral submerged macrophytes of five lakes in the Masurian Lakeland. Transformations have been found in the species composition and structure of the macrophyte community, as well as changes in the phenology, morphology, biomass and chemical composition of selected macrophyte species in littoral habitats of a varying degree of pollution with municipal sewage. In habitats with the highest degree of pollution a specific system of zones (of elimination, degradation and stimulation) of the macrophytes has been distinguished. A field experiment has shown that due to the effect of high concentrations of municipal sewage, the degradation and elimination of the macrophytes are rapid. The amounts of macro- and microelements accumulated in the macrophytes were determined to evaluate the plants as possible biological filters.

KEY WORDS: Lake littoral, submerged macrophytes, water pollution, biological purification of waters.

Contents

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1. INTRODUCTION

The effect of pollutions on aquatic vegetation can be considered from two sides, on the one hand the transformation and destruction of the macrophytes, and on the other hand to determine the role these plants may play in the processes of water purification. Studies on this problem contribute towards the creation of a basis for the protection and recultivation of the macrophytes which are an important biocenotic and environment-forming element of a lake littoral. They will also make it possible to determine the optimum method for cultivation of vegetation in different types of littoral.

The few investigations, carried out so far, of submerged and emergent macrophytes in lakes polluted by municipal and industrial sewage covered the species composition, distribution, and floristic changes (Forsberg 1964, 1965, Suominen 1968, Eloranta 1970, Kurimo 1970, Uotila 1971). The effect of different sewage on the morphology, phenology and the biomass of submerged macrophytes was also analysed (Adams et al. 1971, Bernatowicz et al. 1974, Ozimek and Sikorska 1975, 1976, Pieczyńska, Sikorska and Ozimek 1975).

The possibilities to use emergent macrophytes in the process of water purification were analysed by Seidel (1956, 1966). She has found that emergent macrophytes, and especially *Schoenoplectus lacustris* (L.) Palla, not only persist in highly polluted waters, but show quicker increments there than in the unpolluted habitats. They take up and accumulate large amounts of nutrients, and even toxin substances, e.g., phenols, thereby contributing to the biological water purification.

Wolverton and McDonald (1975) have found that in the tropical and subtropical countries the *Eichhornia crassipes* (Mart.) Solms may considerably aid the process of water purification. Culley and Epps (1973), as well as Sutton and Ornes (1975), suggest that it is possible to use for the same purpose pleustophytes such as: *Lemna*, *Spirodela*, *Wolffia*. These plants contain considerable amounts of nutrients and are easy to harvest by skimming surface with a rake or net.

As regards the submerged macrophytes, there have not been any wide-scope studies published concerning their usefulness in the processes of water purification. Of the few papers published it will be as well to mention that by Miks (1954), who has stated that a dense bottom vegetation may play the role of biological filters and thus contribute to the control of water pollution.

The aim of the present study was to determine the transformation of the littoral macrophytes under the influence of municipal sewage discharged into five lakes of the Masurian Lakeland. The occurrence, species composition, community structure and phenology, condition, morphology, biomass and the chemical composition of five selected species of submerged macrophytes in a littoral of a varying degree of pollution by municipal sewage, and in an unpolluted one have been analysed.

2. AREA AND METHODS

The investigations were carried out in the Masurian Lakeland (northern Poland), in the years 1972–1975, intensive investigations being carried out in the littoral of Mikołajskie Lake, and extensive ones in the littoral of lakes Bełdany, Śniardwy, Tałty and Miłki.

Mikołajskie Lake is a eutrophic, holomictic, with area 460 ha, an average depth 11 m and maximum depth 27.8 m. The length of the shoreline is 14 km. The littoral zone covers 87 ha which constitutes 19% of the lake surface. The samples were collected at seven polluted sites, and at five control sites situated in different parts of the littoral of Mikołajskie Lake, outside the area affected by the municipal sewage. The distribution of sites has been presented in Figure 1.

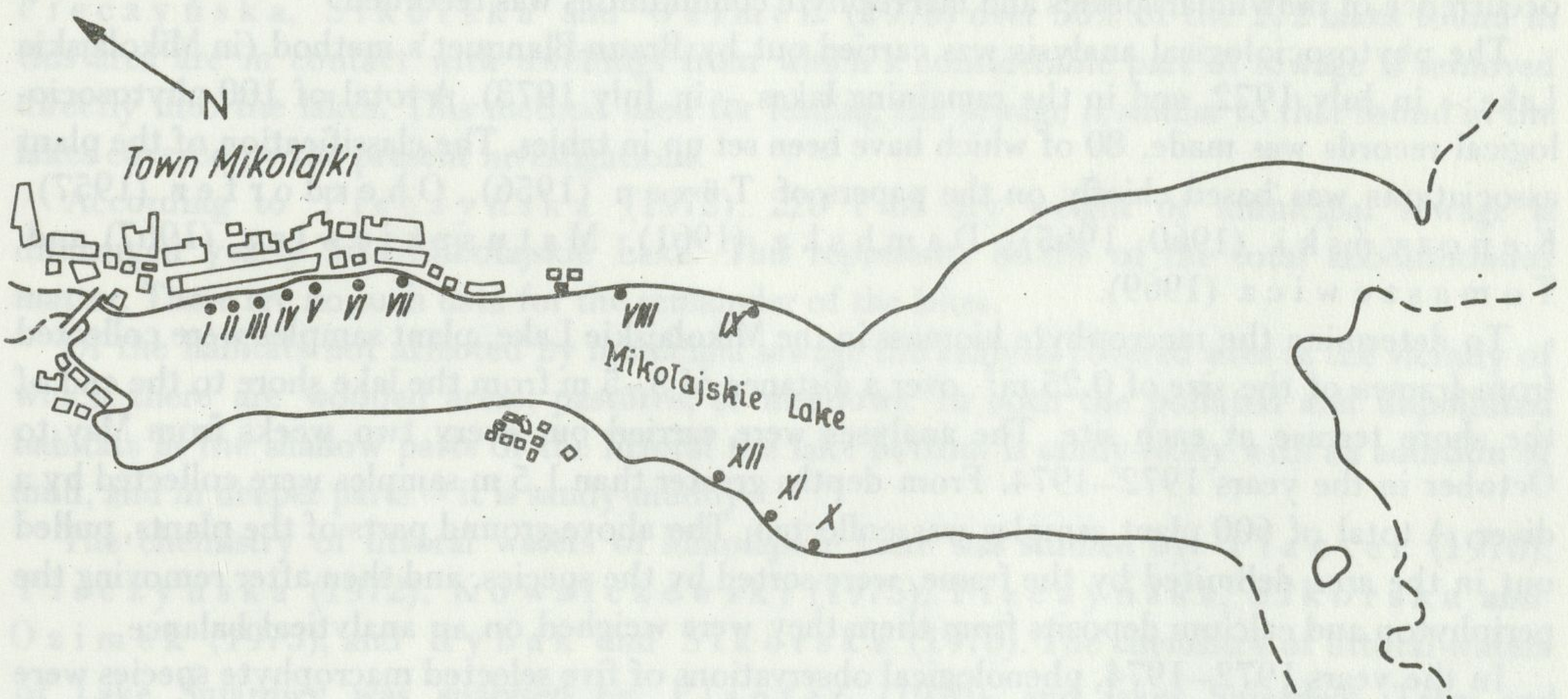

Fig. 1. Distribution of study sites in the littoral of Mikołajskie Lake
I–XII – sites

Table I. Characteristics of lakes investigated extensively

Lakes	Area (ha)	Depth (m) maximum	Depth (m) mean	Development of shore-line	Number of study sites
Śniardwy	10,970.0	23.4	5.9	2.2	6
Bełdany	940.0	46.0	10.0	3.2	4
Tałty	762.0	51.0	13.6	3.2	5
Miłki	24.9	19.0	8.5	1.5	3

Table I contains a general characteristics of the lakes Bełdany, Śniardwy, Tałty and Miłki (extensively studied) and the total number of study sites.

Chemical analyses of the water. The water samples for chemical analyses were collected with a 1-litre Patalas sampler at the distance 0.2, 5 and 10 m from the sewage outlets on polluted sites and at the same distances from the shore in the unpolluted habitats. Analyses were carried out according to the Standard Methods ... (1963), and Just and Hermanowicz (1964). The following were determined: dissolved oxygen (Winkler's method), pH and electrolytic conductivity (electrometrically), calcium, sodium, potassium (flame photometer), phosphates, nitrates, ammonia (colorimetrically), chlorides (Mohr's method). To separate large-particle suspensions, the water for chemical analyses was filtered through a nylon net with a mesh-size of 0.1 mm. In Mikołajskie Lake water samples for chemical analyses were collected in the years 1972–1974, at monthly intervals, from May to September, and in the remaining lakes three times – in July and August 1973, and in July 1974. A total of 350 water samples was collected and analysed.

Analyses of the macrophytes. At each site one profile 20 m wide was delimited, extending from the lake shore to the end of the shore terrace. Within this area the occurrence of individual species and macrophyte communities was recorded.

The phytosociological analysis was carried out by Braun-Blanquet's method (in Mikołajskie Lake – in July 1972, and in the remaining lakes – in July 1973). A total of 100 phytosociological records was made, 80 of which have been set up in tables. The classification of the plant associations was based chiefly on the papers of Tüxen (1956), Oberdorfer (1957), Kępczyński (1960, 1965), Dąmbska (1961), Matuszkiewicz (1967) and Tomaszewicz (1969).

To determine the macrophyte biomass in the Mikołajskie Lake, plant samples were collected from frames of the size of 0.25 m^2, over a distance of 3–5 m from the lake shore to the end of the shore terrace at each site. The analyses were carried out every two weeks from May to October in the years 1972–1974. From depths greater than 1.5 m samples were collected by a diver. A total of 600 plant samples was collected. The above-ground parts of the plants, pulled out in the area delimited by the frame, were sorted by the species, and then after removing the periphyton and calcium deposits from them they were weighed on an analytical balance.

In the years 1972–1974, phenological observations of five selected macrophyte species were carried out every ten days during the period April to October.

Plant materials for chemical analyses were collected at monthly intervals from June to September 1973. A total of 500 samples was collected. The specimens were thoroughly cleaned – all periphyton and calcium deposits were removed from them – and then dried at 70°C. The content of each of the components was calculated per the dry weight of the plants which was determined simultaneously. The following were determined: total nitrogen (Kjeldahl's method), total phosphorus (colorimetrically), potassium, sodium, calcium (flame photometer), iron, magnesium, manganese and zinc (atomic absorption spectrophotometer ASA), chlorine (Husband and Godden's method). Analyses of the chemical composition of the plants were made after Petersburgski (1954), Piper (1957) and Jackson (1958).

Plants to be analysed for chlorophyll content were collected twice in July 1974. The specimens were thoroughly cleaned, and chlorophyll-a was determined, separately in leaves and stems, according to the standard method (Vollenweider 1969).

A field experiment was carried out to establish the type and magnitude of the transformations caused by the influence of municipal sewage in macrophytes that had not previously been affected by it, and to determine the capability to regenerate of the plants subjected to a prolonged influence of the sewage. A detailed description of the experiment is given in Section 7.

3. CHARACTERISTICS OF THE HABITATS STUDIED

The polluted littoral habitats of the five study lakes are located along shores which are in contact with the buildings of towns, villages and tourism centres, which as a rule have no sewerage or sewage treatment plants. The lake littoral is polluted by municipal sewage over: 1% (Śniardwy, Bełdany), 5% (Tałty), 14% (Mikołajskie) up to 50% (Miłki) of the shore line. The studied environments are also polluted by household and dwelling wastes, the most intensive inflow of them exists in the summer, as a result of the presence of tourists in the Masurian Lakeland area. Municipal sewage is carried into the lakes in a centralized (pipes or ditches) and a non-centralized way. This is the usual way of leading sewage in the Masurian Lakeland. According to Pieczyńska, Sikorska and Ozimek (1975) over 50% of the 272 lakes found in this area are in contact with dwellings from which a considerable part of sewage is removed directly into the lakes. This method used for leading the sewage is similar to that found in the lakes covered by the present investigations.

According to Pieczyńska (1972), 220 t of dry weight of municipal sewage is discharged yearly into Mikołajskie Lake. This represents 83.6% of the total allochthonous matter. There are no such data for the remainder of the lakes.

Of the habitats not affected by municipal sewage the analysis covered sites in the vicinity of which there are wooded areas, pastures, or meadows. In both the polluted and unpolluted habitats in the shallow parts of the littoral the lake bottom is sandy-stony with an addition of mud, and in deeper parts – it is sandy-muddy.

The chemistry of littoral waters of Mikołajskie Lake was studied by: Planter (1970), Pieczyńska (1972), Kowalczewski (1975), Pieczyńska, Sikorska and Ozimek (1975), and Rybak and Sikorska (1976). The chemistry of littoral waters of Lake Śniardwy was analysed by Planter (1970), and lakes Śniardwy, Tałty and Bełdany – by Pieczyńska, Sikorska and Ozimek (1975). These papers also discussed polluted habitats showing distinct transformation of physico-chemical properties of water and they characterized a very high astatism which is related mainly to irregular sewage inflow and wave action.

The concentrations of the selected substances brought with the municipal sewage into the littoral of the five lakes are shown in Table II. Their highest content was recorded for sites with centralized sewerage outlet, where particularly high values of conductivity, ammonium nitrogen, chlorides, sodium and phosphates were obtained. At all sites the calcium content was the least variable.

The concentrations of the substances analysed showed a high degree of variation, which was connected mainly with the irregular inflow of sewage. Sites without centralized sewage outlet differed considerably in chemical composition of water from unpolluted sites only in Mikołajskie Lake.

The sites under study are characterized by considerable waves, due to which a fast dilution of the sewage begins already at a short distance from the sewage outlet. In Figure 2 examples

Table II. Range of variation of water chemistry at the study sites (0.2 m from sewage outlet area, or shore) of five lakes in the Masurian Łakeland (May-September 1972, 1973, 1974)

a – polluted sites with centralized sewage outlet, *b* – polluted sites without centralized sewage outlet, *c* – unpolluted sites (control), – – no data, n. d. – not detected

Lakes and sites		pH		Conductivity (μS)		NH_4^+ (mg/l)		NO_3^- (mg/l)		PO_4^{---} (mg/l)		Cl^- (mg/l)		K^+ (mg/l)		Na^+ (mg/l)		Ca^{++} (mg/l)	
		min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.
Mikołajskie	*a*	6.9	8.9	382	1341	0.20	130.00	n. d.	0.03	0.20	45.00	13.0	1156.0	11.0	37.0	11.7	1310.0	44.0	82.0
	b	8.3	8.7	296	550	0.02	2.30	n. d.	0.20	0.30	1.40	8.3	29.8	2.8	6.2	7.9	12.4	40.0	59.0
	c	8.4	8.7	271	325	0.02	0.15	n. d.	0.04	n. d.	0.06	6.9	13.8	2.3	3.0	4.4	8.7	35.0	48.0
Tałty	*a*	7.1	8.5	274	585	0.80	6.50	0.01	0.03	–	–	12.0	38.0	2.3	4.4	11.0	24.0	53.0	98.5
	b	7.9	8.3	280	330	0.02	0.10	0.01	0.02	–	–	9.2	15.9	2.1	3.3	2.6	4.6	48.0	52.5
	c	8.4	8.7	271	282	0.02	0.05	n. d.	n. d.	–	–	8.8	10.2	2.4	2.6	2.6	4.5	47.0	50.0
Mikki	*a*	7.8	8.1	285	523	0.60	10.20	–	–	–	–	12.8	43.0	2.4	6.0	4.6	8.5	39.0	53.0
	b	7.9	8.3	282	350	0.02	0.08	–	–	–	–	9.0	16.2	2.4	4.3	4.0	4.9	39.0	46.0
	c	8.2	8.5	282	315	0.01	0.02	–	–	–	–	11.2	13.0	2.3	2.8	3.6	4.2	38.9	42.0
Śniardwy	*b*	8.3	8.5	276	290	0.01	0.04	n. d.	n. d.	–	–	9.8	12.0	2.1	2.3	3.6	4.8	37.5	49.0
	c	8.3	8.5	274	282	–	–	–	–	–	–	8.2	9.6	2.2	2.4	3.5	4.3	37.0	39.0
Bełdany	*b*	7.9	8.3	270	299	0.02	0.04	n. d.	n. d.	–	–	9.8	15.2	2.3	2.6	2.8	5.5	37.2	58.5
	c	8.1	8.4	270	274	0.01	0.01	n. d.	n. d.	–	–	8.1	9.2	2.3	2.4	3.6	4.3	37.0	39.0

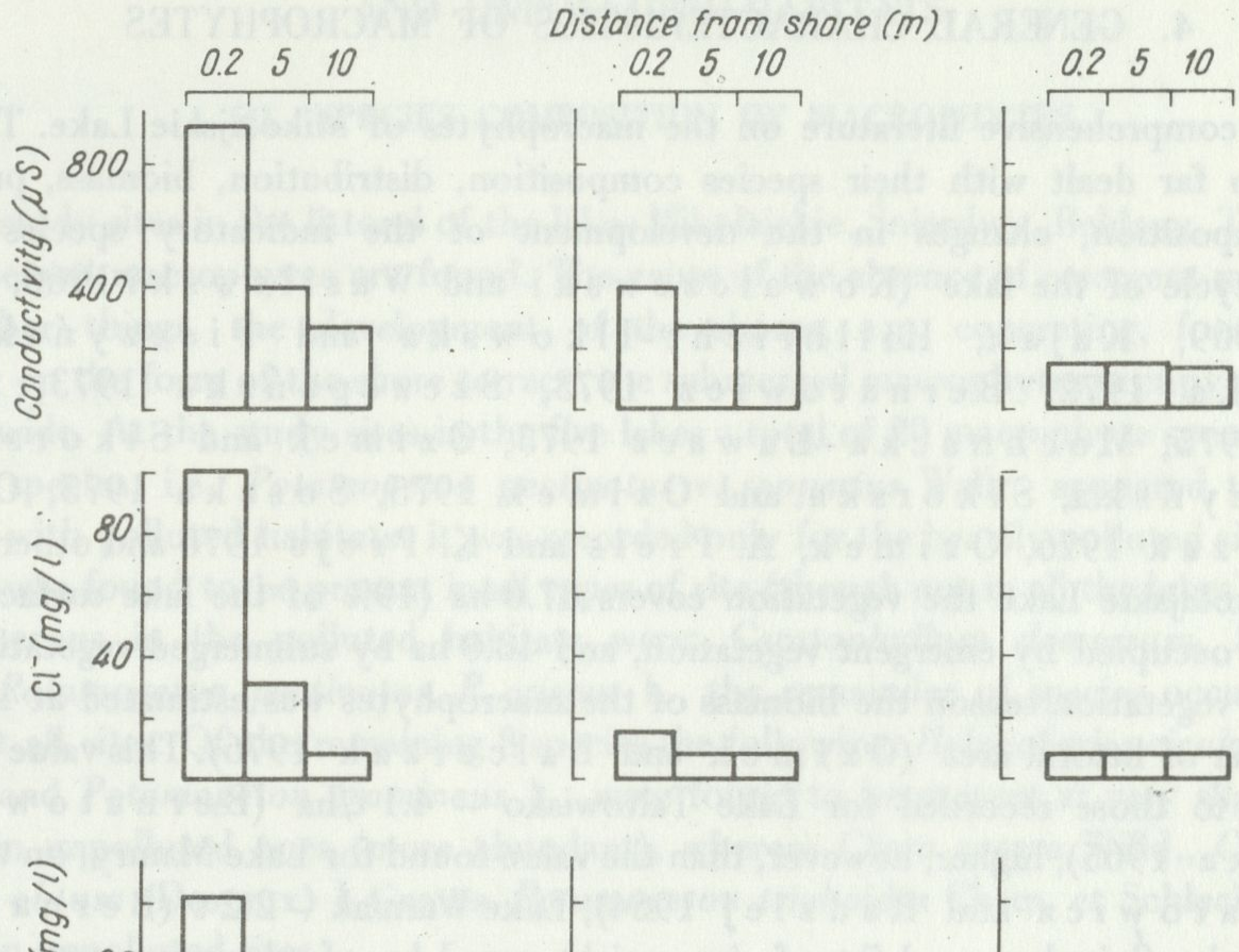

Fig. 2. Change of conductivity, and of chloride and ammonium ion concentration in selected sites in the littoral of Mikołajskie Lake (10 August 1973)

are given of changes in the conductivity, and in the concentration of ammonium (NH_4^+) and chloride (Cl^-) ions at three sites in Mikołajskie Lake in August 1973. With the increasing distance from the place of sewage inflow the greatest differences in the concentration of the substances analysed were found on the sites with centralized sewage outlets. Similar regularities were found at the same types of site in the remaining lakes.

On the basis of the data presented the following site groups can be distinguished in the study area:

1. heavily polluted – sites with centralized sewage outlets (the lakes Mikołajskie, Tałty and Miłki),

2. slightly polluted – sites without centralized sewage outlets (Mikołajskie Lake),

3. very slightly polluted – sites without centralized sewage outlets (the lakes Śniardwy, Bełdany, Tałty and Miłki),

4. unpolluted – control sites, located outside the range of buildings (all the lakes discussed).

Among the five lakes studied the strongest transformation of the chemistry of littoral waters was found for the part of Mikołajskie Lake in the vicinity of the town Mikołajki. This is due to a high number of permanent inhabitants (3,100) and tourists (12,000) visiting the town in summer.

4. GENERAL CHARACTERISTICS OF MACROPHYTES

There is a comprehensive literature on the macrophytes of Mikołajskie Lake. The studies carried out so far dealt with their species composition, distribution, biomass, production, chemical composition, changes in the development of the indicatory species over the phenological cycle of the lake (Kowalczewski and Wasilewski 1966, Szczepański 1969, Kajak, Hillbricht-Ilkowska and Pieczyńska 1972, Pieczyńska 1972, Bernatowicz 1973, Szczepańska 1973, Kowalczewski 1975, Mochnacka-Ławacz 1975, Ozimek and Sikorska 1975, 1976, Pieczyńska, Sikorska and Ozimek 1975, Soszka 1975, Ozimek and Balcerzak 1976, Ozimek, A. Preis and K. Prejs 1976 and others).

In the Mikołajskie Lake the vegetation covers 87.0 ha (19% of the lake surface, 39.0 ha thereof being occupied by emergent vegetation, and 48.0 ha by submerged vegetation. In the middle of the vegetation season the biomass of the macrophytes was estimated at 4.3 t of dry weight per 1 ha of littoral area (Ozimek and Balcerzak 1976). This value was found to be similar to those recorded for Lake Tałtowisko – 4.1 t/ha (Bernatowicz and Pieczyńska 1965), higher, however, than the value found for Lake Mamry, on the average 2.8 t (Bernatowicz and Radziej 1964), Lake Warniak – 2.2 t (Bernatowicz 1969), and Lake Śniardwy – 1.7 t of dry weight per 1 ha of overgrown area (Bernatowicz, Pieczyńska and Radziej 1968) (these lakes are also situated in the Masurian Lakeland).

Phragmites communis Trin., covering 32.3 ha, that is, 84% of the area occupied by all helophytes in Mikołajskie Lake, accounted for 90% of the emergent vegetation biomass of this lake (Kowalczewski and Wasilewski 1966). The biomass of the submerged macrophytes was 2.1 t of dry weight per 1 ha of the overgrown area. Among them the highest biomass have: Characeae, *Ceratophyllum demersum* L., *Elodea canadensis* Rich., *Potamogeton perfoliatus* L. and *Myriophyllum spicatum* L. (Kowalczewski 1975).

The vegetation of Mikołajskie Lake is of a low diversity, the small-lake phytolittoral type, according to Bernatowicz and Zachwieja (1966) classification, dominates there. In the littoral of Mikołajskie Lake a total of 41 macrophyte species was found, forming 17 plant communities (Ozimek and Balcerzak 1976).

In Lake Śniardwy the macrophytes cover 3,784.6 ha, that is 34.5% of the total lake surface, thereof 6.9% emergent macrophytes, and 27.6% submarged macrophytes. The macrophyte biomass was 1.7 t of dry weight per 1 ha of the overgrown area. Helophytes are found to occur up to the depth of 2 m, with *Phragmites communis* dominating among them. Submerged macrophytes occur up to a depth of 6 m, the dominating plants being Characeae, *Ceratophyllum demersum*, *Elodea canadensis* (Bernatowicz, Pieczyńska and Radziej 1968).

In the Tałty-Ryńskie lakes, vegetation occupies 264.2 ha, that is, 14.4% of the lake surface, wherefrom 6.6% emergent macrophytes, and 7.8% submerged macrophytes (data from the Institute of Inland Fisheries). No detailed data are available on the species composition of the macrophytes of the lakes Tałty, Bełdany and Miłki. On the basis of observations it has been found that dominating among the emergent macrophytes of these lakes is *Phragmites communis*, whereas the following are abundant among the submerged macrophytes: *Potamageton perfoliatus*, *P. pectinatus* L., Characeae, *Ceratophyllum demersum* and *Myriophyllum spicatum*.

5. COMPARISON OF THE VEGETATION OF POLLUTED AND UNPOLLUTED HABITATS

5.1. SPECIES COMPOSITION OF MACROPHYTES

At the study sites in the littoral of the lakes Mikołajskie, Śniardwy, Bełdany, Tałty and Miłki only submerged macrophytes are found. The cause of the absence of emergent macrophytes is, among other things, the development of the shores, e.g., concreting, foot-bridges, etc. Depending on the form of the shore terrace, the submerged macrophytes occupy a belt from 15 to 100 m wide. At the study sites in the five lakes a total of 20 macrophyte species was found. Only one species, i.e., *Potamogeton pectinatus* v. *scoparius* Wallr., appeared to be strongly associated with polluted habitats: it was recorded only for the heavily polluted sites. A total of 11 species was found to be present in all types of site (though not in all the lakes). Of these the more numerous in the polluted habitats were: *Ceratophyllum demersum*, *Myriophyllum spicatum*, *Potamogeton pectinatus*, *P. crispus* L., the remainder of species occurring in equal numbers at all sites. Of the remaining 8 species the following: *Heleocharis acicularis* R. et Sch., *Chara* sp. and *Potamogeton gramineus* L., were found to be present at very slightly polluted sites and in unpolluted ones (more abundant), whereas *Chara aspera* Willd., *Ch. vulgaris* L., *Nitellopsis obtusa* (Desvaux) J. Groves, *Potamogeton trichoides* Cham. et Schlecht., *P. pusillus* L. – only in unpolluted sites.

In heavily and slightly polluted sites the smallest number of species was found, relative to the unpolluted sites of the same lake (Table III).

The highest reduction in the number of species was noted for the polluted sites of Mikołajskie Lake, where the total number of species in the lake was 20 (Ozimek and Balcerzak 1976), and at the polluted sites only 11 species were found.

For the very slightly polluted sites and unpolluted ones, no significant differences were noted in the species composition of the macrophytes. As demonstrated previously, hardly any differences were found between these sites in respect of the chemical composition of the water.

Important for the determination of the individual species sensitivity to municipal sewage, apart from the species composition, is the analysis of their distribution. Figure 3 represents a diagram showing the distribution of macrophytes at heavily polluted sites, where with the distance from the area of sewage inflow the level of water pollution decreases. The closest to the area of sewage outlets *Ceratophyllum demersum*, *Potamogeton crispus* (Lake Miłki), *P. perfoliatus*, *Myriophyllum spicatum* (Lake Tałty) and *P. pectinatus* v. *scoparius* (Mikołajskie Lake) occurred.

Taking into account the frequency of the macrophytes in the study habitats of the five lakes, and the distribution of species in the heavily polluted sites, the following can be distinguished:

1. Species with low sensitivity to municipal sewage – *Potamogeton pectinatus* v. *scoparius*, *Myriophyllum spicatum*, *Ceratophyllum demersum*, *Potamogeton crispus*, *P. pectinatus*, *P. perfoliatus*. These occur only, or are found in larger numbers, in polluted sites, and moreover, in sites with a centralized sewage outlets they appear the nearest to the sewage outlets, that is, in habitats with the highest sewage concentration.

2. Species of medium sensitivity – *Potamogeton lucens*, *P. compressus*, *P. obtusifolius*, *Batrachium circinatum*, *Elodea canadensis*, *Fontinalis antipyretica*. Their frequency was the same at all sites. By comparison with the former species group, they grow at a longer distance from the sewage outlets, that is, where the sewage is already diluted considerably.

Table III. Species composition and frequency of macrophytes in the study sites in the littoral of five lakes in the Masurian Lakeland
Sites: *a* – heavily polluted, *b* – slightly polluted, *c* – very slightly polluted, *d* – unpolluted
Occurrence: ++++ – very abundant, +++ – abundant, ++ – rare, + – very rare, – – absent

Species	Mikołajskie			Tałty			Miłki			Śniardwy		Bełdany	
	a	*b*	*d*	*a*	*c*	*d*	*a*	*c*	*d*	*c*	*d*	*c*	*d*
Potamogeton pectinatus v. *scoparius* Wallr.	++++	–	–	–	–	–	–	–	–	–	–	–	–
Ceratophyllum demersum L.	++++	++++	+++	++++	++++	+++	+++	+++	++	+++	+++	++++	+++
Elodea canadensis Rich.	+++	+++	+++	+++	+++	++	++	++	++	++	++	+++	+++
Myriophyllum spicatum L.	+++	++++	++	+++	+++	++	++	++	+	++	++	++	++
Fontinalis antipyretica L.	+++	+++	+++	++	++	++	++	++	++	++	++	+++	+++
Potamogeton pectinatus L.	–	++++	++	+++	+++	++	++	+++	++	+++	++	+++	+++
P. crispus L.	++	++	+	++	+	+	+++	++	+	++	+	++	+
P. perfoliatus L.	++++	++++	++++	++	++	++	–	–	–	+++	+++	++	++
P. compressus L.	+	+	+	+	+	+	+	+	+	+	+	+	+
Batrachium circinatum Fr.	++	++	++	+	+	+	–	–	–	+	+	+	+
Potamogeton lucens L.	++	+	+	+	+	+	–	–	–	+++	++	+	+
P. obtusifolius Mert et Koch	+	+	+	+	++	+	–	+	+	+	+	+	++
Heleocharis acicularis R. et Sch.	–	–	+++	–	+	++	–	+	++	++	+++	+	+++
Chara sp.	–	–	+++	–	+++	++++	–	–	++	+++	++++	++	++++
Ch. aspera Willd.	–	–	++++	–	–	–	–	–	–	–	–	–	–
Ch. vulgaris L.	–	–	+++	–	–	–	–	–	–	–	–	–	–
Nitellopsis obtusa (Desvaux) J. Groves	–	–	++	–	–	–	–	–	–	–	–	–	–
Potamogeton gramineus L.	–	–	+	–	–	–	–	–	–	+	+	–	–
P. trichoides Cham. et Schlecht.	–	–	–	–	–	–	–	–	–	–	–	–	+
P. pusillus L.	–	–	–	–	–	–	–	–	–	–	–	–	+

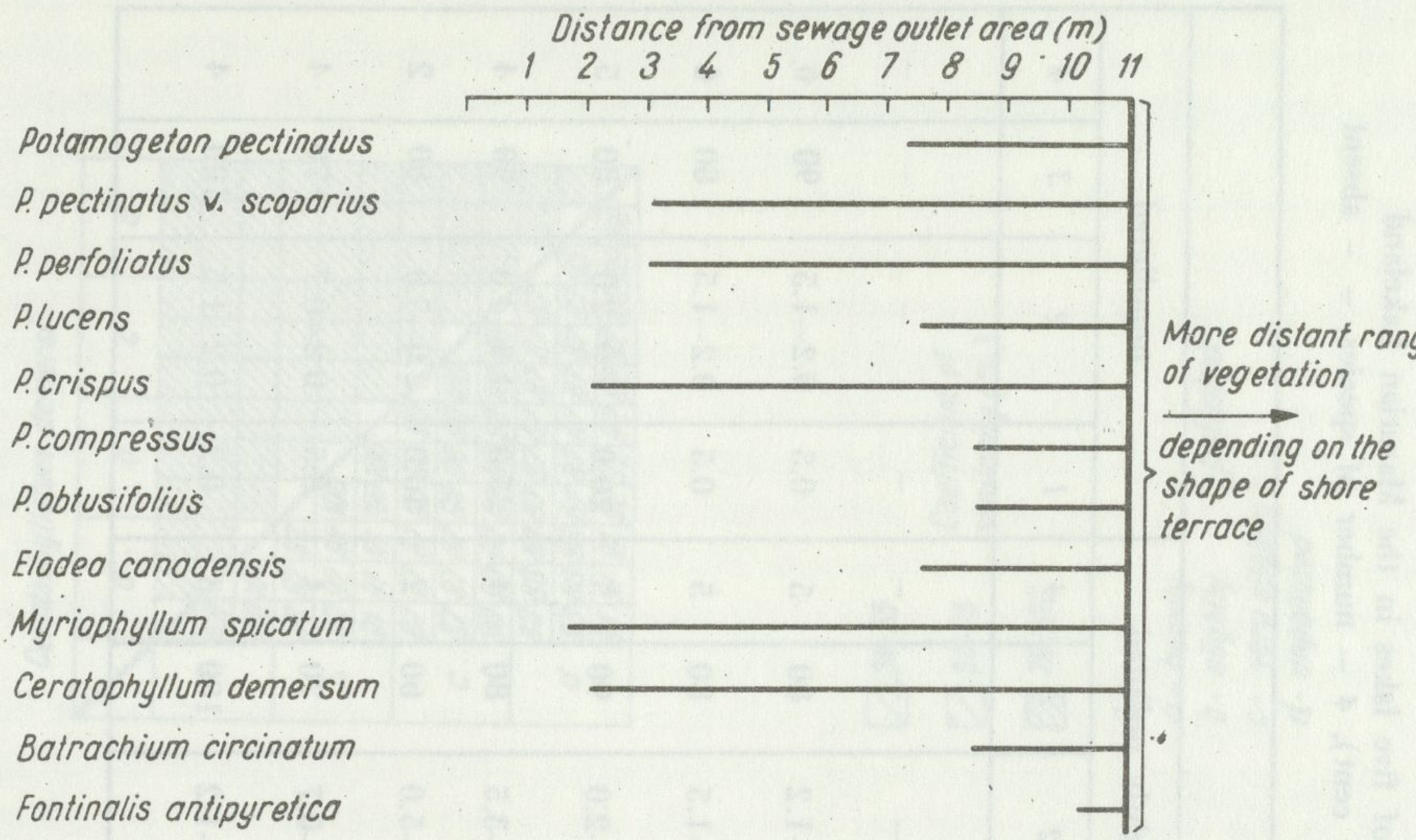

Fig. 3. Diagram to show the distribution of macrophytes in heavily polluted sites in the littoral of Mikołajskie Lake, Lake Tałty and Lake Miłki

3. Very sensitive species – *Heleocharis acicularis*, *Chara aspera*, *Ch. vulgaris*, *Chara* sp., *Nitellopsis obtusa*, *Potamogeton pusillus*, *P. trichoides*, *P. gramineus*. These species occurred only at the very slightly polluted or unpolluted sites, their frequency in the latter being higher.

5.2. MACROPHYTE COMMUNITIES

During earlier investigations of several sites in the littoral of Mikołajskie Lake it was observed that municipal sewage caused a transformation of the macrophyte associations (Ozimek and Sikorska 1976).

Within the scope of the present research a phytosociological analysis has been carried out of the vegetation in the entire littoral of Mikołajskie Lake, and at selected littoral sites of the lakes Śniardwy, Bełdany, Tałty and Miłki.

In the study area three plant associations and four communities of the class Potametea, alliance Eu-Potamion have been identified. The Characeae communities were not analysed in detail.

General data on the occurrence, distribution, number of species and the cover of the communities have been presented in Table IV. Shallow parts of the littoral, up to a depth of 1.5 m, are occupied by phytocenoses of Potametum perfoliati, Potametum lucentis, of the communities with *Potamogeton pectinatus* v. *scoparius*, with *Potamogeton gramineus* and with Characeae, deeper parts (1.5–5.0 m) being occupied by phytocenoses of the community with *Batrachium circinatum*, association Ceratophylletum demersi, and community with *Fontinalis antipyretica*. In general outline, the distribution of the communities at the individual types of site did not differ. Because of their distribution, the most exposed to the sewage are the communities with *Potamogeton pectinatus* v. *scoparius* and Potametum perfoliati, which grow nearest to the areas of sewage outlets.

Table IV. General characteristics of macrophyte communities from different habitats of five lakes in the Masurian Lakeland
1 – distance from shore or from sewage outlet area (m), *2* – depth (m), *3* – cover (per cent), *4* – number of species, – – absent

Communities	Sites															
	heavily polluted				slightly polluted				very slightly polluted				unpolluted			
	1	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
With *P. pectinatus* v. *scoparius*	3	0.3–0.6	40	1	–	–	–	–	–	–	–	–	–	–	–	–
Potametum perfoliati	5	0.5–0.8	40	1	0.5	0.2–1.0	70	3	0.5	0.2–1.2	80	5	0.5	0.2–1.5	90	6
Potametum lucentis	7	0.7–1.5	100	9	0.5	0.5–1.5	80	5	0.5	0.2–1.5	80	5	0.5	0.2–1.5	80	6
With *Batrachium circinatum*	10	1.0–2.0	80	5	12.0	1.0–2.0	80	5	20.0	1.0–2.0	90	5	20.0	1.0–2.0	80	5
Ceratophylletum demersi	11	1.5–3.0	90	4	15.0	1.5–3.5	90	4	25.0	1.5–3.5	80	4	25.0	1.5–4.0	90	4
With *Fontinalis antipyretica*	15	2.0–4.0	60	2	20.0	2.0–5.0	60	2	30.0	2.0–5.0	60	2	40.0	2.0–5.0	60	2
With *Potamogeton gramineus*	–	–	–	–	–	–	–	–	0.5	0.2–0.7	70	4	0.5	0.2–0.7	70	4
With Characeae	–	–	–	–	–	–	–	–	0.2	0.2–1.2	100	3	0.2	0.2–1.5	100	4

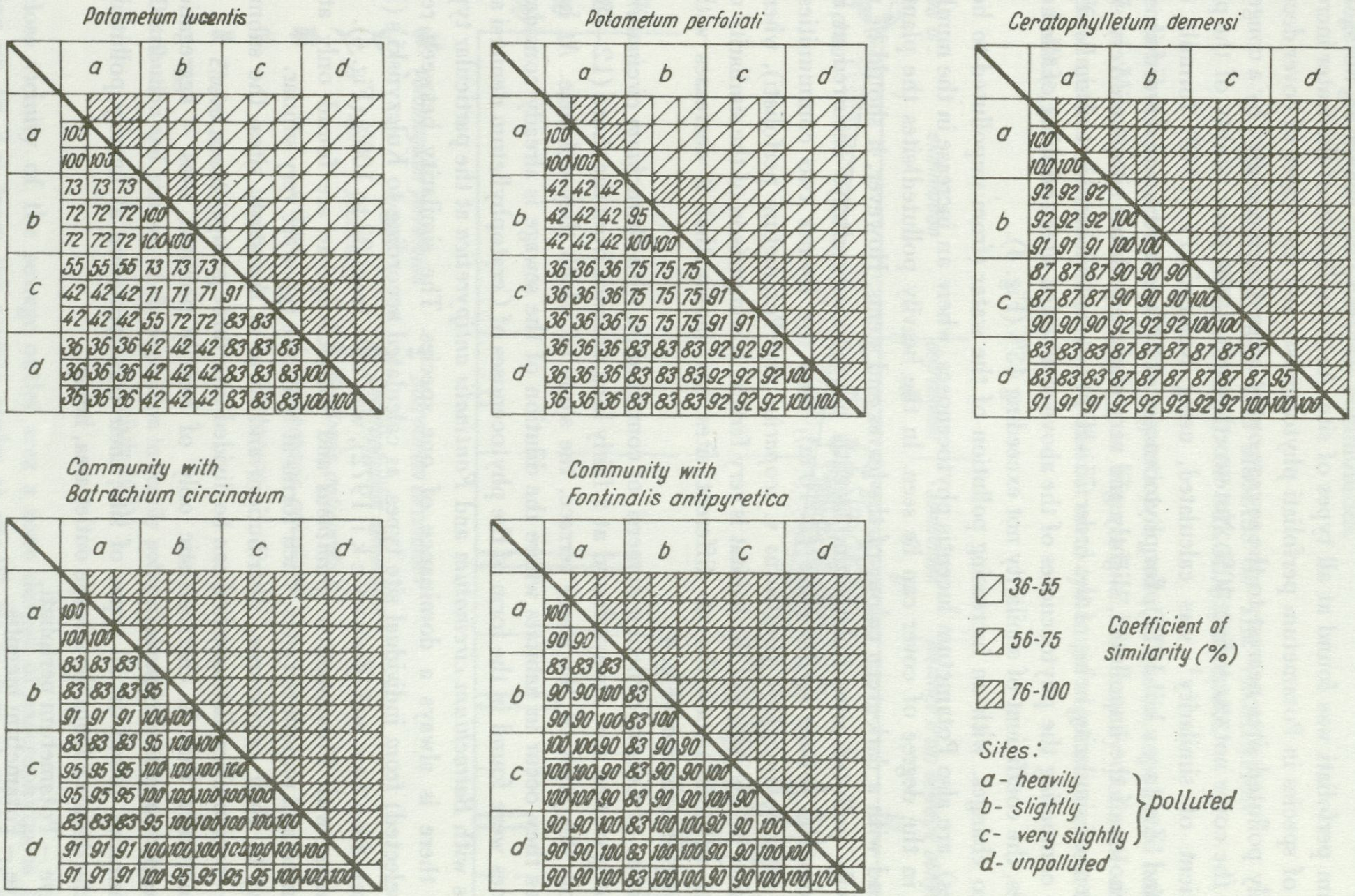

Fig. 4. A comparison of phytocenoses of macrophytes in different habitats of five lakes in the Masurian Lakeland

The community with *Potamogeton pectinatus* v. *scoparius* was found only at heavily polluted sites, nearest to (3 m from) the sewage outlet areas. Noteworthy is that this community forms aggregations of a loose areal structure, and that the plants are in poor condition.

Potametum perfoliati was found at all types of site. As the pollution of the water increases, the number of species in Potametum perfoliati phytocenoses and the degree of cover decrease, and in heavily polluted sites nearest to the sewage outlet areas it is represented by a congeneric aggregation, the cover not exceeding 40%. Noteworthy, too, is the poor vitality of the plants. The coefficient of similarity[1] was calculated, using Kulczyński's (1940) formula (after Szafer and Zarzycki 1972), for phytocenoses of different sites, and it was found that the phytocenoses of the unpolluted, slightly and very slightly polluted sites were very similar (the coefficient of similarity being of the order 75–100%). A much lower level of similarity was found when comparing the phytocenoses of the above-mentioned sites and those of the heavily polluted ones, the coefficient of similarity not exceeding 45% (Fig. 4).

Subject to changes, with an increasing pollution of the water (from unpolluted to heavily polluted sites), are also Potametum lucentis phytocenoses, where an increase in the number of species and in the degree of cover can be seen. In the heavily polluted sites the plants are exuberant and with a dark-green colour of the leaves and stems. However, it should be noted that at heavily polluted sites Potametum lucentis phytocenoses always occurred at longer distances from the sewage outlet areas (7–10 m), than the former two communities (the community with *Potamogeton pectinatus* v. *scoparius* and Potametum perfoliati), where the sewage dilution is very high and the habitat is very fertile. A comparison of the similarity of the phytocenoses of this association at different sites has shown that it decreases with the increasing level of pollution (Fig. 4).

Phytocenoses of Ceratophylletum demersi, of communities with *Batrachium circinatum* and *Fontinalis antipyretica* are always found at a fairly long distance from the shore (12–180 m), depending on the form of the shore terrace, the slope of which they colonize. At heavily polluted sites they occur in habitats where the dilution of the sewage is already considerable. No differences were found in the form of the phytocenoses of Ceratophylletum demersi and of communities with *Batrachium circinatum* and *Fontinalis antipyretica* at the particular types of site, where there is always a dominance of one species. The similarity between records (randomly selected) from individual site types, as calculated according to Kulczyński's (1940) formula (after Szafer and Żarzycki 1972), was high, from 83 to 100% (Fig. 4).

Communities with *Potamogeton gramineus* and with Characeae are found only at very slightly polluted and unpolluted sites. Their forms at both site types are very similar.

According to their occurrence, distribution, and form at the study sites, the submerged macrophyte communities distinguished can be divided into three groups:

1. a community that is characteristic only of heavily polluted sites – aggregation of *Potamogeton pectinatus* v. *scoparius*;

2. communities found on all types of site; their transformation at heavily polluted sites varies with the distance from the sewage outlet area, being:

a. negative – Potametum perfoliati,

b. positive – Potametum lucentis,

---

[1] Coefficient of similarity = $S = \frac{100}{2} \cdot \left(\frac{c}{a} + \frac{c}{b}\right)$ (%), where: c – number of species common to both records, a – number of species in record 1, b – number of species in record 2.

c. not transformed – Ceratophylletum demersi, and communities with *Batrachium circinatum*, and with *Fontinalis antipyretica*;

3. characteristic only of unpolluted and very slightly polluted sites, communities with *Potamogeton gramineus* and Characeae communities.

5.3. DISTRIBUTION AND BIOMASS OF THE VEGETATION IN THE LITTORAL OF MIKOŁAJSKIE LAKE

The distribution and biomass of the vegetation in polluted and in unpolluted habitats of the littoral of Mikołajskie Lake are shown in Figures 5–7. At heavily polluted sites, with a centralized outlets of municipal sewage, a distinct areal system of vegetation, characteristic only of this habitat, is found.

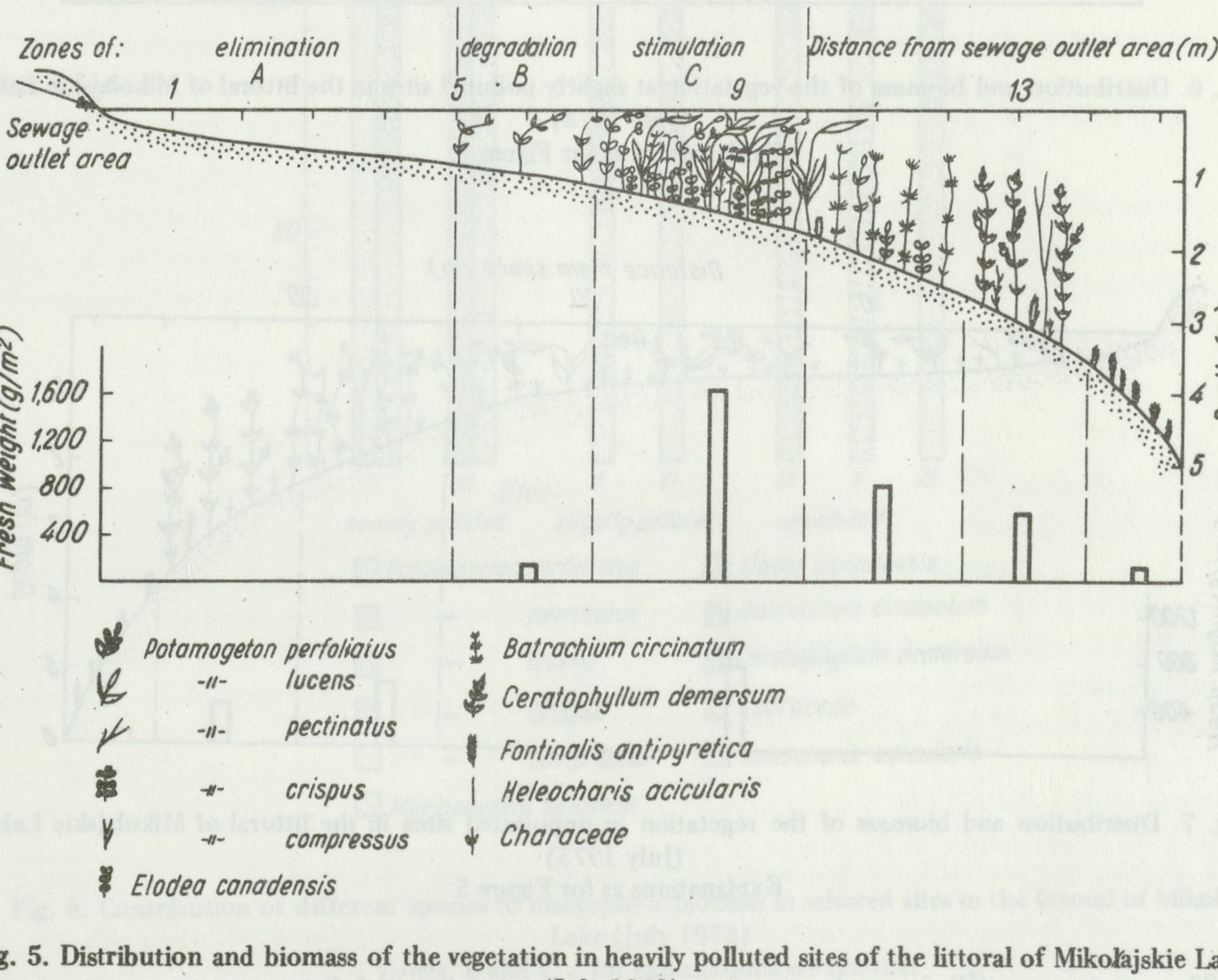

Fig. 5. Distribution and biomass of the vegetation in heavily polluted sites of the littoral of Mikołajskie Lake (July 1973)

In close vicinity of the sewage outlet area a zone devoid of macrophytes is found (A), extending up to 3 m from the sewage outlet at site III, or to 5 m at sites I, II and IV. In summer, *Sphaerotilus natans* Kütz. is noted there in large numbers. The water is characterized by a high concentration of the mineral and organic substances, many times higher than concentrations encountered in the next zones and at slightly polluted and unpolluted sites. Oxygen depletion was often found there. Zone A has been named macrophyte elimination zone.

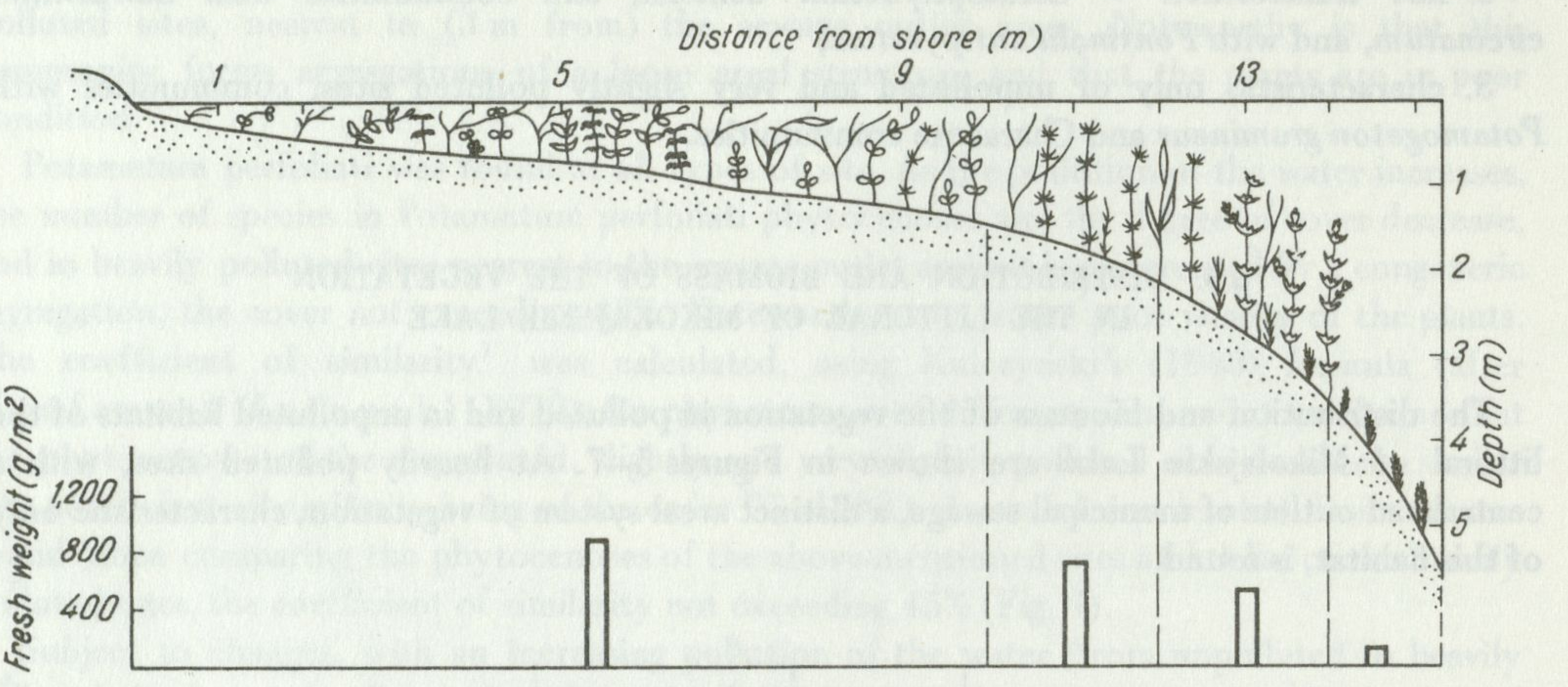

Fig. 6. Distribution and biomass of the vegetation at slightly polluted sites in the littoral of Mikołajskie Lake (July 1973)
Explanations as for Figure 5

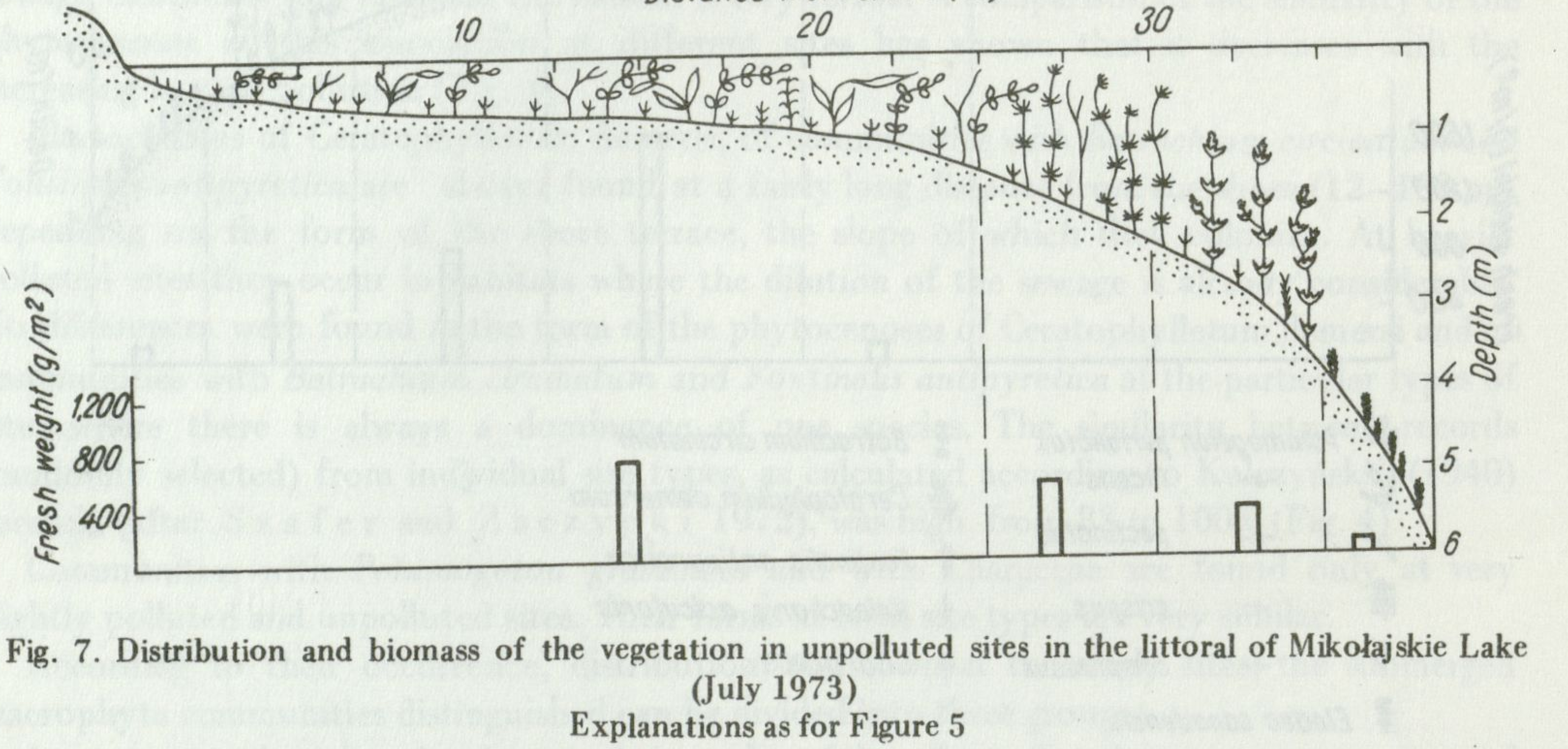

Fig. 7. Distribution and biomass of the vegetation in unpolluted sites in the littoral of Mikołajskie Lake (July 1973)
Explanations as for Figure 5

The next zone (B) is made up of congeneric aggregations of *Potamogeton pectinatus* v. *scoparius*, or *Potamogeton perfoliatus.* They occupy a belt 2–3 m wide. In the middle of the vegetation season, the biomass of the plants in this zone does not exceed 200 g of fresh weight per 1 m^2, being about six times lower than the mean biomass of the submerged macrophytes of the littoral of Mikołajskie Lake (O z i m e k and B a l c e r z a k 1976). Zone B has been named the macrophyte degradation zone.

The C zone – of macrophyte growth stimulation (about 7 m from the sewage outlet area) covers a strip 3 m wide. In the Mikołajskie Lake it is colonized by Potametum lucentis. Density of vegetation is very high here, the size of individual plants is being large, which accounts for the high level of biomass – on an average 1,620 g of fresh weight per 1 m^2. This value is eight times higher than that for the former zone, and also nearly twice as high as the biomass value found for the sites with a slight pollution and those with no pollution (Figs. 5–7).

In summer, of the nine species found in zone C the following account for the major proportion of the biomass: *Potamogeton lucens*, *P. perfoliatus*, *Elodea canadensis*, *Myriophyllum spicatum* (Fig. 8). At distances greater than 10 m from the sewage outlets no evidence was found to indicate an influence of municipal sewage on the plants. The following occur there successively: a community with *Batrachium circinatum*, Ceratophylletum demersi, and a community with *Fontinalis antipyretica*, which, as has been demonstrated in the phytosociological analysis, have the same form in all habitats studied, and attain a similar biomass (Figs. 5–7). They grow outside the range of sewage activity.

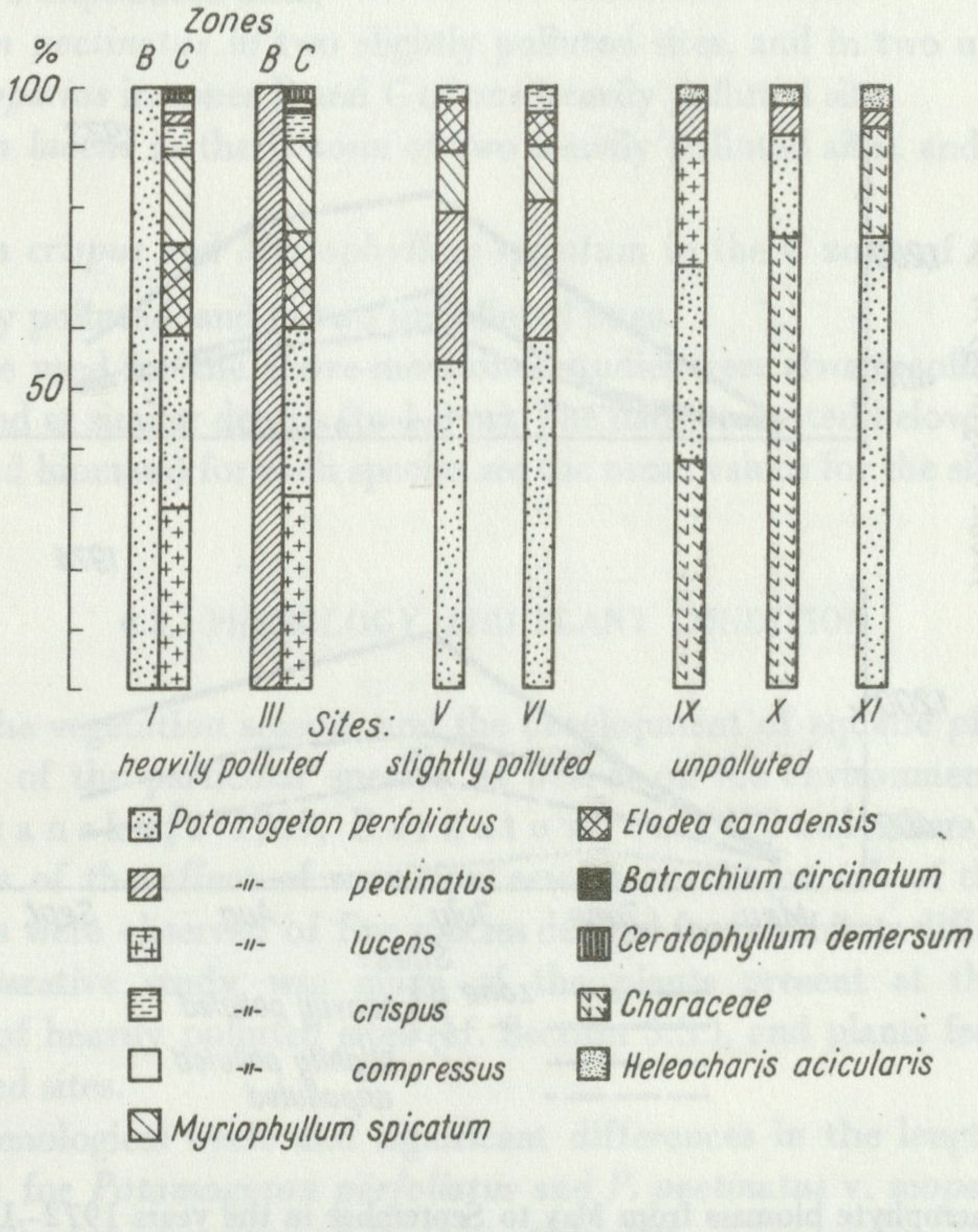

Fig. 8. Contribution of different species to macrophyte biomass in selected sites in the littoral of Mikołajskie Lake (July 1973)

Zones: B and C – for explanations see the text

At slightly polluted and unpolluted sites did not occur the above-described zonation. Starting from the shore, plants form multispecific associations. As regards the macrophyte biomass and its areal diversity, no significant differences could be seen between the slightly polluted sites and the control ones (Figs. 6, 7). However, differences were found in the contribution of the particular species to the biomass. At slightly polluted sites within the strip 0.5 up to 10 m from the lake shore (in shallow lake parts) the highest contribution to the biomass was recorded for: *Potamogeton perfoliatus* and *P. pectinatus* (Fig. 8). At the unpolluted sites, at the same distance from the shore, and at the same depth, Characeae always represent a fairly large proportion of the biomass, from 18 to 75% (Fig. 8). At larger distances (with an increasing depth) the differences between the heavily polluted, slightly polluted and unpolluted sites become blurred.

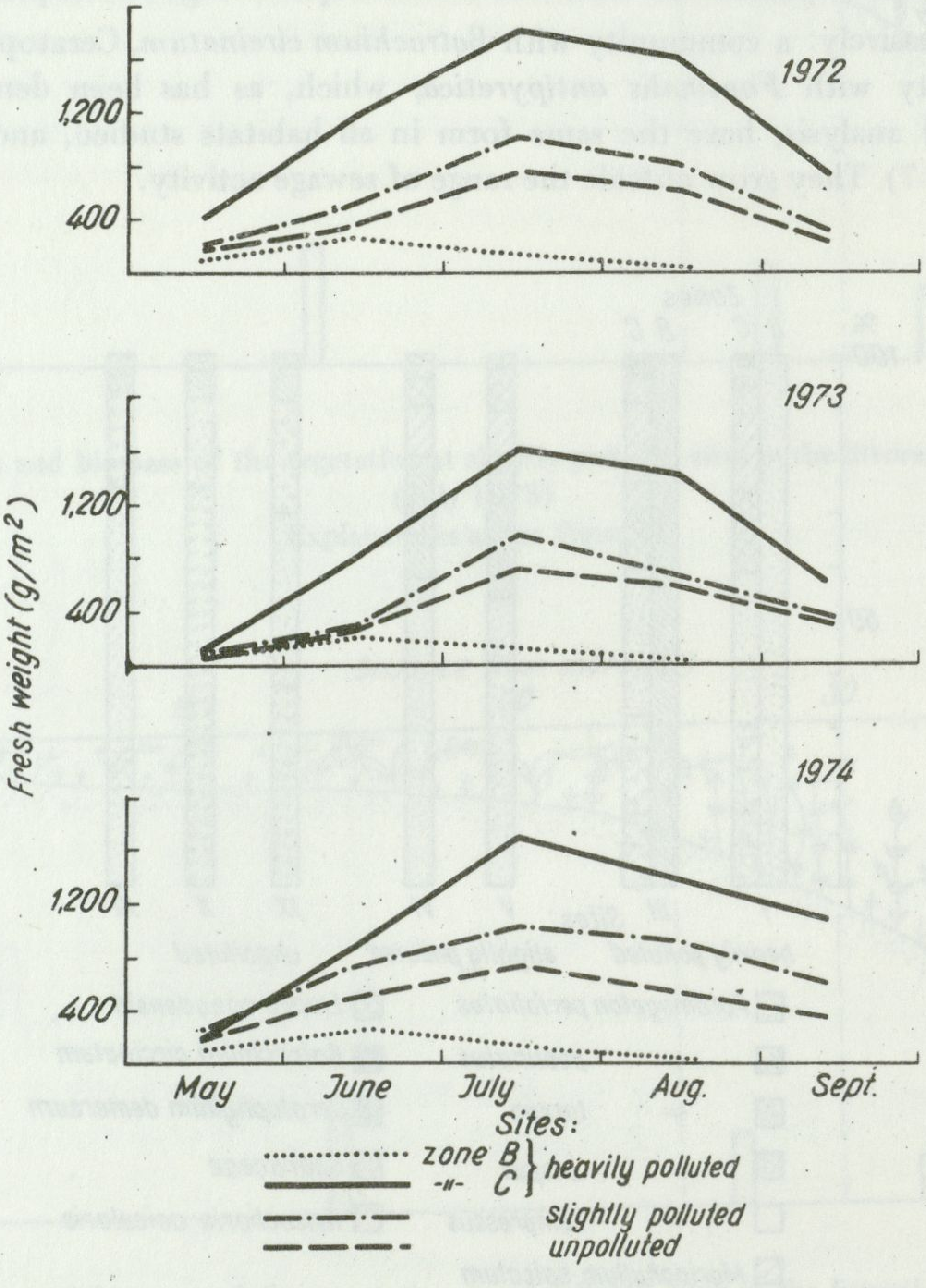

Fig. 9. Changes in macrophyte biomass from May to September in the years 1972–1974 in the littoral of Mikołajskie Lake

Changes in biomass were observed during the vegetation season in the degradation and stimulation zones of four heavily polluted sites, of three slightly polluted, and five unpolluted ones. Presented in Figure 9 are mean biomass values found in these site groups during the particular months of the consecutive study years 1972–1974. In the degradation zone (B), the highest biomass was found in June, that is, in the first period of the growing season. Then a considerable decrease in biomass followed, this being connected with the earlier dying of plants in this zone. In the stimulation zone (C) of heavily polluted sites, at slightly polluted, and unpolluted ones the maximum value of biomass was found in mid-July.

6. EFFECT OF MUNICIPAL SEWAGE ON SELECTED MACROPHYTE SPECIES IN THE LITTORAL OF MIKOŁAJSKIE LAKE

6.1. GENERAL

In order to determine the effect of municipal sewage on each of the submerged macrophyte species, a phenological analysis was carried out, as well as investigations of the condition, morphology and chemical composition of the plants derived from three types of habitat: heavily polluted (of the degradation (B) and stimulation (C) zones), slightly polluted, and unpolluted. Five macrophyte species which occurred in different habitats, were analysed:

1. *Potamogeton perfoliatus* in zones B and C of three heavily polluted sites, in three slightly polluted, and in five unpolluted ones,
2. *Potamogeton pectinatus* in two slightly polluted sites, and in two unpolluted ones, and *P. pectinatus* v. *scoparius* in zones B and C of one heavily polluted site,
3. *Potamogeton lucens* in the C zone of two heavily polluted sites, and in three unpolluted sites,
4. *Potamogeton crispus* and *Myriophyllum spicatum* in the C zone of two heavily polluted sites, in two slightly polluted, and in two unpolluted ones.

The plants to be used for the above-mentioned studies were always collected from the same type of bottom, and at similar depths (to 1.2 m). The data presented below (except the data on the morphology and biomass) for each species are the mean values for the sites listed above.

6.2. PHENOLOGY AND PLANT CONDITION

The length of the vegetation season, and the development of aquatic plants depend on the phenological cycle of the particular species, as well as on the environmental conditions, e.g., temperature (Katanskaja 1969, Bernatowicz 1973 and others).

For the analysis of the effect of municipal sewage on the growth of the macrophytes the phenological cycles were observed of five species derived from habitats differing by the level of pollution. A comparative study was made of the plants present at the degradation and stimulation zones of heavily polluted sites (cf. Section 5.3.), and plants from slightly polluted and from unpolluted sites.

A disturbed phenological cycle and significant differences in the length of the vegetation season were found for *Potamogeton perfoliatus* and *P. pectinatus* v. *scoparius*, colonizing the degradation zone (B) of the heavily polluted sites (Fig. 10).

In this zone, *Potamogeton perfoliatus* occurs from May to the beginning of September. The plants begin to die as early as the beginning of July. On their leaves black necrotic spots appear, at first covering the top and the edges of a leaf, then extending over the whole leaf blade. In mid-July 70% of the leaves of all plants are affected by necroses. At this time the turions' formation was observed. In natural conditions turions appear only at the end of the vegetation season, and they serve the plant to endure the winter. Sculthorpe (1967) reports that turions are the response of the plants to adverse conditions, e.g., low temperature, nutrient deficiency. The phenological observations carried out in the Mikołajskie Lake have shown that the formation of turions, a specific defensive response of the plants, is also induced by municipal pollutions. In mid-August, *P. perfoliatus* is already completely without leaves, and only bare, blackened stems can be seen. In all the remaining, polluted and unpolluted, habitats

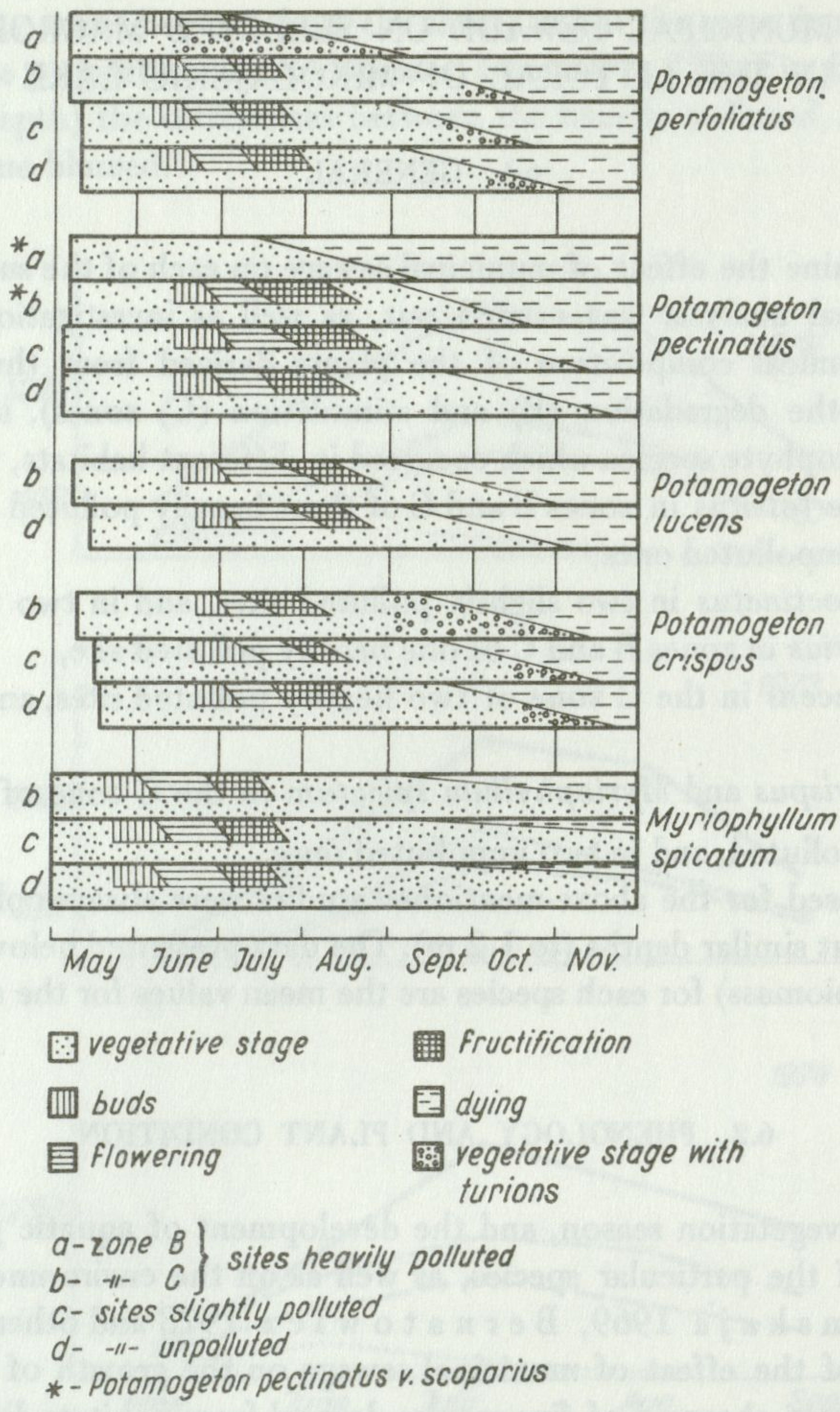

Fig. 10. Phenological cycles of macrophytes in the littoral of Mikołajskie Lake (1972)

the growing season of *P. perfoliatus* is much longer — from April to November. The plants begin to die in September, at the same time also turions are formed (Fig. 10).

In *Potamogeton pectinatus* v. *scoparius*, growing in the degradation zone, leaf chlorosis and a loss of 50% of leaves were found in mid-July. In the B zone, *Potamogeton pectinatus* v. *scoparius* occurs only in its vegetative stage. In the remaining habitats the vegetation season of *Potamogeton pectinatus* lasts much longer, by about 45 days (Fig. 10).

For the remaining species: *Potamogeton lucens*, *P. crispus* and *Myriophyllum spicatum*, not found in the degradation zone (B), no significant differences were found in the duration of each of the phenological phases and the length of the whole growing period in the habitats studied (Fig. 10). The above-described regularities of the earlier dying of plants in the heaviest polluted habitats recurred in three consecutive growing seasons (1972, 1973, 1974).

To be able to compare the condition of the plants colonizing different habitats, a condition coefficient was used, this coefficient being the ratio of the fresh weight of the leaves (healthy,

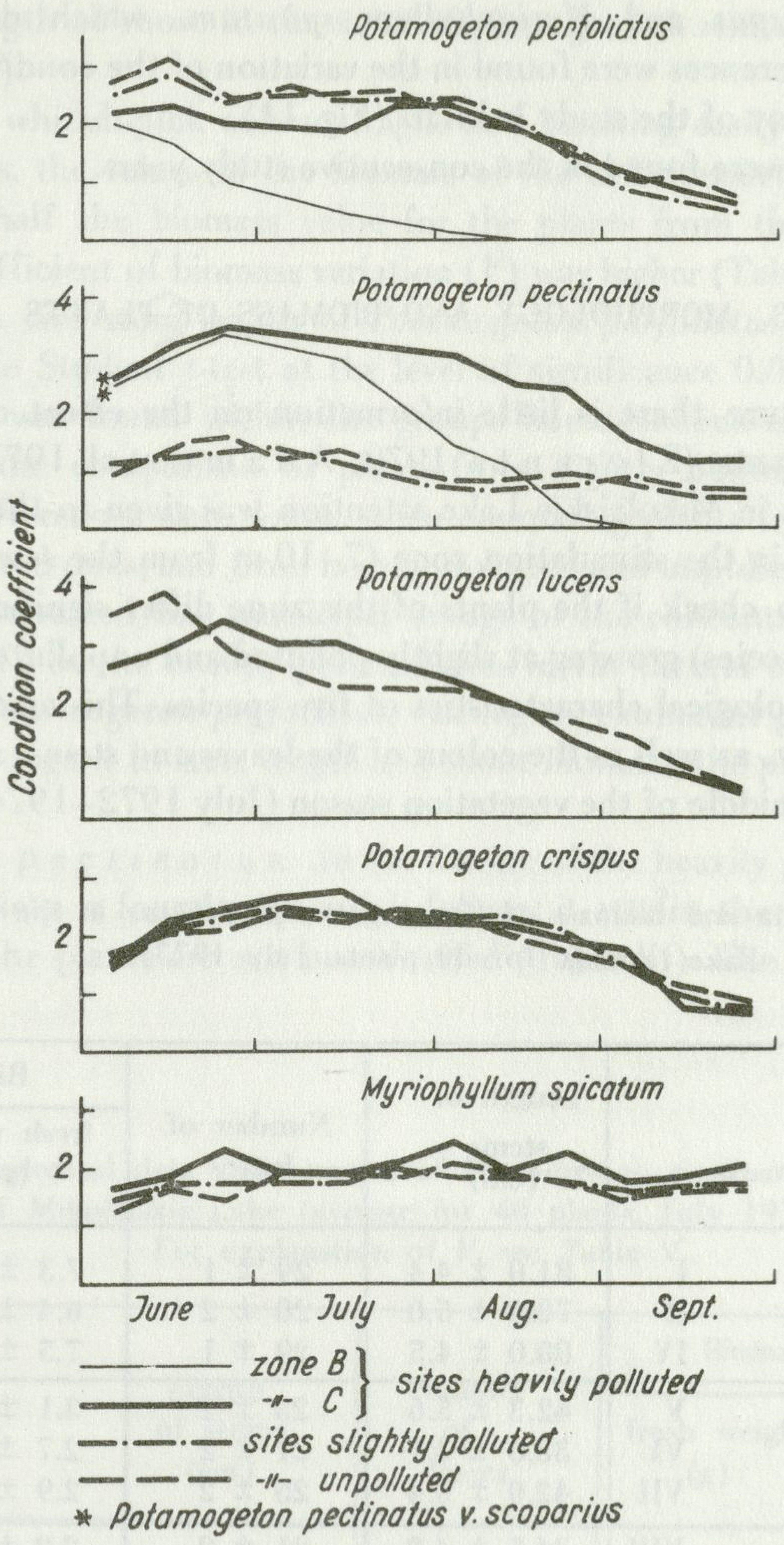

Fig. 11. Change of macrophyte condition coefficient during the vegetation season of 1972 in the littoral of Mikołajskie Lake

without necroses) to the fresh weight of the stems. A coefficient value equal to zero indicates that there are no healthy leaves, the vitality of the plants is low, and photosynthesis is almost completely inhibited. Obviously, the condition coefficient for plants with annual above-ground stems will vary during the vegetation season. A clearly lowered condition was found for *Potamogeton perfoliatus* and *P. pectinatus* v. *scoparius* colonizing the degradation zone (B) of heavily polluted sites, by comparison with the plants from the remaining habitats (Fig. 11). The change in the value of the condition coefficient for these species is very evident: from 2.0 in June to 0 in August – for *P. perfoliatus*, and from 2.5 to 0 in September – for *P. pectinatus* v. *scoparius*. The great differences in the maximum values of the condition coefficient of *P. pectinatus* between the plants of the stimulation zone (C) of the heavily polluted site and those of the remaining habitats result from the fact that at the former site the *scoparius* variety grows, this variety producing many stems and a large number of leaves.

For *Potamogeton crispus* and *Myriophyllum spicatum*, which do not occur in the degradation zone, no differences were found in the variation of the condition coefficient during the vegetation season in any of the study habitats (Fig. 11).

The above regularities were found in the consecutive study years.

6.3. MORPHOLOGY AND BIOMASS OF PLANTS

In the relevant literature there is little information on the effect of pollution upon the morphology of aquatic plants (E l o r a n t a 1970, A d a m s et al. 1971). During the analysis of the plant communities in Mikołajskie Lake attention was given to the exuberant growth of the macrophytes present in the stimulation zone (7–10 m from the sewage outlet area) of the heavily polluted sites. To check if the plants of this zone differ significantly from the plants (belonging to the same species) growing at slightly polluted and unpolluted sites an analysis was carried out of the morphological characteristics of five species. This analysis covered the stem length and foliage density, as well as the colour of the leaves and stems, and the biomass of the individual shoots, in the middle of the vegetation season (July 1972–1974).

Table V. Morphological data and biomass of *Potamogeton perfoliatus* in the littoral of Mikołajskie Lake (average for 30 plants, July 1973)

Sites		Length of stems (cm)	Number of leaves	Biomass of shoots	
				fresh weight (g)	V (%)*
Heavily polluted (zone C)	I	81.0 ± 4.4	29 ± 1	7.3 ± 0.3	16.4
	II	78.5 ± 5.0	28 ± 2	6.4 ± 0.7	34.2
	IV	80.0 ± 4.5	29 ± 1	7.5 ± 0.3	20.0
Slightly polluted	V	42.3 ± 5.6	25 ± 2	3.1 ± 0.6	66.5
	VI	38.0 ± 3.1	21 ± 2	2.7 ± 0.4	52.8
	VII	42.0 ± 5.4	25 ± 2	2.9 ± 0.5	62.3
Unpolluted	VIII	34.5 ± 4.8	21 ± 2	2.2 ± 0.5	65.4
	IX	33.8 ± 3.2	23 ± 2	2.3 ± 0.4	65.6
	X	33.4 ± 4.0	22 ± 2	2.7 ± 0.2	37.0
	XI	32.0 ± 2.9	24 ± 2	2.3 ± 0.3	65.2
	XII	41.2 ± 7.9	32 ± 2	2.9 ± 0.5	48.3

$*V = \frac{\sigma}{\bar{x}} \cdot 100$, σ – standard deviation.

P o t a m o g e t o n p e r f o l i a t u s. In the zone of stimulation of macrophyte growth (C) of the heavily polluted sites this species attains a considerably larger size of the vegetative parts (leaves and stems) than in the remaining habitats. The stem length ranges from 78.5 to 81.0 cm, the leaf length from 2.5 to 6.8 cm, and the breadth from 1.5 to 3.1 cm. In this zone, both the leaves and the stems are of a dark-green colour. At slightly polluted and unpolluted sites, the leaves of *P. perfoliatus* are thick, "leather-like", light-green with a brown margin. Their length varies between 2.2 and 4.8 cm, and their breadth between 1.2 and 2.2 cm. The stems are half the length of those in the zone of plant growth stimulation (C) of the heavily polluted sites (Table V).

The stems are of a whitish-pink colour, fragile and breaking easily. At the slightly polluted and at unpolluted sites, the values of the biomass of the individual shoots of *P. perfoliatus* are similar, being about half the biomass value for the plants from the C zone of the heavily polluted sites. The coefficient of biomass variation (V) was higher (Table V).

The shoot biomass and stem length of *Potamogeton perfoliatus* in all the habitats were compared by using the Student t-test at the level of significance 0.01. A statistical non-significance of differences was found within site groups homogeneous in respect of the level of pollution, as also in the comparison of plants from slightly polluted and unpolluted sites. However, statistical differences were found when comparing plants from heavily polluted sites and from slightly polluted ones, and from heavily polluted and unpolluted sites.

It may, therefore, be stated that municipal sewage of the concentration at which it reaches the stimulation zone (C) of the heavily polluted sites in the littoral of Mikołajskie Lake, has a significant effect on *Potamogeton perfoliatus*, causing its exuberant growth and high biomass values. Moreover, with regard to stem length and shoot biomass, the plants found in the C zone show a lesser variation.

Potamogeton pectinatus. In the C zone of the heavily polluted sites a profusely branched *scoparius* variety is found with a rich foliage; it attains the largest size and biomass, and at the same time the plants are not much varied (Table VI). The leaves and stems are of a dark-green colour.

Table VI. Morphological data and biomass of *Potamogeton pectinatus* in the littoral of Mikołajskie Lake (average for 40 plants, July 1973)
For explanation of V see Table V

Sites		Length of stems (cm)	Number of leaves	Biomass of shoots fresh weight (g)	Biomass of shoots V (%)
Heavily polluted (zone C)*	III	36.5 ± 0.9	98 ± 5	6.4 ± 1.0	20.9
Slightly polluted	V	22.6 ± 1.9	37 ± 2	1.0 ± 0.1	55.0
	VI	24.5 ± 2.2	42 ± 3	1.2 ± 0.2	58.4
Unpolluted	VIII	12.9 ± 1.4	35 ± 3	0.8 ± 0.1	54.2
	IX	18.2 ± 1.6	36 ± 3	1.0 ± 0.1	55.4

**Potamogeton pectinatus* v. *scoparius*.

At the slightly polluted and unpolluted sites, *Potamogeton pectinatus* is of similar form. Its biomass varies between 0.8 and 1.2 g; the leaves are fairly diverse, their diversification being more than twice that found for the heavily polluted site (Table VI).

When comparing, by means of the Student t-test (at the significance level 0.01), the shoot biomass and the stem length of the plants from slightly polluted and unpolluted sites, no significant differences were found, but when comparing plants from heavily polluted sites and those from the rest of sites, statistically significant differences were found.

Table VII. Morphological data and biomass of *Potamogeton lucens* in the littoral of Mikołajskie Lake (average for 30 plants, July 1973)
For explanation of V see Table V

Sites		Length of stems (cm)	Number of leaves	Biomass of shoots	
				fresh weight (g)	V (%)
Heavily polluted (zone C)	I	107.7 ± 15.2	14 ± 2	17.6 ± 2.4	51.7
	IV	97.2 ± 11.3	9 ± 1	12.1 ± 2.0	62.8
Unpolluted	X	56.8 ± 9.7	11 ± 3	8.8 ± 1.8	81.8
	XI	33.4 ± 4.6	8 ± 1	8.6 ± 0.9	51.2
	XII	25.3 ± 3.1	8 ± 1	5.0 ± 0.6	40.0

Potamogeton lucens. It is in the C zone of the heavily polluted sites that this species attains the largest size and biomass (Table VII). In this zone, the leaves and stems of the plants are dark-green in colour, whereas in the remainder of the habitats the leaves are light--green with a brown margin, the stems being of a white-green colour. The variation of the biomass of the individual shoots within all the study sites was high, from 40.0 to 81.8% (Table VII). Statistically significant differences were found between the plants from heavily polluted sites (zone C) and from unpolluted sites.

Potamogeton crispus. Plants derived from three types of site do not differ significantly in respect of their morphology. The stem lengths, the numbers of leaves, and the biomass values of the individuals are similar. They do not differ in colour either, their leaves being of a green colour with a brown margin, the stems – of an olive-green colour.

Myriophyllum spicatum. No significant differences in the morphology and biomass were found among plants derived from three types of site. The variation of shoot biomass, too, was similar in all habitats.

The above regularities discussed for five species were found also in 1972 and 1974.

The effect of the same concentration of municipal sewage varies from species to species. Diluted municipal sewage was found to have a positive effect on the morphology and biomass of three out of the five species studied (*Potamogeton perfoliatus*, *P. lucens* and *P. pectinatus*). *Potamogeton crispus* and *Myriophyllum spicatum* did not differ in respect of their morphology and biomass in any of the habitat types.

6.4. CHEMICAL COMPOSITION OF PLANTS

There is an extensive literature on the content of the essential macro- and microelements in the macrophytes (Gorham 1953, Caines 1965, Allenby 1966, 1968, Boyd 1968, 1970a, 1970b, Bernatowicz 1969, Hutchinson 1975, and many others). It deals with macrophytes derived from unpolluted habitats. Seidel (1966) found a high content of macro- and microelements in emergent macrophytes found in habitats affected by industrial effluents.

Table VIII. Chemical composition of macrophytes in different habitats of the littoral of Mikołajskie Lake (July 1973)

Species	Sites	Per cent									
		N	P	K	Na	Ca	Mg	Cl	Fe	Mn	Zn
Potamogeton perfoliatus	heavily polluted (zone B)	2.30	0.80	2.70	0.80	1.70	1.35	2.35	0.08	0.01	0.008
	heavily polluted (zone C)	2.60	0.76	2.20	0.50	2.00	1.40	1.20	0.05	0.02	0.006
	slightly polluted	2.28	0.65	1.82	0.39	2.10	1.21	0.80	0.04	0.04	0.001
	unpolluted	2.10	0.45	1.30	0.40	1.82	0.80	0.55	0.04	0.06	0.001
Potamogeton pectinatus	heavily polluted (zone B)	3.12	0.80	1.95	1.60	1.60	1.12	2.05	0.09	0.03	0.007
	heavily polluted (zone C)	3.60	0.80	2.10	1.15	1.75	1.30	1.35	0.12	0.05	0.007
	slightly polluted	3.10	0.50	2.50	1.00	2.23	0.60	1.10	0.07	0.03	0.003
	unpolluted	3.20	0.90	3.00	0.72	2.70	0.70	0.80	0.10	0.04	0.004
Potamogeton lucens	heavily polluted (zone C)	3.00	0.61	2.70	1.00	2.12	1.50	1.35	0.06	0.02	0.003
	unpolluted	1.45	0.40	2.55	0.60	2.00	0.70	0.65	0.02	0.03	traces
Potamogeton crispus	heavily polluted (zone C)	2.55	0.62	2.50	0.60	2.75	0.72	1.25	0.09	0.02	0.005
	slightly polluted	2.40	0.59	1.90	0.35	1.65	0.50	0.72	0.06	0.04	0.003
	unpolluted	1.90	0.60	1.90	0.35	1.70	0.60	0.65	0.05	0.04	0.002
Myriophyllum spicatum	heavily polluted (zone C)	2.65	0.40	1.65	1.05	2.50	0.80	1.26	0.10	0.03	0.004
	slightly polluted	2.25	0.35	1.60	0.60	2.60	0.60	0.70	0.05	0.04	0.002
	unpolluted	2.00	0.35	1.50	0.45	2.60	0.60	0.65	0.05	0.05	0.002

In order to determine the magnitude of the effect of municipal sewage upon the chemical composition of submerged macrophytes. an analysis was carried out for the content of seven macroelements (nitrogen. phosphorus. potassium, sodium. calcium, magnesium and chlorine), and of three microelements (iron. zinc and manganese) in five species derived from different habitats in the littoral of Mikołajskie Lake. The results obtained in July 1973 have been presented in Table VIII. The presentation has been restricted to the data for one month, because. as had been found previously, the content of most elements does not vary significantly during the vegetation season (T. Ozimek – unpublished data).

It has been found that in all the plants under study municipal sewage causes a considerable increase in the tissue content of chlorine, sodium, zinc and iron, and to a lesser extent of magnesium. As the pollution increases, the levels of these elements in the plants grow. For instance, the content of chlorine in plants from the slightly polluted sites was about 1.3 times as high as in the plants from the unpolluted sites, and already twice as high in the plants from the stimulation zone, whereas in the plants from the degradation zone of the heavily polluted sites as much as three times as high as in the plants from the unpolluted sites. A reverse relationship was found for manganese, the content of which in the macrophytes was found to decrease as the level of pollution increased. This is probably due to the fact that as a result of a high iron content the uptake of manganese by plants is made difficult (C u r t i s and C l a r k 1958). As regards the remainder of the elements, rather a considerable increase was found of potassium and phosphorus in *Potamogeton perfoliatus*, slight differences in *Potamogeton lucens*, *P. crispus* and *Myriophyllum spicatum* as the pollution of the water increased, and a reverse relationship in *Potamogeton pectinatus.* As far as calcium is concerned, only in *Potamogeton crispus* was a higher content found at the polluted sites, whereas all the other species showed either no differences, or a lower content at the polluted sites.

When comparing the content of elements in the different species, it was found that, apart from a few exceptions, the chemical composition of different species derived from the same habitats was very similar.

The level of nitrogen, phosphorus, calcium, potassium, iron, manganese and zinc in the plants studied (even those from the degradation zone) was within the range reported by various authors for submerged macrophytes derived from unpolluted habitats, but about twice as high content of sodium and magnesium was found in plants from heavily polluted sites as the values reported by other investigators (H a r p e r and D a n i e l 1934, N e l s o n and P a l m e r 1938, G o r h a m 1953, G e r l o f f and K r o m b h o l z 1966, B o y d 1968, 1970b, B e r n a t o w i c z 1969, H u t c h i n s o n 1975).

In addition to the analysis of the macro- and microelements, the content of chlorophyll-a was determined. In the morphological description it has been mentioned that plants growing in habitats varying in the level of pollution differ by the colour of their leaves and stems. These differences were particularly marked in *Potamogeton perfoliatus*, *P. pectinatus* and *P. lucens.* The analysis has shown the largest amounts of chlorophyll-a in the leaves and stems of the species enumerated, growing in the C zone of heavily polluted sites (Fig. 12). The leaves of *P. perfoliatus* and *P. pectinatus*, derived from the B zone of heavily polluted sites were found to contain less chlorophyll-a, relative to the plants from the other habitats (Fig. 12). In these species numerous leaf chloroses and necroses occurred. No significant differences in the content of chlorophyll-a were found between plants from slightly polluted and unpolluted sites. The above regularities have been found also for chlorophyll-b (T. Ozimek – unpublished data).

Municipal sewage, in the concentrations found in zones B and C of the heavily polluted sites in the littoral of Mikołajskie Lake, has a significant effect on the chlorophyll content in the

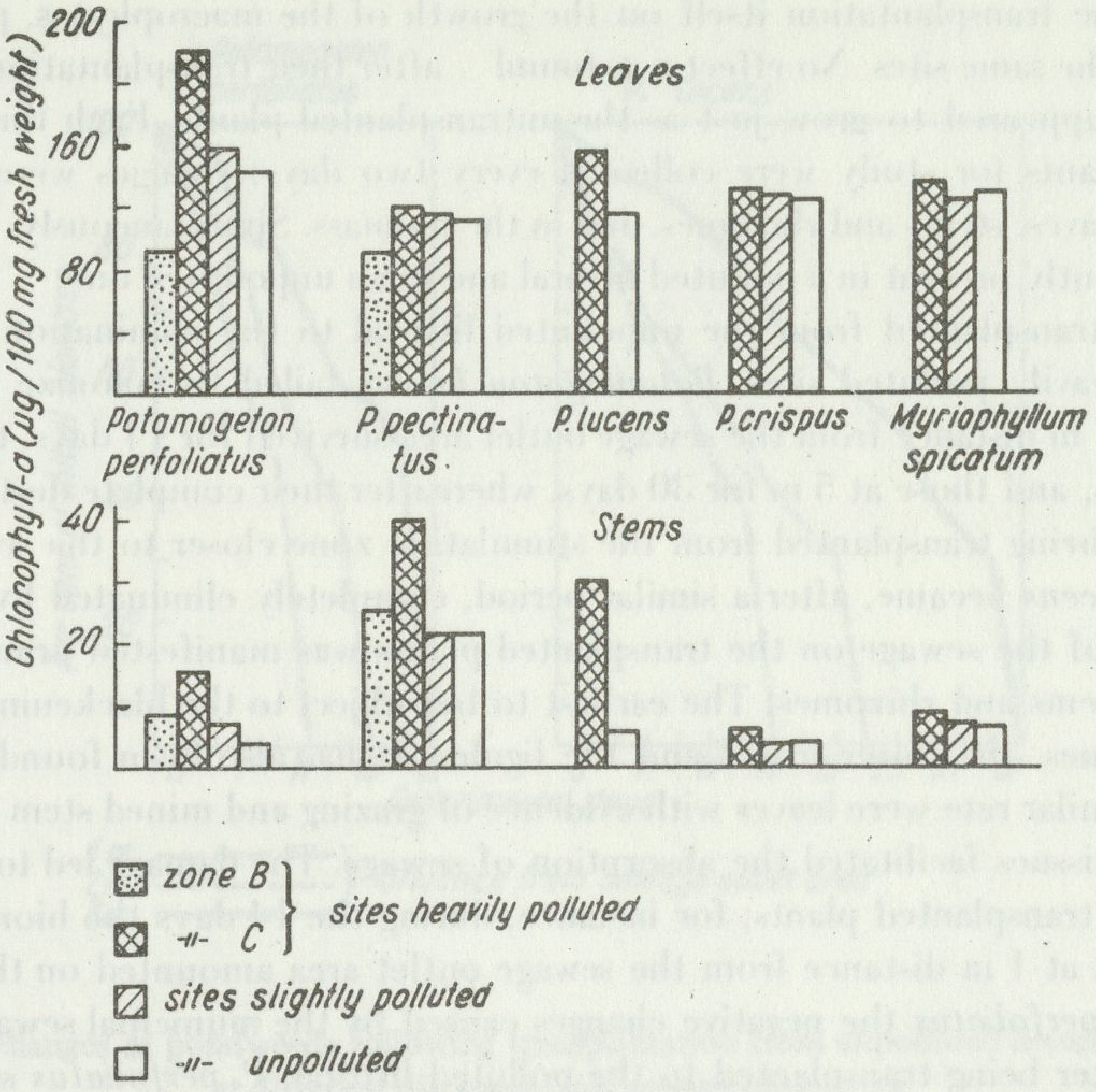

Fig. 12. Chlorophyll-a content in fresh mass of macrophytes in the littoral of Mikołajskie Lake (1973)

leaves and stems of some macrophyte species, and indirectly upon the photosynthetic capabilities of the plants.

7. FIELD EXPERIMENT

A field experiment was made to determine the type and the rate of the transformations of macrophytes under the influence of municipal sewage, and to estimate the possibility to regenerate of plants derived from polluted habitats. Tne experiment consisted in the transplantation of *Potamogeton perfoliatus* and *P. lucens* from an unpolluted littoral to a heavily polluted littoral, and vice versa. Some of the results from the experiments, in which *Potamogeton perfoliatus* was transplanted, have been presented in earlier papers (O z i m e k and S i k o r s k a 1975, 1976).

The experiment was carried out at two heavily polluted sites, with a centralized sewage outlets (I and IV), and at one unpolluted site (XI) in Mikołajskie Lake. These sites have a similar type of bottom (sandy-stony) and a similar wave action intensity.

The plants, carefully pulled out, together with their rhizomes and roots, from the unpolluted littoral were (after being weighed and marked) replanted in the sites affected by sewage, at distances 1, 2 and 5 m from the sewage outlet area towards the middle of the lake. In the unpolluted site, plants from the degradation zone (*Potamogeton perfoliatus*) and the stimulation zone (*P. lucens*) were replanted.

Three replications of the experiment were made: in June, July, August 1973. To check for the effect of the transplantation itself on the growth of the macrophytes, plants were transplanted within the same sites. No effect was found – after their transplantation within the same site the plants appeared to grow just as the untransplanted plants. Each time 60 plants were transplanted. Plants for study were collected every two days: changes were observed in the colour of the leaves, stems and rhizomes, and in the biomass. Simultaneously, investigated were also plants currently present in a polluted littoral and in an unpolluted one.

After being transplanted from the unpolluted littoral to the elimination and degradation zones of the heavily polluted sites, *Potamogeton lucens* failed to colonize the zones. Plants replanted at a 1 m distance from the sewage outlet area survived for 14 days, those replanted at 3 m for 20 days, and those at 5 m for 30 days, whereafter their complete destruction followed. Likewise, after being transplanted from the stimulation zone closer to the sewage outlet area, *Potamogeton lucens* became, after a similar period, completely eliminated by the sewage. The negative effect of the sewage on the transplanted plants was manifested primarily by necroses of the leaves, stems and rhizomes. The earliest to be subject to the blackening and destruction were the rhizomes, the lower leaves and the ligules. It has also been found that affected by necroses at a similar rate were leaves with evidence of grazing and mined stem parts. Mechanical damage to the tissues facilitated the absorption of sewage. The damage led to a decrease in the biomass of the transplanted plants; for instance, during the 14 days the biomass losses to the plants replanted at 1 m distance from the sewage outlet area amounted on the average to 61% (Fig. 13). In *P. perfoliatus* the negative changes caused by the municipal sewage are faster than in *P. lucens*. After being transplanted to the polluted littoral, *P. perfoliatus* survived for about half the period of survival of *P. lucens*, and the rate of destruction of the plants was faster (Fig. 13). This is connected with the morpho-anatomy of the species. The stems and rhizomes of *P. perfoliatus* are thinner, so they are more vulnerable to damage, and are more easily broken by the waves.

The longer the distance from the sewage outlet area, the longer was the period after which necroses and losses to biomass followed, and the period of survival of the plants. This is related to the dilution of the sewage with the distance from its outlets into the lake.

After being transplanted from the stimulation zone (7–10 m from the sewage outlet area) to the unpolluted littoral *Potamogeton lucens* colonized the littoral. The plants grew, increasing the density and the area occupied. The biomass of the transplanted plants increases, and after the 31 experimental days it appeared to have almost doubled (Fig. 14). The transplanted plants survived until October, like those plants which grew there permanently. A comparison of the biomass changes in *Potamogeton perfoliatus* and *P. lucens* has shown that the growth rate of the biomass of *P. lucens* was faster. In the case of *P. perfoliatus*, the individuals transplanted were of a very poor condition, due to which during the first days of the experiment there even occurred losses to the biomass (Fig. 14). After being transplanted to the unpolluted littoral, *P. lucens*, like *P. perfoliatus*, became renewed during the next vegetation season, but no growth was found in the plants transplanted to the littoral affected by the sewage.

On the basis of the field experiment it has been concluded that the absence of vegetation in the elimination zone is caused by the influence of the municipal sewage, and that the degeneration of the macrophytes is fast. The experiment has also shown that there exist considerable regenerative possibilities in the two pondweed species analysed.

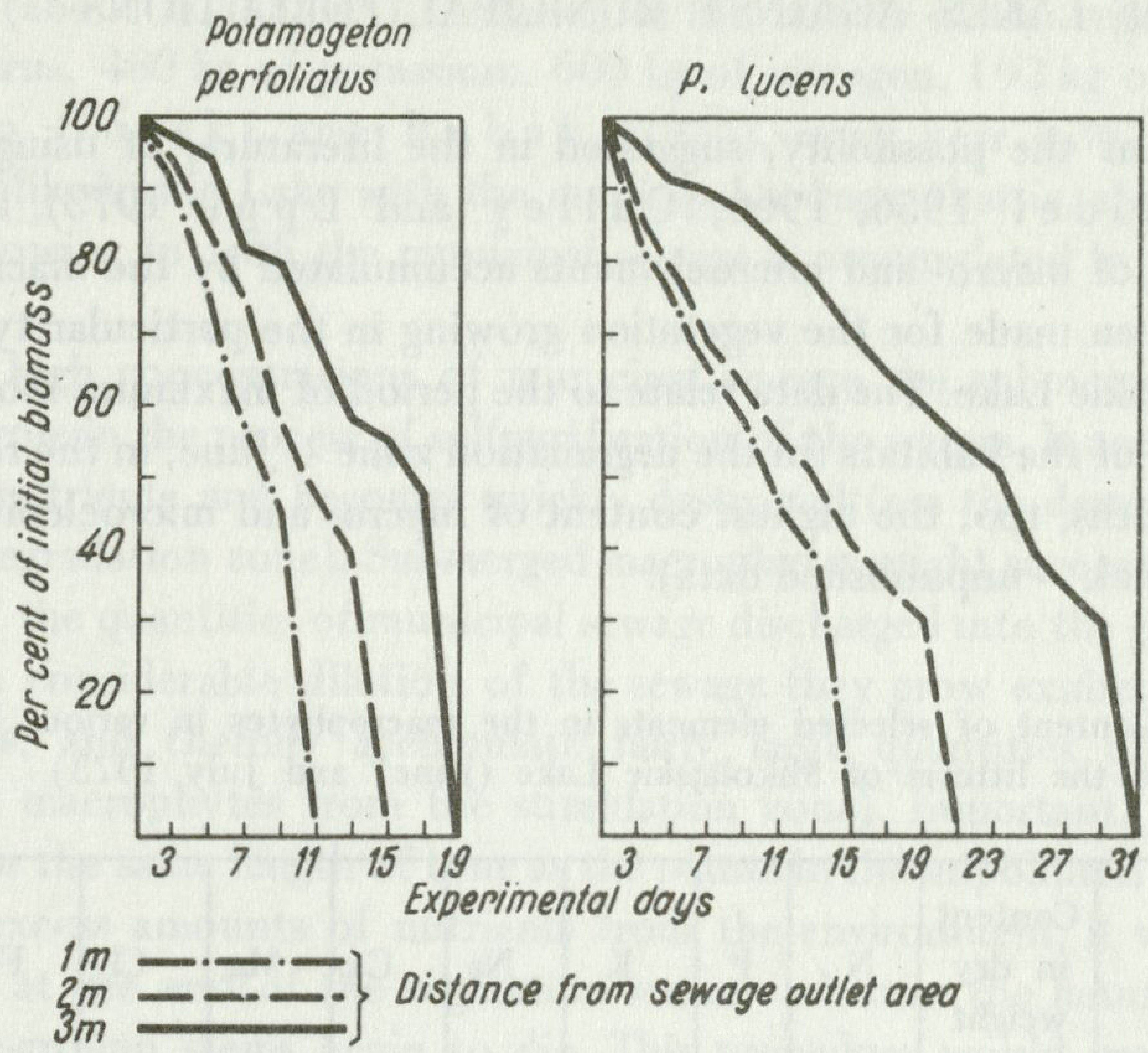

Fig. 13. Biomass changes in pondweeds following transplantation from unpolluted littoral to a polluted one, at different distances from sewage outlet area

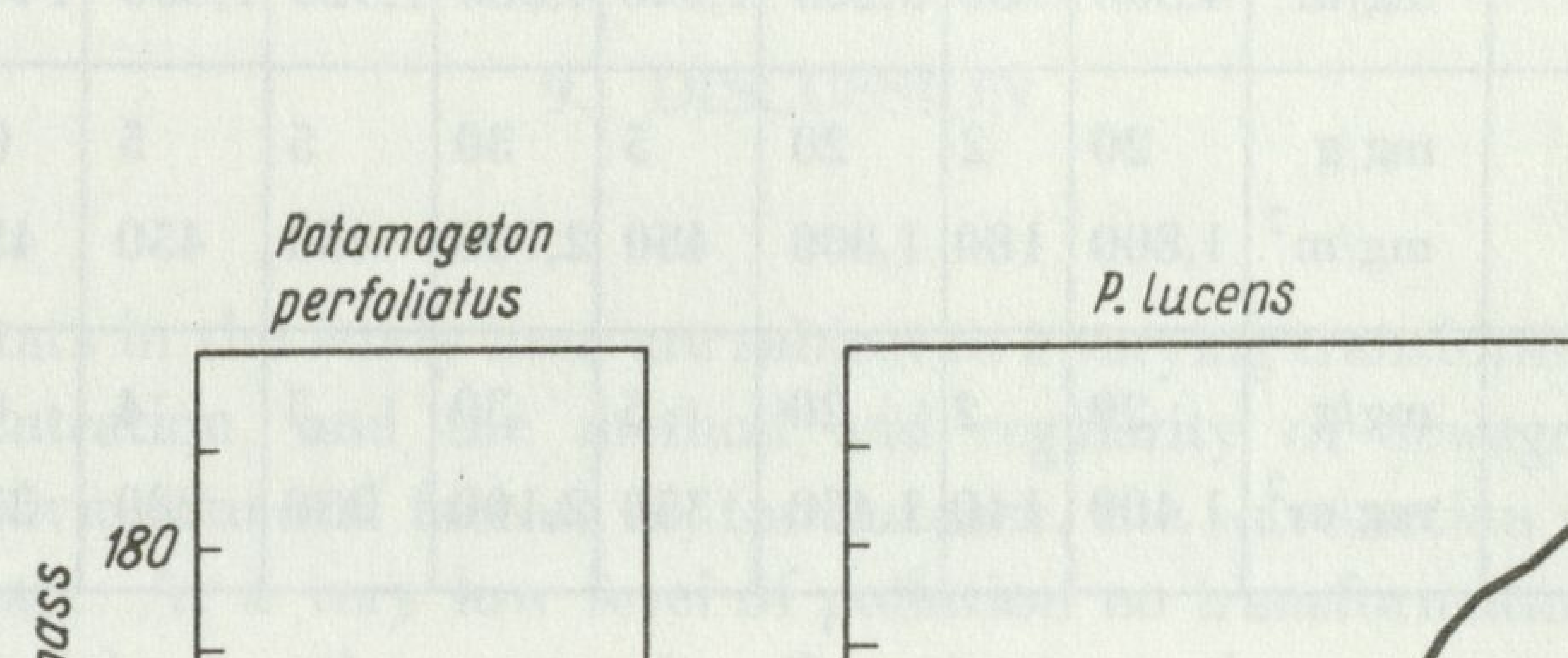

Fig. 14. Biomass changes in pondweeds following transplantation from polluted littoral to unpolluted littoral

8. MACROPHYTES AND THE PROTECTION OF LAKES AGAINST MUNICIPAL POLLUTIONS

Taking into account the possibility, suggested in the literature, of using macrophytes as biological filters (S e i d e l 1956, 1966, C u l l e y and E p p s 1973), a calculation was made of the amount of macro- and microelements accumulated by the macrophytes studied. The estimation has been made for the vegetation growing in the particular types of habitat in the littoral of Mikołajskie Lake. The data relate to the period of maximum biomass value of the plants, found in each of the habitats (in the degradation zone – June, in the remaining habitats – July). In these months, too, the highest content of macro- and microelements in the plants was recorded (T. Ozimek – unpublished data).

Table IX. Content of selected elements in the macrophytes in various habitats of the littoral of Mikołajskie Lake (June* and July 1973)

Sites		Content in dry weight	N	P	K	Na	Ca	Mg	Cl	Fe	Mn	Zn
Heavily polluted	zone B*	mg/g	30	3	30	12	12	10	15	0.7	0.2	0.05
		mg/m^2	600	60	600	200	300	200	300	14.0	4.0	0.10
	zone C	mg/g	30	3	20	10	25	12	10	0.9	0.2	0.04
		mg/m^2	4,800	480	3,200	1,600	4,000	1,920	1,600	144.0	32.0	6.4
Slightly polluted		mg/g	20	2	20	5	30	5	5	0.5	0.4	0.02
		mg/m^2	1,800	180	1,800	450	2,700	450	450	45.0	36.0	1.8
Unpolluted		mg/g	20	2	20	5	30	5	4	0.5	0.5	0.02
		mg/m^2	1,400	140	1,400	350	2,100	350	280	35.0	35.0	1.4

The smallest amounts of macro- and microelements accumulated in the plants per 1 m^2 are found in the degradation zone (B), the largest in the stimulation zone (C) of heavily polluted sites (Table IX). The differences, which are considerable, result from the large differences in the biomass of the plants (the content of macro- and microelements in the plants differs slightly).

In the stimulation zone, by comparison with the degradation zone, the macrophytes attain eight times as high a biomass value.

Although the highest values of the accumulation of elements were found in the stimulation zone of the heavily polluted sites, these values (Table IX) are lower than those reported by S e i d e l (1966) for emergent macrophytes. For instance, according to the above author, *Schoenoplectus lacustris* accumulates 6,720 mg of phosphorus, 3,290 mg of magnesium, 10,300 mg of potassium and 21,170 mg of sodium per 1 m^2 (on experimental plantations). The differences result from better possibilities to accumulate a number of elements, and a higher biomass values attained by *Schoenoplectus lacustris* per 1 m^2 than by the submerged macrophytes analysed in the present paper.

It has been calculated that the vegetation of the whole polluted part of the littoral of Mikołajskie Lake (about 30,000 m^2) contains, in the middle of the vegetation season, about 60 kg of phosphorus, 480 kg of potassium, 600 kg of nitrogen, 192 kg of sodium, 14.4 kg of iron. According to Górski and Rybak (1974), every year 1,362 kg of phosphorus is brought into the Mikołajskie Lake with the municipal sewage, that is, about one twentieth of the phosphorus flowing in with the municipal sewage is accumulated in plants from polluted habitats.

In the case of high concentrations of municipal sewage the submerged vegetation cannot play a significant role in the process of selfpurification of the waters. It accumulates a relatively small amount of nutrients and becomes quickly destroyed (see the description of the macrophytes from the degradation zone). Submerged macrophytes might successfully play the role of biological filters if the quantities of municipal sewage discharged into the given lake were small. In habitats with a considerable dilution of the sewage they grow exuberantly, attaining high values of biomass, and thereby accumulate fairly large quantities of nutrients (see the description of the macrophytes from the stimulation zone). Important, too, is the fact that they are present for the same length of time as the plants in the unpolluted habitats. In order to "take back" the excess amounts of nutrients from the environment, it would be possible to harvest the plants at the end of the vegetation season, when in the natural conditions plants with annual above-ground stems begin to die. This procedure would prevent this important element of the littoral biocenose from being prematurely destroyed. If the harvesting of macrophytes is not applied, they can all the same contribute to the inactivation of part of the nutrients, because some of the macrophytes after their death get into the bottom sediments and are not included in the cycling of the matter in the lake.

9. DISCUSSION

The littoral habitats in the study area are subject to a varying transformation, depending on the amount, concentration, and the method and regularity of sewage discharge, as also indirectly on such environmental factors as, for instance, the wave action which causes a rapid dilution of the sewage. At a very low level of pollution no transformation of the vegetation could be seen, at a low level – there was primarily a change in the species composition, and at a high level – changes in the species composition and structure of the plant communities, and of the phenology, condition, morphology and chemical composition of each of the species.

Dąmbska (1965) has found that the vegetation of the lakes with a low trophic level, e.g., the lobelia lakes, is very sensitive even to slight changes in the chemistry of the water. No such relationship was found in the case of the vegetation studied in five eutrophic lakes, which does not become transformed as a result of small changes in the chemistry of the water, caused by the inflow of municipal sewage. This indicates that the vegetation of the eutrophic lakes is much less sensitive to slight changes in the environment than is the vegetation of the lakes with poor trophic conditions.

Forsberg (1964, 1965) has found that pollutions, among other things, cause the change from the dominance of the stoneworts to the dominance of the pondweeds in lakes. This corresponds to the results obtained from studies of the vegetation of the littoral of Mikołajskie Lake. A comparison of the present distribution of the vegetation in Mikołajskie Lake with the results obtained by B. Solińska in 1962 (unpublished data) has shown a disappearance of species of the family Characeae and a stronger growth of the pondweeds in habitats which border on the town Mikołajki (defined as a slightly polluted sites). Since the time B. Solińska carried out her studies the population of the town Mikołajki has increased, and there has been a considerable increase in tourism in the areas adjacent to the lake, and consequently the amount of sewage and the degree of the pollution of waters have increased. Moreover, the conclusion can be drawn that with a low pollution of water the changes in the environment are great enough to cause the elimination of species sensitive to pollution, but not great enough to cause transformations of the less sensitive plant species that grow there. These species do not show any differences in their phenology, condition, morphology, or significant differences in the chemical composition, relative to the plants in the unpolluted habitats.

In heavily polluted habitats with a centralized sewage outlets Pieczyńska, Sikorska and Ozimek (1975) have distinguished two zones: (1) a saprotrophic zone, being under the direct action of sewage and characterized by the predominance of decomposition processes, elimination, or by highly reduced numbers and biomass of the various groups of organisms (benthos, fauna colonizing stones, periphyton algae), and (2) a polytrophic zone, fertilized by diluted sewage, and with frequent outbreaks of organisms. A similar differentiation is found in the case of the macrophytes. Four stages of the action of sewage on the vegetation are observed as the concentration of the sewage decreases: elimination, degradation, stimulation of growth, and no influence. The range of the particular stages of influence varies with the different groups of organisms, depending on the multiplication rate, and on the morpho-anatomical and physiological characteristics of these organisms. For instance, the zone of mass growth of periphyton algae is found closer to the sewage outlets (2–3 m) than the zone of stimulation of the macrophytes (7–10 m).

The zones of elimination, degradation and of the stimulation of macrophyte growth were distinguished on the basis of a phytosociological analysis (of the distribution, species composition and structure of the communities). That this division into zones was right has been proved by further detailed investigations of the phenology, condition, morphology and chemical composition of five dominant macrophyte species, and the field experiment. Obviously, by using such a method for the analysis more information, and more-detailed information was obtained, but the method is much more laborious than the phytosociological analysis. It appears, therefore, that for a quick assessment of the effect of pollution on an aquatic vegetation, e.g., in investigations based on monitoring, the phytosociological method is very useful.

Klötzli and Grünig (1976) maintain that the morpho-anatomic characteristics, and the chemical composition of the plants can be used as an indicator of environment transformation. As can be concluded from the results analysed in the present paper, the various associations of macrophytes, and the different types of leaf lesions: chloroses and necroses, can also serve as indicators. Their advantage lies in the fact that they are easy to identify in the field (no additional laboratory techniques are required), whereas their disadvantage is that their sensitivity is too low, so they are of diagnostic value only when the transformation of the environment is of a considerable magnitude. In long-term observations the indicators of changes in the environment, due to the influence of sewage, are floristic changes. Apart from the results of the present study, the same conclusion is suggested by the data published by Forsberg (1964, 1965) and Suominen (1968).

The transformations of the submerged macrophytes (elimination and destruction), observed in heavily polluted habitats, indicate that their resistance to pollution is lower than that of the emergent macrophytes, which grow quite well even at high concentrations of municipal sewage and industrial effluents (W o l n y 1962, S e i d e l 1965). This also shows that the possibility is limited of using submerged macrophytes as biological filters in the biological processes of the selfpurification of water.

I wish to express my cordial thanks to Professor Dr. Ewa Pieczyńska for the valuable and careful comments, and the time she kindly spent with me during the preparation of the present paper. I should like to extend my thanks also to my colleagues at the Department of Hydrobiology, Institute of Zoology, University of Warsaw, for the advice and assistance which they were kind enough to give me many a time.

10. SUMMARY

A determination was carried out of the transformations of littoral macrophytes under the influence of municipal sewage, discharged into five lakes of the Masurian Lakeland: Mikołajskie, Bełdany, Śniardwy, Tałty and Miłki.

On the basis of the degree of the changes in the chemistry of the waters of the littoral bordering upon built-up areas three types of site were distinguished: very slightly, slightly and heavily polluted. In Mikołajskie Lake, the most transformed littoral habitats were found in the part of the littoral which borders on the town Mikołajki (Table II).

At very slightly polluted sites (without any significant changes in the chemistry of the water) no differences were found in the species composition (Table III), or in the form of the macrophyte communities (Table IV, Fig. 4), and individual species, relative to the unpolluted sites.

At slightly polluted sites a considerable reduction in the number of species was found, especially of Characeae (*Chara aspera, Ch. vulgaris, Ch.* sp. and *Nitellopsis obtusa*) and *Heleocharis acicularis*, common in the unpolluted littoral (Table III). These species have been defined as sensitive to municipal pollution. In the remaining species, found at these sites, no differences in development (Fig. 10), condition (Fig. 11), morphology, biomass (Tables V–VII), or chemical composition (Table VIII) were found, as compared with the plants derived from unpolluted sites. Thus, the changes in the conditions, caused by the municipal sewage, are in this site group great enough to cause the elimination of the species which are very sensitive to the municipal sewage, but not great enough to cause transformations of the less sensitive plant species found there.

The most changed vegetation was found at heavily polluted sites and with a clearly changed chemistry of the water. Apart from the elimination of certain species (the same as at the slightly polluted sites) a clear transformation was found of the plant communities (Table IV, Fig. 4) and of individual species; of their phenology (Fig. 10), condition (Fig. 11), morphology, biomass (Tables V–VII) and chemical composition (Table VIII). At these sites the following three zones, differing in the degree of submerged macrophyte transformation (Figs. 5–7), were distinguished: the elimination zone, degradation zone and the zone of macrophyte growth stimulation.

A field experiment has shown that high concentrations of municipal sewage cause a fast destruction of macrophytes, leading on to their elimination from the habitat.

In an analysis of the possibility to use submerged macrophytes as biological filters, a calculation was made to determine the amounts of macro- and microelements accumulated in the plants studied (Table IX). This estimation has been done for the submerged vegetation found in habitats with varying levels of pollution, and in an unpolluted site of the littoral of Mikołajskie Lake. It has been found that in the case of high concentrations of municipal sewage submerged macrophytes cannot play a significant role in the process of purification of the lake waters. Macrophytes would be able to play the role of filters if the amounts of municipal sewage discharged into the lake were small. In habitats with a considerable dilution of the sewage the plants grow exuberantly, attain high values of biomass, and, therefore, a considerable amount of elements is accumulated in them.

11. POLISH SUMMARY

Określono przekształcenia makrofitów litoralnych pod wpływem ścieków komunalnych dochodzących do pięciu jezior Pojezierza Mazurskiego. Badania prowadzono w latach 1972–1974 w jeziorach: Mikołajskie, Bełdany, Śniardwy, Tałty i Miłki.

Na podstawie stopnia przekształcenia chemizmu wód litoralu kontaktującego się z zabudowaniami wyróżniono trzy typy stanowisk: bardzo słabo, słabo i silnie zanieczyszczone. Najsilniej przekształcone środowiska litoralne stwierdzono w Jeziorze Mikołajskim w partii litoralu kontaktującej się z miastem Mikołajki (tab. II).

Na stanowiskach bardzo słabo zanieczyszczonych (o nie zmienionym istotnie chemizmie wody) nie stwierdzono różnic w składzie gatunkowym (tab. III), wykształceniu zbiorowisk makrofitów (tab. IV, rys. 4) i poszczególnych gatunków, w porównaniu ze stanowiskami nie zanieczyszczonymi.

Na stanowiskach słabo zanieczyszczonych stwierdzono znaczną redukcję liczby gatunków, przede wszystkim *Characeae* (*Chara aspera*, *Ch. vulgaris*, *Ch.* sp. i *Nitellopsis obtusa*) oraz *Heleocharis acicularis*, pospolicie występujących w litoralu nie zanieczyszczonym (tab. III). Gatunki te uznano za wrażliwe na zanieczyszczenia komunalne. U pozostałych występujących na tych stanowiskach gatunków nie stwierdzono różnic w ich rozwoju (rys. 10), kondycji (rys. 11), morfologii, biomasie (tab. V–VII) i składzie chemicznym (tab. VIII), w porównaniu z roślinami ze stanowisk nie zanieczyszczonych. Zmiany warunków powodowane przez ścieki komunalne są więc w tej grupie stanowisk na tyle duże, że powodują eliminację gatunków bardzo wrażliwych na zanieczyszczenia komunalne, lecz nie na tyle duże by powodować przekształcenia występujących tu mniej wrażliwych gatunków roślin.

Najbardziej zmienioną roślinność obserwowano na stanowiskach silnie zanieczyszczonych, wyraźnie przekształconych pod względem chemizmu wody. Poza eliminacją pewnych gatunków (tych samych jak na stanowiskach słabo zanieczyszczonych) stwierdzono wyraźne przekształcenia zbiorowisk (tab. IV, rys. 4) i poszczególnych gatunków makrofitów: ich fenologii (rys. 10), kondycji (rys. 11), morfologii, biomasy (tab. V–VII) i składu chemicznego (tab. VIII). Na stanowiskach tych wyróżniono trzy strefy o różnym stopniu przekształcenia makrofitów zanurzonych (rys. 5–7). Są to strefy: eliminacji, degradacji i stymulacji rozwoju makrofitów.

Na podstawie eksperymentu terenowego stwierdzono, że pod wpływem wysokich stężeń ścieków komunalnych makrofity ulegają w szybkim tempie destrukcji i są następnie eliminowane ze środowiska.

Analizując możliwość zastosowania makrofitów zanurzonych jako filtrów biologicznych, obliczono, ile w badanych roślinach zakumulowane jest makro- i mikroelementów (tab. IX). Oceny dokonano dla roślinności zanurzonej zasiedlającej środowiska o różnym stopniu zanieczyszczenia i nie zanieczyszczone litoralu Jeziora Mikołajskiego. Stwierdzono, że w przypadku wysokich stężeń ścieków komunalnych makrofity zanurzone nie mogą odegrać istotnej roli w procesie samooczyszczania wód jeziornych. Rolę filtrów makrofity zanurzone mogłyby spełniać przy dopływie niewielkich ilości ścieków komunalnych. W środowiskach o znacznym rozcieńczeniu ścieków rośliny rozwijają się bujnie, osiągają wysoką biomasę i tym samym zakumulowana jest w nich znaczna ilość pierwiastków.

12. REFERENCES

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