



# Principal threats to the conservation of freshwater habitats in the continental biogeographical region of Central Europe

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## Abstract

In this paper, we discuss the threats to freshwater habitats that are highly important to the European Community in the Continental Biogeographical Region of Europe, specifically in Poland. The study covers nine freshwater habitat types distinguished in Natura 2000, Annex I of the Habitats Directive, which is a network of nature protection areas in the territory: standing water bodies (3110, 3130, 3140, 3150, and 3160) and running water (3260, 3220, 3240, and 3270), occurring in 806 Special Areas of Conservation in Poland. Of the 72,673 km<sup>2</sup> total area of freshwater habitat covered by Natura 2000 in Poland, only 25.70% was classified, from the period 2006–2018, as favourable status, whereas 68.72% was classified as unfavourable inadequate or unfavourable bad status. Based on a multivariate analysis, we found that significant differences in the conservation status of freshwater habitats resulted from a variety of threats, pressures, and activities, among which the most significant are urbanization and residential and commercial development; transportation and service corridors; decreased and unstable water resources; fishing and harvesting of aquatic resources; agricultural pollution; improper management and use of the agricultural catchment and forest catchment; changes in biocenotic evolution, invasive species succession, and more intense touristic exploration. The changes in conservation status of habitats 3110, 3130, 3140, 3160, and 3260 are also associated with climate change. Taking into account the threats identified, a list of recommended practices for the freshwater habitat types is presented, to be considered in habitat conservation programmes.

**Keywords** Freshwater habitats · Threats · Biodiversity conservation · Natura 2000

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## Introduction

At a global scale, freshwater is relatively insignificant in terms of area (<1% global surface), but such habitats support a disproportionate number of species (~10% of all known species) (Strayer and Dudgeon 2010). Inland waters and freshwater biodiversity constitute a valuable natural resource, in economic, cultural, aesthetic, scientific and educational terms (Schröter et al. 2005; Dudgeon et al. 2005). Their conservation and management are critical to the interests of all humans, nations and governments, yet inland waters are the most threatened ecosystems worldwide (MEA 2005; Diaz et al. 2019). A review of threats to and conservation challenges faced by global freshwater biodiversity has been the subject of numerous works (MEA 2005; Dudgeon et al. 2005, Strayer and Dudgeon 2010; Collen et al. 2014; UNEP-WCMC, IUCN 2016; Janssen et al. 2016). There is a common consensus, supported by the recent Red List of European Habitats (Janssen et al. 2016) that aquatic and wetland habitats are mainly threatened by hydrological system alterations; climate change, pollution, and invasive species; and, to a lesser extent, by succession, agricultural intensification, forestry, mining, urbanization, transport, and overexploitation of biological resources (Ortmann-Ajkai et al. 2018).

The development of large, continental-scale networks of protected areas has become a key protection activity used around the world (Rodrigues et al. 2004). An example of such a network that stretches across national borders is the European Ecological Network, Natura 2000, which is the world's largest multinationally coordinated conservation infrastructure (Blicharska et al. 2016). According to the European Natura 2000 Barometer (EEA 2018), the network presently includes 27,758 terrestrial and marine Natura 2000 sites covering 1322,630 km<sup>2</sup> in total (18.18% of the land area of the European territory). This network provides ecosystem services worth ca. €200–300 billion/year (EC 2013). The highest number of habitat types of all nine geographical regions in Europe are in the Continental Biogeographical Region (CBR) of Europe. In the CBR, there are 159 habitat types and 184 animal and 102 plant species from over 2000 habitat types, and species are protected on a scale of the European Community listed in the Birds (EC, 2009) and Habitats Directives (EC 1992)—the cornerstones of EU nature conservation. Altogether, within the Continental Region, there are 7,475 Sites of Community Importance (Special Areas of Conservation, SCIs) under the Habitats Directive and a further 1478 Special Protection Areas (SPAs) under the Birds Directive (EC 2016; EEA 2018). According to the European Topic Centre on Biological Diversity (EEA 2008), these locations are estimated to cover more than 10.8% of the total land area in this region.

In the “umbrella effect” of the EU Natura 2000 protected area network, a relatively large portion is focused on freshwater habitats: the network comprises 26 habitat types (Eionet 2018a) including flowing and standing water bodies with submerged, emergent and marginal vegetation that are adapted to occasional flooding and able to develop during dry periods, also including saline and brackish habitats, some temporary waters and a few abiotic types in association with glaciers and ice sheets. Freshwater habitats are widely distributed across Europe but vary in character and distribution according to climatic and geomorphological conditions. Permanent water bodies are mainly located in the northern and Atlantic regions, while temporary waters are typical in Mediterranean areas. Some of these habitats can be included in highly developed hydrographic systems or exist individually or in patches (such as springs or ponds). These habitats are also grouped according to their trophic level, whether they are oligotrophic, mesotrophic, eutrophic or dystrophic, or exhibit a range of such conditions in relation to geomorphic conditions and natural or

anthropogenic supplies of nutrients and minerals from their catchments. Their characteristics are shown in Online Appendix 1.

Freshwater systems are consistently at higher risk of degradation than their terrestrial or marine counterparts (Dudgeon et al. 2005), and the quantity and quality of habitats and abundance of many species is declining. In spite of the “umbrella effect” of the EU Natura 2000 protected area network over freshwater habitats, a number of listed habitat types and species are far from having a favourable conservation status due to their vulnerability to widespread threats. According to the European Red List for terrestrial and freshwater habitats (Janssen et al. 2016), 46% of all freshwater habitats are threatened (critically endangered, endangered, or vulnerable). Three habitats are classified as endangered, whereas nine habitats are vulnerable. The endangered freshwater habitats include 3270 rivers with muddy banks with *Chenopodium rubri* p.p. and *Bidention* p.p. vegetation. The vulnerable freshwater habitats include all other habitats covered by the study in this work. None of the freshwater habitats are critically endangered.

The freshwater habitats within the CBR of Europe are represented by degraded river and lake basins, the ability of which to sustain biodiversity is typically reduced (Abell et al. 2019), and their resilience has been reduced as a consequence of human actions (Folke et al. 2004). Loss of resilience through the combined and often synergistic effects of a variety pressures can make ecosystems more vulnerable to changes that previously could be absorbed. In freshwater habitats, anthropogenic threats may cause loss of resilience, through such actions as removing response diversity, removing whole functional groups of species, or removing whole trophic levels; impacting ecosystems via waste and pollutant emissions and climate change; and altering the magnitude, frequency, and duration of disturbance regimes.

Although the Natura 2000 network spans across the European continent, the majority of studies have been conducted within regions at the sub-national level (Popescu 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) to maintain consistency with the conservation biogeography framework (Kreft and Jetz 2010), which has become increasingly prominent but is still underused in Natura 2000 research (Orlikowska et al. 2016). The examination of entire biogeographical regions in ecological studies would foster more cross-scale cooperation in the practical management of the network, a process that is necessary for attaining conservation goals in large-scale initiatives (Gustafsson et al. 2015). Effective conservation requires the involvement of scientists to implement research results into practice (e.g., Cvitanovica et al. 2016), and the inadequate distribution of research focus across the Natura 2000 network could limit the achievements of the expected conservation outcomes (Hermoso et al. 2017). It is also important to increase the conversion rate from science to practice, implementing solutions related to habitat protection into Member State legislation (Blicharska et al. 2016).

The challenge is to actively strengthen the capacity of ecosystems to sustain desirable pathways and ecosystem statuses (Folke et al. 2004). The EU Biodiversity Strategy to 2020 calls for, among other targets, full implementation of the Natura 2000 Directives (Target 1) and for restoration of at least 15% of the degraded ecosystems (Target 2) by 2020 (EC 2016). To achieve good functionality of the network, knowledge of the ecological conservation and management issues relevant to Natura 2000 is needed, e.g., status of species and habitats and methods of site management (Popescu et al. 2014). To improve evidence-based management and conservation of aquatic habitats covered by Natura 2000, future

research 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).

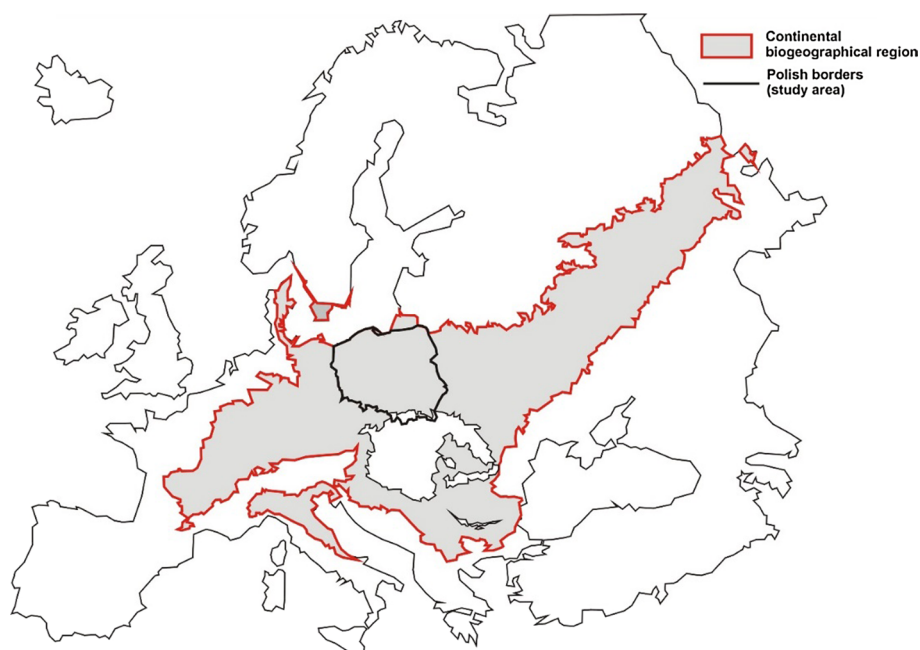
To support management and conservation activities for Natura 2000 sites, the survey presented in this paper focused on examining the status of freshwater ecosystems and water-dependent ecosystems across the CBR of Europe, with particular reference to the area of Poland. The aim of this work was an in-depth analysis of the present threats, pressures, and activities that influence the present condition of inland aquatic ecosystems and to indicate directions for correct actions to achieve favourable conservation status for habitats.

## Materials and methods

### Study area

The continental region covers more than one-quarter of the European Union and runs in a wide band from west to east, from central France through the eastern border of Poland in the north and Romania in the south. Outside the EU, the continental region stretches to the Ural Mountains, on the border with Asia (Fig. 1). In the south, this region is divided into two almost equal parts with high mountain ranges in the Alpine region and the steppe plains of the Pannonian region, also including part of the Adriatic and Baltic coastline.

The CBR, at a crossroads between many different biogeographical zones, shares many species with other regions. In terms of human use, population levels are generally high, especially in the northern urban areas of Germany, Poland, and Denmark. Central Europe



**Fig. 1** Study area in the context of the entire Continental Biogeographical Region of Europe

was, for many years, the industrial heartland of Europe, providing much of its supply of coal, iron ore, copper, and steel. Whole areas are dominated by large industrial zones. Europe's most important rivers flow through the CBR, such as the Danube, Rhine, Loire, Elbe, Po, Vistula, and Oder rivers, which have been canalized and regulated, leading to the extensive loss of floodplain habitats and species. Despite these transformations, the CBR is still relatively rich in terms of the biodiversity of its freshwater habitats. The central part of the CBR is occupied by Polish territory, abundant in a diversity of natural freshwater ecosystems. The presence of lakes is related mainly to postglacial origin, however riverine as well as mountain lakes also exist. Currently, the Natura 2000 network in Poland occupies almost 1/5 of the land area of the country, consisting of 849 habitat areas (SCIs) and 145 bird areas (SPAs). This study covered freshwater habitats occurring in all 806 Special Areas of Conservation in Poland in the continental biogeographic region. Their characteristics is presented in Online Appendix 1.

### Data collection and methods

The overall conservation evaluation of each Natura 2000 site as a habitat includes an assessment of the degree of conservation of the structure and functions, as well as the possibilities for restoration (Mróz 2017). We considered different data were in the analysis of Special Areas of Conservation (SACs) for the Natura 2000 network: standard data forms (GDEP 2018; Eionet 2018a), management plans (GDEP 2017; RDEP 2018), and reporting monitoring by EU Poland SACs (GIEP 2018; Eionet 2018b) from three reporting periods from 2009 to 2018 (2009 to 2011, 2013 to 2014, and 2015 to 2018).

The survey of the habitat types in Annex I of the Habitats Directive includes standing water bodies (habitat codes starting with “31”) and watercourses (habitat codes starting with “32”): 3110 oligotrophic waters containing very few minerals in sandy plains (*Littorelletalia uniflorae*), 3130 oligotrophic to mesotrophic standing waters with vegetation of *Littorelletia uniflorae* and/or *Isoëto-Nanojuncetea*, 3140 hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp., 3150 natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*-type vegetation (in Poland: oxbows and natural eutrophic waterbodies with *Nymphaeion* and *Potamion* community), 3160 natural dystrophic lakes and ponds, 3220 alpine rivers and the herbaceous vegetation along their banks, 3240 alpine rivers and their ligneous vegetation with *Salix elaeagnos*, 3260 water courses of plain to montane levels with *Ranunculion fluitantis* and *Callitriche-Batrachion* vegetation, and 3270 rivers with muddy banks with *Chenopodion rubri* p.p. and *Bidention* p.p. vegetation. Our research covered habitats in 7 of the 11 European biogeographic regions (Table 1). In Poland, almost all studied habitats represent Continental Biogeographic Region (Table 2).

Table 3 lists the model taxa that were used to assess the biodiversity of water habitats as well as the key taxa of aquatic species that are primarily threatened.

The assessment criteria for each habitat type are presented in Online Appendix 2. The overall assessment of the surveyed types of freshwater habitats was based on three main parameters: structure and function, future perspective, and range and surface area (Mróz 2017). The structure includes the physical components of a given habitat type, whereas the habitat functional assessment refers to the ecological processes occurring at a number of temporal and spatial scales and varies 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, with identified pressures, threats, and measures being considered for each of the other three parameters (structure and functions, range, and area). The

**Table 1** Overall assessment survey habitats in biogeographical regions in Europe (data source: Eionet 2018a, b)

Habitat	Special areas of conservation in EU		Biogeographical region						
	Total habitat area (km <sup>2</sup> )	Share of the habitat (%)	ABR	ATL	BOR	CBR	MAC	MED	PAN
3110	14,431.17	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	10,894.93	1.80	XX	U2	U1	U2	XX	XX	U1
3160	21,222.97	3.51	U1	U2	U1	U2	U1	XX	U2
3220	10,595.65	1.75	U1	XX	FV	U2	FV	XX	
3240	355.21	0.06	U1	XX		U2		XX	
3260	2110.07	0.35	U1	U2	U2	U1		XX	U2
3270	327.9	0.05	U2	U2	XX	U2		U2	U1

Biogeographical regions: *ABR* Alpine (reported also as ALP), *ATL* Atlantic, *BOR* Boreal, *CBR* Continental (reported also as CON), *MAC* Macaronesia, *MED* Mediterranean, *PAN* Pannonian. Overall assessment: *FV* favourable, *U1* unfavourable inadequate; *U2* unfavourable bad

Habitats: 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; 3220 Alpine rivers and the herbaceous vegetation along their banks, 3240 Alpine rivers and their ligneous vegetation with *Salix elaeagnos*, 3260 Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation, 3270 Rivers with muddy banks with *Chenopodion rubri* p.p. and *Bidenton* p.p. vegetation

**Table 2** Occurrence of freshwater habitats and freshwater dependent habitats under special areas of conservation in the Continental Biogeographic Region in Poland (data source: Eionet 2018a, b)

Habitat	Number of habitats under SACs in CBR in Poland	Area covered by the habitat type in the CBR	Share of the habitat area in Poland*
		km <sup>2</sup>	%
3110	33	18.8	38.2
3130	45	6	3.3
3140	82	nd	nd
3150	273	4400	70.1
3160	125	1	0.9
3220	17	0.5	0.4
3240	8	nd	nd
3260	104	nd	nd
3270	67	nd	nd

\* 28 EU Member States = 100%

Explanation of a habitat code, please see Table 1

nd No data

**Table 3** The list of freshwater habitats and freshwater dependent habitats in SACs with typical vegetation species

Habitats codes and names (Annex I of the Habitats Directive)	Synonym names of habitats	Typical vegetation species
3110 Oligotrophic waters ( <i>Littorelletalia uniflorae</i> )	Lobelia lakes—Oligotrophic waters containing very few minerals of sandy plains ( <i>Littorelletalia uniflorae</i> )	<i>Isoetes echinospora</i> , <i>Isoetes lacustris</i> , <i>Littorella uniflora</i> , <i>Lobelia Dortmanna</i> , <i>Luronium natans</i> , <i>Myriophyllum alterniflorum</i>
3130 Oligo-to-mesotrophic waters ( <i>Littorelletea Isoëto-Nanojuncetea</i> )	Oligotrophic to mesotrophic standing waters with vegetation of the <i>Littorelletea uniflorae</i> and/or of the <i>Isoëto-Nanojuncetea</i>	<i>Carex bohemica</i> , <i>Coleanthus subtilis</i> , <i>Crasula aquatic</i> , <i>Cyperus fuscus</i> , <i>Dichostylis micheliana</i> , <i>Elatine alsinastrum</i> , <i>Elatine hexandra</i> , <i>Elatine hypopiper</i> , <i>Elatine triandra</i> , <i>Eleocharis acicularis</i> , <i>Eleocharis multicaulis</i> , <i>Eleocharis ovata</i> , <i>Gnaphalium uliginosum</i> , <i>Juncus bufonius</i> , <i>Juncus bulbosus</i> , <i>Juncus capitatus</i> , <i>Juncus tenageta</i> , <i>Limosella aquatic</i> , <i>Lindernia procumbens</i> , <i>Littorella uniflora</i> , <i>Lythrum hyssopifolia</i> , <i>Myriophyllum alternifolium</i> , <i>Peplis portula</i> , <i>Pitularia globulifera</i> , <i>Plantago intermedia</i>
3140 Hard oligo-mesotrophic waters with benthic vegetation of <i>Chara</i> spp.	Hard oligo-mesotrophic waters with benthic vegetation of <i>Chara</i> spp.	<i>Chara aspera</i> , <i>Chara contraria</i> , <i>Chara filiformis</i> , <i>Chara globularis</i> , <i>Chara hispida</i> , <i>Chara intermedia</i> , <i>Chara polyacantha</i> , <i>Chara rudis</i> , <i>Chara strigosa</i> , <i>Chara tomentosa</i> , <i>Chara virgate</i> , <i>Lychnothamnus barbatus</i> , <i>Nitella flexilis</i> , <i>Nitella mucronata</i> , <i>Nitella opaca</i> , <i>Nitella syncarpa</i> , <i>Nitellopsis obtuse</i> , <i>Tolypella glomerata</i>
3150 Natural eutrophic lakes with <i>Magnopotamion</i> or <i>Hydrocharition</i> -type vegetation	Oxbow lakes and natural eutrophic water bodies with communities of Nymphaion, Potamion	<i>Batrachium circinatum</i> , <i>Elodea canadensis</i> , <i>Lemna minor</i> , <i>Lemna trisulca</i> , <i>Myriophyllum spicatum</i> , <i>Myriophyllum verticillatum</i> , <i>Polygonum amphibium</i> fo. <i>natans</i> , <i>Potamogeton crispus</i> , <i>Potamogeton lucens</i> , <i>Potamogeton natans</i> , <i>Spirodela polyrrhiza</i> , <i>Zannichellia palustris</i>

**Table 3** (continued)

Habitats codes and names (Annex I of the Habitats Directive)	Synonym names of habitats	Typical vegetation species
3160 Natural dystrophic lakes and ponds	Natural dystrophic lakes	<i>Nuphar lutea</i> , <i>Nuphar pumila</i> , <i>Nymphaea alba</i> , <i>Nymphaea candida</i> , <i>Nymphaea x borealis</i> , <i>Potamogeton gramineus</i> , <i>Potamogeton natans</i> , <i>Scorpidium scorpioides</i> , <i>Spartanium minimum</i> , <i>Sphagnum contortum</i> , <i>Sphagnum cuspidatum</i> , <i>Sphagnum denticulatum</i> , <i>Sphagnum fallax</i> , <i>Sphagnum inundatum</i> , <i>Sphagnum</i> spp., <i>Utricularia australis</i> , <i>Utricularia intermedia</i> , <i>Utricularia minor</i> , <i>Utricularia ochroleuca</i> , <i>Utricularia</i> spp. <i>Warnstorfia exannulata</i> , <i>Warnstorfia fluitans</i>
3220 Alpine rivers and the herbaceous vegetation along their banks	Alpine rivers and the herbaceous vegetation along their banks	<i>Calamagrostis pseudophragmites</i> , <i>Chaenorhium minor</i> , <i>Chamaenerion palustre</i> , <i>Equisetum variegatum</i> , <i>Festuca rubra</i> subsp. <i>Vulgaris</i> , <i>Galeopsis angustifolia</i> , <i>Galeopsis ladanum</i> , <i>Leontodon hispidus</i> , <i>Linaria vulgaris</i> , <i>Myricaria germanica</i> , <i>Poa granitica</i> , <i>Reseda lutea</i> , <i>Rumex scutatus</i> , <i>Salix eleagnos</i> , <i>Silene vulgaris</i> subsp. <i>Prostrata</i> , <i>Tussilago farfara</i>
3240 Alpine rivers and their ligneous vegetation with <i>Salix elaeagnos</i>	Alpine rivers and their ligneous vegetation with <i>Salix elaeagnos</i>	<i>Calamagrostis pseudophragmites</i> , <i>Calystegia sepium</i> , <i>Humulus lupulus</i> , <i>Myricaria germanica</i> , <i>Phalaris arundinacea</i> , <i>Salix daphnoides</i> , <i>Salix eleagnos</i> , <i>Salix fragilis</i> , <i>Salix purpurea</i> , <i>Salix triandra</i> , <i>Stachys palustris</i> , <i>Symphytum officinale</i>
3260 Water courses of plain to montane levels with <i>Ranunculus fluitantis</i> and <i>Callitriche-Batrachion</i> vegetation	Water courses of plain to montane levels with the <i>Ranunculus fluitantis</i> and <i>Callitriche-Batrachion</i> vegetation	<i>Batrachium aquatile</i> , <i>Batrachium baudotii</i> , <i>Batrachium fluitans</i> , <i>Batrachium peltatum</i> , <i>Batrachium penicillatum</i> , <i>Batrachium trichophyllum</i> , <i>Callitriche cophacarpa</i> , <i>Callitriche hamulata</i> , <i>Fontinalis antipyretica</i> , <i>Groenlandia densa</i> , <i>Potamogeton nodosus</i> , <i>Scapania undulata</i>



**Table 3** (continued)

Habitats codes and names (Annex I of the Habitats Directive)	Synonym names of habitats	Typical vegetation species
3270 Rivers with muddy banks with <i>Chenopodium rubri</i> p.p. and <i>Bidention</i> p.p. vegetation	Rivers with muddy banks with <i>Chenopodium rubri</i> p.p. and <i>Bidention</i> p.p. vegetation	<i>Alopecurus aequalis</i> , <i>Bidens cernua</i> , <i>Bidens radiata</i> , <i>Bidens tripartite</i> , <i>Chenopodium acerifolium</i> , <i>Chenopodium ficifolium</i> , <i>Chenopodium polyspermum</i> , <i>Chenopodium rubrum</i> , <i>Cyperus fuscus</i> , <i>Echinochloa crus-gali</i> , <i>Gnaphalium uliginosum</i> , <i>Juncus bufonius</i> , <i>Limosella aquatica</i> , <i>Polygonum hydropiper</i> , <i>Polygonum lapathifolium</i> s.l., <i>Polygonum minus</i> , <i>Ranunculus sceleratus</i> , <i>Rorippa palustris</i>

assessment of range and surface area must be sufficiently large in relation to favourable reference values. Based on Mróz (2017), the values of the indices for natural habitat status, expressed numerically or descriptively, are evaluated on a three-level scale: FV, favourable status; U1 unfavourable inadequate; and U2 unfavourable bad (or could be XX, unknown).

The classification threats, pressures, and activities of the studied habitats were acquired for the reference list of threats, pressures and activities (Eionet 2018a). We analysed positive and negative impacts on the following scale: A—high impact, B—low impact, C—slight impact, and X—not determined (Eionet 2018a). The following values were assigned impact intensity: A=5, B=3, C=2, and X=1. The total measure of impact was determined by multiplying the percentage of the positions of a given impact reference list of threats to habitat by the intensity of interaction.

## Statistical analyses

The statistical analyses were performed on a database consisting of 153 identified threats, pressures, and activities for the nine habitats studied. The total number of occurrences was 383. To determine 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 CANOCO 5.0 software (Microcomputer Power, Ithaca, New York, USA) (ter Braak and Šmilauer 1998; Lepš and Šmilauer 2014). Prior to PCA ordination, the data were log-transformed to improve normality. To further understand the dissimilarities between the freshwater habitats based on the threats identified for an individual habitat, we performed hierarchical clustering analysis (HCA) and heat map analysis. HCA is often introduced as a family of techniques to describe and represent the structure of the pairwise dissimilarities amongst objects. We chose a non-specific filtering option with a threshold of the interquartile range <0.5 to eliminate all threats with low variability. This method 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 (Lepš and Šmilauer 2014). 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 techniques, such as PCA, are complementary. HCA and the heat map were created using PC-ORD 6.08 (MjM Software, Gleneden Beach, Oregon, USA).

## Results

Only 25.70% of the surveyed freshwater habitats in Poland were classified as having a favourable status (FV), whereas 68.72% were classified as being in an unsatisfactory state (U1 unfavourable inadequate or U2 unfavourable bad, Table 4). The best-preserved habitat types, with a score > 25% in the FV category in the overall assessment, were in 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. The structure and function parameter, which is the most susceptible to threat effects, had the highest values in habitats 3260 > 3160 > 3110 > 3150 (> 25% FV), whereas the following habitats had the lowest scores: 3220 > 3130 > 3140 (> 30% U2). The future perspective parameter had the highest values in habitats 3160 > 3130, 3220 > 3150 > 3110 > 3270 (> 25% FV), and habitat 3220 had the lowest value (> 30% U2). The range and surface area parameter had the

**Table 4** The share of conservation statuses of freshwater habitats in SACs in the CBR in Poland

Habitat	Structure and function				Future perspective				Range and surface area				Overall assessment		
	FV	U1	U2	XX	FV	U1	U2	XX	FV	U1	U2	XX	U1	U2	XX
3110	33.33	40.0	26.67		46.67	40.0	13.3		80.0	13.33	6.67		53.33	26.67	
3130	18.75	18.75	37.50	25.0	50.0	12.5	12.5	12.5	25.0	18.75	43.75	12.5	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	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	40.74	29.63	
3160	71.43	7.14	14.29	7.14	85.71	7.14	7.14		100.0				14.29	14.29	7.14
3220		50.0	50.0		50.0	16.67	33.33		83.33		16.67		50.0	50.0	
3260	83.33	8.33	8.33		100.0				58.33	33.33	8.33		33.33	16.67	
3270		90.91	9.09		36.36	63.64			36.36	63.64			90.91	9.09	
Mean	32.16	35.05	25.64	7.14	55.24	27.97	9.67	5.56	63.62	19.95	11.83	6.08	40.79	27.93	5.58

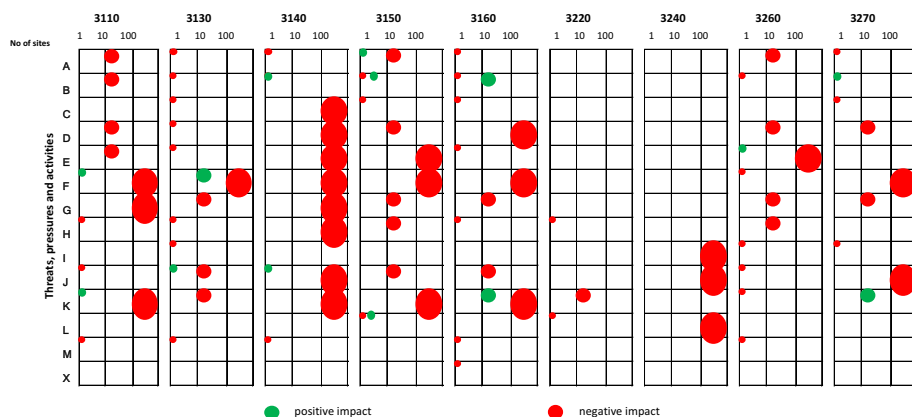
Data are given in %

Denotations: please see Table 1

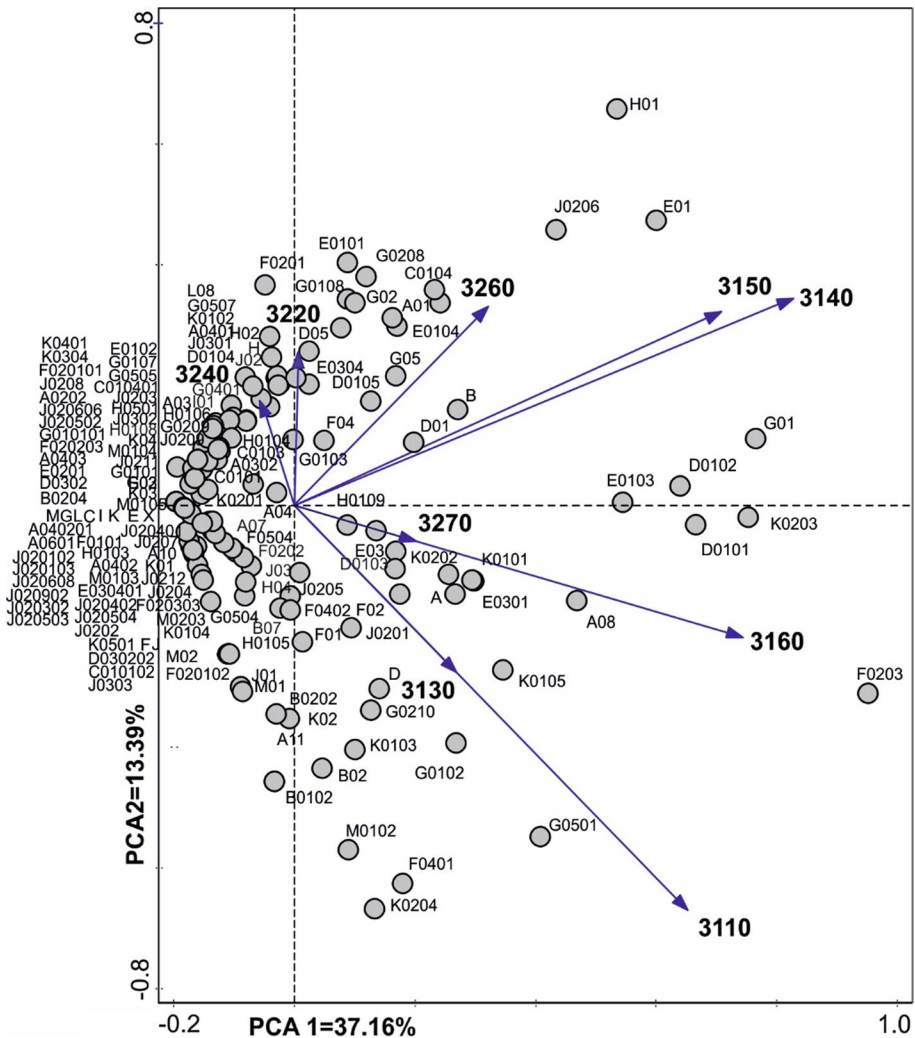
highest values in habitats 3160 > 3220 > 3110 > 3140 > 3150 > 3260 > 3270 (> 25% FV), and habitat 3130 had the lowest value (> 30% U2).

The main groups of threats, pressures, and activities identified for freshwater habitats in Special Areas of Conservation (SACs) in the CBR in Poland are presented in Fig. 2. Agriculture (A) has a number of negative impacts on freshwater habitats, which are most evident for the following habitats: 3110, 3150, 3260 > 3130, 3140, 3160, and 3270. 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, 3160, and 3260) and positive effects on habitats (e.g., 3160 > 3140, 3150, and 3270). Among the negative anthropogenic influences are pollution (H; 3140 > 3150, 3260 > 3110, 3130, and 3160); human intrusions and disturbances (G; 3110, 3140 > 3130, 3150, 3160, 3260, and 3270) and tourism (reported most often); transportation and service corridors (D; 3140, 3160 > 3110, 3150, 3260, and 3270 > 3130); urbanization and residential and commercial development (E; 3140, 3150, and 3260 > 3110 > 3130); biological resource use other than for agriculture and forestry (F; 3110, 3130, 3140, 3150, 3160, and 3270 > 3260); and mining, material extraction, and energy production (C; 3140 > 3130, 3150, 3160, and 3270). Geological events (L) and natural catastrophes—most often inundation—were identified as important hazards for habitat 3240. The development of alien and invasive species strongly affects habitats 3240 > 3130, 3260, and 3270, and natural biotic and abiotic processes (K) affect habitats 3110, 3140, 3150, and 3160 > 3130, 3220 > 3260). Negative impacts associated with climate change (M) were detected mostly for habitat types 3110, 3130, 3140, 3160, and 3260.

PCA verified the relationship between a given habitat type and its threats, pressures, and activities (Fig. 3). PCA showed that the surveyed habitat types are determined by the first two components against the vectors associated with the various threats. The first (PC1) and second (PC2) PCA components explained 32.53% and 16.45% of the total variance,



**Fig. 2** Main groups of threats, pressures and activities identified for freshwater 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: habitat type codes—please see Table 1. Main groups of threats, pressures and activities (Eionet 2018a): A—Agriculture; B—Silviculture, forestry; C—Mining, material extraction and energy production; D—Transportation and service corridors; E—Urbanisation and residential and commercial development; F—Biological resource use other than agriculture and forestry; G—Human intrusion and disturbance; 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

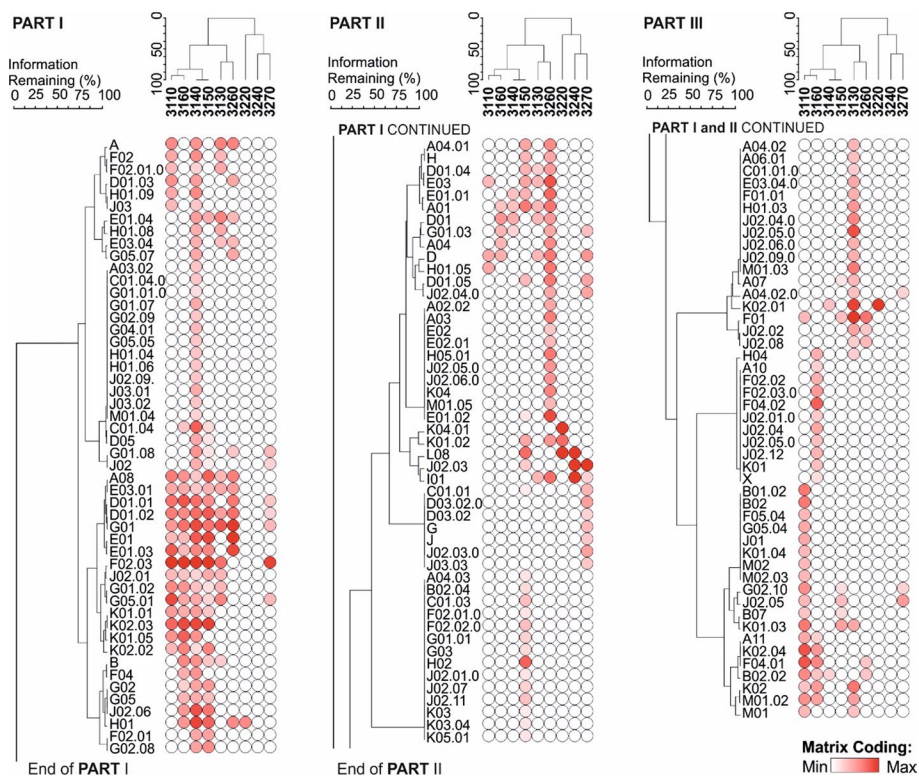


**Fig. 3** Biplot of PCA ordination axes for freshwater habitat types and their threats, pressures and activities. For explanation of the habitat codes, please see Table 1. Main groups of threats, pressures and activities (Eionet 2018a): A—Agriculture; B—Silviculture, forestry; C—Mining, material extraction and energy production; D—Transportation and service corridors; E—Urbanisation and residential and commercial development; F—Biological resource use other than agriculture and forestry; G—Human intrusion and disturbance; 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 detailed list of threats is presented in Online Appendix 3

respectively. PC1 is mainly associated with standing water habitats (the codes starting with “31”), representing a wide range of different trophic levels: from oligotrophic to eutrophic and dystrophic. PC1 showed the highest positive correlation with habitats 3140, 3160, 3150, and 3110 (PC1,  $r=0.8272$ ,  $0.7442$ ,  $0.7082$ , and  $0.6527$ , respectively). The most important threats identified for 3160 are recreational fishing (F02), fertilization (A08) and urbanization (E01). Human intrusion and transportation (G01) threaten 3140, whereas

urbanized areas and human habitation (E01) are threats for 3150. PC2 is more associated with flowing water ecosystems with codes starting with “32”; however, the correlations are not as significant as habitats representing water reservoirs. PC2 showed the highest association with habitats 3260 ( $r=0.3701$ ), 3220 ( $r=0.3437$ ), and 3240 ( $r=0.1701$ ). An analysis of PC2 showed that the most important threats identified for 3260 appear to be silviculture and forestry (B), urbanized areas and human habitation (E01), and surface water pollution (H01). Various impacts from human intrusions, urbanization, and transportation (G, D, and E, respectively) pose a threat for 3220, whereas the impact of agriculture is the greatest threat to 3240.

The results obtained from the 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 six clusters of threats and three clusters of habitat types. Among the surveyed freshwater habitats, a group of four habitat types (3110, 3160, 3140, and 3150) focused on water body habitats (lake habitats). The other habitats included three (3220, 3240, and 3270) water-course-focused habitats (fluvial habitats) and two (3130 and 3260) clusters of habitats with different water flows but with low or moderate trophic values.



**Fig. 4** Two-way hierarchical cluster analysis (TW-HCA) exposing the relationship between clusters of freshwater habitats and the threats, pressures and activities. Heat map colours indicate the minimum (light pink) to maximum (red) relationship gradient between freshwater habitats and threats, pressures and activities. For codes of habitats and threats, please see Fig. 3 and Online Appendix 3

The main threats affecting the cluster of lake habitats (3110, 3160, 3140, and 3150) are anthropogenic (A08, H01.05, H01.08, H02.06, H02.07, and E03.01) eutrophication, caused by the nutrient transfer from catchments significantly influenced by agricultural activities, urbanized areas (E01.03), transportation (D01.01) and service corridors (D01.02), and, to a lesser extent, natural interactions (K02.03 and K01.05) (Fig. 4). The threats attributed to the cluster of fluvial habitats (3220, 3240, and 3270) are mainly related to human-induced natural system modifications (J) through changes in hydraulic conditions (J02), mainly the improper modification of hydrographic functioning including canalization and water deviation (J02.03). The disappearance of natural processes results from the lack of flood impacts (L08), such as abiotic (slow) natural processes (K01 and K01.04) and interspecific floral relations (K04.01). The negative pressure on these habitats is also caused by the incursion of invasive non-native species (I01).

The threats attributed to clusters, including habitats 3130 (oligo-to-mesotrophic waters, *Littorelletea Isoëto-Nanojuncetea*) and 3260 (water courses of plain to montane levels with *Ranunculon fluitantis* and *Callitricho-Batrachion* vegetation), are mainly related to human-induced natural system modifications (J) through changes in hydraulic conditions (J02), mainly through the improper modification of hydrographic functioning, including flooding modifications (J02.04 and J02.05, Fig. 4). Also important for both habitats are threats caused by urbanized areas, human habitation (E01, E01.02, E01.03, and E01.04), household discharge (E03, E03.04, and H05.01), and agricultural activities (A), particularly those involving fertilizer (A08), crop changes (A02.02), the disposal of household or recreational facility waste (E03), and/or unsewered populations, as well as roads (D01) and railway lines (D01.04), which contribute to of surface waters pollution (H01.05). To a lesser extent, the threats to these habitats are associated with invasive non-native species (I01).

## Discussion

Freshwater habitat types show significant differences in resilience to threats, pressures and activities as they can occur at a variety of scales and differ greatly in their inherent variability. Both groups of standing and running water bodies within the CBR area in Europe are mainly in danger of habitat loss, which is also the greatest threat to freshwater biodiversity (Čížková et al. 2013; Zorilla-Miras et al. 2014; Hein et al. 2016). A key driver of habitat loss is land-use change (Janssen et al. 2016). Landscapes have changed dramatically in the last 50 years resulting from a combination of factors, including human population growth and rapid technological advancement (Freudenberger et al. 2013). Many studies have highlighted high rates of land-use change since the period after World War II, which has been associated with human population growth and processes such as urban sprawl, mass migration, and agricultural intensification (Van Eetvelde and Antrop 2004; Amici et al. 2015). Similar phenomena, such as urbanization and residential and commercial development, have directly and indirectly affected the catchment areas of the studied freshwater habitats, such as 3110, 3130, 3140, 3150, 3160, and 3260, as well as their structure and functions (Foley et al. 2005, Amici et al. 2015). Biodiversity losses induced by changes in land use are driven not only by urban sprawl and agricultural intensification but also by the abandonment of traditional rural landscapes, which leads to the initiation of natural succession (Agnoletti 2014; Beilin et al. 2014). This trend was observed even in regions with decreasing populations outside of Poland, notably in Italy and eastern Germany (Ustaoglu and



Williams 2017). In the case of numerous standing water habitats, another problem is highlighted: whether the ecosystem change is a result of natural succession or human activity (Abell et al. 2019).

Intensive grazing and cultivation in the catchment area was indicated as a cause of the poor condition of the studied habitats (3110, 3130, 3140, 3150, 3160, and 3260). The growing farm and parcel sizes and increasing mechanization have resulted in homogenization of the mosaic-like cultural landscapes and, to a large extent, the synchronized management of activities, resulting in a decrease in land-use diversity (Grzybowski 2014). This result has also led to a reduction in the richness of semi-natural components associated with management practices. In this study, the poor management of forms of nature conservation and absent or improperly directed conservation measures were indicated for habitats 3140 and 3260 (Fig. 4).

We stated that negative impacts on the conservation status of examined habitats 3110, 3130, 3140, 3150, 3160, 3260, and 3270 are caused by transportation and service corridors including parking areas (threats to habitats 3110, 3140, and 3260) and railway lines (threats to habitats 3150, 3130, and 3260). Transportation is associated with an increasingly dense road network, which contributes to the barrier effect leading to biodiversity and ecosystem fragmentation and finally their loss (Hawbaker and Radeloff 2004; Freudenberger et al. 2013). Moreover, an escalation in traffic volume affects biodiversity through noise, artificial lighting, pollution, and other direct variables (Parris and Schneider 2009; Selva et al. 2011). Increased traffic density has been reported (Alkemade et al. 2009; Eigenbrod et al. 2009) as having a negative impact on biodiversity on larger landscape scales within the “road-effect zone”.

Significant threats to freshwater habitats in the CBR have resulted from human-induced changes in hydraulic conditions that have modified entire natural systems. A negative impact on the habitat conservation status has occurred in habitats 3110, 3130, 3140, 3150, 3160, 3260, and 3270 (Figs. 2, 3, 4). Related regulatory issues, such as riverbed incision, lowering of the groundwater level, and changes in catchment land use, are commonly reported as the main causes of biodiversity loss in flood-prone areas (e.g., Hein et al. 2016; Janssen et al. 2016).

A particularly vulnerable group of aquatic habitats to external threats are floodplain water bodies, which are commonly known as biodiversity hotspots. Their high biological diversity is maintained due to mosaics of numerous aquatic habitats (Ward and Stanford 1995; Wilk-Woźniak et al. 2019), and succession is a key natural process in floodplains (Ortmann-Ajkai et al. 2018). The biodiversity of floodplain habitats (mainly 3150) is threatened by numerous factors, such as water regulation, drainage (Tockner and Stanford 2002; Čížková et al. 2013), land-use change (Zorilla-Miras et al. 2014; Hein et al. 2016), overexploitation (Harrison et al. 2010), point source and diffuse chemical pollution from neighbouring agricultural land (Glińska-Lewczuk 2005; Hein et al. 2016), the spread of invasive species (Mölder and Schneider 2011; Hein et al. 2016), and climate change (Tockner and Stanford 2002; Čížková et al. 2013).

A major cause of freshwater species and habitat losses has been channelization of rivers and their associated floodplain habitats (Clarke 2015). Such interactions were indicated mainly for habitats 3260 and 3270 (Fig. 4). Large, lowland river systems are naturally highly connected across their flood plains with small waterbodies, wetlands, and multiple channels that are all connected during periods of flooding and high water (Amoros and Bornette 2002; Grzybowski 2014). A loss of river system continuity in lake habitats (3110, 3130, 3140, 3150, and 3160) and water abstractions from surface waters (3140, 3150, and 3160) were demonstrated in our study, affecting the status of conservation habitats (Fig. 4).



This connectivity can provide potential refuge from high flow and pollution events, which is important for maintaining conditions for a range of species (e.g., Amoros and Bornette 2002).

Flooding modifications often affect a mosaic of habitats differing in sediment properties, humidity, abundance, composition, and succession states of fauna and flora, as well as productivity and diversity (Hefting et al. 2013). Flooding modifications were indicated as a threat to habitats 3130 and 3140 and were shown to be an indirect threat to all habitats except 3220 and 3240 (Fig. 4). Due to reduced hydromorphological dynamics, most floodplains in Europe have been degraded. This result has led to, among other things, a decrease in the habitat types that are an essential part of floodplains (Percic et al. 2009).

Habitat conditions in active floodplain areas have often been substantially altered by human impacts, not only by hydrotechnical structures but also by pollution from fertilizers and chemical contaminants, the introduction of invasive species, or by intensive forestry (e.g., Schnitzler et al. 2005; Mitsch et al. 2012). Surface water pollution, reported as a cause of poor habitat conservation status, was indicated for all lake habitats (3110, 3130, 3140, 3150, and 3160). In habitats 3110 and 3260, an important role of discharge from the agricultural or forest catchment was indicated. In habitats 3140 and 3260, the poor management of watercourse maintenance was indicated (Fig. 4). A negative example of the effect of nutrient input by fertilization of adjacent meadows to ditches on phytodiversity was given, e.g., by Müller et al. (2016). Depending on the heterogeneity of humidity, the succession stage of a ditch, and the intensity and frequency of maintenance, ditches are not only characterized by a distinct species composition but they also provide important habitats for rare species and species relevant for conservation (Garniel 2000; Herzon and Helenius 2008). One should remember, however, that the pivotal role of a reclamation ditch is to drain an area towards a recipient (river or lake). Thus, ditches can also accelerate nutrient transfer from meadows and pastures and increase the pollutant load discharged directly to water bodies. As a result, overfertilisation has become a key factor decreasing the conservation status of floodplain lakes (3150) in rural areas (Glińska-Lewczuk 2005).

In view of the above, irregular ditch cleaning 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 on the local scale. As nitrogen accumulates especially in irrigation ditches, the removal of biomass after mowing may be favourable for species that are sensitive to nutrient-rich conditions. The strong impact of mowing time and frequency on species composition has been well studied (Manhoudt et al. 2007; Meier et al. 2017), and the temporal diversity of disturbances has been highlighted as especially relevant for regional species diversity in agricultural landscapes (Meier et al. 2017). Therefore, the scope, frequency, and type of maintenance work on the drainage network affect the condition of the examined aquatic habitats that are important for the EU.

Biological invasions, together with habitat disturbance, are among the main causes of biodiversity decline in inland aquatic habitats (Rodríguez-Merino et al. 2018). The number of non-native aquatic plant species in Europe has increased since the early 1990s (Keller et al. 2011) as humans are vectors for these species in a highly globalized world. The lack of barriers allows their numbers to continually increase (Havel et al. 2015; Strayer 2010). Additionally, habitat alterations can create invasion opportunities, which can transform natural habitats and thus create new niches, a process that facilitates the establishment of various non-native aquatic species (Zedler and Kercher 2004).

Threats of invasive and other problematic species were not frequently reported in the studied habitats except for habitats 3130, 3240, and 3260 (Fig. 4). The data collected for the needs of our survey do not confirm the occurrence of the following species that have been

indicated as threatening the local diversity of freshwater habitats in the CBR in Poland: *Cabomba caroliniana*, *Eichhornia crassipes*, *Elodea nuttallii*, *Hydrocotyle ranunculoides*, and *Myriophyllum heterophyllum* (Rodríguez-Merinoa et al. 2018). However, the following species were identified in the littoral zone of the habitats studied, which, in Poland, the Czech Republic (Vardarman et al. 2018), and in central European protected areas (Braun et al. 2016) pose a significant threat to the conservation of biological diversity: *Fallopia* spp., *Heracleum mantegazzianum*, *Impatiens glandulifera*, and *Solidago* spp. Interestingly, some researchers (Rodríguez-Merinoa et al. 2018) have reported that non-native species are more common in anthropogenic environments than native species. Such environments can be suitable for the formation of unoccupied niches that can be filled by non-native species (Catford and Downes 2010). Therefore, in the case of interference in water habitats, these ecosystems must be protected against the expansion of alien species.

Although the present invasion level is relatively low, the early detection of their localities is essential to eliminate non-native species as sources of reproduction. 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. Such factors 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). A positive relationship between Invasive Alien Species (IAS) occurrence and proximity to streams has also been confirmed (Foxcroft et al. 2007; Catford et al. 2011), 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 streams and rivers subsequently act as spread vectors.

To address the problem of the increasing number of alien neophytes that occur in and around human-made habitats (Lososová et al. 2006; Lambdon et al. 2008), the efforts in terms of prevention, early detection and rapid response, and eradication and management of invasions in Special Areas of Conservation need to be strengthened. A solution can be found in habitat suitability models that have been applied to define the locations most threatened by invasive alien species and to select those areas for regular monitoring (Vardarman et al. 2018).

There is a consensus among many scientists that the earth's climate is changing and will continue to change at an increasingly rapid pace (Wuebbles et al. 2017). Although the consequences of climate change for freshwater ecosystems are difficult to assess, some of the damaging effects are already clear and likely to increase in both direct and indirect ways (Janssen et al. 2016; Molina-Navarro et al. 2018). Among the indirect effects of climate variability are extreme hydrological phenomena as floods and droughts, which are depicted in Fig. 4.

We only found a direct relationship between poor habitat conservation status and climate change for habitats 3110, 3130, 3140, 3160, and 3260 (Figs. 2, 3, 4). Climate change leads to modifications in the composition, intensity, and frequency of particular environmental elements, which, in turn, lead to increasing threats to extremely rare or even non-existent phenomena in specific areas (Morelli et al. 2016).

The effects of climate change can be also predicted to further impact ecosystems by causing changes in species, phenology, range, and community composition (Chen et al. 2011). According to Pallemearts et al. (2005), assuming even the most optimistic projections of the level of mitigation that can be achieved, freshwater aquatic ecosystems will still be significantly exposed to the impacts of climate change. The European Union published a white paper on climate change adaptation (EC 2009a, b), in which a framework was set out to enhance the EU's resilience to the impacts of climate change. Although ecosystems

are threatened by climate change, they are also part of the adaptation solutions as they perform important services for society such as climate regulation, carbon sequestration, flood protection, and soil erosion prevention. To safeguard these services for society, resilient ecosystems are needed that are able to cope with the impacts of climate change, such as the increased hydrological dynamics caused by weather extremes and the shifting of suitable climate zones.

An increasing problem of water-dependent habitats in the CBR in Europe is the reduction in groundwater levels resulting from natural- and human-induced hydrological modifications and climate change. These same factors are also responsible for the degradation of floodplain systems, particularly riverbed incision and floodplain aggradation (Pataki et al. 2013). Despite the diversity of solutions that can be implemented to replenish water resources or slow down or even reset the degradation of aquatic ecosystems, other co-existing factors may still pose threats.

Our results show that even well-protected conservation areas can become focal points for tourism and recreational activities that may reduce habitat quality and biodiversity (Dudgeon et al. 2005). Thus, for most of the global land surface, trade-offs between conservation of freshwater biodiversity and human use of ecosystem goods and services are necessary.

### Conservation opportunities and challenges

Our research confirms Dudgeon's conclusions (Dudgeon et al. 2005), that the threats to global freshwater biodiversity can be grouped under interacting categories: flow modification, water pollution, overexploitation, destruction or degradation of habitat, and invasion by alien species. Maintaining the natural variability in flows and water levels is therefore essential to underpin conservation strategies for freshwater biodiversity and habitats (Folke et al. 2004; Kingsford 2011; Goode et al. 2012; House et al. 2017; Creed et al. 2018). Environmental changes occurring at the global scale, such as nitrogen deposition, shifts in precipitation and runoff patterns and climate change (e.g., Creed et al. 2018; Abell et al. 2019), are superimposed upon all of these threat categories. Consideration of these processes results in more effective conservation of freshwater biodiversity (Hermoso et al. 2018; Abell et al. 2019).

Conservation planning has experienced significant advances in the last decade, including the development of new methods and tools addressing the specific needs of freshwater ecosystems (Hermoso et al. 2016). To be effective, conservation planning for freshwater biodiversity must incorporate key aspects of freshwater ecology such as longitudinal connectivity (Ward and Stanford 1995; Amoros and Bornette 2002). This method is necessary to ensure the maintenance of ecosystem processes, such as migrations or the flux of nutrients and energy, and to minimize the negative effect of threats within protected areas that might undermine conservation efforts (Nel et al. 2007; Roux et al. 2008). Conservation action at the catchment scale, involving interconnected landscape units, is also needed for certain terrestrial taxa that undertake seasonal migrations, but the shortcomings inherent in fortress conservation are particularly acute for freshwater biodiversity (Dudgeon et al. 2005). Effective preservation of biodiversity associated with freshwater habitats must therefore take account of the year-round habitat use and movements by terrestrial, riparian and amphibian fauna (e.g. frogs, water dragons and snakes, platypuses, otters, and many water birds), as well as the needs of the strictly aquatic biota. Maintenance of some semblance of the natural flow variability and the flood/drought cycle of rivers and their

floodplains, vernal pools, and water-level fluctuations in wetlands and along lakeshores, will also be essential (Dudgeon et al. 2005).

The conservation and management of freshwater ecosystems are critical to the interests of all humans, nations and governments, providing a broad variety of valuable goods and services for human societies. Having multiple human uses and forms of management is beneficial for maintaining landscape heterogeneity and states of dynamic equilibrium between human activity and ecological processes, for example, the reintroduction of grazing in lake catchments (Pretty et al. 2009; Middleton 2012). By emphasizing the role of broad-scale heterogeneity on biodiversity patterns, previous studies (Amici et al. 2015; Babai et al. 2015) have confirmed that similar policy adjustments are key to conserving not only cultural and historical values but also the rich biological heritage of European landscapes.

Thus, complex management actions need to be performed to mitigate anthropogenic threats and act as amplification factors for processes and phenomena in complex water-based systems. Protection of freshwater biodiversity in the long term must include reserves that protect key, biodiversity-rich water bodies (especially those with important species radiations) and their catchments, as well as species- or habitat-centred plans that reconcile biodiversity protection and societal use of water resources in the context of human-modified ecosystems. We found it extremely important to mimic the natural flow regime because it influences aquatic biodiversity via several interrelated mechanisms that operate over different spatial and temporal scales (Bunn and Arthington 2002). Taking the above into account, as well as relevant literature, we compiled a list of practices (Table 5) supporting conservation of freshwater habitats in reference to the recognized threats.

## Conclusions

The most significant threats to freshwater habitats in the Continental Biogeographical Region result from human-induced changes in hydraulic conditions that have modified entire natural systems. Based on a multivariate analysis (Figs. 3, 4), we found that significant differences in the conservation status of freshwater habitats have resulted from a variety of threats, pressures, and activities, among which the most significant are urbanization and residential and commercial development (3110, 3130, 3140, 3150, 3160, and 3260); transportation (3110, 3130, 3140, 3150, and 3160) and service corridors (3260 and 3270), including parking areas (3110, 3140, and 3260); railway lines (3150, 3130, and 3260); decreased (3110, 3130, 3140, 3150, and 3160) and unstable water resources (3260 and 3270); fishing and harvesting of aquatic resources (3110, 3130, 3140, 3150, and 3160); agricultural pollution (3110, 3130, 3140, 3150, 3160, and 3260); improper management and use of agricultural catchment (3130, 3140, 3150, 3160, and 3260) and forest catchment (3130, 3140, 3150, and 3160); changes in biocenotic evolution, succession, and plant species composition (3110, 3140, 3160, 3150 and 3260, 3220); succession of invasive species (3130, 3240, and 3260); and increasingly intense touristic exploration (3110, 3130, 3140, 3150, 3160 3260, and 3270). Only in the case of habitats 3110, 3130, 3140, 3160, and 3260 were the changes in conservation status associated with climate change. The most impacted habitats were 3140 (hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp.) and 3110 (oligotrophic waters, *Littorelletalia uniflorae*) while the least impacted were habitats 3220 (alpine rivers and the herbaceous vegetation along their banks) and 3240 (alpine rivers and their ligneous vegetation with *Salix elaeagnos*).

**Table 5** A list of recommended of conservation practices in the direct and indirect surroundings of freshwater habitats

Conservation practice	Habitat code										References
	3110	3130	3140	3150	3160	3220	3240	3260	3270		
The aim is to reduce nutrient and sediment runoff that reaches the water: reduce arable land; restore grassland; increase the presence of meadows	xxx	xx	xx	xxx	x	x	x	xx	x	Toporowska et al. (2018); Hermoso et al. (2018); Naiman and Decamps (1997); Beltran et al. (2011); Leyssen et al. (2014); House et al. (2015)	
	xxx	xxx	xxx	xxx	xxx	x	x	xx	x		
Reduce fertilizers used	xxx	xxx	xxx	xx	xx	x	x	xx	x	Toporowska et al. (2018); Ostrofsky (1978); Naiman and Decamps (1997); Beltran et al. (2011)	
Maintain low concentrations of nutrients (nitrogen and phosphorus) and calcium, low electrolytic conductivity, keep high transparency and low colour that allow the existence and development of vegetation lobelia, <i>Chara</i> spp.; manage unpaved roads	xxx	xxx	xxx	xx	xx	x	x	xx	x	Wilk-Woźniak et al. (2019); Naiman and Decamps (1997); Roni et al. (2008); Goode et al. (2012); Beltran et al. (2011)	
Establish buffer zones between arable lands and freshwater habitats by creating grass/bush/tree strips to stop nutrient and sediment runoff; reduce inflow of suspended material into water habitats. Protecting riparian buffers is almost universally considered an effective conservation activity, although larger upstream catchment conditions may override riparian benefits	xxx	xxx	xxx	xxx						Abell et al. (2019); Wilk-Woźniak et al. (2019); Hermoso et al. (2018); Naiman and Decamps (1997); Franklin et al. (2019)	
Implement agricultural best management practices and good agricultural practices recognised on the national or international level (FAO, EU Nitrates Directive, etc.); location—some sub-catchments or even stream reaches may support higher priority freshwater biodiversity elements and ecosystem processes than others, but most terrestrial PAs have not been sited with these elements in mind	xxx	xxx	xxx	xxx	xxx	x	x	x	x	Zedková et al. (2014); Abell et al. (2019); Thieme et al. (2016); Herbert et al. (2010); Juffe-Bignoli et al. (2016); Hermoso et al. (2018); Ellison et al. (2009)	
Create buffer zones using groups of woody and shrub vegetation –explanation as above			xx	xx				xxx		Zedková et al. (2014)	
Prohibit meadow fertilization	xxx	xxx	xxx	xx	xxx	x	x	x		Ostrofsky (1978)	

Table 5 (continued)

Conservation practice	Habitat code							References
	3110	3130	3140	3150	3160	3220	3240 3260 3270	
Increase the presence of broadleaved forest to counteract erosion; coniferous forest in immediate surroundings is not recommended since it lowers water pH	xxx	xxx	xxx	xxx				Wilk-Woźniak et al. (2019)
Stabilize hydrological conditions; avoid extreme flows; the inflow and outflow of watercourses into oxbows and small reservoirs affects the quality of these habitats	xxx	xxx	xxx	xxx	xxx	x	xx	Wilk-Woźniak et al. (2019); Beltran et al. (2011); Doulgeris and Argyroudi (2018); Leyssen et al. (2014); House et al. (2015)
Exclude livestock from streams, reduce grazing intensity, and provide livestock with alternative water sources	xxx	x	xxx	xx	xx	xx	xxx xxx	Ellison et al. (2009); Sievers et al. (2017); Leyssen et al. (2014); House et al. (2015)
Maintain green zones in and around urbanized areas	xxx	x	xxx	xxx			xx	Wilk-Woźniak et al. (2019); Gold et al. (2019)
Maintain proper water and sewage management	xx	x	xxx	xx	x	x	xx x	Ostrowsky (1978); Gold et al. (2019)
Keep water as a living part of urbanized areas	xxx	xxx	xxx	xxx	xxx	xx	xxx x	Abell et al. (2019); Beltran et al. (2011); Doulgeris and Argyroudi (2018); Leyssen et al. (2014); House et al. (2015)
Properly manage mines and excavations so as to not to destroy hydrological conditions				xxx	xxx	xxx	xxx	Nielsen and Kelly (2016); Sheridan et al. (2018); Cravotta et al. (2013); Worku (2017)
Prohibit the creation of mines and excavations	xx	xx		xxx	xxx	xxx	xxx	Kunz (2016); Worku (2017); Kapuska et al. (2015)
Remove vegetation from the bottom and slopes of water reservoirs (mow rushes, remove plant biomass)	x	xxx	xxx	xx	xxx	xxx	xx xx	Giusevelli and Le Nédic (2004); Franklin et al. (2019); Stefanidis et al. (2019); Harvey et al. (2019); Strayer (2010); Francis et al. (2019); Leyssen et al. (2014); House et al. (2015)
Counteract water brownification	xxx			xxx				Górniak et al. (1999); Creed et al. (2018); Leonardos et al. (2008)
Implement rational fisheries management		xxx		xxx			xx xx	Salmi et al. (2004)
Prohibit fisheries	xxx		xx		xxx		x	Wilk-Woźniak et al. (2019)

**Table 5** (continued)

Conservation practice	Habitat code										References
	3110	3130	3140	3150	3160	3220	3240	3260	3270		
Mitigate climate change (manifesting itself largely through hydrological impacts)	xx	xx	xx	x	xx	x	x	xx	x	Kingsford (2011); Goode et al. (2012); Creed et al. (2018); Folke et al. (2004); House et al. (2017)	
Mitigate the outcomes, threats outside the borders of a protection area (e.g., dams, water withdrawals, agriculture, mining, forestry, or urbanization) can impinge upon the ecosystems and species within them; spatial scale—small protected areas may have little impact, although if they drain to or comprise small headwater streams, the impact may be proportionately greater than if they are located further downstream in river networks	xxx	xxx	xxx	xxx	xxx			xxx		Folke et al. (2004); Death and Collier (2010); Thieme et al. (2016); Abell et al. (2019); Doulgieris and Argroudi (2018); Díez et al. (2015); Biró et al. (2018); Hermoso et al. (2016); Genseberger et al. (2016); Leyssen et al. (2014); House et al. (2015)	
Prohibit afforestation—many but not all studies of afforestation, i.e., planting tree stands where there were none previously, focus on plantation forestry, looking primarily at the impacts of afforestation with non-native (typically conifer) species on stream chemistry	xxx	xxx	xxx					x		Tierney et al. (1998); Friberg et al. (1998); Sievers et al. (2017)	
Reforestation—it may be assumed that on balance the impacts of reforestation using native species should be positive for freshwater biodiversity in the long term	x	x	xx	xxx				xxx		Filoso et al. (2017); Yeung et al. (2017); Leyssen et al. (2014)	
Limit tourist and recreational facilities	xxx	x	xxx	xx	xxx		xxx		xxx	Reeves (2002); Gerlak (2004)	
Manage fire risk	xx	x	xxx	x	xxx					Bisson et al. (2003); Pilliod et al. (2003); Bixby et al. (2015)	
Restore ecosystem services	xxx	xxx	xxx	xxx	xx			xx		Kapuska et al. (2015); Folke et al. (2004); Díez et al. (2015); Biró et al. (2018); Hermoso et al. (2016); Genseberger et al. (2016)	

Table 5 (continued)

Conservation practice	Habitat code										References
	3110	3130	3140	3150	3160	3220	3240	3260	3270		
Consider cumulative anthropogenic impacts	xxx	x	xxx	x	x		xx			Wang et al. (2019); Bloom et al. (2013); Abell et al. (2019); Beltran et al. (2011); Hein et al. (2018)	

For explanation of habitat codes, please see Table 1; note: xxx—very important; xx—important; x—favourable



The threats and the scale of the problem presented in this work are mostly related to negative human-induced impacts on freshwater ecosystems, which is in line with the global decline in biodiversity, which occurs at a much faster rate in aquatic than in most terrestrial systems (Vaughn 2010). Freshwater habitats and freshwater-dependent habitats require the careful, sustainable management of their natural resources, considering all their functions: natural, landscape, social, and economic. Actions are needed to enhance catchment-level and cross-sectional cooperation among different administrative and operational actors and institutes, such as public administrations implementing the WFD, the administrative bodies involved in implementing the Habitats and Birds directives, non-governmental organizations (NGOs), and the private sector.

Together with the current publication, the list of recommended practices, produced as part of this work, will help policy makers assess progress towards reaching the 2020 biodiversity objectives and targets and will support implementation of relevant EU legislation, such as the EU Habitats Directive. This list can also be used in a wide range of applications in policy, science and public awareness work.

The cause of the identified pressures and threats revealed in the study may be the weak and insufficient nature conservation laws in Poland. Although the Polish regulations recognize that aquatic ecosystems are beneficial for human beings, as visible in spatial management, nature conservation, forestry, and water management, these regulations are not harmonized with each other (Stępniewska et al. 2018). Regulations that allow for the adjustment of existing legal tools are urgently required. This change should limit the impact of the existing pressures on freshwater habitats.

The modern concept of the conservation of biological diversity assumes complex measures that are aimed not only at protecting exceptionally valuable and relatively large sites included in special protected natural areas, but also small sites including land for economic use. Under the conditions of exceptionally high anthropogenic impacts on aquatic ecosystems, enhancing control over catchment land use for agricultural land, forests, and recreation areas is a pressing conservation task in all areas of the CBR in Europe.

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