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Waterbodies in the Floodplain of the Drava River Host Species-Rich Macrophyte Communities despite *Elodea* Invasions

Igor Zelnik *, Mateja Germ, Urška Kuhar and Alenka Gaberščik

Department of Biology, Biotechnical Faculty, University of Ljubljana, Jamnikarjeva 101, 1000 Ljubljana, Slovenia
* Correspondence: igor.zelnik@bf.uni-lj.si

Abstract: The contribution discusses macrophyte communities in natural and man-made waterbodies located on the active floodplain along the Drava river (Slovenia). We presumed that these different types of wetlands host a great number of macrophyte species, but this diversity may be affected by the presence of alien invasive species *Elodea canadensis* and *E. nuttallii*. Presence, relative abundance, and growth forms of plant species along with selected environmental parameters were monitored. Correlation analyses and direct gradient analyses were performed to reveal the possible relations between the structure of macrophyte community and environmental parameters. Number of macrophytes in surveyed water bodies varied from 1 to 23. Besides numerous native species we also recorded *Elodea canadensis* and *E. nuttallii*, which were present in 19 out of 32 sample sites, with *E. nuttallii* prevailing. The less invasive *E. canadensis* was absent from ponds and oxbow lakes but relatively abundant in side-channels, while *E. nuttallii* was present in all types but dominant in ponds. The most abundant native species were *Myriophyllum spicatum* and *M. verticillatum*, *Ceratophyllum demersum* and *Potamogeton natans.* Correlation analyses showed no negative effect of the invasive alien *Elodea* species to the species richness and diversity of native flora. Positive correlation between the abundance of *E. nuttallii* and temperature of the water was obtained.

Keywords: macrophytes; small water bodies; wetlands; alien invasive species; *Elodea*; flood plain

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1. Introduction

Rivers are complex ecosystems that change in time and space due to ecological and hydro-morphological processes [1]. River flow determines processes that affect the shape and distribution of habitats, and thus associated biotic communities [2]. The diversity of river channel and floodplain wetlands support the diversity of biotic communities. These habitats enable the establishment and dispersal of organisms, which ultimately affects biodiversity patterns [3], especially in macrophytes that have relatively low dispersal ability [4].

The global increase in energy and water demand of the human population resulted in alterations of river channels that affected the function of rivers and adjacent floodplains, as well as wetlands along these rivers such as oxbow lakes, side channels, backwaters, ponds etc. [5]. Williams et al. [6] emphasized that such small waterbodies can contribute significantly to regional biodiversity, including macrophyte communities [7], and are important for the conservation and management of the local biodiversity [8–10]. Oxbow lakes may be especially rich since they represent a transition between lotic and lentic ecosystems [11]. Sustainable catchment management should be based on the knowledge of the biodiversity in different water bodies within these catchments [12] and its vulnerability. Such water bodies have a great potential for the conservation of biological diversity and are recognised for their importance for ecosystem services [13], even though they have received relatively little attention. This situation is different along the Danube river, where these water bodies were studied by many researchers (e.g., Otahelová et al. [14]; Schmidt-Mumm and Janauer [15]; Vukov et al. [16]; Gyosheva et al. [17]). The increase in the proportion of urban and agricultural land-use within the catchment areas of mentioned habitats results in a decrease in species richness, thus, for efficient conservation of their biodiversity, actions at a local and regional spatial scale are required [18].

Macrophytes are an important element of the aquatic ecosystem since they are the basis for energy flow and nutrient cycling, and they affect sedimentation processes [19,20]. Macrophyte stands are habitats, refugia and a source of organic material for a range of other organisms [21,22]. Brysiewicz et al. [23] also discovered that species occurrences and abundances of fish fauna in small waterbodies were associated with the amount of macrophytes growing in them. High macrophyte abundance may significantly alter the chemical and biological structure of the ecosystem [24], while degradation of macrophyte communities may cause a reduction in diversity of organisms dwelling in these macrophyte stands [25]. By nutrient uptake from water and sediment, macrophytes ameliorate water quality and affect the quality water and sediment [20,21]. The affinity for specific water and sediment properties in different species make them valuable indicators of water and sediment quality [26–29].

Small sized water bodies are often subjected to extreme water level fluctuations, which are more pronounced in hydrologically isolated systems, where accelerated succession often occurs [30]. These water level fluctuations may also cause the dieback of some plant species, and consequently a release of nutrients [31], and a decrease in biodiversity. They effect aquatic vegetation, the trophic state of the ecosystem, and consequently affect the diversity and abundance of macroinvertebrates within the macrophyte stands [32]. Another threat to local biodiversity, especially diversity of freshwater biota, is the spread of alien invasive species that is often reported as one of the major factors for its decline [33]. Vukov et al. [16] report that *Elodea canadensis* and *E. nuttallii* have been rapidly spreading along the whole Danube, which was documented in [34]. However, the negative influence of these species is not always significant and there may also be some positive effects on target ecosystems [35,36], like new habitat formation for aquatic fauna or cyanobacterial blooms prevention, especially in lentic waterbodies. The extent of the effect of a certain invasive species for the functioning of target ecosystems largely depends on its abundance [37].

In this paper, we studied macrophyte communities in natural and man-made shallow waterbodies located on the active floodplain along the Drava river in Slovenia, within the section with generally preserved morphological conditions but with modified hydrology, to estimate their potential for the conservation value for macrophyte biodiversity. Since these habitats represent different types of wetlands, we hypothesised that they harbour a great number of macrophyte species and so mitigate their loss in other sections of the river, which are affected by numerous hydropower-plants and their impoundments. We also hypothesised that species diversity may be affected by the presence of invasive alien species of the genus *Elodea*. Deeper understanding of such water bodies will facilitate effective conservation and management of floodplains and support their ecosystem services.

2. Materials and Methods

2.1. Study Area

Studied wetlands are found within the active floodplain of the Drava river in northeast Slovenia, between the town Maribor and the state border with Croatia (Figure 1). The river Drava is among the biggest tributaries of the Danube river and gathers water from Italy, Austria, Slovenia, Croatia and Hungary. The hydrological regime of the surveyed section of the river has been modified, since a great proportion of the water from the river Drava is diverted into artificial channels that supply the water for Hydropower-plants. The advantage of this fact is that there have been no major changes in the morphological conditions of the old river channel and adjacent floodplain, where the studied wetlands occur. As the reference habitats, four reaches in the main channel of the Drava river were also surveyed. Beyond the edges of the floodplain, the land use is characterized by intensive agriculture with cultivated and uncultivated land mosaic.

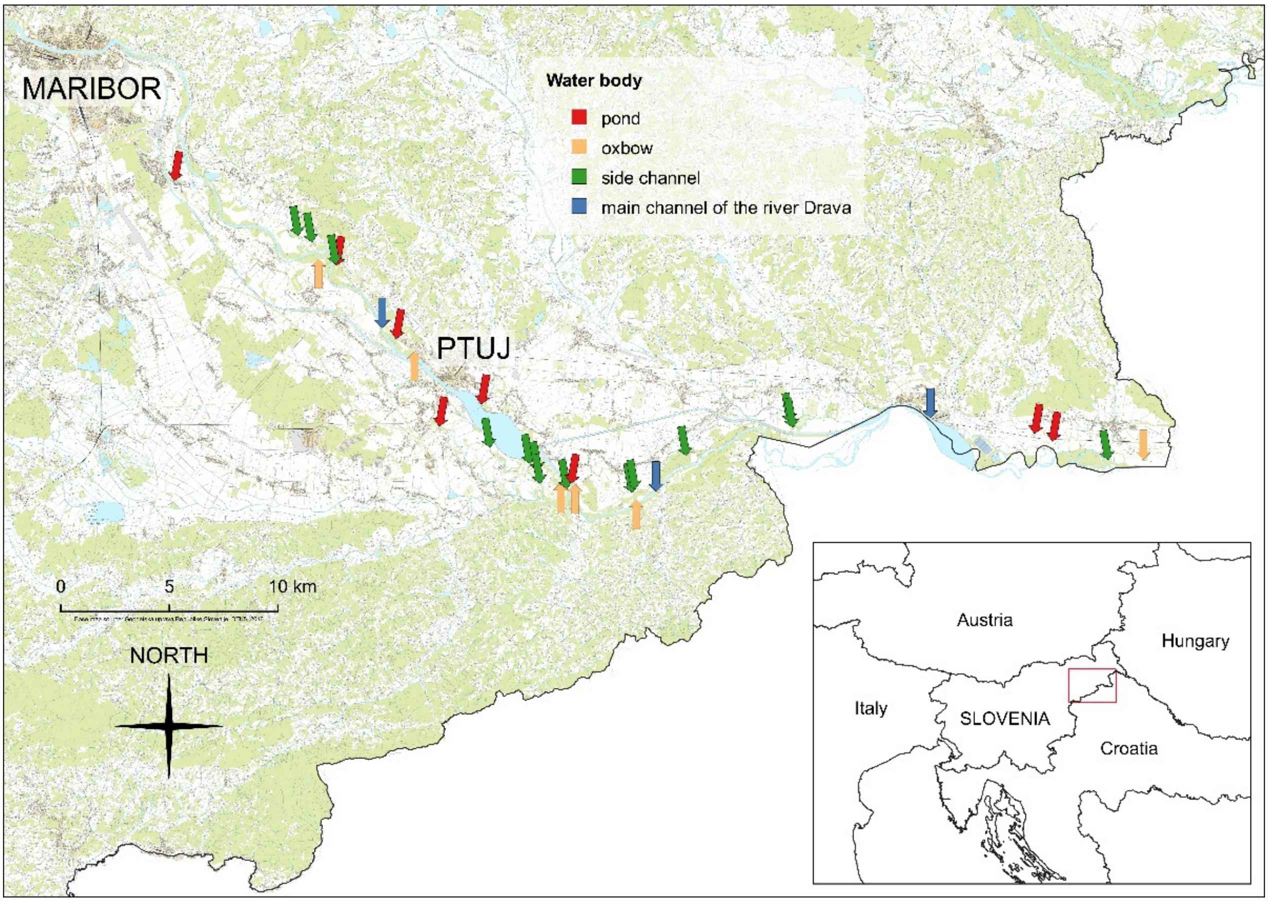

Figure 1. Distribution of the studied waterbodies in the floodplain of the Drava river (Base map source: Surveying and Mapping Authority of the republic of Slovenia (2016).

2.2. Macrophyte Data Set

Surveys were carried out in the years 2015–2016. Since we surveyed different types of the waterbodies the approaches were combined [22]—in ponds, the entire length (<100 m) was examined, whereas in oxbows, side-channels and the river we examined at least 100 m long sections. We recorded emergent, floating-leaved and submerged vascular plants, bryophytes and charophytes. The presence and abundance of macrophytes were evaluated from the boat or from the bank and collected with a stick with hooks. Macrophyte species abundance was estimated as a relative plant biomass using a five-degree scale, namely 1—very rare, 2—rare, 3—commonly present, 4—frequent, and 5—predominant, as proposed by Kohler and Janauer [38]. These values were transformed by the function x^3, as suggested by Schneider and Melzer [27]. The plants that were sampled in the phenological phase, which prevented identification to the species level, were only recorded on the genus level (e.g., *Carex*, *Callitriche*). Species names followed the nomenclature of Euro+Med Plantbase [39].

We classified the macrophytes into the following growth forms: natant (leaves or whole plants floating at the water surface); submerged (assimilation areas submerged in water column); amphiphytes (having the ability to produce terrestrial and aquatic growth forms, or aquatic and aerial leaves); and helophytes (anchored in the water-saturated sediment, with plant assimilation areas permanently in the air). For the purpose of correlation analyses and comparisons of average abundances, the ordinal values of the Kohler-scale were transformed into quantitative values ("quantities") [40]. We equalized the transformed values as percentage cover-abundance values according to [41].

2.3. Environmental Parameters

The assessment of environmental conditions was performed in the sites as the survey of macrophytes. We also assessed parameters like land-use type beyond the riparian zone, characteristics of the riparian zone (width, completeness, and vegetation type), and morphology (bank structure) [42]. Each parameter includes four categories comprising quality gradient, coded numerically from 1 to 4:1 presented good, close to natural condition, while quality gradient values from 2 to 4 indicate worsening of environmental conditions. Results of the assessment of the land-use and the width of riparian zone are presented in Table 1. Apart from the mentioned environmental parameters, we also recorded the basic physical and chemical parameters (temperature of the water, pH, conductivity, concentration of dissolved O_2, saturation with O_2) with the multimeter (Eutech PCD-650, Singapore).

Table 1. Characteristics of the catchment area of specific waterbodies. Width of the riparian zone, where woody or herbaceous wetland vegetation is thriving and prevailing land-use behind the riparian zone is presented.

Location	Width of Riparian Zone	Land-Use behind the Riparian Zone	Type
1	1–5 m	arable land, grassland, houses	river
2	1–5 m	arable land, grassland, houses	pond
3	1–5 m	arable land, grassland, houses	channel
4	1–5 m	arable land, grassland, houses	channel
5	1–5 m	arable land, grassland, houses	oxbow
6	<1 m	mainly arable land or urban area	pond
7	1–5 m	mainly arable land or urban area	channel
8	<1 m	arable land, grassland, houses	river
9	<1 m	mainly arable land or urban area	pond
10	1–5 m	mainly arable land or urban area	oxbow
11	<1 m	mainly arable land or urban area	pond
12	5–30 m	grassland, forest and/or wetland, some arable land	pond
13	5–30 m	grassland, forest and/or wetland, some arable land	channel
14	1–5 m	mainly arable land or urban area	channel
15	<1 m	arable land, grassland, houses	channel
16	1–5 m	arable land, grassland, houses	channel
17	<1 m	arable land, grassland, houses	oxbow
18	<1 m	mainly arable land or urban area	channel
19	5–30 m	arable land, grassland, houses	pond
20	<1 m	mainly arable land or urban area	oxbow
21	1–5 m	arable land, grassland, houses	channel
22	1–5 m	arable land, grassland, houses	channel
23	<1 m	arable land, grassland, houses	oxbow
24	1–5 m	arable land, grassland, houses	river
25	<1 m	arable land, grassland, houses	channel
26	<1 m	mainly arable land or urban area	channel
27	<1 m	mainly arable land or urban area	channel
28	5–30 m	arable land, grassland, houses	river
29	1–5 m	arable land, grassland, houses	pond
30	1–5 m	arable land, grassland, houses	pond
31	1–5 m	grassland, forest and/or wetland, some arable land	channel
32	1–5 m	mainly arable land or urban area	oxbow

2.4. Statistical Analyses

Correlation analyses between species and parameters was calculated with PAST, version 2.17c [43]. Kendall *tau* correlation coefficients were calculated.

Detrended correspondence analysis (DCA) was performed in the first step of gradient analyses. This analysis also informed us whether the gradients in the matrix of plant species are linear or unimodal, and which direct gradient analysis to use in further analyses. When we performed DCA with the matrix of functional types/growth forms, the eigenvalue for the first axis was lower than 0.4 (0.08) and we selected Redundancy analysis (RDA), as suggested by ter Braak and Verdonschot [44]. These results provided the information about the relationships between environmental factors and the structure of macrophyte community and their growth forms, respectively.

We used forward selection of the variables (499 permutations were performed) to rank the relative importance of explanatory variables. Only the variables with significance $p < 0.05$ were considered in further analyses. All analyses were performed with CANOCO for Windows 4.5 program package [45].

3. Results

The entire list of macrophytes comprised of 73 plant taxa, while the number of macrophytes in specific waterbodies varied from 1 to 23 (Figure 2). Beside numerous native species, waterbodies also host two invasive alien species of *Elodea*, namely *Elodea canadensis* and *E. nuttallii*, present in 19 out of 32 sample sites (Figure 3), with *E. nuttallii* prevailing. The most abundant native species were *Myriophyllum spicatum* and *M. verticillatum*, *Ceratophyllum demersum* and *Potamogeton natans*, which were also present in various locations (Figure 4). Natant species *Nuphar luteum* was present at one site only.

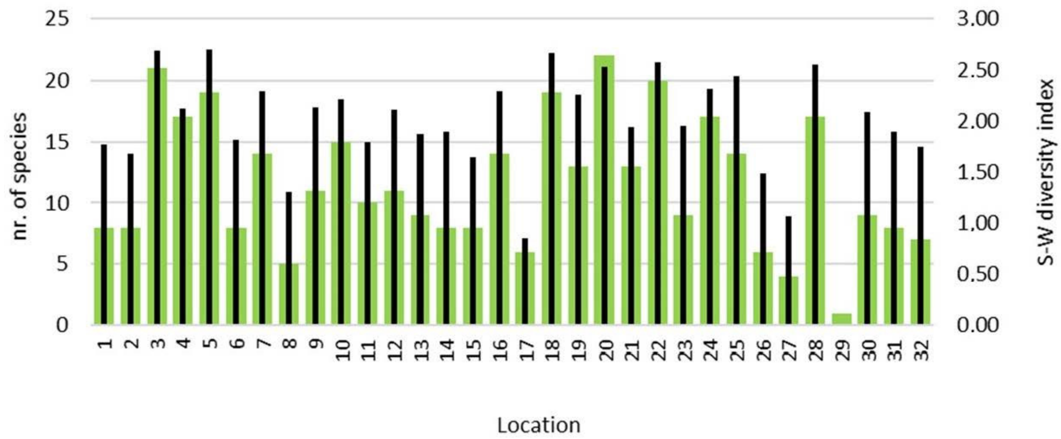

Figure 2. Total species number (green bars) and Shannon–Wiener (S–W) diversity index (black lines) in surveyed waterbodies.

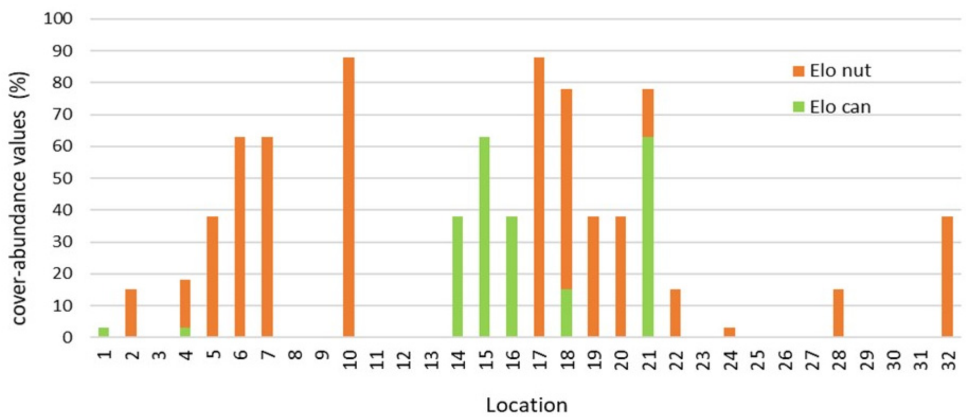

Figure 3. Relative abundance of invasive alien species *Elodea canadensis* and *E. nuttallii* in surveyed waterbodies.

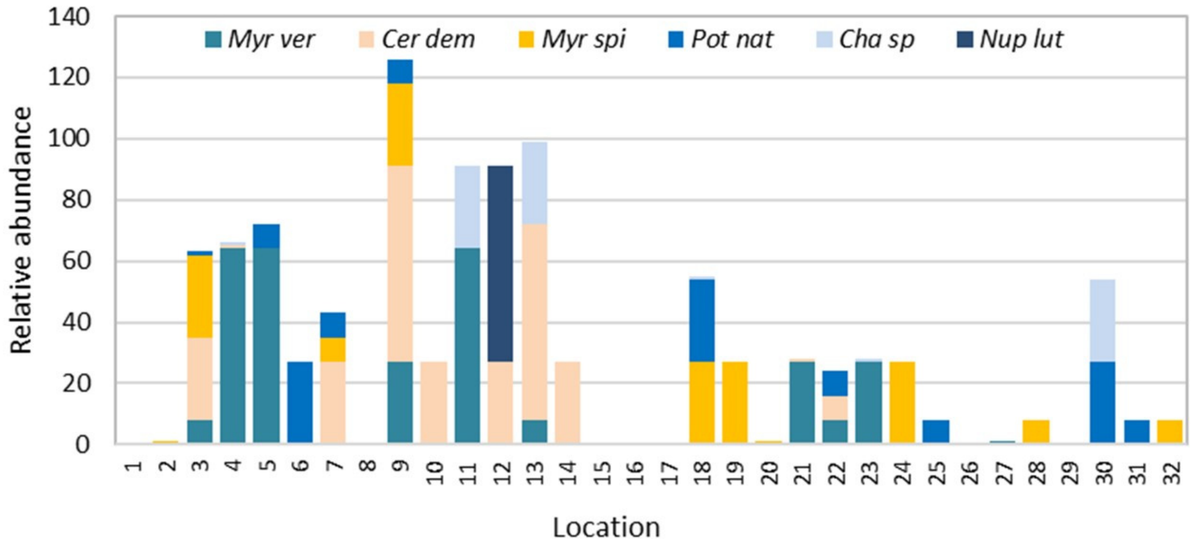

Figure 4. Relative abundance of native hydrophyte species with total abundance more than 2% present in surveyed waterbodies: *Myr ver—Myriophyllum verticillatum*, *Cer dem—Ceratophyllum demersum*, *Myr spi—Myriophyllum spicatum*, *Pot nat—Potamogeton natans*, *Cha* sp—*Chara* species, *Nup lut—Nuphar luteum*.

E. nuttallii was the most abundant among all hydrophyte species, with more than 25% of the total abundance, followed by *M. verticillatum*, *C. demersum*, *E. canadensis* and *M. spicatum* (Figure 5).

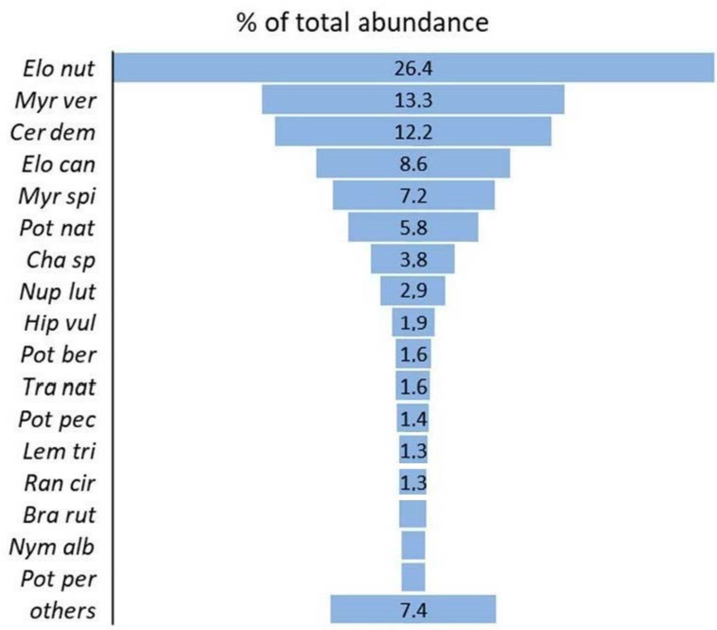

Figure 5. Ratio of total relative abundance of hydrophyte species that presented more than 1% in surveyed waterbodies: *Elo nut—Elodea nuttallii*, *Myr ver—Myriophyllum verticillatum*, *Cer dem—Ceratophyllum demersum*, *Elo can—Elodea canadensis*, *Myr spi—Myriophyllum spicatum*, *Pot nat—Potamogeton natans*, *Cha* sp—*Chara* species, *Nup lut—Nuphar luteum*, *Hip vul—Hippuris vulgaris*, *Pot ber—Potamogeton bertholdii*, *Tra nat—Trapa natans*, *Pot pec—Potamogeton pectinatus*, *Lem tri—Lemna trisulca*, *Ran cir—Ranunculus circinatus*, *Bra rut—Brachythecium rutabulum*, *Nym alb—Nymphaea alba*, *Pot per—Potamogeton perfoliatus, others*—the sum of abundances of species with less than 1%.

The DCA analysis shows the similarity of surveyed sites in terms of the structure of macrophyte communities in the peak vegetation period. The closer sites are on the ordination plot, the more similar are the macrophyte communities. It is evident that the type of aquatic ecosystem does not dictate the macrophyte community structure (Figure 6).

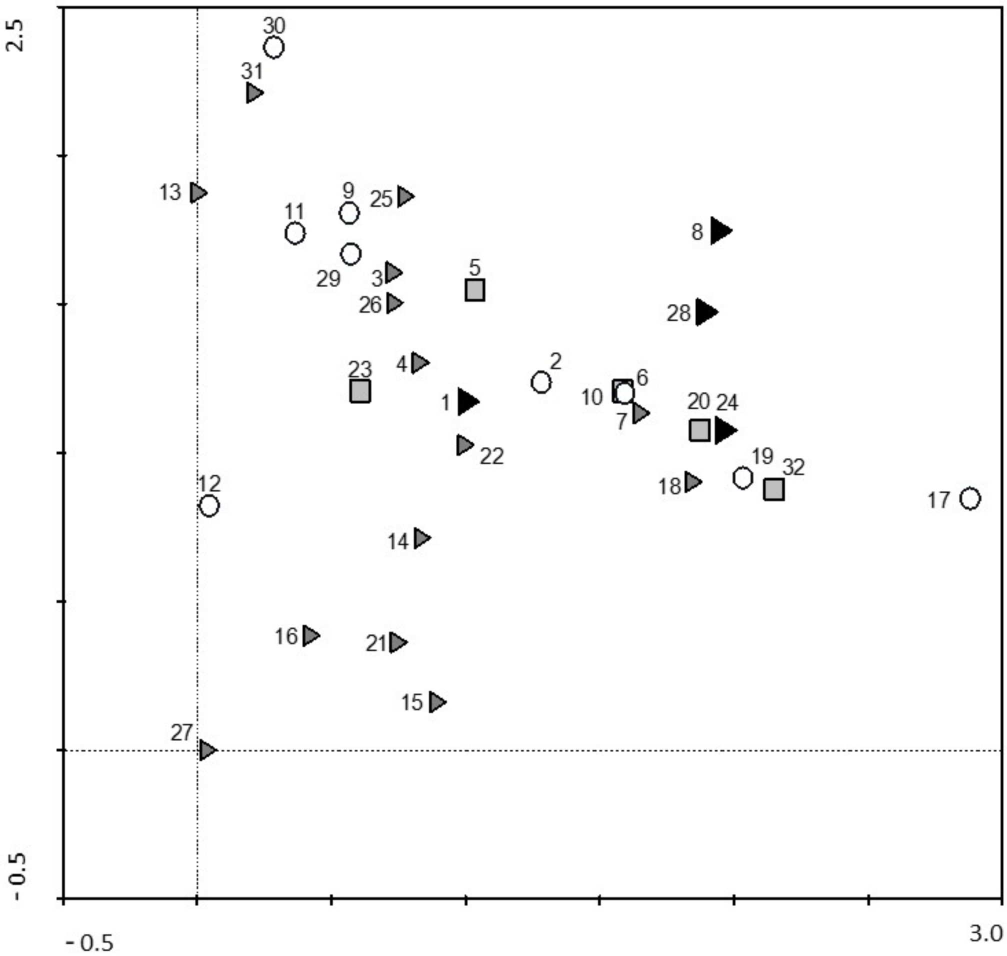

Figure 6. Detrended correspondence analysis ordination diagram showing the similarity of the macrophyte stands in different sites. Numbers from 1 to 32 indicate the location of the site with respect to the river Drava flow direction. Different symbols indicate different water bodies (white circles—ponds, light grey squares—oxbows, small dark grey right triangles—side channels, black right triangle—sample sites in the main channel of the river Drava.

Redundancy analysis revealed that the presence and abundance of *Elodea* affected the presence of native groups of macrophytes (Figure 7). When testing both species of *Elodea* separately, *E. nuttallii* explained 9% and *E. canadensis* 3%. However, when we tested sum of abundances of both species, this parameter explained 14% of macrophytes species parameters variability. Vectors representing the number and abundance of plant groups are in the opposite direction to *Elodea* vector. The distribution of the locations along this vector shows that the locations 10 and 17 are the most abundant with *Elodea*, as is also evident from Figure 3.

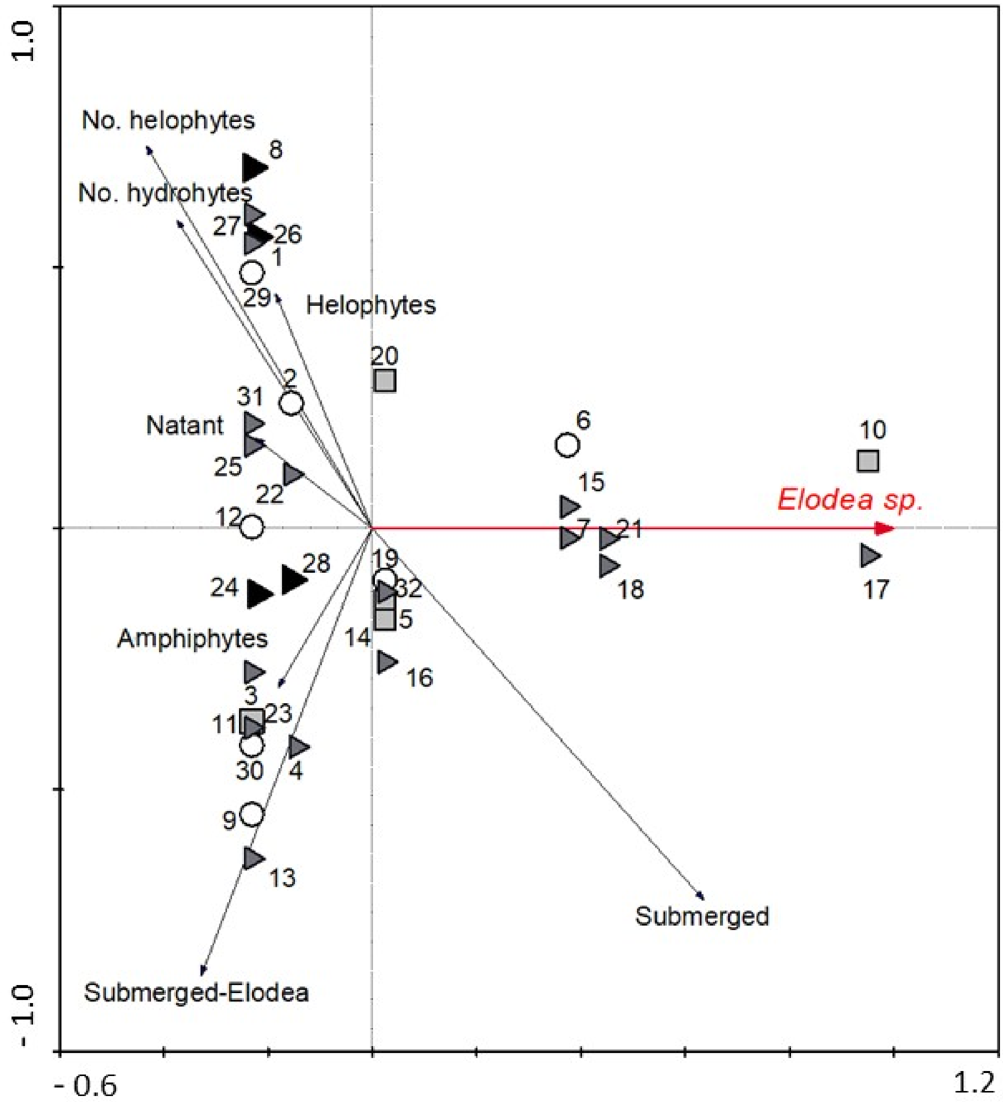

Figure 7. Redundancy analysis plot showing the relationship between the number of different ecological groups of macrophytes and relative abundance of their growth forms and *Elodea* species abundance. Abundance of submerged plants is represented by two parameters, including and excluding *Elodea* (-Elodea). Different symbols indicate different water bodies (white circles—ponds, light grey squares—oxbows, small dark grey right triangles—side channels, black right triangle—sites in the main channel of the river Drava.

Correlation analyses revealed no significant negative effect of the alien *Elodea* species to the native flora of the studied water bodies (Table 2). We calculated positive correlation between the abundance of *E. nuttallii* and temperature of the water, and the share of arable land in the catchment areas of the studied wetlands.

The abundance of *E. nuttallii* was negatively correlated with the sum of abundances of floating-leaved macrophytes (*Nymphaea alba* and *Spirodela polyrhiza*).

Average values for specific types of the studied waterbodies are listed in Table 3. *E. canadensis* was absent in lentic ecosystems but relatively abundant in side-channels, while *E. nuttallii* was present in all types but was dominant in ponds, where its average cover-abundance value was 48%. Despite this fact the species richness and diversity of native flora was not lower, but even higher in ponds than in larger oxbow lakes.

Table 2. Correlation coefficients (Kendall *tau*) between the abundance of *Elodea canadensis*, *E. nuttallii* and the sum of both species with diversity indices of native flora as well as with selected environmental parameters. Only significant ($p < 0.05$) correlations are shown. (* $p = 0.05$).

Variable	*E. canadensis*	*E. nuttallii*	*E. canadensis* and *nuttallii*
Number of native taxa	n.s.	n.s.	n.s.
Total abundance of plants	n.s.	0.2679	0.2669
Shannon–Wiener diversity index	n.s.	n.s.	n.s.
Concentration of O_2 [mg/L]	n.s.	0.2679	n.s.
Temperature of the water [°C]	n.s.	0.2614 *	n.s.
Cover of floating-leaved macrophytes	n.s.	−0.2782	n.s.
Land-use in the catchment	n.s.	0.2988	0.2805
Abundance of *Nymphaea alba*	n.s.	−0.2617	−0.3079
Abundance of *Spirodela polyrhiza*	n.s.	−0.2886	n.s.

Table 3. Average abundances (in %) of IAS *Elodea canadensis* and *E. nuttallii* in four types of waterbodies and average values of species-richness and diversity of native flora.

	Oxbows	Ponds	Side-Channels	River
E. canadensis	0	0	15.7	0.75
E. nuttallii	14.5	48	12.2	4.5
Nr. of native taxa	8	10.5	11.4	9.5
S–W diversity index	1.7	1.9	2	1.9

4. Discussion

Small waterbodies are often intact and unpolluted, and as such they present a refuge for species which have disappeared from larger, more disturbed, water bodies [13]. In the case of the Drava river, the sections upstream the studied area are degraded and converted into the chain of reservoirs for HPPs. The surveyed ecosystems occur within the active floodplain, which remained relatively intact in terms of morphological alterations. However, in different river-fed wetlands, the flood regimes affect macrophytes community traits and thus the structure and function of the wetlands [46]. The entire set of the studied waterbodies hosted 73 macrophyte species, which is a rather high number in comparison to river habitats, where in over 1000 reaches of 33 Slovenian rivers 87 species were recorded [47]. In similar studies within the Danube river corridor, Schmidt-Mumm and Janauer [15] recorded 78 species in 49 transects sampled in oxbows and side-channels in Austria, while Gyosheva et al. [17] recorded 112 species within a much larger set of 144 samples from Bulgaria.

The study of macrophytes in subtropical ponds revealed that pond size was positively related to richness of emergent and floating species, and the isolation of the pond negatively affected the richness of amphibious species, which was a consequence of their dispersal strategies [48], but our results do not confirm such relations. Emergent species in the studied waterbodies presented a great share of species, namely 43. This high helophyte diversity may be a consequence of relative naturalness of the adjacent parts of their catchment areas within the floodplain and supported by rich seed banks as shown in a case of small ponds [7].

Diverse and abundant stands of helophytes provide a protection for hydrophytes in the water since they act as their buffer zones. Despite this protection, native species could be endangered by alien *Elodea*, as both species of *Elodea* found in surveyed water bodies usually exhibit high growth rates with a high tolerance to a wide range of environmental conditions, low vulnerability to grazing and other stress factors, high distribution and reproduction potential [49]. Our results revealed no influence from both *Elodea* species on the floristic composition of aquatic vegetation (Figure 2), which is stronger in the case of *E. nuttalli* since its abundance is responsible for 9% of variability of macrophyte stands. Besides, *E. nuttallii* is also documented to replace *E. canadensis* from several waterbodies where it has established before the invasion of *E. nuttallii* [50,51]. The ecophysiological differences between both species explain the invasion success of *E. nuttallii* over *E. canadensis* [52]. Szabó et al. [53] found out that under more eutrophic conditions, *E. nuttallii* grows quicker and reaches the water surface sooner in comparison to *E. canadensis.* In addition, intensive branching outcompetes all other plants, including *E. canadensis*.

In our case, no evident impact on the native plant diversity was confirmed, neither in case of single *Elodea* species, nor when both species were present (Table 2). One of the reasons is that the hydromorphological characteristics of the majority of studied waterbodies has not been modified, except the ponds that are of anthropogene origin. This also explains the highest abundance of *E. nuttallii* in the ponds (Table 3). Otahelová et al. [14] report that new man-modified aquatic habitats have been successfully invaded by *E. nuttallii*. Mazej-Grudnik and Germ [54] report that *E. nuttallii* can cause severe problems in water bodies that are heavily modified due to human activity. The reason for lower competitive ability of *E. nuttallii* over *E. canadensis*, as well as other submerged species, is connectivity of these waterbodies with the main course of the Drava river [55] that floods the entire floodplain during the extreme events. Vukov et al. [16] report that both species are characteristic for aquatic habitats with lower levels of connectivity with main channels. There is also a difference between these two species in their preference to the reaction of the water, according to Ellenberg indicator values (EIV) for reaction [56]. *E. canadensis* has a relatively high EIV = 7 (out of 9) for water pH, while *E. nuttallii* is indifferent to pH (x). Since the catchment area above the studied section of the Drava river is mostly in the Central Alps and built mainly by non-carboniferous rocks, the sediments forming the floodplain of the Drava river and the river itself contain relatively low contents of basic cations and provide habitats with relatively low pH. This might explain lower abundance values of *E. canadensis* in comparison to *E. nuttallii* in these ecosystems and its absence from lentic habitats (Table 3).

We obtained positive correlation between the abundance of *E. nuttallii* and temperature of the water, thus further increasing in temperatures of these small waterbodies may favour the spread of *E. nuttalli*. Mazej Grudnik et al. [57] report that one can expect a more invasive character of *E. nuttallii* in the years with higher temperatures in January and March.

On the other hand, the abundance of *E. nuttallii* was negatively correlated with the sum of abundances of floating macrophytes (e.g., *Nymphaea alba* and *Spirodela polyrhiza*). However, it is not a case for all floating species, since a study with *Lemna* revealed the opposite result, especially under low nutrient concentrations [58]. *Elodea* is effective in using nutrients as phosphorus and nitrogen, which results in nutrient deficiency for other primary producers [59]. In our case it seems that nutrients were not a problem, since the conductivity was relatively high; therefore, better position regarding light conditions in floating-leaved macrophytes in comparison to submerged *Elodea* deprived this species. We presume that the spreading of floating species may help to suppress the spread of these two IAS in the waterbodies. Netten et al. [60] found out that the free-floating *Salvinia natans* in mesocosms benefited from increased temperature and increased nutrient concentrations and lowered the potential of submerged *E. nuttallii* to take advantage of such conditions. Their results also indicate that with global warming, invasive free-floating plants might become more successful and cause decline of submerged plants. The environment below floating plants is poorer with light [61]. Deliberate introduction of the pleustophyte *Spirodela polyrhiza*, which is a native species and distributed in waterbodies in the studied region, would be easy to imply, but it may also affect other submerged species so the use of such a measure for mitigation of the spread of these invasive species should be studied in advance. The study in Slovenian watercourses revealed that the abundance of *E. canadensis* is negatively related to abundance of *M. spicatum* [62], which is also highly invasive in USA [63]. This effect was only partly confirmed in the present study. According to this knowledge, we strongly discourage the removal of the stands of *M. spicatum* as well as any other native macrophyte.

5. Conclusions

Surveyed water bodies along the river Drava harboured a high number of species. Against expectations, the presence of alien *E. nuttallii* and *E. canadensis* exerted no effect on presence and abundance of hydrophytes, possibly due to water level fluctuations in these water bodies. *E. nuttallii* reached the highest abundance in ponds, which are the only group of anthropogenic ecosystems. We can conclude that maintenance of good ecological status of waterbodies, including their morphology, is among the most important measures to prevent the spreading of invasive species.

Different hydrological dynamics, as one of the consequences of the climate changes, has led to increased frequency of the floods as well as droughts. Small water bodies and wetlands, respectively, found within the floodplains can mitigate both types of events since they enable substantially longer water retention than do regulated rivers. The maintenance and hydrological connectivity of these waterbodies in sufficient extent could not only contribute to higher species diversity but could also reduce the flood-waves and supply the water for the baseflow at lower water levels due to their retention capacity.

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