JOURNAL OF WATER AND LAND DEVELOPMENT
ISSN 1429–7426, e-ISSN 2083-4535

Polish Academy of Sciences (PAN), Committee on Agronomic Sciences
Section of Land Reclamation and Environmental Engineering in Agriculture
Institute of Technology and Life Sciences (ITP)

JOURNAL OF WATER AND LAND DEVELOPMENT
2020, No. 45 (IV–VI): 133–142
https://DOI.org/10.24425/jwld.2020.133055

Available (PDF): http://www.itp.edu.pl/wydawnictwo/journal; http://journals.pan.pl/jwld

Received 3.01.2020
Reviewed 14.02.2020
Accepted 18.02.2020

Effect of the quality of shallow groundwaters on the occurrence of selected relic plant species of peatlands in the Łęczna-Włodawa Lakeland

Artur SERAFIN [1], Magdalena POGORZELEC [2], Urszula BRONOWICKA-MIELNICZUK [3] ✉

[1] University of Life Sciences in Lublin, Faculty of Production Engineering, Department of Environmental Engineering and Geodesy, Lublin, Poland
[2] University of Life Sciences in Lublin, Faculty of Biology, Animal Sciences and Bioeconomy, Department of Hydrobiology and Protection of Ecosystems, Lublin, Poland
[3] University of Life Sciences in Lublin, Faculty of Production Engineering, Department of Applied Mathematics and Computer Science, Lublin, Poland

For citation: Serafin A., Pogorzelec M., Bronowicka-Mielniczuk U. 2020. Effect of the quality of shallow groundwaters on the occurrence of selected relic plant species of peatlands in the Łęczna-Włodawa Lakeland. Journal of Water and Land Development. No. 45 (IV–VI) p. 133–142. DOI: 10.24425/jwld.2020.133055.

Abstract

The aim of the study was to compare the physical-chemical quality parameters of shallow groundwater quality in peat bogs of the Łęczna-Włodawa Lake District in the context of the occurrence of selected boreal species of plant relics: dwarf birch (*Betula humilis* Schrank), downy willow (*Salix lapponum* L.) and swamp willow (*Salix myrtylloides* L.). Analyzes of shallow groundwater quality parameters included physical-chemical parameters: reaction (pH), electrolytic conductivity (*EC*), dissolved organic carbon (DOC), total nitrogen (TN), ammonium nitrogen (NH_4), nitrite nitrogen (NO_2), nitrate nitrogen (NO_3), total phosphorus (TP), phosphate (PO_4), sulfate (SO_2), sodium (Na), potassium (K), calcium (Ca) and magnesium (Mg) by certified laboratory tests.

It was found that the natural hydrochemical specification of peat bogs is characterized by fluctuations associated with the dynamics of internal metabolism of peat ecosystems without the visible impact of anthropopressure. This is confirmed by the concentration of nutrients: TN at the study sites were within a broad range of mean values: 16.92–45.31 $mg \cdot dm^{-3}$; NH_4 (0.55–0.76 $mg \cdot dm^{-3}$); NO_2 (0.06–4.33 $mg \cdot dm^{-3}$); and NO_3 did not exceed 0.2 $mg \cdot dm^{-3}$, and concentration of TP adopted mean values in a range of 0.22–0.42 $mg \cdot dm^{-3}$.

The studied physical-chemical factors of shallow groundwater were within the habitat preferences of the studied species, but in differentiated qualitative and quantitative ways determined optimal conditions for building the population of the studied species. Particularly values of TP lower than other obtained values in a range of: 0.08–0.32 $mg \cdot dm^{-3}$; PO_4 = 0.1 $mg \cdot dm^{-3}$; TN = 2.2–21.2 $mg \cdot dm^{-3}$; NH_4 = 0.1–0.46 $mg \cdot dm^{-3}$; DOC = 24.6–55.9 $mg \cdot dm^{-3}$, as well as higher than average pH values in a range of: 5.34–5.95 and concentration of Ca = 5.67–28.1 $mg \cdot dm^{-3}$ and Mg = 0.56–2.41 $mg \cdot dm^{-3}$, as well as *EC* = 72.1–142.3 $\mu S \cdot cm^{-1}$ can be treated as a condition favouring proper development of the population of dwarf birch. For *Salix lapponum*: a reduced level of values of nitrogen fractions (TN = 3.01–18.84 $mg \cdot dm^{-3}$; NH_4 = 0.1–0.41 $mg \cdot dm^{-3}$), a reduced level of values of phosphorus fractions (TP = 0.09–0.44 $mg \cdot dm^{-3}$; PO_4 = 0.1–0.44 $mg \cdot dm^{-3}$), part of ions (Ca = 4.39–19.63 $mg \cdot dm^{-3}$; Mg = 0.77–3.37 $mg \cdot dm^{-3}$), pH = 5.9–6.4, *EC* = 124–266 $\mu S \cdot cm^{-1}$ and DOC = 24.1–57.5 $mg \cdot dm^{-3}$. For the equally studied *Salix myrtylloides*, such conditions were met by: TP = 0.1–0.41 $mg \cdot dm^{-3}$; PO_4 = 0.1–0.18 $mg \cdot dm^{-3}$, DOC = 27.5–50.9 $mg \cdot dm^{-3}$, pH = 5.3–5.94 and *EC* = 62.2–139.3 $\mu S \cdot cm^{-1}$.

Key words: *groundwater quality, peatlands, physical-chemical parameters, relic species, shallow groundwaters*

INTRODUCTION

The chemical composition of both surface and underground waters is therefore a resultant of the geochemistry of landscape depending on its geological and topographic features – overland flow and landscape retention [SZAFRAŃSKI *et al*. 1998]; specific climatic conditions; regional and local water management; type and intensity of land use in a given area; as well as type of vegetation [GRZYWNA 2014; MARCINEK *et al*. 1994]. The species composition and life forms of the flora, and mosaic character of phytocoenoses determine the potential of the biogeochemical barrier of plant assemblages – retention of biogenic substances and other pollutants [SERAFIN *et al*. 2019b].

Among anthropogenic factors, industry, municipal management, transportation, and tourism and recreation have the greatest contribution in polluting waters [SERAFIN *et al*. 2018; SOOMERS *et al*. 2013]. In the case of peatlands, the vicinity of agricultural areas constitutes the primary source of biogenic substances and post-production pollutants for this type of environment, causing a change in its fertility towards eutrophy [MISZTAL *et al*. 1992; SERAFIN *et al*. 2019b; SERAFIN, POGORZELEC 2011].

The quality of groundwaters is also closely related to rural settlement (point pollution sources), responsible for the highest concentrations of organic pollutants, ammonium nitrogen (NH_4), total phosphorus (TP), phosphates (PO_4), and chlorides (Cl). Moreover, villages have been recognized as having the strongest impact on the quality of surface waters [BURCZYK *et al*. 2015; ORZEPOWSKI *et al*. 2014].

An increase in the trophic status and productivity of habitats determined by a change in the chemical specification of groundwaters affects the qualitative transformation of the biocoenotic composition of phytocoenoses. The consequence of such a situation is monotypisation of biocoenoses determined by the development of competitive fast growing plants [WASSEN *et al*. 2005], e.g. common reed (*Phragmites australis*), and loss of biological diversity [BANASZUK, KAMOCKI 2016].

In a further perspective, this may lead to the transformation of turf peatland ecosystems into forest assemblages [OLACZEK *et al*. 1990]. The effect of such transformations in the peatlands of the Łęczna-Włodawa Lakeland is therefore a transformation of hydrological conditions concerning management of water resources, as well as the quality of groundwaters [SERAFIN *et al*. 2018].

A further consequence of such habitat transformations is the loss of local sites of occurrence of plant species failing to withstand revolutionary changes in the environment. They are often rare and protected Pleistocene boreal relics – species of willows: downy willow (*Salix lapponum*), swamp willow (*Salix myrtylloides*), and dwarf birch (*Betula humilis*) [POGORZELEC 2008; POGORZELEC 2009; SERAFIN *et al*. 2015a; SERAFIN *et al*. 2015b; SERAFIN *et al*. 2018; SERAFIN *et al*. 2019a; SOŁTYS, RÓŻYCKI 1996], playing an important role in the preservation of the species richness of the flora [GRANDCOLAS *et al*. 2014].

Numerous scientific studies and environmental monitoring provide vast amounts of data on the migration of pollutants to surface waters. The qualitative state of groundwaters of the first aquifer is considerably less investigated [ZBIERSKA *et al*. 2011].

Therefore, the investigation of the effect of physical-chemical groundwater parameters on the specificity of occurrence of rare and protected boreal relics is the primary element of the efficiency of their protection, and in the perspective of regulating water relations, as well as shaping the environment.

The aim of the study was therefore to compare the physical-chemical quality parameters of shallow groundwater quality in peat bogs of the Łęczna-Włodawa Lake District (Middle-East Poland) in the context of the occurrence of selected boreal species of plant relics: dwarf birch (*Betula humilis* Schrank), downy willow (*Salix lapponum* L.) and swamp willow (*Salix myrtylloides* L.) based on previous research [SERAFIN *et al*. 2015a, SERAFIN *et al*. 2015b; SERAFIN *et al*. 2018; SERAFIN *et al*. 2019a].

In the habitat aspect, all species of the analysed glacial relics prefer similar sites on mineral-humus and organic soils, considerably moist, oligotrophic, or mesotrophic, but rich in organic matter, neutral in terms of acidification or with acidic and moderately acidic reaction. As a result of dehydrogenation of the habitats of their occurrence related to the regulation of water relations, they are threatened or seriously threatened by extinction – they are subject to species protection [POGORZELEC 2008; POGORZELEC 2009; POGORZELEC *et al*. 2014; SERAFIN *et al*. 2015a; SERAFIN *et al*. 2015b; SERAFIN *et al*. 2019a; ZARZYCKI, KORZENIAK (eds.) 2002].

Therefore, the information obtained broadens knowledge about the issues of active protection of such species by specifying ranges of fluctuations in habitat factors and the most optimal conditions for the implementation of their life strategy.

STUDY METHODS

Based on reconnaissance research in the field, supported by laboratory analyses of shallow groundwaters in peatlands, representative locations were selected in the Łęczna-Włodawa Lakeland for different types of regional ecological research [SERAFIN *et al*. 2015a; SERAFIN *et al*. 2015b; SERAFIN *et al*. 2018; SERAFIN *et al*. 2019]. They were seminatural places with potentially limited human pressure and regulated hydrological relations (the Polesie National Park and its surroundings). Selected objects are: lake-peatland complexes: Lake Bikcze (B), Lake Karaśne (K), Lake Długie (D), Lake Moszne (M), Lake Lubowierz (L); forest peatland Blizionki (BZ), and wilderness Dekowina (DK) – Fig. 1.

Depending on the object, study sites were designated with the natural character confirmed by the botanical research, purposely diversified in terms of their abundance in the analysed species and the research procedure was conducted.

For dwarf birch they were sites: K, B, M, D, L and DK, for downy willow: K, L and BZ, and for swamp willow: M, DK and B. Sequences of abundance of particular places of occurrence of plant species in selected locations at the study sites were as follows: dwarf birch: K > B > M

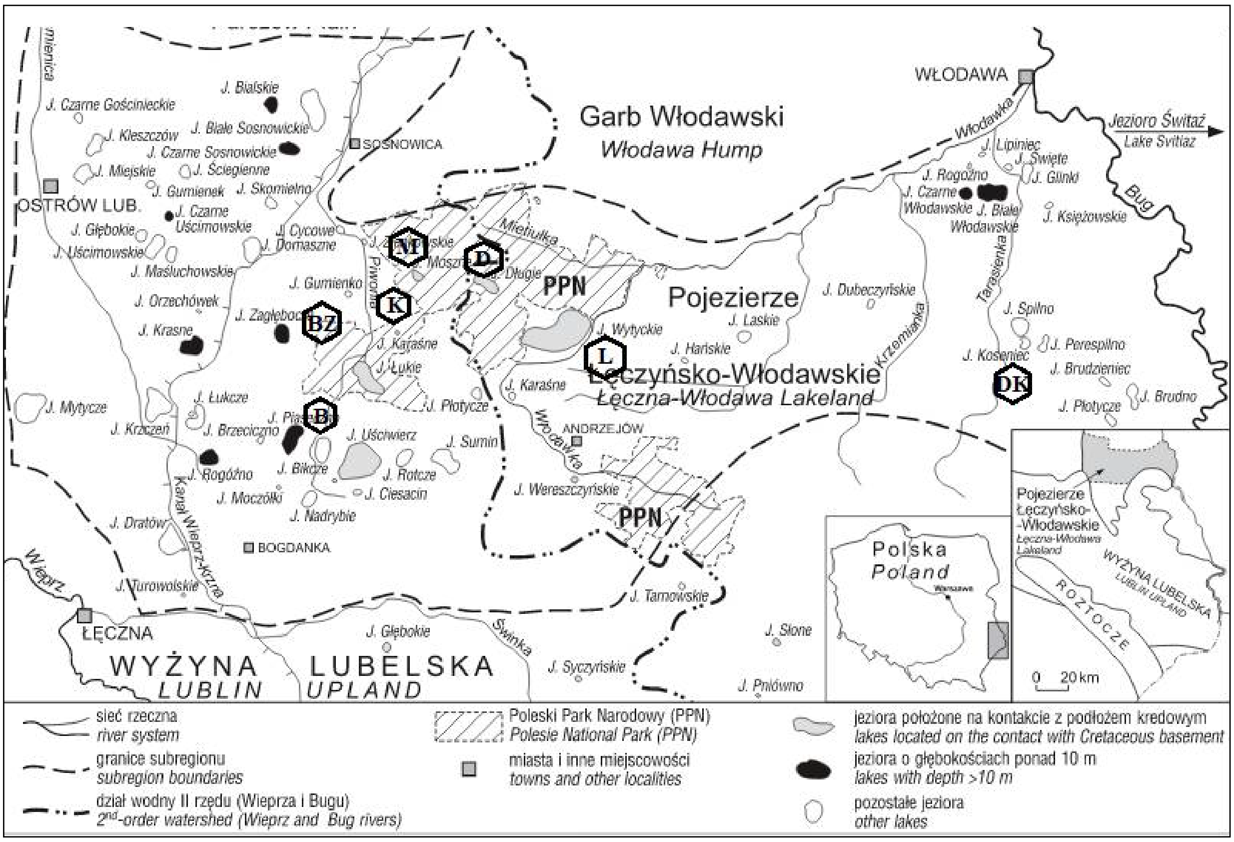


Fig. 1. Location of the study sites in the Łęczyńsko-Włodawskie Lake District; B, D, K, M, L, DK = dwarf birch sites, K, L, BZ = downy willow sites, B, M, DK = swamp willow sites; source: SERAFIN *et al*. [2019b], changed

= D = L = DK; downy willow: K > L > BZ (recent extinction of the species), and swamp willow: M > DK > B.

Next, in the centre of the study sites, piezometers were installed for sampling shallow groundwaters for laboratory analyses. Groundwater samples from the piezometers in the peatlands were collected for laboratory analyses three times (willow relics) or seven times (dwarf birch) in the vegetative season, over three – willow relics: 2011–2013 to four study seasons – dwarf birch: 2011–2014 [SERAFIN *et al*. 2015a; SERAFIN *et al*. 2015b; SERAFIN *et al.* 2018; SERAFIN *et al*. 2019a].

The analyses of quality parameters of shallow groundwaters important for the functioning of peatland phytocoenoses in the context of habitats covered the determination of 14 physical-chemical properties such as: reaction (pH), electrolytic conductivity (*EC*), dissolved organic carbon (DOC), nitrogen fractions: total nitrogen (TN), ammonium nitrogen (NH_4), nitrite nitrogen (NO_2), nitrate nitrogen (NO_3), phosphorus fractions: total phosphorus (TP), phosphate phosphorus (PO_4), concentration of sulphates (SO_4) and selected cations: sodium (Na), potassium (K), calcium (Ca), and magnesium (Mg).

The laboratory research was performed each time by means of certified methods at the Central Agroecological Laboratory of the University of Life Sciences in Lublin.
Results of the laboratory research were analysed in statistical terms for all sites (collective box plots), permitting the determination of the ecological tolerance of the analysed plant species in reference to each physical-chemical parameter of shallow groundwaters. Due to the rejection of hypotheses about the normality of distribution and homogeneity of variance, this part of analysis was carried out based on nonparametric methods. Therefore, the nonparametric Kruskal–Wallis test (K–W rank sum test) was applied with post hoc analysis assuming a significance level of 0.05. Box plots (upper and lower quartile) referred to K-W testing (*p*-value) provided information on the range of values of physical-chemical water properties important for a higher percent contribution of a given species. The principal components analysis (PCA) was performed for parameters which the K-W test indicated as significant. K-W tests and PCA analysis were carried out in the Statistica 13.

RESULTS AND DISCUSSION

Based on direct observations during water sampling for laboratory analyses, it was found that the level height of groundwaters in peatlands was determined to remain at a constant level, approximate to the level of peat, and showed inconsiderable oscillations only related to periods of seasons of the year, when higher hydration was recorded after snowmelts in the spring season, and somewhat lower in the summer period (therefore it was not the limiting factor). A lower level of groundwaters with similar dynamics was characteristic of sites not developing lake-peatland complexes – Blizionki (BZ), as well as Dekowina (DK) and Lubowierz (L – remains of an overgrown lake).

All study sites were therefore characterised by considerable hydration with intensity related to the character of the location itself (its relations to the close vicinity of the lake) and seasons of the year (snowmelt, dynamics of atmospheric precipitation).

The most important parameters of habitat quality of shallow groundwaters in peatlands may be biogenic substances [IGRAS, JADCZYSZYN 2008].

Natural plant communities have a great ability of self-regulation, and determine the circulation of biogenic substances [KÖSTER 2001]. Nonetheless, nutrients released in the process of mineralisation of organic or matter or of allochthonous origin are not fully retained by largely inefficient plant communities. They can then migrate from the soil to groundwaters, shaping their habitat quality in a secondary way [KIRYLUK, WIATER 2004]. The dynamics of biophysical-chemical processes in peatlands determined by the effect of human activity (e.g. changes in water regime, vicinity of agricultural areas) causes considerable fluctuations of the levels of the substances [BANASZUK, KAMOCKI 2016].

In terms of abundance of nutrients, concentrations of TN at the study sites were within a broad range of mean values: 16.92–45.31 mg·dm^{-3}; NH_4 (0.55–0.76 mg·dm^{-3}); NO_2 (0.06–4.33 mg·dm^{-3}); and NO_3 did not exceed 0.2 mg·dm^{-3}, and concentration of TP adopted mean values in a range of 0.22–0.42 mg·dm^{-3} (Fig. 2).
Higher mean values of nitrogen and phosphorus fractions were recorded for the sites of occurrence of relic species of willows: *Salix myrtilloides* – Bikcze (B**)**, Dekowina (DK), and Moszne (M), and *Salix lapponum* – Karaśne (K**)**, Blizionki (BZ), and Lubowierz (L). The situation was determined by incidentally high single results considerably diverging from the median for all the obtained values of biogenic substances (Fig. 2), and their variable values for particular study sites.

The possibilities of secondary eutrophication of peatland ecosystems can also be determined by the degree of their acidification and content of sulphur compounds in the soil solution [SAPEK 2014], as well as the concentration of sodium, potassium, calcium, and magnesium – the main base elements participating in shaping the reaction of soil solutions [LIGĘZA, SMAL 2004]. Their amount is regulated by sorption or release from sorption complexes of peatlands [STOLARCZYK *et al*. 2017].

The reaction of groundwaters at the sites of occurrence of all the analysed plant species was slightly acidic (pH = 5.61–5.67 – Fig. 2) and suitable for transitional bog and fen habitats occurring in the Łęczna-Włodawa Lakeland. The reaction values were stabilised, optimising the availability of nutrients for plants in the habitat. Mean values of SO_4 ion concentrations oscillated in a range of 2.51–4.94 mg·dm^{-3} (Fig. 2). The sequence of base metals for all sites and analysed plant species was as follows: Ca > Na > K > Mg, and based on the obtained values it did not suggest rapid phenomena of ion exchange between the sorption complexes and the soil solution (with the exception of incidental single results), although it evidenced greater presence of calcium hydroxides in the soil solution (regional condition). This points to the natural character of metabolic processes of the peatlands, because the agricultural use of the catchment favours an increase in the concentration of magnesium, calcium, and to an inconsiderable degree sodium, and a decrease in the concentration of potassium in its waters [POKŁADEK *et al*. 2011]. Very high Ca:Mg ratio, observed as the synthesis of information from obtained study results, also confirms lack of intensification of human pressure, because low values of such cation relations suggest the effect of municipal pollutants from built-up areas [BURCZYK *et al*. 2015; ORZEPOWSKI, PULIKOWSKI 2008].

Similarly, mean values of *EC* constituting an intermediate measure of assessment of water mineralisation and pollution, adopting a range of 99.28–184.8 µS·cm^{-1} (Fig. 2), did not suggest considerable intensification of human pressure at the study sites.

The basic factor of humeutrophication of groundwaters in peatlands is also the quantity and quality of dissolved organic matter (DOC), determining the availability of bioavailable forms of nitrogen and phosphorus related to humic substances the abundance of which depends on the dehydration of the peat deposit [GÓRNIAK 1996]. Values of the index for all the analysed plant species at the sites of their occurrence adopted the mean range of values from 40.35 to 50.21 mg·dm^{-3} (Fig. 2), not determining greater possibilities of secondary mobilisation of biogenic compounds for plants.

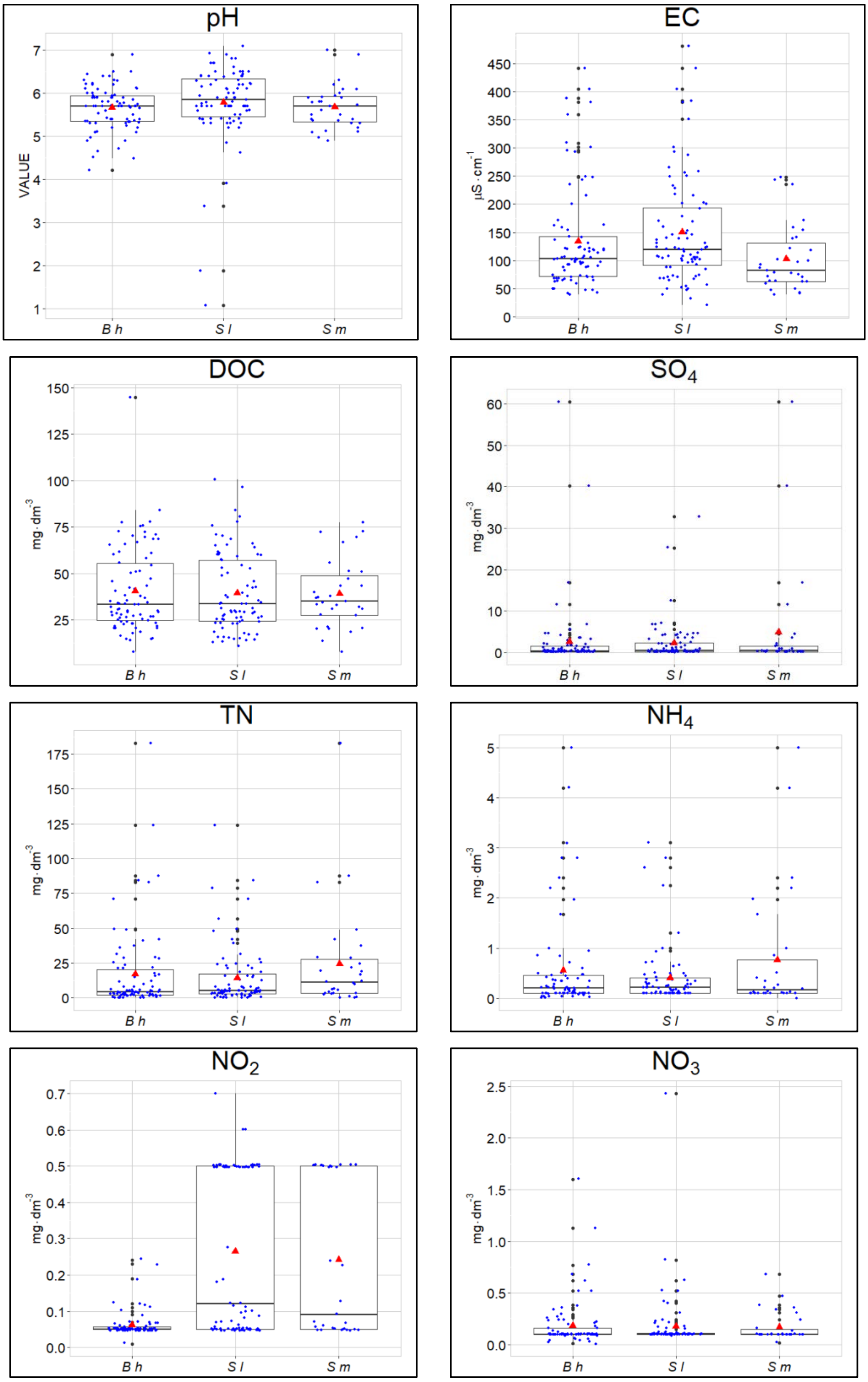
Reaction values, contents of sulphur substances, metals determining reaction, and DOC and *EC* in groundwaters of the sites of occurrence of glacial relics did not suggest the intensification of biophysical-chemical processes related to anthropogenic dehydrogenation of peat deposits. This confirmed the thesis on the natural character of the habitats and regulated water relations of selected study sites.

Like in the case of biogenic substances, part of other parameters analysed specifically for a given species and particular study sites showed incidental deviations of results, providing a misleading image of intensity of a given parameter.

For boreal relics, such factors were: *EC*, DOC, SO_4, Na, and Ca at sites of occurrence of *Betula humilis*, SO_4 and Na for sites of *Salix myrtilloides*, and for the occurrence of *Salix lapponum*: Na ions (Fig. 2).

Such issues should be associated with the dynamics of the internal metabolism of peatland ecosystems, shaped by co-occurring processes of mineralisation of organic matter and bioretention of nutrients by plant assemblages. They are characterised by labile balance determined by variable metabolic activity of microorganisms, variable productivity capacities of the flora, and temporally and spatially diverse development of the abiotic factors of the habitat [BANASZUK, KAMOCKI 2016]. Another important issue is the rate of exchange of groundwaters – in locations not developing lake-peatland complexes (low rate of exchange of groundwaters), the values of biogenic substances were considerably higher.

The broad amplitude of values of the majority of qualitative parameters of groundwaters in peatlands at the sites of occurrence of the analysed plant species confirmed the broad range of their ecological tolerance in reference to the character of the ecosystem (peatland), to the parameters,


pH
VALUE
B h
S l
S m
EC
µS · cm-1
DOC
mg · dm-3
SO4
TN
NH4
NO2
NO3

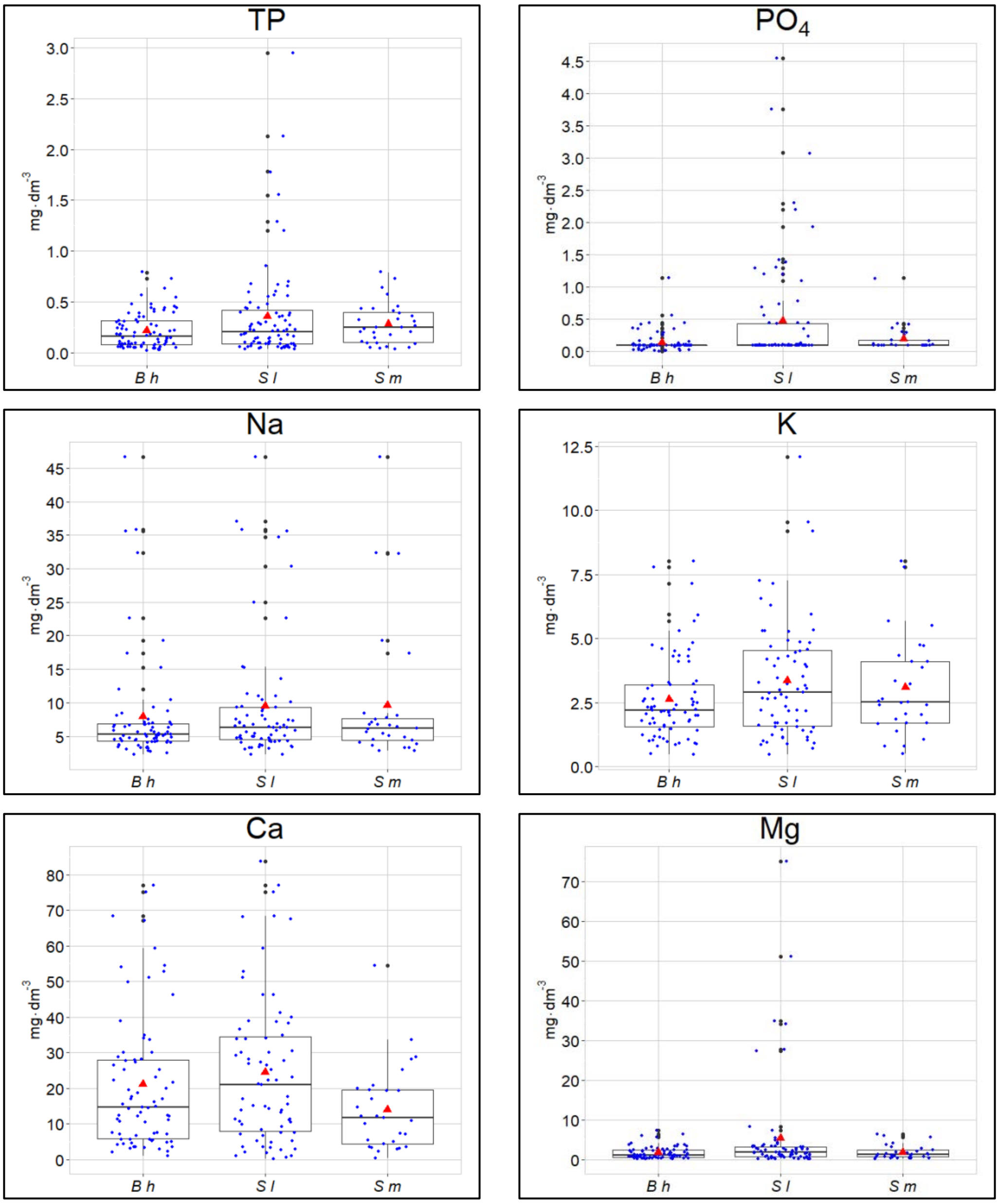


Fig. 2. Distribution of the values of the investigated physical-chemical parameters of piezometric groundwater at the study sites of relic plants: *Bh* = *Betula humilis*, *Sl* = *Salix lapponum*, *Sm* = *Salix myrtylloides*; pH = reaction, *EC* = electrolytic conductivity, DOC = total organic carbon, TN = total nitrogen, NH_4 = ammonium nitrogen, NO_2 = nitrite nitrogen, NO_3 = nitrate nitrogen, TP = total phosphorus, PO_4 = phosphate phosphorus, SO_4 = sulphates concentration, Na = sodium concentration, K = potassium concentration, Ca = calcium concentration, Mg = magnesium concentration; source: own study

and to regional locations. It was therefore concluded – the potentially favourable habitat conditions of occurrence of boreal relics outside of their compact range [JABŁOŃSKA 2009; POGORZELEC 2008; POGORZELEC *et al*. 2014].

Based on the this scientific research it was determined that values of biogenic substances in groundwaters of peatlands related to the occurrence of the analysed species were different for different species and study sites, and reflected the intensification of processes related to the eutrophication of the habitat to various degrees, however without exceeding mean mesotrophic values. Due to the location of the study sites in an area of potentially limited human pressure, this confirms the thesis on the effect of internal metabolism on the trophic status of peatland ecosystems [BANASZUK, KAMOCKI 2016; SMOLDERS *et al*. 2006].

The measure of specificity of occurrence of particular boreal relics is variability of hydrochemical conditions in reference to their sites. This is of particular importance in the case of analysis of locations the most abundant in the analysed species.

In reference to glacial relicts, higher values of parameters: pH, *EC*, and Ca in comparison to other sites were recorded for the study site on Lake Karaśne (K), constituting the site of the highest % contribution of Arctic dwarf birch in the phytocoenosis. In the case of N_{total}, NH_4, and DOC, their values at site Karaśne are lower in comparison to sites Dekowina (DK) and Lubowierz (L). In the case of phosphorus fractions, similar values were observed at sites K, D, and M, and higher for the remaining sites. For potassium, similar values were found for sites K, B, M, and L, inconsiderably higher in the case of site DK, and somewhat lower for site D. Values of Mg ions at site K were comparable to site B, and in the case of the remaining sites lower. Some physical-chemical water parameters, i.e. Na, SO_4, NO_2, and NO_3, had comparable values for all study sites, and therefore had no limiting effect on the abundance of the population of dwarf birch.

The lowest values of groundwater quality parameters in peatlands (with the exception of pH, *EC*, and SO_4 ion concentration) were recorded for the site of the most abundant population of *S. myrtilloides* on Lake Moszne (M). The lowest mean amplitude of the values of the analysed physical-chemical water parameters in the habitats, considering all the analysed sites of occurrence of the species in the Łęczna-Włodawa Lakeland, concerned the following parameters: NO_2, NO_3, SO_4, and Na, treated as factors limiting the occurrence of the analysed species, whereas TP, K, Ca, Mg, DOC, pH, and *EC* showed the highest amplitude, and in reference to the % contribution of the analysed species in the phytocoenoses, affecting the possibility of its occurrence to a variable degree. The lowest values of biogenic substances – the majority of fractions of nitrogen and phosphorus – were determined for *Salix lapponum* at the site most abundant in the species on Lake Karaśne (K). A small amplitude of values of TN, NO_3, phosphorus fractions, DOC, and pH was also recorded here. Among qualitative parameters of peatland groundwaters, NO_2, NO_3, SO_4, as well as K, Na, and Mg showed a similar distribution analysed separately at particular study sites – the distribution of values of the parameters was invariable in the habitats.

In spite of similar habitat requirements of the analysed plant species, the heterogenous distribution of values of variable physical-chemical parameters of groundwaters characterised their occurrence in a variable way.

The box-and-whisker plots show the distribution of the observations. In particular, the box represents the first and third quartiles. The horizontal line across the central region of the box represents the median. The mean value of the data is marked by a red filled triangle. The whiskers are drawn to the most extreme observations located no more than 1.5 times the inter-quartile range away from the box. When there are no outliers, the whiskers indicate the minimum and maximum values. The plot presents observed values of particular parameters, marked with blue dots.

More complete information on the concentration of the analysed habitat parameters in reference to the specificity of occurrence of boreal relics at particular sites is provided by results of statistical non-parametric Kruskal–Wallis tests (KW) at a significance level of 5% (Tab. 1–3). They permitted the determination of favourable conditions of groundwater quality for more abundant occurrence of the analysed species in the Łęczna-Włodawa Lakeland.

In the case of dwarf birch, the most statistically significant differences occurred between sites more abundant in individuals of the species (K, B), and sites DK and L with mutually similar and lower percent contribution of the analysed species in the phytocoenoses. They concerned the following values: TN, NH_4, TP, PO_4, DOC, pH, *EC*, as well as Mg and Ca. Particularly values of TP lower than other obtained values in a range of: 0.08–0.32 $mg·dm^{-3}$; PO_4 = 0.1 $mg·dm^{-3}$; TN = 2.2–21.2 $mg·dm^{-3}$; NH_4 = 0.1–0.46 $mg·dm^{-3}$; DOC = 24.6–55.9 $mg·dm^{-3}$, as well as higher than average pH values in a range of: 5.34–5.95 and concentration of Ca = 5.67–28.1 $mg·dm^{-3}$ and Mg = 0.56–2.41 $mg·dm^{-3}$, as well as *EC* = 72.1–142.3 $µS·cm^{-1}$ (Fig. 2, Tab. 1) can be treated as a condition favouring proper development of the population of dwarf birch in the Łęczna--Włodawa Lakeland.

Higher values of Ca and lower than average values of PO_4 also constituted favourable conditions for a higher abundance of the population of dwarf birch, which is probably related to the presence of soils rich in calcium hydroxides, binding phosphates and therefore limiting the dispersion of competitive fast-growing grasses and tree species [JABŁOŃSKA 2009].

For *Salix lapponum*, as a group of conditions contributing to its more abundant occurrence can be considered: a reduced level of values of nitrogen fractions (TN = 3.01–18.84 $mg·dm^{-3}$; NH_4 = 0.1–0.41 $mg·dm^{-3}$), a reduced level of values of phosphorus fractions (TP = 0.09–0.44 $mg·dm^{-3}$; PO_4 = 0.1–0.44 $mg·dm^{-3}$), part of ions (Ca = 4.39–19.63 $mg·dm^{-3}$; Mg = 0.77–3.37 $mg·dm^{-3}$), pH =

Table 1. Values of the Kruskal–Wallis test statistics, *p*-values and results of multiple comparisons for significantly variable parameters at particular study sites of *Betula humilis* occurrence

Analysed parameter	Kruskal–Wallis χ^2 statistic	*p*-value	Multiple comparison test, Kruskal–Wallis test														
			B-D	B-DK	B-K	B-L	B-M	D-DK	D-K	D-L	D-M	DK-K	DK-L	DK-M	K-L	K-M	L-M
TN	26.54	<0.0001															
TP	27.12	<0.0001															
NH_4	31.10	<0.0001															
PO_4	15.95	<0.0001															
DOC	31.31	<0.0001															
pH	50.39	<0.0001															
EC	47.47	<0.0001															
Mg	25.03	<0.001															
Ca	33.99	<0.001															

Explanations: sites for which significant differences were obtained at a significance level of 0.05 are marked with grey colour; TN = total nitrogen, TP = total phosphorus, NH_4 = ammonium nitrogen, PO_4 = phosphate phosphorus, pH = reaction, DOC = total organic carbon, *EC* = electrolytic conductivity, Mg = magnesium concentration, parameters SO_4, NO_2, NO_3, K, and Na – no significant differences.
Source: own study.

Table 2. Values of the Kruskal–Wallis test statistics, *p*-values and results of multiple comparisons for significantly variable parameters at particular study sites of *Salix lapponum* occurrence

Analysed parameter	Kruskal–Wallis χ^2 statistic	*p*-value	Multiple comparison test, Kruskal–Wallis test		
			BZ-L	BZ-K	L-K
TN	9.81	0.0074			
TP	21.40	<0.001			
NH_4	9.49	0.0087			
PO_4	32.39	<0.001			
DOC	17.82	0.0001			
pH	17.52	0.0002			
EC	19.73	0.0001			
Mg	6.58	0.0372			
Ca	12.69	0.0017			

Explanations: as in Tab. 1.
Source: own study.

Table 3. Values of the Kruskal-Wallis test statistics, *p*-values and results of multiple comparisons for significantly variable parameters at particular study sites of *Salix myrtylloides* occurrence

Analysed parameter	Kruskal–Wallis χ^2 statistic	*p*-value	Multiple comparison test, Kruskal–Wallis test		
			B-DK	B-M	DK-M
TN	11.24	0.0036			
TP	12.29	0.0021			
NH_4	9.86	0.0072			
PO_4	9.05	0.0108			
DOC	14.79	0.0006			
pH	15.64	0.0004			
EC	6.16	0.0460			
Mg	6.41	0.0405			

Explanations: as in Tab. 1.
Source: own study.

5.9–6.4, *EC* = 124–266 $\mu S \cdot cm^{-1}$ and DOC = 24.1–57.5 $mg \cdot dm^{-3}$ (Fig. 2, Tab. 2).

For the equally studied *Salix myrtylloides*, such conditions were met by: TP = 0.1–0.41 $mg \cdot dm^{-3}$; PO_4 = 0.1–0.18 $mg \cdot dm^{-3}$, DOC = 27.5–50.9 $mg \cdot dm^{-3}$, pH = 5.3–5.94 and *EC* = 62.2–139.3 $\mu S \cdot cm^{-1}$ (Fig. 2, Tab. 3).

This confirms findings from earlier scientific papers concerning relic willows in the Łęczna-Włodawa Lakeland [POGORZELEC 2008; POGORZELEC *et al*. 2014; URBAN, WAWER 2001].

In spite of similar habitat requirements, the occurrence of the analysed species in the Łęczna-Włodawa Lakeland was often determined, in a variable way, by different physical-chemical parameters describing the habitat quality of their sites of occurrence. It was therefore determined that on the study sites existing variable additional hydrochemical conditions affecting the occurrence of peatland plants at sites with preliminarily confirmed preferential values of groundwater quality parameters.

The statistical analyses were supplemented by indirect ordinance methods (PCA) aimed at detecting the structure and general patterns between the analysed physical-chemical water parameters at particular sites. The principal components (PCA) analysis was performed for parameters which the K-W test indicated as significant.

In the case of *Betula humilis*, the first two components explain 55.4% of the total variation (Fig. 3a). The first

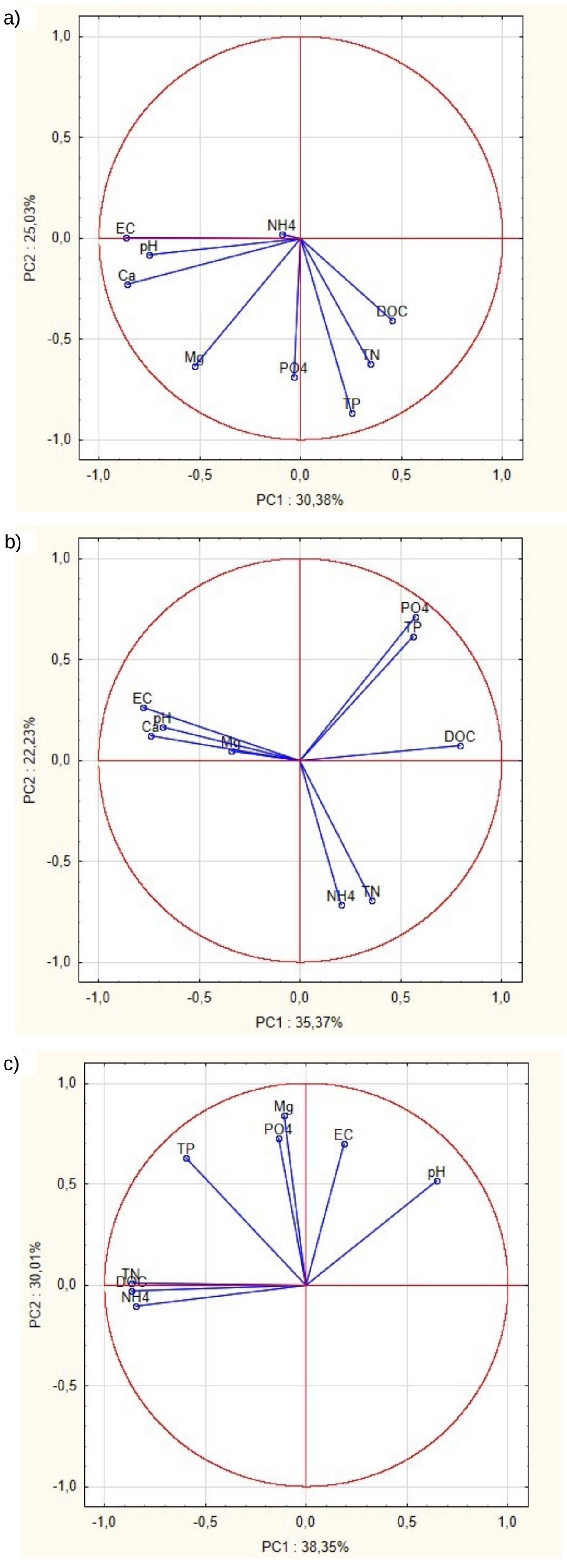


Fig. 3. Principal component analysis (PCA) for physical-chemical parameters of groundwater for investigated speciesstudy sites: a) *Betula humilis*, b) *Salix lapponum*, c) *Salix myrtylloides*; source: own study

component (PC1) is associated with the parameters *EC*, pH and Ca, while the second (PC2) with TP, TN, PO_4 and Mg. There is a strong positive correlation between the parameters *EC*, pH and Ca as well as TP and TN. In contrast, a correlation close to zero is characterized by the relationship between DOC and Mg, TN and Ca, pH and TP as well as *EC* and PO_4 (Fig. 3a). For *Salix lapponum*, the first two components explain 57.59% of the total variability (Fig. 3b). The first component (PC1) is associated with the parameters DOC, pH, *EC* and Ca, while the second (PC2) with TN, TP, NH_4 and PO_4. In addition, a very strong positive correlation can be found between the parameters for which the vectors representing them overlap (TP and PO_4, pH, *EC* and Ca, NH_4 and TN) – Figure 3b. In a case of *Salix myrtylloides*, the cumulative variance for the first two major components was 68.36% (Fig. 3c). The first component (PC1) is associated with the DOC, TN and NH_4 parameters, while the second (PC2) with Mg, PO_4 and EC. In addition, a very strong positive correlation can be found between TP, DOC and NH_4 as well as PO_4 and Mg and close to zero between pH and TP (Fig. 3c).

CONCLUSIONS

The dynamics of habitat transformations in the peatlands of the Łęczna-Włodawa Lakeland, however, determines considerable disturbances of the abiotic and biocoenotic conditions of habitats causing a reduction of the number of sites of occurrence and individuals building local populations of the species. In such a situation, the specificity of its occurrence can be a reflection of transformations in their habitats, particularly in reference to hydrochemical conditions, often modified anthropogenically.

The optimal values of groundwater quality parameters determined in the research, favouring a greater share of the studied boreal relics in plant communities, are only partly within the limits described in the literature as the best. This probably results from the abiotic features of sites of occurrence outside the compact range, including climatic features of the peatlands of the Łęczna-Włodawa Lakeland, where higher abundance of boreal relics is characterised by regionally determined hydrochemical specificity of habitats (probable regional evolutionary adaptation). The characteristics of occurrence of such species in reference to hydrochemical parameters of habitats are therefore of regional dimension determined by the abiotic features of the Łęczna-Włodawa Lakeland.

Based on the hydrochemical specification of the habitats of the studied species, the following conclusions can be drawn.

1. Quality parameters of shallow groundwaters in the peatlands of the Łęczna-Włodawa Lakeland (selected representative places) do not point to intensified human pressure or deregulation of hydrological relations.
2. Natural hydrochemical specification of peatlands is characterised by fluctuations related to the dynamics of the internal metabolism of the ecosystem.
3. The analysed physical-chemical parameters of shallow groudwaters are within the habitat preferences of the analysed species.
4. The same habitat preferences do not reflect the same values of physical-chemical water parameters important for building populations of the analysed species.
5. The occurrence of the analysed plant species is determined by the hydrochemical specification of the habitat, but the characteristics of their occurrence point to its specific hydrochemical parameters only to a low degree.

FUNDING

Publication is funded by the Polish National Agency for Academic Exchange under the International Academic Partnerships Programme from the project „Organization of the 9th International Scientific and Technical Conference entitled Environmental Engineering, Photogrammetry, Geoinformatics – Modern Technologies and Development Perspectives”.

REFERENCES

BANASZUK P., KAMOCKI A. K. 2016. Statyczny jakościowy bilans wodny jako podstawa renaturyzacji ekosystemów hydrogenicznych w dolinie górnej Biebrzy [Quality water balance as a base for wetlands restoration in the upper Biebrza Valley]. Inżynieria Ekologiczna. Vol. 48 p. 96–106. DOI 10.12912/23920629/63277.

BURCZYK P., RAWICKI K., GAŁCZYŃSKA M., BRYSIEWICZ A., MARCINIAK A. 2015. Ocena stężenia magnezu i wapnia w wodach gruntowych na terenach rolniczych Pomorza Zachodniego [An assessment of magnesium and calcium content in groundwater in agricultural areas of Pomorze Zachodnie]. Woda-Środowisko-Obszary Wiejskie. T. 15. Z. 3 (51) p. 15–23.

GÓRNIAK A. 1996. Substancje humusowe i ich rola w funkcjonowaniu ekosystemów słodkowodnych [Humic substances and their role in the functioning of freshwater ecosystems]. Rozprawy Uniwersytetu Warszawskiego. T. 448. Białystok. Dział Wydawnictw Filii Uniwersytetu Warszawskiego. ISBN 83-86423-51-X pp. 151.

GRANDCOLAS P., NATTIER R., TREWICK S. 2014. Relict species: A relict concept?. Trends in Ecology and Evolution. Vol. 29(12) p. 655–663. DOI 10.1016/j.tree.2014.10.002.

GRZYWNA A. 2014. Chemiczne wskaźniki jakości wody w zlewni lasów parczewskich [Chemical water quality indicators in basin forest Parczew]. Inżynieria Ekologiczna. Vol. 36 p. 120–127. DOI 10.12912/2081139X.08.

IGRAS J., JADCZYSZYN T. 2008. Zawartość azotanów i fosforanów w płytkich wodach gruntowych w Polsce [Contents of nitrogen and phosphorus compounds in the shallow groundwaters in Poland]. Problemy Inżynierii Rolniczej. Nr 2(60) p. 91–101.

JABŁOŃSKA E. 2009. Brzoza niska *Betula humilis* Schrank w Polsce – status fitocenotyczny, warunki siedliskowe, zagrożenia i ochrona [*Betula humilis* Schrank in Poland – phytocoenotic status, habitat conditions, threats and protection]. PhD Thesis. [Access 29.11.2019]. Available at: https://www.researchgate.net/publication/270283403

KIRYLUK A., WIATER J. 2004. Stężenie składników pokarmowych w wodach odpływających z ekstensywnych ekosystemów łąkowych [Concentration of nutrients in water flowing from extensive meadow ecosystems]. Woda-Środowisko-Obszary Wiejskie. T. 4. Z. 2a(11) p. 445–453.

KÖSTER T. 2001. The productivity and nutrient cycle of natural grassland. Zeszyty Problemowe Postępów Nauk Rolniczych. Z. 478 p. 47–53.

LIGĘZA S., SMAL H. 2004. Odczyn, przewodnictwo właściwe oraz stężenie pierwiastków zasadowych w roztworach glebowych gleb użytkowanych jako wybiegi na fermach gęsi [Reaction, electrical conductivity and concentration of alkaline elements in soil solutions from the soils located in goose farms]. Annales UMCS. Sect. E. Vol. 59(4) p. 1613–1619.

MARCINEK J., KOMISAREK J., KAŹMIEROWSKI C. 1994. Dynamika składników rozpuszczalnych w wodach gruntowych uprawnych gleb płowych i czarnych ziem [Dynamics of solutes concentration in ground water of cultivated Hapludalfs and Endoaquolls]. Roczniki AR Poznań. Melioracje i Inżynieria Środowiska. T. 268(15) p. 69–82.

MISZTAL M., SMAL H., GÓRNIAK A. 1992. Ground water inflow of nutrients to the lake from differently utilized catchments. Water Research. Vol. 26. Iss. 9 p. 1237–1242. DOI 10.1016/0043-1354(92)90184-6.

OLACZEK R., KUCHARSKI L., PISAREK W. 1990. Zanikanie obszarów podmokłych i jego skutki środowiskowe na przykładzie województwa piotrkowskiego (zlewni Pilicy i Warty) [The disappearance of waterlands and its environmental effects on the basis of the Piotrkow Voivodeship (the Pilica and Warta basins)]. Studia Ośrodka Dokumentacji Fizjograficznej Vol. 18 p. 141–199.

ORZEPOWSKI W., PARUCH A.M., PULIKOWSKI K., KOWALCZYK T., POKŁADEK R. 2014. Quantitative and qualitative assessment of agricultural water resources under variable climatic conditions of Silesian Lowlands (Southwest Poland). Agricultural Water Management. Vol. 138 p. 45–54. DOI 10.1016/j.agwat.2014.02.012.

ORZEPOWSKI W., PULIKOWSKI K. 2008. Magnesium, calcium, potassium and sodium content in groundwater and surface water in arable lands in the commune (gmina) of Kąty Wrocławskie. Journal of Elementology. Vol. 13. Iss. 4 p. 605–614.

POGORZELEC M. 2008. Influence of chosen environmental abiotic factors on *Salix lapponum* L. populations functioning in Polesie Lubelskie Region. Polish Journal of Environmental Studies. Vol. 17(4) p. 139–144.

POGORZELEC M. 2009. Downy willow (*Salix lapponum* L.) as a component of different phytocoenosis in Poleski National Park. Acta Agrobotanica. Vol. 62(1) p. 107–116. DOI 10.5586/aa.2009.013

POGORZELEC M., BRONOWICKA-MIELNICZUK U., BANACH B., SZCZUROWSKA A., SERAFIN A. 2014. Relict boreal willows (*Salix lapponum* and *Salix myrtilloides*) as an element of phytocoenoses overgrowing the water bodies in Eastern Poland. Applied Ecology and Environmental Research. Vol. 12(2) p. 441–456. DOI 10.15666/aeer/1202_441456.

POKŁADEK R., KOWALCZYK T., ORZEPOWSKI W., PULIKOWSKI K. 2011. Na, K, Ca and Mg concentrations in effluent water drained from agricultural catchment basins in Lower Silesia. Journal of Elementology. Vol. 16(3) p. 467–480. DOI 10.5601/jelem.2011.16.3.11.

SAPEK B. 2014. Nagromadzanie i uwalnianie fosforu w glebach – źródła, procesy, przyczyny [Soil phosphorus accumulation and release – sources, processes, causes]. Woda-Środowisko-Obszary Wiejskie T. 14. Z. 1(45) p. 77–100.

SERAFIN A., POGORZELEC M. 2011. Changes in the flora of the eastern and southern parts of lake Piaseczno embankment in the years 2003–2010. Acta Agrobotanica. Vol. 64(4) p. 141–150. DOI 10.5586/aa.2011.055.

SERAFIN A., POGORZELEC M., BANACH B., MIELNICZUK J. 2015a. Habitat conditions of the endangered species *Salix myrtilloides* in Eastern Poland. Dendrobiology. Vol. 73 p. 55–64. DOI 10.12657/denbio.073.006.

SERAFIN A., POGORZELEC M., BANACH B., SZCZUROWSKA A., MIELNICZUK J. 2015b. Physico-chemical groundwater conditions at *Salix lapponum* stands in Eastern Poland. Dendrobiology. Vol. 73 p. 65–74. DOI 10.12657/denbio.073.007.

SERAFIN A., URBAN D., BRONOWICKA-MIELNICZUK U., SZCZUROWSKA A. 2018. To what degree can the specifics of occurrence of glacial relic *Betula humilis* Schrank be an indicator of habitat conditions of moderate climate peatlands?. Water. Vol. 10, 1062 p. 1–19. DOI 10.3390/w10081062.

SERAFIN A., POGORZELEC M., BRONOWICKA-MIELNICZUK U. 2019a. Hierarchisation of abiotic environmental properties – methodical study for research on the ecology of plants conducted in peat bog habitats. Applied Ecology and Environmental Research. Vol. 17. Iss. 2 p. 4081–4096. DOI 10.15666/aeer/1702_40814096.

SERAFIN A., SENDER, J., BRONOWICKA-MIELNICZUK U. 2019b. Potential of shrubs, shore vegetation and macrophytes of a lake to function as a phytogeochemical barrier against biogenic substances of various origin. Water. Vol. 11, 290 p. 1–33. DOI 10.3390/w11020290.

SMOLDERS A.J.P., LAMERS L.P.M., LUCASSEN E.C.H.E.T., VAN DER VELDE G., ROELOFS J.G.M. 2006. Internal eutrophication: How it works and what to do about it – A review. Chemistry and Ecology. Vol. 22(2) p. 93–111. DOI 10.1080/02757540600579730.

SOŁTYS M., RÓŻYCKI A. 1996. Rzadkie i zagrożone gatunki flory naczyniowej w Poleskim Parku Narodowym. W: Funkcjonowanie ekosystemów wodno-błotnych w obszarach chronionych Polesia [Rare and endangered vascular flora species in the Polesie National Park. In: The functioning of wetland ecosystems in protected areas of Polesie]. Ed. S. Radwan. Lublin. Wydaw. UMCS p. 89–93.

SOOMERS H., KARSSENBERG D., VERHOEVEN J.T.A., VERWEIJ P.A., WASSEN M.J. 2013. The effect of habitat fragmentation and abiotic factors on fen plant occurrence. Biodiversity and Conservation. Vol. 22 p. 405–424. DOI 10.1007/s10531-012-0420-1.

STOLARCZYK M., GUS M., JELONKIEWICZ Ł. 2017. Zmiany we właściwościach chemicznych gleb torfowych wskutek odwodnienia na przykładzie Tarnawy Wyżnej (Bieszczady Zachodnie) [Changes in the chemical properties of peat soils as a result of drainage on the example of Tarnawa Wyżna (Western Bieszczady Mts.)]. Roczniki Bieszczadzkie. T. 25 p. 387–402.

SZAFRAŃSKI CZ., FIEDLER M., BYKOWSKI J. 1998. Czasowo-przestrzenna zmienność chemizmu wód na Pojezierzu Gnieźnieńskim na przykładzie obiektu Mokronosy [Groundwater quality in the agricultural microcatchment on Gniezno Lakeland]. Przegląd Naukowy Wydziału Melioracji i Inżynierii Środowiska. Vol. 16 p. 262–269.

URBAN D., WAWER M. 2001. *Salix lapponum* L. i *S. myrtilloides* L. in the area of Sobibór in the Łęczyńsko-Włodawskie Lake District. Annalles UMCS. Vol. 56(11) p. 83–93.

WASSEN M.J., VENTERINK H.O., LAPSHINA E.D., TANNEBERGER F. 2005. Endangered plants persist under phosphorus limitation. Nature. Vol. 437 p. 547–550. DOI 10.1038/nature03950.

WOJCIECHOWSKI I. 1997. Funkcjonowanie ekosystemów torfowiskowych [The functioning of peat ecosystems]. Lublin. AR w Lublinie – Katedra Ekologii Ogólnej pp. 23.

ZARZYCKI K., KORZENIAK U. (eds.). 2002. Ecological indicator values of vascular plants of Poland. Kraków. Inst. Botaniki PAN. ISBN 83-85444-95-5 pp. 182.

ZBIERSKA J., ŁAWNICZAK A.E., KUPIEC J., ZBIERSKA A. 2011. Stężenie składników biogennych w wodach gruntowych i podziemnych w zlewni bezpośredniej Jeziora Niepruszewskiego narażonego na zanieczyszczenia pochodzenia rolniczego [Nutrient concentration in ground and underground water in the Niepruszewskie Lake catchment vulnerable to nitrate from agricultural sources]. Nauka Przyroda Technologie. T. 5. Z. 5 #103.