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VASCULAR PLANT BIODIVERSITY OF FLOODPLAIN FOREST GEOBIOCOENOSIS IN LOWER MORAVA RIVER BASIN (FOREST DISTRICT TVRDONICE), CZECH REPUBLIC

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ABSTRACT

This paper presents an evaluation of full-area floristic mapping of floodplain forest in Tvrdonice forest district (Židlochovice Forest Enterprise) based on a single forest stand inventory. The study area encompasses 2,200 ha of forests, where 769 segments were inventoried, and 46,886 single records about presence of vascular plant species were catalogued. We found 612 species (incl. subspecies and hybrids), out of which 514 were herbs, 98 were woody plants, 113 were endangered species and 170 were adventive species. The average area of a segment is 2.86 ha. The mean number of species per segment is 60.97 in a range of 4–151.

Key words: biodiversity, vascular plants, floodplain forest, forest district Tvrdonice, Czech Republic

INTRODUCTION

Formations of floodplain forests in Europe are classified as azonal; however, their vegetation differs in particular parts of Europe both in its physiognomy and species composition (Bohn et al. 2003). Floodplains and floodplain forests in alluvia of large rivers are dynamic ecosystems, which are subject to fast changes in the temporal as well as spatial sense (Klimo et al. 2008). They are relatively young communities, as regards their development, and are affected by two main ecological factors – more or less cyclic flooding and a high level of the groundwater (Maděra et al. 2008). Their genesis and especially florogenesis has also been affected by the broad surroundings of the floodplains, i.e. the entire river drainage basin. The cyclic character of floods and the migration of diaspores of many species by water (Boedeltje 2004) were the factors that have been enriching the flora of floodplain forests for centuries. Considering the ever more frequent deposition of material from the entire drainage basins and global eutrophication on the one hand, as well as the natural fast decomposition of organic mass on the other hand, these sites are very well supplied with nutrients and in recent decades have also been supplied or even oversaturated with nitrogen. The significance of floodplain forests for biodiversity has been mentioned in many studies (Tabacchi et al. 1996, Naiman & Decamps 1997, Schnitzler et al. 2007); however, the condition of river ecosystems in Europe is currently affected by a number of negative anthropogenic factors (Wenger et al. 1990).

The biodiversity of vascular plants in the study area has been affected significantly by the forest management in the area, i.e. the way the landscape in the entire drainage basin has been managed. The floodplain was densely populated in the period of Great Moravia. In the Middle Ages, the forest communities were harvested with very short rotation periods (as frequently as 7 years), managed as coppice forests or coppice with standards. Pasture was created in the floodplain forests in the historical times and the forest was regenerated by agroforestry (Nožička 1956; Hrib 2004) and in the most recent decades by various forms of uniform clear-cutting with broadcast soil preparation. Regeneration has always been achieved using autochthonous woody plants; therefore, nowadays, there are valuable forest stands that can be referred to as man-made natural ecosystems (Maarel 1975).

South-Moravian lowland floodplains, together with the adjacent Slovakian and Lower Austrian floodplains, are the most extensive complex within central Europe; recently, they have been a subject of research of more and more studies. They are significant forest coenoses covering the broad floodplains of lower reaches of large rivers, well-known for their dynamic development (Maděra 2001a, 2001b) and high production of biomass (Klimo & Hager 2000; Penka et al. 1985). The afore-mentioned floodplain forests in the Czech Republic are managed by the Židlochovice Forest Enterprise and are divided into three forest districts (Valtice, Tvrdonice and Soutok). Floristic-oriented studies from the area of the confluence of the Morava and the Dyje rivers have been published only recently. Horák (1961) focused on the typology of floodplain forests, Vicherek et al. (2000) dealt with a floristic inventory in map squares regardless of forest or non-forest biotopes, Danihelka et al. (1995) and Danihelka & Šumberová (2004) described the distribution of selected taxa. Maděra et al. (2011) presented the results of a floristic inventory of floodplain forests within the Valtice forest district.

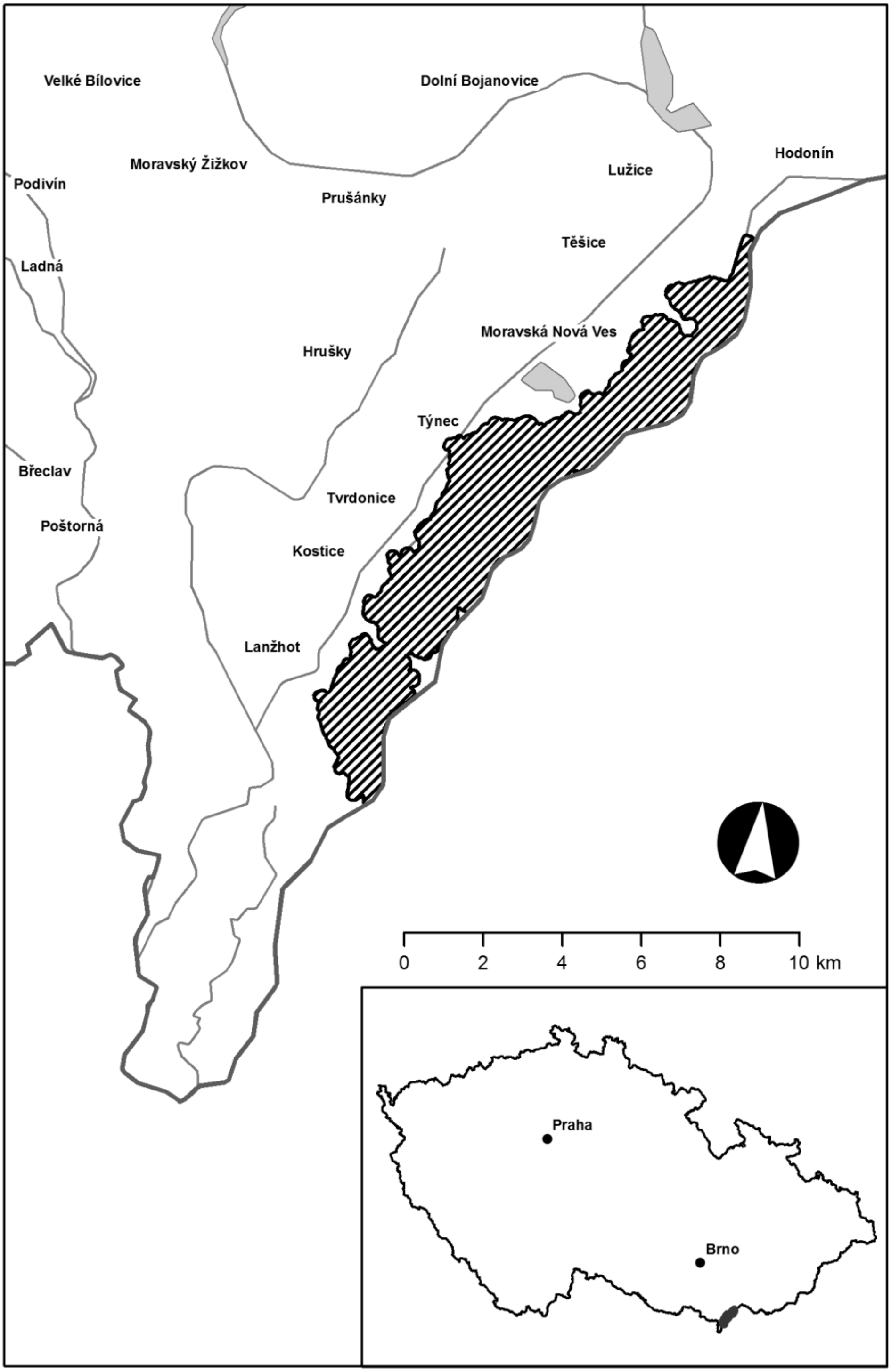
The aims of this paper are to continue the work presented in the last mentioned publication and introduce another stage of the floristic inventory of floodplain forests, this time within the Tvrdonice forest district of the Židlochovice Forest Enterprise, as a model of diversity of vascular plants in floodplain forests of the Lower Morava Basin. The results should serve as a significant source of information for the zonation of Dolní Morava Biosphere Reserve, the studied area being its part.

MATERIAL AND METHODS

Study area

The area of 2,200 ha of floodplain forest along the lower reaches of the Morava river between towns Lanžhot and Hodonín was inventoried. This is the Tvrdonice forest district, Židlochovice Forest Enterprise, which is a part of state forests managed by Lesy ČR s.p. The Morava river in the studied area forms the border between the Czech Republic and Slovakia (Fig.1). A short description of the historical development of the area and its significance for nature conservation was presented in the previous study (Maděra et al. 2011), which concerned the Valtice forest district.

Fig. 1: Study area



Methods

All vascular plants in the area of the Tvrdonice forest district were recorded between 2007 and 2011 down to the level of a segment; each segment corresponds to one stand group (exceptionally, similar groups are put together or non-homogeneous groups are divided). The presence of species in each segment is ticked in a list that includes 263 most common species of herbs in south-Moravian floodplains. Rare species and woody plants are added to the list. We used nomenclature according to Kubát et al. (2002). The occurrence of species growing only at the segment edges (stand adjacent to a forest road, a water current, a clearing, a meadow) and dominant species (species of over 40% cover) are marked differently. The terrain survey needs to be conducted in two aspects: spring (March 20–May 31) and summer (June 1–November 30); also fresh clearings and young plantings were inventoried. The ticking lists are then transferred to a database and further processed. The segment after digitalisation becomes a site (a point in the point map). The digitalisation and creation of the species distribution maps was implemented in the GIS environment (ArcGIS).

RESULTS

The total study area is 2,200 ha of forest; 769 segments were explored and 46,886 records on the presence of vascular plant taxa were taken. According to the records, there are 612 species (and lower taxa, or hybrids) in the area, out of which there are 514 herbs and 98 woody plants. The mean size of a segment is 2.86 ha. On average, there are 60.97 taxa (range of 4–151) per segment (most segments containing 40–59 species). The numbers of species within a segment are distributed slightly unequally – there are more segments with lower numbers of species than average (412) and fewer segments with higher numbers (357) (Fig.2). On average, there are 9.39 species of woody plants and 51.58 species of herbs in a segment. The spatial distribution of the segments with their highlighted significance for biodiversity (the number of species per segment) is illustrated in Fig. 3.

Fig. 2: Frequency of segments according to containing number of species

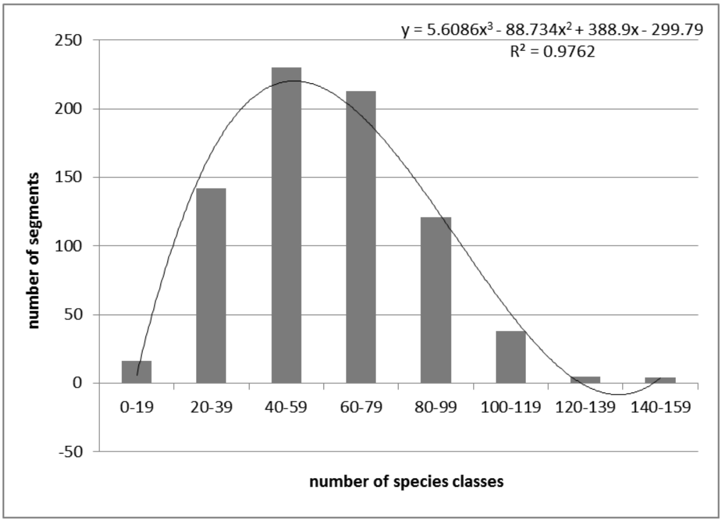
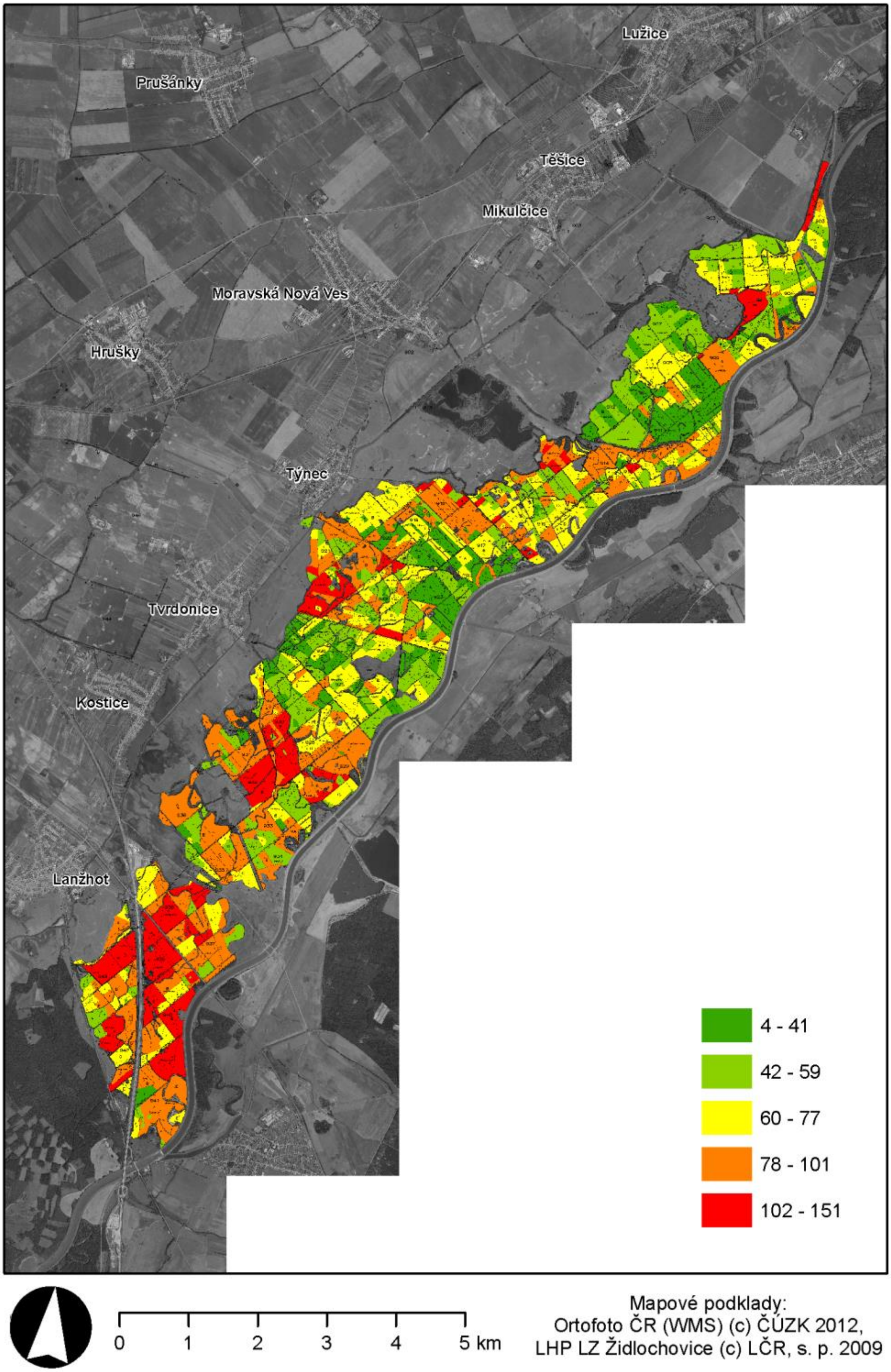


Fig. 3: Map of the number of all vascular plant species per segment



We also examined the frequency of species occurrence (presence of a taxon in segments) in the area (Table 1). The analysis shows that 110 species (i.e. nearly 15%) occur in one segment only, 281 species (i.e. 37%) are present in 1–9 segments; it means that the species scarcely occur in the area and are rare. The table also shows that another 196 species (i.e. 25%) are present in 10–99 segments. These species can be referred to as scattered. 135 species (i.e. 17.5.%) are present in over 100 segments – these species are abundant. Only 25 species occur in over 60% of segments (Table 2) – the species with high stability. This group contains most species of the herb layer of floodplain forests considered typical species of subclass *Ulmenion* (Neuhäuslová 2001). Only two adventive species are in this group – invasive neophyte *Aster lanceolatus* and naturalised archeophyte *Arctium lappa*.

Table 1: The frequency of species occurrence

Classes of segments number	Number of species
700 +	2
600-699	8
500-599	12
400-499	13
300-399	17
200-299	26
100-199	57
0-99	477
90-99	0
80-89	9
70-79	14
60-69	17
50-59	16
40-49	14
30-39	23
20-29	36
10-19	67
1-9	281

Table 2: Species with occurence frequency over 60% of segments

Species	No. of segments
Aster lanceolatus	731
Rubus caesius	708
Urtica dioica	694
Geum urbanum	670
Glechoma hederacea	653
Carex riparia	626
Galium aparine	626
Quercus robur	624
Acer campestre	608
Symphytum officinale	603
Brachypodium sylvaticum	599
Festuca gigantea	594
Rumex sanguineus	594
Arctium lappa	573
Deschampsia cespitosa	569
Torilis japonica	565
Phalaris arundinacea	555
Iris pseudacorus	539
Lysimachia nummularia	534
Fraxinus angustifolia	512
Cirsium arvense	512
Dactylis polygama	509
Taraxacum sect. *Ruderalia*	493
Ficaria verna	481
Poa palustris	471

From the perspective of nature preservation, it is interesting to evaluate the proportion of adventive species (based on Pyšek et al. 2002) and endangered species (based on Holub & Procházka 2000). Considering merely the number of species (Fig. 4), over a quarter (27.7%, i.e. 170 taxa) are various categories of adventive species and 18.4% (113) taxa are species with various levels of conservation status. However, Fig. 5 has a higher information capacity concerning the role of these groups in the area. It shows the results categorised based on the number of records of the species in the segments. Based on this, the proportion of adventive species drops to 18% (8,455 records) and the proportion of endangered species to 7% (3,478 records). Neither of this is sufficiently informative, as the presence of taxa in segments does not give any idea about their cover. For example, *Aster lanceolatus,* a significant invasive neophyte, is present in over 95% of segments and it is dominant in the herb layer synusia in 18% of them; the dominance is the most frequent in stands up to 10 years of age (Řepka & Maděra 2009a). By contrast, *Arctium lappa* is present in 74% of segments, but always relatively scarcely.

Fig. 4: Proportion of adventive, threatened and others vascular plant species in the area of study

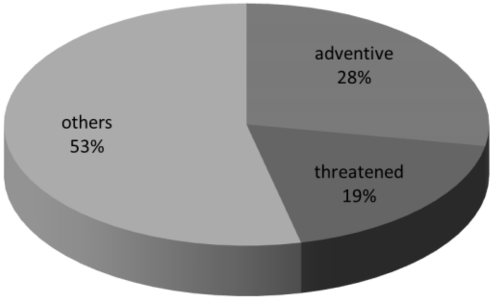
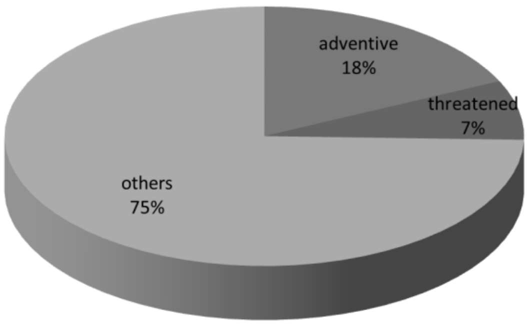


Fig. 5: Proportion of adventive, threatened and others vascular plant species in the area of study according to the number of records



Within the set of adventive species, archeophytes (58.8%) slightly prevail over neophytes (41,2 %); there are 48, i.e. 28% of invasive species in total (Fig. 6, Table 3), according to Pyšek et al. (2002) we distinguish archeophytes (arc) and neophytes (neo), in detail (cas – casual, nat – naturalised and inv – invasive). On average, there are 11 adventive species in a segment (range of 0–46). Only 3 segments contained no adventive species. There were up to 10% of adventive species in 124 segments, 10–20% in 403 segments, 20–30% in 198 segments, 31–40% in 34 segments, and 41–50% of adventive species in 8 segments. Two segments even contains over 50% of adventive species. The loading of individual segments by the presence of adventive species is illustrated in the map, Fig. 7, neophytes especially are pictured in the map, Fig. 8.

Table 3: The abundance of different categories of adventive species
(according to Pyšek et al. 2002)

adventive species category	all species		herbs		woody plants	
	species number	records number	species number	records number	species number	records number
ar cas	8	90	5	8	3	82
ar nat	77	3509	71	3443	6	66
ar inv	15	1665	15	1665	0	0
neo cas	17	142	5	11	12	131
neo nat	20	626	16	590	4	36
neo inv	33	2423	25	2043	8	380

Fig. 6: Proportion of adventive species (according to Pyšek et al. 2002) in the area of study

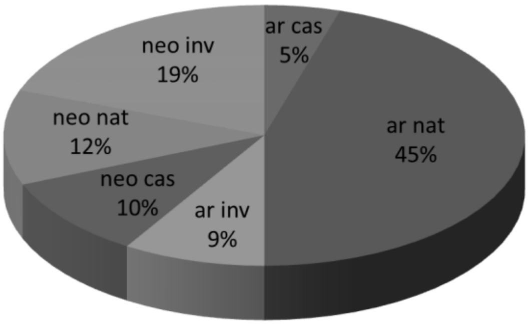


Fig. 7: Map of the number of adventive vascular plant species per segment

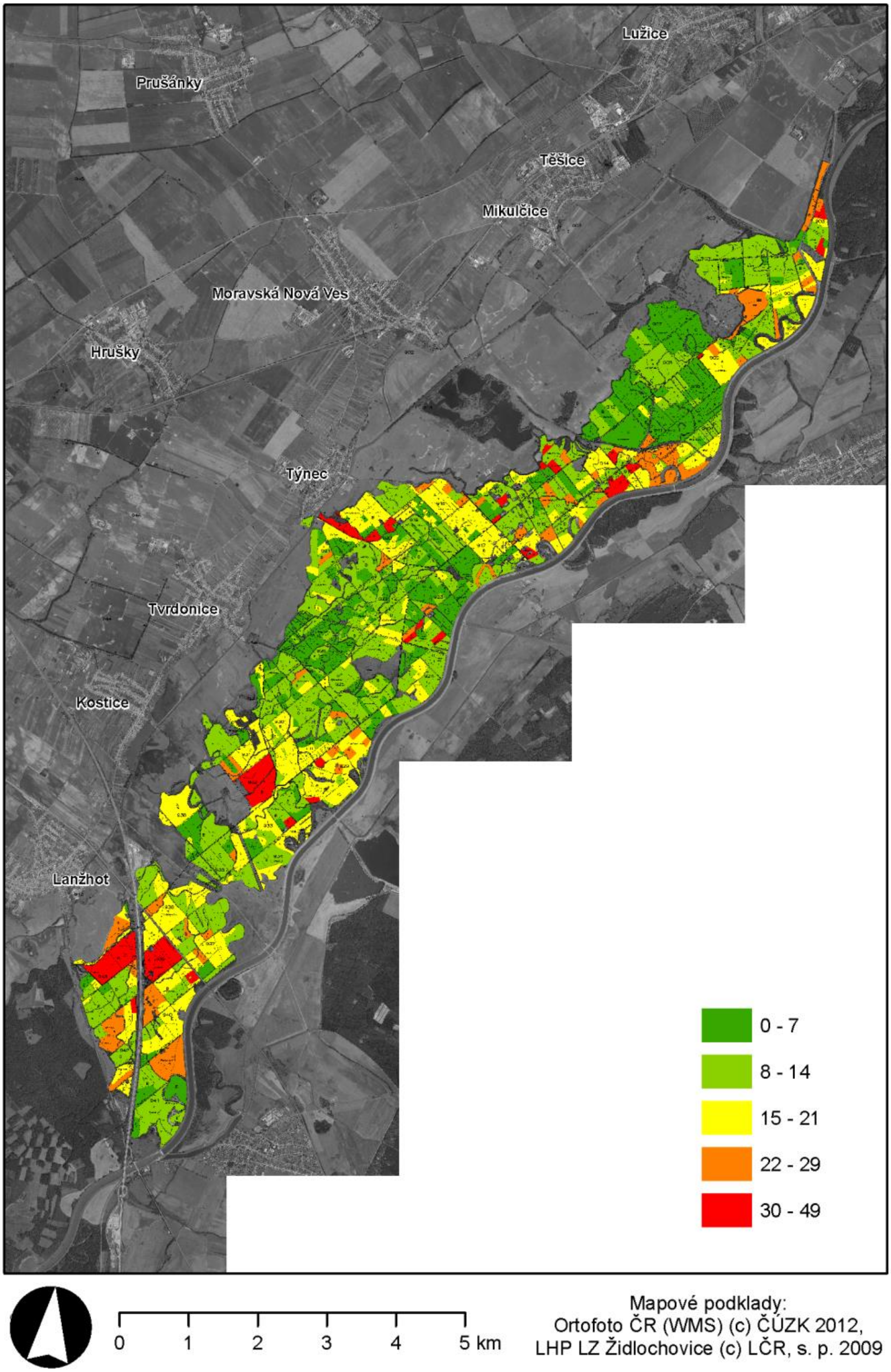
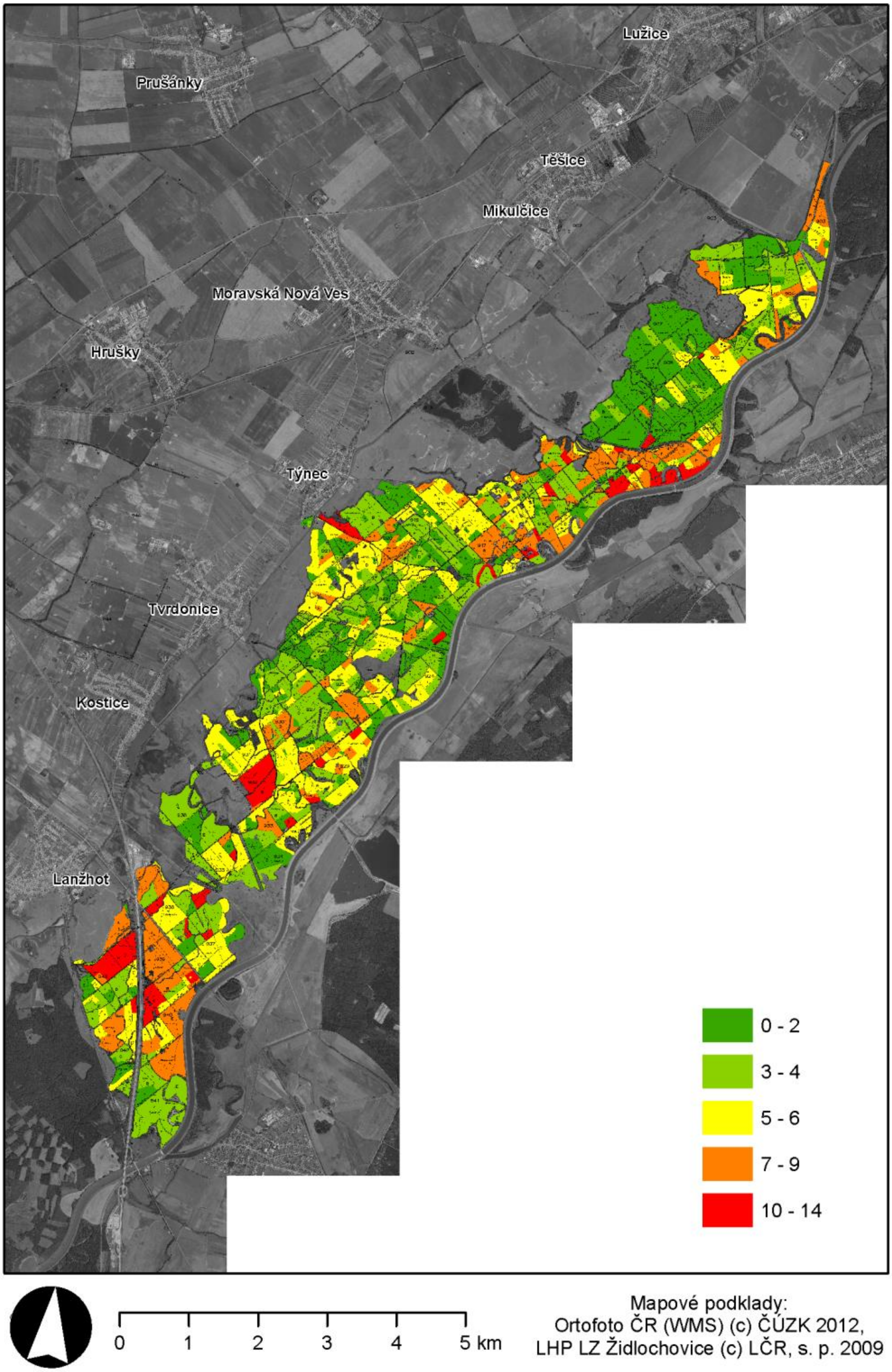


Fig. 8: Map of the number of vascular plant neophytes per segment



As concerns threatened species, 19.46% of species are protected by law, the rest are within various categories of the Red List. There are 8 critically endangered species, 34 strongly endangered and 25 endangered, the other 46 species are within C4 category – requiring further attention (Fig. 9, Table 4). The analysis shows that the mean number per segment is 4.52 species (range of 0–17). Threatened species are not present in 14 segments only; in the others there is at least one threatened species. Most segments (307) contain 6–9% of threatened species; 10 segments even over 15%. The most of threatened species (66%) are present in 1–10 segments and only 7% of threatened species are present in over 100 segments. The spatial distribution of the numbers of threatened species of plants in the segments is shown in the map, Fig. 10. The map in Fig. 11 shows the species of categories C1 (critically endangered) and C2 (strongly endangered).

Table 4: The abundance of threatened vascular plants species
(according to Holub & Procházka 2000)

threat and protection category	all species		herbs		woody plants	
	species number	records number	species number	records number	species number	records number
§1	7	49	7	49	0	0
§2	11	72	11	72	0	0
§3	4	17	3	16	1	1
C1	8	62	8	62	0	0
C2	34	825	31	705	3	120
C3	25	749	23	236	2	513
C4	46	1842	36	1262	10	580

Fig. 9: Proportion of threatened species in the area of study

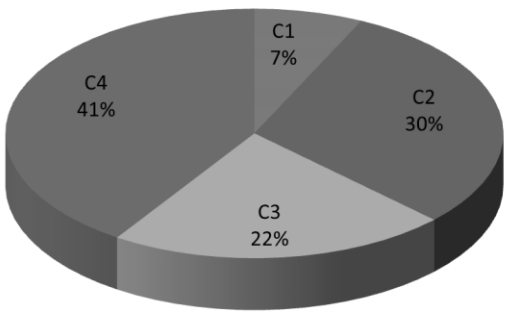


Fig. 10: Map of the number of endangered vascular plant species per segment according to Pyšek et al. (2002)

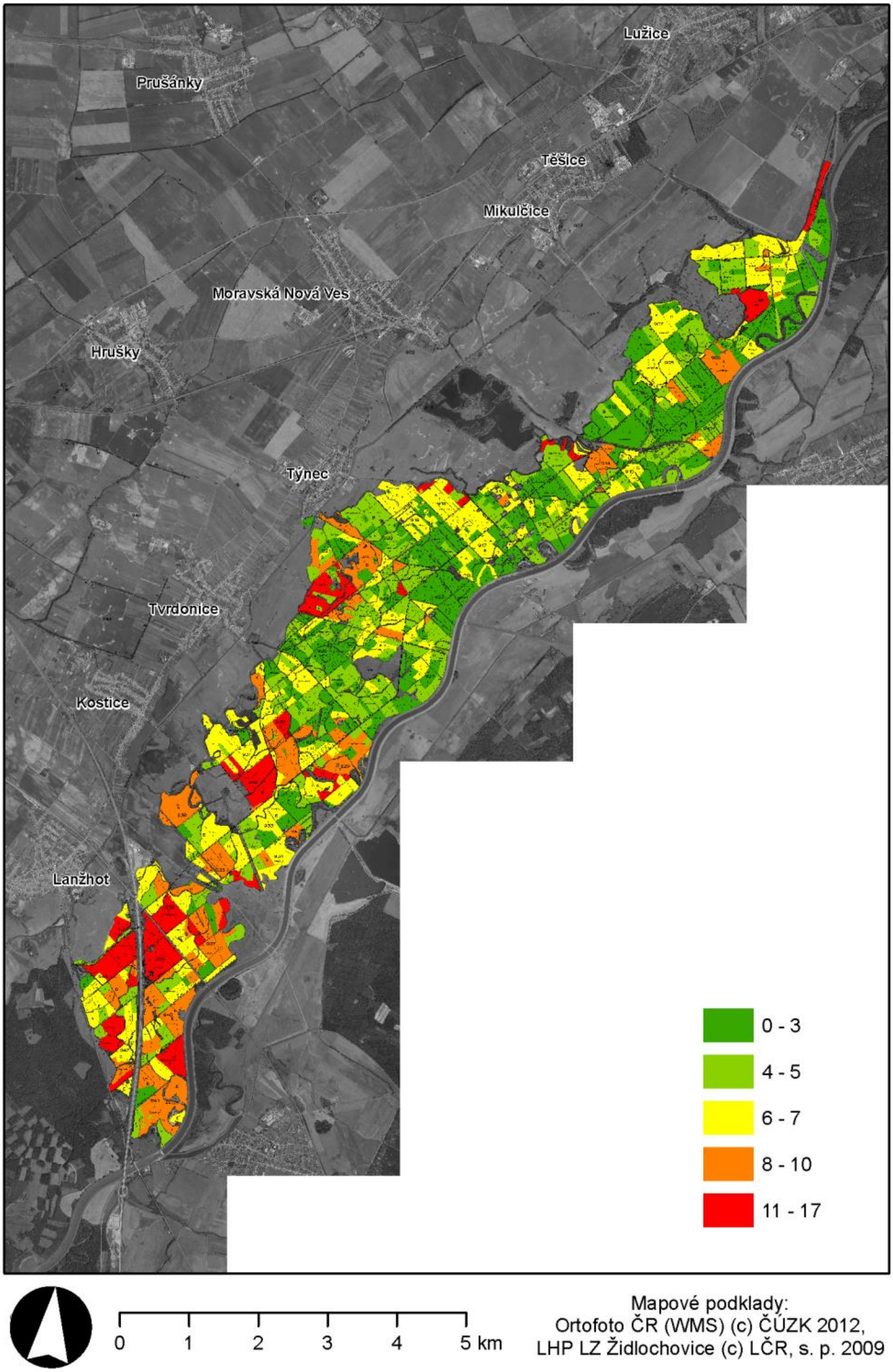
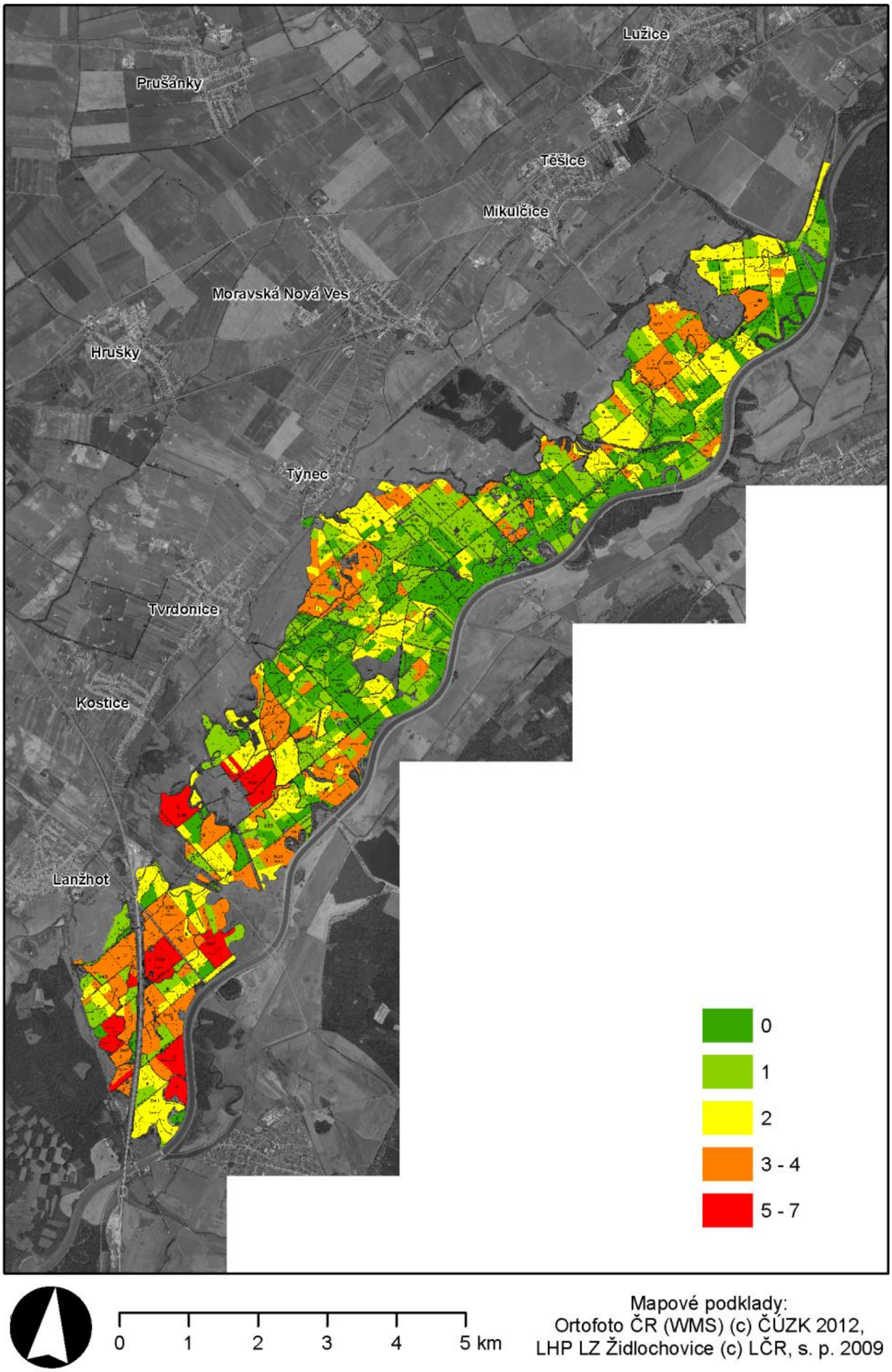


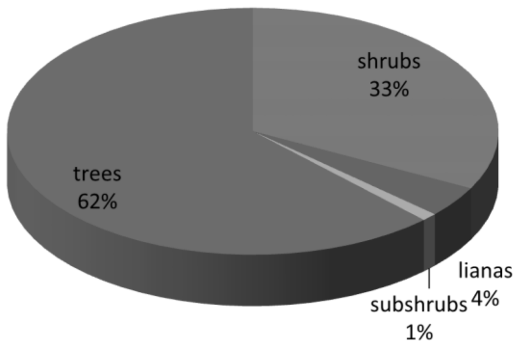
Fig. 11: Map of the number of critical (C1) and strong endangered vascular (C2) plant species per segment according to Holub & Procházka (2000)



Diversity of woody plants in the floodplain forests

As has been mentioned, we found 98 species, subspecies and hybrids of woody plants in the study area. Based on Úradníček et al. (2010), woody plants are not only trees and shrubs but also semi-shrubs (e.g. *Solanum dulcamara*) or woody lianas (e.g. *Hedera helix*) and shrublets, whose representative has not been found in the area (Fig.12).

Fig. 12: Proportion of life form occurence of woody plants



Out of the total number of woody plants found, there are 25 abundant species (occurrence in over 100 segments), 31 scattered species (10–99 segments) and 42 rare species (1–9 segments) – 23 species were recorded in one segment only.

From the perspective of autochthonous character, 33 recorded species are various types of adventive species (Table 5). There are 8 recorded invasive neophytes, a more significant presence being recorded for *Acer negundo* – in nearly 24% of segments and *Populus x canadensis* – in 18% of segments. The former is the only one that propagates spontaneously, the others are grown (besides hybrid poplars, *Fraxinus pennsylvanica* and *Quercus rubra*) and spread less. Pyšek et al. (2002) also categorised the frequently grown *Juglans nigra* as an occasionally wild-growing neophyte; however, in the conditions of a floodplain we can assume at least a very good naturalisation as it often regenerates naturally – it was recorded in 10% of segments.

Table 5: The presence of adventive woody plants species in segments
(according to Pyšek et al. 2002)

Species	number of segments	proportion of segments	adventive species category	
Malus domestica	73	9.49	cas	ar
Morus alba	5	0.65	cas	ar
Vitis vinifera subsp. *vinifera*	4	0.52	cas	ar
Pyrus communis	34	4.42	nat	ar
Malus x *dasyphylla*	13	1.69	nat	ar
Prunus insititia	11	1.43	nat	ar
Juglans regia	5	0.65	nat	ar
Prunus domestica	2	0.26	nat	ar
Prunus cerasus	1	0.13	nat	ar
Juglans nigra	78	10.14	cas	neo
Aesculus hippocastanum	27	3.51	cas	neo
Tilia tomentosa	15	1.95	cas	neo
Populus balsamifera	2	0.26	cas	neo
Juglans x intermedia	2	0.26	cas	neo
Abies grandis	1	0.13	cas	neo
Eleagnus angustifolia	1	0.13	cas	neo
Gleditsia triacanthos	1	0.13	cas	neo
Picea pungens	1	0.13	cas	neo
Pinus jeffreyi	1	0.13	cas	neo
Platanus x *hispanica*	1	0.13	cas	neo
Thuja occidentalis	1	0.13	cas	neo
Acer negundo	184	23.93	inv	neo
Populus x *canadensis*	139	18.08	inv	neo
Robinia pseudacacia	25	3.25	inv	neo
Quercus rubra	16	2.08	inv	neo
Fraxinus pennsylvanica	12	1.56	inv	neo
Parthenocissus inserta	4	0.52	inv	neo
Ailanthus altissima	2	0.26	inv	neo
Mahonia aquifolium	1	0.13	inv	neo
Physocarpus opulifolius	1	0.13	inv	neo
Prunus cerasifera	20	2.60	nat	neo
Ribes rubrum	11	1.43	nat	neo
Pinus nigra	1	0.13	nat	neo

15 species of the woody plants fall within threatened species of some category (Table 6) but only *Cornus mas* is protected by law and it was found in one segment only. Floodplain forests are indispensable biotopes of strongly endangered woody species, *Malus sylvestris* (70 segments), *Populus nigra* (33 segments) and endangered *Fraxinus angustifolia* (512 segments). There is also a strong population of elms, both *Ulmus laevis* and *Ulmus minor* (348 and 151 segments, respectively).

Table 6: The presence of threatened woody plant species

Species	threat category	number of segments
Cornus mas	§3 (C4)	1
Malus sylvestris	C2	70
Populus nigra	C2	33
Quercus cerris	C2	17
Fraxinus angustifolia	C3	512
Prunus mahaleb	C3	1
Ulmus laevis	C4	348
Ulmus minor	C4	151
Viscum album	C4	28
Loranthus europaeus	C4	25
Pyrus pyraster	C4	20
Euonymus verrucosa	C4	3
Viburnum lantana	C4	2
Berberis vulgaris	C4	1
Sorbus aria	C4	1

It is typical of floodplain woody plants that they grow to vast dimensions within their species (Maděra et al. 2007). Huge specimens can be found both in the stands and the meadows, riparian stands and forest edges with a high density. Their ecological significance is great; they are biotopes for a number of specially protected insects and birds, they form the landscape character, and they often represent the last remnants of local populations. Therefore, they need to be devoted sufficient attention in management (Rychtecká & Dreslerová 2009).

Diversity of herbs in the floodplain forests

We determined 514 species, subspecies and hybrids of herbs in the synusia of floodplain forest herb layer. Out of the total number of herbs found, there are 112 abundant species (occurrence in over 100 segments), 161 scattered species (10–99 segments) and 241 rare species within the area (1–9 segments) – 90 species were found in one segment only.

From the perspective of autochthonous character, 137 recorded species are various types of adventive species (Table 7), out of which there are 91 archeophytes and 46 neophytes, 40 invasive species. The more significant invasive archeophytes are *Cirsium arvense* in 66%

of segments, *Plantago major* (40% of segments), *Tanacetum vulgare* (36% of segments), *Cirsium vulgare* (31% of segments) and *Tripleurospermum inodorum* (24% of segments). Only the first mentioned species is dominant in forest edges and openings. The most significant and highly aggressive invasive neophyte in the area is *Aster lanceolatus,* whose presence in nearly 95% of segments and frequent dominance in younger and older stands of the floodplain forest presents a problem with almost no solution any more (Řepka & Maděra 2009a). The other abundant invasive neophytes in the area are *Impatiens parviflora, Bidens frondosa, Erigeron annuus, Solidago gigantea, Conyza canadensis, Rudbeckia laciniata, Helianthus tuberosus, Impatiens glandulifera* and species of genus *Amaranthus.* These species usually grow in clearings and newly established cultures and only the first two mentioned ones penetrate into forest communities.

Table 7: The presence of adventive herb species in segments
(according to Pyšek et al. 2002)

Species	number of segments	proportion of segments	adventive species category	
Avena sativa	3	0.39	cas	ar
Panicum miliaceum	2	0.26	cas	ar
Brassica napus	1	0.13	cas	ar
Cannabis sativa	1	0.13	cas	ar
Hordeum distichon	1	0.13	cas	ar
Cirsium arvense	512	66.49	inv	ar
Plantago major	308	40.00	inv	ar
Tanacetum vulgare	284	36.88	inv	ar
Cirsium vulgare	239	31.04	inv	ar
Tripleurospermum inodorum	188	24.42	inv	ar
Ballota nigra	51	6.62	inv	ar
Viola odorata	35	4.55	inv	ar
Melilotus alba	19	2.47	inv	ar
Melilotus officinalis	13	1.69	inv	ar
Atriplex sagittata	5	0.65	inv	ar
Chenopodium pedunculare	5	0.65	inv	ar
Bryonia alba	2	0.26	inv	ar
Conium maculatum	2	0.26	inv	ar
Atriplex oblongifolia	1	0.13	inv	ar
Cardaria draba	1	0.13	inv	ar
Arctium lappa	573	74.42	nat	ar
Carduus crispus	429	55.71	nat	ar
Lapsana communis	351	45.58	nat	ar
Bromus sterilis	170	22.08	nat	ar
Echinochloa crus-galli	139	18.05	nat	ar
Lactuca serriola	132	17.14	nat	ar
Polygonum aviculare	118	15.32	nat	ar
Chenopodium polyspermum	102	13.25	nat	ar
Mentha arvensis	89	11.56	nat	ar
Sonchus asper	84	10.91	nat	ar
Atriplex patula	79	10.26	nat	ar
Pastinaca sativa	77	10.00	nat	ar
Chelidonium majus	74	9.61	nat	ar
Capsella bursa-pastoris	73	9.48	nat	ar
Sonchus arvensis	67	8.70	nat	ar
Setaria pumila	66	8.57	nat	ar

Species	number of segments	proportion of segments	adventive species category	
Medicago lupulina	62	8.05	nat	ar
Lamium album	58	7.53	nat	ar
Cichorium intybus	57	7.40	nat	ar
Lamium purpureum	50	6.49	nat	ar
Silene latifolia	47	6.10	nat	ar
Fallopia convolvulus	44	5.71	nat	ar
Bromus tectorum	43	5.58	nat	ar
Vicia hirsuta	42	5.45	nat	ar
Sonchus oleraceus	36	4.68	nat	ar
Bromus hordeaceus	31	4.03	nat	ar
Portulaca oleracea	27	3.51	nat	ar
Solanum nigrum	24	3.12	nat	ar
Convolvulus arvensis	23	2.99	nat	ar
Carduus acanthoides	22	2.86	nat	ar
Setaria viridis	22	2.86	nat	ar
Crepis biennis	20	2.60	nat	ar
Bromus commutatus	19	2.47	nat	ar
Linaria vulgaris	18	2.34	nat	ar
Vicia angustifolia	17	2.21	nat	ar
Arctium tomentosum	14	1.82	nat	ar
Sambucus ebulus	12	1.56	nat	ar
Erysimum cheiranthoides	10	1.30	nat	ar
Geranium pusillum	10	1.30	nat	ar
Setaria verticillata	10	1.30	nat	ar
Veronica arvensis	10	1.30	nat	ar
Digitaria sanguinalis	9	1.17	nat	ar
Senecio vulgaris	9	1.17	nat	ar
Verbena officinalis	9	1.17	nat	ar
Crepis capillaris	7	0.91	nat	ar
Tragopogon dubius	6	0.78	nat	ar
Leonurus cardiaca	5	0.65	nat	ar
Armoracia rusticana	4	0.52	nat	ar
Saponaria officinalis	4	0.52	nat	ar
Bromus japonicus	3	0.39	nat	ar
Eragrostis minor	3	0.39	nat	ar
Hordeum murinum	3	0.39	nat	ar
Myosotis arvensis	3	0.39	nat	ar
Synapis arvensis	3	0.39	nat	ar
Vicia villosa	3	0.39	nat	ar
Descurainia sophia	2	0.26	nat	ar
Lathyrus tuberosus	2	0.26	nat	ar
Thlaspi arvense	2	0.26	nat	ar
Vicia sativa	2	0.26	nat	ar
Vicia villosa subsp. varia	2	0.26	nat	ar
Arctium lappa x tomentosum	1	0.13	nat	ar
Avena fatua	1	0.13	nat	ar
Berteroa incana	1	0.13	nat	ar
Crepis tectorum	1	0.13	nat	ar
Cynodon dactylon	1	0.13	nat	ar
Euphorbia peplus	1	0.13	nat	ar
Malva neglecta	1	0.13	nat	ar
Nepeta cataria	1	0.13	nat	ar

Species	number of segments	proportion of segments	adventive species category	
Papaver rhoeas	1	0.13	nat	ar
Parietaria officinalis	1	0.13	nat	ar
Physalis alkekengi	1	0.13	nat	ar
Sagittaria latifolia	6	0.78	cas	neo
Bromus carinatus	2	0.26	cas	neo
Crepis foetida	1	0.13	cas	neo
Helianthus annuus	1	0.13	cas	neo
Zea mays	1	0.13	cas	neo
Aster lanceolatus	731	94.94	inv	neo
Impatiens parviflora	274	35.58	inv	neo
Bidens frondosa	267	34.68	inv	neo
Conyza canadensis	174	22.60	inv	neo
Solidago gigantea	168	21.82	inv	neo
Rudbeckia laciniata	80	10.39	inv	neo
Helianthus tuberosus	66	8.57	inv	neo
Impatiens glandulifera	63	8.18	inv	neo
Arrhenatherum elatius	60	7.79	inv	neo
Amaranthus retroflexus	44	5.71	inv	neo
Amaranthus powellii	30	3.90	inv	neo
Solidago canadensis	27	3.51	inv	neo
Epilobium ciliatum	22	2.86	inv	neo
Echinocystis lobata	14	1.82	inv	neo
Reynoutria japonica	6	0.78	inv	neo
Galinsoga parviflora	3	0.39	inv	neo
Juncus tenuis	3	0.39	inv	neo
Geranium pyrenaicum	2	0.26	inv	neo
Matricaria discoidea	2	0.26	inv	neo
Rumex thyrsiflorus	2	0.26	inv	neo
Aster novi-belgii	1	0.13	inv	neo
Galinsoga quadriradiata	1	0.13	inv	neo
Oenothera biennis	1	0.13	inv	neo
Reynoutria sachalinensis	1	0.13	inv	neo
Veronica persica	1	0.13	inv	neo
Erigeron annuus	255	33.12	nat	neo
Oxalis fontana	141	18.31	nat	neo
Trifolium hybridum	129	16.75	nat	neo
Galega officinalis	20	2.60	nat	neo
Chenopodium strictum	14	1.82	nat	neo
Datura stramonium	7	0.91	nat	neo
Xanthium albinum	6	0.78	nat	neo
Agrostis gigantea	4	0.52	nat	neo
Medicago sativa	4	0.52	nat	neo
Amaranthus albus	2	0.26	nat	neo
Asclepias syriaca	2	0.26	nat	neo
Sisymbrium strictissimum	2	0.26	nat	neo
Acorus calamus	1	0.13	nat	neo
Erechtites hieraciifolia	1	0.13	nat	neo
Oxalis corniculata	1	0.13	nat	neo
Oxalis dillenii	1	0.13	nat	neo

As regards specially protected and threatened species, there are 98 of them in the area (Table 8). 21 species within the total number of 137 records in the segments are protected by law. Floodplain forests are very significant biotopes for species such as *Leucojum aestivum* (37 of segments), *Euphorbia palustris* (29), *Carex strigosa* (241), *Carex divulsa* (47), *Cardamine dentata* (123) and *Carex riparia* (626). Other species, indicating heavy-textured soils with varying humidity or subhalophilous, occur mainly in floodplain meadows and edges or clearings within forests – *Viola elatior, Scutellaria hastifolia, Carex melanostachya, Gratiola officinalis, Teucrium scordium, Lathyrus palustris, Pulicaria dysenterica, Leonurus marubiastrum, Lycopus exaltatus, Sonchus palustris, Lythrum virgatum, Sonchus palustris, Cnidium dubium, Silaum silaus, Trifolium fragiferum, Inula salicina,* and *Galium boreale*. Marshlands, water streams and their edges are important biotopes for species such as *Juncus atratus, Cardamine parviflora, Ceratophyllum submersum, Hottonia palustris, Sium latifolium, Potamogeton nodosus, Hydrocharis morsus-ranae, Najas marina, Butomus umbellatus, Cardamine matthioli, Leersia oryzoides, Scrophularia umbrosa* or *Veronica scutellata, Carex buekii*. Elevated sandy dunes contain species such as *Scilla drunensis, Galanthus nivalis, Equisetum ramosissimum*.

Table 8: The presence of threatened herb species

Species	threat category	number of segments
Leucojum aestivum	§1, C1	37
Cardamine parviflora	§1, C1	5
Viola elatior	§1, C1	3
Euphorbia lucida	§1, C1	1
Juncus atratus	§1, C1	1
Lathyrus palustris	§1, C2	1
Euphorbia palustris	§2, C2	29
Thalictrum flavum	§2, C2	11
Senecio sarracenicus	§2, C2	8
Scutellaria hastifolia	§2, C2	7
Gratiola officinalis	§2, C2	6
Allium angulosum	§2, C2	5
Carex melanostachya	§2, C2	2
Ceratophyllum submersum	§2, C1	1
Scilla drunensis	§2, C2	1
Teucrium scordium	§2, C2	1
Viola pumila	§2, C2	1
Epipactis albensis	§2, C2	1
Hottonia palustris	§3, C3	8
Galanthus nivalis	§3, C3	7
Equisetum ramosissimum	§3, C3	1
Pulicaria dysenterica	C1	12
Ranunculus sardous	C1	2
Carex strigosa	C2	241
Cardamine dentata	C2	123
Odontites verna	C2	89
Leonurus marrubiastrum	C2	64
Carex divulsa	C2	47

Species	threat category	number of segments
Bromus commutatus	C2	19
Sium latifolium	C2	12
Althaea officinalis	C2	6
Cerastium dubium	C2	6
Potamogeton nodosus	C2	5
Hydrocharis morsus-ranae	C2	4
Lycopus exaltatus	C2	4
Sonchus palustris	C2	3
Cnidium dubium	C2	3
Dipsacus laciniatus	C2	2
Centaurium pulchellum	C2	1
Lythrum virgatum	C2	1
Najas marina	C2	1
Parietaria officinalis	C2	1
Lotus tenuis	C3	47
Silaum silaus	C3	36
Pseudolysimachion longifolium	C3	33
Trifolium fragiferum	C3	22
Verbascum blattaria	C3	16
Butomus umbellatus	C3	13
Virga pilosa	C3	12
Verbena officinalis	C3	9
Corydalis pumila	C3	8
Leersia oryzoides	C3	5
Scrophularia umbrosa	C3	5
Cardamine matthioli	C3	4
Carex curvata	C3	2
Lathyrus latifolius	C3	2
Agrimonia procera	C3	1
Cyperus fuscus	C3	1
Lactuca quercina	C3	1
Myosurus minimus	C3	1
Potamogeton lucens	C3	1
Thalictrum lucidum	C3	1
Carex riparia	C4a	626
Senecio erraticus	C4a	154
Aethusa cynapioides	C4a	100
Cerastium lucorum	C4a	69
Cucubalus baccifer	C4a	65
Carex buekii	C4a	59
Epipactis helleborine	C4a	27
Veronica montana	C4a	27
Arum cylindraceum	C4a	17
Vicia dumetorum	C4a	13
Veronica scutellata	C4a	10
Verbascum austriacum	C4a	9
Carex disticha	C4a	8

Species	threat category	number of segments
Serratula tinctoria	C4a	6
Galium boreale	C4a	5
Myosotis sparsiflora	C4a	5
Barbarea stricta	C4a	4
Melica transsilvanica	C4a	4
Bromus japonicus	C4a	3
Carex otrubae	C4a	3
Carex pseudocyperus	C4a	3
Centaurium erythraea	C4a	3
Lemna trisulca	C4a	3
Schoenoplectus lacustris	C4a	3
Inula salicina	C4a	2
Atriplex oblongifolia	C4a	1
Corydalis intermedia	C4a	1
Cynodon dactylon	C4a	1
Elytrigia intermedia	C4a	1
Kohlrauschia prolifera	C4a	1
Lavatera thuringiaca	C4a	1
Potentilla arenaria	C4a	1
Veronica verna	C4a	1
Carex chabertii	C4b	21
Xanthium albinum	C4b	6
Cerastium pumilum	C4b	2

DISCUSSION

Professional literature seldom provides results of a full-area inventory of floodplain forests. Trinajstič et al. (2005) present the richness of flora in floodplain forests of northern Croatia with a number of 437 species. Although our study area lies in the northern part of the Pannonian Basin, the total number of found species is higher than in its southern part, i.e. the species diversity of lowland floodplain forests of northern Croatia (612 versus 437 species of vascular plants). Other data come from geographically distant areas: Lyon and Sagers (1998) found 65 families in the floodplain of the Current and Jacks Fork Rivers, North America, and in agreement with our results they ascertained low fidelity of the found species – only fidelity of 42 species out of the 269 recorded ones was over 10%. Tabacchi et al. (1996) found 1,396 plant species along the entire corridor of the Adour River (SW France), which accounts for a fifth of the flora of France. The species diversity of south-Moravian floodplain forests we established also corresponds to about a fifth of the flora of the Czech Republic. The highest biodiversity was found by Pott et al. (2011) in the tropical South American Pantanal wetland, where nearly 2,000 species were recorded in an area of over 150,000 km^2 in various types of vegetation. The study of Schnitzler et al. (2007) summarised available articles focused on the diversity of riparian forests across the whole of Europe and recorded 1,380 species. Even these sparse data testify to the considerable significance of floodplain forests for the maintenance of diversity of vascular plants.

Most authors examine the species diversity of floodplain forests using sample plots, not full-area terrain surveys, and thus they naturally reach lower numbers than we have recorded. Ernault et al. (2006) found 334 species of plants in twenty plots of the Seine floodplain forests, each having an area of 1 km^2. Goebel et al. (2006) used 417 plots of 1 m^2 in size and determined 162 species of plants in various river systems in NE Wisconsin. Mölder et al. (2011) explored the diversity of flora along the Danube River and found 165 species of higher plants, including 22 graminoids (13%), 100 forbs (61%) and 43 woody species (26%). Only woody plants were examined by Santos (2010). She recorded 53 species, out of which 28 were endemic, in 70 river plots of 2 km in length on the Sado and Guadiana watersheds in southern Portugal. Paal et al. (2007) studied the floodplain forests in Estonia in 79 subnatural stands. The ground vegetation was described using randomly located sample quadrats of 1 x 1 m; their number was 15–20 per stand. The total species list included 372 plant species: 17 species in the tree layer, 17 in the shrub layer, 225 in the herb layer and 100 species in the moss layer. A total of 269 herb and 70 tree species were identified on 94 sample plots by Lyon and Sagers (1998), within the Ozark National Scenic Riverways (ONSR), a forest corridor enclosing a 161 km stretch of the Current River and a 55 km stretch of the Jacks Fork River in southwest Missouri, USA. Similarly, McLane et al. (2012) recorded 193 plant species within the Cypress Creek NWR, Illinois, U.S.A., out of which 56 were woody plants, in 80 plots of 1 m^2. Archaux et al (2010) sampled vascular flora in 181 poplar plantations along the Seine and Aube rivers within plots of 200 m^2 in area. They recorded 211 plant species (32 forest species, 40 tall herbs and 48 meadow plants, 38 ruderal species, 53 other species – aquatic, generalist, field plants). Schnitzler (1997) showed 106–157 plant species (incl. 37–56 woody species) from the Ill, Rhine, Loire and Allier floodplains, Trémolieres et al. (1998) presented only 37 woody species in the Rhine floodplain, but these were bound to the communities of alluvial hardwood forests. Godreau et. al. (1999) in their study from the Saone floodplain mentioned 104 plant species in riverine wetlands, 208 plant species in grasslands, unfortunately the number of forest species is not given.

High native plant diversity in riparian biotopes is largely associated with natural disturbance, particularly flooding and scour by seasonal and storm related flood pulses, which create regeneration microsites and mediate resource competition among species (Naiman & Decamps 1997; Naiman et al. 1993, 2005). Frequent natural or anthropogenic disturbances, however, can also create conditions conducive to alien plant establishment (De Ferrari & Naiman 1994; Pyšek & Prach 1994; Planty-Tabacchi et al. 1996; Pyle 1995; Stohlgren et al. 1998).

We found 170 adventive species in the study area, it is 26% of all vascular plants creating the floodplain forest communities. Williams (2010) described forty alien plant species (17.8% of the total surveyed flora) from 42 survey sites across the seven islands of the Allegheny River Islands Wilderness (northwestern Pennsylvania). Košir et al. (2013) presented up to 15% proportion of neophytes in phytocoenological plots along the Mura River (NE Slovenia). Schnitzler et al. (2007) summarised 1,380 species across European riparian forests, 45 (3.3%) of these were exotic species. Many exotics found in their study were introduced intentionally either from North America (51%) or Asia (38%). The exotics belong to various life-forms: approximately 50% are grasses (polycarpic perennials, summer and autumn annuals), while the rest are phanerophytes, equally distributed among trees, shrubs and liana life-forms. Most of the exotics are thermophilous and light-demanding pioneer species from warm temperate floodplains. Thirty-two percent are from the *Asteraceae* family. The distribution of exotics in the 177 communities recorded is highly unequal. Twenty-six are present at low levels in very few communities; seven have an intermediate distribution; and twelve (27%) are abundant in a large range of habitats (in compliance with our results there are for example *Impatiens parviflora*, *Erigeron* *canadensis* or *Solidago gigantea*). McLane et al. (2012) recorded a 14.4% proportion of exotic species in the basin of the Cypress Creek NWR, Illinois, U.S.A., and Uowolo et al. (2005) even higher – 30% proportion of exotic species – along the Yampa and Green rivers (northwest Colorado, USA). Concerning neophytes, the Upper Danube flora yielded five species (7%), the Middle Danube Flora nine species (14%) and the Lower Danube Flora eight species (10%). The most important non-native tree species were *Fraxinus pennsylvanica* (Middle and Lower Danube), *Acer negundo* (Middle Danube) and *Robinia pseudoacacia* (Upper Danube), which reached considerable proportions in the tree layer. Frequent non-native herb species were *Impatiens parviflora* and *Solidago gigantea* (Upper and Middle Danube), *Aster parviflorus*, *Oxalis stricta* (Middle Danube) and *Aster lanceolatus* (Lower Danube). The invasive shrub species *Amorpha fruticosa* was very common on the Lower Danube (Mölder & Schneider 2011). Also Chmura & Sierka (2006) in their study of Polish floodplain forests consider *Impatiens parviflora* to be a significant invasive species. Magee et al. (2008) evaluated the importance of alien species in the existing vegetation along wadeable streams of a large, topographically diverse river basin in eastern Oregon, USA; they identified 60 alien species and 355 native species. Alien species occurred in 93% of sample plots, in all community types, and along all sampled stream reaches, with relative alien cover (RAC) ranging from 0.1% to 47% and 1 to 24 alien species occurring along individual stream reaches. RAC differed among community types: it was the greatest in arid associations (shrubland/grassland), followed by associations with limited tree canopy cover (meadows, dry forest), and the lowest in moist, closed forest associations.

Floodplains are considered vulnerable to exotic species (Hood & Naiman 2000; Harris et al. 2005), due to the combined influence of intensive human exploitation, a high degree of hydrological connectivity that facilitates propagule dispersal and the high spatial and temporal heterogeneity inherent to these systems. Globally, anthropogenic alterations to floodplain hydrological regimes have frequently resulted in riparian species invasions (Richardson et al. 2007). Vegetation changes are partially structured by reduced flood frequency favouring increased abundance of exotic, sexually reproducing annuals at drier sites. Sites of low flood frequency are more sensitive to future exotic weed invasion. Flow restoration is predicted to benefit propagule dispersal of species adopting dual regeneration strategies, which are predominantly natives in this system (Stokes et al. 2010). The invasion by alien plant species is a major challenge to the conservation and management of riparian areas, which can alter ecosystem structure and function in undesirable ways (Hood & Naiman 2000; Stohlgren et al. 1998). The invasive species capable of becoming dominant are the most dangerous, and in the study area it is *Aster lanceolatus* (Řepka et al. 2009). Brewer (2010) described a similar example: a significant negative effect of species richness on invasive grass *M. vimineum* abundance. Altogether, his results suggest that the same factors that reduce biotic resistance have even greater direct positive effects on the abundance of invasive grass and native floodplain specialists. According to investigation of Saccone et al. (2010), *Acer negundo* showed both a high survival in the shade and a high growth in full light. This species could be an example of adaptive plasticity that certainly represents a competitive advantage over native species. Another example is mentioned by Hanula & Horn (2011); they investigated the effects of the invasive shrub Chinese privet (*Ligustrum sinense*) and two methods (mulching or hand-felling) of removing it from riparian forests on butterfly communities. Pyšek & Prach (1993) named four significant invasive species in riparian habitats of central Europe: *Impatients glandulifera*, *Heracleum mantegazzianum*, *Reynoutria japonica* and *R. sachalinensis*; none of these has caused a significant problem in the study area.

Technical regulations of the water regime within floodplains can also impact on the species diversity of floodplain forests. For example, Trémoliéres et al. (1998) compared various sections of an alluvial hardwood forest along the Rhine. Using six plots of about 2,000 m^2, they found 63 species (25 woody species) in a flooded floodplain, 121 species (45 woody species) in a floodplain that had not been flooded for 30 years, and 95 species (47 woody species) in a floodplain not flooded for 130 years. Deiller et al. (2001) mentioned that the species richness of the extant vegetation increases with the duration of interruption of the floods in the Rhine forest as a result of introduction of flood-intolerant species in the unflooded forest. By contrast, Uowolo et al. (2005) recorded a 40% higher number of species in unregulated floodplain of the Yampa river in contrast to the regulated Green River. Other authors also document the changes in species composition and spatial structure of the synusia of floodplain forest herb layer (Vašíček 1985, Vrška 1997, 1998, Maděra 2001a, 2001b; Viewegh 2002, Unar & Šamonil 2008, Santos 2010) or in the tree layer (Schnitzler 1994; Trémoliéres et al. 1998; Janík et al. 2008, 2011) in dependence on drying of floodplain forests, when flood-intolerant and mesic species can arrive.

Much fewer studies deal with threatened species in floodplains. De Nooij (2006) presented 136 threatened species of vascular plants related to occurrence in river floodplains in Holland. Godreau et al. (1999) found 31 regionally threatened plant species in all biotopes (wetlands, grasslands) in the Saone floodplain; surprisingly, in floodplain forests none such species was found. Similarly, a study by Oťahelová et al. (1992, 1997) mentioned 129 rare or threatened plant and moss species in the Slovakian part of the Morava river polder. Based on their results, the biotope of floodplain forest is insignificant for the threatened species, comprising only 4% of found species. Floodplain meadows, water biotopes, wetlands, acid sands, bare bottoms and even anthropogenic biotopes (dams, road edges, fallows) are more significant as they contain more threatened species. However, our results show that the floodplain forests are significant biotopes for threatened species – we have recorded a total of 113, which is 19.46% of all species. This discrepancy can be perhaps explained by the insufficiently consistent approach of the florists to the full-area forest inventory as the orientation in them is difficult and demanding. A lot of species occur in forests only rarely and they need not be discovered unless the forest is scoured thoroughly.

CONCLUSIONS

From the perspective of species diversity of vascular plants, floodplain forests in the Tvrdonice forest district are a highly valuable area containing many threatened species. However, there is a high proportion of adventive species. The most significant of them is *Aster lanceolatus*, which poses a serious problem due to its presence in nearly 95% of segments as well as its ability to create dominant stands considerably reducing the species diversity.

The high number of adventive species and their relatively high occurrence are caused by a number of factors. The most significant of them are the used ways of stand regeneration with the broadcast soil preparation - agroforestry in history and in more recent decades ploughing, raking of the soil profile with stumps into mounds, or milling (Řepka, Maděra 2009b). The primary vector for the spread of these species is the river and its flooding system; however, stand fragmentation (Dynesius & Nilsson 1994) and their connection by forest roads, clearings, and canals also played their role after the regulation of the Morava river and elimination of regular floods (Penka et al. 1991, Horák 1964).

The full-area floristic inventory provides unique results. It expands our knowledge about the significance of floodplain forests for biodiversity and enables us to create maps of occurrence of particular species, places with high diversity and places with the troublesome occurrence of adventive species. These geographic models can be well used for the management of forest stands or the zonation of Dolní Morava Biosphere Reserve.

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