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Habitat requirements of *Elodea canadensis* Michx. in Polish rivers

by

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Abstract

The main objectives of this work were to investigate the range of habitat conditions (in terms of water chemistry and hydromorphological parameters) at sites colonized by *Elodea canadensis* and to analyze the species composition of communities with this plant species. We analyzed physicochemical, hydromorphological and biological data from 1135 sites located in Polish rivers to identify environmental factors that determine the occurrence of *Elodea canadensis*. Canadian waterweed was present at 18.1% of the analyzed river sites, located mainly in the lowlands (26.2% of all lowland sites).The results show that *Elodea canadensis* prefers moderately mineralized water (545 ± 329 μS cm^{-1}), rich in calcium and magnesium carbonates (174 ± 63 mg $CaCO_3$ l^{-1}, 84.1 ± 31.4 mg Ca^{2+} l^{-1} and 11.1 ± 6.4 mg Mg^{2+} l^{-1}), with moderate concentrations of chlorides and sulfates (38.9 ± 59.1 mg Cl^- l^{-1} and 62.3 ± 50.9 mg SO_4^{2-} l^{-1}) and in terms of nutrients, it prefers water from moderately rich to mesotrophic and eutrophic. This plant has high light requirements and grows mainly in unshaded sections of shallow rivers. The studied species avoids sections of rivers strongly transformed and those with reinforced banks and bottoms. Canadian waterweed occurs mostly in the company of vascular macrophytes associated with slow-flowing rivers with sandy bottom material, indicating mesotrophic and eutrophic water.

Key words: Canadian waterweed, submerged macrophyte, ecological amplitude, rivers, habitat condition

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Introduction

Most lotic waters provide a variety of habitats that create niches for heterogeneous vegetation. Medium-sized rivers in particular provide perfect conditions for highly diverse hydrophyte vegetation (Hussner & Lösch 2005). Species composition and abundance of freshwater macrophytes in lotic waters are determined by a few physical and chemical factors, such as current velocity (Janauer et al. 2010; Steffen et al. 2014), water depth (Steffen et al. 2014) and water chemistry (Riis et al. 2000; Coops et al. 2007; Maggioniet al. 2009) as well as grain size and nutrient content of the bottom sediments (Riis et al. 2000; Matsui 2014). Moreover, the water regime, described by duration, frequency as well as the rate of filling and drying, is an important factor determining the development of plant communities and patterns of vegetation zonation in aquatic ecosystems (Barrat-Segretain & Cellot 2007). Furthermore, the anthropogenic influence, land use in the riparian zone and bank structure are the most important parameters for the formation of macrophyte communities (Ot'ahel'ová et al. 2007). Ecosystems disturbed by human impact are more prone to invasions of alien species than undisturbed ecosystems, because plant communities in such conditions become more susceptible to invasion of non-native species (Hussner et al. 2010; Kolada & Kutyła 2016).

Elodea canadensis Michx. (Canadian waterweed) is an alien, invasive macrophyte species originating from North America (Hussner 2012). *E. canadensis* was first noted in Europe in 1836 in Great Britain (Moore and More 1866, reviewed in Simpson 1984) and recently, it is one of the most widespread alien aquatic plants, reported in 41 European countries (Hussner 2012). In some countries, this species rapidly spreads and displaces native species (Hussner et al. 2010; Mjelde et al. 2012), while in others, it does not demonstrate its invasive nature (Josefsson & Andersson 2001; Kuhar et al. 2010). Kolada & Kutyła (2016) also did not confirm the invasive nature of Canadian waterweed in Polish lakes and pointed to its non-aggressive integration with native vegetation.

E. canadensis is a cosmopolitan, submerged macrophyte rooted in sediment and playing an important role in the ecology of many littoral zones (Simpson 1986; Carbiener et al. 1990; Kähkönen & Manninen 1998; Janauer et al. 2010). It is capable of quick vegetative reproduction by stem fragments and overwintering buds (turions), which are easily dispersed by currents and animals (Barrat-Segretain 2001). It has a very high ecological tolerance and can be found in all kinds of water except salt water and waters extremely deficient in organic substances (Kłosowski & Kłosowski 2007). According to Szoszkiewicz et al. (2010b) and Haury et al. (2006), it can be found in waters with average nutrient content, ranging from mesotrophic to eutrophic ones. In rivers of northwest Germany, however, *E. canadensis* is also associated with soft water (Steffen et al. 2014). According to Kuhar et al. (2010), in Slovenia, *E. canadensis* prefers rivers flowing through agricultural landscapes, with a narrow, disturbed riparian zone and sediment consisting of gravel, sand, and silt with either coarse or fine organic matter particles. The species studied has been successfully employed in testing the accumulation of selected heavy metals (e.g. Ni, Cr) and enantiomers of organophosphorus pesticides, p'-DDT and o, p'-DDT, through its roots and the whole plant (Kähkönen & Manninenem 1998; Garrison et al. 2000; Jianping et al. 2000; Thiébaut et al. 2010; Hansen et al. 2011). According to Karen et al. (1998) and Garrison et al. (2000), it can be used for phytoremediation of polluted sites due to its ability to accumulate toxic chemicals and thus to remove them from the environment. Busuioc et al. (2012) also proved that *E. canadensis* is highly capable of accumulating Fe, Co, Zn, and Cu. According to Samecka-Cymerman & Kempers (2003), the positive correlations between the amount of Al, Cr, and Cu in bottom sediments and plant material confirm the usefulness of *E. canadensis* in monitoring the level of river pollution with these metals. Kolada & Kutyła (2016) examined *E. canadensis* in Polish lakes and demonstrated that the occurrence of this aquatic species in lake ecosystems is determined by altitude and water quality. These important results have prompted us to explore this problem in Polish rivers, the more that the Canadian waterweed is an invasive species and plays an important role in ecosystems as a bioaccumulator of trace metals and organic compounds (Kähkönen & Manninenem 1998; Garrison et al. 2000; Jianping et al. 2000; Thiébaut et al. 2010; Hansen et al. 2011). Although several studies on *E. canadensis* in rivers have been carried out (Szoszkiewicz et al. 2010a; Wiegleb et al. 2014; 2015; O'Hare et al. 2006), surveys on such a large scale in rivers have not yet been carried out in Poland. The presented results are based on the largest database of rivers in Poland, surveyed by a single team, using the same methods. The main objectives of this work were to investigate the range of habitat conditions (in terms of chemistry and hydromorphological parameters) at river sites colonized by *E. canadensis* and to analyze the accompanying species.

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Materials and methods

Study area

The study was based on a countrywide survey conducted in Poland, with a dataset for 1135 river sites (Fig. 1). We analyzed 206 sites with *Elodea canadensis*, located in 173 water courses (the full list is presented in Appendix 1). The database was completed between 2003 and 2014. The basic parameters describing the studied rivers containing *E. canadensis* are presented in Table 1 (altitude, width and depth of a riverbed, bottom sediments, flow types, river valley land use, physical and chemical water parameters, and hydromorphological parameters) and in Table 2 (concentrations of macroelements and trace metals in water).

Macrophyte surveys

Macrophyte surveys were carried out during the intensive growth of most aquatic plants (from mid-June to mid-September). Field surveys were conducted using the Macrophyte Method for River Assessment (Szoszkiewicz et al. 2010b). This method is currently an official monitoring approach to rivers in Poland (Dziennik Ustaw 2016). The macrophyte assessment was based on the presence of algae, mosses, horsetails, liverworts, monocotyledonous and dicotyledonous plant species that are biological indicators of water quality. All submerged, free floating, semi-terrestrial and emergent plants were considered. The assessment also included macrophytes attached to or rooted in parts of the river bank substrate where they were likely submerged for most of the year. In wadeable survey sites, an

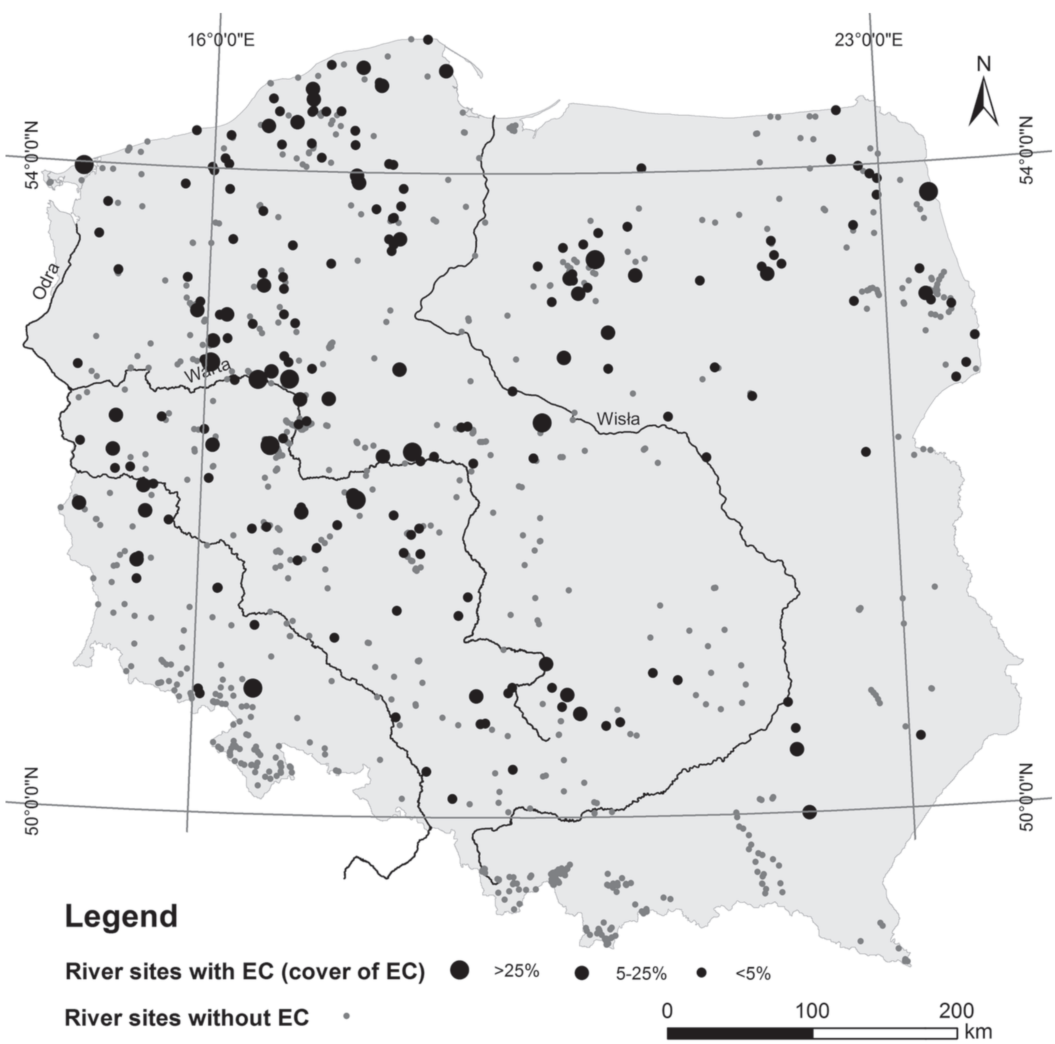

Figure 1

Distribution of the surveyed river sites (N = 206)

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Table 1

Descriptive statistics of major habitat characteristics of the surveyed rivers (N = 206)

Environmental variables	Units	Min.	Median	Max	Coefficient variation
Physical and chemical parameters of water					
pH	-	6.90	7.76	9.30	0.04
Alkalinity	mg $CaCO_3$ l^{-1}	37	165	490	0.36
Conductivity	µS cm^{-1}	192	449	2990	0.60
Total phosphorus	mg P l^{-1}	0.02	0.19	3.47	1.48
Reactive phosphorus	mg PO_4^{3-} l^{-1}	0.02	0.35	8.58	1.80
Nitrate nitrogen	mg N l^{-1}	0.01	0.57	12.90	1.48
Ammonium nitrogen		0.00	0.16	12.96	2.78
Dimensions of a riverbed					
Average width	m	1.5	5.5	45.0	0.97
Average depth		0.13	0.59	1.65	0.54
Hydromorphological metrics					
Altitude	m a.s.l.	1	97	464	0.65
HQA index	0-100	15	39	79	0.34
HMS index	0-120	0	29	109	0.93
RHQ index	50-600	107	305	490	0.25
RHM index	0-240	0	34	174	0.98
Shading of riverbed	%	0	12	90	1.15
Bottom sediments					
Granulometry index	1-6	1.00	2.09	5.00	0.30
Cobble	%	0	0	53	2.69
Gravel/pebble		0	10	93	1.21
Sand		0	57	100	0.56
Silt		0	7	100	1.35
Peat		0	0	93	5.85
Anthropogenic		0	0	100	3.00
Flow types					
Flow type index	1-6	1.00	1.51	4.13	0.42
Chute	%	0	0	19	1.82
Broken standing waves		0	0	10	3.21
Unbroken standing waves		0	0	58	2.21
Rippled		0	13	93	1.04
Smooth		0	63	100	0.49
No perceptible flow		0	3	100	1.79
Land use in a river valley					
Forest	%	0	19	100	0.92
Wetland		0	0	74	1.75
Grassland		0	30	100	0.80
Arable land		0	0	81	1.56
Urban area		0	0	100	1.63

aquascope was used to support the observations. The macrophyte survey was conducted over reaches of 100 m length. The survey includes a list of species and estimated ground cover of plants. The presence of each species was recorded with their percentage cover using the following nine-point scale: < 0.1%, 0.1-1%, 1-2.5%, 2.5-5%, 5-10%, 10-25%, 25-50%, 50-75% and > 75%. Based on the collected field data, the numerical index MIR (Macrophyte Index for Rivers) was computed (Szoszkiewicz et al. 2010b). It reflects river degradation, especially eutrophication and ranges from 10 (most degraded rivers) to 100 (highest quality). To assess the ecological status of the river, the calculated values of the MIR index were referenced to the current standards (Dziennik Ustaw 2016).

Hydrochemical parameters

During plant and hydromorphological surveys, three subsamples of water were randomly collected from each river site in the river midstream at a depth of 0.5-1 m. Water samples were not collected

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Table 2

Descriptive statistics of concentrations of elements in water of selected *Elodea canadensis* rivers (based on data from the State Environmental Monitoring)

Elements	Units	Min.	Median	Max	Coefficient variation
Al (aluminum)	µg Al l^{-1}	5	24	370	1.38
As (arsenic)	µg As l^{-1}	0.3	1.3	32.5	1.54
B (boron)	µg B l^{-1}	9	26	409	1.09
Ba (bar)	µg Ba l^{-1}	5	35	108	0.66
Ca (calcium)	mg Ca l^{-1}	19.4	79.6	191.1	0.37
Cd (cadmium)	µg Cd l^{-1}	0.01	0.10	7.70	2.64
Cl (chlorine)	mg Cl^- l^{-1}	3.5	17.6	440.1	1.52
Cr (chromium)	µg Cr l^{-1}	0.02	0.63	42.50	2.23
Cu (cooper)	µg Cu l^{-1}	0.20	2.77	101.00	2.08
F (fluorine)	mg F^- l^{-1}	0.02	0.18	1.75	1.18
Fe (iron)	µg Fe l^{-1}	1	133	1172	1.06
Hg (mercury)	µg Hg l^{-1}	0.01	0.10	3.28	1.87
K (potassium)	mg K l^{-1}	0.2	4.0	30.0	0.99
Mg (magnesium)	mg Mg l^{-1}	2.0	9.9	35.8	0.57
Mn (manganese)	µg Mn l^{-1}	2	110	492	0.85
Na (sodium)	mg Na l^{-1}	0.7	9.5	247.0	1.67
Ni (nickel)	µg Ni l^{-1}	0.25	2.50	34.73	1.35
Pb (lead)	µg Pb l^{-1}	0.20	2.50	33.00	1.48
S (sulfur)	mg SO_4^{2-} l^{-1}	4.6	44.9	342.9	0.82
Se (selenium)	µg Se l^{-1}	0.3	2.9	25.0	1.05
Zn (zinc)	µg Zn l^{-1}	0.3	10.0	244.8	1.89

during rainy weather or periods with heavy runoff; if necessary, an additional visit was organized. Prior to analysis, all water samples were filtered using Sartorius cellulose filters with a nominal pore size of 0.45 µm, except for those used for the determination of total phosphorus. Water samples were cooled below 10°C and all parameters were analyzed in a laboratory within a 12h period. Electrical conductivity and pH were measured by digital potentiometers. Alkalinity was measured with sulfuric acid to the end point pH of 4.5 in the presence of methyl orange. Concentrations of phosphate (molybdenum blue method), total phosphorus (molybdenum blue method after microwave mineralization in MARS 5X), nitrate nitrogen (cadmium reduction method), and ammonium nitrogen (Nessler's method) were determined using a spectrophotometer HACH DR/2800.

Information about concentrations of 21 elements in water was obtained from the State Environmental Monitoring. The research was carried out in laboratories accredited by the Polish Centre for Accreditation. Table 2 shows the average annual values as a mean of twelve measurements (Ca^{2+}, Mg^{2+}, Cl^-, F^-, and SO_4^{2-}), or as a mean of four measurements (Al, As, B, Ba, Cd, Cr, Cu, Fe, Hg, K, Mn, Na, Ni, Pb, Se, and Zn).

Calcium and magnesium were determined by titration with EDTA (PN-ISO 6058:1999, PN-ISO 6059:1999) or by atomic absorption spectrometry (PN-EN ISO 7980:2002); sodium and potassium were measured by atomic absorption spectrometry (PN-ISO 9964-2:1994); chlorides were analyzed using the Mohr method, i.e. titration with silver nitrate in the presence of chromate as indicator (PN-ISO 9297:1994); sulfur was determined gravimetrically with barium chloride (PN-ISO 9280:2002); fluorides were measured using ion chromatography (PN-EN ISO 10304-1:2009). Trace elements were determined by atomic emission spectrometry with inductively coupled plasma (PN-EN ISO 11885:2009) and by atomic absorption spectrometry with a graphite tube (PN EN ISO 15586:2005) or with flame atomization (PN ISO 8288:2002). Mercury was determined by atomic fluorescence spectrometry with amalgamation enrichment (PN-EN ISO 17852:2009).

Measurement accuracy was determined by comparing the results of the determination of three separated portions of each sample, which were analyzed using the identical methods. Blank samples were digested in the same manner.

Hydromorphological surveys

Hydromorphological evaluation was conducted at each site according to the River Habitat Survey (RHS) method (Environment Agency 2003; Szoszkiewicz et al. 2012). The RHS data were collected from 500 m

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stretches of rivers. The RHS surveys were performed in ten profiles (spot checks) distributed at 50 m intervals. The macrophyte survey section was located inside each RHS site, always between the 6th and 8th spot check. Four numerical metrics based on the RHS protocol were produced: Habitat Quality Assessment – HQA, Habitat Modification Score – HMS (Raven et al. 1998; Szoszkiewicz et al. 2012), River Habitat Quality – RHQ, and River Habitat Modification – RHM (Tavzes & Urbanic 2009). The range of variability of the analyzed hydromorphological indices is given in Table 1. High values of HQA and RHQ indicate an extensive presence of a number of natural river features and high landscape diversity along the river. High HMS and RHM values indicate extensive anthropogenic alteration such as bank and channel re-sectioning and reinforcement or other river engineering constructions. The grain size composition and flow types were derived from the RHS database. Six flow types and six types of riverbed material were distinguished (Table 1). We also calculated the granulometry index and the flow type index (Jusik et al. 2015).

The granulometry index (GM_{index}) reflects the average grain size composition of the riverbed associated with the kinetic energy of the flow. It is based on the parameter "dominant channel substrate in spot checks" assessed using the RHS method (section E).

The flow type index (FT_{index}) reflects the average riverbed hydraulic characteristics associated with parameters such as slope, flow velocity and depth. It is based on the parameter "dominant flow type in spot checks" by the RHS method (section E).

Statistical analysis

Factor analysis (principal components analysis – PCA) with varimax normalized rotation was used to uncover the structure of environmental matrices and reveal environmental gradients. The ecological amplitude of *E. canadensis* was identified based on descriptive statistics of environmental variables (minimum, median, maximum and coefficient of variation). All calculations were performed with the Statistica 12.5 software (StatSoft Inc. 2014). Taxonomic diversity of macrophytes accompanying *E. canadensis* was analyzed using detrended correspondence analysis (DCA) from CANOCO for Windows version 4.55 (TerBraak & Smilauer 2002). Rare taxa found at up to three sampling sites were excluded from the analysis. DCA analysis of the biological data revealed that the first gradient length was 3.201 SD (standard deviation), indicating that the biological data exhibited unimodal responses to underlying environmental variables.

Results and discussion

Habitat description of rivers

Principal components analysis resulted in a simplified habitat description of the analyzed matrix. The first three factors were responsible for 43.5% of the sample variance. Table 3 presents three principal components and their corresponding eigenvalues after varimax normalized rotation; each of the three eigenvalues was responsible for more than 10% of the variance. The first principal component was strongly correlated with human impact, especially the degree of hydromorphological modification. It was negatively correlated with a percentage of urban areas, the RHM index, and the HMS index. The second principal component was strongly correlated with physico-chemical water parameters reflecting the eutrophication. It was strongly positively correlated with total phosphorous, reactive phosphorous, and ammonia nitrogen. Finally, the third principal component was strongly correlated with high hydromorphological naturalness, forests as a land-use type and shading of a riverbed. The PCA results show that the analyzed database was characterized by a strong human impact gradient associated with hydromorphological modification of a riverbed and changes in land use and eutrophication. In the studied rivers, pH was the most stable environmental variable (CV = 0.04) and ammonium nitrogen – the most diverse one (CV = 2.78) (Table 2).

Ecological amplitude of *E. canadensis*

E. canadensis occurs in lowland rivers throughout Poland (Fig. 1). It rarely occurs in upland rivers, and only up to an altitude of about 500 m a.s.l. (Table 1). The species was not found in mountain rivers. It prefers small and medium sandy lowland rivers (78% of the analyzed sites). Moreover, it occurs in gravelly lowland streams (14%), gravelly and sandy upland (7%) and stony siliceous upland watercourses (only three sites located in the Zadrna and Sopot rivers). The ecological status of the studied river sites, based on the MIR index, was as follows: 45% classified as good, 40% moderate, 8% very good and 7% poor. No Canadian waterweed sites were classified into bad ecological status.

Canadian waterweed has high light requirements and occurs mainly in unshaded sections of shallow rivers (often flowing through meadows) with an average depth of about 0.6 m (Table 1). It occurs in places with a dominant laminar flow (smooth) or slight turbulence (rippled). The median of the FT_{index} is 1.51. It

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Table 3

Factor loadings of the first three principal components

Environmental variables	Factor1	Factor 2	Factor 3
Physical and chemical parameters of water			
pH	0.198	0.089	0.199
Alkalinity	0.019	0.539	-0.166
Conductivity	-0.057	0.451	-0.149
Total phosphorus	-0.061	0.934*	-0.036
Reactive phosphorus	-0.040	0.904*	0.005
Nitrate nitrogen	0.041	0.094	0.013
Ammonia nitrogen	-0.035	0.718*	-0.033
Dimensions of a riverbed			
Average width	0.282	-0.215	0.042
Average depth	0.213	-0.281	-0.248
Hydromorphological metrics			
Altitude	0.106	-0.149	0.060
HQA index	0.409	-0.074	0.789*
HMS index	-0.759*	0.001	-0.361
RHQ index	0.614*	-0.174	0.150
RHM index	-0.788*	-0.040	-0.322
Granulometry index	-0.423	-0.195	0.432
Flow type index	0.127	-0.192	0.595
Shading of riverbed	0.145	0.036	0.682*
Land use in a river valley at a distance of 50 m from the banks			
Forests	0.357	-0.070	0.731*
Wetlands	0.224	-0.059	0.028
Grassland	0.482	0.050	-0.617*
Arable land	-0.567	0.213	-0.085
Urban area	-0.819*	-0.127	-0.021
Eigenvalues (λ)	3.546	3.048	2.967
Percentage variance (%)	16.1	13.9	13.5

* – factor loadings > 0.6

avoids highly turbulent flow of high kinetic energy and marginal dead-water zones (Fig. 2). Waterweed occurs mostly in sandy bottom sections (median GM_{index} = 2.09), with some admixture of coarse mineral (gravel/pebble) and fine organic fraction (silt) (Fig. 3). It prefers moderately natural (HQA = 41 ± 14, RHQ = 307 ± 76) and moderately transformed (HMS = 32 ± 30, RHM = 40 ± 40) river sections, usually with a straightened planform, a uniform bank profile, re-sectioned and reinforced by fascines. It was not found in strongly transformed river sections (reinforced by concrete, sheet piling, cladding, cobblestones, and gabion) and those with reinforced banks and bottoms. *E. canadensis* was most often found in grasslands or forest river sections (Fig. 4), but moderately shady, on average 10-20% (Table 1).

In the present study, the pH of water from *E. canadensis* stands varied from 6.90 to 9.30 and was higher than the optimum range (pH 6-7) for the photosynthesis of *E. nuttallii* (Jones et al. 2000), which has very similar ecological and physiological requirements (Barrat-Segretain 2001). This is consistent with Santos et al. (2011), who stated that biomass of Canadian waterweed is positively correlated with pH. According to Santos et al. (2011), *E. canadensis* shows a higher growth rate and higher cover in areas with high conductivity, thus higher salinity. Also in the present study, Canadian waterweed prefers moderately mineralized water (545 ± 329 µS cm^{-1}), rich in calcium and magnesium carbonates (174 ± 63 mg $CaCO_3$ l^{-1}, 84.1 ± 31.4 mg Ca^{2+} l^{-1} and 11.1 ± 6.4 mg Mg^{2+} l^{-1}), with moderate concentrations of chlorides and sulfates (38.9 ± 59.1 mg Cl^{-} l^{-1} and 62.3 ± 50.9 mg SO_4^{2-} l^{-1}). The average concentrations of Cl^{-} and SO_4^{2-} in

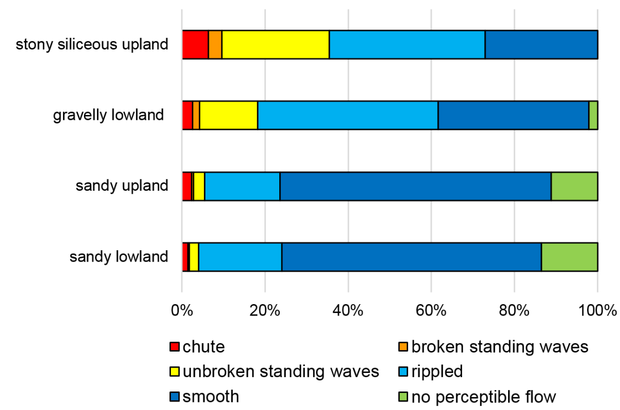

Figure 2

Percentage of each flow type (chute, broken standing waves, unbroken standing waves, rippled, smooth and no perceptible flow) in relation to all *Elodea canadensis* sites in four biocenotic types of rivers based on the RHS method (Environment Agency 2003; Szoszkiewicz et al. 2012)

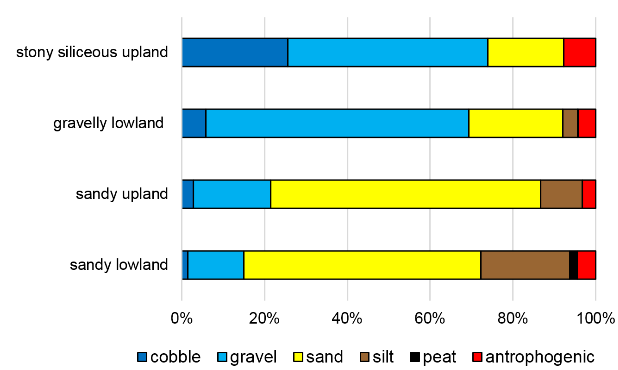

Figure 3

Percentage of each bottom sediment type (cobble, gravel, sand, silt, peat and anthropogenic) in relation to all *Elodea canadensis* sites in four biocenotic types of rivers based on the RHS method (Environment Agency 2003; Szoszkiewicz et al. 2012)

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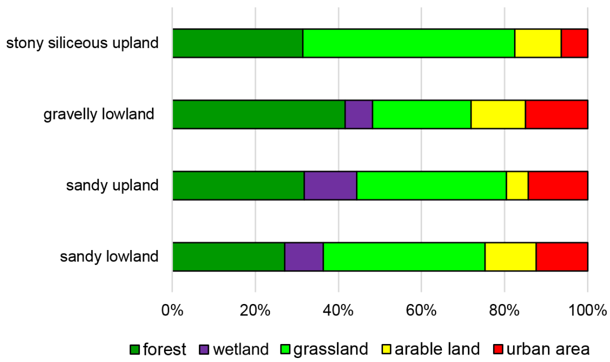

Figure 4

Percentage of each land-use type in river valleys (forest, wetlands, grassland, arable land, urban area) in relation to land use at all *Elodea canadensis* sites in four biocenotic types of rivers based on the RHS method (Environment Agency 2003; Szoszkiewicz et al. 2012)

the surveyed rivers were similar to that in the water of the Wielkopolska district (Poland) where *E. canadensis* stands were examined by Samecka-Cymerman & Kempers (2003). It also tolerates considerable salinity of the water (up to 247 mg Na l^{-1}, 440 mg Cl^{-} l^{-1} and 343 mg SO_4^{2-} l^{-1}).

In terms of nutrients, *E. canadensis* prefers water from mesotrophic to eutrophic (0.70 ± 1.25 mg PO_4^{3-} l^{-1}, 1.17 ± 1.73 mg N_{NO3-} l^{-1}, and 0.44 ± 1.21 mg N_{NH4+} l^{-1}). This is in accordance with Thiébaut (2005), Kuhar et al. (2010) and Zehnsdorfet al. (2015) who reported that *E. canadensis* grows successfully under a wide range of environmental conditions, ranging from mesotrophic to eutrophic ones. Also Kolada & Kutyła (2016) showed that *E. canadensis* is most frequently accompanied by phytocoenoses of submerged macrophytes typical of mesotrophic and meso-eutrophic conditions. On the other hand, Meilinger et al. (2005); Dodkins et al. (2012) as well as Samecka-Cymerman & Kempers (2003) reported that Canadian waterweed belongs to nutrient tolerant taxa and is associated with high nutrient enrichment. Thriving in eutrophic water is probably enabled by its tolerance to low light intensity, even though it also tolerates high light without photoinhibition (Madsen et al. 1991).

In the studied rivers, concentrations of trace metals were generally at low levels (Table 2) and were in ranges characteristic of clean water bodies (Kabata-Pendias 2011), although the content of metals in water from some study sites was very high, e.g.: 3.28 μg Hg l^{-1} (the Meszna river, site Kąty, 2006), 7.70 μg Cd l^{-1}, 32.5 μg As l^{-1}, 33.0 μg Pb l^{-1}, and 101 μg Cu l^{-1} (the Kania river, site Gostyń, 2006), 245 μg Zn l^{-1}, 409 μg B l^{-1}, and 492 μg Mn l^{-1} (the Przemsza river, site Będzin, 2006). These metal concentrations were significantly higher than those determined in water of waterweed stands in Poland (Samecka-Cymerman & Kempers 2003) and in north-eastern France (Thiébaut et al. 2010).

Macrophyte species accompanying *E. canadensis*

The Detrended Correspondence Analysis (DCA) ordination of the macrophyte species is presented in Fig. 5. The first axis (λ_1 = 0.303) can be identified with the kinetic energy of water (current velocity), which directly affects the degree of riverbed material fragmentation and the observed types of flow. Aquatic bryophytes and some filamentous algae (e.g. *Hildenbrandia rivularis*) as well as vascular macrophytes associated with the community of *Ranunculion fluitantis* (genera *Batrachium* and *Callitriche*) prefer more turbulent and fast flows, while floating-leaved macrophytes and pleustophytes – no flow (Fig. 5). The second axis (λ_2 = 0.248) was correlated with the concentration gradient of nutrients in the water of the surveyed rivers.

E. canadensis occurs most often with vascular macrophytes associated with slow-flowing rivers with sandy bottom material, indicating mesotrophic and eutrophic water (Fig. 5). In the studied material, the Canadian waterweed occurred accompanied by 105 taxa of macrophytes, including 13 macroscopic algae, 11 bryophytes and 81 vascular plants. The most dominant emergent species were (Fig. 5): *Alisma plantago-aquatica*, *Berula erecta*, *Butomus umbellatus*, *Iris pseudacorus*, *Lycopus europaeus*, *Lysimachia vulgaris*, *Mentha aquatica*, *Myosotis palustris*, *Phalaris arundinaceae*, *Ranunculus sceleratus*, *Rorippa amphibia*, *Scrophularia umbrosa*, *Sparganium emersum*, *S. erectum*, and *Veronica anagallis-aquatica*. Among submerged plant species, *Batrachium circinatum* and *Potamogeton obtusifolius* were most common, while among pleustophytes, *Lemna minor* dominated. The filamentous algae *Cladophora* sp. also occurred, a tolerant taxon which is an indicator of eutrophication (Haury et al. 2006; Szoszkiewicz et al. 2010b).

Comparison of *E. canadensis* in rivers and lakes

The average contribution of *E. canadensis* in the lake phytolittoral varied between 2.3 and 5.5% (Kolada & Kutyła 2016) and was similar to its average contribution in the studied rivers (5.9%), although the species was more common in lakes (40% of the studied lakes) studied by Kolada & Kutyła (2016) than in rivers (26% of the studied river sites). The reason may be greater heterogeneity of habitat conditions in lotic ecosystems.

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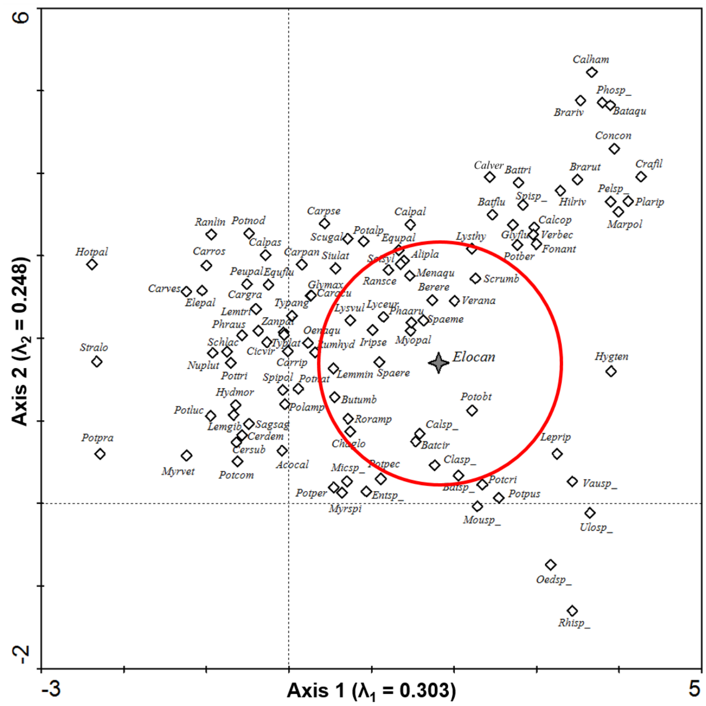

Figure 5

DCA ordination diagrams of macrophyte species. The circle indicates the most common species occurring with *Elodea canadensis*

For comparison, the CCA ordination diagrams of plant communities accompanying *Elodea canadensis* in Polish lakes examined during the State Environmental Monitoring (area > 50 ha) and presented in Kolada & Kutyła (2013), Fig. 4b.

Abbreviations:

Acocal – *Acorus calamus*, Alipla – *Alisma plantago-aquatica*, Bataqu – *Batrachium aquatile*, Batcir – *Batrachium circinatum*, Batflu – *Batrachium fluitans*, Battri – *Batrachium trichophyllum*, Batsp_ – *Batrachospermum* sp., Berere – *Berula erecta*, Brariv – *Brachythecium rivulare*, Butumb – *Butomusum bellatus*, Calcop – *Callitriche cophocarpa*, Calham – *Callitriche hamulata*, Calpal – *Caltha palustris*, Calpas – *Calla palustris*, Calver – *Callitriche verna*, Calsp_ – *Callitriche* sp., Caracu – *Carex acutiformis*, Cargra – *Carex gracilis*, Carpan – *Carex paniculata*, Carpse – *Carex pseudocyperus*, Carrip – *Carex riparia*, Carros – *Carex rostrata*, Carves – *Carex vesicaria*, Cerdem – *Ceratophyllum demersum*, Cersub – *Ceratophyllum submersum*, Chaglo – *Chara globularis*, Cicvir – *Cicuta virosa*, Clasp_ – *Cladophora* sp., Concon – *Conocephalum conicum*, Crafil – *Cratoneuron filicinum*, Elepal – *Eleocharis palustris*, Elocan – *Elodea canadensis*, Entsp_ – *Enteromorpha* sp., Equflu – *Equisetum fluviatile*, Equpal – *Equisetum palustre*, Fonant – *Fontinalis antipyretica*, Glyflu –*Glyceria fluitans*, Glymax – *Glyceria maxima*, Hilriv – *Hildenbrandia rivularis*, Hotpal – *Hottonia palustris*, Hydmor – *Hydrocharis morsus-ranae*, Hygten – *Hygroamblystegium tenax*, Iripse – *Iris pseudacorus*, Lemgib – *Lemna gibba*, Lemmin – *Lemna minor*, Lemtri – *Lemna trisulca*, Leprip – *Leptodictyum riparium*, Lyceur – *Lycopus europaeus*, Lysthy –*Lysimachia thyrsiflora*, Lysvul – *Lysimachia vulgaris*, Marpol – *Marchantia polymorpha*, Menaqu – *Mentha aquatica*, Micsp_ – *Microspora* sp., Mousp_ – *Mougeotia* sp., Myopal – *Myosotis palustris*, Myrspi – *Myriophyllum spicatum*, Myrvet – *Myriophyllum verticillatum*, Nuplut – *Nuphar lutea*, Oedsp_ – *Oedogonium* sp., Oenaqu – *Oenanthe aquatica*, Pelsp_ – *Pellia* sp., Peupal – *Peucedanum palustre*, Phaaru – *Phalaris arundinacea*, Phosp_ – *Phormidium* sp., Phraus –*Phragmites australis*, Plarip – *Platyhypnidium riparioides*, Polamp – *Polygonum amphibium*, Potalp – *Potamogeton alpinus*, Potber – *Potamogeton berchtoldii*, Potcom – *Potamogeton compressus*, Potcri – *Potamogeton crispus*, Potluc – *Potamogeton lucens*, Potnat – *Potamogeton natans*, Potnod – *Potamogeton nodosus*, Potobt – *Potamogeton obtusifolius*, Potpec – *Potamogeton pectinatus*, Potper – *Potamogeton perfoliatus*, Potpra – *Potamogeton praelongus*, Potpus – *Potamogeton pusillus*, Pottri –*Potamogeton trichoides*, Ranlin – *Ranunculus lingua*, Ransce – *Ranunculus sceleratus*, Rhisp_ – *Rhizoclonium* sp., Roramp –*Rorippa amphibia*, Rumhyd – *Rumex hydrolapathum*, Sagsag – *Sagittaria sagittifolia*, Schlac – *Schoenoplectus lacustris*, Scisyl – *Scirpus sylvaticus*, Scrumb – *Scrophularia umbrosa*, Scugal – *Scutellaria galericulata*, Siulat – *Sium latifolium*, Spaeme – *Sparganium emersum*, Spaere – *Sparganium erectum*, Spipol – *Spirodela polyrhiza*, Spisp_ – *Spirogyra* sp., Stralo – *Stratiotes aloides*, Typang – *Typha angustifolia*, Typlat – *Typha latifolia*, Ulosp_ – *Ulothrix* sp., Vausp_ – *Vaucheria* sp., Verana – *Veronica anagallis-aquatica*, Verbec – *Veronica beccabunga*, Zanpal – *Zannichellia palustris*

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In terms of abiotic factors, *E. canadensis* prefers deeper and larger lakes, with a long water retention time, lower trophic status of waters and better ecological status (Kolada & Kutyła 2016). Other studies indicate that Canadian waterweed is common in water depths between 4 and 8 m (Nichols & Shaw 1986). However, Kłosowski et al. (2011) reported that *E. canadensis* phytocoenoses are associated with the shallowest parts of lakes. In the present study, it occurs more often in small and shallow streams (average depth of 0.6 m and width of 5.5 m). In terms of trophic and ecological status, the results obtained for the studied rivers and Portuguese rivers (Dodkins et al. 2012) were similar to those obtained for lakes – mesotrophic to eutrophic conditions and at least good ecological status (53% of all sites) (Kolada & Kutyła 2016). It should be added, however, that the conductivity and concentration of nutrients in water were higher in rivers than in lakes – the conductivity was on average 449 μS cm^{-1} in the studied rivers and 303 μS cm^{-1} in lakes (Kolada & Kutyła 2016), whereas the content of phosphorus was 0.19 mg P l^{-1} in rivers and 0.043 mg P l^{-1} (Kolada & Kutyła 2016) in lakes, respectively. Also alkalinity was slightly higher in rivers, on average 165 mg $CaCO_3$ l^{-1}, while in lakes it was 130 mg $CaCO_3$ l^{-1} (Kolada & Kutyła 2016). On the other hand, average pH was higher in lakes – 8.3 (Kolada & Kutyła 2016) and 7.76 in rivers.

In the analyzed Polish lakes, 78 hydrophyte communities were identified. *Elodea canadensis* forms a compact plant community in the vicinity of other submerged phytocoenoses (elodeids and charids). The most common are plant communities such as: *Charetum fragilis*, *Charetum rudis*, *Myriophyllum alterniflorum*, *Potametum alpinii*, *P. compressi*, *P. lucentis*, *P. obtusifolii*, *P. pusilli*, *Ranunculetum circinati* (Kolada & Kutyła 2016). Macrophytes in rivers were assessed based on the Macrophyte Method for River Assessment, i.e. based on species rather than plant communities, so direct comparison with lakes is not possible. In addition, charids are a very important group in lakes (represented by e.g. *Charetum fragilis* and *Charetum rudis*), especially those with at least good ecological status, preferred by *Elodea canadensis*, while they are very rare in rivers. Only *Chara globularis* (syn. *Chara fragilis*) from this group was found in the studied rivers, at 4 sites. In total, 105 taxa of macrophytes were identified in rivers, including 81 vascular plants. Most of the studied rivers were dominated by relatively shallow sections (0.13-1.65 m, mean 0.59 m), therefore, the Canadian waterweed was accompanied by numerous emergent species – rushes, in addition to the submerged macrophytes (e.g. *Batrachium circinatum*, *Potamogeton obtusifolius*). The most important of them, occurring in at least 50% of the *Elodea canadensis* sites, were: *Berula erecta, Mentha aquatica, Myosotis palustris, Sparganium emersum and Veronica anagallis-aquatica*.

Conclusions

In summary, *Elodea canadensis* was commonly found in lowland rivers throughout Poland, but rarely in upland streams. The species has high light requirements and occurs mainly in unshaded sections of shallow rivers. It occurs in places with a dominant laminar flow (smooth) or slight turbulence (rippled), most often in sandy bottom sections of rivers, with some admixture of coarse mineral (gravel/pebble) and fine organic fraction. Canadian waterweed prefers sections of rivers that are moderately hydromorphologically transformed, usually with a uniform bank profile, re-sectioned and reinforced by fascines. It prefers moderately mineralized water, rich in calcium and magnesium carbonates, with moderate concentrations of chlorides and sulfates and mesotrophic to eutrophic conditions. Therefore, light and nutrient concentrations in water can be very important factors regulating the abundance and range of Canadian waterweed populations in Polish rivers. *Elodea canadensis* occurs mostly with vascular macrophytes associated with slow-flowing rivers, with sandy bottom material, indicating mesotrophic and eutrophic water.

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Appendix 1

List of the surveyed river sites (N = 206) with *Elodea canadensis*. Geographical names are based on the National Register of Geographical Names and topographic maps on a scale of 1:10 000.

No.	Name of the river	The nearest place	Province	Year of survey	Geographical coordinates		No. of a grid ATPOL square	Cover of *E. canadensis**
1.	Baczyna	Lubin, ul. Sikorskiego	dolnośląskie	2013	51°23'38.6"N	16°12'14.1"E	BE13	2
2.	Biała (Biela)	Struga	lubuskie	2008	52°06'34.8"N	15°07'42.0"E	AD36	3
3.	Białka	Koniecpol	śląskie	2011	50°45'43.2"N	19°40'33.2"E	DE87	5
4.	BiałkaLelowska	Lelów	śląskie	2010	50°41'09.2"N	19°37'17.7"E	DE97	4
5.	Blizna	Szczebra	podlaskie	2004	53°54'27.0"N	22°58'49.3"E	FB29	2
6.	Błędzianka	PuszczaRomnicka	warmińsko-mazurskie	2011	54°20'25.9"N	22°35'03.7"E	FA86	3
7.	Bóbr	Żelisław	lubuskie	2005	51°34'18.0"N	15°24'43.0"E	AD98	1
8.	Brda	Piła - Młyn	kujawsko-pomorskie	2005	53°30'49.2"N	17°53'06.4"E	CB85	1
9.	Brda	Zapora (Mylof)	pomorskie	2006	53°46'22.1"N	17°43'07.6"E	CB54	3
10.	Bukówka (Kamionka)	Kuźniczka	wielkopolskie	2005	52°56'46.1"N	16°12'38.3"E	BC44	2
11.	Bytowa	Bytów	pomorskie	2013	54°10'02.2"N	17°29'04.0"E	CB03	4
12.	Chotla	ZaspyMałe	zachodniopomorskie	2006	54°01'44.2"N	16°09'30.5"E	BB14	1
13.	Ciemna	Tursko	wielkopolskie	2009	51°52'19.4"N	17°56'49.0"E	CD65	1
14.	Cieszynka	Bukowo	zachodniopomorskie	2008	53°05'45.1"N	16°11'55.6"E	BC24	5
15.	Cieszynka	Człopa, ul. Młyńska	zachodniopomorskie	2008	53°05'23.1"N	16°07'19.2"E	BC23	1
16.	Czapliniecka Struga	Czaplinek	zachodniopomorskie	2013	53°33'43.3"N	16°13'48.9"E	BB74	4
17.	Czarna	Okonek	wielkopolskie	2011	53°32'08.3"N	16°51'13.1"E	BB78	3
18.	Czarna Przemsza	Sosnowiec, ul. Będzińska	śląskie	2006	50°17'51.8"N	19°08'15.6"E	DF33	1
19.	Czarna Struga	Nowa Sól, os. Konstytucji 3 maja	lubuskie	2013	51°48'20.3"N	15°41'32.1"E	BD60	1
20.	Czarna Woda	Ostrowo	pomorskie	2006	54°49'49.6"N	18°14'22.8"E	CA38	3
21.	Czarna Woda	Sępolno	wielkopolskie	2008	52°22'35.8"N	16°00'40.7"E	BD02	2
22.	Czarnka	Opole, ul. Adama	opolskie	2011	50°37'04.9"N	17°59'37.0"E	CF05	4
23.	Czerska Struga	Czersk	pomorskie	2013	53°47'33.0"N	17°58'42.0"E	CB46	3
24.	Czerska Struga	Końskie Błota	pomorskie	2006	53°43'04.0"N	17°53'35.9"E	CB55	4
25.	Czerwona	Łasin Koszaliński	zachodniopomorskie	2006	54°13'37.5"N	15°48'06.6"E	BA92	1
26.	Dar (Sienica)	Dębno	zachodniopomorskie	2008	52°44'44.1"N	14°41'28.1"E	AC53	2
27.	Dobrzyca	Czapla	zachodniopomorskie	2004	53°16'58.2"N	16°34'07.2"E	BC06	5
28.	Dojca	Obra	wielkopolskie	2008	52°04'29.3"N	16°04'34.1"E	BD32	3
29.	dopływ Grabowej	Wielin (rez. Wieleń)	zachodniopomorskie	2005	54°09'31.5"N	16°42'27.7"E	BB08	4
30.	dopływ Krąpielicy (Młynówki)	Stargard Szczeciński, Park Panorama	zachodniopomorskie	2013	53°20'30.9"N	15°03'11.7"E	AB96	4
31.	Drawa	Sitnica	zachodniopomorskie	2009	53°06'52.6"N	15°53'24.2"E	BC22	6
32.	Dzierżęcinka	Koszalin, ul. Batalionów Chłopskich	zachodniopomorskie	2007	54°12'21.8"N	16°10'10.4"E	BB04	3
33.	Flinta	Jaracz	wielkopolskie	2008	52°42'26.3"N	16°51'41.5"E	BC68	8
34.	Flinta	Ryczywół	wielkopolskie	2009	52°48'34.1"N	16°50'45.0"E	BC58	2
35.	Flinta	Skrzetusz	wielkopolskie	2005	52°50'43.4"N	16°48'05.3"E	BC58	2
36.	Gizela (Gryźlina)	Zajączki	warmińsko-mazurskie	2005	53°33'26.5"N	19°52'57.9"E	DB78	2
37.	Główna	Mechowo	wielkopolskie	2007	52°26'47.9"N	17°02'55.9"E	BC99	2
38.	Główna	Poznań, ul. Hlonda	wielkopolskie	2007	52°25'32.4"N	16°57'56.3"E	BD09	1
39.	Gniły Potok	Mościsko	dolnośląskie	2011	50°46'52.8"N	16°35'35.4"E	BE86	9
40.	Grabiczek	Grabin	warmińsko-mazurskie	2004	53°37'40.3"N	20°02'25.3"E	DB69	2
41.	Grabowa	Sulechówko	zachodniopomorskie	2011	54°16'25.8"N	16°33'54.9"E	BA97	6
42.	Graniczna	Żarkowo	pomorskie	2011	54°22'31.7"N	17°19'40.0"E	CA82	3
43.	Gryżynka (Gryżyński Potok)	Grabin	lubuskie	2003	52°07'23.7"N	15°16'45.9"E	AD27	2
44.	Gwda	Piła - Kalina	wielkopolskie	2009	53°06'18.7"N	16°47'02.9"E	BC28	1
45.	Ilanka	Maczków	lubuskie	2004	52°16'17.7"N	14°45'32.3"E	AD14	1
46.	Iławka	Młody Bór	warmińsko-mazurskie	2007	53°32'14.4"N	19°40'15.4"E	DB77	4
47.	Jerzgnia	Ciszewo	podlaskie	2007	53°37'28.2"N	22°42'11.7"E	FB67	1
48.	Kanal Nowa Ulga	Warszawa, os. Iskra	mazowieckie	2013	52°13'13.8"N	21°06'03.4"E	ED27	4
49.	Kanał Augustowski	Białobrzegi	podlaskie	2012	53°48'18.3"N	22°57'57.8"E	FB49	3
50.	Kanał Grójecki	Wola Podłężna	wielkopolskie	2012	52°14'27.2"N	18°20'42.0"E	CD28	2
51.	Kanał Lodowy	Gidle	łódzkie	2007	50°57'19.1"N	19°28'13.6"E	DE66	5
52.	Kanał Łeby	Cecenowo	pomorskie	2006	54°39'03.3"N	17°33'29.8"E	CA53	6
53.	Kanał Łęg - Klewiec	Krawce	podkarpackie	2014	50°31'15.2"N	21°53'47.3"E	FF13	4
54.	Kanał Młyński	Słupsk	pomorskie	2011	54°27'44.7"N	17°02'17.3"E	CA70	2
55.	Kanał Słupi	Słupsk	pomorskie	2011	54°26'55.9"N	17°01'58.4"E	CA70	6
56.	Kanał Turośl	pow. Turośli	podlaskie	2011	53°23'34.4"N	21°44'05.3"E	FB91	1
57.	Kanał Warty	Częstochowa	śląskie	2011	50°48'19.0"N	19°08'03.8"E	DE83	1
58.	Kanał Zuzanka	Włocławek, ul. Graniczna	pomorskie	2013	52°38'52.8"N	19°08'30.5"E	DC73	3

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No.	Name of the river	The nearest place	Province	Year of survey	Geographical coordinates		No. of a grid ATPOL square	Cover of *E. canadensis**
59.	Kania	Gostyń, ul. Fabryczna	wielkopolskie	2013	51°52'53.2"N	17°01'14.3"E	BD69	5
60.	Kania	pon. Gostynia	wielkopolskie	2008	51°54'36.4"N	17°00'54.2"E	BD59	3
61.	Kicz	Tuchola	kujawsko-pomorskie	2013	53°35'13.9"N	17°51'21.8"E	CB75	2
62.	Kirsna	Swajnie	warmińsko-mazurskie	2006	54°01'28.5"N	20°30'17.8"E	EB22	3
63.	Kisewa (Kisewska Struga)	Nowa Wieś Lęborska	pomorskie	2013	54°33'30.8"N	17°43'45.1"E	CA64	4
64.	Kłonecznica	Kłonecznica	pomorskie	2011	53°58'48.1"N	17°30'33.6"E	CB23	5
65.	Kłonecznica	Mielno	pomorskie	2009	53°56'34.9"N	17°29'59.9"E	CB33	4
66.	Konopka	Częstochowa - Sabinów	śląskie	2011	50°46'18.3"N	19°05'43.0"E	DE83	3
67.	Kończak	Podlesie	wielkopolskie	2004	52°45'02.4"N	16°40'29.6"E	BC67	5
68.	Korytnica	Jaźwiny	zachodniopomorskie	2004	53°10'00.2"N	15°54'58.6"E	BC12	2
69.	Krztynia	Tęgobórz	śląskie	2011	50°38'33.0"N	19°47'57.4"E	DF08	5
70.	Krzycki Rów	Krzekotów	kujawsko-pomorskie	2004	52°46'46.8"N	17°59'12.2"E	CC66	5
71.	Kulawa	Laska	pomorskie	2009	53°56'08.9"N	17°32'01.9"E	CB33	6
72.	Kulawa	Wawrzonowo	pomorskie	2011	53°57'08.8"N	17°31'59.3"E	CB33	4
73.	Kwacza	Kwakowo (odc. nie renat.)	pomorskie	2012	54°22'06.5"N	17°01'10.0"E	CA80	4
74.	Kwacza	Kwakowo (odc. renat.)	pomorskie	2012	54°22'32.6"N	17°01'47.2"E	CA80	3
75.	Kwisa	Luboszów	dolnośląskie	2006	51°25'53.9"N	15°23'56.9"E	AE07	3
76.	Kwisa	Trzebów	lubuskie	2007	51°33'02.7"N	15°23'38.9"E	AD98	5
77.	Lega	Olecko, ul. Partyzantów	warmińsko-mazurskie	2004	54°02'21.1"N	22°30'31.2"E	FB15	1
78.	Leśna Prawa	Topiło (rez. Olszynka Myśliszcze)	podlaskie	2004	52°38'50.8"N	23°40'24.4"E	GC64	4
79.	Lewińska Struga	Kołczewo	zachodniopomorskie	2014	53°58'44.8"N	14°37'56.6"E	AB24	7
80.	Liswarta	Tanina	śląskie	2007	50°45'13.7"N	18°46'56.7"E	DE81	6
81.	Liśnica	Białogard, ul. Nadbrzeżna	zachodniopomorskie	2013	54°00'14.3"N	15°59'02.8"E	BB23	2
82.	Liwiec	Nadkole	mazowieckie	2005	52°35'25.1"N	21°35'09.1"E	FC80	3
83.	Lubsza (Lubica)	Stargard Gubiński	lubuskie	2006	51°53'01.6"N	14°47'13.1"E	AD54	6
84.	Lutynia	Wilkowyja	wielkopolskie	2006	51°59'41.1"N	17°32'17.5"E	CD42	6
85.	Lutynia	Wola Książęca	wielkopolskie	2006	51°57'57.1"N	17°34'12.2"E	CD53	7
86.	Łabianka	Łabno	podlaskie	2007	53°24'18.5"N	21°56'28.9"E	FB82	1
87.	Łącza (Złoty Potok)	Czerwieńsk	lubuskie	2005	52°00'46.7"N	15°25'32.6"E	AD48	6
88.	Łupawa	Smołdzino, ul. Mostowa	pomorskie	2011	54°39'43.2"N	17°12'48.6"E	CA51	2
89.	Łutownia	Stara Bialowieża	podlaskie	2004	52°44'01.8"N	23°47'07.9"E	GC55	3
90.	Mała Panew	Brusiek	śląskie	2009	50°34'49.3"N	18°49'15.8"E	DF01	1
91.	Mała Wełna	Kiszkowo	wielkopolskie	2004	52°35'23.5"N	17°16'05.6"E	CC81	5
92.	Mała Wkra (Wikierka)	Stare Miasto	warmińsko-mazurskie	2009	53°27'52.4"N	20°00'22.7"E	DB89	7
93.	Meszna	Dziedzice-Kąty	wielkopolskie	2007	52°14'34.8"N	17°50'38.1"E	CD25	2
94.	Miała	Kamiennik	wielkopolskie	2006	52°48'31.7"N	15°59'03.3"E	BC52	3
95.	Miała	Piłka	wielkopolskie	2004	52°47'44.1"N	16°03'07.9"E	BC53	7
96.	Mierzawa	Słaboszowice	świętokrzyskie	2007	50°35'13.6"N	20°11'13.4"E	EF01	2
97.	Mierzawa	Tarnawa	świętokrzyskie	2014	50°33'55.8"N	20°02'56.8"E	EF00	2
98.	Mławka	Szreńsk	mazowieckie	2004	53°00'31.6"N	20°07'40.9"E	EC30	5
99.	Moszczenica	Sławno, ul. Wojska Polskiego	zachodniopomorskie	2013	54°21'52.3"N	16°40'27.0"E	BA87	4
100.	Mroczanka	Mroczno	warmińsko-mazurskie	2009	53°20'56.6"N	19°44'16.2"E	DB97	6
101.	Murynia	Spie	podkarpackie	2014	50°23'24.8"N	21°54'05.8"E	FF23	6
102.	Narew	Siemieniakowszczyzna	podlaskie	2003	52°54'09.1"N	23°53'39.3"E	GC35	1
103.	Nida (Wkra)	Nidzica, Park Gregoriusa	warmińsko-mazurskie	2012	53°21'41.1"N	20°25'10.0"E	EB92	5
104.	Niesób (Samica)	Kępno	wielkopolskie	2013	51°16'52.0"N	17°59'25.9"E	CE25	3
105.	Noteć	Ciszewo	wielkopolskie	2005	53°03'07.1"N	16°54'03.4"E	BC38	2
106.	Noteć	Kolonia Mchówek	kujawsko-pomorskie	2004	52°25'40.9"N	18°41'04.9"E	DD00	3
107.	Noteć	Morzyce	wielkopolskie	2004	52°25'23.3"N	18°37'09.4"E	DD00	1
108.	Ochnia	Kutno, ul. Zamkowa	łódzkie	2013	52°13'51.4"N	19°21'11.6"E	DD25	2
109.	Okalica	Lębork, ul. Chopina	pomorskie	2013	54°32'25.9"N	17°45'22.6"E	CA64	6
110.	Oleśnica	Stolec	łódzkie	2009	51°22'01.8"N	18°41'36.6"E	DE20	2
111.	Ołobok	Sławin	wielkopolskie	2004	51°38'28.7"N	18°03'09.9"E	CD86	4
112.	Omulew	Obory	mazowieckie	2005	53°19'03.9"N	21°05'16.3"E	EC06	4
113.	Orla	Jutrosin	wielkopolskie	2013	51°39'35.8"N	17°10'56.1"E	CD80	2
114.	Orla	Skałów	wielkopolskie	2009	51°48'18.0"N	17°22'57.3"E	CD71	2
115.	Orzyc	Przeradowo	mazowieckie	2005	52°46'36.9"N	21°12'47.5"E	EC67	1
116.	Ostroroga	Biezdrowo	wielkopolskie	2004	52°41'17.8"N	16°18'08.8"E	BC64	2
117.	Ostróżek	Szczukowice	świętokrzyskie	2014	50°53'16.6"N	20°30'54.8"E	EE73	4
118.	Paklica	Międzyrzecz, ul. Garncarska	lubuskie	2008	52°26'36.1"N	15°34'31.1"E	AC99	2
119.	Parsęta	Dębczyno	zachodniopomorskie	2005	53°59'01.0"N	16°00'18.0"E	BB23	4
120.	Parsęta	Pustkowie	zachodniopomorskie	2014	53°44'36.5"N	16°32'09.8"E	BB56	3

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121.	Parsęta	Stare Dębno	zachodniopomorskie	2005	53°52'22.5"N	16°10'35.8"E	BB34	3
122.	Pasłęka	Wymój	warmińsko-mazurskie	2006	53°39'45.9"N	20°20'43.0"E	EB61	4
123.	Piława	Szwecja	wielkopolskie	2003	53°21'27.1"N	16°33'04.1"E	BB96	4
124.	Pisa	Pupki	warmińsko-mazurskie	2007	53°20'52.5"N	21°47'22.8"E	FB91	5
125.	Pisa	Szast	warmińsko-mazurskie	2007	53°33'01.4"N	21°50'24.4"E	FB71	3
126.	Pisa	Wincenta	warmińsko-mazurskie	2007	53°27'34.7"N	21°51'55.0"E	FB82	1
127.	Pissa (Pisia)	Gółkowo	kujawsko-pomorskie	2005	53°12'04.1"N	19°33'03.1"E	DC16	1
128.	Pliszka	Drzewce	lubuskie	2004	52°13'51.1"N	15°05'51.1"E	AD16	5
129.	Płoska	Kołodno	podlaskie	2011	53°10'48.3"N	23°25'08.9"E	GC02	5
130.	Płoska	Przechody	podlaskie	2004	53°08'07.1"N	23°28'04.8"E	GC12	2
131.	Płośniczanka	Prętki	warmińsko-mazurskie	2009	53°17'17.4"N	19°55'14.5"E	DC09	4
132.	Płytnica	Ptusza	wielkopolskie	2011	53°20'14.7"N	16°45'49.3"E	BB98	3
133.	Pokrzywna	Osówka	pomorskie	2011	54°10'18.7"N	17°01'19.9"E	CB00	1
134.	Pokrzywnica	Końska Wieś	wielkopolskie	2009	51°38'01.5"N	18°13'03.4"E	CD97	4
135.	Pokrzywnica	Sławoborze	zachodniopomorskie	2007	53°53'40.7"N	15°42'31.3"E	BB31	1
136.	Postomia	Sulęcin, ul. Chrobrego	lubuskie	2013	52°26'26.0"N	15°06'38.1"E	AC96	5
137.	Powa	Rumin	wielkopolskie	2008	52°12'38.5"N	18°12'41.0"E	CD27	2
138.	Prostynia	Prostynia	zachodniopomorskie	2008	53°18'55.5"N	15°46'28.7"E	BB91	1
139.	Przykopa (Łącza)	Korzonek	opolskie	2007	50°16'59.0"N	18°17'53.6"E	CF48	3
140.	Pyszna	Staw	wielkopolskie	2009	51°15'10.4"N	18°36'01.6"E	DE30	2
141.	Raciążnica	Raciąż, ul. 19 stycznia	mazowieckie	2013	52°46'56.6"N	20°07'21.7"E	EC60	3
142.	Radew	Bardzlino	zachodniopomorskie	2007	54°03'43.3"N	16°07'02.6"E	BB14	1
143.	Rakówka	Nowy Sumin	kujawsko-pomorskie	2004	53°35'20.7"N	17°58'20.6"E	CB76	6
144.	Reda	Mrzezino	pomorskie	2012	54°38'13.2"N	18°26'24.0"E	CA59	5
145.	Rgilewka	Grzegorzew	wielkopolskie	2004	52°11'58.5"N	18°44'33.7"E	DD21	3
146.	Rospuda	Józefowo	podlaskie	2003	53°56'18.2"N	22°54'13.3"E	FB28	3
147.	Rospuda	Raczki	podlaskie	2011	53°59'23.9"N	22°47'13.0"E	FB27	2
148.	Rów Polski	Kłoda Mała	wielkopolskie	2013	51°47'02.1"N	16°40'31.7"E	BD76	4
149.	Ruda	Rybnik - Wielkopole	śląskie	2007	50°06'50.0"N	18°33'12.9"E	CF69	3
150.	Rurzyca	Krępsko	wielkopolskie	2011	53°15'49.9"N	16°46'33.3"E	BC08	4
151.	Sama	Karczemka	wielkopolskie	2004	52°41'55.3"N	16°32'30.7"E	BC66	7
152.	Samica Stęszewska	Krąplewo	wielkopolskie	2004	52°17'26.2"N	16°41'07.3"E	BD17	8
153.	Samica Stęszewska	Mirosławki	wielkopolskie	2005	52°18'53.9"N	16°38'55.0"E	BD16	4
154.	Sanna	Szlachetczyzna	podkarpackie	2014	50°41'04.9"N	21°49'52.3"E	FF93	2
155.	Sierpienica	Sierpc, ul. 11 listopada	mazowieckie	2013	52°51'23.4"N	19°40'14.1"E	DC57	5
156.	Skarlanka	Otręba	warmińsko-mazurskie	2004	53°25'23.6"N	19°24'26.1"E	DB95	2
157.	Skotawa	Dębnica Kaszubska	pomorskie	2005	54°22'17.6"N	17°09'58.2"E	CA81	3
158.	Skrwa	Gostynin, ul. Parkowa	mazowieckie	2008	52°25'44.7"N	19°27'31.5"E	DD06	1
159.	Skrwa	Ziejka	mazowieckie	2008	52°27'08.4"N	19°26'40.1"E	DC96	8
160.	Słopica (Człopica)	Huta Szklana	wielkopolskie	2004	52°55'49.0"N	16°03'51.5"E	BC43	5
161.	Słupia	Gołębia Góra	pomorskie	2005	54°15'27.8"N	17°28'51.1"E	CA93	4
162.	Słupia	Włynkowo	pomorskie	2005	54°30'45.2"N	17°01'14.6"E	CA60	5
163.	Sokołda	Straż	podlaskie	2003	53°20'00.2"N	23°22'07.3"E	GB92	2
164.	Sopot	Hamernia (rez. Czartowe Pole)	lubelskie	2009	50°26'27.7"N	23°06'33.4"E	GF12	1
165.	Stążka (Ruda)	Rudzki Młyn	kujawsko-pomorskie	2004	53°33'11.7"N	17°54'15.7"E	CB75	3
166.	Stołunia (Łobżonka)	Stołuńsko	wielkopolskie	2007	53°25'39.5"N	17°15'27.0"E	CB81	1
167.	Strug	Biała	podkarpackie	2014	49°59'47.7"N	22°00'01.8"E	FF64	5
168.	Struga (Bawół)	Katy	wielkopolskie	2004	52°14'25.1"N	17°49'52.1"E	CD25	6
169.	Struga Goleniowska	Goleniów	zachodniopomorskie	2013	53°33'48.1"N	14°49'55.5"E	AB65	1
170.	Struga Rynek	Lorki	warmińsko-mazurskie	2009	53°22'20.9"N	19°46'00.7"E	DB98	3
171.	Supraśl	Zarzeczany	podlaskie	2004	53°06'28.9"N	23°40'26.9"E	GC14	3
172.	Swędrnia	Dębe	wielkopolskie	2006	51°47'34.9"N	18°12'15.6"E	CD77	4
173.	Swędrnia	Kalisz-Winiary	wielkopolskie	2006	51°45'09.3"N	18°07'30.0"E	CD76	1
174.	Szarka	Chojniki	wielkopolskie	2008	52°17'00.4"N	16°06'08.0"E	BD13	5
175.	Szpatnica	Dębianka	wielkopolskie	2009	51°34'54.0"N	16°59'31.8"E	BD99	4
176.	Śląska Ochla	Jeleniów	lubuskie	2009	51°51'26.6"N	15°27'21.3"E	AD58	5
177.	Śląski Rów	Laskowa	dolnośląskie	2013	51°46'12.4"N	16°31'41.1"E	BD75	1
178.	Ślina	Zawady	podlaskie	2003	53°09'12.7"N	22°40'17.9"E	FC17	2
179.	Średzka Woda	Środa Śląska	dolnośląskie	2013	51°10'21.0"N	16°35'13.0"E	BE36	4
180.	Toczna	Łosice	mazowieckie	2005	52°12'52.1"N	22°42'53.6"E	FD18	3
181.	Trojanka	Mściszewo	wielkopolskie	2008	52°34'54.0"N	16°58'35.3"E	BC89	5
182.	Trcianka (Niekurska Struga)	Trzcianka, ul. Kościuszki	wielkopolskie	2012	53°02'28.4"N	16°27'51.2"E	BC36	1

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No.	Name of the river	The nearest place	Province	Year of survey	Geographical coordinates		No. of a grid ATPOL square	Cover of *E. canadensis**
183.	Warkocz	Niestachów	świętokrzyskie	2007	50°50'27.0"N	20°45'29.1"E	EE75	1
184.	Wda	Loryniec	pomorskie	2008	54°02'58.2"N	17°53'20.2"E	CB25	1
185.	Wda	Odry	pomorskie	2008	53°54'02.3"N	18°00'05.3"E	CB36	2
186.	Wda	Schodno	pomorskie	2008	54°03'18.3"N	17°50'39.4"E	CB25	4
187.	Wel	Lidzbark	warmińsko-mazurskie	2009	53°15'11.1"N	19°49'37.1"E	DC08	6
188.	Wel	Straszewy - rez. Piekiełko	warmińsko-mazurskie	2009	53°20'00.2"N	19°46'13.6"E	DC08	2
189.	Wełna	Pruśce	wielkopolskie	2003	52°46'21.8"N	17°05'23.6"E	CC60	2
190.	Widawa	Kolonia Grędzina	dolnośląskie	2007	51°06'24.3"N	17°22'44.1"E	CE41	2
191.	Wielki Kanał Brdy	Fojutowo	pomorskie	2011	53°43'16.4"N	17°54'11.5"E	CB55	1
192.	Wieprza	Kolonia Stary Kraków	zachodniopomorskie	2011	54°26'38.0"N	16°36'20.0"E	BA77	2
193.	Wieprza	Korzybie	pomorskie	2005	54°18'11.5"N	16°52'03.7"E	BA99	5
194.	Wieprza	Kwisno	pomorskie	2006	54°05'05.6"N	17°07'52.5"E	CB10	1
195.	Wiercica	Przyrów	śląskie	2011	50°48'19.3"N	19°31'21.9"E	DE86	1
196.	Wietcisa	Głodowo	wielkopolskie	2008	52°16'11.2"N	18°07'45.0"E	CD17	7
197.	Wirenka (Wirynka)	Komorniki, ul. Ogrodowa	wielkopolskie	2009	52°20'07.4"N	16°48'53.6"E	BD18	2
198.	Wkra	Pomiechówek	mazowieckie	2005	52°28'45.5"N	20°43'24.9"E	EC94	2
199.	Wołczenica	Świętoszewko	zachodniopomorskie	2004	53°45'35.8"N	14°54'17.0"E	AB46	3
200.	Wołkuszanka	Wołkusz	podlaskie	2004	53°48'24.1"N	23°30'47.6"E	GB32	7
201.	Wołkuszek (Perstunka)	Wołkusz	podlaskie	2004	53°48'21.2"N	23°31'04.4"E	GB32	2
202.	Zadrna	Czadrów	dolnośląskie	2011	50°45'57.2"N	16°03'19.0"E	BE82	4
203.	Zadrna	Krzeszów	dolnośląskie	2012	50°44'07.0"N	16°04'19.6"E	BE82	1
204.	Zimna Woda	Drutarnia	śląskie	2010	50°35'00.6"N	18°52'14.9"E	DF02	1
205.	Zimnica	Lubin	dolnośląskie	2013	51°23'43.0"N	16°12'38.9"E	BE13	3
206.	Zimny Potok	Krępa Mała	lubuskie	2004	52°01'25.4"N	15°31'22.8"E	AD49	3

* – nine-scale cover using the Macrophyte Method for River Assessment: < 0.1% (1), 0.1-1% (2), 1-2.5% (3), 2.5-5% (4), 5-10% (5), 10-25% (6), 25-50% (7), 50-75% (8) and > 75% (9) (Szoszkiewicz et al. 2010b)

DE GRUYTER
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