EKOLOGIA POLSKA (Ekol. pol.)	35	3–4	679–698	1987

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THE INFLUENCE OF THE MIRE PROPORTION IN A DRAINAGELESS CATCHMENT AREA ON THE TROPHIC STATUS OF MIRE WATERS *

ABSTRACT: Significant differences in the chemistry of their waters (pH value, total ion concentration, content of dissolved organic matter, Ca^{2+} and P-PO_4^{3-} ion levels) were found between minerotrophic and ombrotrophic mires differing in the mire to catchment area ratio. Conditions for catchment area water feeding to mires determine the trophic type of mires, and affect the chemical composition of marsh waters within particular types.

KEY WORDS: Catchment area, minerotrophic fens, ombrotrophic bogs, mineral phosphorus, calcium, dissolved organic matter.

1. INTRODUCTION

The chemistry of mire waters is of decisive importance to the development of a specific type of marsh vegetation, and thereby to the evolution of a whole peat-land (K u l c z y ń s k i 1949, S j ö r s 1950, M o o r e and B e l l a m y 1974), whereas the factors mainly responsible for its formation and nature are external hydrological conditions.

Topographically, mires are often found in runoffless hollows, that is, within closed catchment areas that have no surface drainage. Two main ways of nutrient input are recognized in these mire ecosystems. Namely, with precipitation and with the water fed from the catchment area. If the basic source of nutrients is rainfall, then favourable conditions arise for the development of an ombrotrophic bog. If, however, the amount of water fed from the catchment area is considerable, then we are usually dealing with a minerotrophic fen (I n g r a m 1983).

The main purpose of the present study is to analyse the effect of the proportions of nutrients supplied to mires along the above-mentioned routes on the chemical

* This study was financially supported under project MR II/15.

properties of mire waters, such as: pH, total ion concentration, content of dissolved organic matter, content of the Ca^{2+} and $P\text{-}PO_4^{3-}$ ions. The analysis will consist in the determination of the relationship between the indices considered and an abiotic factor, the catchment area ratio.

The regularity has been known that high values of pH and calcium concentration indicate minerotrophic conditions of mire waters, while their low values are indicate of ombrotrophic mires (Gorham 1956a, 1956b, Bellamy 1968, Heinselman 1970). The remaining indices should contribute to a better assessment of the trophic status of mire waters.

2. STUDY AREA

The study was carried out in an area west of Mikołajki in the Masurian Lakeland, north-eastern Poland (Fig. 1). The eastern part of the study area lies within the region of the Great Masurian Lakes, and its western part in the Mrągowo Lakeland.

The climatic conditions of the environs of Mikołajki are influenced by the continental and Sub-Boreal climates. The temperatures are below the all-country average temperatures, winters are long and with a snow cover, the growing season is shorter, and the mean annual precipitation ranges from 525 mm to 600 mm.

Geomorphologically, the landscape of the area considered is typically a landscape with lakes and hillocks, formed during the last, the Würm glaciation. There are many lakes there, the following being the largest of them: Jorzec, Głębokie (both of them in a

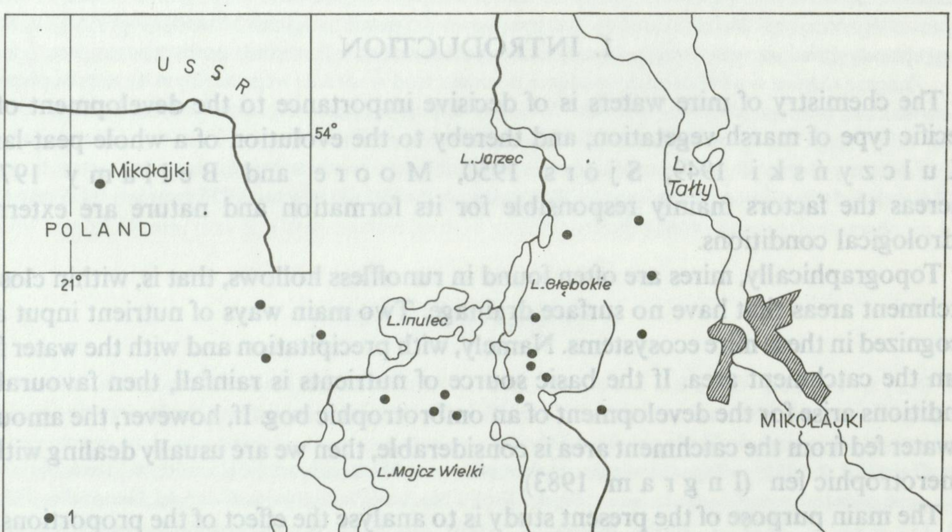

Fig. 1. Location of the study area and sampling stations (1)

glacial trough), Majcz Wielki and Inulec (Fig. 1). Distinct amidst the surface features are morainic hill ranges, ground moraine rolling surface, and a varied relief that has formed there as a result of glacifluvial processes, with kame hillocks and ice-block depressions. The latter (still partly occupied by lakes) have become marshy, and at present they are peat-lands. Since there is no river erosion, mires located in basins have no surface drainage (unless a drainage system has been made by man), and their hydrological regime to a large extent depends on the size of drainageless basin, that is to say, runoffless catchment area (K r u k 1987).

The present explorations covered 19 mires: 12 fens and 7 bogs. There was one study station in each mire, except a bog in an area south of Lake Głębokie (Fig. 1), where 2 stations were set up in clearly distinguishable mire parts. Studies were thus conducted at 20 stations.

The vegetation cover of the peat-lands under study is diversified and includes communities of annuals – reed and sedge fens, and woods and scrub – alder swamps, willow swamps and pine bogs (Table 1). In three bogs and one fen there co-occur plant associations characteristic of transition bogs. The substrate consists of low-moor peat (primarily alder swamp peat, magnocaricetum peat, and reed peat) and raised sphagnum peat (Table 1). The degree of their decomposition (assessed from the content of macrofragments) was much lower in bogs than in the minerotrophic fen group (Table 1). Bogs also differed from fens in the water table oscillation amplitude. In the former the oscillations never exceeded 0.5 m, in the latter they were often above 1 m (Table 1). Seasonal peat-land water table variation is correlated with the relative size of the runoffless basin of a mire (K r u k 1987).

The bogs that were studied represent the continental type, with a flat or slightly uplifted surface (J a s n o w s k i 1975).

The catchment areas of the mires under consideration are used mainly for agriculture (except catchment areas of 3 bogs situated in a wood dominated by coniferous trees). The soils of the catchment area are made up of loams and loamy sands, that is to say, deposits with rich sorption complexes of mineral origin.

Table 1. Natural characteristics of mires in the neighbourhood of Mikołajki in the Masurian Lakeland

Mire types	Vegetation cover	Main peat types according to origin *	Degree of peat decomposition (%)	Range of seasonal water-table variation ** (cm)
Bogs (ombrotrophic) $n = 7$	peat moss bogs, pine bogs	sphagnum peat	5 – 20	25 – 46
Fens (minerotrophic) $n = 12$	reed and sedge fens, willow swamps, alder swamps	reed peat, magnocaricetum peat, alder swamp peat	50 – 80	60 – 130

*K l o s s et al. (1987). **K r u k (1987).

3. METHODS

Measuring the quantity of catchment area groundwaters drained into a mire is methodically complicated. It may, however, be assumed that under the same climatic conditions the quantity of underground inflow from a catchment area depends on the surface area of the latter (from a larger catchment area a higher inflow can be expected). Thus, the ratio between the quantity of water fed into a mire from precipitation and that supplied by subsurface flow depends (approximately) on the area ratio between the mire surface receiving precipitation and the catchment area from which water is drained into the mire.

This ratio can be expressed as the proportion of a mire in a runoffless catchment area, i.e., the percentage of mire area in the total area including the mire and its surface catchment area, that is to say, a whole runoffless basin (K r u k 1987). The higher the value of the ratio, the greater the contribution of precipitation in comparison with underground feeding.

For the chemical indices to provide a picture, as exact as possible, of the nutrient conditions for the growth of helophytes, samples were collected in April (1983), that is, before the beginning of the growing season and immediately after the inflow of thaw waters to mires from their catchment areas. Sampling was done once, during 2 days at all the 20 stations. Surface water samples (18 stations) were collected at random in the central part of each mire from different depths over an area of several m^2, and shallow groundwaters (2 stations) were sampled from plastic groundwater gauges. At each station 1 sample was collected – about 5 l water from 10–15 scoops.

Immediately after being collected the samples were filtered through GF/F Whatman mineral filter paper, and, within 1–2 days, were transported to the laboratory, where part of the water was evaporated in evaporating dishes at 60°C and the residue was weighed. It was then incinerated at 480°C and the ash was weighed, too. A calculation per 1 l gave the total (approximate) ion concentration in the waters analysed. The content of dissolved organic matter was calculated by subtracting the ash content in 1 l from the sediment left after the evaporation of 1 l water. The ph was determined with an electrode pH-meter. Mineral phosphorus content was estimated with the aid of a "Specol" spectrophotometer, whereas calcium was determined in toluene-preserved samples by the atomic adsorption method.

For the determination of the chemical composition of the groundwaters reaching a mire, these waters were sampled in the lower parts of the catchment areas of 3 mires. A water sample was taken as soon as the water had reached a groundwater gauge. In its analysis the above procedure was used.

To determine the relationship between the indices under consideration, statistical inference, based on the correlation and linear regression calculus, was used. To select a regression curve equation that would give the highest correlation coefficient, the distribution of variables was tested by the course of linear, logarithmic, exponential and power functions.

4. RESULTS

4.1. THE TROPHIC STATUS OF MIRE WATERS

The highest hydrogen ion concentrations were found in the waters of bogs bearing peat mosses and pine woods — pH up to 3.8, the lowest in waters of reed and sedge fens — pH up to 8.2. Waters of minerotrophic mires and waters of ombrotrophic mires clearly differed in acidity (Table 2).

Table 2. Comparison of the chemical composition of water in 2 mire types (mean values and variation range)

Chemical index	Bog (ombrotrophic) waters $n = 8$	Fen (minerotrophic) waters $n = 12$	Significance level of difference in mean values
pH	4.4 * 3.8 – 6.0	7.1 * 6.4 – 8.2	< 0.001
Total concentration of ions ($mg \cdot l^{-1}$)	43.3 29.5 – 72.1	192.8 55.7 – 416.6	< 0.001
Content of dissolved organic matter ($mg \cdot l^{-1}$)	117.2 35.3 – 311.2	66.1 22.7 – 166.4	> 0.05
Ca^{2+} content ($mg \cdot l^{-1}$)	1 1 – 3	61 13 – 96	< 0.001
Content of $P-PO_4^{3-}$ ($\mu g \cdot l^{-1}$)	73 3 – 344	9 0.5 – 27	> 0.05

* Negative logarithm of mean hydrogen ion concentration.

The content of mineral compounds in bog water on an average comes up to 43.3 $mg \cdot l^{-1}$, and in fen water — 192.8 $mg \cdot l^{-1}$ (Table 2). In this case, too, the peat mire types differ clearly.

A different situation is seen as regards the distribution of dissolved organic matter. Ombrotrophic peat-bog waters contain on an average twice as much of it — 117.2 $mg \cdot l^{-1}$ as minerotrophic mires — 66.1 $mg \cdot l^{-1}$ (Table 2) but the difference is not statistically significant.

Most conspicuous are differences in the distribution of Ca^{2+} concentrations. Bog waters contain minimum amounts of this element (1 – 3 $mg \cdot l^{-1}$). By contrast, fen waters contain an average of several dozen (up to 96) mg Ca^{2+} per litre (Table 2).

Likewise, the content of the mineral phosphorus fraction appears to be unevenly distributed in the peat-mire types under study. A higher content of phosphate ions is found in the waters of peat-moss bogs (the average for ombrotrophic bogs is 73 $\mu g \cdot l^{-1}$), and a lower in the waters of minerotrophic mires — 0.5 to 27 $\mu g \cdot l^{-1}$ (Table 2). The difference between the mean values is in this case statistically insignificant (Table 2).

Table 3. Areas of mires and of drainageless catchment areas with mires, and the mire area to drainageless catchment area ratios (mean values and range of variation)

Mire types	Mire area in ha (A)	Area of drainageless catchment area with mire in ha (B)	Mire area to drainageless catchment area ratio ($\frac{A}{B} \cdot 100\%$)
Bogs (ombrotrophic) $n = 7$	4.77 0.32 – 19.50	14.95 1.34 – 34.03	31.9 * 19.8 – 57.3
Fens (minerotrophic) $n = 12$	0.46 0.04 – 1.55	3.92 0.61 – 11.05	11.7 * 6.4 – 20.2

* Difference of mean values, significant at the < 0.001 level.

Thus, for all the indices taken into account clear differences were found (although sometimes statistically insignificant) between the two peat-mire types distinguished. Moreover, a comparison of the minimum and maximum levels of the indices in Table 2 shows a variation gradient from extreme ombrotrophic to extreme minerotrophic conditions.

This tendency seems to correspond with the fact that the catchment area ratio used (percentage of peat-mire in its drainageless catchment area) clearly separates minerotrophic peat-mires from ombrotrophic peat-mires. Fens have definitely larger (relatively) surface catchment areas, that is their proportion in their drainageless catchment areas is smaller – 6.4 to 20.2%, compared with bogs, where a bog represents 19.8 to 57.3% of its drainageless catchment area (Table 3).

On the basis of Table 2 it is possible to roughly establish the limit between the above-enumerated mire trophic types in the study area. It is roughly equal to a 20% mire proportion in a runoffless catchment area. This means that if there is no surface drainage and the area of a peat-land catchment area is over four times as large as the area of the peat-land, then it may be expected that the factor determining the trophic status of its waters will be groundwater inflow from the catchment area.

In connection with the above, the thesis can be put forward that one of the important causes of differences in the chemistry of waters derived from different mires (Table 2) is differences in the mire-catchment area ratio, presented in Table 3. It is, however, necessary to carry out a more accurate analysis of the distribution of the variables to see if it does not alter this general thesis.

4.2. EFFECT OF THE MIRE PROPORTION IN A DRAINAGELESS CATCHMENT AREA ON THE TOTAL CONTENT OF IONS AND OF THE CA^{2+} IONS

Groundwaters from peat-land catchment areas contain over a dozen times more ions (therein several dozen more calcium) than does precipitation water (Table 4). It is, therefore, right to state that ion (mainly calcium) concentration in mire waters should

Table 4. Comparison of the contents of: total of ions, Ca^{2+} and $P-PO_4^{3-}$ in rainfall and groundwaters fed into mires in the environs of Mikołajki

Kinds of water	Total concentration of ions ($mg \cdot l^{-1}$)	Ca^{2+} content ($mg \cdot l^{-1}$)	$P-PO_4^{3-}$ content ($\mu g \cdot l^{-1}$)
Precipitation waters *	33.1	1.3	30
Groundwaters from mire catchment areas **	360.4	86.0	13

* Mean values of 1982, A. Stachurski and J. R. Zimka (unpublished data). ** Mean values of 1982 and first 3 months of 1983 for $n = 36$.

depend on the area ratio between the mire and its catchment area. By accepting this concept one would expect that with a decrease in the relative size of the catchment area of a mire, that is, as the proportion of a mire in its drainageless catchment area increases, the content of ions falls.

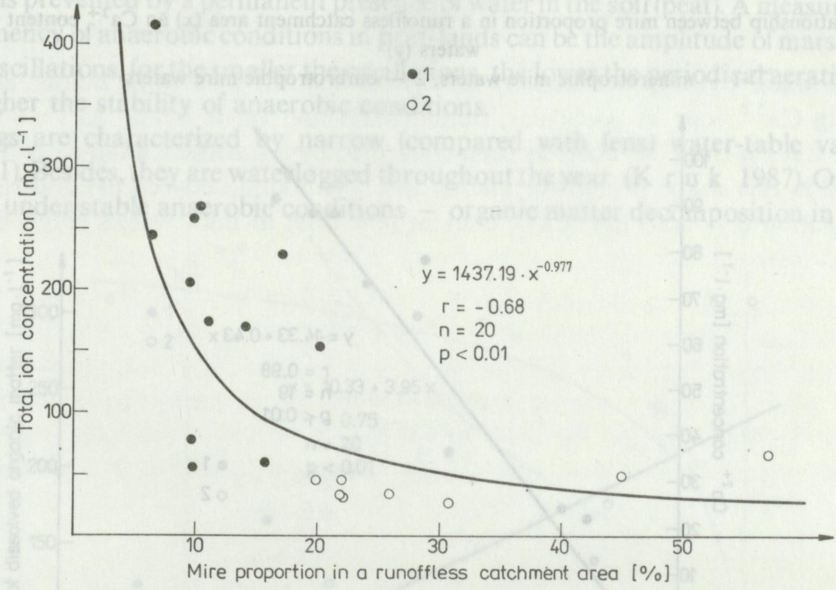

Fig. 2. Relationship between mire proportion in a runoffless catchment area (x) and total concentration of ions in mire waters (y)

1 — minerotrophic mire waters, 2 — ombrotrophic mire waters

It can be seen, however, that the total ion concentration and Ca^{2+} content in bog waters do not vary in relationship to the area ratio between a bog and its runoffless catchment area (Figs. 2, 3). The hypothetically assumed even distribution of these variables in bog waters does not, therefore, exist (Figs. 2, 3). At the same time the values of the indices under consideration in rainfall and in bog waters are similar (Tables 2, 4).

These findings clearly indicate that ions from catchment areas do not reach central

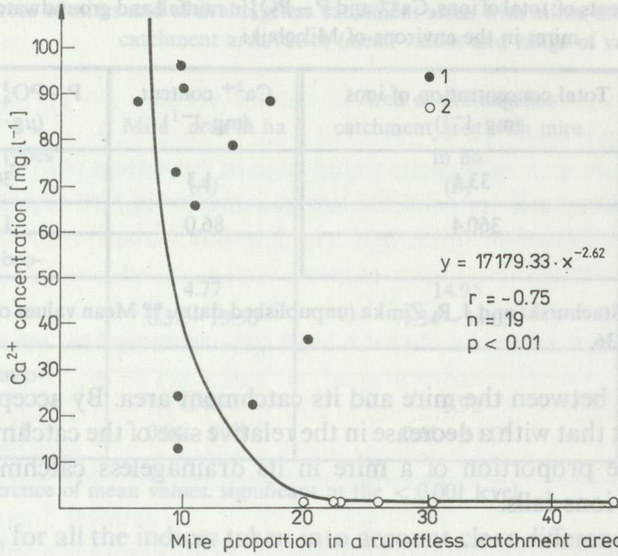

Fig. 3. Relationship between mire proportion in a runoffless catchment area (x) an Ca^{2+} content in mire waters (y)

1 — minerotrophic mire waters, 2 — ombrotrophic mire waters

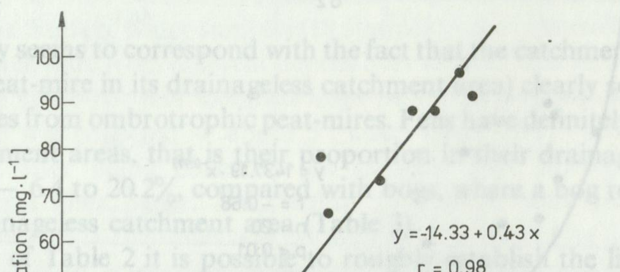

Fig. 4. Relationship between total concentration of ions (x) and Ca^{2+} content in mire waters (y)

1 — minerotrophic mire waters, 2 — ombrotrophic mire waters

part of bogs which are made up of peat mosses. In this case the main source of nutrients, and an external agent affecting the chemistry of bog waters is precipitation.

The different origin of bog water calcium, compared with that of fen water, is further confirmed by the analysis of Ca^{2+} content distribution in relationship to the total ion concentration in the waters of the mires under study. As can be seen from Figure 4, the very high correlation ($r = 0.98$) is the result of variation of both of the indices only in the waters of minerotrophic fens flooded by groundwaters from their catchment areas. No variation can be seen in the distribution of the two indices in bog waters (Fig. 4).

In view of the above, it is possible to modify the thesis which assumes that the content of nutrients in mire waters depends on the relative size of a mire in its runoffless catchment area, by adding that this relationship has its limits beyond which there develop ombrotrophic bogs with waters which contain ions (especially Ca^{2+}) in quantities independent of the inflow of groundwaters from the catchment area, and thereby independent of the size of the latter.

4.3. EFFECT OF THE MIRE PROPORTION IN A DRAINAGELESS CATCHMENT AREA ON THE CONTENT OF DISSOLVED ORGANIC MATTER

Colloid particles of complex organic acids are the products of decomposition under anaerobic conditions (P o n n a m p e r u m a 1972), where their complete mineralization is prevented by a permanent presence of water in the soil (peat). A measure of the permanency of anaerobic conditions in peat-lands can be the amplitude of marsh water table oscillations, for the smaller the oscillations, the lower the periodical aeration, and the higher the stability of anaerobic conditions.

Bogs are characterized by narrow (compared with fens) water-table variation (Table 1). Besides, they are waterlogged throughout the year (K r u k 1987). Owing to this – under stable anaerobic conditions – organic matter decomposition in bogs is

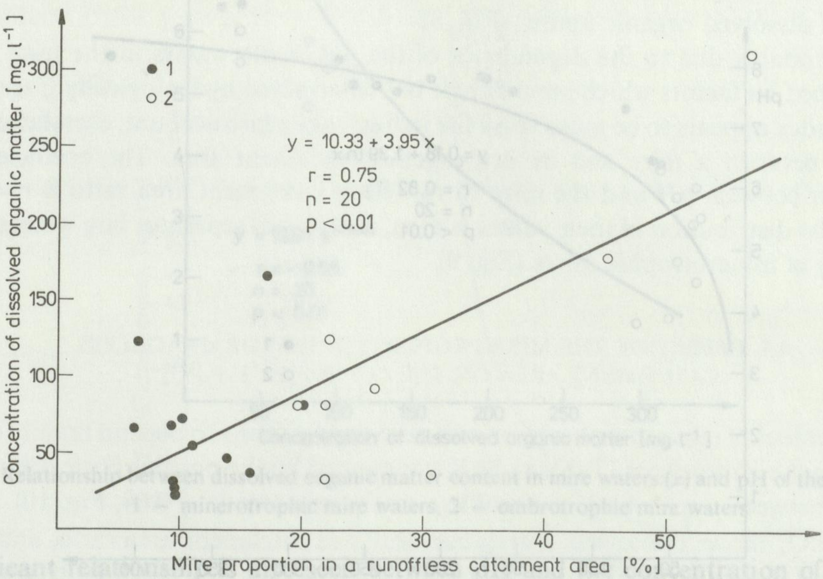

Fig. 5. Relationship between mire proportion in a runoffless catchment area (x) and dissolved organic matter content in mire waters (y)
1 – minerotrophic mire waters, 2 – ombrotrophic mire waters

slow. This is indicated by a lower degree of decomposition of the moss (bog) peat – 5–20%, compared with that of the fen peat – 50–80% (Table 1). On the other hand, water table oscillations in mires depend, to a large extent, on the percentage of mire area in its drainageless basin or catchment area, as has been documented for the area under consideration (K r u k 1987).

The above regularities permit the conclusion that the quantity of dissolved organic matter in mire waters (as the results of the decomposition rate related to the stability of anaerobic conditions which is dependent on mire water level oscillations) will also appear to depend on the mire area to whole drainageless catchment area ratio. This conclusion is empirically confirmed by a high coefficient (0.75) of correlation between the content of dissolved organic matter and the proportion of mire in its drainageless catchment area (Fig. 5). The limit between minerotrophic mires and ombrotrophic mires is clear, and the linear form of the regression equation indicates a uniform distribution of the indices analysed (Fig. 5).

4.4. EFFECT OF THE MIRE PROPORTION IN A DRAINAGELESS CATCHMENT AREA ON THE pH VALUE

Mire water pH depends directly on factors such as in organic matter content, including Ca^{2+} ions in particular, humic acids and fulvic acids (G i v e n and D i c k e n s o n 1975). This has been confirmed by a statistical analysis of the data obtained in this study. A high correlation has been found between pH and total ion concentration ($r = 0.82$) and Ca^{2+} content ($r = 0.89$) in mire waters (Figs. 6, 7). A

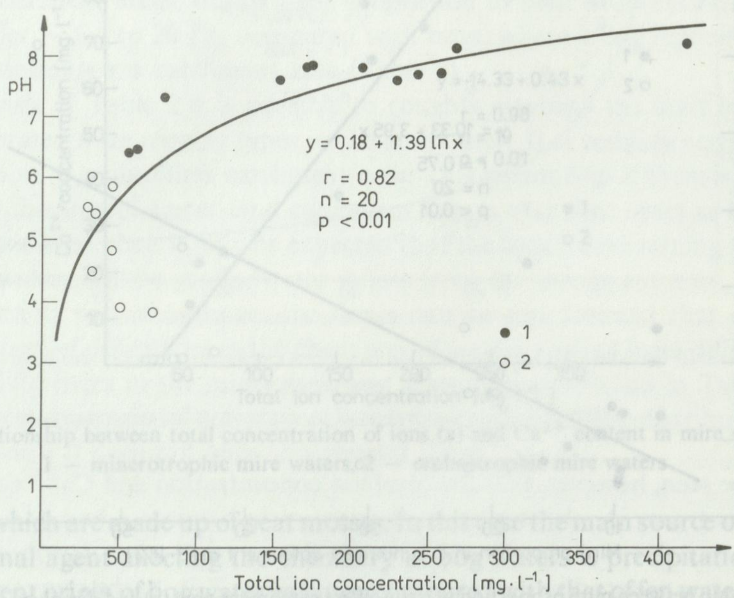

Fig. 6. Relationship between total concentration of ions in mire waters (x) and pH of these waters (y)
1 – minerotrophic mire waters, 2 – ombrotrophic mire waters

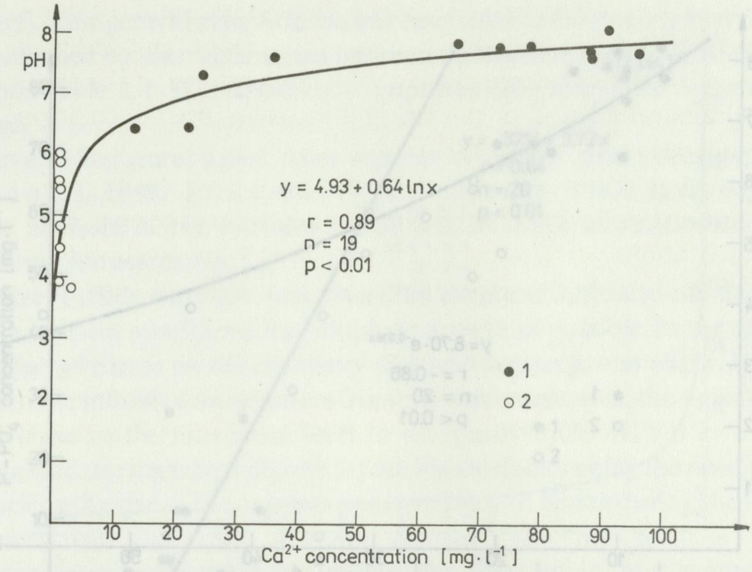

Fig. 7. Relationship between Ca^{2+} content in mire waters (x) and pH of these waters (y)
1 — minerotrophic mire waters, 2 — ombrotrophic mire waters

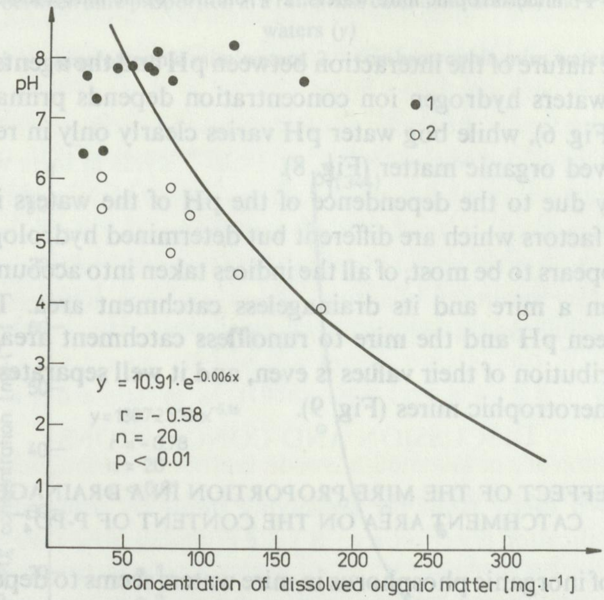

Fig. 8. Relationship between dissolved organic matter content in mire waters (x) and pH of these waters (y)
1 — minerotrophic mire waters, 2 — ombrotrophic mire waters

significant relationship is also seen between pH and the concentration of dissolved organic matter ($r = -0.58$) in the waters that were analysed (Fig. 8).

An analysis of the distribution of the above variables, with distinction made between minerotrophic and ombrotrophic mires (Figs. 6–8), indicates that in each of

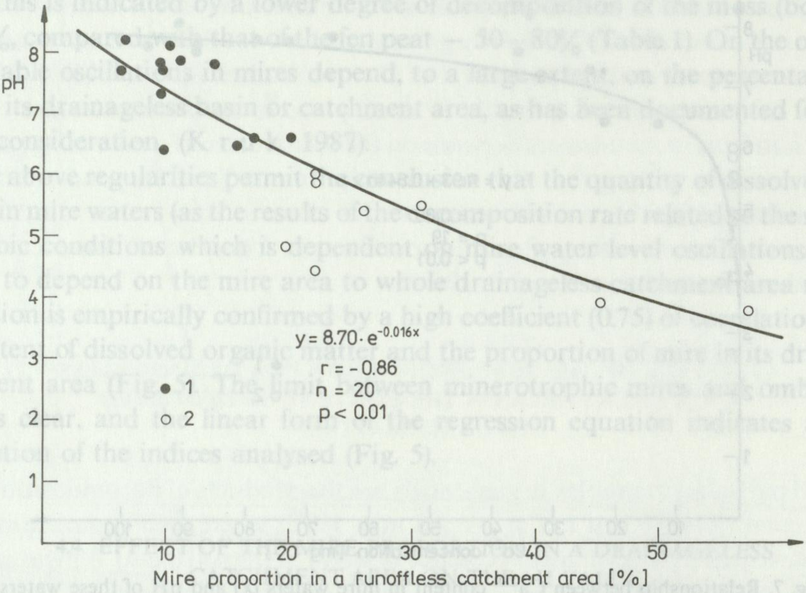

Fig. 9. Relationship between mire proportion in a drainageless catchment area (x) and pH of mire waters (y)
1 – minerotrophic mire waters, 2 – ombrotrophic mire waters

the mire types the nature of the interaction between pH and the agents determining it is different. In fen waters hydrogen ion concentration depends primarily on the total content of ions (Fig. 6), while bog water pH varies clearly only in relationship to the content of dissolved organic matter (Fig. 8).

It is probably due to the dependence of the pH of the waters in the mire types distinguished on factors which are different but determined hydrologically (Figs. 2, 5) that this index appears to be most, of all the indices taken into account, correlated with the ratio between a mire and its drainageless catchment area. The coefficient of correlation between pH and the mire to runoffless catchment area ratio is $r = 0.86$ (Fig. 9). The distribution of their values is even, and it well separates bog waters from the waters of minerotrophic mires (Fig. 9).

4.5. EFFECT OF THE MIRE PROPORTION IN A DRAINAGELESS CATCHMENT AREA ON THE CONTENT OF P-PO_4^{3-}

The content of inorganic phosphorus in mire waters seems to depend mainly on the input from the atmosphere (Table 4). This is indicated by the positive correlation with the ratio between a mire and its runoffless catchment area ($r = 0.64$, Fig. 10). As an index, P-PO_4^{3-} shows the lowest correlation with the catchment area ratio, and their distribution is of an ordered (to a small extent) nature in the case of minerotrophic and ombrotrophic mires (Fig. 10).

The content of the PO_4^{3-} ions in mire waters appears to depend mainly on their pH – the correlation coefficient being $r = -0.78$ (Fig. 11). The distribution of these

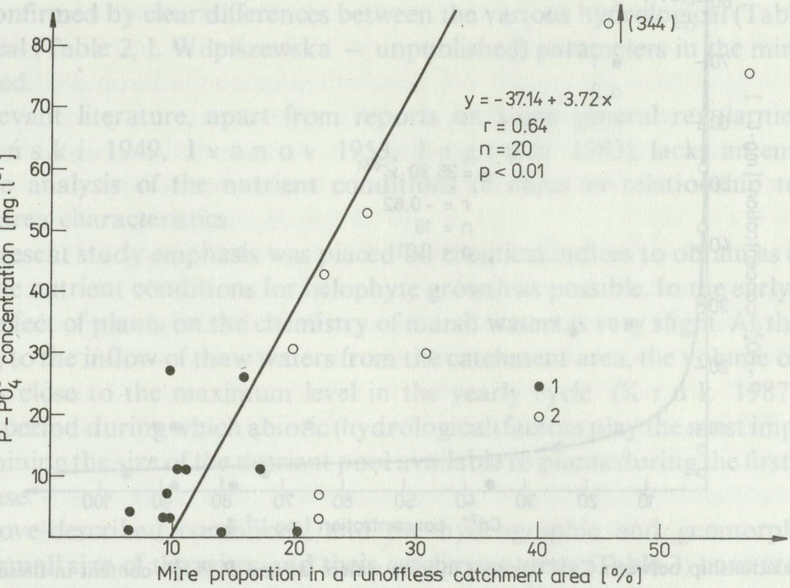

Fig. 10. Relationship between mire proportion in a runoffless catchment area (x) and P-PO_4^{3-} content in mire waters (y)

1 — minerotrophic mire waters, 2 — ombrotrophic mire waters

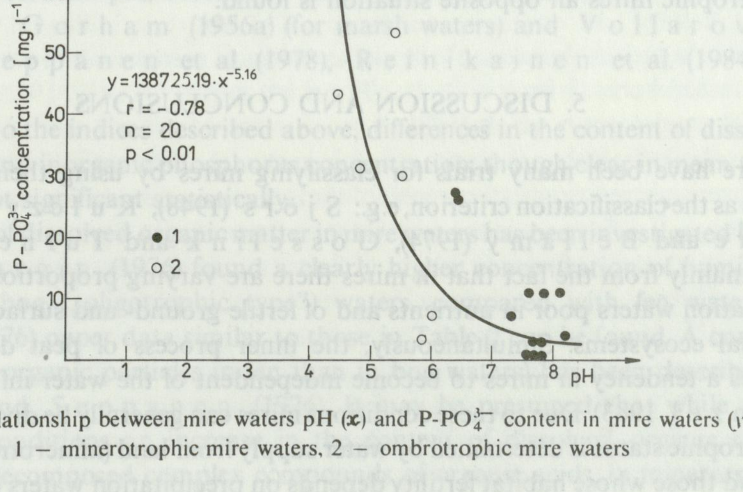

Fig. 11. Relationship between mire waters pH (x) and P-PO_4^{3-} content in mire waters (y)

1 — minerotrophic mire waters, 2 — ombrotrophic mire waters

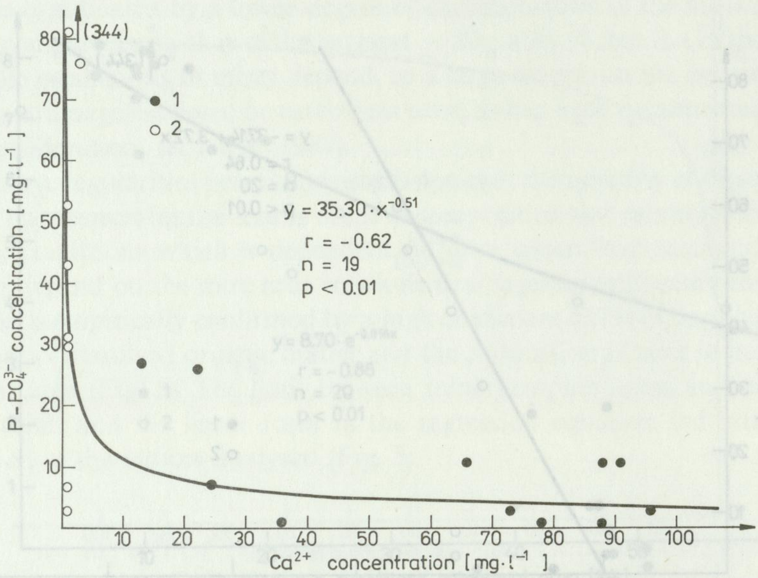

Fig. 12. Relationship between Ca^{2+} content in mire waters (x) and $P\text{-}PO_4^{3-}$ content in these waters (y) 1 – minerotrophic mire waters, 2 – ombrotrophic mire waters

variables indicates that if pH drops below about 5.5, $P\text{-}PO_4^{3-}$ concentration begins to rise (Fig. 11), so this only applies to bogs.

An inverse correlation of inorganic phosphorus concentration with pH suggests an antagonistic relationship between $P\text{-}PO_4^{3-}$ and Ca^{2+} levels in mire water. Indeed, as indicated by the negative correlation coefficient $r = -0.62$ and the graphic distribution (Fig. 12), these ions show a tendency to exclude each others. In the waters of ombrotrophic mires (in most cases) higher $P\text{-}PO_4^{3-}$ concentrations are characteristically accompanied by minimum quantities of calcium ions, whereas in the waters of minerotrophic mires an opposite situation is found.

5. DISCUSSION AND CONCLUSIONS

There have been many trials for classifying mires by using their alimentation systems as the classification criterion, e.g.: Sjörs (1948), Kulczyński (1949), Moore and Bellamy (1974), Gosselink and Turner (1978). This results mainly from the fact that in mires there are varying proportions of inflow of precipitation waters poor in nutrients and of fertile ground- and surface-waters from terrestrial ecosystems. Simultaneously, the inner process of peat deposit growth indicates a tendency in mires to become independent of the water inflow from land (Frenzel 1983). Due to these conditions mires can generally be divided into those whose trophic status is determined by water supply from land (minerotrophic mires – fens), and those whose habitat fertility depends on precipitation waters (ombrotrophic mires – bogs). This general classification has been used in the present study. Its clarity has been confirmed by clear differences between the various hydrological (Tables 1, 2) and chemical (Table 2, I. Wilpiszewska – unpublished) parameters in the mire types distinguished.

The relevant literature, apart from reports on some general regularities (e.g., Kulczyński 1949, Ivanov 1953, Ingram 1983), lacks an empirical comparative analysis of the nutrient conditions of mires in relationship to their catchment area characteristics.

In the present study emphasis was placed on chemical indices to obtain as exact a picture of the nutrient conditions for helophyte growth as possible. In the early spring period the effect of plants on the chemistry of marsh waters is very slight. At the same time, owing to the inflow of thaw waters from the catchment area, the volume of water in a mire is close to the maximum level in the yearly cycle (Kruk 1987). It is, therefore, a period during which abiotic (hydrological) factors play the most important role, determining the size of the nutrient pool available to plants during the first spring growth phase.

The above-described conditions, and the hydrographic and geomorphologic position, a small size of the mires and their catchment areas (Table 3) have created a convenient situation for the carrying out of comparative catchment area studies.

In the Masurian Lakeland, the chemical composition of the water of minerotrophic mires and that of ombrotrophic mires differ primarily in pH, Ca^{2+} content and the total level of ions (Table 2). This has been confirmed by the results from studies carried out in different geographic regions: in the USA by Bellamy (1968), Heinselman (1970), Boetler and Verry (Ingram 1983), in British Isles by Gorham (1956a), Gorham and Pearsal (1956), in Scandinavia by Sjörs (1950), Tolonen and Seppänen (1976), in central Europe by Pietsch (1976), and in the European part of the USSR by Jefimov and Jefimova (1973), and Largin (1976). There have also been earlier reports on the relationship between pH, overall ion concentration and content of calcium ions (Figs. 4, 6, 7) by Gorham (1956a) (for marsh waters) and Vollarovich et al. (1967), Seppänen et al. (1978), Reinikainen et al. (1984) (for surface peat).

By contrast to the indices described above, differences in the content of dissolved organic matter and inorganic phosphorus concentration, though clear in mean values (Table 2), are not significant statistically.

The content of dissolved organic matter in mire waters has been investigated by few researchers. Largin (1976) found a clearly higher concentration of humic and fulvic acids in bog („oligotrophic type") waters, compared with fen waters. In Pietsch (1976) paper data similar to those in Table 2 can be found. A converse tendency (more organic particles in fen than in bog waters) has been described by Tolonen and Seppanen (1976). It may be presumed that while under ombrotrophic conditions an increase in the content of dissolved organic matter depends on undecomposed complex compounds of organic acids, in minerotrophic mire waters such an increase may most likely be caused by the growth of algae. For in fertile marsh waters algal production can be several times as high as in ombrotrophic waters (Tolonen and Seppänen 1976). In the graphical picture of the relationship between the amount of dissolved organic matter and pH (Fig. 8) this non-homogeneous origin of organic matter in mire waters can probably be seen.

The distribution of P-PO_4^{3-} concentration between minerotrophic and ombrotrophic mire waters (Table 2) differs from the result obtained by Jefimov and Jefimova (1973), Pietsch (1976) (for H_2PO_4), or by Tolonen and Seppänen (1976) (for total phosphorus). Gorham (1956b) also found slight PO_4^{3-} concentrations in bog waters.

To explain the possibility of finding high P-PO_4^{3-} levels in bog waters (Table 2), it is necessary to use experimental studies. It was due to such studies that Waughman (1980) found significant differences between the amount of readily soluble P-PO_4 in fen peat (0.01% of total content of phosphorus) and that found in bog peat (up to 5%). Besides, on the basis of his own results and those of 7 other authors the above investigator has presented a clear relationship between the quantity of P leached from peat and the pH of the latter. It appears that peat with a low pH, derived from bogs, generally contains several times as much dissolved P-PO_4 as fen peat (Waughman 1980). *Sphagnum* peat with a low pH has also been known to be less capable of phosphorus sorption from solutions than is fen peat with a high calcium content and pH (Isirimach et al. 1970).

The results of the above experiments are supported by the field observations presented in this paper. This is indicated by the high coefficient (−0.78) of correlation between the pH of mire waters and the amount of P-PO_4^{3-} contained in them (Fig. 11). The pH values of waters and peat from the same localities are similar (Sonesson 1970). Differences in sorption between bog and fen peat are indirectly confirmed by the inverse correlation of inorganic phosphorus concentration with the content of Ca^{2+} − $r = -0.62$ (Fig. 12). The geochemical substrate for these phenomena is probably provided by phosphorus interactions with Fe and Al under varying acidity and anaerobic conditions. The above is indicated by compounds formed in reactions between these elements. Such compounds have been found by many researchers (Sinha 1971, Ponnamperuma 1972, Damman 1978, Seppänen et al. 1978).

The above findings permit the conclusion that the differences in the concentration of inorganic phosphorus in the waters of the mires considered in the present study may be the result of differences in the sorptive properties of peat. Higher P-PO_4^{3-} levels in bog waters seem to result from the release of these ions due to increased quantities of water in low pH mires during the thaw. Maybe, this feature is peculiar to flat bogs of the continental type, which are then highly waterlogged. It should also be noted that important amounts of P-PO_4^{3-} in the mires considered are input with precipitation (Table 4). This means that ombrotrophic bogs with a very limited groundwater runoff (Kruk 1987), located in basins without surface drainage, can represent a trap for phosphorus.

The 20% mire proportion in a drainageless catchment area, established on the basis of the data in Table 3 as sufficient for the persistence and development of a bog, may be treated only as a rough estimate. For it is known that in young-glacial areas groundwater flow conditions are highly varied, and the natural hydrological system is disturbed by the activity of man (especially reclamation and peat deposit exploitation). In spite of this, the catchment area ratio, used in the present study, can be used as a simple indicator of the threat to the nutrient conditions of a mire from the catchment area part used for agricultural purposes.

The clear differences in the chemical indices analysed between minerotrophic and ombrotrophic mire waters indicate that in an agricultural landscape the nutrient--content contrast between fens and bogs continues to increase (Table 2). The pressure of a cultivated and fertilized catchment area leads to a further fertilization of fens and restriction of bogs to areas whose drainage basins are small, relatively. This nutrient--content diversification dependent on the catchment area, of mires in runoffless basins is also confirmed by the analysis of the occurrence of plant community types in relationship to the area percentage of mires in those basins. Mires which represent the smallest area proportion in their basins in general bear "eutrophic" plant communities dominated by reeds, sedges and willow scrubs (K l o s s et al. – in 1987).

The results from the analyses of regression and correlation between the chemical indices and the hydrological factor (Figs. 2, 3, 5, 9, 10) make it possible to state that the relationship varies. For on the one hand the effect of the catchment area factor on the total concentration of ions (Fig. 2) and Ca^{2+} content (Fig. 3), i.e., components primarily of catchment area origin (Table 4), does not involve the isolated waters of ombrotrophic mires, and on the other, a linear distribution of the content of dissolved organic matter and P-PO_4^3 in relation to the catchment area factor (Figs. 9, 10) indicates that there is another (in addition to water inflow from the catchment area) hydrological factor, also dependent on the catchment area. This factor probably is the extent of water table variation in mires (Table 1, K r u k 1987). It is responsible for the stability of anaerobic conditions and the associated decomposition and sorption processes in peat.

The catchment area factor, in this paper expressed as the proportion of a mire in a runoffless drainage basin, determines the trophic status of mire waters, whether via the input of elements from the catchment area, or its effect on the extent of seasonal peat aeration. Its clearest illustration is provided by its strong ($r = 0.86$) and even (Fig. 9) action on the mire water pH – an index simultaneously dependent on: content of inorganic matter (mainly calcium) and organic acids.

The results presented in this paper permit the conclusion to be drawn that the mire area to drainageless catchment area ratio affects the trophic status of the mire waters. Firstly, it diversifies mires into two types: minerotrophic and ombrotrophic. In this case the mire proportion in a runoffless catchment area expresses the proportion of precipitation water and that from land. Secondly, this proportion has an effect on the nutrient content in the two mire types. In minerotrophic mires it affects the volume of the fertile groundwater inflow, and in ombrotrophic mires it is responsible for the stability of the mire water level.

6. SUMMARY

Mires located in areas without surface drainage are suplied with nutrients from two main sources: groundwater inflow from the catchment area and precipitation. The volume ratio between these two inputs determines the nutrient content in mire waters. This ratio has been expressed as the percentage of mire area in the area of runoffless catchment area.

In spring, the chemistry of surface waters or shallow groundwaters was studied at 20 sampling stations located in 19 small mires in the neighbourhood of Mikołajki in the Masurian Lakeland (Fig. 1). The following were determined: pH, total concentration of ions, content of Ca^{2+}, dissolved organic matter and of P-PO_4^{3-}. Considerable differences were found between minerotrophic and ombrotrophic mire waters. For example, the mean pH value of fen waters was 7.1 while that of bogs was 4.4 (Table 2). Mean ion content in the former water type was 192.8 mg·l^{-1}, and in the latter only 43.3 mg·l^{-1} (Table 2). Definitely diverse, too, was the mean calcium level – 61 and 1 mg·l^{-1}, respectively (Table 2). In bog waters larger quantities (compared with minerotrophic fens) of dissolved organic matter were found – on an average 117.2 mg·l^{-1}, compared with 66.1 mg·l^{-1}, and P-PO_4^{3-} – on an average 73 μg·l^{-1}, compared with 9 μg·l^{-1} in fen waters (Table 2).

In ombrotrophic bogs the bog proportion in drainageless catchment area was clearly higher – 19.8 – 57.3% then in minerotrophic fens – from 6.4 to 20.2% (Table 3). Thus, if a mire represents less than about 20% of runoffless catchment area, then, due to the presence of agriculture, there are favourable conditions for the development of fens.

The analysis of regression and correlation was then used to study the relationship between the above-enumerated chemical indices in mire waters and the mire-catchment area ratio. It has been found that all the chemical indices analysed show a statistically significant dependence on the percentage of a mire in runoffless catchment area (Figs. 2, 3, 5, 9, 10). This phenomenon can generally be attributed to differences in the chemistry of precipitation waters and groundwaters from the catchment area, the two main sources of nutrient input in mires (Table 4). The most dependent on the catchment area ratio is the pH of mire waters (Fig. 9), and the least dependent – P-PO_4^{3-} content (Fig. 10).

The interaction between chemical indices in mire waters was also analysed. A correlation was found between the total concentration of ions, Ca^{2+} content and pH in mire waters (Figs. 4, 6, 7). It has been found that the pH of bog waters and that of fen waters are determined by different agents: in fen waters by inorganic components (Fig. 4), including calcium ions (Fig. 6) from the catchment area and in bog waters – dissolved autogenous organic matter (Fig. 8). The level of pH affects the concentration of P-PO_4^{3-} in mire waters (Fig. 11). In mire waters Ca^{2+} and PO_4^{3-} appear to be inversely correlated (Fig. 12).

The percentage of a mire in drainageless catchment area exerts an influence on the former not only by determining one of two opposite trophic types (minerotrophic or ombrotrophic), but also by affecting the fertility within both of them: in fens through the volume of inflow of nutrient-rich waters from the catchment area, and in bogs via the stability of water relations which determines a low organic matter decomposition rate.

7. POLISH SUMMARY

Torfowiska położone na obszarach powierzchniowo bezodpływowych mają dwa główne źródła związków biogennych: dopływ wód gruntowych ze zlewni i opad atmosferyczny. Wzajemna proporcja między tymi dwoma dojściami decyduje o trofii wód torfowiskowych. Do wyrażenia tej proporcji posłużono się wskaźnikiem zlewniowym udziału torfowiska w swojej zlewni bezodpływowej.

Na 20 stanowiskach położonych w 19 niewielkich torfowiskach w okolicach Mikołajek na Pojezierzu Mazurskim (rys. 1) zbadano w okresie wiosennym skład chemiczny wód powierzchniowych lub płytkich gruntowych. Oznaczono: pH, ogólne stężenie jonów oraz zawartości Ca^{2+}, rozpuszczonej materii organicznej i P-PO_4^{3-} Znaleziono znaczne różnice pomiędzy wodami torfowisk minerotroficznych i ombrotroficznych. I tak, średnia wartość pH wód torfowisk niskich wynosi 7,1, podczas gdy wód torfowisk

wysokich 4,4 (tab. 2). Średnia zawartość jonów w wodach pierwszego typu osiąga wielkość 192,8 $mg \cdot l^{-1}$, a w wodach drugiego typu tylko 43,3 $mg \cdot l^{-1}$ (tab. 2). Również zdecydowanie zróżnicowane jest średnie stężenie wapnia, odpowiednio 61 i 1 $mg \cdot l^{-1}$ (tab. 2). Wody torfowisk wysokich mają natomiast większe ilości (w porównaniu z wodami torfowisk minerotroficznych) rozpuszczonej materii organicznej – średnio 117,2 $mg \cdot l^{-1}$ w porównaniu z 66,1 $mg \cdot l^{-1}$ oraz $P\text{-}PO_4^{3-}$ – średnio 73 $\mu g \cdot l^{-1}$ w porównaniu z 9 $\mu g \cdot l^{-1}$ w wodach torfowisk niskich (tab. 2).

Z kolei torfowiska ombrotroficzne mają wyraźnie wyższe wartości wskaźnika udziału torfowiska w swojej zlewni bezodpływowej 19,8 – 57,3% w porównaniu z torfowiskami minerotroficznymi – od 6,4 do 20,2% (tab. 3). Tak więc, jeżeli udział torfowiska w swojej zlewni bezodpływowej jest mniejszy niż ok. 20%, to w związku z presją rolniczej zlewni dogodne warunki do rozwoju mają torfowiska niskie.

Zbadano następnie, wykorzystując analizę regresji i korelacji, zależność wyżej wymienionych wskaźników chemicznych w wodach bagiennych od czynnika zlewniowego. Okazało się, że wszystkie badane wskaźniki chemiczne wykazują istotne statystycznie uzależnienie od udziału torfowiska w swojej zlewni bezodpływowej (rys. 2, 3, 5, 9, 10). Ogólnych przyczyn tego zjawiska można się doszukiwać w różnicach pomiędzy składem chemicznym wód opadowych i gruntowych ze zlewni, jako dwóch głównych dróg zaopatrywania torfowiska w związki biogenne (tab. 4). Najsilniejszą zależność od czynnika zlewniowego ma wartość pH wód bagiennych (rys. 9), a najsłabszą zawartość $P\text{-}PO_4^{3-}$ (rys. 10).

Zbadano również interakcje pomiędzy wskaźnikami chemicznymi w wodach torfowisk. Silne zależności znaleziono pomiędzy ogólnym stężeniem jonów, zawartością Ca^{2+} i pH w wodach bagiennych (rys. 4, 6, 7). Dowiedziono, że pH wód torfowisk wysokich i niskich kształtują odmienne czynniki. W przypadku wód torfowisk niskich są to składniki nieorganiczne (rys. 4), w tym jon wapniowy (rys. 6) pochodzenia zlewniowego, a w wodach torfowisk wysokich autogenna rozpuszczona materia organiczna (rys. 8). Z kolei wartość pH decyduje o stężeniu $P\text{-}PO_4^{3-}$ w wodach torfowych (rys. 11). Pomiędzy zawartością jonów Ca^{2+} i PO_4^{3-} w wodach bagiennych zachodzi zależność odwrotna (rys. 12).

Udział torfowiska w zlewni torfowiskowej oddziałuje na torfowisko nie tylko implikując dwa przeciwstawne typy troficzne (minerotroficzny i ombrotroficzny), ale również wpływając na żyzność w obrębie tych dwóch typów. Mianowicie, w torfowiskach niskich poprzez wielkość dopływu bogatych w związki biogenne wód ze zlewni, a w torfowiskach wysokich poprzez stabilność stosunków wodnych, która warunkuje słabe tempo rozkładu materii organicznej.

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(*Received 28 April 1986*)