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The chemistry of water and bottom sediments in relation to zooplankton biocenosis in small agricultural ponds

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Abstract

This study analyzed the chemistry and structure of planktonic fauna communities in small water bodies located within agricultural areas of different levels of anthropogenic transformation in the Wielkopolska region. Distance from farm buildings was a decisive factor when choosing the bodies of water for this study. A distinctive feature of the chemical characteristics of the examined water bodies was a high concentration of biogenic substances. The presence of biologically available mineral elements stimulated the development of algae, which was reflected in high concentrations of chlorophyll. High trophic conditions in the waters of the investigated ponds were also confirmed when analyzing the zooplankton community structure.

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INTRODUCTION

Small water bodies located within an agricultural landscape belong to ecosystems which are rarely addressed in the scientific literature. There is still a lack of typology of such waters as well as relative estimation of water resource size. However, small water bodies are marginal habitats because of their extreme soil-physical, chemical and microclimatic conditions; therefore their ecological significance is recognized and they are allowed to persist and serve as a refugium for flora, fauna and remnants of natural and semi-natural vegetation (Oertli et al. 2002, Joniak et al. 2007). The high phosphorus and nitrogen input into the aquatic environment resulting in the eutrophication of all inland surface water remains the major problem of water management in most European countries (Gelbrecht et al. 2005). According to the most recent literature, nitrogen compounds, which are included in artificial fertilizers, are one of the major factors responsible for accelerating the eutrophication of surface waters (Fairchild et al. 2005). This influences the quality of inland waters, which are endangered by the increase of trophic conditions as a result of enrichment from the catchment area (Joniak et al. 2006).

From the hydrological point of view water bodies play an important role, e.g. they contribute to moisturizing soils, however, their overeutrophication degrades their waters to a degree at which they almost resemble sewage conditions. In relation to sediments, visible consequences of eutrophication are quality changes: from hard sandy into soft and more organic. Sediments of such a type cause an increase in the internal enrichment in phosphorus, which accelerates the eutrophication (Dondajewska 2008). In the case of large water bodies (lakes, dam reservoirs) numerous methods for improving the water conditions have been described (eg Gołdyn 2000), while small water bodies have always been neglected. However, the development of certain rush and water vegetation, which play a major role in the intake of biophile nutrients, would be a simple solution in this case (Joniak et al. 2007).

In the Wielkopolska region, due to the frequency of land melioration, water supplies are among the most restricted in Poland. In such circumstances help for dry agricultural soils could be found in bogs and marshes, including small water bodies. Their importance in the landscape has been widely described, especially in the context of their environmental relationships or as a biogeochemical barrier (Hillbricht-Ilkowska 2005). Along with the constantly increasing trophic conditions of surface waters more and more attention should be paid to investigations of the bottom sediments. In the surface layer of the sediments considerable quantities of biogens are accumulated, which under anoxic conditions may be released into the water, thus accelerating the eutrophication process (Sobczyński and Joniak 2008). The aim of this investigation was to estimate the changeability of abiotic features of the aquatic environment and their impact on the structure of planktonic fauna communities in small water bodies undergoing anthropogenic influence of different levels of intensity connected with the location of those ponds within a pastoral catchment area.

MATERIALS AND METHODS

The examination of the physical-chemical features of water and bottom sediment was carried out during the summer of 2006 in 5 small (<2 ha), shallow water bodies (depth max. 1.1 m) located in the agricultural landscape of the Wielkopolska Lowland: Cotoń (No 1), Cotoń D (No 2), Cotoń O (No 3), Cotoń P (No 4) and Przysieka (No 5). All the investigated water bodies were situated in the neighborhood of the farms of two villages (Gniezno Lakeland; Żnin District, 52°40'N, 17°39'E). The area of examination is characterized by very low precipitation, which is responsible for supplying the upland areas with water. A common feature of those ponds was the occurrence of a layer of surrounding meadows. The distance from the farm buildings (±250 m) was a decisive factor while choosing the bodies of water for this study. It was decided that the location of the ponds in the neighbourhood of the farms would increase the probability of accelerating the effect of human impact and thus the effect of water degradation. For instance, ponds No. 2 and 4 displayed some traces of recent discharge of liquid waste products from domestic stock-farming. In the studied ponds there were no distinctly developed macrophyte communities observed, with the exception of pond No. 1 where stands of *Ceratophyllum demersum* and *Potamogeton natans* were identified.

The analysis included water and bottom sediments of all the water bodies and also two vegetated stations in pond No 1. Temperature, dissolved oxygen (DO), pH, electric conductivity (EC) and Secchi depth were measured directly at the sampling sites. In order to avoid disturbances connected with diurnal fluctuations of the intensity of photosynthesis the examination was carried out in the mid-day hours (between 11 A.M. and 3 P.M.). In water samples taken 5 cm under the surface the water colour, dissolved organic matter (DOM), total phosphorus (TP), total reactive phosphates (TRP), nitrate (N_{NO3}), nitrite (N_{NO2}), ammonium nitrogen (N_{NH4}) and total hardness ($CaCO_3$) were analyzed using the methods reported by Hermanowicz et al. (1999). Chlorophyll *a* was measured after extraction in 90% acetone. Water trophy was assessed according to the Carlson (1977) classification. The samples of bottom sediments were collected by a Kajak sampler (10 cm thick layer). After drying, the amounts of nitrogen (in a Kjeltec System), total phosphorus and organic matter in each sample were analysed (after sample combustion at 550ºC). The materials of the deposits were classified according to the content of their organic matter (Dobrzański and

Zawadzki 1981). The plankton material was taken in triplicate at each station using a plexiglass core sampler. Samples were concentrated using a 45 µm plankton net and fixed immediately with 4% formalin. Statistical calculations were conducted with Statistica 7.0 software.

RESULTS

The waters of the examined ponds located within the pastoral catchment area were characterized by a strong differentiation of oxygen concentration – from very low in ponds No. 2 and 4 (<1 mg l^{-1} O_2) to very high in No. 5 (19.1 mg l^{-1} O_2). The main reason for these discrepancies relates to the differentiated level of the load of organic matter between these water bodies. This was also confirmed by the values of absorbance of UV radiation and by water colour – from light yellow in pond No. 1 to dark brown in No. 4. A strong rotting smell in ponds No. 2 and 4 was noted. The pH ranged between neutral in ponds No. 2 and 4 up to alkaline (>8.0) in No. 1 and 5. The water salinity was between 355 to 1000 µS cm^{-1} (Table 1). Total hardness in most of the investigated ponds was high, with the exception of pond No. 2.

The main feature of the chemical characteristics of waters of the examined water bodies was a high concentration of biogenic elements, especially of phosphorus, phosphates and ammonium nitrogen. The presence of biologically available mineral elements stimulated the development of algae, which was reflected in high concentrations of chlorophyll *a* (Table 1). In four ponds eutrophy was recorded, while in one (No 4) hypertrophy was recorded. Phosphorus, whose index reached over 100 points in each water body, was a decisive factor in determining high values of TSI. High trophic conditions in the waters of the investigated ponds were also confirmed when analyzing the zooplankton community structure. Rotifer species *Anuraeopsis fissa* (Gosse) dominated in four of the ponds and in three of them its population reached over 90% of the total rotifer abundance. In the fifth pond another rotifer species – *Keratella cochlearis* f. *tecta* (Lauterborn) dominated.

The very high participation of phosphates in the TP pool, reaching over 75%, indicated a high bioavailability of these compounds to algae. The differentiation of the phytoplankton biomass between particular ponds was considerably high (minimum 18.3 µg l^{-1}, maximum 42.2 µg l^{-1}). This indicates that the development of phytoplankton depended on a number of environmental factors, not only on the biogenic group. No relationship between the phytoplankton biomass and the concentration of nitrogen or phosphorus forms was recorded, even though these forms are decisive for algae growth and development. However, a statistical analysis revealed a negative relationship between the concentration of chlorophyll *a* and DOM ($r = -0.64$, $\alpha<0.002$,

Table 1

The physical-chemical characteristics of water and bottom sediments of the researched water bodies (C.d. – *Ceratophyllum demersum*, P.n. – *Potamogeton natans*).

Parameter	Waters											Bottom sediments	
	Colour	DOM	EC	DO	TP	TRP	N_{NH4}	N_{NO3}	N_{min}	Hardness	Chl *a*	TP	TN
Pond/station	mg l^{-1} Pt	m^{-1}	µS cm^{-1}	mg l^{-1}	mg l^{-1} P		mg l^{-1}			mg l^{-1} $CaCO_3$	µg l^{-1}	mg P kg	mg N kg
No 1	32	2.2	953	7.7	1.41	1.37	1.38	0.12	1.5	368	29.4	201	1020
No 1 C.d.	38	3.8	930	6.6	1.49	1.32	0.56	0.15	0.72	352	3.9	-	-
No 1 P.n.	28	2.7	951	7.6	1.4	1.1	1.23	0.13	1.36	358	10.3	-	-
No 2	220	3.3	355	0.7	1.73	1.61	4.76	0.42	5.2	134	18.3	238	2660
No 3	68	1.8	977	7.8	1.45	1.33	1.64	0.16	1.8	236	28.9	449	5060
No 4	420	4.1	410	0.6	2.5	0.41	5.84	0.82	6.7	362	28.3	478	1670
No 5	44	1.1	883	19.1	0.26	0.19	0.94	0.11	1.1	486	42.2	234	2380

n=21), which fully reflects the negative influence of a surplus of organic compounds on the planktonic organisms.

The examined water bodies were differentiated with respect to the concentration of mineral nitrogen forms in the water. This mainly concerns ammonium ions, which in ponds No. 2 and 4 occurred in concentrations exceeding lethal doses for animal organisms and especially for fish (Table 1). In the case of zooplankton both these water bodies, and especially pond No. 4, registered the lowest mean abundance of zooplankton communities, however, lethal doses of ammonium did not seem to have a strong effect. This is possibly connected with the fact that all these water bodies were of eutrophic character and zooplankton was dominated by typically eutrophic forms which often tolerate high concentrations of nutrients. High concentrations of ammonium nitrogen are typical for contaminated waters, where, as a result of the deoxydation disturbances in organic matter, decomposition with the participation of bacteria microflora occur. In waters with hypoxia a decrease in the concentration of nitrates as a result of denitrification and/or their dissimilative reduction into ammonium nitrogen occurs. An increase in the concentration of nitrites which accompanies this process was also recorded – maximum 0.056 mg l^{-1} N_{NO2} (mean 0.035 mg l^{-1} N_{NO2}). Other chemical processes were found to occur in the small water bodies No. 1, 3 and 5, where better oxygen saturation in the water stimulated biochemical transformations of non-organic forms of nitrogen, presenting a different picture of the water chemistry (Fig. 1). The concentrations of biologically available nitrates occurring in the investigated ponds were low (< 1 mg l^{-1} N_{NO3}), however, in ponds No. 2 and 4 their concentrations were about 3-4 times higher than in the remaining water bodies. Low concentrations of this form of nitrogen are typical for good oxygen conditions.

In pond No. 1, where particular microhabitats within macrophyte species *Ceratophyllum demersum* and *Potamogeton natans* were also distinguished, a spatial analysis of the changeability of the water chemistry was carried out. In the macrophyte stations, especially with *Ceratophyllum demersum* a higher concentration of DOM than in open water was recorded (Table 1). In the same places lower concentrations of dissolved oxygen, ammonium and mineral compounds were found. Overshading of the open water area, due to the small surface of these ponds and the partial surrounding of the pond's banks by a line of trees, may have also contributed to the inhibition of the algae development. In all cases (total Crustacea, *Trichocerca rattus* (O.F. Müller), *Chydorus sphaericus* (O.F. Müller), *Simocephalus exspinosus* (Koch), *Ceriodaphnia pulchella* Sars) zooplankton densities revealed a negative relationship with chlorophyll *a* concentration (Table 2), which suggests that in the investigated ponds zooplankton was able to control phytoplankton biomass.

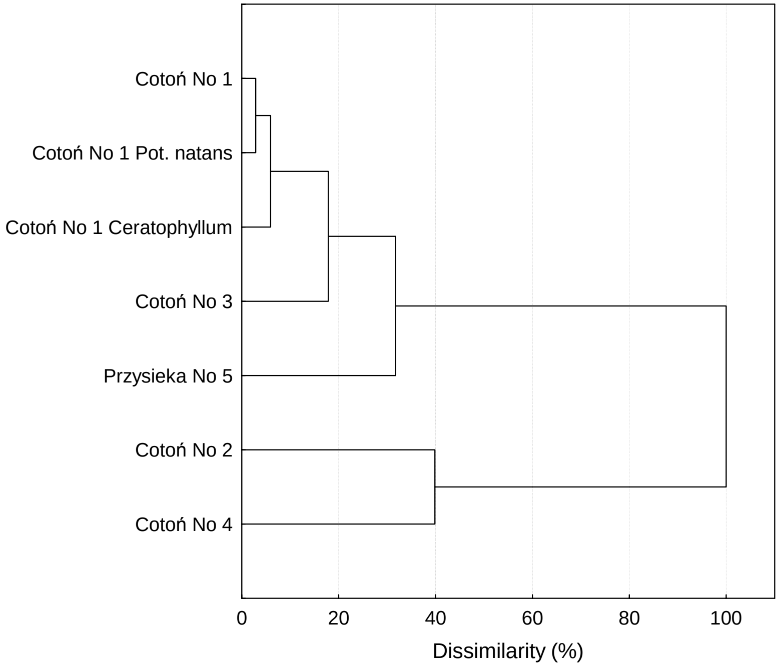

Fig. 1. The differentiation of physical-chemical variables of pond water (full linkage method with Manhattan or city-block distance).

The spatial differentiation between the aquatic vegetation stands and open water zone was found also in the case of zooplankton. Macrophyte stands were characterized by much richer communities and crustacean abundance was found to be statistically much higher among the hornwort stand followed by the stand of pondweed compared to the open water area. Moreover, *Ceriodaphnia quadrangula* (O.F. Müller) also revealed significant differentiation between the studied stations, with its highest densities among the *Ceratophyllum demersum* bed and the lowest in the open water area. It has been suggested that the differentiation of the zooplankton numbers between the investigated habitats may have been the result of predation as well as of the different nutritional sources present in these stations.

The mechanism of bottom sediment enrichment of biogenic substances in the nutrient bank in the water may also have a decisive effect on the biocoenotic structure. In pond numbers 1, 2, and 3 organic-mineral sediments occurred (organic matter <20%), in pond No. 4 organic (23%), and in No. 5 typically mineral (1%). The maximum concentration of nitrogen was recorded in the

Table 2

Coefficient of correlations for densities of particular zooplankton species and physical-chemical parameters of the water (DO – dissolved oxygen, N_{min} – mineral nitrogen, TP – total phosphorus, Chl-*a* – chlorophyll *a*, EC – electric conductivity)

Species	Parameter	r	*p*
Rotifera	TP	-0.45	0.029
Crustacea	DO	-0.50	0.021
	Chl *a*	-0.80	0.000
Bdelloidae	pH	-0.74	0.000
	TP	0.67	0.001
	DO	-0.63	0.002
Filinia longiseta	pH	0.54	0.011
	N_{min}	-0.54	0.012
	TP	-0.54	0.012
	DO	0.58	0.006
	EC	0.57	0.007
Keratella cochlearis f. *tecta*	pH	0.55	0.009
	N_{min}	-0.55	0.009
	EC	0.56	0.008
Lecane closterocerca	TP	0.66	0.001
	N_{min}	0.51	0.017
Lepadella patella	pH	-0.50	0.020
	TP	0.67	0.001
	DO	-0.55	0.010
	EC	-0.61	0.003
Synchaeta kitina	pH	0.49	0.025
	N_{min}	-0.47	0.032
	EC	0.50	0.019
Trichocerca rattus	DO	-0.46	0.036
	Chl *a*	-0.55	0.009
	TP	0.53	0.013
Ceriodaphnia pulchella	pH	0.45	0.041
	Chl *a*	-0.71	0.000
Chydorus sphaericus	Chl *a*	-0.79	0.000
Simocephalus exspinosus	Chl *a*	-0.82	0.000

sediments of pond No. 3 (Table 1), where, in the conditions of high water oxygenation, a high mineralization of organic matter took place. The overloading of the waters of ponds 2 and 4 by nitrogen compounds was not reflected in their concentrations in the bottom sediments. Moreover, the differentiation in the nitrogen concentrations in the sediments of the investigated water bodies was considerable, even though these concentrations were similar in the water. Such great discrepancies obtained in these ponds may have been connected with the dissimilarity of the quality features of sediments as well as with the moderation of the process of organic matter decomposition related to oxygen deficiency. Over 70% of the bottom sediments of pond No. 4 consisted of mineral silty fractions (the diameter of grains <0.0002 mm). This feature of the sediments was created from organic matter complexes of a high strength of bonding and by the immobilization of dissolved mineral compounds, especially of phosphates. This phenomenon was confirmed by the highest concentrations of phosphorus in sediments (478 mg kg^{-1} P). In the sediments of the second pond (No. 2) a 50% participation of easily permeable sand fractions (grain-size 0.5-1.0 mm) was recorded. The range of the phosphorus concentration changeability in the sediments was much smaller than the nitrogen (Table 1).

DISCUSSION

Small water bodies favour the creation of a mosaic structure of water vegetation, which in turn may contribute to the differentiation of the physical-chemical features of a habitat (Joniak et al. 2007). The character of surface waters depends to a large extent on the allochtonic parameters connected with the character and size of the catchment area. In small water reservoirs also an important role, if not the most important, is played by autochtonic parameters. In addition tophysical (sedimentation) and chemical (biodegradation of organic matter) parameters, the abundance and structure of aquatic macrophytes should be considered (Asaeda et al. 2000).

Small midfield water bodies in agricultural landscapes are marginal habitats because of the extreme physical-chemical conditions of their water and deposits; their ecological significance is recognised and they play an important biocoenotic role, which is reflected in the diversity of their zooplankton communities. Despite the important role played by these ponds, intensification of agriculture and the negative impact of human activity leads to their destruction by excessive eutrophication, the dumping of liquid wastes and hence to their decline.

The pastoral ponds are exposed to the additional inflow of great amounts of organic carbon from the humus compounds, which contribute the main part of DOM in the underground waters (Szpakowska 1999). The source of high concentrations of ammonia nitrogen is mainly inflow with rain and underground waters from the catchment area as well as some chemical processes, e.g. dissimilative reduction of nitrate or the changing, together with the dissolved oxygen concentration, direction of nitrification and to a great extent an effect of ammonification of organic matter which causes a release of ammonium from amino acids (Kajak 2001). The fractional differentiation of bottom sediment matter and the share of organic matter leads to different levels of mineral compounds in water. This confirms the role of the sediment quality in the process of the bonding of mineral products of mineralization of organic matter, which in the case of phosphorus is always lower (Sondergaard et al. 2003).

The dominant rotifer species in the researched ponds, *Anuraeopsis fissa* (Gosse) and *Keratella cochlearis* f. *tecta* (Lauterborn), are indicators of high trophy (Karabin 1985, Radwan et al. 2004), so their mass occurrence as well as the high densities of the zooplankton communities suggest a high trophy in these ponds. Phosphorus, whose index was always highest among all the trophic indexes (Carlson 1977), was a decisive factor influencing the level of trophic conditions. The reason for such a great differentiation of the water chemistry lies possibly in the morphological build of both macrophyte species. *Ceratophyllum demersum* is characterized by much greater dissection of its leaves, great areas of which are available for periphytic colonisation (Carpenter and Lodge 1986), compared to the much simpler build of *Potamogeton natans*, which is characterised by sparse plant stem structure with smooth and almost branchless shoots. There is evidence that different plant species possess various algae periphyton communities (Blindow 1987) which may in turn influence the physical-chemical features of the aquatic habitat. The more dense the macrophyte stand the higher the opportunities for an increase in the capacity of mechanisms of release and intake of nutritional substrates and oxygen from water. Low concentrations of chlorophyll *a* indicated the activity of complex macrophyte-periphyton, which best reflects the efficiency of grazing on phytoplankton organisms from water (Moss 1990). Aquatic plants are also known to play an extremely important role in the structuring of freshwater communities thereby influencing the interactions between predators and prey and acting as a food source (Jeppesen et al. 1998). The negative relationship between zooplankton densities and chlorophyll *a* concentration suggests that in the investigated ponds zooplankton was able to control phytoplankton biomass. Such a negative correlation between zooplankton abundance and the rates of primary production, measured as chlorophyll *a* content, has also been recorded by several other authors (e.g. Irfanullah and Moss 2005). The higher abundance of cladocerans within the most heterogeneous and dense habitat reflects more advantageous refuge conditions within the complex macrophyte stand in the pond with fish predation.

To sum up, it should be said that the small midfield water bodies in agricultural landscapes are marginal habitats because of the extreme physical-chemical conditions of their water and deposits; their ecological significance is recognised and they play important biocoenotic role, which is reflected by, for example, the diversity of their zooplankton communities. Despite the important role played by these ponds, intensification of agriculture and the negative impact of human activity leads to their destruction by excessive eutrophication and the dumping of liquid wastes.

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