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Spatial structure of vegetation in a small charophyte dominated lake

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Abstract: The aim of the paper was to recognize the current spatial structure and organization of vegetation and the diversity of charophytes on an ecosystem scale of a small, outflow Lake Jasne (Western Poland). The lake is characterized by limited anthropogenic pressure and forested catchment basin. The study was performed in the vegetative season 2010. The vegetation was studied along transect, using the mid-European Braun-Blanquet method of phytosociological relevés. Additionally, basic physical-chemical parameters were measured, to characterize habitat conditions of the lake. The results of physical-chemical analyses evidenced high water quality, and obtained parameter values were typical for mesotrophy. The vegetation survey revealed that almost 70% of the lake's bottom was overgrown by vegetation. The transects documented the structure of phytolittoral typical for chara-lake and the spatial dominance of charophytes in the studied lake (charophyte meadows reached up to 64% of the phytolittoral area). Charophytes were also defining the maximum depth extent of vegetation in Lake Jasne, reaching 5.6 m. As many as 10 charophyte species were stated: *Chara virgata, Ch. aspera, Ch. filiformis, Ch. globularis, Ch. intermedia, Ch. polyacantha, Ch. rudis, Ch. tomentosa, Nitella flexilis* and *Nitellopsis obtusa*, out of which 7 build their own communities. The large number of species (10 of 35 identified so far in Poland) and communities (7 of 30 identified in Poland), as well as their share in phytolittoral, define Lake Jasne as a valuable refuge of European natural habitat, code 3140.

Key words: charophytes, Characeae, spatial structure of vegetation, chara-lake

1. Introduction

Charophytes, representing family Characeae (Charales, Charophyceae, Chlorophyta), submerged macroscopic green algae, are well distributed all over the world and occur in various types of aquatic environments (marine, brackish and freshwater, standing and flowing, permanent and ephemeral). Most freshwater species prefer alkaline lake ecosystems (Wood & Imhori 1965; Krause 1997; Martin *et al.* 2003).

Lakes in which charophytes form communities, built by diverse species, are observed more and more rarely. Dense charophyte meadows are mostly limited to the littoral zone, usually between less than 1 m to about 10 m in depth (Garcia 1994). They occur in oligotrophic to moderately eutrophic (mostly mesotrophic), unpolluted waters (Hutchinson 1975; Moore 1986; Krause 1997). High abundance and diversity of charophyte flora and vegetation in aquatic ecosystems is commonly considered as an indicator of good water quality (Forsberg 1964; Forsberg *et al.* 1990; Krause 1981, 1997; Schwarz & Hawes 1997). It was stated, that with the increase in trophy and decrease in water quality, charophytes disappear as ones of the first within submerged vegetation (Ozimek & Kowalczewski 1984; Blindow 1992a, 1992b; Simons & Nat 1996; Schwarz *et al.* 1999; Auderset Joye *et al.* 2002). For many years such negative reaction was interpreted as an effect of high phosphorus concentration toxicity (Forsberg 1964; Blindow 1988; Simons *et al.* 1994; van den Berg *et al.* 1998a and references quoted therein). Thus, these macroalgae are considered as sensitive bioindicators and a tool in the classifications of trophy or ecological status (Poikane *et al.* 2003; van de Weyer 2004; Ciecierska 2008 and literature quoted therein). Nowadays, light limitation, as an indirect effect of high nutrient concentration and phytoplankton biomass production, is considered most relevant for charophyte occurrence (Ozimek & Kowalczewski 1984; Blindow 1992a; van den Berg *et al.* 1998b; Schwarz *et al.* 1999; Pełechaty *et al.* 2004).

One of the most interesting regions of Poland, as regards the diversity of lakes, is Lubuskie province (mid-Western Poland). For many previous years this region was among poorly recognized parts of Poland, as far as the hydrobiological research is concerned. Due to the varied postglacial relief, highest forestry, low population density and no heavy industry this region is characterized by diverse types of well preserved lakes, that is favorable for high species diversity. Charophyte investigations conducted so far in this region (Dąmbska 1962, 1964, 1966; Pełechaty *et al.* 2007; Pełechaty & Pukacz 2008; Kraska 2009) indicated 23 species, representing 5 genera known from Poland (*Chara*, *Nitellopsis*, *Lychnothamnus*, *Nitella* and *Tolypella*).

An example of a well preserved charophyte-rich ecosystem is mid-forest Lake Jasne. Ecological studies, which have been carried out within this lake since 2004, have revealed this is a typical chara-lake, with a high abundance of charophyte flora and vegetation (Pełechaty *et al.* 2007, 2010). The aim of this macro-scale study was to recognize the current spatial organization and structure of vegetation and the diversity of charophytes in Lake Jasne.

2. Materials and methods

2.1. Object of study

The object of presented study, Lake Jasne, is localized in a mesoregion of Torzym Plain in mid-western Poland (Fig. 1). The lake is placed in the most

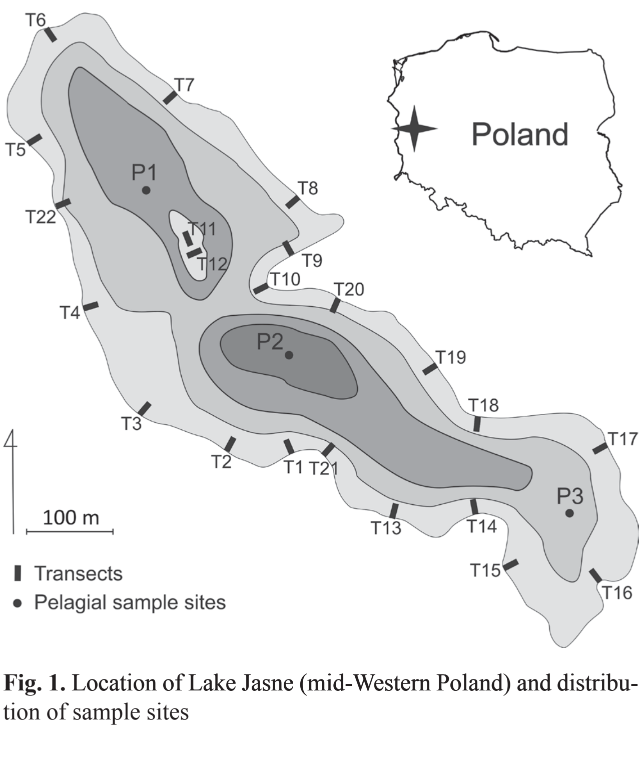


Fig. 1. Location of Lake Jasne (mid-Western Poland) and distribution of sample sites

southern part of Gronów-Rzepin-Torzym postglacial tunnel-valley (52°17’7”N, 15°03’6”E). The nearest place, Torzym, is about 3 km north from the lake. The lake’s direct drainage basin constitutes a partial catchment of the left-side tributary of the Ilanka River. Over 90% of the drainage basin is covered by forests (mostly pine forests), which is an important isolating factor owning to highly inclined slopes. During the summer season, Lake Jasne is commonly used for recreation purposes, so all around a few unguarded beaches and several fishing sites are situated.

It is a small outflow lake with the area of 15.1 ha and maximum depth of 9.6 m (mean depth: 4.3 m), which belongs to the group of moderately shallow lakes (Pełechaty *et al.* 2007). The lake basin consists of three separate basins (Fig. 1). The central basin is the deepest part of the lake with no fully developed vertical stratification and warm above-bottom waters. The SE basin is most shallow and it adjoins a small peatland, which was formerly a part of the lake. The NW basin is the biggest and in its central part, a ca. 100 m long and 50 m width shallowness is situated. The littoral is very diversified around the lake – from very mild to very steep bottom slopes and from mineral to organic substratum, however, the mineral substratum predominate up to ca. 3 m depth. At the deepest parts of the bottom, fine-grained organic substratum was predominating.

2.2. Methods

The field study was performed at the peak of growing season (July 2010). To recognize the species composition and spatial structure of the vegetation in Lake Jasne the mid-European Braun-Blanquet (1964) method of phytosociological relevés was used. In each record all species were listed and the percentage of area covered by species was estimated according to the following scale: r – <0,1%; + – 0,1%; 1 – 2,5%; 2 – 5-25%; 3 – 25-50%; 4 – 50-75%; 5 – 75-100%. The phytosociological reléves of 16 m^{-2} were performed every 1 m of depth (starting from the shore to the maximum depth of vegetation) along 22 transects established perpendicularly to the shoreline (Fig. 1). The transects were localized arbitrary around the lake, to reflect the vegetation structure. For the vegetation, mapping of additional relevés and notes were also performed. The submerged vegetation was surveyed by diving. The rush vegetation was studied along the whole shore, by boat and using the anchor.

Charophyte communities were classified according to Gąbka and Pełechaty (2006) and vascular vegetation was classified according to Brzeg and Wojterska (2001). The nomenclature of charophyte species was given according to Krause (1997).

To characterize habitat conditions of the lake, the basic physical-chemical analyses of pelagial water were performed for each of the main basins. Water temperature, oxygen concentration, conductivity and pH were measured by means of portable field measurement equipment (Elmetron CX-401, CyberScan 200) in central part of each basin. For further analyses under laboratory conditions, water samples were collected with 1 dm^3 plastic bottles, preserved with chloroform and stored in the refrigerator.

The anion (Cl^-, NO_3^-, NO_2^-, SO_4^{2-}, PO_4^{3-}) and cation (NH_4^+, Ca^{2+}, Mg^{2+}) concentrations were determined using Metrohm ion chromatograph, the 881 Compact IC Pro model (Metrohm, Switzerland). For the determination of anions, Metrosep A Supp 4/5 Guard (the guard column) and Metrosep A Supp 5 (the separating column) were used. The mobile phase employed was 3.2 mM Na_2CO_3/1.0 mM $NaHCO_3$, which flowed at 0.7 ml min^{-1}. When cations were determined, Metrosep C 4 Guard (the guard column) and Metrosep C4 150 (the separating column) were applied. The mobile phase employed was 0.7 mM $C_7H_5NO_4$/1.7 mM HNO_3, flowing at 0.9 ml min^{-1}.

Water colour determinations were performed based on the visual method against a platinum scale. Total alkalinity was determined by titrating a water sample against indicators (methyl orange). The alkalinity results were then converted to HCO_3^- mgl^{-1}. This was done by multiplying the alkalinity results by 61 $gmol^{-1}$ (where 61 $gmol^{-1}$ is the molar mass of HCO_3^-).

3. Results

The results of physical-chemical analyses evidenced high water quality in the studied Lake Jasne and a minor variability of all analyzed parameters among the sampling sites (Table 1). The temperature measurements showed no fully developed vertical stratification and oxygen deficiency below 6 m depth. Considering the mean depth and the structure of lake basin it can be concluded that most of the lake was polymictic.

The concentrations of total phosphorus and total nitrogen were low, as compared to other lakes in this region. The values of mineral forms of phosphorus were below the detection level. Within the nitrogen speciation forms, nitrates revealed the highest values.

Lake Jasne belongs to the moderately hard water ecosystems, which was indicated by all parameters within the hardness complex and was reflected by the alkaline pH values (Table 1).

Based on the phytosociological survey, 13 communities representing 3 classes: *Phragmitetea australis, Potametea* and *Charetea fragilis,* were distinguished (Fig. 2). Macrophytes occupied almost 70% of the lake's bottom. Vascular vegetation, represented by 3 helophyte and 3 elodeid communities were distributed poorly as single patches in the lake. The dominant type of the lake's vegetation were charophyte meadows, which covered the area of 9.4 ha (64% of phytolittoral). As many as 10 charophyte species, representing 3 genera were identified, among which 7 built communities. Apart from common species (*Chara aspera, Ch. virgata, Ch. globularis, Ch. rudis, Ch. tomentosa, Nitella flexilis* and *Nitellopsis obtusa*) also some rare to the Polish charophyte flora were identified – *Chara filiformis, Ch. polyacantha* and *Ch. intermedia*. One of these three species, *Ch. polyacantha*, formed extensive

Table 1. Variability of physical-chemical parameters of water within the pelagial sites (N=3) in Lake Jasne

		Minimum	Maximum	Mean	Standard deviation
Temperature	[°C]	23.10	24.00	23.40	0.52
SD visibility	[m]	3.40	3.60	3.50	0.12
O_2	[mg l^{-1}]	6.50	6.70	6.57	0.12
pH	-	7.40	8.20	7.67	0.46
Conductivity	[µS cm^{-1}]	238.00	244.00	240.00	3.46
Alkalinity	mval l^{-1}	1.50	1.60	1.57	0.06
HCO_3^-	[mg l^{-1}]	91.50	97.60	95.57	3.52
TP	[mg l^{-1}]	0.07	0.09	0.08	0.01
PO_4^{3-}	[mg l^{-1}]	b.d.	b.d.	b.d.	b.d.
TN	[mg l^{-1}]	0.75	0.88	0.81	0.07
NO_3^-	[mg l^{-1}]	0.53	0.66	0.59	0.35
NO_2^-	[mg l^{-1}]	b.d.	b.d.	b.d.	b.d.
NH_4^+	[mg l^{-1}]	0.03	0.07	0.04	0.02
$N_{org.}$	[mg l^{-1}]	0.16	0.72	0.38	0.17
Ca^{2+}	[mg l^{-1}]	51.48	54.17	52.62	1.39
Mg^{2+}	[mg l^{-1}]	2.44	2.49	2.46	0.03
Hardness	[°dH]	7.92	8.31	8.09	0.20
SO_4^{2-}	[mg l^{-1}]	56.16	57.83	57.18	0.89
Cl^-	[mg l^{-1}]	12.44	12.74	12.62	0.15

Explanation: bd – below detection level

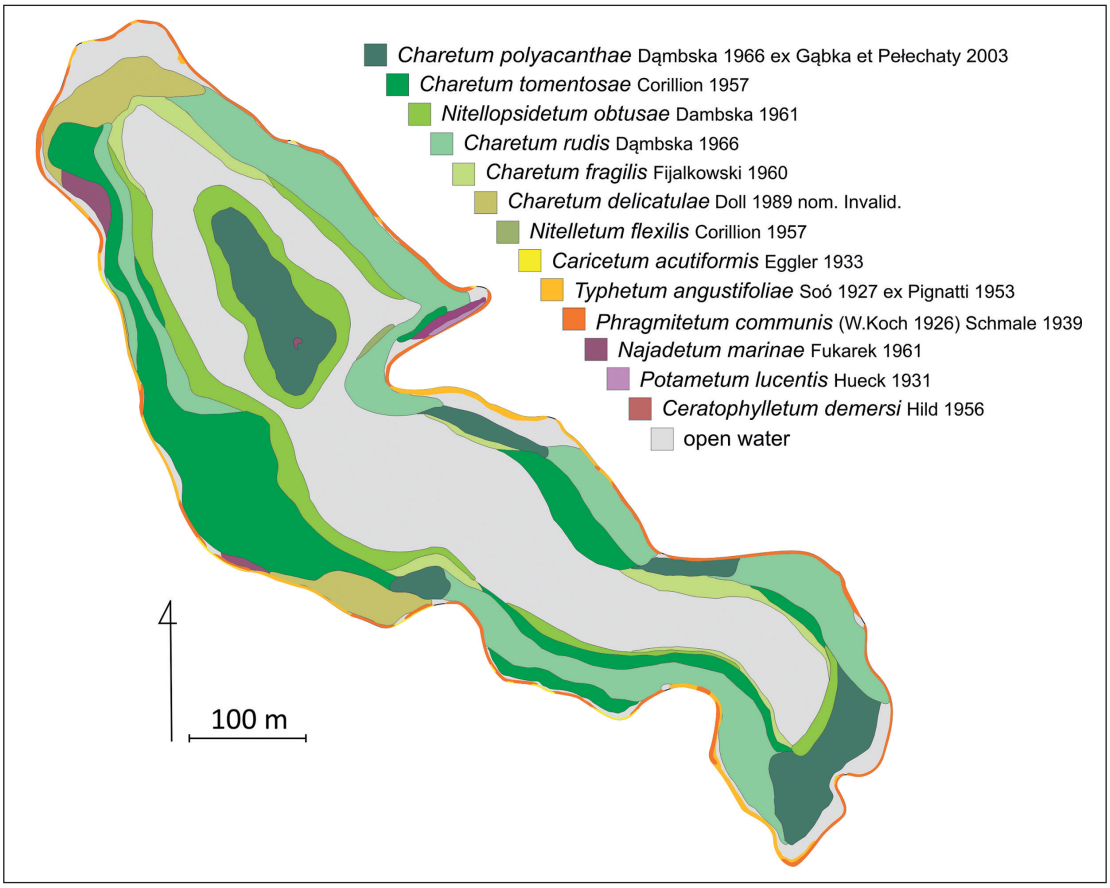


Fig. 2. The map of spatial structure of vegetation in Lake Jasne

phytocoenoses of *Charetum polyacanthae*, whereas the two others were only accompanying species in the patches of *Charetum tomentosae*. Apart from *Ch. polyacantha* community, the phytolittoral area was dominated by *Ch. rudis, Ch. tomentosa* and *N. obtusa* meadows. The communities were monospecific or built by distinctly dominating species with several accompanying species. The boundaries between neighboring communities were unequivocal, thus, complex and transitional communities were observed rarely. Charophytes defined also the maximum depth extent of vegetation in the lake, reaching the depth of 5.6 m.

The structure of phytolitoral presented in transects (Fig. 3a-e) documented the spatial dominance of charophytes in the studied lake. Rush vegetation, represented mostly by *Phragmites austalis* and *Typha latifolia* communities, was poorly developed as a narrow belt along the lake shore. Next to the rushes or just starting from shoreline, charophyte meadows developed, forming a specific zonation (Figs. 2 and 3a-d). The elodeids formed communities just at a few sites, also forming a belt zonation at the intermediate depths (Fig. 3e). At the shallowest sites (<2m), charophyte meadows were built by small species: *Ch. virgata* or minor forms of *Ch. polyacantha* and *Ch. rudis*. At the intermediate depths (2-4 m), the communities were developed best as compact carpets, built by typical species forms. At the deepest littoral parts (>4m) the meadows were also well developed, built by *N. obtusa* communities and belt-formed, narrow communities of *Ch. globularis* and *N. flexilis*. A specific element of the structure of Lake Jasne vegetation was the shallowness in the central part of NW basin, occupied by two monospecific charophyte communities (Fig. 3d). The central part of this shallowness was covered by a rare to Poland community of *Ch. polyacantha*, which was surrounded by a wide and compact belt of *Nitellopsis obtusa*.

4. Discussion

Lake Jasne belongs to a transitional group of lakes between deep, fully stratified and dimictic water bodies, on the one hand, and typically shallow, polymictic lakes, on the other. Therefore, most of the lake's area is well mixed that causes constant nutrient circulation between sediments and waters and thus makes N and P available for biota. Nevertheless, the lake has a low fertility with the trophy state index (TSI, Carlson 1977) indicating mesotrophic conditions and a low phytoplankton biomass, which contributes to a good

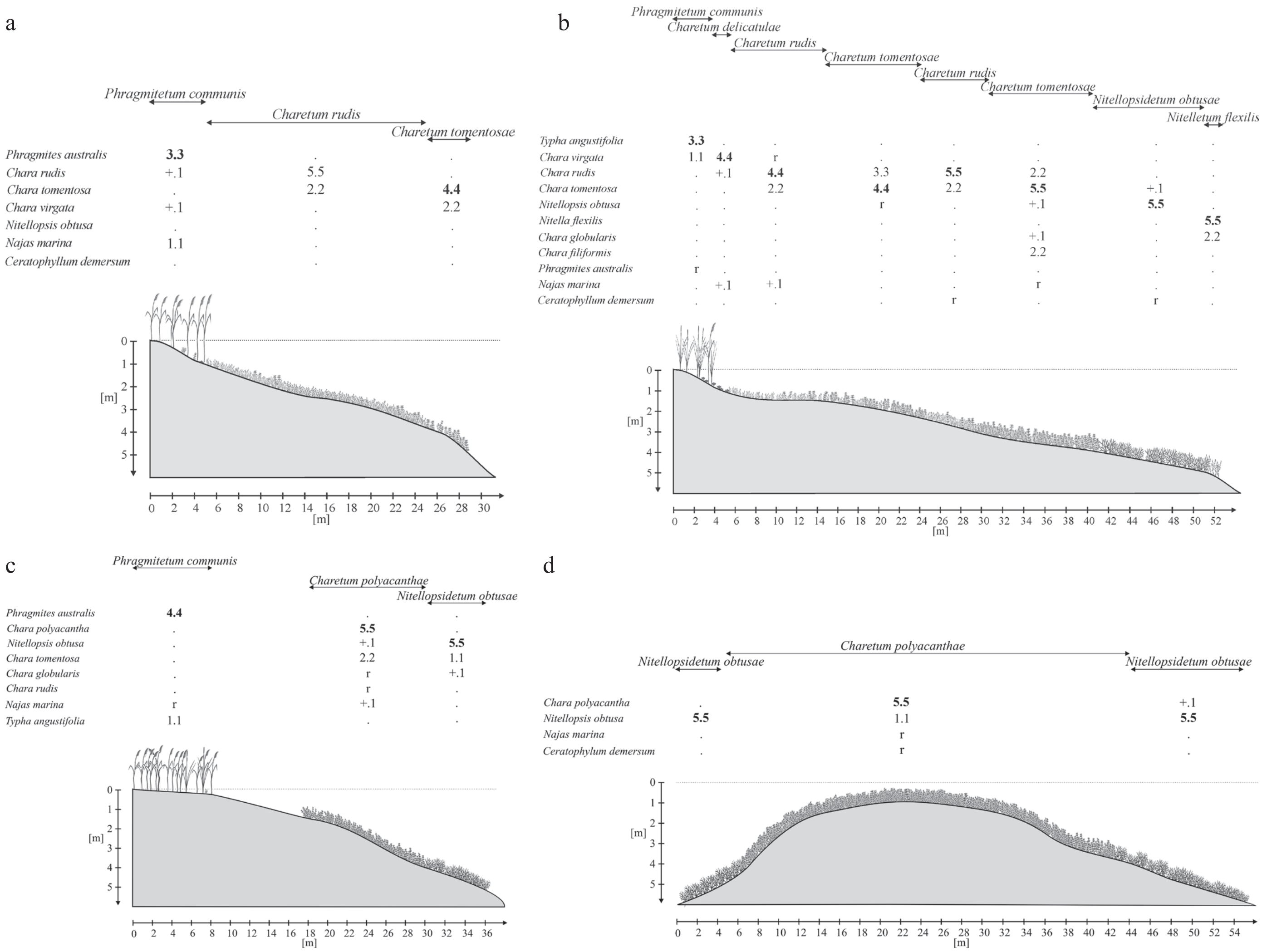
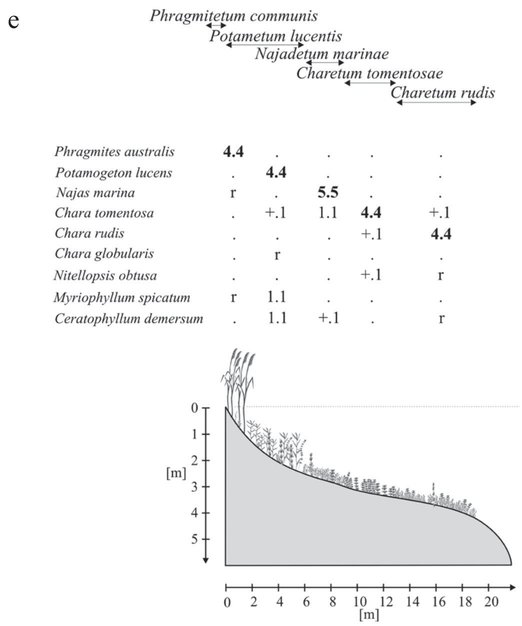


Fig. 3. Example transects representative of spatial structure of vegetation in Lake Jasne, congruent with the transect numbers at Fig. 1: a – T21, b – T22, c – T16, d – T12, e – T9



ecological state of Lake Jasne (Pełechaty *et al.* 2007). Limited anthropogenic pressure and forested catchment basin support and protect a high water quality. As a result, the lake is a good representative of the European natural habitat, code 3140: hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp (Council Directive 92/43/EEC, Interpretation Manual – EUR 27, Piotrowicz 2004). In turn, extensive charophyte communities may influence water properties and act as a specific "environmental engineer" resulting in shifts in phytoplankton structure and water clarity (eg. van den Berg *et al.* 1998b; van Donk & van de Bund 2002) and, ultimately, in a good ecological state of the lake (Ciecierska 2008). TSI values, separately calculated in this study for total phosphorus (TSI TP) and visibility (TSI SD), seem to support this thesis. The mean TSI TP was 67 and indicated eutrophic water, whereas the mean TSI SD was 42, being a value typical of mesotrophy. Intensified particle sedimentation from the water, lowered sediment resuspension, nutrient uptake and storage in phytomass, precipitation of carbonates and co-precipitation of phosphates, refugial role for zooplankton grazing on phytoplankton and other direct and indirect interactions between macrophytes and phytoplankton are listed among the main mechanisms responsible for the maintenance of clear water state (eg. van Donk & van de Bund 2002 and references quoted therein; Scheffer & van Nes 2007). The structure of the Lake's Jasne vegetation, with a large area covered by charophyte meadows may be a reasonable explanation of the high water quality and a good ecological state. Charophyte vegetation is claimed to be particularly responsible for the influence on the water quality of lakes (van den Berg *et al.* 1998b).

Floristic and phytocoenotic structures of vegetation, the main subject of this study, reflect the above-mentioned good ecological conditions in the lake, this being emphasized by a minor contribution of common vascular communities, such as *Ceratophylletum demersi*, and a dominance of charophyte meadows. Not only the area covered by characeans but also the number of species and associations seems worth to be highlighted.

Considering the species number of Characeae found so far in the Polish waters (35 species: 34 given in Siemińska *et al.* 2006 and a new to Poland *Ch. baueri* reported in Pukacz *et al.* 2009), the species identified in Lake Jasne constitute 28% of the Polish charophyte flora. Apart from common and well distributed species, also endangered and protected charophytes occurred in the lake. *Ch. polyacantha* and *Ch. filiformis* are protected and along with *Ch. intermedia* and *Ch. aspera* are placed in "Red list of plants and fungi in Poland" among endangered species (Siemińska *et. al.* 2006). By contrast to *Ch. globularis*, *Ch. virgata*, *Nitellopsis obtusa*, *C. tomentosa* and *Nitella flexilis*, which belong to the most common charophytes, the above-mentioned species, particularly *Ch. filiformis* and *Ch. intermedia*, are rarely noted within the region of Ziemia Lubuska (Pełechaty *et al.* 2007; Kraska 2009) and other parts of Poland (Gąbka & Pełechaty 2003; Bociąg 2006; Gąbka 2009; Gąbka & Owsianny 2012).

As compared to previous studies performed in the region, described in details by Pełechaty *et al.* (2007) and Kraska (2009), Lake Jasne is nowadays characterized by the highest number of charophyte species – 43% of the flora documented in the region since the beginning of this century (23 species; Pełechaty & Pukacz 2006; Pełechaty *et al.* 2007, 2010) and 40% of all species (25), which have ever been identified in the waters of Ziemia Lubuska (Dąmbska 1962, 1964, 1966; Dąmbska & Kraska 1978; Kraska 2009 and the authors' studies).

Regarding charophyte associations from the *Charetea fragilis* class, whose phytocoenoses developed in Lake Jasne, the majority are rather common in the region and – on a broader scale – in mid-western Poland (Brzeg & Wojterska 2001), this particularly concerns *Nitellopsidetum obtusae, Charetum delicatulae, Charetum fragilis, Charetum tomentosae*. *Charetum rudis* and *Nitelletum flexilis* are rare. The rarest and most precious association is *Charetum polyacanthae*, represented in the lake by extensive phytocoenoses (Figs. 2, 3d). This community is rarely observed in Poland and its distribution is restricted to mesotrophic lakes (Gabka & Pełechaty 2003; Gąbka & Owsianny 2012). Taking the state of threat under consideration (Brzeg & Wojterska 2001), *Charetum polyacanthe* belongs to the group of endangered communities. According to the cited authors, *Charetum rudis* belongs to this group too.

In conclusion, it should be stressed that a large numbers of species (10 out of 35 identified so far in Poland) and communities (7 out of 15 identified in the region and of 30 in Poland) make Lake Jasne a valuable refuge of European habitat 3140, and it is recommended that the lake's species and phytocoenotic diversity are regularly monitored in conjunction with conservation measures and sustainable use of the lake (Piotrowicz 2004).

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