POLISH JOURNAL OF ECOLOGY (Pol. J. Ecol.)	50	4	515–525	2002

Regular research paper

Izabela WILPISZEWSKA, Marek KLOSS

Department of Plant Ecology, Institute of Ecology PAS, Dziekanów Leśny,
05-092 Łomianki, Poland, e-mail: ekolog@warman.com.pl; ekofito@pan.pl

WETLAND PATCHES (POTHOLES) IN A MOSAIC LANDSCAPE (MASURIAN LAKELAND, POLAND): FLORISTIC DIVERSITY AND DISTURBANCE

ABSTRACT: In 1999 the vegetation of 145 small (1 ha) wetlands was analysed in the Inulec Lake catchment, which makes up a part of the Jorka River-Lake system (the Masurian Lakeland, north--eastern Poland). In total, 22 plant communities were identified and their distribution was described. Willow communities were the most frequent in the examined area. Changes occurring in phytocoenoses over the period of 20 years were assessed. Most of the plant communities have retained their natural character.

KEY WORDS: wetlands, potholes, plant communities, long-term changes in vegetation, Masurian Lakeland, N-E Poland.

1. INTRODUCTION

The Masurian Lakeland was formed by the Baltic glaciation. This region largely differs from the rest of Poland with respect to its geomorphology, climate, hydrology, and hydrogeology. Its soils are extremely diverse and they support numerous and rich plant communities (Gotkiewicz *et al.* 1990). Specific local habitat conditions and relief shaped factors determining water balance in young-glacial areas differently than in other regions of Poland. According to the authors cited above, steep slopes and high soil cohesion cause that the surface runoff overbalances water infiltration, especially in arable land.

In agricultural catchments with a large proportion of wetlands characterized by high retention values, the total nutrient outflow is reduced. For this reason, for example, the annual nutrient outflow loads from the entire Krutynia catchment also in the Masurian Lakeland were 0.14-0.25 kg ha^{-1} for phosphorus and 2.14-2.30 kg ha^{-1} for nitrogen, whereas annual runoff from agricultural land alone was 1.30 kg P ha^{-1} and 20.54 kg N ha^{-1}. This comparison clearly shows that the structure of the catchment and the way of its use have an important effect on nutrient flux (Kufel 1999). Similar patterns in a lakeland landscape were found by other authors (Hillbricht-Ilkowska 1993, 1999, Kruk and Podbielska 1999).

The role of surface runoff as an important factor responsible for geomorphological changes on lakeland slopes in young glacial landscapes has been reported by other authors (Smolska *et al.* 1995). The process shows a clear time-related dynamics. It is slow in winter and early spring, moderate in summer, whereas reaches highest rates in late spring (May, June). It is also high during the periods of autumn rainfall. The mean rate of slope erosion in the Masurian Lakeland was estimated at 30-150 kg of soil/ha/year during 1955-1963 (Niewiadomski and Skrodzki 1964 cited in Smolska *et al.* 1995).

Surface runoff in young glacial areas was described also by Bajkiewicz-Grabowska (1985) as the dominating factor. She noticed that in the Jorka basin its rate was limited by intermittent streams, absence of a direct contact between lakes and arable land, and fairly large number of areas without surface runoff. The basic components of the latter are hollows without surface runoff (so called potholes), typical of the young glacial landscape. The bottoms of most hollows are occupied by wetlands that are analysed in the present paper.

Potholes and their wetlands were the object of diverse studies concerning:

• their typology and factors determining water flow and nutrient cycling (Kruk 1987a, b),

• origin, natural conditions, and anthropogenic transformations (Kloss *et al.* 1987),

• flora and phytosociology (Kloss and Wilpiszewska 1983, 1985; Kucharski and Samosiej 1990; Koc 1994a, b, c, d, e; Kloss 1995a; Pałczyński 1996a; Kaźmierczak 1997),

• peat characteristics (Kloss 1993, 1995 b, Pałczyński 1996 b),

• various components of water balance and biogeochemical processes (Kruk 1990; 1996a, b, c; 1997),

• ecological determinants of their function in a young glacial agricultural landscape (Koc and Polakowski 1990; Wilpiszewska 1990; Koc 1991; Kruk 1991; Wilpiszewska and Kloss 1993; Kloss and Wilpiszewska 1994; Wilpiszewska 1999).

Up to recent times, the wetlands in potholes were considered as agricultural wasteland. With increasing knowledge of their function, their positive effects on environment as well as on surrounding biocoenoses were recognized, and in the system of land classification they were categorized as ecologically useful land (Olaczek 1990). At present, our knowledge on them is more satisfying but still not complete. Among diverse positive functions of these wetlands, one of the most important is their beneficial effect on the quantity and quality of the ground outflow. Most often, water circulating in a young glacial landscape ends up in a lake.

The objectives of this paper are:

• analysis of spatial diversity of plant communities in wetlands of selected lake catchment,

• assessment of their closeness to the natural state.

2. STUDY AREA AND METHODS

The study was conducted in Masurian Lakeland, namely in the Inulec Lake catchment, which represents a middle part of the Jorka River-Lake system (Fig. 1). This is an area of 8.69 km^2 with diverse, young glacial relief. The landforms are dominated by morain hills and meltwater hollows. The elevations range from 122 to 161 m above sea level. Hydrographic components include Inulec Lake (161 ha), two permanent streams and four intermittent streams (Bajkiewicz-Grabowska 1985). The dominant type of surface deposits is boulder clay, whereas soils are mainly brown. Depressions are filled with organic deposits, mainly peats and gyttjas.

In 1999, all plant communities overgrowing wetlands of the Inulec Lake catchment were identified, based on the phytosociological classification according to Braun-Blanquet (1964) and Matuszkiewicz (1981). A part of the characteristics of these plant communities was taken from earlier papers of the authors (Kloss and Wilpiszewska 1983, 1985). Phytocoenoses were mapped using 1:10 000 hypsometric maps. Vegetation syntaxa were named after Matuszkiewicz (1981).

3. RESULTS

3.1. DIVERSITY OF WETLAND VEGETATION

An inventory of 145 wetlands occurring in potholes of various kinds was made. The majority of them, that is, 123 or 85% of the total number of wetlands under study were situated at the bottoms of depressions without surface outflow. Hardly 22 wetlands, that is

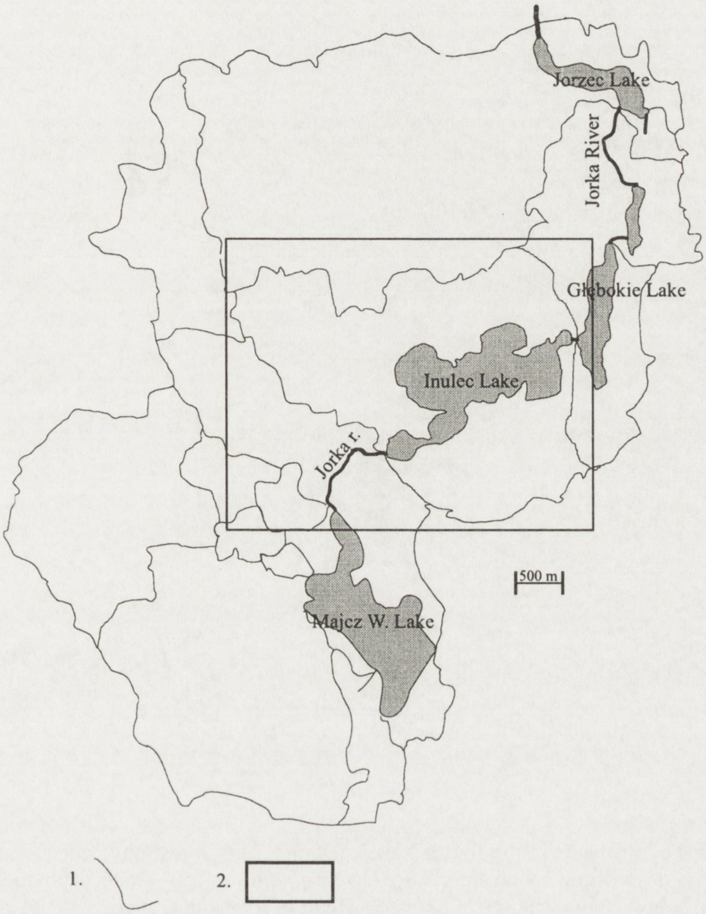

Fig. 1. The Jorka River-Lake system
1– the borders of catchment area, 2– the Inulec Lake catchment.

15% of the total number of wetlands under study, were situated at the bottoms of depressions with runoff. In general, the investigated objects were small, covering 0.8 ha on the average and rarely exceeding 1 ha.

The density of wetland patches in the Inulec Lake catchment was high, 21 per one square kilometre of the land surface (excluding the lake). The density of wetlands without surface outflow was 18 per km^2.

The total area of the 145 wetlands studied was 114,1 ha, accounting for 16% of the land area and for 13% of the total area of the Inulec Lake catchment (Table 1). Wetlands were evenly distributed over the catchment area (Fig. 2). In the landscape they formed patches of different shapes and sizes, enriching its biological diversity.

On the basis of phytosociological examinations, 22 plant communities were identified:

Class: *Lemnetea* R. Tx. 1955
Lemno-Spirodeletum polyrrhizae W. Koch 1954 em. Müll. et. Görs 1960
Class: *Potamogetonetea* R. Tx. et Prsg. 1942
Nupharo-Nymphaeetum albae Tomasz. 1977
Class: *Phragmitetea* R. Tx. et Prsg. 1942
Alliance: *Phragmition* W. Koch 1926
Phragmitetum (Gams 1927) Schmale 1939
Equisetetum limosi Steffen 1939
Typhetum latifoliae Soo' 1927
Typhetum angustifoliae (Allorge 1922) Soo' 1927
Acoretum calami Kobendza 1948
Alliance: *Magnocaricion* W. Koch 1926
Phalaridetum arundinaceae Libb. 1931
Caricetum acutiformis Sauer 1937
Iridetum pseudoacori Eggler 1933
Caricetum elatae W. Koch 1926

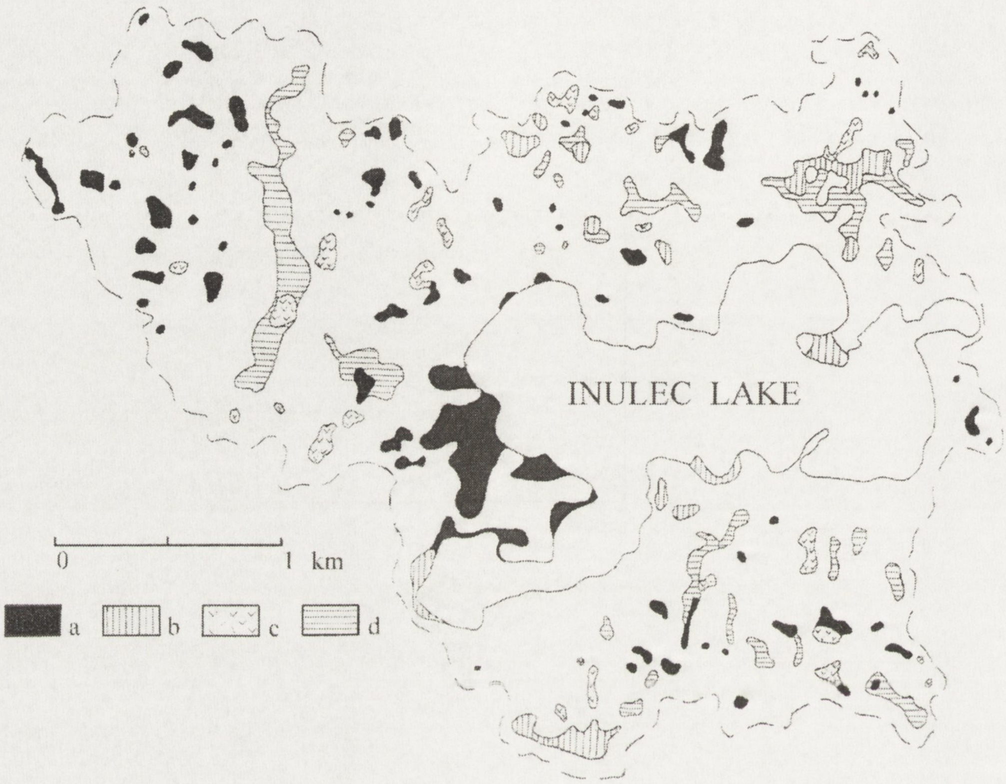

Fig. 2. Phytocoenoses of wetlands in the Inulec Lake catchment: a – forest phytocoenoses of the class *Alnetea glutinosae*; b – shrub phytocoenoses of the class *Alnetea glutinosae*; c – reedbed phytocoenoses of the class *Phragmitetea*; d – meadow phytocoenoses of the class *Molinio-Arrhenatheretea*.

Caricetum vesicariae Br.-Bl. et Denis 1926
Caricetum gracilis R. Tx. 1937
Class: *Molinio-Arrhenatheretea* R. Tx. 1937
Scirpetum sylvatici Knapp 1946
Cirsio-Polygonetum bistortae R. Tx. 1951
Epilobio-Juncetum effusi Oberd. 1957
community with *Deschampsia caespitosa*
community with *Urtica dioica*
community with *Cirsium arvense*
Class: *Alnetea glutinosae* Br.-Bl. et R.Tx. 1943
Carici elongatae-Alnetum W. Koch 1936
Carici acutiformis-Alnetum Scamoni 1953
Salicetum pentandro-cinereae Pass. 1961

Depending on water regime, habitat fertility, extent of human interference, diverse plant communities have been developed in wetlands. For the purpose of this work, a simplified classification into four basic types of plant communities is used:

• forest phytocoenoses of the class *Alnetea glutinosae*, represented here mainly by the association *Carici elongatae-Alnetum*,

• shrub phytocoenoses of the class *Alnetea glutinosae*, represented here mainly by the association *Salicetum pentandro-cinereae*,

• reedbed phytocoenoses of the class *Phragmitetea* and aquatic phytocoenoses of the class *Lemnetea* or *Potamogetonetea*,

• meadow phytocoenoses of the class *Molinio-Arrhenatheretea*.

Wetlands with several intertwined plant communities were classified to one of the groups mentioned above based on the vegetation type occupying the largest area. Figure 2 shows the distribution of the identified four types of plant communities overgrowing the depressions in the Inulec Lake catchment. Table 1 characterizes the abundance-surface proportion of these basic types of wetland phytocoenoses. The most frequent type was willow shrubberies *Salicetum pentandro-cinereae*. These phytocoenoses dominated in 78 potholes, what makes up for 54% of their total number (n=145). Their mean size was 0.6 ha. It should be noted that the size of wil-

Table 1. The abundance-surface characteristics of different types of wetland plant communities

Vegetation type	Number of wetlands	% of total wetland number	Area of wetlands (ha)	% of total wetland area	Mean wetland size (ha)	% of total catchment area (without lake)
Forest phytocoenoses of the class *Alnetea glutinosae* (mainly *Carici elongatae-Alnetum*)	13	9	16.2	14	1.2	2.3
Shrub phytocoenoses of the class *Alnetea glutinosae* (mainly *Salicetum pentandro-cinereae*)	78	54	46.6	41	0.6	6.6
Reedbed phytocoenoses of the class *Phragmitetea*	28	19	14.3	13	0.5	2.0
Meadow phytocoenoses of the class *Molinio-Arrhenatheretea*	26	18	37.0	32	1.4	5.2
Total	145	100	114.1	100	0.8	16.1

low shrubberies bordering on the lake varied from 0.25 to 10.32 ha, 2.6 ha on the average, whereas the mean size of mid-field willow shrubberies was only 0.4 ha.

Genetically associated with phytocoenoses of willow shrubberies are alderwoods of the class *Alnetea glutinosae*. They were found in 13 potholes (9% of their total number) and occupied 1.2 ha on the average. They were disturbed in places by uncontrolled felling of single trees. Most often they did not form hummock structure typical of alderwoods.

In the catchment under study, reedbed phytocoenoses (including aquatic communities) were equally frequent as patches of meadow vegetation. They differed in the mean size, which was 0.5 ha for reedbeds and 1.4 ha for meadows.

3.2. EVALUATION OF WETLAND VEGETATION

The evaluation of plant communities in wetlands of the Inulec Lake catchment was performed with reference to earlier studies of the plant cover conducted in 1979-1981 (Kloss and Wilpiszewska 1983, 1985). Three categories of wetlands and their phytocoenoses were distinguished:

- wetlands with natural and substitute vegetation showing however some characteristics of natural communities,
- wetlands with managed meadows,
- wetlands with degraded vegetation.

The first group consisted of wetlands dominated by permanent forest and shrub communities of the class *Alnetea glutinosae*. In single cases depressions with reedbed vegetation were also included. A distinctive feature of plant communities of the first group is that they have remained unchanged since the early 1980s. They proved to be most resistant to the impact of environmental changes over a period of the last 20 years.

The second group comprised wetlands with managed meadows. These were phytocoenoses of mown meadows and, less often, pastures. The species composition of meadow patches was largely dependent on the application of fertilizers and the frequency of mowing.

The third category grouped depressions with vegetation of degraded habitats, mainly of meadows. As a result of drainage of organic soils and peat mineralization when large amounts of nitrogen and phosphorus are released, meadow communities were colonized by nitrophilous plants. The number of species characteristic of the class *Molinio-Arrhenatheretea* decreased in favour of taxa of the class *Artemisietea*. Lack of care for maintaining the network of draining ditches caused secondary paludification of these habitats. The waterlogged meadows were invaded by phytocoenoses of *Phalaridetum arundinaceae* and sedge communities of the alliance *Magnocaricion*. In places there occurred reedbeds made up of *Phragmites australis* and *Typha latifolia*. Changes in the

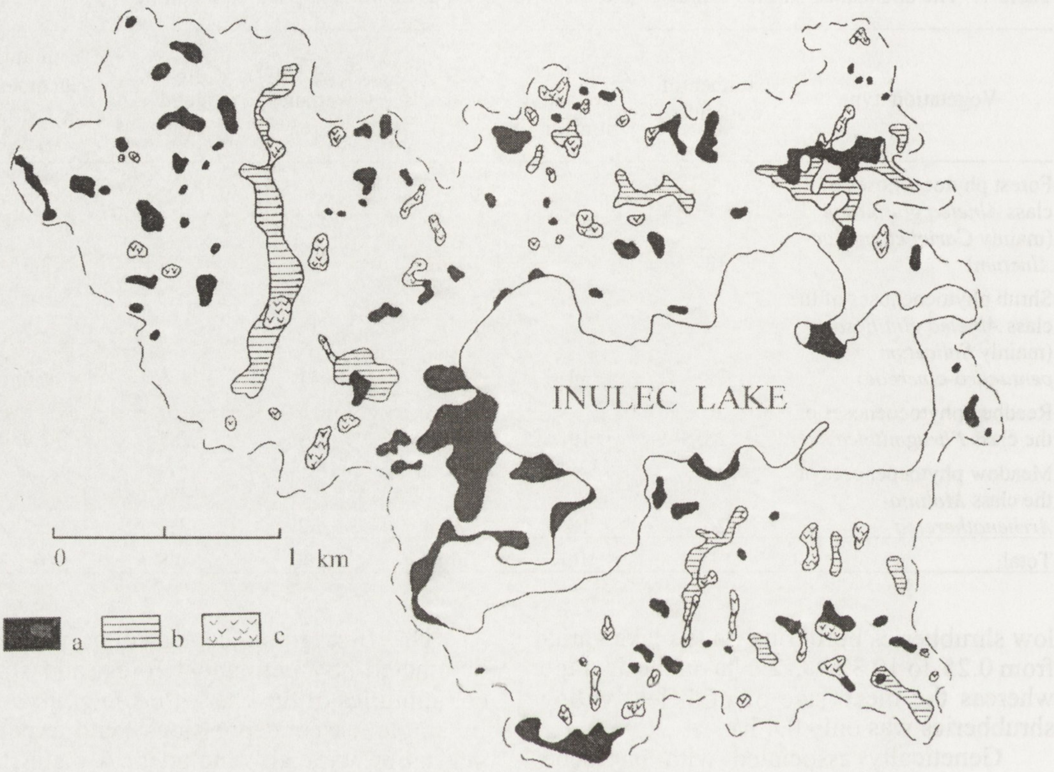

Fig. 3. Evaluation of the wetland vegetation in the Inulec Lake catchment: a – wetlands with some characteristics of natural vegetation, b – wetlands with vegetation of managed meadows, c – wetlands with vegetation of degraded habitats.

Table 2. Characteristics of the contribution of the evaluated wetland groups

Evaluated wetland groups	Number of wetlands	% of total wetland number	Area of wetlands (ha)	% of total wetland area	Mean wetland size (ha)
Wetlands with natural and substitute vegetation showing some characteristics of natural communities	85	59	60.3	53	0.7
Wetlands with meadow vegetation (managed)	12	8	30.5	27	2.5
Wetlands with degraded vegetation	48	33	23.3	20	0.5
Total	145	100	114.1	100	0.8

species composition and degradation of meadows were also due to abandonment of their management. Factors influencing long-term devastation of the plant cover of wetlands included also contamination by liquid manure and filling in the depressions with communal waste, as it was the case of a few wetlands east of Inulec Lake.

Fig. 3 shows the distribution of the three categories of wetlands and their plant communities in the Inulec Lake catchment. Table 2 characterizes the abundance and cover of the evaluated groups of phytocoenoses. Of 145 analysed wetlands, as many as 85 retained the vegetation typical of natural communities. It is represented mainly by willow thickets *Salicetum pentandro-cinereae*. However, the vegetation of 48 wetlands was indicative of habitat degradation. They were mostly meadows of very small area, their average size being 0.5 ha. Due to their small surfaces, they were under heavy impact of the catchment. In comparison, the mean size of the depressions occupied by managed meadows was 5 times higher and attained 2.5 ha. Some other equally small wetlands overgrown with reedbed vegetation were also transformed by man impact. In general, it can be stated that degraded wetlands were evenly distributed throughout the Inulec Lake catchment, that is, no long-term trend was found in their distribution.

3. DISCUSSION

Wetlands are a specific component of the young glacial landscape. Using the concept of Forman and Godron (1981, 1986), who distinguished three basic components of the landscape structure: corridors, patches, and matrix, the wetlands developed in potholes should be allocated to patches. According to this concept, patches are components that can readily be distinguished in the matrix, and that can be differentiated with respect to their origin and size.

Functionally they can be considered as barrier or buffer systems in the landscape, counteracting the export of nutrients (Sharpley *et al.* 1995).

The importance of potholes in the young glacial landscape as factors modifying biogeochemical processes occurring in this region is indicated by their large numbers. In the Masurian Lakeland there are about 84 000 hollows without surface outflow. Their mean density varies between 3 and 15 per km^2, maximally reaching 30 (Nowicki 1987, cited after Koc and Polakowski 1990). In the examined Inulec Lake catchment there are 14 potholes per km^2.

Kucharski and Samosiej (1993) proposed to establish a network of mid-field depressions protected by law. This would enable the preservation of 90% of the vascular plants growing in hydrogenic habitats. The above authors studied a fragment of the lakeland in northern Poland. In this region, intensive agriculture has been developed for centuries, and the vegetation has been subjected to dynamic, anthropogenic transformations. They conclude that in order to preserve the local flora the number of wetland patches in crop fields should be not less than 20 per 10 km^2, and the joint area of these marginal habitats should be not less than 14.5 ha 10 km^{-2}.

Comparison of the data for the two young glacial areas seems to be interesting. When calculated per 10 km^2, 210 wetlands were found in the land part of the Inulec Lake catchment, and they covered a joint area of 161.2 ha. The results compared in such a way seem to speak in favour of the investigated fragment of the Masurian Lakeland. But although the number of mid-field hollows is large, there is a real threat of their degradation because of lack of a rational concept for their protection.

The analysis presented in this paper shows that signs of degradation occurred in 48 wetlands (33% of the total number of the study objects). In the past they were subjected to various forms of man impact such as deforestation, peat exploitation, drainage, and eutrophication (Kloss *et al.* 1987). At present, degradation of wetlands is primarily caused by the mineralization of organic matter due to excessive drainage, neglecting the maintenance of drainage ditches and secondary paludification, cessation of meadow management, and eutrophication caused by nutrient runoff from crop fields. Small catchments are most vulnerable to these impacts (Table 2). Also the size of their micro-catchments is important – the greater their sizes, the heavier its impact on the wetland patch (Kloss *et al.* 1987).

Wetlands of mid-field depressions perform many important functions in the landscape. Among others, they may function as biogeochemical barriers. This rises a question about the scale of the effects of the total system of potholes on the quality of water inflowing to Inulec Lake. As empirical studies are lacking, we can only consider various aspects of this problem. It is known from the literature that potholes significantly influence not only the amount but also the quality of ground waters. They reduce the surface outflow of some nutrients to lakes, thus counteracting eutrophication, limiting non-point contamination in the agricultural landscape. Vegetation, especially mid-field tree stands and meadows have a pronounced effect on the chemical composition of water. It has been found that the concentration of nitrates in ground waters percolating under such systems was markedly reduced. To give an example, at a distance of 50 m from the edge of a woodlot, $N\text{-}NO_3$ concentration was reduced to one-22nd of that in the crop field, whereas the concentrations of $P\text{-}PO_4$, K, Ca, and Mg were reduced by half. These effects were not restricted to inorganic compounds. A similar decrease was observed in the content of humus in the ground water under a meadow (Ryszkowski *et al.* 1990). The barrier efficiency with respect to humus substances can be important, for example, to water transport of heavy metals bound in complexes with dissolved organic matter. It should be added that water flow is dependent on a large array of factors such as weather, especially on the amount of precipitation, wind velocity, physico-chemical soil properties, and the like. It is known that water flow can be largely modified by small bodies of water dispersed in farmland, what has special significance in the case of nitrogen and phosphorus compounds. The effectiveness of this process is much more pronounced during the growing season than in winter. Large amounts of nitrogen are deposited in bottom sediments, and even larger amounts are released to the atmosphere as an effect of denitrification, in the form of molecular nitrogen, nitric oxides or ammonia (Ryszkowski and Życzyńska-Bałoniak 1998).

Water circulation is largely dependent on the properties of a catchment such as the surface structure determining the intensity of runoff, as well as the in-depth structure determining pathways of ground water flow and flow velocity, and also the rate of ground water outflow (Gotkiewicz *et al.* 1990).

Plant cover of the catchment, and especially the type and density of biogeochemical barriers, are extremely important for limiting the dispersal of various chemical compounds with water. In five catchments a significant correlation was obtained between the proportion of the area covered with forest and meadows and the concentration of $N\text{-}NO_3$ in the outflow. It has been estimated that when biogeochemical barriers took 5% of the catchment surface, $N\text{-}NO_3$ concentration at an average precipitation level did not exceed 8 mg l^{-1}, and when the contribution of barriers was 17%, nitrate concentration did not exceed 5 mg l^{-1}. These results were obtained for the infiltration typical of grey brown podzolic and brown podzolic soils on loam (Ryszkowski and Życzyńska-Bałoniak 1998) in central part of the Polish lowlands near Poznań. Thus it is difficult to compare the latter with the results obtained for the Masurian Lakeland. However, if we would like to reflect how big is the percentage contribution of all biogeochemical barriers in the Inulec Lake catchment, it would turn out that they occupy 13.1% of the above surface. This implies that the concentrations of nitrates reaching Inulec Lake should be largely reduced. In a nearby area, Kruk (1996 a) estimated that the reduction of mineral elements in the outflow from mires without surface runoff, also in the central part of the Jorka River catchment, was over 60% for total nitrogen and to 30% for sodium, calcium, magnesium, and sulphate ions. He concluded that the preservation of small wetlands in farmland, accounting for 4% of the basin area, would enable a low cost removal of as much as about 70% of nitrogen from subsurface waters flowing to streams and lakes.

In the examined Inulec Lake catchment, small wetlands cover as much as 13.1 % of its area. Do these wetlands retain 70% of total nitrogen, or perhaps more than that? In our opinion it would be important to evaluate empirically the scale of the effect of wetlands on the quality of water inflowing to Inulec Lake, and also to estimate the impact of wetland degradation on this process. At present it can certainly be stated that potholes perform a positive function in the agricultural landscape (Wilpiszewska 1990, Koc and Polakowski 1990, Koc 1991, Kruk 1991, Wilpiszewska and Kloss 1993, Kloss and Wilpiszewska 1994, Wilpiszewska 1999). That is why the ever increasing degradation of these habitats is so alarming.

ACKNOWLEDGEMENTS: The study was supported by the Polish Committete for Scientific Research; project number 6PO4F 024 11.

4. SUMMARY

In 1999, a study was made on the vegetation of the Inulec Lake catchment, which constitutes a part of the Jorka River-Lake system in the Masurian Lakeland, N-E Poland (Fig. 1). This is a diverse, young glacial landscape with numerous morain hills and depressions. Among depressions there are potholes filled in with wetlands of various types, in particular with peatlands. They perform many important functions in the landscape, including the role of biogeochemical barriers. The paper focuses on (1) the analysis of spatial diversity of wetland vegetation in the Inulec Lake catchment, and (2) the assessment of degree of their disturbance. An inventory of 145 wetlands was made,

covering a joint area of 114.1 ha, or 16% of the land part of the Inulec Lake catchment. They were classified to 22 plant communities and allocated to four basic types of plant communities:

- forest phytocoenoses of the class *Alnetea glutinosae*, represented mainly by the association *Carici elongatae-Alnetum*,
- shrub phytocoenoses of the class *Alnetea glutinosae*, represented mainly by the association *Salicetum pentandro-cinereae*,
- reedbed phytocoenoses of the class *Phragmitetea* and aquatic phytocoenoses of the class *Lemnetea* or *Potamogetonetea*,
- meadow phytocoenoses of the class *Molinio-Arrrhenatheretea*.

Figure 2 shows the distribution of these basic vegetation types in potholes. Table 1 characterizes the abundance and cover of the main types of wetland vegetation. Plant communities were evaluated by comparing the present results with the results of the study on plant cover conducted in this area during 1979-1981. Three categories of wetlands and their phytocoenoses were distinguished:

- wetlands with natural vegetation and substitute vegetation showing some characteristics of natural communities,
- wetlands with managed meadows,
- wetlands with degraded vegetation.

Figure 3 shows the distribution of the distinguished categories of wetlands and their plant communities. Table 2 characterizes the abundance and cover of the evaluated groups of phytocoenoses. Of 145 analysed wetlands, as many as 85 retained their natural character. The distribution of degraded wetlands is uniform over the Inulec Lake catchment and does not show long-term trends.

5. REFERENCES

Bajkiewicz-Grabowska E. 1985 – Factors affecting nutrient budget in lakes of the r. Jorka watershed (Masurian Lakeland, Poland). I. Geographical description, hydrographic components and man's impact. – Ekol. pol. 33.2: 173-200.

Braun-Blanquet J. 1964 – Pflanzensoziologie. Grundzuge der Vegetationskunde – Springer, Wien – New York, 865 pp.

Forman R. T. T., Godron M. 1981 – Patches and structural components for a landscape ecology – BioScience 31: 733-740.

Forman R. T. T., Godron M. 1986 – Landscape ecology – John Wiley and Sons, New York.

Gotkiewicz J., Hutorowicz H., Lossow K., Mosiej J., Pawłat H., Szymczak T., Traczyk T. 1990 – Czynniki kształtujące obieg wody i biogenów w krajobrazie młodoglacjalnym [Factors determining water and nutrient flux in a young glacial landscape] (In: Obieg wody i bariery biogeochemiczne w krajobrazie rolniczym [Water circulation and biogeochemical barriers in agricultural landscape], Eds: L. Ryszkowski, J. Marcinek, A. Kędziora) – Zakład Badań Środowiska Rolniczego i Leśnego PAN, Poznań, pp. 105-126. (in Polish)

Hillbricht-Ilkowska A. 1993 – Biogeochemical diversity of fluvial waters and their effect on lake ecosystems in Suwałki Landscape Park (North-Eastern Poland) – Ekol. Pol. 41: 173–193.

Hillbricht-Ilkowska A. 1999 – Jezioro a krajobraz: związki ekologiczne, wnioski dla ochrony [Lake and landscape, ecological relations, conclusions pertaining to protection], (In: "Funkcjonowanie i ochrona ekosystemów wodnych na obszarach chronionych" [Function and protection of aquatic ecosystems in protected areas] Eds: B. Zdanowski, M. Kamiński and A. Martyniak) – Wydawnictwo IRŚ, Olsztyn, pp. 19–40 (in Polish)

Kaźmierczak E. 1997 – The vegetation of kettle-holes in central Poland – Acta Phytogeogr. Suec. 83, Uppsala, 97 pp.

Kloss M. 1993 – Differentiation and development of peatlands in hollows without run-off on young glacial terrains – Pol. ecol. Stud. 19, 3-4: 115-219.

Kloss M. 1995a – Zbiorowiska leśne i zaroślowe bezodpływowych mokradeł na Pojezierzu Mazurskim [Forest and shrub communities of wetlands without run-off in the Masurian Lakeland] – Las Polski, 21: 20-21. (in Polish)

Kloss M. 1995b – Typy hydrologiczne torfowisk w zagłębieniach bezodpływowych na Pojezierzu Mazurskim a zbiorowiska roślinne [Hydrological types of mires and vegetation in hollows without run-off in Masurian Lakeland] – Sylwan 5: 25-29. (in Polish)

Kloss M., Kruk M., Wilpiszewska I. 1987 – Geneza, charakterystyka przyrodnicza i przekształcenia antropogeniczne zagłębień bezodpływowych we współczesnym Krajobrazie Pojezierza Mazurskiego [The genesis, description of natural conditions and antropogenic transformations of undrained mired basins in present–day landscape of the Masurian Lakeland] – Kosmos 36, 4: 621-641. (in Polish)

Kloss M., Wilpiszewska I. 1983 – O roślinności niewielkich zagłębień bezodpływowych okolic Mikołajek i potrzebie ich ochrony [On the vegetation in small hollows without outflow in the environs of Mikołajki and on the need for their protection] – Chrońmy Przyrodę Ojczystą 4: 25-29. (in Polish)

Kloss M., Wilpiszewska I. 1985 – Vegetation of hollows without run-off in the Jorka watershed – Pol. ecol. Stud. 11, 2: 209-214.

Kloss M., Wilpiszewska I. 1994 – Uwagi o rozwoju i funkcjonowaniu ekosystemów torfowiskowych w zagłębieniach bezodpływowych na Pojezierzu Mazurskim [Some remarks on development and functioning of mire ecosystems in hollows without run-off in the Masurian Lakeland] – Kosmos 43, 2: 259-272. (in Polish)

Koc J. 1991 – Ocena roli ekologicznej zagłębień terenowych w krajobrazie rolniczym Pojezierza Mazurskiego [Ecological role of potholes in the agricultural landscape of the Masurian Lakeland] – Ph.d. thesis, mscr. ART.-Olsztyn pp. 106. (in Polish)

Koc J. 1994 a – Roślinność śródpolna zagłębień bezodpływowych Pojezierza Olsztyńskiego, I. Klasa Phragmitetea, zw. Phragmition [Vegetation of potholes in farmland of the Olsztyńskie Lakeland, I. Class Phragmitetea, alliance Phragmition] – Acta Acad. Agricult. Tech. Olst., Agricultura, 58: 3-16. (in Polish)

Koc J. 1994b – Roślinność śródpolna zagłębień bezodpływowych Pojezierza Olsztyńskiego, II. Klasa Phragmitetea, związki: Sparganio-Glycerietum fluitantis i Magnocaricion [Vegetation of potholes in farmland of the Olsztyńskie Lakeland, II. Class Phragmitetea, alliances: Sparganio-Glycerietum fluitantis and Magnocaricion] – Acta Acad. Agricult. Tech. Olst., Agricultura, 58: 17-26. (in Polish)

Koc J. 1994c – Roślinność śródpolna zagłębień bezodpływowych Pojezierza Olsztyńskiego, III. Klasy: Lemnetea, Potamogetonetea, Bidentetea tripartiti, Plantaginetea majoris [Vegetation of potholes in farmland of the Olsztyńskie Lakeland, III. Classes: Lemnetea, Potamogetonetea, Bidentetea tripartiti, Plantaginetea majoris] – Acta Acad. Agricult. Tech. Olst., Agricultura, 58: 27-35. (in Polish)

Koc J. 1994d – Roślinność śródpolna zagłębień bezodpływowych Pojezierza Olsztyńskiego, IV. Klasy: Scheuchzerio-Caricetea fuscae, Molinio-Arrhenatheretea, Alnetea glutinosae [Vegetation of potholes in farmland of the Olsztyńskie Lakeland, IV. Classes: Scheuchzerio-Caricetea fuscae, Molinio-Arrhenatheretea, Alnetea glutinosae] – Acta Acad. Agricult. Tech. Olst., Agricultura, 58: 36 – 44. (in Polish)

Koc J. 1994e – Roślinność śródpolna zagłębień bezodpływowych Pojezierza Olsztyńskiego, V. Charakterystyka florystyczna [Vegetation of potholes in farmland of the Olsztyńskie Lakeland, V. Floristic characteristics] – Acta Acad. Agricult. Tech. Olst., Agricultura, 58: 45-57. (in Polish)

Koc J., Polakowski B. 1990 – Charakterystyka zagłębień bezodpływowych na Pojezierzu Mazurskim w aspekcie przyrodniczym, urządzeniowym i rolniczym [Characteristics of potholes in the Masurian Lakeland in biological, management and agricultural aspects] (In: Użytki ekologiczne w krajobrazie rolniczym [Ecologically useful land in agricultural landscape], Ed. R. Andrzejewski) – Wydawnictwo SGGW-AR, Warszawa, pp. 25-57. (in Polish)

Kruk M. 1987a – Types of basins without drainage and factors affecting the water cycle in them in the present-day landscape of the Masurian Lakeland – Ekol.pol. 35, 3-4: 655-678.

Kruk M. 1987b – The influence of the mire proportion in a drainagless catchment area on the trophic status of mire waters – Ekol. pol. 35: 679-698.

Kruk M. 1990 – The processing of elements by mires in agricultural landscape mass balances based on sub-surface hydrology – Ekol. pol. 38,1: 73-117.

Kruk M. 1991 – Znaczenie torfowisk w krążeniu składników mineralnych w krajobrazie [The role of peatlands in nutrient cycling in a landscape] – Wiad. Ekol. 37: 79-96. (in Polish)

Kruk M. 1996a – Ocena redukcji składników mineralnych w odpływie z zabagnionych obszarów powierzchniowo bezodpływowych w krajobrazie rolniczym [Reduction of nutrients in the outflow from mire areas without surface run-off in an agricultural landscape] – Acta Acad. Agricult. Tech. Olst., 22: 159-169. (in Polish)

Kruk M. 1996b – Znaczenie zbiornikow astatycznych w odpływie składników mineralnych z bagien typu niskiego [The significance of astatic reservoirs in nutrient outflow from minerotrophic mires] – Acta Acad. Agricult. Tech. Olst., 22: 171-180. (in Polish)

Kruk M. 1996c – Biogeochemical consequences of watershed inflow of mineral elements into fens in agricultural landscape – Pol. ecol. Stud. 22, 3-4: 105-127.

Kruk M. 1997 – Effect of draining on nitrogen flow through lowland mires in agricultural landscape – Ekol. pol. 45: 441-460.

Kruk M. , Podbielska K. 1999 – Odpływy składników mineralnych ze zlewni Mazurskiego Parku Krajobrazowego i jego rolniczej otuliny [Outflow of minerals from the catchment area of Mazurian Landscape Park and its agricultural surroundings], (In: "Funkcjonowanie i ochrona ekosystemów wodnych na obszarach chronionych" [Function and protection of aquatic ecosystems in protected areas] (Eds: B. Zdanowski, M.Kamiński and A. Martyniak) – Wydawnictwo IRŚ, Olsztyn. pp. 167–170. (in Polish)

Kucharski L., Samosiej L. 1990 – Szata roślinna zagłębień śródpolnych Kujaw Południowych [Vegetation of potholes in the farmland of Kujawy Południowe region] (In: Użytki ekologiczne w krajobrazie rolniczym [Ecologically useful land in agricultural landscape], Ed. R. Andrzejewski) – Wydawnictwo SGGW-AR, Warszawa, pp. 68-82. (in Polish)

Kucharski L. Samosiej L. 1993 – Wyznaczanie optymalnej sieci zagłębień śródpolnych w celu ochrony zasobów gatunków dziko rosnących w krajobrazie rolniczym [Determining the optimal net of mid-field depressions for preserving wildly growing species in agricultural landscape] – Acta Univ. Lodz., Folia bot. 10: 109-121. (in Polish)

Kufel L. 1999 – Transport pierwiastków biogennych w zlewniach Mazurskiego Parku Krajobrazowego [Nutrient transport in catchment areas of Mazurian Landscape Park] (In: "Funkcjonowanie i ochrona ekosystemów wodnych na obszarach chronionych" [Function and protection of aquatic ecosystems in protected areas], Eds: B. Zdanowski, M. Kamiński and A. Martyniak) – Wydawnictwo IRŚ, Olsztyn. pp. 153–165. (in Polish)

Matuszkiewicz W. 1981 – Przewodnik do oznaczania zbiorowisk roślinnych Polski [A guide for identifying plant communities of Poland] – Państwowe Wydawnictwo Naukowe, Warszawa, 298 pp. (in Polish)

Niewiadomski W., Skrodzki M. 1964 – Nasilenie spływów i zmywów a system rolniczego zagospodarowania stoku [Intensification of runoff and denudation versus agricultural management of a slope] – Zesz. Nauk. WSR Olsztyn, 17, 2. (in Polish)

Nowicki Z. 1987 – Hydrologiczne i techniczne możliwości retencjonowania wód na Pojezierzu Mazurskim [Hydrological and technical capabilities of water retention in the Masurian Lakeland]– ART. – Olsztyn, Ph.d. thesis, mscr. (in Polish)

Olaczek R. 1990 – Siedliska marginalne w systemie klasyfikacji gruntów i problem użytków ekologicznych [Marginal habitats in the system of classification of arable land and the problem of areas of ecological utility] – (In: Użytki ekologiczne w krajobrazie rolniczym [Ecologically useful land in agricultural landscape], Ed. R. Andrzejewski) – Wydawnictwo SGGW-AR, Warszawa, pp. 7-24. (in Polish)

Pałczyński A. 1996a – Szata roślinna torfowisk zlewni rzek Dajny i Jorki na Pojezierzu Mrągowskim oraz rzeki Szeszupy na Pojezierzu Suwalskim [Vegetation of peatlands in the Dajna and Jorka river basins in the Mrągowskie Lakeland and in the Szeszupa River basin in the Suwalskie Lakeland] (In: Funkcjonowanie systemów rzeczno-jeziornych w krajobrazie pojeziernym: rzeka Krutynia (Pojezierze Mazurskie) [Function of river-lake systems in a lakeland landscape: Krutynia river (Masurian Lakeland)] – Zeszyty Naukowe Komitetu "Człowiek i Środowisko", 13: 377-397. (in Polish)

Pałczyński A. 1996b – Paleofitosocjologiczne badania torfowisk w zlewniach Dajny i Jorki (Pojezierze Mrągowskie) oraz rzeki Szeszupy (Pojezierze Suwalskie) [Paleophytosociological studies of peatlands in the Dajna and Jorka river basins (Mrągowskie Lakeland) and in the Szeszupa river basin (Suwalskie Lakeland)] (In: Funkcjonowanie systemów rzeczno-jeziornych w krajobrazie pojeziernym: rzeka Krutynia (Pojezierze Mazurskie) [Function of river-lake systems in a lakeland landscape: Krutynia river (Masurian Lakeland)]) – Zeszyty Naukowe Komitetu "Człowiek i Środowisko", 13: 399-421. (in Polish)

Ryszkowski L., Bartoszewicz A., Marcinek J. 1990 – Bariery biogeochemiczne [Biogeochemical barriers] (In: "Obieg wody i bariery biogeochemiczne w krajobrazie rolniczym") [Water circulation and biogeochemical barriers in agricultural landscape], Eds: L. Ryszkowski, J. Marcinek and A. Kędziora) – Zakład Badań Środowiska Rolniczego i Leśnego PAN, Poznań. pp. 167–181. (in Polish)

Ryszkowski L., Życzyńska-Bałoniak I. 1998 – Ograniczanie zanieczyszczeń obszarowych przez bariery biogeochemiczne [Reduction of area contamination by using biogeochemical barriers] (In: "Kształtowanie środowiska rolniczego na przykładzie Parku Krajobrazowego im. Gen. D. Chłapowskiego" [Management of an agricultural environment, using Gen. D. Chłapowski Landscape Park as an example], Eds: L. Ryszkowski and S. Bałazy) – Zakład Badań Środowiska Rolniczego i Leśnego PAN, Poznań. pp. 67–80. (in Polish)

Sharpley A. N., Hedley M. J., Siebbsen E., Hillbricht-Ilkowska A., House W. E., Ryszkowski L. 1995 – Phosphorus transfer from terrestial to aquatic ecosystems (In: Phosphorus cycling in terrestial and aquatic ecosystems, Ed. H. Tiessen) – SCOPE – UNEP, John Willey and Sons, pp. 171-200.

Smólska E., Mazurek Z ., Wójcik J. 1995 – Dynamika procesów geomorfologicznych na stoku pojeziernym jako czynnik środowiskotwórczy [Dynamics of geomorphological processes on slopes as a factor of habitat formation in lakeland landscape], (In: "Problemy ekologii krajobrazu pojeziernego Polski płn-wschodniej " [Ecological problems of the Lakeland Landscape in North-Eastern Poland], Eds: E. Dąbrowska-Prot and J. Łuczak) – Zeszyty Naukowe Komitetu " Człowiek i Środowisko", 12. pp. 205–220. (in Polish, English summary).

Wilpiszewska I. 1990 – Productivity and chemical valorization of mire vegetation in postglacial agricultural landscape – Ekol.pol. 38, 1: 3-72.

Wilpiszewska I., Kloss M. 1993 – Peatlands of hollows without run-off as an element of young glacial landscape" – Mesogée, Bulletin du Museum d'Histoire naturelle de Marseille, vol. 53: 61-70.

Wilpiszewska I. 1999 – Ekoużytki sposobem na ekokrajobraz [Ecologically useful land as a means for landscape management] – Przyroda Polska, 1: 12-13. (in Polish)

(*Received after revising January 2002*)