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THE STRUCTURE OF MACROPHYTES IN INFLOW AND OUTFLOW LITTORALS IN THREE LAKES OF THE KRUTYNIA RIVER (MAZURIAN LAKELAND, POLAND)*

ABSTRACT: Species structure and biomass of macrophytes were analyzed in lake-river transitory zones along transects extending water courses. It was stated that at the place of stream's inflow, the lake's littoral was longer by about 50%, had a more gentle inclination of bottom slope, was more species-diversified and was marked for a greater biomass of macrophytes than outflow littoral of the lake.

KEY WORDS: macrophytes, plant biomass, inflow and outflow littoral.

1. INTRODUCTION

Lakes of the Mazurian Lakeland have been fairly thoroughly examined with regard to numerous aspects (morphometry, fauna, flora, chemism of water and sediment, primary production, etc.). By far less information may be found on rivers and smaller water courses of this region. Polish as well as foreign literature comprises only scanty works on conditions in transitory zones between river and lake ecosystems (e.g. Michalski 1946–1947, Forest and Mills 1971, Fisher and Carpenter 1976, Forest 1977, Engel 1985).

With this in mind, studies were carried out which focused on capturing the effect of water courses on vegetation of littoral in flow-through lakes in places of inflow and outflow of streams. The present work is a recapitulation of the initial stage of studies conducted in lakes of Krutynia River basin. The lakes are linked with smaller or larger water courses of different flow rate, bottom type, etc.

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2. THE SITE AND METHODS

The Krutynia River flows in the Mazurian Lakeland in the Mazurian Great Lake District, in the Pisa River basin. Its total length, the lakes included, amounts to about 100 km, while its basin covers an area of about 722 km^2 (D ę b s k i 1954) and provides about 25% of total water inflow to the Mazurian Great Lakes (K o n d r a c k i and M i k u l s k i 1958). Krutynia drains about 50 lakes

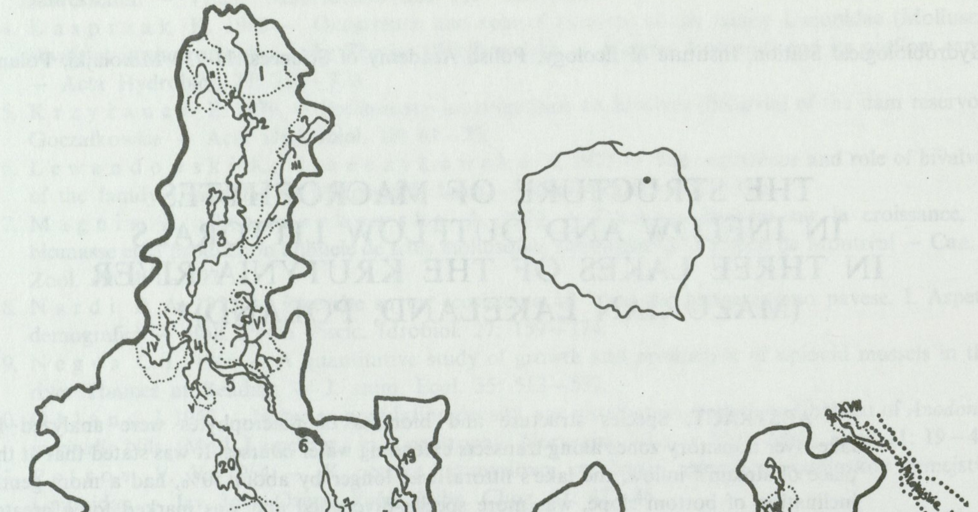

Fig. 1. Map of Krutynia drainage basin

Dotted line – borders of selected watersheds. I – XVII – numbers of watersheds and respective streams. Lakes: 1 – Warpuny, 2 – Zyndaki, 3 – Gielądzkie, 4 – Lampackie, 5 – Lampasz, 6 – Kujno, 7 – Dłużec, 8 – Białe, 9 – Gant, 10 – Zyzdrój Wielki, 11 – Zyzdrój Mały, 12 – Spychowskie, 13 – Zdrużno, 14 – Uplik, 15 – Mokre, 16 – Krutyńskie, 17 – Gardyńskie, 18 – Malinówko, 19 – Krzywe, 20 – Piłakno, 21 – Babięty, 22 – Krawno, 23 – Mojtyny, 24 – Kołowin, 25 – Tejsowo (after L. Kufel – unpublished data)

(Fig. 1) and its hydraulic gradients amount to 1.4% at hardwaters, 0.2% in the lower course of the river and 0.05% in its mouth section. Mean flow rate at the mouth comes to about 4 m^3 (Kondracki and Mikulski 1958).

The studies were conducted on three flow-through lakes situated in the Krutynia River basin.

Kujno Lake (Fig. 1) had the smallest area and maximum depth of all the studied reservoirs (Table 1). It is located in the upper part of the Krutynia River basin, among nine other lakes situated on the main flow line. In its north-western part, the lake is fed with a water course passing through a fracture in moraine ridge (Fig. 2) and flowing from the Lampackie Lake (Kondracki and Mikulski 1958). The stream is about 1.5 km long and 2–6 m wide and has a fairly rapid current. Except for some sections, its bottom is stony. In place where the stream inflows the Kujno Lake, its both banks are overgrown with multi-species rushes dominated by *Phragmites australis* Cav. (Trin.) ex Steud. The width of the water

Table 1. Morphometrical characteristics of lakes (Kondracki and Mikulski 1958)

Parameters	L. Kujno	L. Tejsowo	L. Spychowskie
Area (ha)	24.0	29.8	48.8
Length max. (m)	1150.0	925.0	1100.0
Width max. (m)	300.0	400.0	650.0
Length of shore-line (m)	2700.0	2275.0	3400.0
Depth max. (m)	6.0	15.8	7.7
Depth mean (m)	2.8	4.5	2.3
Development of shore-line ($m \cdot ha^{-1}$)	1.5	1.1	1.3

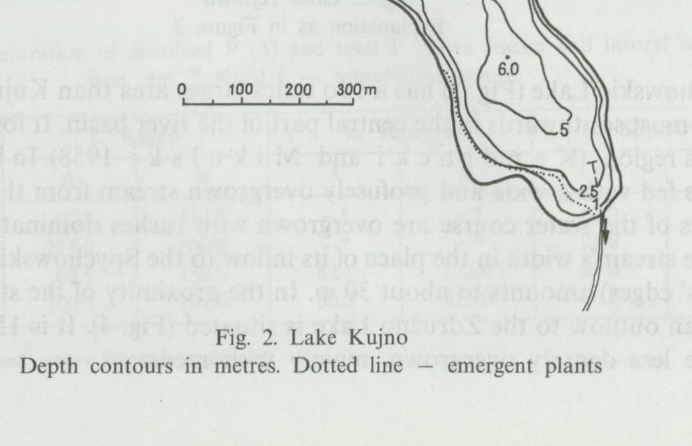

Fig. 2. Lake Kujno
Depth contours in metres. Dotted line — emergent plants

course between the rushes' edges is about 10 m. In the south-western part of the lake there is an outflow to the Dłużec Lake, about 1 km long and of a less swift current. In the place of its outflow from the lake, the banks of the stream are vigorously overgrown with reed rushes, the width of the water course coming to about 8 m.

Tejsowo Lake – the deepest of the examined lakes (Table 1), is an intermoraine reservoir, situated in the lower course of the Babięta River (Fig. 1). In the south-western part the lake is fed with a 5 km long tributary flowing from the Babięty Małe Lake. All along its length between the two reservoirs the stream is shallow, has swift current and stony bottom and is marked for a fairly large gradient amounting to about 8 m (K o n d r a c k i and M i k u l s k i 1958). Another stream draining the Kały, Krawno Małe and Krawno Wielkie Lakes inflows to the same part of the lake (Fig. 3). It is slightly deeper and has a less rapid current than the other. In place where the two streams inflow to the lake, their banks are profusely overgrown with rushes dominated by sedges and reeds and with sporadic alder shrubs. The width of the streams' mouths is about 18 and 15 m. In the north-western part of the lake there is found an outflow through Krutynia to the Zyzdrój Lake, its width amounting to about 10 m (measured between the rushes' edges).

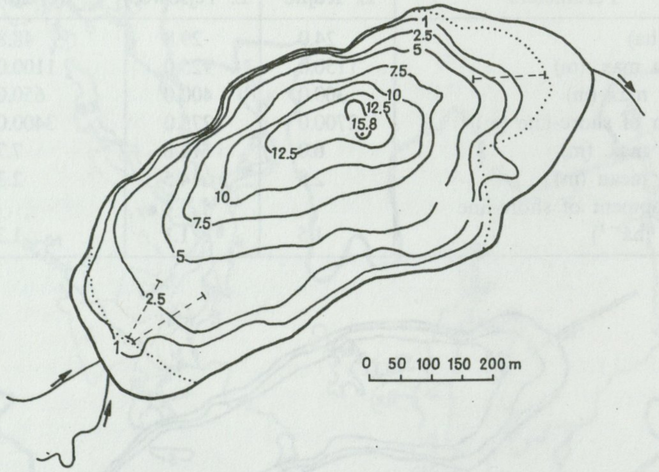

Fig. 3. Lake Tejsowo
Explanation as in Figure 2

Spychowskie Lake (Fig. 1) has a two times larger area than Kujno (Table 1) and is located most southwards in the central part of the river basin. It forms a pool in an outwashes region (K o n d r a c k i and M i k u l s k i 1958). In its northern part the lake is fed with a wide and profusely overgrown stream from the Zyzdrój Lake. The banks of the water course are overgrown with rushes dominated by reeds and sedge. The stream's width in the place of its inflow to the Spychowskie Lake (between the rushes' edges) amounts to about 30 m. In the proximity of the stream's inflow to the lake, an outflow to the Zdrużno Lake is situated (Fig. 4). It is 15 m wide and its banks are less densely overgrown, mainly with reeds.

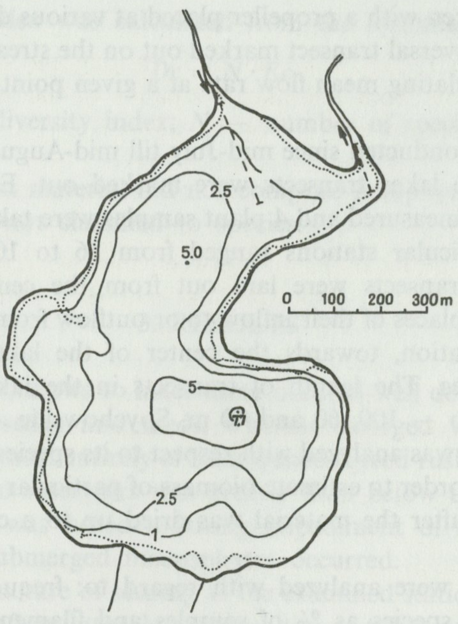

Fig. 4. Lake Spychowskie
Explanation as in Figure 2

Analysis of phosphorus content in water of streams and littorals of the lakes (within the study sites) revealed that inflow littoral of the Kujno Lake was the richest in phosphorus. In any of the water bodies there were not captured any regularities in differences between phosphorus content in water of streams and littorals (Table 2, Kufel – unpublished data).

On the basis of hydrometric propeller method and the following formula (M i k u l s k i 1978):

$$V = \alpha + \beta n$$

where: V – flow rate, α and β – coefficients of hydrometric propeller, n – the number of propeller's revolutions per 1 s, the flow rate was calculated of water in streams before the inflow to reservoirs and below the outflow from the lakes.

Table 2. Concentration of dissolved P (A) and total P (B) in stream and littoral waters (μm · dm^{-3}; Kufel I. – unpublished data)

Stand	L. Kujno		L. Tejsowo		L. Spychowskie	
	A	B	A	B	A	B
Inflow stream	87.5	112.5	–*	–*	63.0	113.0
Inflow littoral	275.0	800.0	–*	–*	25.0	100.0**
Outflow littoral	62.5	150.0	62.5	275.0	25.0	100.0**
Outflow stream	100.0	162.5	50.0	225.0	50.0	88.0

* No data. **Inflow and outflow littorals are connected.

Measurements were taken with a propeller placed at various depth from the bottom at several spots of transversal transect marked out on the stream. The obtained data were the basis for calculating mean flow rate at a given point of transect in vertical profile of the stream.

The studies were conducted since mid-July till mid-August 1986. In inflow and outflow littorals of the lakes transects were marked out. Every 5 m along each transect the depth was measured and 4 plant samples were taken. A total number of samples taken at particular stations ranged from 36 to 100, depending on the transect length. The transects were laid out from the center of inflowing and outflowing streams (in places of their inflow to or outflow from a reservoir), from the belt of emerged vegetation, towards the center of the lake up to the reach of submerged macrophytes. The length of transects in the lakes was: in Kujno – 120 and 55 m, Tejsowo – 100, 60 and 40 m, Spychowskie – 120 and 60 m. The sampled plant material was analyzed with respect to its species composition and was divided accordingly in order to estimate biomass of particular plant species. Biomass (dry wt) was denoted after the material was dried up to a constant weight at the temperature of 105°C.

The obtained data were analyzed with regard to: frequency of occurrence of particular macrophyte species as % of samples and filamentous algae in general, their contribution to biomass, depth range of plant occurrence, differences between inflow and outflow littoral of a reservoir as well as differences noted between particular lakes.

In comparative analyses similarity index was applied, calculated from the formula by Kulczyński (1940) supplied by Szafer and Zarzycki (1972):

$$S = \frac{100}{2} \cdot \frac{c}{a} + \frac{c}{b} \quad (\%)$$

where: S – similarity index, c – the number of species commonly occurring at the two examined stations (i.e. in the inflow and outflow littoral of the reservoir), a – the number of plant species occurring at one station (inflow littoral), b – the number of plant species occurring at the other station (outflow littoral). The coefficient in question was also applied for comparing biomass of plants at the two stations as well as to compare particular lakes.

An attempt was also made to denote dominance structure and plant species diversity in the examined communities, using the method and formulas suggested by Cieślak (1980) for studies on plant associations. The index of equalization of species dominance structure was calculated on the basis of the formula:

$$Ec = \frac{(d1 + 2d2 + 3d3 + \ldots\ldots + ndn) - 50}{N \cdot 50}$$

where: Ec – index of dominance equalization; $d1$, $d2$, $d3$ ... dn – dominance of particular species denoted in %; 1, 2, 3 ... n – numbers denoting particular species arranged in a series of decreasing dominance; N – number of species ($N = n$).

Species diversity index was calculated from the formula:

$$Dc = N \cdot Ec$$

where: Dc — species diversity index; N — number of species; Ec — dominance equalization index.

The analysis of plant material did not comprise helophytes. Filamentous algae and charophytes were not classified to species.

3. RESULTS

In places of streamy inflows to lakes there occured well developed, multi-species rushes, dominated by sedge and reeds, whereas emerged vegetation of outflow littorals was made up almost entirely of homogeneous reed rushes. Mean flow rate in streams before inflow to reservoirs was greater than below the outflows from the lakes (Table 3). There was noted a strong impediment of flow in places where abundant clusters of submerged macrophytes occurred.

Distribution and structure of settling at the examined stations was characteristic of lake littoral, yet in inflow littorals communities of submerged plants and plants

Table 3. Velocity of water flow ($m \cdot s^{-1}$) in streams entering to lakes (A, A′) and outflowing from lakes (B)

Distances along transversal transects (m)	L. Kujno		L. Tejsowo			L. Spychowskie	
	A	B	A	A′	B	A	B
0.5		0.10					0.51
1.0	0.18	0.12				0.18	0.64
1.5							0.49
2.0	0.26	0.23	0.51	0.46	0.09	0.10	0.69
2.5							0.96
3.0	0.35	0.38			0.06		0.96
3.5							0.81
4.0	0.35	0.28				0.10	0.91
4.5							1.21
5.0	0.29	0.03	0.64	0.63	0.07		1.29
6.0	0.17					0.11	
7.0					0.11		
8.0			0.49	0.81		0.12	
9.0					0.11		
10.0					0.08	0.15	
12.0			0.69	0.74			
14.0				0.51			
15.0			0.81			0.15	
17.0			0.91				
20.0						0.12	

with floating leaves were more species-diversified and particular species of macrophytes had a more mosaic occurrence (Figs. 5, 6, 7). A littoral-typical structure was recorded, i.e. two layer communities composed of rooted plants with floating leaves and submerged rooted plants. An admixture to these two groups were free-floating: *Lemna minor* L. and *Hydrocharis morsus-ranae* L.

The length of outflow phytolittoral (measured from the belt of emerged vegetation) was by about 50% smaller than of the inflow one, although in both cases the plants reached almost the same depth range (Figs. 5, 6, 7); depth in outflow littoral increased much more abruptly. Only in much shallowed Spychowskie Lake, the bottom along transect initially sloped down but then the depth decreased (Fig. 7).

In transitory zones of lakes three groups of macrophytes occurred, the greatest number of species of the genus *Potamogeton* occurring among submerged vegetation (Table 4). There were noted differences in the number and frequency of occurrence of particular plant species between the two kinds of littorals (Fig. 8) and between particular lakes. In the Kujno Lake the most frequently occurring species was *Nuphar luteum* (L.) Sm. (over 90% of samples), in Tejsowo — *Ceratophyllum demersum* L. (almost 100% of samples), whereas in samples taken in the Spychowskie

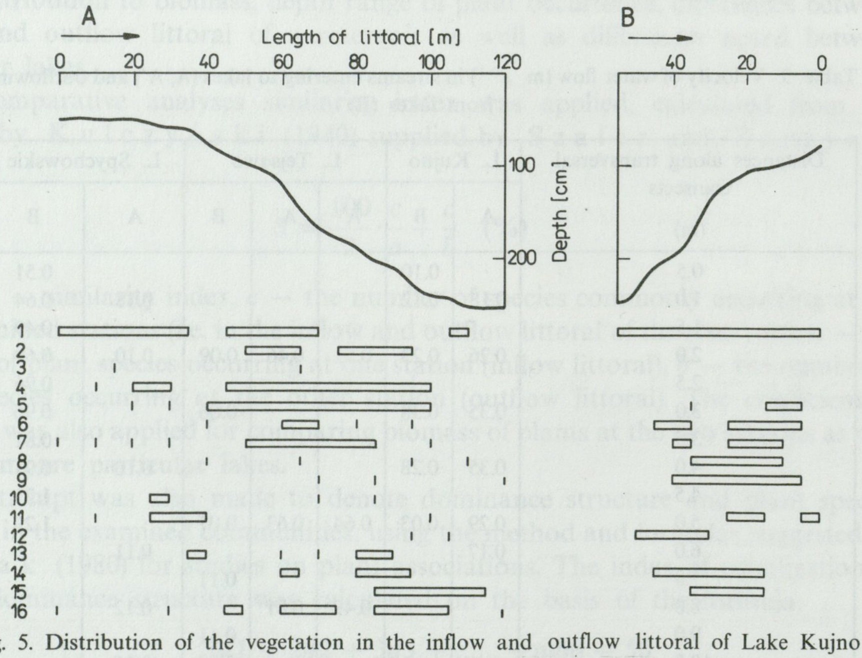

Fig. 5. Distribution of the vegetation in the inflow and outflow littoral of Lake Kujno

A — inflow littoral, B — out-flow littoral; 1 — *Nuphar luteum*, 2 — *Nymphaea alba*, 3 — *Hydrocharis morsus-ranae*, 4 — *Lemna minor*, 5 — *L. trisulca*, 6 — *Ceratophyllum demersum*, 7 — *Elodea canadensis*, 8 — *Batrachium circinatum*, 9 — *Fontinalis antipyretica*, 10 — *Stratiotes aloides*, 11 — *Potamogeton perfoliatus*, 12 — *P. pectinatus*, 13 — *P. compressus*, 14 — *P. mucronatus*, 15 — *Chara* spp., 16 — filamentous algae

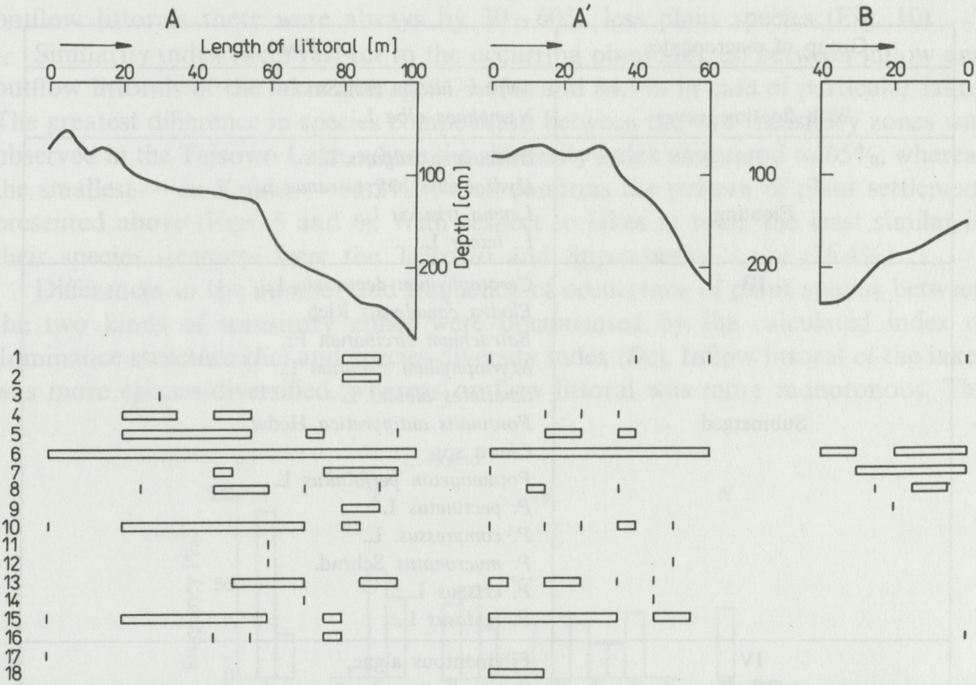

Fig. 6. Distribution of the vegetation in the inflow and outflow littoral of Lake Tejsowo
A, A' – inflow littoral, B – out-flow littoral. Numbers 1–10 as in Figure 5; 11 – *Potamogeton pectinatus*, 12 – *P. compressus*, 13 – *P. mucronatus*, 14 – *Chara* spp., 15 – filamentous algae, 16 – *Utricularia vulgaris*, 17 – *P. crispus*, 18 – *P. nodosus*

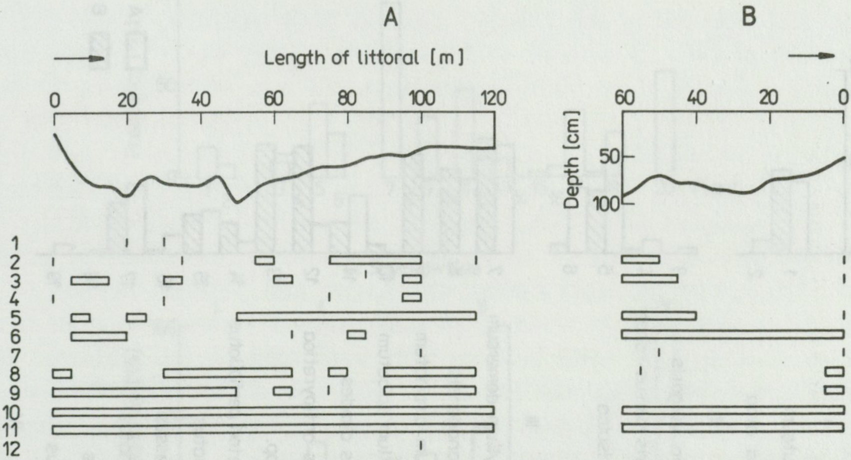

Fig. 7. Distribution of the vegetation in the inflow and outflow littoral of Lake Spychowskie
A, B – as in Figure 5; 1 – *Lemna minor*, 2 – *L. trisulca*, 3 – *Ceratophyllum demersum*, 4 – *Elodea canadensis*, 5 – *Batrachium circinatum*, 6 – *Fontinalis antipyretica*, 7 – *Potamogeton perfoliatus*, 8 – *P. pectinatus*, 9 – *P. mucronatus*, 10 – *Chara* spp., 11 – filamentous algae, 12 – *Myriophyllum spicatum*

Table 4. Floristic composition of the lake littoral

Group of macrophytes	Plant
I With floating leaves	*Nuphar luteum* (L.) Sm. *Nymphaea alba* L.
II Floating	*Utricularia vulgaris* L. *Hydrocharis morsus-ranae* L. *Lemna trisulca* L. *L. minor* L.
III Submerged	*Ceratophyllum demersum* L. *Elodea canadensis* Rich *Batrachium circinatum* Fr. *Myriophyllum spicatum* L. *Stratiotes aloides* L. *Fontinalis antipyretica* Hedw. *Chara* spp. *Potamogeton perfoliatus* L. *P. pectinatus* L. *P. compressus.* L. *P. mucronatus* Schrad. *P. crispus* L. *P. nodosus* L.
IV Others	Filamentous algae

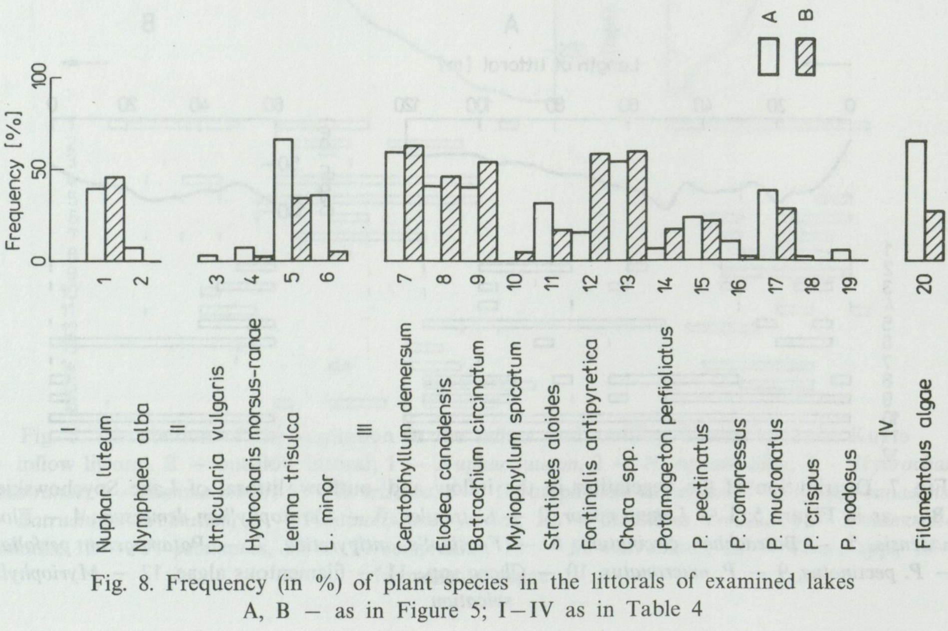

Fig. 8. Frequency (in %) of plant species in the littorals of examined lakes
A, B – as in Figure 5; I–IV as in Table 4

Lake there always occurred charophytes and filamentous algae (Fig. 9). In the lakes' outflow littorals there were always by 30–60% less plant species (Fig. 10).

Similarity index (with respect to the occurring plant species) between inflow and outflow littorals of the lakes averaged 71.7%, and 84.1% in case of particular lakes. The greatest difference in species composition between the two transitory zones was observed in the Tejsowo Lake, where the similarity index amounted to 65%, whereas the smallest – in Kujno – 81.2%, which confirms the pattern of plant settlement presented above (Figs. 5 and 6). With respect to lakes in total, the least similar in their species structure were the Tejsowo and Spychowskie Lake (76.4%).

Differences in the number and frequency of occurrence of plant species between the two kinds of transitory zones were documented by the calculated index of dominance structure (*Ec*) and species diversity index (*Dc*). Inflow littoral of the lakes was more species-diversified, whereas outflow littoral was more monotonous. The

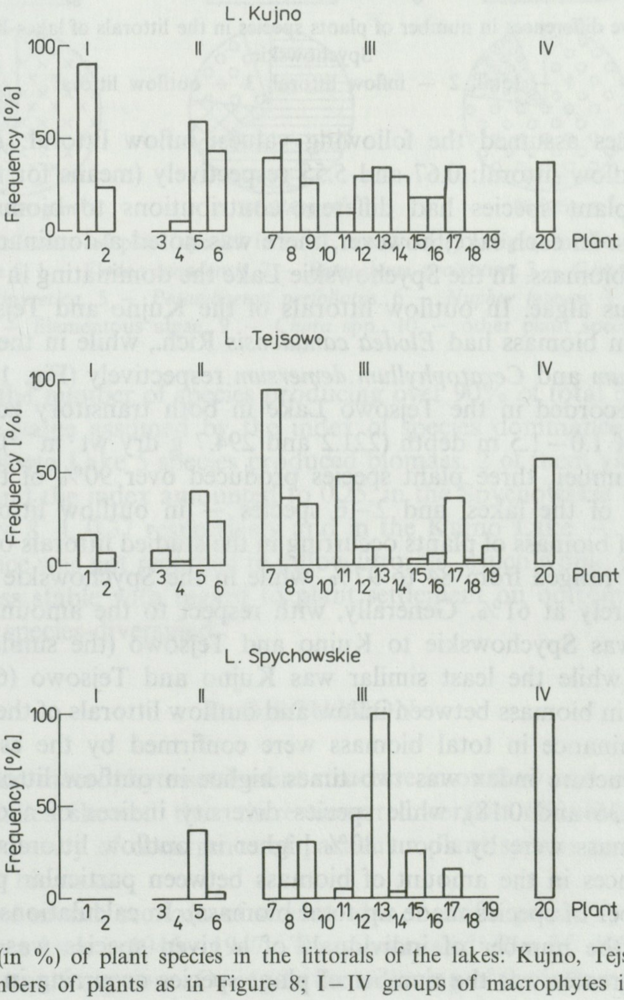

Fig. 9. Frequency (in %) of plant species in the littorals of the lakes: Kujno, Tejsowo, Spychowskie 1–20 numbers of plants as in Figure 8; I–IV groups of macrophytes in Table 4

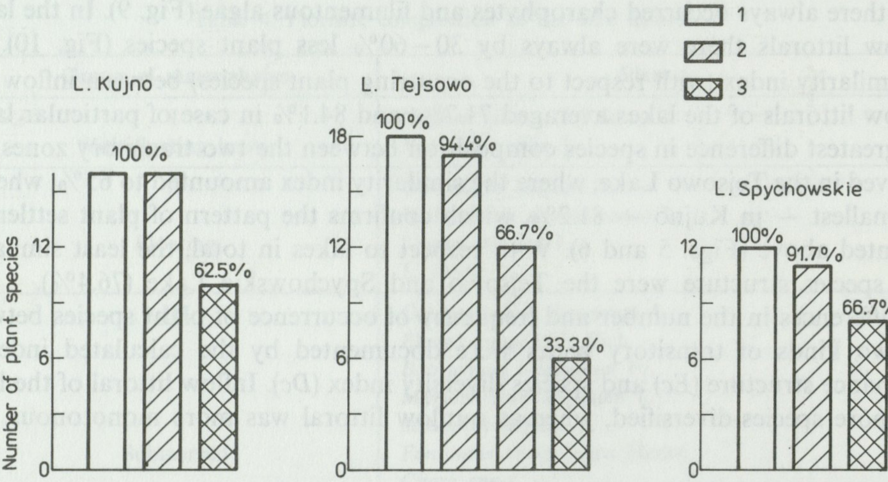

Fig. 10. Quantitative differences in number of plants species in the littorals of lakes Kujno, Tejsowo and Spychowskie

1 – total, 2 – inflow littoral, 3 – outflow littoral

calculated indices assumed the following values: inflow littoral: $Ec = 0.58$ and $Dc = 8.32$; outflow littoral: 0.67 and 5.55 respectively (means for the three lakes).

Particular plant species had different contributions to biomass in the two transitory zones. In each lake, however, there was noted a dominance of one plant species in total biomass. In the Spychowskie Lake the dominating in the two littorals were filamentous algae. In outflow littorals of the Kujno and Tejsowo Lakes the greatest share in biomass had *Elodea canadensis* Rich., while in the inflow littorals – *Nuphar luteum* and *Ceratophyllum demersum* respectively (Fig. 11). The greatest biomass was recorded in the Tejsowo Lake in both transitory zones and it was characteristic of 1.0–1.5 m depth (221.2 and 294.7 g dry wt $\cdot$ m^{-2}). Regardless the total species number, three plant species produced over 90% of total biomass in inflow littorals of the lakes, and 2–6 species – in outflow littoral (Fig. 11).

Similarity of biomass of plants occurring in the studied littorals of the Kujno and Tejsowo Lakes ranged from 84 to 97%, while in the Spychowskie Lake the index figured out merely at 61%. Generally, with respect to the amount of phytomass, more similar was Spychowskie to Kujno and Tejsowo (the similarity index was 79 and 73%), while the least similar was Kujno and Tejsowo (63%).

Differences in biomass between inflow and outflow littorals of the lakes as well as in species dominance in total biomass were confirmed by the estimated indices. Dominance structure index was two times higher in outflow littorals than in the inflow ones (0.36 and 0.18), while species diversity indices of a community with respect to biomass were by about 30% higher in outflow littorals (i.e. there were smaller differences in the amount of biomass between particular plant species yet a greater number of species made up total biomass). In calculations of values of the above indices the number of individuals of a given species was replaced by its biomass. The greater was the number of plant species occurring in outflow littoral,

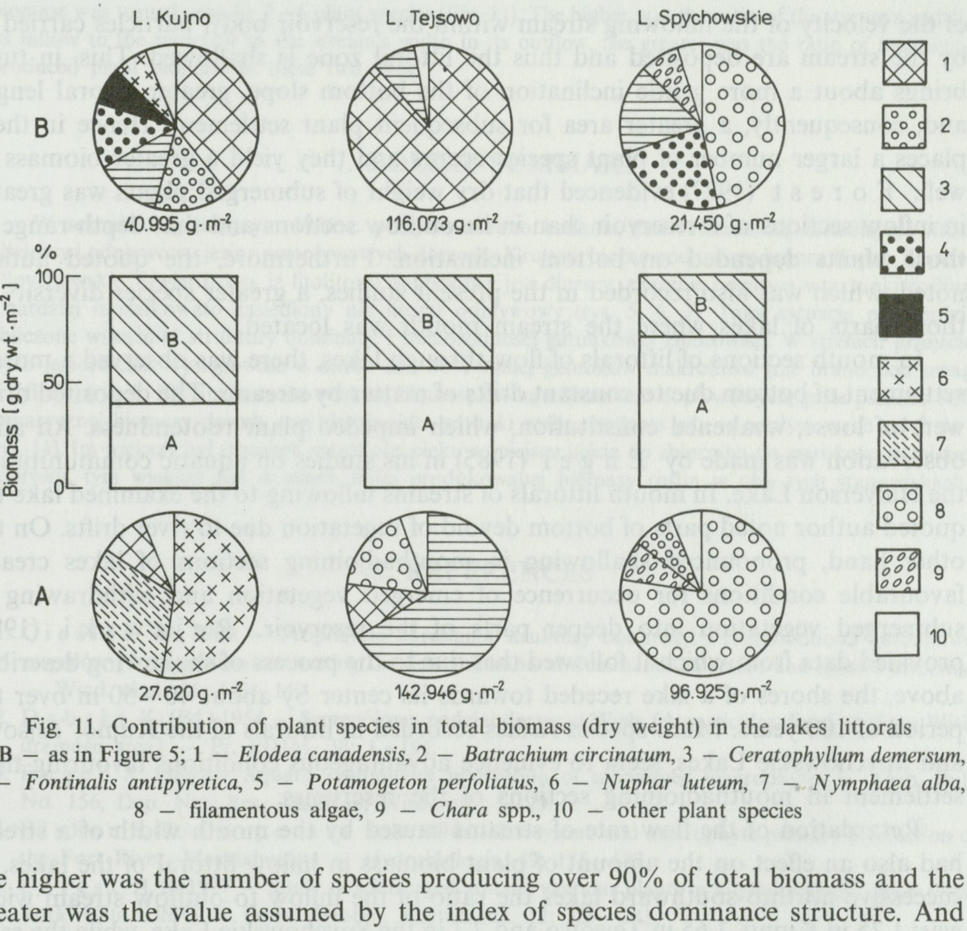

Fig. 11. Contribution of plant species in total biomass (dry weight) in the lakes littorals A, B — as in Figure 5; 1 — *Elodea canadensis*, 2 — *Batrachium circinatum*, 3 — *Ceratophyllum demersum*, 4 — *Fontinalis antipyretica*, 5 — *Potamogeton perfoliatus*, 6 — *Nuphar luteum*, 7 — *Nymphaea alba*, 8 — filamentous algae, 9 — *Chara* spp., 10 — other plant species

the higher was the number of species producing over 90% of total biomass and the greater was the value assumed by the index of species dominance structure. And thus: in the Tejsowo Lake 5 species produced biomass, 2 of them yielded over 90% of phytomass, and the index amounted to 0.25; in the Spychowskie Lake the values in question were 8, 4, 0.37 respectively and in the Kujno Lake — 10, 6, 0.46. The above dependence was not recorded in inflow littorals, which would point to the fact that they are less stable with regard to plant settlement on bottom slope and that they are more species-diversified.

4. DISCUSSION

The studies on macrophyte settlement structure in outflow and inflow littorals of the examined lakes showed that there occurred certain differences both in the number and frequency of occurrence of particular plant species as well as in their contribution to biomass.

Shallowing of mouth sections of streams due to drifts primarily to fine particle matter (M i c h a l s k i 1946—1947, T a y l o r and R o f f 1982) extends into the stream-lake transitory zone. Owing to the widening of the inflow and retardation of the velocity of the inflowing stream within the reservoir body, particles carried in by the stream are deposited and thus the littoral zone is shallowed. This, in turn, brings about a more gentle inclination of the bottom slope, greater littoral length and, consequently, a greater area for subsequent plant settlement. Hence in these places a larger number of plant species occurs and they yield a greater biomass as well. Forest (1977) evidenced that dry weight of submerged plants was greater in inflow sections of a reservoir than in its outflow sections and that depth range of those plants depended on bottom inclination. Furthermore, the quoted author noted, which was also recorded in the present studies, a greater species diversity in those parts of lakes where the stream mouth was located.

In mouth sections of littorals of flow-through lakes, there was observed a mosaic settlement of bottom due to constant drifts of matter by streams. The deposited drifts were of loose, weakened constitution, which impeded plant rootendness. An alike observation was made by Engel (1985) in his studies on aquatic communities in the Halverson Lake. In mouth littorals of streams inflowing to the examined lake the quoted author noted parts of bottom devoid of vegetation due to river drifts. On the other hand, pronounced shallowing in mouthadjoining sections of lakes creates favourable conditions for occurrence of emerged vegetation and withdrawing of submerged vegetation into deeper parts of the reservoir. Rejewski (1981) provided data from which it followed that due to the process of shallowing described above, the shores of a lake receded towards its center by about 40 – 50 m over the period of 100 years. Multi-species rushes recorded in littorals of the Kujno, Tejsowo and Spychowskie Lakes, seem to evidence advantageous conditions favouring their settlement in mouthadjoining sections of the reservoirs.

Retardation of the flow rate of streams caused by the mouth width of a stream had also an effect on the amount of plant biomass in inflow littoral of the lakes. In successive northto-southward lakes the ratio of the inflow to outflow stream width was: 1.25 in Kujno, 1.65 in Tejsowo and 2.7 in the Spychowskie Lake, while the ratio of biomass was: 0.67, 1.23 and 4.52 respectively.

The preliminary studies and observations made in the examined lakes indicated that differences in the structure of plant settlement in the river-lake and lake-river transitory zones resulted primarilly from conditions in mouth-adjoining parts of the lakes arising in effect of matter drifts by streams.

6. SUMMARY

In the vegetative season of 1986 studies were conducted on vegetation settling in inflow and outflow littorals of flowtrough lakes in the Krutynia River basin, examining the Kujno, Tejsowo and Spychowskie Lakes. It was found out that inflow phytolittoral was longer, much richer in plant species and of more mosaic settling pattern than the outflow littoral (Figs. 5, 6, 7). It was further confirmed by the calculated indices of dominance structure and species diversity of a community. In lake-stream transitory zones by about 30 – 60% less species of macrophytes occurred (helophytes having not been taken into account) (Figs. 8, 10). A greater biomass of plants was recorded in outflow littorals, where the three dominating species accounted for over 90% of total biomass, whereas in inflow littorals an alike percentage of total

biomass was turned over by 2–6 plant species (Fig. 11). The higher was the ratio of the stream's width in its inflow to the reservoir to the stream's width in its outflow, the greater was the ratio of amounts of produced plant biomass in these two sites.

7. POLISH SUMMARY

W sezonie wegetacyjnym 1986 r. przeprowadzono badania nad roślinnością zasiedlającą litoral ujściowy i odpływowy jezior przepływowych dorzecza Krutyni, biorąc pod uwagę jeziora Kujno, Tejsowo i Spychowskie. Stwierdzono, iż fitolitoral dopływowy jest dłuższy, znacznie bogatszy w gatunki roślinne i bardziej mozaikowato zasiedlony niż litoral odpływowy (rys. 5, 6, 7). Taką sytuację potwierdziły obliczone wskaźniki struktury dominacji i różnorodności gatunkowej zbiorowisk. W strefach przejściowych jezioro-ciek występowało o około 30–60% mniej gatunków makrofitów (nie brano pod uwagę helofitów) (rys. 8, 10). Stwierdzono większą biomasę roślin w litoralach dopływowych, gdzie przeszło 90% sumarycznej biomasy dawały trzy dominujące gatunki roślin, podczas gdy w odpływowych od 2 do 6 (rys. 11). Im większy był stosunek szerokości cieku w miejscu ujścia do zbiornika do szerokości w miejscu odpływu, tym większy był stosunek ilości produkowanej biomasy roślin w obu tych stanowiskach.

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