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THE PRINCIPAL THREATS TO THE STANDING WATER HABITATS IN THE CONTINENTAL BIOGEOGRAPHICAL REGION OF CENTRAL EUROPE

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ABSTRACT

This paper discusses threats of standing water habitats of high importance to the European Community in the Continental Biogeographical Region (CBR) of Europe, specifically in Poland, as a reference. The study covers five standing water habitats types distinguished in Natura 2000: 3110, 3130, 3140, 3150, 3160, occurring in 806 Special Areas of Conservation (SACs) in Poland. The most significant threats to standing water habitats in the Continental biogeographical region, result from human-induced changes in hydrological conditions that have modified whole natural systems. Based on multivariate analysis, we found that significant differences in the conservation status of the standing water habitats resulted from a variety of threats, pressures, and activities, among which the most significant are decreased and unstable water resources (3110, 3130, 3140, 3150, 3160), fishing and harvesting aquatic resources (3110, 3130, 3140, 3150, 3160), pollution from use of the catchment (3130, 3140, 3150), improper management and use of the agricultural catchment (3110, 3130, 3140, 3150, 3160) and forest catchment (3110, 3140, 3160), urbanisation, residential and commercial development (3150, 3140), transportation and service corridors (3140> 3160 > 3110, 3150), including parking areas (3140), changes in biocenotic evolution, succession, plant species composition (3110, 3130, 3140, 3150, 3160), succession of invasive species (3130), and more intense touristic exploration (3110, 3130, 3140, 3150, 3160). Only in the case of habitats 3110, 3130, 3140 changes in their conservation status have been associated with climate change.

Keywords: threats, freshwater habitats, biodiversity conservation, Natura 2000

INTRODUCTION

At a global scale, freshwater is relatively insignificant in terms of area (<1 % global surface) but it supports a disproportionate number of species (∼10 % of all known species) (Strayer & Dudgeon, 2010). Freshwater ecosystems have lost a greater proportion of their species and habitat than ecosystems on land or in the ocean, and they face increasing threats from dams, water withdrawals, pollution, invasive species, and overharvesting (MEA, 2005; Revenga *et al.*, 2005). Freshwater ecosystems and the diverse communities of species found in lakes, rivers, and wetlands may be the most endangered of all (MEA, 2005).

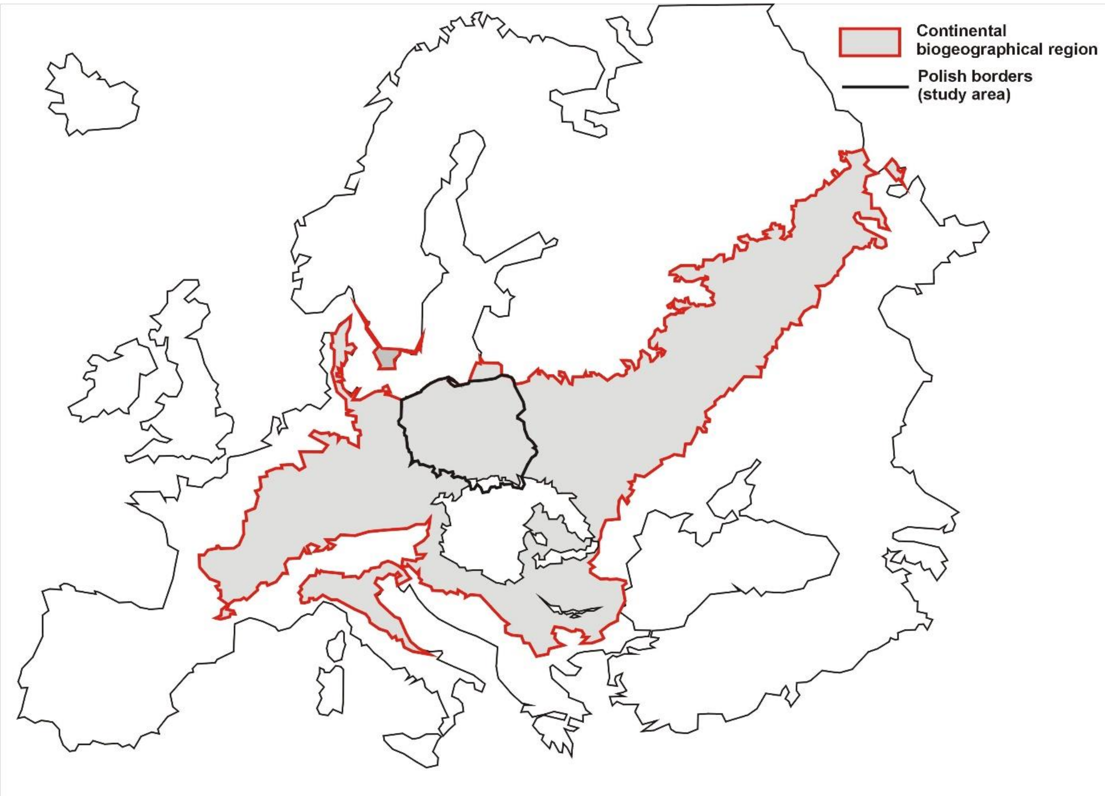
The development of large-scale networks of protected areas is a key activity that is used for protection around the world (Rodrigues *et al.*, 2004). This research was conducted within the borders of the European Ecological Network—Natura 2000. The latter is the world's largest multinational coordinated conservation infrastructure (Blicharska *et al.,* 2016a). The network provides ecosystem services worth ca. 200–300 billion Euro/year (EC, 2013). Natura 2000 is also becoming an essential component of the European Green Infrastructure strategy aimed at mitigating fragmentation and increasing the spatial and functional connectivity between protected and unprotected areas (Maes *et al.*, 2012; Estreguil *et al.*, 2014; Orlikowska *et al.*, 2014). Natura 2000 is a network of core breeding and resting sites for rare and threatened species as well as some rare natural habitat types which are protected in their own right. It stretches across all 28 EU countries, both on land and at sea. The aim of the network is to ensure the long-term survival of Europe's most valuable and threatened species and habitats, listed under both the Birds Directive (EC, 2009) and the Habitats Directive (EC, 1992). According to the European Natura 2000 Barometer (EEA, 2018), the network presently comprises 27,758 terrestrial and marine Natura 2000 sites covering 1,322,630 km^2 in total (18.18 % of the land area) in the European territory of the 28 Member States of the European Union, which has determined the legal framework for creating the European ecological network Natura 2000, the main instrument for maintaining biological diversity in the EU territory.

A relatively large portion of the ecological research on the Natura 2000 network has focused on a few (or a single) species within one or a few sites (Orlikowska *et al.*, 2016). In spite of the fact that the Natura 2000 network spans the European continent, the majority of studies were conducted within regions at the sub-national level (Popescu *et al.,* 2014). To improve evidence-based management and conservation, future research on Natura 2000 should focus on examining the network's adaptive capacity, its coherence and the links between different Natura 2000 sites, as well as relations to conservation activities outside the network (Davis *et al.,* 2014). The scarcity of studies pertaining to larger spatial scales may have negative consequences for the conservation of species and habitats that are dependent on large-scale patterns and processes (Rattisab *et al.,* 2018). There is a need for biodiversity conservation actions to be tailored to biogeographic conditions (Gustafsson *et al.,* 2015). This would be consistent with the conservation biogeography framework (Kreft & Jetz, 2010), which has become increasingly prominent in recent years, but, as yet, is underutilized in Natura 2000 research (Orlikowska *et al.,* 2016). Moreover, the examination of entire biogeographical regions in ecological studies would foster more cross-scale cooperation in practical management of the network, a process that is necessary for attaining conservation goals in large-scale initiatives (Gustafsson *et al.*, 2015; Guerrero *et al.*, 2015). Effective conservation requires the involvement of scientists to implement research results into practice (e.g., Cvitanovica *et al.*, 2016), and inadequate distribution of research focus across the Natura 2000 network could be a problem for achieving the expected conservation outcomes (Hermoso *et al.,* 2017; Toomey *et al.,* 2017). The aim of this work is to demonstrate the diversity of standing water habitats as well as their condition and participation in the continental biogeographical region in Poland in relation to the threats, pressures, and activities.

STUDY AREA

The CBR covers more than a quarter of the Union European and runs a wide band from the west to east, from central France through the eastern ends Poland in the north and Romania in the south. Outside the EU region Continental stretches to the Ural Mountains, on the border with Asia (Fig. 1). In the south, it is divided into two almost equal parts with high mountain ranges in the Alpine region and the steppe plains of the Pannonian region. It includes also part of the Adriatic and Baltic coastline. The Continental region is covered in whole or in part territories of thirteen European Union countries. These are large areas of Poland, Germany, France, Italy, the Republic Czech and Bulgaria, as well as a significant part of Denmark, Belgium, Luxembourg, Austria, Slovenia, Romania and Sweden.

Fig. 1: Study area in the context of the entire continental biogeographical region of Europe



According to the European Topic Center on Biological Diversity (European Environment Agency), the number of habitat types from Annex I Habitats Directive (EC, 1992) in the CBR is 159 and is the highest of all 9 biogeographical regions in Europe. Altogether, within the Continental Region there are 7,475 Sites of Community Importance (SCIs) under the Habitats Directive and a further 1,478 Special Protection Areas (SPAs) under the Birds Directive (EC, 2016; EEA, 2018). There is often considerable overlap between some SCIs and SPAs which means that the figures are not cumulative. Nevertheless, it is estimated that together they cover more than 10 % of the total land area in this region. Currently, the Natura 2000 network in Poland occupies almost 1/5 of the land area of the country. It consists of 849 habitat areas (SCIs) and 145 bird areas (SPAs). The study covered freshwater habitats occurring in all 806 Special Areas of Conservation in Poland within Continental biogeographic region.

MATERIAL AND METHODS

Data collection and methods

The overall conservation value of each Natura 2000 site for a habitats include an assessment of the degree of conservation of the structure and functions, as well as their possibilities for restoration (Mróz, 2017). Data was taken into account in the analyzes Special Areas of Conservation (SACs) for the Natura 2000 network: Standard Data Forms (GDEP, 2018; Eionet, 2018a), management plans (GDEP 2017; RDEP 2018), reporting monitoring by EU Poland SACs (Eionet 2018b), from three reporting periods: 2009 to 2018. The habitat types survey includes water bodies: 3110 Oligotrophic waters (*Littorelletalia uniflorae*); 3130 Oligo to mesotrophic waters (*Littorelletea Isoëto-Nanojuncetea*); 3140 Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp; 3150 Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition* - type vegetation; 3160 Natural dystrophic lakes and ponds. Researched covered habitats are in 7 of 11 Europe regional biogeographic regions (Table 1). In Poland, the studied habitats occur in both biogeographic regions: alpine and Continental (Table 2).

The overall assessment of the surveyed types of freshwater habitats was based on 3 main parameters: structure and function, future perspective as well as range and surface area. The structure is the parameter which comprises physical components of a given habitat type, while the assessment of habitat's functions refers to the ecological processes occurring at a number of temporal and spatial scales and vary greatly between habitat types. The future perspective indicates the direction of expected changes in conservation status in the near future based on the current status, identified pressures, threats, and measures being taken for each of the other three parameters (structure and functions, range, and area), while the assessment of range and surface area must be sufficiently large in relation to favorable reference values.

Table 1: Overall assessment survey habitats within biogeographical regions in Europe

Habitats	Special Areas of Conservation in EU		Biogeographical regions						
	Surface of the habitat (km^2)	Percentage of share of the habitat (%)	ALP	ATL	BOR	CON	MAC	MED	PAN
3110	14431.17	2.39	FV	U2	U1	U1		XX	
3130	9599.53	1.59	FV	U2	U1	U2	U1	U1	U1
3140	3074.68	0.51	U1	U2	U1	U2		U1	XX
3150	10894.93	1.80	XX	U2	U1	U2	XX	XX	U1
3160	21222.97	3.51	U1	U2	U1	U2	U1	XX	U2

Biogeographical regions: ALP – Alpine, ATL – Atlantic, BOR- Boreal, CON – Continental, MAC – Macaronesia, MED – Mediterranean, PAN – Pannonian; Overall assessment: FV – Favourable, U1 - Unfavourable – inadequate, U2 - Unfavourable – bad. * - Priority feature; Habitat: 3110 Oligotrophic waters (*Littorelletalia uniflorae*), 3130 Oligo to mesotrophic waters (*Littorelletea Isoëto-Nanojuncetea*), 3140 Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp, 3150 Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition* - type vegetation, 3160 Natural dystrophic lakes and ponds

Table 2: Occurrence of Standing Water Habitats in SACs in Poland

Habitats	Number of habitats under Special Areas of Conservation in Poland		Area covered by habitat type in the biogeographic region	Percentage of surface on the area of the habitat per Member State in UE
			km^2	%
	CON	CON/ALP	CON	CON
3110	33	33	18.8	38.2
3130	45	45	6	3.3
3140	82	82	nd	nd
3150	273	273	4400	70.1
3160	125	126	1	0.9

Explanation of a habitat code, see Table 1

The classification threats, pressures, and activities of habitats studied were accepted for Reference list of Threats, Pressures and Activities (final version) (Eionet, 2018a). We analyzed positive and negative impacts on the scale: A—high impact, B—small impact, C—slight impact, X—not determined (Eionet, 2018a). The following values have been assigned to the intensity of impact: A = 5; B = 3; C = 2; X = 1. The total measure of impact was determined by multiplying the percent of positions with a given impact by intensity of interaction.

Statistical analyses

The statistical analyses were performed on the database consisting on 153 identified threats, pressures, and activities for the nine habitats studied (the total number of occurrences was 383). To elucidate the presence of any relationship between habitat types and threats, pressures, and activities, and to identify the main patterns in the dataset, a principal component analysis (PCA) was performed using the software CANOCO 5.0 (ter Braak & Šmilauer, 1998; Lepš & Šmilauer, 2014). A preliminary detrended correspondence analysis (DCA) revealed the first gradient length of 3.03 SD, tests carried out previous to the analyses showed that the studied system has an unimodal character, therefore validating the use of unimodal ordination programs (ter Braak & Smilauer, 1998; Lepš & Šmilauer, 2014).

Prior to PCA analysis, all variables were standardized to zero mean and unit variance. For further understanding the dissimilarities between the peatland habitats based on threats identified for an individual habitat, we performed hierarchical clustering analysis (HCA) and heat map analysis. HCA is often introduced as the family of techniques aiming to describe and represent the structure of the pairwise dissimilarities amongst objects. We chose non-specific filtering option with a threshold of interquartile range < 0.5 to eliminate all threats with low variability. This enhanced the readability of the heat map. We clustered the points representing rows and columns in the reduced factor space with Euclidean distance by Ward's hierarchical clustering algorithm. The advantage of Ward's clustering is that it minimizes the error sum of squares or error variance at each step of clustering. Clustering algorithms and ordination technique as PCA are complementary. HCA and the heat map were performed using the XLSTAT ver. 2018.3 software for data analysis and statistical application available for Microsoft Excel® by Addinsoft.

RESULTS

Only 31.12 % of the surveyed freshwater habitats in Poland are in favorable status (FV) state, while as many as 59.95 % are classified as being in an unsatisfactory state (U1 or U2, Table 3). The best-preserved habitat types, with a score >25 % in the FV category in the overall assessment showed the following decreasing order: 3160 > 3260 > 3150 > 3130. The most threatened habitats with a score >30 % in U2 in the overall assessment were 3220 > 3130 > 3140 (Table 3). The structure and function parameter, which is the most susceptible to treatment effects, indicated the highest values in habitats in the following order: 3260 > 3160>3110>3150 (>25 % FV, Table 3), and habitats 3220 > 3130 > 3140 had the lowest values (>30 % U2, Table 3). The future perspective parameter indicated the highest values in habitats 3160 > 3130, 3220>3150 > 3110 > 3270 (>25 % FV, Table 3), and habitat 3220 had the lowest value (>30 % U2, Table 3). The area parameter indicated the highest values in habitats 3160 > 3220 > 3110 > 3140 > 3150 > 3260 > 3270 (>25 % FV, Table 3), and habitat 3130 assumed the lowest value (>30 % U2, Table 3).

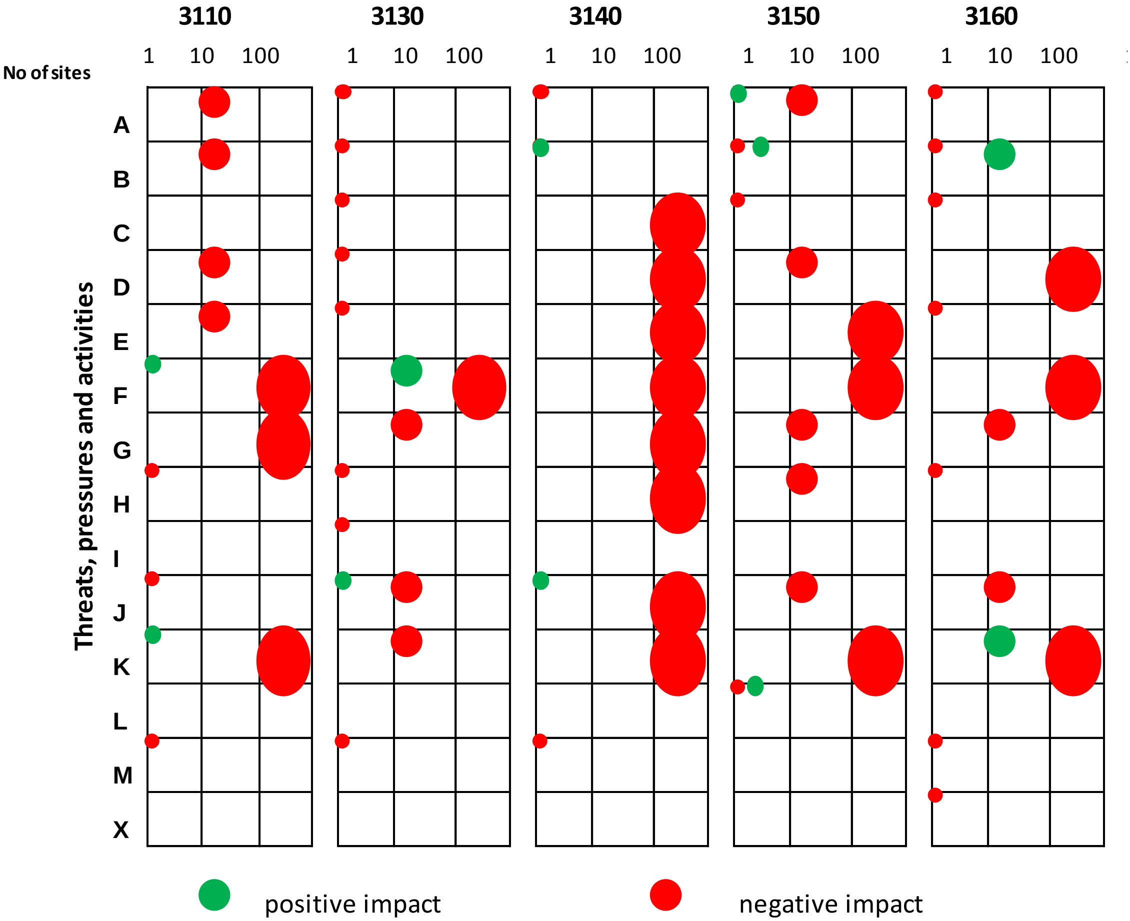
Table 3: The share of a conservation statuses of Standing Water Habitats in SACs of CBR in Poland. Data are given in %

	Structure and function				Future perspective				Range, surface area				Overall assessment			
Habitat	FV	U1	U2	XX	FV	U1	U2	XX	FV	U1	U2	XX	FV	U1	U2	XX
3110	33.33	40.0	26.67		46.67	40.0	13.3		80.0	13.33	6.67		20.0	53.33	26.67	
3130	18.75	18.75	37.5	25.0	50.0	12.5	12.5	12.5	25.0	18.75	43.75	12.5	25.0	18.75	43.75	12.5
3140	20.83	20.83	33.33	25.0	25.0	54.17		20.83	66.67	8.33		25.0	16.67	25.0	33.33	25.0
3150	29.63	44.44	25.93		48.15	29.63	11.11	11.11	59.26	22.22	7.41	11.11	29.63	40.74	29.63	
3160	71.43	7.14	14.29	7.14	85.71	7.14	7.14		100				64.29	14.29	14.29	7.14
Mean	34.79	26.23	27.54	11.43	51.11	28.69	8.81	8.89	66.19	12.53	11.57	9.72	31.12	30.42	29.53	8.93

Denotations: see Table 1

The main groups of threats, pressures, and activities identified for peat habitats at SACs in the CBR area in Poland are presented in Figure 2. Agriculture (A) causes a number of negative impacts on freshwater habitats, which is most visible for the following habitats in the following order: 3110, 3150 > 3130, 3140, 3160 (Fig. 2). However, proper management of agricultural land in the vicinity of lakes could be an effective tool for their protection (e.g., 3150). Similarly, forest management may have both negative (e.g., 3110 > 3130, 3150, and 3160) and positive effects on the habitats (e.g., 3160 > 3140 and 3150). Among the negative anthropogenic influences reported are pollution (H; 3140 > 3150 > 3110, 3130, and 3160); human intrusions and disturbances (G; 3110, 3140 > 3130, 3150, and 3160); tourism (reported most often); transportation and service corridors (D; 3140 and 3160 > 3110 and 3150 > 3130); urbanization; residential and commercial development tourism (E; 3140 and 3150 > 3110 > 3130); biological resource use other than for agriculture and forestry (F; 3110 and 3130, and 3140, 3150, and 3160); mining; extraction of materials; and energy production (C; 3140 > 3130, 3150, and 3160). In addition, the development of alien and invasive species has strongly affected habitat 3130 and natural biotic and abiotic processes (without catastrophes) (K) in the following habitats in the following order: 3110, 3140, 3150, 3160 > 3130. Negative impacts associated with climate change (M) have been detected mostly for habitat types 3110, 3130, 3140, and 3160.

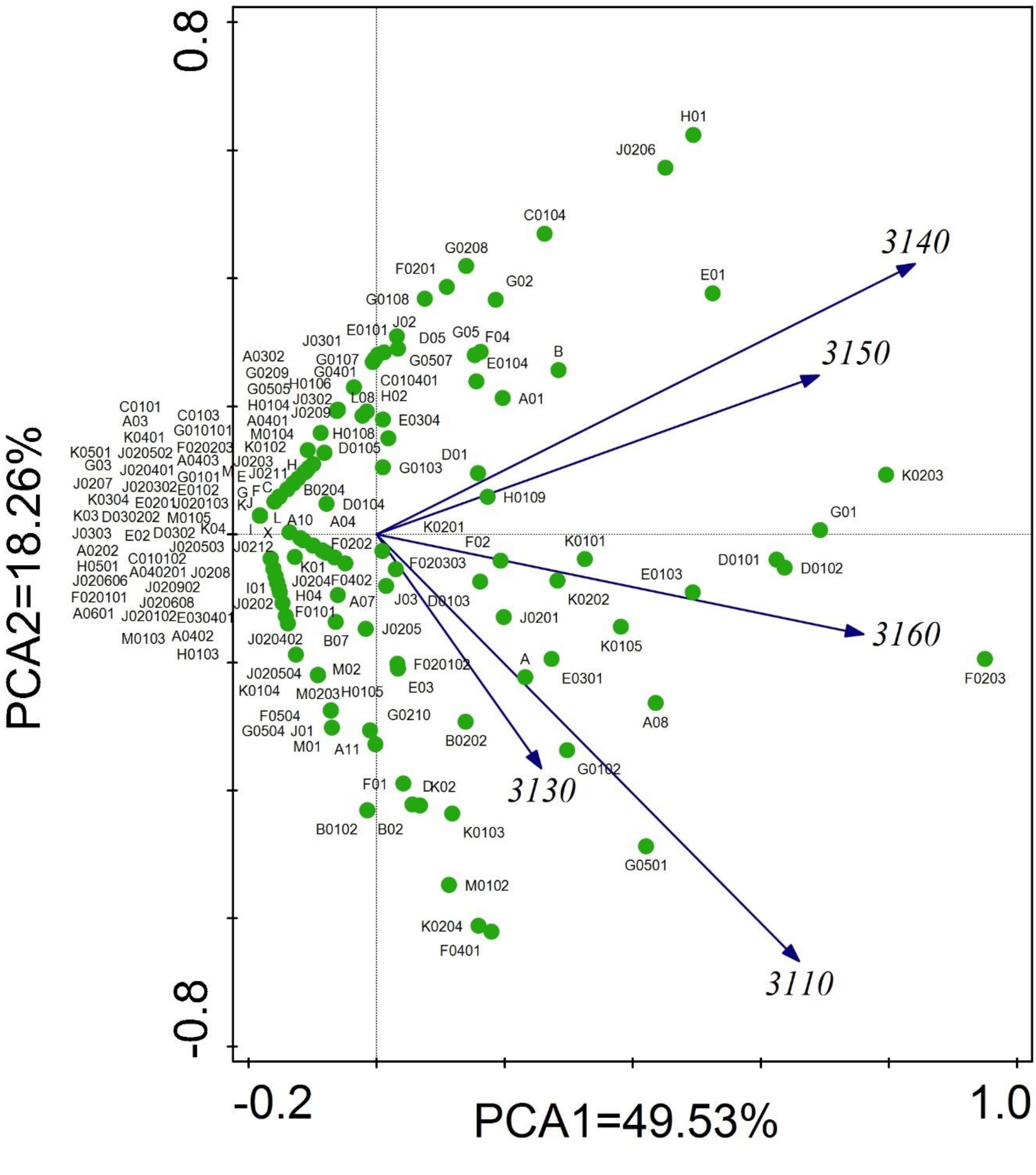
Fig. 2: Main groups of threats, pressures and activities identified for Standing Water Habitats at SACs in the CBR in Poland



A bubble size is proportional to the number of impacted sites. Numbers of impacted sites are shown on a log-scale (x-axis). Denotations: codes of habitat types – please see Table 1. Main groups of threats, pressures and activities (Eionet 2018a): A – Agriculture; B - Sylviculture, forestry; C - Mining, extraction of materials and energy production; D - Transportation and service corridors; E - Urbanisation, residential and commercial development; F - Biological resource use other than agriculture & forestry; G - Human intrusions and disturbances; H – Pollution; I - Invasive, other problematic species and genes; J - Natural system modifications; K - Natural biotic and abiotic processes (without catastrophes); L - Geological events, natural catastrophes; M - Climate change

The application of PCA verified the relationship between a habitat type and its threats, pressures, and activities (Fig. 3). PCA showed that the surveyed habitat types are determined by the first two components of the vectors associated with the various threats. The first and second PCA components explained 49.53 % and 18.26 % of the total variance. The first component showed the highest positive correlation with habitats 3110, 3140, 3150, and 3160 (PCA1, respectively $r = 0.6597$, $r = 0.8406$, $r = 0.6910$, $r = 0.7602$). The second component showed the highest negative correlation with habitats 3110 and 3130 (PCA2, respectively $r = -0.6671$, $r = -0.3652$), but it showed a positive correlation with habitat 3140 (PCA2, respectively $r = 0.4227$).

Fig. 3: Biplot of PCA ordination axes for lakes habitat types and threats, pressures and activities



Explanation of a habitat code, see Table 1; Threats (Eionet 2018a): A – agriculture; A01 - cultivation; A02.02 - crop change; A03 - mowing / cutting of grassland; A03.02 - non intensive mowing; A04 – grazing; A04.01 - intensive grazing; A04.02 - non intensive grazing; A04.02.01 - non intensive cattle grazing; A04.03 - abandonment of pastoral systems, lack of grazing; A06.01 - annual crops for food production; A07 - use of biocides, hormones and chemicals; A08 – fertilisation; A10 - restructuring agricultural land holding; A11 - agriculture activities not referred to above; B - sylviculture, forestry; B01 - forest planting on open ground; B01.02 - artificial planting on open ground (non-native trees); B02 - forest and plantation management & use; B02.01 - forest replanting; B02.02 - forestry clearance; B02.04 - removal of dead and dying trees; B07 - forestry activities not referred to above; C - mining, extraction of materials and energy production; C01.01- sand and gravel extraction; C01.01.02 - removal of beach materials; C01.03 - peat extraction; C01.04 – mines; C01.04.01 - open cast mining; C01.04.02 - underground mining; D - transportation and service corridors; D01 - roads, paths and railroads; D01.01m- paths, tracks, cycling tracks; D01.02 - roads, motorways; D01.03 - car parcs and parking areas; D01.04 - railway lines, TGV; D01.05 - bridge, viaduct; D03.02 - shipping lanes; D03.02.02 - passenger ferry lanes (high speed); D05 - improved access to site; E - urbanisation, residential and commercial development; E01 - urbanised areas, human habitation; E01.01 - continuous urbanisation; E01.02 - discontinuous urbanisation; E01.03 - dispersed habitation; E01.04 - other patterns of habitation; E02 - industrial or commercial areas; E02.01 – factory; E03 – discharges; E03.01 - disposal of household / recreational facility waste; E03.04 - other discharges; E03.04.01 - costal sand suppletion/ beach nourishment; F - biological resource use other than agriculture & forestry; F01 - marine and freshwater aquaculture; F01.01 - intensive fish farming, intensification; F01.03 - bottom culture; F02 - fishing and harvesting aquatic resources; F02.01 - professional passive fishing; F02.01.01 – potting; F02.01.02 – netting; F02.02 - professional active fishing; F02.02.03 - demersal seining; F02.03 – leisure fishing; F02.03.02 - pole fishing; F02.03.03 - spear-fishing; F03.02.09 - other forms of taking animals; F04 - taking / removal of terrestrial plants, general; F04.01 - pillaging of floristic stations; F04.02 - collection (fungi, lichen, berries etc.); F05.04 – poaching; G - human intrusions and disturbances; G01 - Outdoor sports and leisure activities, recreational activities; G01.01 - nautical sports; G01.01.01 -motorized nautical sports; G01.02- walking, horse riding and non-motorised vehicles; G01.03 - motorised vehicles; G01.07 – scuba diving, snorkelling; G01.08 - other outdoor sports and leisure activities; G02 - sport and leisure structures; G02.08 - camping and caravans; G02.09 - wildlife watching; G02.10 - other sport/leisure complexes; G03 - interpretative centres; G04.01 - military manouvres; G05 - other human intrusions and disturbances; G05.01 - trampling, overuse; G05.04 - vandalism; G05.05 - intensive maintenance of public parcs /cleaning of beaches; G05.07 - missing or wrongly directed conservation measures; H – pollution; H01 - pollution to surface waters (limnic, terrestrial, marine & brackish); H01.03 - other point source pollution to surface water; H01.04 - diffuse pollution to surface waters via storm overlows or urban run-off; H01.05 - diffuse pollution to surface waters due to agricultural and forestry activities; H01.06 - diffuse pollution to surface waters due to transport and infrastructure without connection to canalization/sweepers; H01.08 - diffuse pollution to surface waters due to household sewage and waste waters; H01.09 - diffuse pollution to surface waters due to other sources not listed; H02 - pollution to groundwater (point sources and diffuse sources); H04 - air pollution, air-borne pollutants; H05.01 - garbage and solid waste; I - invasive, other problematic species and genes; I01 - invasive non-native species; J - natural system modifications; J01 - fire and fire suppression; J02 - human induced changes in hydrological conditions; J02.01 - landfill, land reclamation and drying out, general; J02.01.02 - reclamation of land from sea, estuary or marsh; J02.01.03 - infilling of ditches, dykes, ponds, pools, marshes or pits; J02.02 - removal of sediments (mud...); J02.03 - canalisation & water deviation; J02.03.02 – canalisation; J02.04 - flooding modifications; J02.04.01 – flooding; J02.04.02 - lack of flooding; J02.05 - modification of hydrographic functioning, general; J02.05.02 - modifying structures of inland water courses; J02.05.03 - modification of standing water bodies; J02.05.04 – reservoirs; J02.06 - water abstractions from surface waters; J02.06.06 - surface water abstractions by hydro-energy; J02.06.08 - surface water abstractions for navigation; J02.07 - water abstractions from groundwater; J02.08 - raising the groundwater table /artificial recharge of groundwater; J02.09 - saltwater intrusion of groundwater; J02.09.02 - other intrusion; J02.11 - siltation rate changes, dumping, depositing of dredged deposits; J02.12 - dykes, embankments, artificial beaches, general; J03 - other ecosystem modifications; J03.01 - reduction or loss of specific habitat features; J03.02 - anthropogenic reduction of habitat connectivity; J03.03 - reduction, lack or prevention of erosion; K - natural biotic and abiotic processes (without catastrophes); K01 - abiotic (slow) natural processes; K01.01 – erosion; K01.02 - silting up; K01.03 - drying out; K01.04 - submersion; K01.05 - soil salinization; K02 - biocenotic evolution, succession; K02.01 - species composition change (succession); K02.02 - accumulation of organic material; K02.03 - eutrophication (natural); K02.04 - acidification (natural); K03 - interspecific faunal relations; K03.04 – predation; K04 – interspecific floral relations; K04.01 – competition; K05.01 - reduced fecundity/ genetic depression in animals (inbreeding); L - geological events, natural catastrophes; L08 - inundation (natural processes); M - climate change; M01 - changes in abiotic conditions; M01.02 - droughts and less precipitations; M01.03 - flooding and rising precipitations; M01.04 - pH-changes; M01.05 - water flow changes (limnic, tidal and oceanic); M02 - changes in biotic conditions; M02.03 - decline or extinction of species; X - no threats or pressures

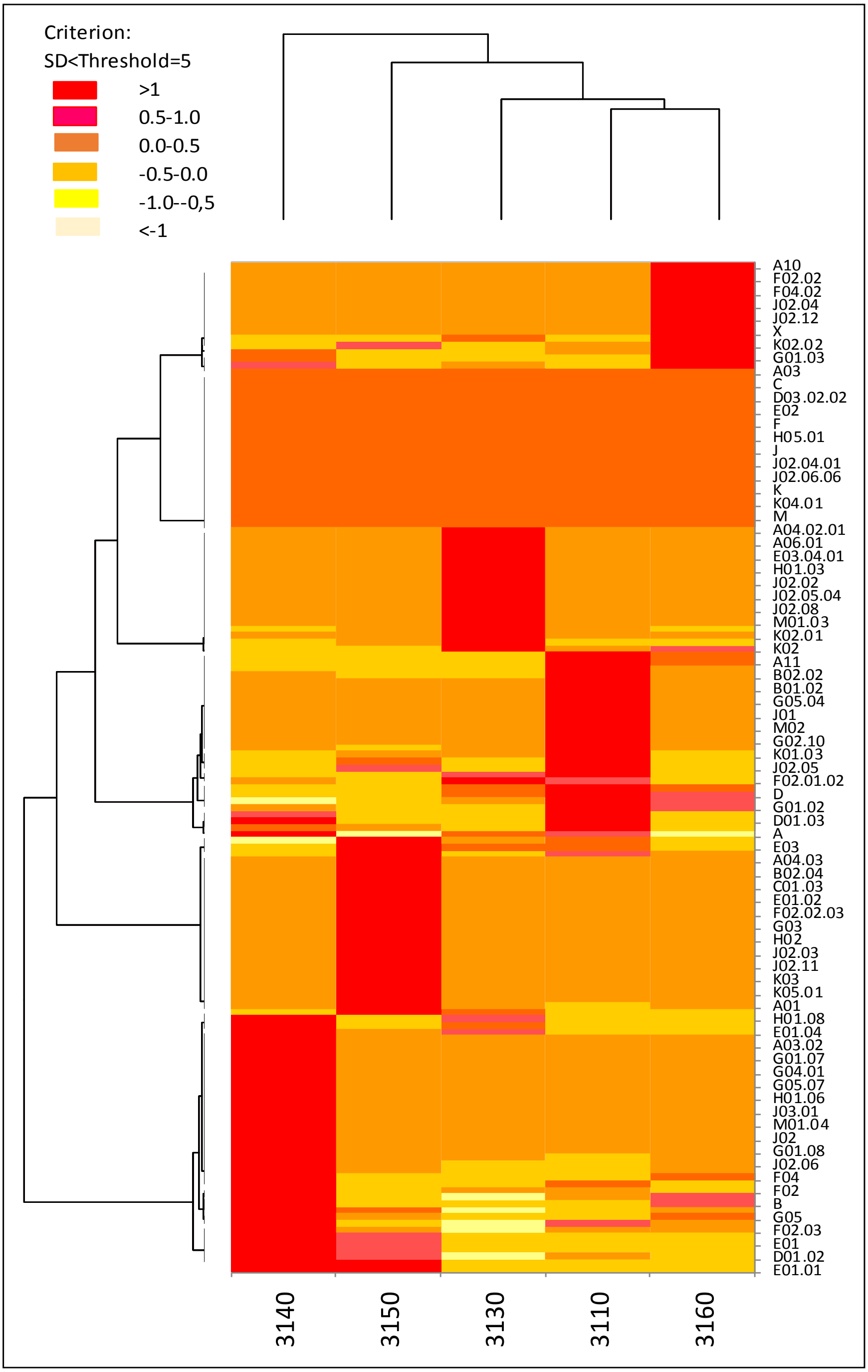
The results achieved in PCA are consistent with the results of a two-way hierarchical cluster analysis (TW-HCA). The heatmap (Fig. 4) visualizes a data matrix with rows and columns ordered according to clustering in the form of hierarchical classification trees of both columns and rows, with ‘cuts’ yielding five clusters of threats and three clusters of habitat types. Among the surveyed lake habitats, there was a group of four habitat types (3110, 3130, 3160) focused on water body habitats (lake habitats). The other four habitats created individual clusters (3140; 3150).

The threats attributed to cluster of lakes habitats (3110, 3130, 3160) (Fig. 4) are related mainly to human-induced natural system modifications (J) through changes in hydrological conditions (in habitats 3160: J02.04, J02.12, K02.02; 3110: J02.05; K01.03; 3130: J02.02; J02.05.04; J02.08, E03.04.01), improper management of land agricultural practices (in habitats 3160: A10; 3110: A11, 3130: A04.02.01, A06.01) forest management (in habitats 3110: B01.02, B02.02; 3160: F04.02), and intense touristic exploration of lakes (in habitats 3160: G01.03; 3110: G05.04., G01.02, G02.10), which contributes to the pollution of surface water (H01.03). In the case of habitats 3110 and 3130, changes in conservation have been associated with climate change (M01.03, M02). The observed changes were related to biocenotic evolution, succession (K.02), and species composition change (K02.02).

The main threats affecting clusters of natural eutrophic lakes (3150) are human pressures (C01.03, H02, H01.08, F 02.02.03, G03, J02.03, J02.11) caused by eutrophication, feeding with biocides from the catchment under the significant influence of agricultural activities (A01), urbanized areas (E01.01, E01.02, E03), freshwater aquaculture, including leisure fishing (F02.02.03) and, to a lesser extent, natural interactions (K03, K05.01) (Fig. 4).

The main threats affecting the cluster of habitat 3140 (hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp.; Fig. 4) have resulted from a variety of threats, pressures, and activities, among which the most significant are the pollution of surface water (H01.06, H01.08) and groundwater (H02.06, H02.07) as well as the development of roads, paths, and railroads (D01.02) parking areas (D01.03), urbanization, residential and commercial development (E01, E01.01, E01.04), intensive tourist traffic, outdoor sports, leisure and recreational activities (G01.07, G01.08, G04.01, G05), agriculture (A), silviculture, forestry (B), and fishing and harvesting aquatic resources (F02, F02.03). These pressures are also related to the negative pressure of water deficits, which mainly results from human-induced changes in hydrological conditions, changes in the hydrographic network (J02), and water abstractions from surface waters (J02.06), causing a reduction or loss of specific habitat features (J03.01). Changes in the habitat protection status of habitat 3140 are associated with missing or wrongly directed conservation measures (G05.07) and climate change (M01.04).

Fig. 4: Two-way hierarchical cluster analysis (TW-HCA) exposing relationship between clusters of lakes habitats and the threats, pressures and activities



Heat map colours indicate minimum (yellow) to maximum (red) relationship gradient between peatlands habitats and threats, pressures and activities. Codes of habitats and threats – see Fig. 3

DISCUSSION

According to the recent Red List of European Habitats (Janssen *et al.,* 2016), aquatic and wetland habitats are mainly threatened by hydrological system alterations as well as by climate change, pollution and invasive species, and, to a lesser extent, by succession, agriculture intensification, forestry, mining, urbanization, transport, and overuse of biological resources (Ortmann-Ajkai *et al.,* 2018). The most significant threats to standing water habitats within the continental biogeographical region result from human-induced changes in hydrological conditions that have modified whole natural systems. Using a multivariate analysis (Fig. 3,4), we found that significant differences in the conservation status of the standing water habitats resulted from a variety of threats, pressures, and activities, among which the most significant were decreased and unstable water resources (3110, 3130, 3140, 3150, 3160); fishing and harvesting aquatic resources (3110, 3130, 3140, 3150, 3160); pollution from use of the catchment (3130, 3140, 3150); improper management and use of the agricultural catchment (3110, 3130, 3140, 3150, 3160) and forest catchment (3110, 3140, 3160); urbanization; residential and commercial development (3150, 3140, 3150 > 3110); transportation and service corridors (3140> 3160 > 3110, 3150); including parking areas (3140); changes in biocenotic evolution, succession, and plant species composition (3110, 3130, 3140, 3150, 3160); succession of invasive species (3130); and more intense touristic exploration (3110, 3130, 3140, 3150, 3160). Only in the case of habitats 3110, 3130, and 3140 have changes in the conservation status been associated with climate change. The most impacted habitats are 3140 (hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp) and 3110 (oligotrophic waters, *Littorelletalia uniflorae*).

The loss of freshwater habitats

Habitat loss has been, and still is, the greatest threat to biodiversity (Čížková *et al.,* 2013; Zorilla-Miras *et al.,* 2014; Hein *et al.,* 2016). Many studies have highlighted high rates of land use change since the period after World War II, associated with human population growth and processes such as urban sprawl, mass migration to cities, and agricultural intensification (see, e.g., Houghton, 1994; Van Eetvelde & Antrop 2004; Lepers *et al.,* 2005, Amici *et al.,* 2015). Landscapes have changed dramatically in the last 50 years as a result of a combination of factors including human population growth and rapid technological advancement (Freudenberger *et al.,* 2013). Land use change is one of the main components of global change and significantly affects the ecosystem structure and functions of lakes (Lambin *et al.,* 2001; Foley *et al.,* 2005, Amici *et al.,* 2015) and contributes to the loss of habitats (Janssen *et al.,* 2016). Similar phenomena, such as residential and commercial development, concern the catchment of the studied standing water habitats (3150, 3140, 3150 > 3110). Biodiversity losses induced by land use change are driven not only by urban sprawl and agricultural intensification, but also by abandoning traditional rural landscapes to the dynamics of natural succession (Agnoletti, 2014; Beilin *et al.,* 2014). The issue of the development of rural areas that are located far from city boundaries including uncontrolled development of the land was observed as part of the study in the catchment of lake habitats (Fig. 3, 4); trends were observed even in regions with decreasing populations outside Poland, notably in Italy and Eastern Germany (Ustaoglu & Williams, 2017).

The rapid shift from natural ecosystems to cultural landscapes has introduced novel feedback processes with unexpected consequences (Ellis & Ramankutty, 2008). Negative impacts on the conservation status of examined habitats 3140 > 3160 > 3110, and 3150 were caused by transportation and service corridors (including parking areas—threat to habitat 3140). The main effects that roads have on biodiversity and ecosystems can be summarized as follows: fragmentation caused by an increase in road density, which may also lead to habitat loss and barrier effects (e.g., Sanderson *et al.*, 2002; Hawbaker & Radeloff, 2004; Freudenberger *et al.*, 2013); an escalation in traffic volume, which affects biodiversity through noise, artificial lighting, pollution, and other direct variables (e.g., Parris & Schneider, 2009; Selva *et al.*, 2011); and the buffer effect caused by increases in traffic density, which impacts biodiversity at larger landscape scales within the so-called ‘‘road-effect zone’’ (Forman & Deblinger, 2000; Alkemade *et al.*, 2009; Eigenbrod *et al.*, 2009).

The growing farm and parcel sizes and increasing mechanization have resulted in homogenization of the mosaic-like cultural landscape to a large extent as well as synchronization of management activities, and as a result, decreased land-use diversity (Grzybowski, 2014). This includes a reduction in the richness of cultural components associated with the management practices. In this study, poor management of nature conservation and missing or wrongly directed conservation measures was indicated for habitat 3140 (Fig. 4). However, places where diversity of life in all of its manifestations (biological, cultural, and linguistic) is high are called biocultural diversity hotspots (Maffi & Woodley, 2010; Babai *et al.*, 2015). Interestingly, high species and, in particular, habitat diversity is often retained in these cultural landscapes where the lifestyle, culture, and accompanying farming practices have preserved the greatest number of unique, “traditional” features (Palang *et al.*, 2006; Plieninger *et al.*, 2006; Babai *et al.*, 2014).

Improper management and use of the agricultural catchment (3110, 3130, 3140, 3150, 3160) and forest catchment (3110, 3140, 3160) was indicated as the cause of the poor condition of the studied habitats (3110, 3130, 3140, 3150, 3160, and 3260, Fig. 4.). Restoring surrogate ecological processes and achieving agricultural extensification, for example, through the reintroduction of herbivore grazing through rewilding in the catchment of lakes, may be effective in a few cases (Middleton, 2013; Sandom *et al.*, 2013). It should be recognized that multiple human uses and forms of management are beneficial for maintaining landscape heterogeneity and states of dynamic equilibrium between human activity and ecological processes (Pretty *et al.*, 2009). By emphasizing the role of broad-scale heterogeneity on biodiversity patterns, previous studies confirmed (Amici *et al.*, 2015; Babai *et al.*, 2015) that similar policy adjustments are key to conserving not only the cultural and historical value, but also the rich biological heritage of European landscapes. Our study (Fig. 2) also indicated that proper management of agricultural land in the vicinity of lakes may become an effective tool for their protection (3150); similarly, forest management may have positive effects on the habitats (3160 > 3140, 3150).

The biodiversity of freshwater habitats

Hydroserial succession is a key natural process in floodplains (Ortmann-Ajkai *et al.*, 2018). High diversity is maintained in the successional series of numerous habitats (Ward & Stanford, 1995). Changes in biocenotic evolution, succession, and plant species composition were indicated in the studied lake and river habitats (3110, 3130, 3140, 3150, 3160, Fig. 2, 3, 4). The biodiversity of lake ecosystems is threatened by numerous factors, such as land use change (Zorilla-Miras *et al.*, 2014; Hein *et al.*, 2016), water regulation, drainage (Tockner *et al.*, 2002; Čížková *et al.*, 2015), over-exploitation (Harrison *et al.*, 2010), pollution from the neighboring agricultural land (Blackwell and Pilgrim, 2011; Hein *et al.*, 2016), spread of invasive species (Mölder & Schneider, 2011; Hein *et al.*, 2016), and climate change (Tockner *et al.*, 2002; Čížková *et al.*, 2015).

The significant threats to the studied standing water habitats within the continental biogeographical region have resulted from human-induced changes in hydrological conditions that have modified whole natural systems. A negative impact on the conservation status of habitats has been demonstrated in habitats 3110, 3130, 3140, 3150, and 3160 (Fig. 2, 3, 4). Related regulatory issues, lowering the groundwater level, terrestrial transformation, and consequently, increasing hydromass succession are the main causes of the loss of biodiversity (Hein *et al.*, 2016; Janssen *et al.*, 2016, Schindler *et al.*, 2016).

Loss of continuity of the river system with the lake habitats (3110, 3130, 3140, 3150, 3160) and water abstractions from surface waters (3140, 3150, 3160) were demonstrated in the study, affecting the status of conservation habitats (Fig. 3, 4). This connectivity and the potential refuge it can provide from high flow and pollution events is important for maintaining conditions for a range of species (e.g., Bornette *et al.*, 1998; Amoros & Bornette, 2002)

The reduced hydromorphological dynamics in floodplain areas in Europe, observed as a result of degradation, causes the reduction of dynamic habitat types, which are an important part of flood plains (Percic *et al.*, 2009). Flooding modifications were indicated as a threat to habitats 3130 and 3140 as well as being an indirect threat for all habitats (Fig. 2, 3 4). Flooding areas represent habitats with high levels of structural and functional dynamics that are primarily induced by downstream flow (Brooker *et al.*, 2007). Flooding modifications are often characterized by a mosaic of habitats differing in humidity, sediment properties, abundance, composition, and succession state of fauna and flora as well as productivity and diversity (Hefting *et al.*, 2013).–

Human impact, such as floodplain disconnection, river damming, aggradation, introduction of invasive species, or intense forestry, pollution by fertilizers and chemical contaminants, caused changes in habitat conditions (eg Schnitzler *et al.*, 2005; Mitsch *et al.*, 2012). A negative effect on phytodiversity in ditches by nutrient input from fertilization of adjacent meadows was observed by Müller *et al.*, (2016). Pollution to surface waters, reported as the cause of the poor conservation status of the habitats, was indicated for all lake habitats (3110, 3130, 3140, 3150, 3160). In habitat 3110, an important role of discharge from the agricultural or forest catchment was indicated; in habitat 3140, poor management of the maintenance of watercourses was shown (Fig. 3, 4). Depending on the heterogeneity of humidity, the succession stage of the ditch, and the intensity and frequency of maintenance, ditches are not only characterized by a distinct species composition but also constitute important habitats for rare species and species relevant for conservation (Garniel, 2000; Herzon & Helenius, 2008), which affects the protection status of water body habitats (Grzybowski 2014). Irregular cleaning of the ditches with differences in timing, partial cleaning, or half site cleaning (Garniel, 2000), and a cleaning frequency of 2–3 years (Van Strien *et al.*, 1991) have been shown to maximize phytodiversity at the local scale. As nitrogen accumulates especially in irrigation ditches, removing the biomass after mowing may be favourable for species sensitive to nutrient-rich conditions. The strong impact of mowing time and frequency on species composition is well-studied (e.g. Hobbs & Huenneke, 1992; Geertsema & Sprangers, 2002; Manhoudt *et al.*, 2007; Meier *et al.*, 2017), and temporal diversity of disturbances was highlighted to be of special relevance for regional species diversity in agricultural landscapes (Buhk *et al.*, 2007; Meier *et al.*, 2017).Therefore, the scope, frequency, and type of maintenance work of the drainage network affect the condition of the examined aquatic habitats that are important for the EU.

Biological invasions

The threat of invasive and other problematic species in the studied habitats has not been frequently reported, apart from in habitat 3130 (Fig. 2). While the present level of invasion is relatively low, it is clear that early detection of invaded locations is essential to prevent them serving as sources for the wider spreading of such species. The rate of spread of indigenous species and the invasion of non-indigenous species are affected by many factors that differ along spatial and temporal scales, making generalization difficult. Such factors may include climate and local weather patterns, vegetation structure, resource availability, the number of species present in secondary regions, propagule pressure, and associated ecosystem processes, such as competition, disease, and adaptation (Foxcroft *et al.*, 2007). Long-distance seed dispersal along roads has long been recognized as a routine, rather than occasional, phenomenon (Von Der Lippe & Kowarik, 2007). A positive relationship has also been confirmed between Invasive Alien Species (IAS) occurrence and proximity to streams (Catford *et al.*, 2011; Foxcroft *et al.*, 2007; Richardson *et al.*, 2007), especially for *I. glandulifera* (Čuda *et al.*, 2017) and *Fallopia spp*. (Mandák *et al.*, 2004). These species show a strong preference for such habitats, and the streams subsequently act as spread vectors. A higher number of alien neophytes appear to occur in and around human-made habitats (Lososová *et al.*, 2006; Lambdon *et al.*, 2008; Řepka *et al.*, 2015). These aspects should be included in the management of habitats; as part of the prevention of invasive alien species spread into protection areas, the monitoring efforts should be aimed at specific protected areas and boundaries crossing urban sites, such as garden colonies or discontinuous urban land. While variation in invasive alien species occurrence in different regions makes the proposal of generalized measures for Sites of Community Importance (SCI) protection difficult, mapping and, if possible, elimination of invasive alien species from those areas surrounding the SCI is a clear priority. Habitat suitability models could be applied in order to define the locations most threatened by invasive alien species dispersal and to select those areas most in need of regular monitoring (Pluess *et al.*, 2012; Vardarman *et al.*, 2018).

Climate changes

The consensus of a large body of scientific work clearly indicates that the Earth's climate is changing and will continue to change at an increasingly rapid pace (Wuebbles *et al.*, 2017, Royal Society, 2017). The impact of climate change is difficult to assess, but some damaging effects are already clear and are likely to increase (Janssen *et al.*, 2016). Water scarcity and Water pollution are among the main challenges faced by the European Union (Molina-Navarro *et al.*, 2018) as related effects of climate variability which leads to floods and droughts, which is indirectly seen in our study (Fig. 4); however, the direct relationship between the poor conservation status of the habitats in the collected data was only associated with habitats 3110, 3130, and 3140 (Fig. 2., 3, 4).

Climate change leads to modifications in the composition, intensity, and frequency of particular environmental elements, which can threaten extremely rare or even inexistent phenomena in a specific area (Morelli *et al.*, 2016). Climate change is predicted to further impact ecosystems by causing changes in species, phenology, ranges, and community compositions (Chen *et al.*, 2011).

Lakes ecosystems are threatened by climate change, they are also part of the adaptation solution, as they perform important services for society, such as carbon sequestration, flood protection, climate regulation and soil erosion prevention. To safeguard these services for human society, resilient habitats that are able to cope with the impact of climate change, such as the increased dynamics caused by weather extremes and the shifting of suitable climate zones, are needed. The European Union published a White Paper on climate change adaptation (EA, 2009) in which a framework is set out to enhance the EU's resilience to the impact of climate change. Wetlands and aquatic plants and habitats are relatively tolerant to a wide range of environmental factors, assuming adequate water conditions are present. Hydrospheral succession is accelerated by the lowering of groundwater levels, which is the primary factor that determines the water level of oxbow lakes (van Geest *et al.*, 2005). The reduction of groundwater levels, in turn, is a consequence of two other main threats: hydrological modifications and climate change. Climate change, riverbed incision, and floodplain aggradation are causes of degradation of floodplain systems (Pataki *et al.*, 2013). Water replenishment implementations can slow down or reset succession, but even in this case, there are other threatening factors that have been described earlier in this work. The effects of climate change are mostly intensified by the anthropogenic elements in complex environmental systems, which act as amplification factors for processes and phenomena (Fig. 4).

CONCLUSIONS

The presented ample of threats and the scale of the problems related to mostly negative human-induced impacts on lakes ecosystems is in line with the global decline in biodiversity, which is at a much faster rate in aquatic than in most terrestrial systems (Vaughn, 2010). Standing water habitats and freshwater dependent habitats require careful sustainable management of their natural resources, taking into account all their functions: natural, landscape, social, economic. Almost 50% of European water bodies are failing to achieve the environmental objectives set by the Water Framework Directive in 2016 (Voulvoulis *et al.*, 2017). Harmonizing the implementation of many directives controlling ecosystem services, biodiversity and cultural heritage is to ensure the future sustainable use of freshwater wetlands including lakes systems. Actions are also needed to enhance the implementation of the Water Framework Directive by public administrations, the involvement of administrative bodies in implementing the Habitats and Birds directives, to enhance catchment-level and cross-sectional cooperation among different administrative and operational actors and institutes and non-government organization (NGOs) and the private sector.

Our findings prove that successful conservation programs for freshwater habitats of the continental type should be undertaken to achieve the protection and preservation of direct and indirect surroundings. The cause of the identified pressures and threats revealed in the study may be the insufficiently strict nature conservation laws in Poland. Although the Polish regulations clearly recognize that ecosystems are beneficial for human beings, as is visible in spatial management, nature conservation, and forestry and water management, these regulations are not harmonized with each other (Stępniewska *et al.*, 2018). It is necessary for regulations to allow for the adjustment of existing legal tools. This should limit the impact of existing pressures on freshwater habitats.

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