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The presence of invasive alien plant species in different habitats: case study from Slovenia

Razširjenost tujerodnih invazivnih vrst rastlin v različnih habitatih: primer iz Slovenije

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Abstract: Invasive alien plants present a threat to diversity of native species. An attempt to evaluation of potential endangerment of specific habitats due to the presence of invasive alien plant species was made and results are presented in this paper. Data about the presence of invasive alien plants in specific habitats were extracted from the database Flora of Slovenia (at the Centre for Cartography of Fauna and Flora). The list of the most frequent invasive alien plant taxa in natural and semi-natural habitats is presented as well as the lists of invasive alien plants with potentially most negative influence on the biodiversity in different habitats. In general, taxa with potentially most negative influence on the biodiversity of natural habitats in Slovenia are: *Robinia pseudacacia*, *Solidago gigantea, Fallopia japonica* and *F.* × *bohemica, Rudbeckia laciniata, Helianthus tuberosus*. In the dataset the highest number of data about presence of invasive alien plants referred to riparian zones (44%). The second highly infected group of habitats was floodplain woods. According to the Ellenberg indicator values the most of the invasive alien plants prefer nutrient-rich and sunny sites. The negative effect of *Fallopia* × *bohemica* on light conditions in established stands and consequently on the species richness of native plants was also detected.

Keywords: invasive alien plants, habitats, biodiversity, Slovenia, riparian zones.

Izvleček: Invazivne tujerodne vrste rastlin ogrožajo pestrost domorodnih vrst. V članku so prikazani rezultati poskusa ovrednotenja potencialne ogroženosti posameznih habitatov zaradi prisotnosti invazivnih tujerodnih vrst rastlin. Podatki o prisotnosti invazivnih tujerodnih rastlin v posameznih habitatih, so pridobljeni iz podatkovne zbirke Flora Slovenije (na Centru za Kartografijo Favne in Flore). Predstavljen je seznam najbolj pogostih invazivnih tujerodnih vrst rastlin v naravnih in sonaravnih habitatih kot tudi seznam invazivnih tujerodnih vrst rastlin, ki imajo potencialno najbolj negativen učinek na biodiverziteto v različnih habitatih. Na splošno so taksoni s potencialno najbolj negativnim učinkom na biodiverziteto v naravnih habitatih Slovenije naslednji: *Robinia pseudacacia*, *Solidago gigantea, Fallopia japonica* in *F.* × *bohemica, Rudbeckia laciniata* ter *Helianthus tuberosus*. V podatkovni bazi se je največ tovrstnih podatkov nanašalo na obrežne pasove (44%). Druga najbolj okužena skupina habitatov so bili poplavni in močvirni gozdovi. Glede na Ellenbergove indikatorske vrednosti večini invazivnih tujerodnih vrst ustrezajo s hranili bogata sončna rastišča.

Ugotovili smo tudi negativni učinek taksona *Fallopia × bohemica* na svetlobne razmere in posledično na vrstno pestrost v dobro razvitih sestojih omenjenega taksona.

Ključne besede: invazivne tujerodne rastline, habitati, biodiverziteta, Slovenija, obrežni pasovi.

Introduction

The spreading of invasive alien plant species affects the diversity of native plants and animals in infected ecosystems (Essl and Rabitsch 2002). Invasive alien species are considered to be the second largest reason for biodiversity loss worldwide (Vitousek 1996). When invasive alien plant species dominate in the community, they alter the conditions in the ecosystem in a way that it becomes unsuitable for thriving of native plants (Hejda and Pyšek 2008). Main reasons for negative impacts on biodiversity are competitive exclusion of native species, alteration of ecosystems structure and availability of resources, as well as change of microclimate (Essl and Rabitsch 2002).

Vilá et al. (2011) found out that invasive alien plant species significantly reduced fitness and growth of native plant species by 41.7 and 22.1%, respectively, and changed plant community structure by decreasing species abundance (43.5%) and diversity (50.7%).

The most vulnerable areas are those with high number of endemic species. It is expected that invasive alien species would affect the biodiversity of aquatic ecosystems, especially standing waters, to the greatest extent, while among terrestrial ecosystems the biodiversity of Mediterranean ecosystems is under the greatest pressure (Essl and Rabitsch 2002).

In Central Europe neophytes occur predominately in ecosystems with frequent human or natural disturbances (Pyšek 1998, Kowarik 1999). Their colonization is possible especially in places where different disturbance have caused damage or clearances in closed stands.

Several authors (e.g. Rejmánek et al. 2005, Simonová and Lososová 2008, Šilc 2010) claim, that in general the antropogenic vegetation is most infected with invasive alien plants due to strong and frequent disturbances. However, in Central Europe in the majority of habitat types the endangerment of native flora and fauna is relatively low (Essl and Rabitsch 2002). From the aspect of biodiversity maintenance the most problematic is the impact of invasive alien species in natural and semi-natural habitats, especially in floodplain woods, riparian zones along the streams and in Pannonian lowland forests (Essl and Rabitsch 2002).

The greatest changes in structure and above all in functioning of ecosystems are expected for those invasive alien plant species that represent the new growth forms in infected ecosystem or growth forms that used to be rare in such ecosystem. That causes changes in density and coverage of the vegetation and may also cause a total change of the structure of such vegetation (Kowarik 1999). Species with greater life span – e.g. perennials instead of annuals or woody species instead of the herbs and grasses – often use the resources more efficiently that leads into significant changes in the availability of resources (light, nutrient contents, litter production) as well as in the production of the ecosystems (Gurevitch et al. 2002, Larcher 2003). Invasive alien plants also change the speed and direction of the succession (Řehounková and Prach 2008).

Therefore, the species like *Impatiens glandulifera*, *Fallopia japonica*, *F.* x *bohemica*, which are much taller than native species in the herb layer of riparian zones and floodplain woods, cause the increase of the thickness of the herb layer (Kowarik 1999). On the other hand the species *Acer negundo* builds additional lower tree layer in floodplain woods. Additional shading might negatively influence the growth and establishment of native species.

Invasive alien tall-herbs, such as *Fallopia japonica, Fallopia × bohemica, Solidago gigantea, Solidago canadensis, Helianthus tuberosus* and other similar species can greatly reduce the speed of the succession of forest communities, since the conditions for germination and growth of the woody species are very poor in such stands (Essl and Rabitsch 2002). Mentioned fast growing species can significantly increase the productivity of infected ecosystems.

Species *Fallopia japonica* has established in coastal and inland wetlands, riparian zones, ruderal sites, settlements and along the roads (Roufied et al. 2011).

Black-locust (*Robinia pseudacacia*) is in general, very invasive species in Europe. Its threat to the biodiversity was proved several times (Somodi et al. 2012, Benesperi et al. 2012). It prevents the regeneration of native plant species and changes the ecosystems, mostly due to enrichment of soil with nitrogen with the help of symbiotic N-fixing bacteria. Because of this reason black-locust stands contain mostly nitrophilous species and ruderal generalists instead of a local flora (Řehounková and Prach 2008). If this species occurs during secondary succession, it changes the site essentially because of N-fixing and so does the direction of the succession leading into creation of ecosystem and/or community which is not expected in natural conditions (Řehounková and Prach 2008). Results published by Kleinbauer et al. (2010) show that climate changes would favour the distribution and establishment of this species in central Europe even more. Beside the threat to diversity of plant species its negative influence to diversity of bird species was detected as well.

The share of invasive alien species is the highest in areas with warmer climate. In Slovenia, the frequency of invasive alien plant species decreases with decreasing mean annual temperature (Šilc et al. 2012). The threat to diversity due to invasive alien plant species is mostly limited to the lowlands and to the zone up to the 600 m a.s.l., respectively.

The aim of present research was to examine the presence of invasive alien plant species in different habitats in Slovenia and to estimate their potential threat to biodiversity.

Methods and materials

Distribution of invasive alien plant species in specific habitats was surveyed using the data from the database Flora of Slovenia of the Centre for Cartography of Fauna and Flora (CCFF), which gathers the highest number of data needed for the performance of such analyses for the territory of Slovenia. Data from the mentioned database were used for all of the analyses in present paper. The only data about presence of invasive alien plant species that could be used from this database were those that also contain the information about the habitat where they had been found. This database of floristic relevés was made with very low bias towards the certain taxa or just selected habitats. About 3.500 suitable data were extracted from the database that met the mentioned criteria and were considered in this survey.

For the assessment of potentially negative influence of invasive alien plant species to the habitats, which is likely to occur due to their distribution and capabilities to compete with native species for light, space and nutrients in the habitat, we tried to adequately evaluate these taxa on the basis of their characteristics, using the equation (a+b)/2 where:

a stands for life span of the taxon was determined in accordance with its life form and data in determination key (Martinčič et al. 2007): 1 – annual, 2 – biennial, 3 – perennial herb, 4 – woody species.

b presents a potential influence on the availability of resources (light, nutrients) at the site, which bases on data about habitus of the taxon. This parameter was calculated as the average value following the equation: (b1+b2)/2 where:

- b1 stands for the height of the taxon: 1 – lower herb layer in the stands (mostly <1 m); 2 – tall-growing herbs and shrubs (1–3 m); 3 – tall shrubs and lianas (>3 m); 4- trees;
- b2 presents the estimate of the shading ability, which includes data about the size and shape of the laminas as well as the density and distribution of the leaves on the shoots (that influences the shading ability of plants). The shading ability was expressed as a quantity gradient (1–4; 1 – low shading ability, 2 – moderate shading ability, 3 – high shading ability, 4 – very high shading ability).

Considering the frequency of occurring in specific habitats based on the mentioned database, we have multiplied the characteristics of the taxon that were supposed to represent the potential impact on the diversity of native species with the frequency rank of invasive alien plant species in specific habitat. On the basis of these semi-quantitative total estimates we ranked invasive alien plant taxa.

In this way we selected taxa from the list of invasive alien plants that were supposed to have the greatest potentially negative effect to the biodiversity in natural and semi-natural habitats (extensively managed) with considerably high diversity of native species: forests and other forest habitats, floodplain woods and swamps, riparian zones, dry grasslands, wetlands.

On the basis of the Ellenberg indicator values (Ellenberg et al. 1992) ecological preferences of some of the most invasive alien plant species were also analysed in relation to: light intensity (L), temperature (T), moisture (F), soil reaction (R) and available nutrients (N).

In the riparian zone of Glinščica stream the intensity of photosynthetically active radiation (PAR) was measured on the sites with the taxon *Fallopia* × *bohemica* as well as on the sites without the mentioned taxon. In the same sites/plots all present species of vascular plants were recorded and their coverage was estimated.

Results and discussion

Most frequent invasive alien plant species according to the data from the mentioned data base (CCFF) are listed in Table 1 (according to the number of data about invasive alien plant species in all habitats from floristic records). Only the taxa which are present in at least 10 localities are presented.

Beside some exceptions, this list (Tab. 1) includes the same taxa as the list of the experts from Austria (Essl and Rabitsch 2002) who have included the most problematic invasive species regarding the conservation of biodiversity in natural and semi-natural habitats. Although most frequent invasive alien plant species *Erigeron annuus* is less important from the aspect of nature conservation, since it occurs mostly in sites under strong human influence, having minor effects on natural plant communities due to its habitus and short life span.

Beside the species in Table 1, two invasive alien plants should be mentioned, namely *Pistia stratiotes* L. and *Spiraea japonica* L. f., which have only local distribution.

Table 2 presents the most frequent invasive alien plants in natural and semi-natural habitats (extensively managed) with considerably high diversity of native species: forests and other forest habitats, floodplain woods and swamps, riparian zones, dry meadows, wetlands.

The taxa present in this table (Tab. 2) are the same as in the previous case (Tab. 1), where all data from the mentioned database were considered, the difference occur only in the order of the taxa. In some taxa, the number of the data / localities is much lower here as well. In these ecosystems 1st and 3rd position belonged to tall-growing perennials, tree species black-locust took 2nd place while

Table 1: The most common invasive alien plant species.
Tabela 1: Najpogostejše invazivne tujerodne vrste rastlin.

	No. of data
1. *Erigeron annuus* (L.) Pers.	462
2. *Solidago gigantea* Aiton	447
3. *Robinia pseudacacia* L.	403
4. *Impatiens glandulifera* Royle	338
5. *Elodea canadensis* Michx.	228
6. *Fallopia japonica* (Houtt.) Ronse Decr. and *F.* × *bohemica* (Chrtek & Chrtkova) J.P. Bailey	185
7. *Rudbeckia laciniata* L.	175
8. *Echinocystis lobata* (Michx.) Torr. & A. Gray	139
9. *Impatiens parviflora* DC.	135
10. *Solidago canadensis* L.	130
11. *Ambrosia artemisiifolia* L.	129
12. *Juncus tenuis* Willd.	127
13. *Helianthus tuberosus* L.	111
14. *Acer negundo* L.	63
15. *Parthenocissus quinquefolia* (L.) Planch.	46
16. *Ailanthus altissima* Desf.	44
17. *Bidens frondosa* L.	25
18. *Commelina communis* L.	18
19. *Parthenocissus inserta* (Kerner) Fritsch	18
20. *Pinus strobus* L.	18
21. *Aster squamatus* (Spreng.) Hieron.	16
22. *Physocarpus opulifolius* (L.) Maxim.	15
23. *Quercus rubra* L.	15
24. *Duchesnea indica* (Andrews) Focke	14
25. *Telekia speciosa* (Schreb.) Baumg.	12
26. *Asclepias syriaca* L.	11
27. *Cuscuta campestris* Yunck.	11

annuals with lower habitus *Erigeron annuus* and *Ambrosia artemisifolia* occurred less frequently in natural habitats (42 and 43% lower frequency). Their low-growing form and life strategy do not enable their establishment in the stands resulting in their lower invasiveness.

In case of aquatic habitats data for *Elodea canadensis* Michx. (228 data) and *Pistia stratiotes* L were included in the database. The latter species was not considered in further analysis, since all of the data (21) are confined to a relatively small area.

Based on the frequency, life-span and influence on the availability of resources (light, nutrients) 18 invasive alien plant taxa (from Tab. 2) which are supposed to have the most negative influence on the biodiversity of natural and most preserved habitats, were chosen using the mentioned estimates (see Tab. 3). To provide the representative list, only taxa that were supported with the data from at least 20 locations in the database were considered.

Table 2: The most common invasive alien plant species in natural and extensively managed habitats. Taxa with at least 10 data / localities in the data-base are listed only.

Tabela 2: Najpogostejše invazivne tujerodne vrste rastlin v naravnih in ekstenzivno gospodarjenih habitatih. Seznam vključuje le tiste taksone, za katere so v podatkovni bazi podatki iz vsaj 10 lokalitet.

	No. of data
1. *Solidago gigantea* Aiton	390
2. *Robinia pseudacacia* L.	311
3. *Impatiens glandulifera* Royle	305
4. *Erigeron annuus* (L.) Pers.	267
5. *Fallopia japonica* (Houtt.) Ronse Decr. and *F.* × *bohemica* (Chrtek & Chrtkova) J.P. Bailey	152
6. *Rudbeckia laciniata* L.	149
7. *Echinocystis lobata* (Michx.) Torr. & A. Gray	127
8. *Impatiens parviflora* DC.	99
9. *Helianthus tuberosus* L.	97
10. *Juncus tenuis* Willd.	93
11. *Solidago canadensis* L.	92
12. *Ambrosia artemisiifolia* L.	73
13. *Acer negundo* L.	55
14. *Parthenocissus quinquefolia* (L.) Planch.	36
15. *Ailanthus altissima* Desf.	29
16. *Bidens frondosa* L.	21
17. *Aster squamatus* (Spreng.) Hieron.	16
18. *Physocarpus opulifolius* (L.) Maxim.	14
19. *Pinus strobus* L.	12
20. *Quercus rubra* L.	11

Based on the data from the used database Flora of Slovenia (CCFF) the species *Robinia pseudacacia* is the invasive alien plant species with potentially most negative influence on the biodiversity. It is followed by tall-growing perennial herbs with rhizomes: *Solidago gigantea, Fallopia japonica* and taxon *Fallopia* × *bohemica*.

Species with potentially strong negative influence to biodiversity are also tall-growing perennial herbs *Rudbeckia laciniata* and *Helianthus tuberosus*, which often form dense up to 3m high stands. Such stands are mostly found in riparian zones of the streams.

Tree species *Ailanthus altissima* and *Acer negundo* also belong to the invasive alien plants with most negative influence on the biodiversity.

The species *Solidago canadensis* tends to have slightly less harmful effect on biodiversity like *S. gigantea.* Vast stands in natural habitats are found in the riparian zones along the streams and man-made standing waters as well as on the edge of floodplain woods.

The next pair of species from the list (Tab. 4) presents the lianas *Parthenocissus quinquefolia* and *Echinocystis lobata* where the latter is much more frequent, especially in the riparian zones along streams and man-made standing waters as well as on the edge of floodplain woods.

The species *Elodea canadensis* is most widespread invasive alien plant among the aquatic macrophytes in the territory of Slovenia. This species seemed to be invasive only in reservoirs and degraded streams in lowlands.

Species with potentially negative influence on the biodiversity in wet habitats are also: *Impatiens glandulifera, Juncus tenuis, Impatiens parviflora* and *Bidens frondosa*. Species from this list that thrive in dry sites are *Erigeron annuus* and *Ambrosia artemisiifolia.*

Based on our estimates other invasive alien plant species represent minor threat to biodiversity due to their local / limited distribution, or due to

Table 3: The estimate of the characteristics of plants related to competitive ability of the taxon, which were the basis for estimation of potential negative influence in certain habitats.
Tabela 3: Ocena značilnosti rastlin, ki vplivajo na kompetitivne sposobnosti taksona in so bile osnova za oceno potencialno negativnega učinka v določenih habitatih.

Taxon	Life span	Plant height	Shading ability	Frequency rank of the taxon	Total estimate
	a	b1	b2		
Robinia pseudacacia L.	4	4	4	4	4.0
Solidago gigantea Aiton	3	2	2	4	2.5
Fallopia japonica (Houtt.) Ronse Decr.	3	3	4	3	2.4
Rudbeckia laciniata L.	3	2	3	3	2.1
Helianthus tuberosus L.	3	2	3	3	2.1
Ailanthus altissima Desf.	4	4	4	2	2.0
Acer negundo L.	4	4	4	2	2.0
Solidago canadensis L.	3	2	2	3	1.9
Parthenocissus quinquefolia (L.) Planch.	4	3	4	2	1.9
Echinocystis lobata (Michx.) Torr. & A. Gray	1	3	4	3	1.7
Elodea canadensis Michx.	3	1	2	3	1.7
Impatiens glandulifera Royle	1	2	2	4	1.5
Juncus tenuis Willd.	3	1	1	3	1.5
Erigeron annuus (L.) Pers.	1	1	1	4	1.0
Pinus strobus L.	4	4	4	1	1.0
Quercus rubra L.	4	4	4	1	1.0
Ambrosia artemisiifolia L.	1	1	2	3	0.9
Impatiens parviflora DC.	1	1	2	3	0.9
Physocarpus opulifolius (L.) Maxim.	4	2	3	1	0.8
Bidens frondosa L.	1	2	2	2	0.8
Pistia stratiotes L.	3	1	4	1	0.7
Aster squamatus (Spreng.) Hieron.	1	1	1	1	0.3

the fact that characteristics of those plant species reflect in their lower invasiveness.

Forest habitats

There are few established neophytes in Central European zonal forest communities (Kowarik 1999), moreover their frequency is also decreasing with increasing altitude. Situation is different in lowland forests, especially in areas with higher mean annual temperature, like the major part of sub-Mediterranean and sub-Pannonian phytogeographic area. Especially in these areas black-locust and tree of heaven seemed to be very invasive tree species. In some areas of Lower Carniola the species *Pinus strobus* is frequent, since it was massively planted in the past.

About 5.1% of the data about presence of invasive alien plant species refers to the forest habitats (Tab. 5). These data include also forest edges, where especially invasive alien herbaceous species occur more often than deeper in the forest stand, where the light intensity in under-storey is low. Considering also hedges, forest clearings and shrublands (together 3.7%), which are more outstanding habitats due to frequent disturbances, this number is higher – i.e. 8.8%. Floodplain woods and swamps, which are subjected to more frequent disturbances and therefore higher possibility of spreading of invasive alien plants along the streams, are presented in a special part. List of invasive alien plant species with potentially most negative influence on the biodiversity in forest habitats are presented in Table 5.

Table 4: List of invasive alien plant taxa with potentially most negative influence on the biodiversity in natural and extensively managed habitats.
Tabela 4: Seznam invazivnih tujerodnih rastlinskih taksonov s potencialno najbolj negativnim učinkom na biodiverziteto v naravnih in ekstenzivno gospodarjenih habitatih.

	No. of data
1. *Robinia pseudacacia* L.	311
2. *Solidago gigantea* Aiton	390
3. *Fallopia japonica* (Houtt.) Ronse Decr. and *F.* × *bohemica* (Chrtek & Chrtkova) J.P. Bailey	152
4. *Rudbeckia laciniata* L.	149
5. *Helianthus tuberosus* L.	97
6. *Ailanthus altissima* Desf.	29
7. *Acer negundo* L.	55
8. *Solidago canadensis* L.	92
9. *Parthenocissus quinquefolia* (L.) Planch.	36
10. *Echinocystis lobata* (Michx.) Torr. & A. Gray	127
11. *Elodea canadensis* Michx.	228
12. *Impatiens glandulifera* Royle	305
13. *Juncus tenuis* Willd.	93
14. *Erigeron annuus* (L.) Pers.	267
15. *Ambrosia artemisiifolia* L.	73
16. *Impatiens parviflora* DC.	99
17. *Bidens frondosa* L.	21

Table 5: Invasive alien plant species with potentially most negative influence on the biodiversity in forest habitats.
Tabela 5: Invazivne tujerodne vrste rastlin s potencialno najbolj negativnim učinkom na biodiverziteto v gozdnih habitatih.

	No. of data
Robinia pseudacacia	28
Solidago gigantea	23
Juncus tenuis	14
Rudbeckia laciniata	10
Erigeron annuus	25
Impatiens glandulifera	12
Impatiens parviflora	13

Species *Robinia pseudacacia* is frequent in hedges, while in shrublands and afforesting areas species like *Solidago gigantea, Robinia pseudacacia* and *Solidago canadensis* are common. Species *Impatiens glandulifera, Rudbeckia laciniata, Solidago gigantea* and *Solidago canadensis* are found in forest clearings.

Floodplain woods and swamps

Neophytes and invasive species among them have great influence on the ecosystem structure and biodiversity in floodplain woods and swamps in the alluvial plains. The establishment of invasive alien plants in these ecosystems is easier due to outstanding impacts of human- or nature-induced disturbances (Kowarik 1999). The highest number of invasive alien plant species can be found in lowland floodplain woods in sub-Pannonian phytogeographic area.

In mentioned forest types 11.8% of the data about presence of invasive alien plant species in the database are found, that is much more than in other forest types (5.1%). Considering also the fact that 60% of Slovenia is covered in forests among which these floodplain woods represent only a small share, the biodiversity in these habitats is probably much more threatened. According to our data invasive alien plants with potentially most negative influence on biodiversity in floodplain woods and swamps are listed in Table 6.

Species *Robinia pseudacacia* and *Acer negundo* are frequent in the tree layer of floodplain

Table 6: Invasive alien plant species with potentially most negative influence on biodiversity in floodplain woods and swamps.
Tabela 6: Invazivne tujerodne vrste rastlin s potencialno najbolj negativnim učinkom na biodiverziteto v logih in močvirnih gozdovih.

	No. of data
Robinia pseudacacia	53
Solidago gigantea	69
Fallopia japonica and F. × *bohemica*	37
Impatiens glandulifera	60
Echinocystis lobata	31
Rudbeckia laciniata	20
Helianthus tuberosus	18
Acer negundo	11
Solidago canadensis	13
Impatiens parviflora	25
Erigeron annuus	27

woods. Liana *Echinocystis lobata* is also frequent. Among the herb invasive alien plant species most frequent are the following species: *Solidago gigantea, Fallopia japonica, Impatiens glandulifera*.

Ruderal habitats

Since these habitats are greatly exposed to antropogenic disturbances they host a high share of neophytes and invasive species, respectively. In general, settlements are starting-points for the spreading of mentioned species as well as the environment where they are most frequent. The share of neophytes in the flora of a settlement increases with the size of a settlement.

Since these man-made habitats host mostly antropogenic vegetation types, the threat to biodiversity is far less important than in natural habitats. The aspects that are problematic are the facts that these habitats (Tab. 7) are the starting-points for the spreading of mentioned species into the natural environment and that traffic infrastructure represents a very important corridor for spreading of invasive alien plants.

Waters

In the mentioned data-base (CCFF), 7.3% of data about invasive alien plant species refers to the two hydrophytes, namely *Elodea canadensis* (92 % of these data) and *Pistia stratiotes*.

Elodea canadensis

According to the data set this species is more frequent in streams (162 data) than in standing waters (66 data) like ponds, oxbow-lakes and various reservoirs.

Kuhar et al. (2010) surveyed 785 km of reaches from 39 Slovenian streams. Mentioned species was found in 12 streams, in 132 reaches (of 1227 investigated) and in 99 km of those streams. Well developed stands of *E. canadensis* were found in 47 km of streams (6% of total surveyed length). Relative biomass of this species was low, what points to the fact, that this species in not invasive in the streams of Slovenia. It was not the only species in any reach, only rarely occurred as dominant species. This species mostly thrives in diverse communities.

The species *E. canadensis* is rarely found in naturally preserved streams (Šraj-Kržič et al. 2007). It prefers the streams running through agricultural landscape and have narrow, more or less disturbed riparian zone with moderate presence of retention structures (enable the growth of such stands). It prefers fine sediment that is a mixture of pebbles, sand, silt and detritus. Species was not found in reaches with higher current velocity and in streams in karst area (Kuhar et al. 2010) due to the frequent and strong changes in water level.

Martinčič et al. (2007) claim that more suitable habitat for this species are eutrophic standing waters with fine and nutrient-rich sediments (e.g.

Table 7: The most frequent invasive alien plant species in the settlements and traffic infrastructure.
Tabela 7: Najpogostejše invazivne tujerodne vrste rastlin v naseljih in prometni infrastrukturi.

	No. of data	
	Settlements including parks	Traffic infrastructure
% of data in data-base	9.2	5.3
Erigeron annuus	68	53
Robinia pseudacacia	45	17
Juncus tenuis	22	*
Solidago gigantea	18	14
Fallopia japonica and F. × bohemica	17	*
Impatiens glandulifera	16	*
Impatiens parviflora	14	13
Rudbeckia laciniata	14	*
Solidago canadensis	12	12
Ambrosia artemisifolia	10	25

accumulation lakes). Important characteristic is the allelopathic potential of the plants against epiphytes and phytoplankton that increase the transparency of water around the *Elodea* stand and contribute to their survival in more productive water (Erhard and Gross 2006).

However, *E. canadensis* did not express its invasive character in Slovenian running waters. In spite of numerous competitive advantages *E. canadensis* could be substituted by other, more successful invasive species *E. nuttallii* what occurred in France (Thiebaut, 2007). *E. nuttallii* was more competitive than *E. canadensis* and vegetative fragments of *E. nuttallii* also had higher survival rates following artificial disturbances than those of *E. canadensis*. *E. nuttallii* occurs in Slovenia in the stands of *E. canadensis*, and it is likely that it becomes a successful alternative for *E. canadensis* in the case of nutrient enrichment. So far this species was found in accumulation lakes on the Drava River (Mazej and Germ, unpublished) and in the Ledava River (Kiraly et al. 2007).

Pistia stratiotes

Species was discovered for the first time in Slovenia in the year 2001. It was found in the oxbow-lake near the village Prilipe, which is conditioned with water from the permanent thermal spring. Šajna et al. (2007) noticed a decrease in presence of native submerged macrophytes in this previously species-rich ecosystem. In the year 2004 a thick layer of this species completely covered the water surface all year long. Despite the removal every autumn, this species overgrow the lake every spring (Šajna et al. 2007). The Topla Stream is a potential source for further spreading of this species.

Riparian zones

Similarly like in northern Italy (Assini et al. 2009), Austria (Essl and Rabitsch 2002) or elsewhere in central Europe (e.g. Pyšek et al. 2012), neophytes are very widespread and abundant in the riparian zones along the streams and standing waters in Slovenia. More than 44% of all data about invasive alien plant species in used database (CCFF) refer to riparian zones. Like in several other parts of central Europe invasive alien plants are very frequent in riparian zones along the streams (Essl and Rabitsch 2002, Assini et al. 2009, Pyšek et al. 2012).

Woody or wetland vegetation in riparian zone has exceptional role in maintenance and increase of biodiversity in terrestrial and aquatic ecosystems. Riparian zone is transition between terrestrial and aquatic ecosystems and it is subjected to many unfavourable influences that reflect in its specific structure (Richardson et. al 2007). Riparian zone:

- maintains biodiversity of the landscape and increases the biodiversity of the aquatic ecosystem and the adjacent habitats,
- is the habitat and the corridor for native species,
- influences the quality and amount of organic matter in water ecosystem,
- is a buffer zone, which decreases the pollution from farmlands, prevents bank erosion and has a favourable influence on the ecological condition of the aquatic ecosystem.

Many invasive alien plants are very successful in colonization of the riparian zone. This is a serious problem in Slovenia as well as in Europe. Stream ecosystem is very prone to the spreading of invasive alien plants, especially due to its dynamic hydrology and its role as a corridor for their spreading (Richardson et al. 2007). Invasive alien species spread also to adjacent natural habitats.

Riparian zones along the streams

In the riparian vegetation along the streams (riparian reeds and sedges, tall-forbes, willow and alder communities, pioneer vegetation of gravel-beds and sands) stands consisting of invasive alien plants are common. In comparison to other considerably natural plant communities the highest share of alien species can be found here, among them several species are invasive. Invasive alien plants often form dominant stands. In general their share is the highest in riparian zones along the nutrient-rich lowland reaches of the streams. In such reaches the substrate consists mostly of finer particles like sand, clay or detritus.

The high frequency of invasive alien plant species in the riparian zones along the streams could be explained mostly with frequent and strong natural disturbances, which are the consequences of strong alternation of water level (contemporary flooding and sediment deposition as well as bank erosion). Additionally there is also contribution

of simple way of spreading along the streams and human influence like eutrophication of stream and catchment area, hydro-technical measures on the banks (bank reinforcements, channel regulations...). Settlements and traffic infrastructure are also common along the streams, facilitating the spreading of invasive alien plants.

28.5% of the data about presence of invasive alien plant species from our data-base refer to their presence in the riparian zones along the streams, which is the highest number among all surveyed habitats. Invasive alien plant species with potentially most negative influence on biodiversity in riparian zones along the streams are listed in Table 8.

Gravel-beds:

Alien species are common in gravel-beds along the middle part of the watercourses in many parts of Central Europe. Among them ruderal plant species like *Erigeron annuus* occur frequently. With increasing altitude along the headwaters, the number of invasive alien species decreases.

Presence of invasive alien plants on gravel-beds slightly differs from the general pattern found in riparian zones along the streams (data from gravel-beds represent 11% of the mentioned data). Taxa with potentially most negative influence on biodiversity on gravel-beds are listed in Table 8.

Riparian zones around the standing waters

Invasive alien plants occur less frequently in the riparian zones or littoral around the standing waters than along the streams for several afore mentioned reasons. These riparian zones contain 15.7% of the data about invasive alien plant species from data-base. The most frequent species are: *Solidago gigantea, Impatiens glandulifera, Robinia pseudacacia, Erigeron annuus, Rudbeckia laciniata, Juncus tenuis, Acer negundo, Solidago canadensis, Echinocystis lobata, Ambrosia artemisifolia, Bidens frondosa, Fallopia japonica, Helianthus tuberosus*.

Riparian zones around the standing waters of human origin:

Invasive alien plants occur in littoral of different types of man-made lentic water bodies which vary considerably in their size. This group of water bodies consists of different types of the ponds (karst ponds, fish-ponds, pools or puddles), accumulation lakes, abandoned clay-pits

Table 8: Invasive alien plant species with potentially most negative influence on biodiversity in riparian zones along the streams.

Tabela 8: Invazivne tujerodne vrste rastlin s potencialno najbolj negativnim učinkom na biodiverziteto v obrežnih pasovih vzdolž vodotokov.

	No. of data	
	riparian zones along watercourses	gravel-beds only
Robinia pseudacacia	101	*
Solidago gigantea	139	10
Fallopia japonica and F. × bohemica	84	10
Impatiens glandulifera	125	14
Echinocystis lobata	63	*
Rudbeckia laciniata	48	*
Helianthus tuberosus	41	12
Solidago canadensis	33	*
Acer negundo	20	*
Erigeron annuus	75	11
Ailanthus altissima	12	*
Impatiens parviflora	36	*
Juncus tenuis	19	*
Parthenocissus quinquefolia	10	*
Ambrosia artemisiifolia	22	*

and gravel-pits filled with water. These water bodies are most common type of lentic waters in Slovenia and together represent nearly one half of the total surface of all standing waters. Invasive alien plant species with potentially most negative influence on biodiversity in riparian zones around the man-made standing waters are listed in Table 9.

Table 9: Invasive alien plant species with potentially most negative influence on biodiversity in riparian zones around the standing waters.
Tabela 9: Invazivne tujerodne vrste rastlin s potencialno najbolj negativnim učinkom na biodiverziteto v obrežnih pasovih stoječih voda.

	No. of data	
	Man-made	Oxbow-lakes
Robinia pseudacacia	66	10
Solidago gigantea	69	31
Rudbeckia laciniata	34	20
Impatiens glandulifera	50	28
Juncus tenuis	33	*
Erigeron annuus	52	10
Acer negundo	10	*
Echinocystis lobata	15	*
Solidago canadensis	11	*

Riparian zones around the oxbow-lakes:

Oxbow-lakes are a special type of lentic ecosystems found also in Slovenia that are being formed in alluvial plains of lowland reaches of the rivers. They are mostly found along the Mura and Sava Rivers, only some cases are found along the Kolpa and Vipava Rivers. The majority of the data about presence of invasive alien plants in these habitats refer to the oxbow-lakes from lower parts of the Mura and Sava Rivers. Invasive alien plant species with potentially most negative influence on biodiversity in riparian zones around the oxbow-lakes are listed in Table 9.

Agricultural land

About 6.3% of the data on invasive alien plant species is connected with agricultural land. Smaller part of these data can be found on the arable land (1.3%), while major part of the data (5%) refers to different grassland types.

Most common invasive alien plant species on arable land are ruderals *Erigeron annuus* and *Ambrosia artemisifolia*.

Most common invasive alien plant species in grasslands are: *Erigeron annuus, Robinia pseudacacia, Solidago gigantea, Solidago canadensis, Rudbeckia laciniata.* Species *Erigeron annuus* was most common in intensively cultivated meadows as well as in dry-meadows. The mentioned ruderal species *Erigeron annuus* and tree species *Robinia pseudacacia* are most frequent invasive alien plant species in grasslands on the territory of Austria (Essl and Rabitsch 2002), especially in drier sites.

Wetlands

Inland wetlands

About 3% of the data on presence of invasive alien plant species come from inland wetlands (swamps, intermittent lakes, wet grasslands). None of those species seemed to be problematic in these habitats. As the species with potentially most negative influence on biodiversity *Solidago gigantea* and *Erigeron annuus* were selected.

Coastal wetlands

Only 1% of the data on presence of invasive alien plant species come from the coastal wetlands. The most common invasive alien plant species is *Aster squamatus.* Besides, widespread black-locust (*Robinia pseudacacia*) is found in these habitats as well.

Ecological preferences of some of the most invasive alien plant taxa

The greatest deviations from moderate Ellenberg indicator values (value 5 is in the middle on the ordinal scale 1-9 according to Ellenberg et al. 1992) were detected in the case of N values that indicate preference for nutrient-rich sites. N values of invasive alien species ranged from 3 to 9 (mean = 7.3), while L values that indicate the preference for open non-shaded sites ranged from 4 to 9 (mean = 7.2). Both deviations were more outstanding in the case of herb species. Predominantly higher values than average were detected also for soil reaction (6.9), temperature (6.4) and moisture of the site (6.3).

Based on these results it can be confirmed that invasive alien plants prefer nutrient-rich, open (e.g. non-forest) sites on soils with basic reaction as well that they thrive better in warm and moist sites. Their invasiveness is potentially the highest in such conditions. Ecosystems where such condition are found are those, where high contents of nutrients are available to plants (fertilization, alluvial deposits) and primary woody vegetation was removed (e.g. degraded riparian zones, degraded floodplain woods, abandoned arable land and intensively fertilized meadows).

The influence of taxon Fallopia × bohemica on the biodiversity

According to the data from literature (e.g. Child et al. 1992, Gerber et al. 2008, Strgulc-Krajšek and Jogan 2011) and our results from previous vegetation periods, we can affirm the known negative influence of invasive plant species on the biodiversity.

Light intensity was measured in three vegetation types / plant communities found in riparian zone along the Glinščica stream. About 20 cm above the grounds the measured values differed significantly. Light intensity in the flood meadows was on average 1200 µmol/m^2 s, in tall-forbs it was 460, while in the stands consisting of the taxon *Fallopia × bohemica* light intensity reached only 20 µmol/m^2 s, that presents less than 1% of full day-light measured during this analysis.

However, unification of site conditions in the stands with dominant taxon *Fallopia × bohemica* and deterioration of light conditions in different habitat types was detected.

Conclusions

Data about the presence of invasive alien plants in specific habitats were extracted from the database Flora of Slovenia (at the Centre for Cartography of Fauna and Flora). The list of the most frequent invasive alien plant taxa in the mentioned database is presented (Tab. 1) as well as the list of invasive alien plants in natural and semi-natural habitats (Tab. 2). In general, the most frequent invasive alien plant species is *Erigeron annuus,* while in natural and extensively managed habitats the species *Solidago gigantea, Robinia pseudacacia* and *Impatiens glandulifera* are more frequent as the afore mentioned species.

An attempt to evaluation of potential endangerment of specific habitats due to the presence of invasive alien plant species was also made (Tabs. 3-4). The lists of invasive alien plants with potentially most negative influence on the biodiversity in different habitats are presented (Tabs. 5-9). In general, taxa with potentially most negative influence on the biodiversity of natural habitats in Slovenia are the following: *Robinia pseudacacia*, *Solidago gigantea, Fallopia japonica* and *F. × bohemica, Rudbeckia laciniata, Helianthus tuberosus*. In the dataset 44% of data about presence of invasive alien plants referred to riparian zones and among these two thirds referred to riparian zones along the streams. These habitats are most infected in Slovenia according to our data. The second highly infected group of natural habitats were floodplain woods. According to Ellenberg Indicator Values the most of the invasive alien plants prefer nutrient-rich and sunny sites.

To get more representative results about the presence and establishment of invasive alien plant species in specific habitats, additional systematic surveys should be done all over the territory of Slovenia. For total estimate of the potential negative effect of invasive alien plant species some other plant characteristics could be included that would better reflect the invasiveness of analysed plant taxa. However, an example of evaluation of potential endangerment of specific habitats due to the presence of invasive alien plant species was made. Further research in this field is needed since these plants present a threat to diversity of native species.

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