

**HISTORICAL RECONSTRUCTION OF EXPANSION OF NON-NATIVE
PLANTS IN THE NITRA RIVER BASIN (SW SLOVAKIA)**

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Mariánska 10, SK-949 01 Nitra, Slovak Republic***Abstract****FEHÉR, A. (2007): Historical reconstruction of expansion of non-native plants in the Nitra River Basin (SW Slovakia). - Kanitzia 15: 47-62.**

Non-native alien species have been expanding in the Nitra catchment area since the Early Neolithic and Eneolithic. Species composition, space structure and physiognomy of the riparian plant communities have been changing on the river-banks in consequence of plant invasions. Two main periods of „great plant expansions” have been distinguished in this paper: the archeophytic period (before 1500 A.D.: expansion of aliens in man-made habitats, semi-natural phytocoenoses and new clayey river banks) and the neophytic period (after 1500 A.D.: new non-native species from Asia and America in new habitats created by river and channel regulations). Many models of biological invasion (dispersion or diffusion models) do not consider the environmental changes induced by man in different time horizons. We propose to include the man-made changes both qualitatively and quantitatively.

Key words: archeophytes, expansion, historical reconstruction, invasive species, neophytes, Nitra River, non-native plants, Slovakia

Introduction

„Movement of biota” is a natural dispersion process (cf. MOONEY, DRAKE 1987 etc.). At the present various linear R-D models („reaction-diffusion models”, e.g. HASTINGS 1996), SEIBS models („spatially explicit, individual-based simulation”), their integrated modifications (HIGGINS et al. 1996) or statistical methods (WILLIAMSON, FITTER 1996) are most often used to model the spatial expansion of invasive species. The non-linear character of the invasion process has been taken into account in models containing dispersion elements both for short and long distances (the so called „stratified diffusion”) (SHIGESADA et al. 1995, SHIGESADA, KAWASAKI 1997). The absence of deterministic predictability is modelled by the chaos theory which is on the other hand hardly applicable in practice. In the process of biological invasions a small parameter change can lead to a sudden and dramatic change both quantitative and qualitative. Invasive behaviour is apparently not the result of some common properties of invasive species, but it is the result of a coincidence between the properties of a species and the environmental conditions (CRAWLEY 1997). Plant invasiveness is neither a life form nor a taxonomic issue, but a set of properties of species enabling growth in certain habitats. Even though the environmental conditions have been changing in time and space, many ecological models do not take into account such changes and are oriented at invasive species in an invariable (!), (almost) homogeneous habitat.

Differences in the successfulness of various strategists are also quite significant (GRIME 1977, 1979), only few introduced species invade successively advanced plant communities. A great importance can be ascribed to the landscape fragmentation that makes the penetration of invasive plant species into a phytocenosis easier and accelerates the extinction of native species (SUAREZ et al. 1998, CUI, CHEN 1999 etc.). Habitats affected (or degraded) and fragmented by man's activity were, beginning with the Neolithic, often invaded by apophytes and archeophytes and over some past 500 years also by neophytes. These phytocenoses changed their original structure (floristic composition, trophic relations, energy flow), physiognomy, seasonal dynamics, etc. Also the dynamics of the environmental sources exploitation along the ecological gradient is being changed, some theories even say that the spirit of invasions rests just in fluctuation of the environment sources (DAVIS et al. 2000).

Rivers are very important in spreading of non-native plants (cf. PYŠEK, PRACH 1993, 1994, BALOGH et al. 1994 etc.) and there are only few papers that includes history of biological invasions (e.g. KOVÁCS 2006). In this paper „invasive” plants are alien species the distribution and/or abundance whose in the wild is increasing regardless of habitat (terminology cf. PYŠEK 1995). Archeophytes are species introduced before 1500 (or 1492) and neophytes are naturalized aliens introduced since 1500. Expanding native species (apophytes) are not included in our paper. The author wanted to point to the dynamics of plant invasions within the changing environmental conditions, especially as the consequence of human activity in the selected area. The Nitra River Basin is a good model area (FEHÉR, KONÉKOVÁ 2005a, 2005b), having a rich history and it has been settled by man from the Paleolithic.

Material and methods

Characteristics of the studied area

The Nitra River springs from the southern slopes of the Malá Fatra mountains (in the Western Carpathians). At present its redirected main course mouths into the Váh River at Komona. The area of its basin is 5.144 km², the length of main flow is 196,7 km. The catchment its area belongs to the European continental climatic area of the temperate zone. Along with the west ocean air circulation there is also a south air circulation from the Mediterranean. Following the climatic classification, the territory of the Nitra River Basin can be divided into three regions: a) cold region with July temperatures of 12-16 °C, b) moderately warm region spread on mountain hillsides up to about 800 m above the sea level and c) warm region with 50 summer days in a year and maximum temperatures above 25 °C. On the mountain ranges rainfalls are quite frequent (up to 800 mm per year), in the plain part of the catchment area rainfalls are least (540-600 mm). Upstream the rocky and high plains are on calciferous substrate with rendzinas, singly with beech and oak forests and semi-natural grasslands. In the central section there are proluvial uplands having loess and clay with illimerized soils and oak-hornbeam forests while at the downstream there are fluvial lowlands with hydromorphous soils and fragments of hygrophilous vegetation (agricultural landscape with intensive land use). Along the stream there are young aggradation embankments and alluvial forests and secondary meadows.

The flora of the upstream belongs to the West Carpathian flora region (Carpatum occidentale) namely to its two zones: the high-Carpathian flora zone (Eucarpa-

ticum: Malá Fatra) and the Pre-Carpathian flora (Praecarpaticum: Stráovské and Súovské vrchy, Vtánik, Tribe). The longest section belongs to the region of the Pannonian flora - Pannonicum, more nearly to the zone of Eupannonian xerothermic flora - Eupannonicum (The Danube lowland). At the present time alders (*Alnus* spp.), willows (*Salix* spp.) and poplars (*Populus* spp.) grow within the riparian habitats. From the original willow-poplar floodplain forests only fragments have been preserved due to the water flow regulations. Below the dominant tree-layer there is a shrub-layer poor in species whose development is dependent partially on the regime of temporary surface floods (*Ulmus laevis*, *Sambucus nigra*, *Rubus caesius* etc.). The coverage of herb species (including ecotones) is usually quite high and often related to the domination of some species with a high rate of propagation: *Phalaroides arundinacea*, *Urtica dioica* etc. Species from contact phytocenoses often infiltrate the riparian plant communities. A high share of sites is occupied by nitrophilous plants especially in places where the tree layer has not been canopied.

Reconstruction of the expansion of non-native plant species

The occurrence of allochthonous species has been reconstructed on the basis of archeobotanical findings, available literature data and on the basis of herbaria [Slovak National Museum in Bratislava (BRA), Department of Botany at the Comenius University in Bratislava (SLO), Botanical Institute of the Slovak Academy of Sciences in Bratislava (SAV), Nitra Regional Museum (NIM), Department of Botany at the Slovak Agricultural University in Nitra (NI), Danubian Region Museum in Komárno (PMK), Natural History Museum in Prague (PR) and the Hungarian Natural History Museum in Budapest (BP)]. The funds of the Upper Nitra Museum in Prievidza (HMP) and the Tribe Museum in Topoňany (TYM) have not been studied from technical reasons. Our evaluation of the species allochthonousness was based on the study of HALADA (1997) and MARHOLD & HINDÁK (1998).

Inventory of the present expansion of invasive plant species

Occurrence of the invasive plants has been studied along the whole length of the Nitra River from 1997 to 2007. The records on the occurrence of invasive species have been made gradually by 1000 m long sections along the main river course when the following data have been recorded: taxon (according to MARHOLD, HINDÁK 1998), locality (geographic and topographic position on maps 1:5.000 and 1:100.000), biotop/habitat (according to RUŽÍKOVÁ et al., 1996), population size and/or abundance of species. Plant species names were adjusted according to MARHOLD & HINDÁK (1998). Slovak and Hungarian geographical names, ahead the Slovak ones.

Settlements:

Bojnice - Bajmóc, Čakajovce - Csekej, Čereňany - Cserenye, Dolné Krškany - Alsókööröskény, Hurbanovo - Ógyalla, Jelšovce - Nyitraegerszeg, Komárno - Komárom, Komjatice - Komját, Komoňa - Kamocsa, Lučianky - Sarlókajsza, Martovce - Martos, Nesvady - Naszvad, Nitra - Nyitra, Nové Zámky - Érsekújvár, Palárikovo - Tótmegyer, Rudno - Rudna, Šurany - Nagysurány, Topoňany - Nagytapolcsány, Tvrdosovce - Tardoskedd, Veľké Ripňany - Nagyrippény, Vráble - Verebely, Výšapy-Opatovce - Vicsápapáti, Zbehy - Üzbég
Rivers: Cetínka - Cétényke, Nitra - Nyitra, Nová Nitra - Új-Nyitra, Stará Nitra - Öreg-Nyitra, Váh - Vág, ťitava - Zsitva

Results and discussion

The archeophytic period - phase 1

According to the geobotanical studies, the upper and central reaches of the Nitra River in the past were accompanied by the elm floodplain woods and montane and sub-montane alder woods of *Ulmenion*, the *Alnenion glutinoso-incanae*, *Salicion elaeagni* and *Salicion triandrae* alliances and sub-alliances, the down reach by willow-poplar floodplain woods of *Salicion albae* and *Salicion triandrae* alliances (MICHALKO et al. 1987). The origin of the so called cultural landscape in Central Europe dates back to the Neolithic (around 5 000 years before our era). The neolithic farmers settled in drier and warmer territories on loess and terrace areas up to 300 m a.s.l. They avoided sloppy locations. In the anthropically affected landscape new ecosystems developed and from natural forests (and climax forest-steppe residues) also woodless replacement plant communities rich in species originated (KRIPPEL 1986, LIPSKÝ 1999, MOLNÁR, KUN 2000 etc.). The riparian habitats have been affected slightly.

In the oldest reports from Central Europe from the mid 5th century before our era, the Greek author Herodotos gives that the Danube had the same flow water level all the year round which proves continuous forest stands in its basin, of course to a certain degree (most probably the alluvium was not deforested so much). Some five hundred years later Strabon writes that the inhabitants of forests along the Danube kept cattle and that was possible only at least under a partial deforestation. It was found, by evaluation of archeobotanical findings (HAJNALOVÁ 1989), that the apophytes and the first non-native plant species (weeds), introduced by man mainly accidentally, expanded in the Nitra River Basin from the Early Neolithic and Eneolithic (starting agriculture) (Tab. 1). The archeophytes were mostly sub-xerothermic hemerophilous species of segetal and ruderal habitats of human settlements and archaic agro-phytocenoses (they were rare on the low and wet river banks). They came mainly from the Pontic areas and expanded together with cultivated crops. The greatest growth in the number of new species was recorded in the Neolithic which was connected with the beginnings of farming (the first occurrence of anthropogenic habitats).

Tab. 1. Occurrence of non-native plant species in the Nitra River Basin from the Neolithic to the 18. century

[archeobotanical database: HAJNALOVÁ 1989 completed by BENKOVÁ et al. 1991, HAJNALOVÁ et al. 1997, HAJNALOVÁ, MIHÁLYIOVÁ 1997, 1998, HAJNALOVÁ et al. 2006; origin of species after HALADA 1997 and MARHOLD, HINDÁK 1998].

Taxon	Origin	LN EN	BR	LAT	ROM NM	6-11	12-18	ND
<i>Agrostemma githago</i>	Ar			X	X	X	X	
<i>Anagallis arvensis</i>	Ar					X	X	
<i>Asperula arvensis</i>	Ar				X	X	X	(X)
<i>Asperula</i> sp.	G	X						
<i>Atriplex sagittata</i>	Ar				X			
<i>Atriplex</i> sp.	A					X	X	
<i>Avena sativa/fatua</i>	B/Ar		X					
<i>Avena sterilis</i>	TA	X						
<i>Avena</i> sp.	G	X			X	X		
<i>Bromus arvensis</i>	Ar	X	X			X		

Bromus secalinus	Ar			X				
Bromus sp.	G	X		X				
Bupleurum rotundifolium	Ar					X	X	
Camelina sativa	Ar				X		X	
Cannabis sativa	B				X			
Chelidonium majus	A?			X	X			(X)
Chenopodium album	A?	X	X	X	X	X	X	(X)
Chenopodium hybridum	A?	X	X	X	X		X	(X)
Chenopodium polyspermum	A?		X		X			
Chenopodium sp.	G	X	X	X	X	X	X	
Cirsium sp.	G	X	X		X			(X)
Convolvulus arvensis	A?						X	
Cuscuta sp.	G						X	
Digitaria ischaemum	A?							(X)
Echinochloa crus-galli	Ar	X	X					
Fallopia convolvulus	Ar	X		X	X	X	X	(X)
Galeopsis tetrahit	A?					X	X	
Galium sp.	G	X		X	X	X	X	(X)
Lapsana communis	A?						X	
Lepidium ruderae	Ar		X					
Lithospermum arvense	Ar			X	X		X	(X)
Lolium temulentum	Ar		X					
Lolium sp.	G		X					
Papaver sp.	G				X		X	
Polycnemum arvense	A?				X			
Polygonum aviculare	A?	X	X		X	X	X	
Polygonum sp.	G				X			
Portulaca oleracea	Ar				X			
Reseda lutea	A					X	X	
Rumex sp.	G	X			X		X	
Salvia sp.	G							(X)
Setaria pumila	Ar						X	
Setaria verticillata/viridis	Ar/Ar	X				X	X	
Setaria viridis	Ar				X			
Setaria sp.	G						X	(X)
Sinapis arvensis	B						X	
Solanum nigrum	A?				X			
Stachys arvensis	A?	X			X			(X)
Stachys sp.	G	X		X	X		X	(X)
Stellaria media	A?					X		
Stellaria sp.	G				X			
Thlaspi arvense	A?			X				
Veronica hederifolia	Ar			X		X	X	(X)
Xanthium sp.	G						X	

Abbrev*): like in Fig. 1 and ND - no date, X - occurrence of species, A - permanently established alien species, A? - possibly alien species, Ar - archeophyte, B - cultivated species occasionally escaping from culture, G - genus including alien species, TA - taxon absent in the checklist of vascular plants in Slovakia after MARHOLD, HINDÁK (1998), but alien after DOSTÁL, ČERVENKA(1991-1992).

*) Further classification for Ar and TA: casAr - casual archeophyte, natAr - naturalized archeophyte, invAr - invasive archeophyte (Lecture note, Balogh)

The archeophytic period - phase 2

Further species appeared in the Bronze Age, La Tène, Roman Age during the period of Migration of Nations and in the Early and Late Middle Ages (Fig. 1). During the late Bronze Age (1250-700 B.C.) new farming technologies started. The field erosion became more intensive and run-off water transporting more materials to the rivers formed a new type of alluvium with sedimented clay (LO EK 1977 etc.). The Celtic material and technology revolution could promote this process and the new wide riparian habitats with clayey soils created conditions for new phytocoenoses. During the Roman Age, and in the period of Migration of Nations new land use measures were developed. Neither the Slavonic period nor the coming of Old Hungarians increased markedly the number of allochthonous species.

In the pre-historical periods alien plants invading riparian phytocoenoses from human settlements and cultivated lands were still rare (tree stands were canopied) and respectively: several nitrophilous herb species of riparian and other natural habitats colonized the new ruderal sites far from the river (*Urtica dioica*, *Galium aparine*, *Arctium lappa*, *Aegopodium podagraria*, *Anthriscus sylvestris* etc.).

The boundaries of the vegetation mosaic or the abundance of some species could be influenced by the so called „Little Climatic Optimum” in 800-1200 A.D., when the temperature was higher with a lower precipitation (e.g. GYULAI 2000, 2001). A lower water level at drier sandy and clayey river banks could create convenient conditions for subxerothermic non-native plants originated from the man-made habitats (ruderalisation of riparian habitats). In this period Nitra and its surroundings were densely settled (Great Moravia, Old Hungary) and an extended direct human impact is supposed (also transfer of ruderal species to new habitats).

In the medieval written documents, e.g. in 1075, large meadows and clear-cut areas are reported to have been used for grazing cattle, horses, sheep and oxen in the wide alluvium of the Nitra and itava rivers („pratis ... latissima enim et longa sunt ad

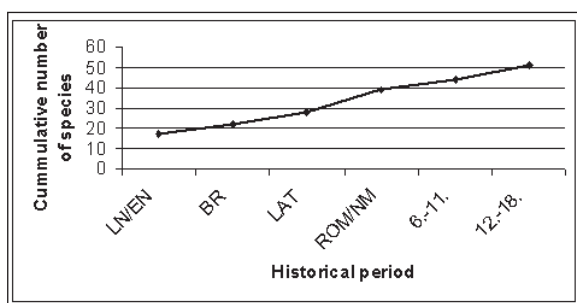


Fig. 1. Cumulative number of non-native plant species (including species with doubtful origin) found in archeobotanical findings in the Nitra River Basin

Abbreviations: LN/EN - Late Neolithic and Eneolithic (4000-1900 B.C.), BR - Bronze Age (1900-700 B.C.), LAT - La Tène (420-0 B.C.), ROM/NM - Roman Age and Nations Migration (0-6. cent. A.D.), 6.-11. - 6.- 11. cent., 12.-18. - 12.-18. cent.

pastum animalium, equiorum, ovium, boum”). Grasslands on the Nitra River banks were mentioned again in 1113 („trans aquam est alter terminus ... factus in prato”). In the same document poplars (*Populus*) and willows (*Salix*) were also given as boundary trees of the property of the Benedictine Monastery in Nitra and also non-identified wood species stand on the bank of the river („dues arbores super aquam”, „terminus fluvius ... sunt arbores”, „iuxta fluvium est arbor” etc.) (MARSINA 1971). Historically preserved is another written document of 1247 men-

tioning willow and poplar stands on the banks of the Nitra River („ad salicem gibbum, hinc ad tres arbores populaes”) (MARSINA 1987). There are many wood species reported in archeobotanical findings (e.g. in the 9.-10. cent. in Čakajovce: *Fraxinus* sp., *Ulmus* sp., *Quercus* sp., *Acer* sp., *Populus* sp. etc., HAJNALOVÁ 1993). Names of alluvial tree species have been preserved as geographical names of settlements near the Nitra River [in 1173 and 1235: Tupulchan - Topo any (Slovak topo = poplar), in 1326: Egurzegh (in Hungarian Egerszeg) - now Jelšovce (Hungarian éger/Slovak jelša = alder) etc.], (KROPILÁK 1977). The hemerophilous (often subxerothermic) herbs from the „Little Climatic Optimum” could be suppressed by the new climatic changes in the Early Medieval Cool Period (1200-1450) (but maintained by human activities, e.g. deforestation, higher farming level, grazing etc.). The open grasslands expanded and the „road-side” species increased their area (e.g. *Plantago lanceolatus*, cf. JANKOVSKÁ 1996). The disturbed riparian sites with rich soils could be settled by plant communities (or facies) including archeophytes (and apophytes like *Persicaria* spp., *Rumex* spp., *Atriplex prostrata*, *Alliaria petiolata*, *Chelidonium majus*, *Geum urbanum* etc.), e.g. *Lamio albi-Chenopodietalia boni-henrici* Kopecký 1969 (*Galio-Urticetea* Passarge ex Kopecký 1969) or *Bidentetalia tripartiti* Br.-Bl. et R. Tx. ex Klika et Hada 1994 (*Bidentetea tripartiti* R. Tx. et al. in R. Tx. ex von Rochow 1951). The historical documents gave the first reports about the channel regulations (mill channels, property boundaries etc.), e.g. in Výapy-Opatovce in 1433 (MOL DL12454) or in Rudno in 1496 (MOL DL95726).

The neophytic period - phase 1

The new expansion of non-native plant species is connected with new geographical discoveries (1492: America), transportation (mobilities), the changes in riparian plant communities related to the regulation of channels (new uncovered, deforested areas, locally artificial and drier river banks!), and/or intense creation and exploitation of existing alluvial meadows. The existing dikes were maintained by the local people, e.g. in Nové Zámky and Zbehy in 1571 (MOL UC 43:3a). In the 17-18th century there were extended meadows in the Nitra River Basin (e.g. the annual hay production in Čereňany was 54 carts in 1671, MOL UC 87:80) and the wet meadows were proposed to be drained (e.g. in 1787, PANKL, BERNOLÁK 1964). In the 18-19th century the downstream of the Nitra River was slow, transported clay and fine gravel, flooded big areas and its wide alluvium was covered by marsh, reed and meadows (e.g. in Nesvady, Hurbanovo, Martovce, FÉNYES 1994, BÉL 1996). The first „big” regulations of the Nitra River channel were done at the beginning of the 18th century at the so called Sihot' in Nitra (GERGELYI 1969), but up until the 19th century no major interventions into the river network were made. In 1851 the first co-operative against the flood was established on the left bank of the river Váh including a part of the Nitra River (KOŠOVAN 1967, 1975). The left, less important branch of the Nitra River called Cetínka in the 60-ies of the 19th century „became overgrown with reed” (NAGY 1864). The increased flows in spring months and sudden thaws of ice caused inundation of wide alluviums of the Nitra still in the mid of the 19th century (for instance in 1863, 1868). Millers, in order to have enough water, used to build water-gates (along the section from Dolné Krškany up to the confluence with the Váh there were 11 mills). In 1868 a part of the Nitra downstream channel was cleaned „from sludge, reed and mainly from tree and shrub roots”, trees were removed in concave

to a distance of about 3 m, on the convex about 2 m from the waterside together with roots (KOŠOVAN 1967). The deforestation created new sites for nitrophilous tall-herb communities with possible occurrence of alien plants. The alkali habitats (salt marshes and steppes) expanded after the hydro-ameliorations and the largest area they covered was reached in the 19th century (e.g. in Šurany, Komjatice, Tvrdošovce, FEHÉR 2007).

The first (riparian) neophytes were introduced mainly from the North America (weeds and escaping cultivated plants) and Asia (e.g. ornamental plants, also c.f. influence of the Turkish invasion, PINKE, PÁL 2005). During the evaluation of floristic records from the mid of the 19th century (SCHILLER 1863, 1864) it has been found that the representation of the non-native species in riparian associations was at that time 12,5 %, and on sandy terraces the alien species represented even 26% proportion, apparently as a result of regular but natural disturbances. In flooded forests there were less exotic plant species (10%, but the invasive neophytes were completely missing) and on floodplain meadows there were by 6 % more of them.

KNAPP (1865) in his work gave the first „complete” list of plant species within the Nitra District (Tab. 2). He, as the first, points to the occurrence of invasive neophytes *Aster x salignus* (locality Bojnice) and *Oenothera biennis* agg. (locality Ve ké Ripňany). This last species from the subject-matter territory was also pointed to a year later by SCHILLER (1866). In the mid of the 19th century in the Komárno District, to which also the Nitra downstream belonged (FÉNYES 1994), the non-native species were represented especially on ruderal sites (*Chenopodium ambrosioides*, *Datura stramonium*, *Xanthium spinosum*, *Xanthium strumarium* i.). In the forests of the southern Komárno District already the East Asian species *Ailanthus altissima* could already be recorded.

In the catchment area of the Nitra River large areas were observed which could not be worked because of the high ground water level. Within the years 1895-1897, 71 km of dikes were built on the downstream of the Nitra (KOŠOVAN 1967, 1975). These changes created new space for invasive species. The canopied woodlands were gradually cut or fragmented and new nitrophilous tall herb riparian phytocoenoses were developed (or extended).

From the end of the 19th century a floristic characteristic of the historical Nitra District has been preserved (PANTOCSEK 1898). This region is partially identical with the catchment area of the middle stream of the Nitra River. The proportion of exotic species on ruderal sites reached even 49,5%. Along the water flows of the Nitra District (e.g. along the Váh River) the proportion of the native and non-native species was different: the alien species formed „only” 39% of the overall number of the found out species, including subxerothermic species as result of man`s impact on riparian habitats (Tab. 3). From the North American neophytes only one species was observed: *Solidago canadensis* (at the Váh River). On sand and gravel river terraces (where the natural disturbances were regular) the proportion of alien species was already even 60%. A new habitat type suitable for spreading of neophytes was the railway embankment accompanied by line-vegetation. Along the railway at Nové Zámky and in Palárikovo archeophytes dominated and the list only gives one North American neophyte: *Conyza canadensis* (the proportion of non-native species along the railway was even 67%). *Lycium barbarum* grew on xerothermic sites and *Inula helenium* occurred on meadows. The apophyte *Telekia speciosa* could be found in the forests but the author does not give whether they were original populations or populations introduced from other sites. PANTOCSEK (1898) evaluated

the nativeness of plants and gave these aliens (A - alien, A? - probably alien, P - now-days evaluated as native): *Abutilon theophrasti* (A), *Acorus calamus* (A), *Agrimonia eupatoria* (P), *Althaea pallida* (A?), *Anchusa italica* (P), *Artemisia absinthium* (A?), *Asperugo procumbens* (A?), *Astragalus asper* (P), *Calcitrapa solstitialis* (A), *Chenopodium ambrosioides* (A), *Chenopodium botrys* (A), *Crepis nicaeensis* (A), *Dictamnus albus* (P), *Conyza canadensis* (A), *Euclidium syriacum* (A?), *Euphorbia* sp. div., *Heliotropium europaeum* (A?), *Hyoscyamus niger* (A), *Isatis tinctoria* (A), *Lappula squarrosa* (A?), *Myagrum perfoliatum* (A), *Oenothera biennis* (A), *Orlaya grandiflora* (A?), *Papaver rhoeas* (A), *Pyrethrum parthenium* (A), *Raphanus raphanistrum* (A), *Reseda* sp. (A), *Rubia tinctorum* (A), *Salvia aethiopis* (P), *Solanum nigrum* (A?), *Teucrium scorodonia* (A?), *Trifolium incarnatum* (A).

Tab. 2. Non-native plants or plant species with doubtful origin and their habitat conditions in the Nitra River Basin in the 19. century

(data sources: K - KNAPP 1865 and P - PANTOCSEK 1898)

Species	Habitat
<i>Amaranthus lividus</i>	In vineyards, gardens and ruderal sites (K).
<i>Amaranthus retroflexus</i>	In gardens, fields, fallows and railway embankments (K, P).
<i>Apera spica-venti</i>	In crops (K).
<i>Aster x salignus</i>	In wetland (K).
<i>Avena fatua</i>	In segetal plant communities (P).
<i>Cardaria draba</i>	In ruderal habitats and road-sides (K, P).
<i>Chenopodium ambrosioides</i>	In ruderal and riparian habitats (K, P).
<i>Chenopodium botrys</i>	In xeric habitats (K, P).
<i>Convolvulus arvensis</i>	In segetal plants communities, grasslands and field margins (K, P).
<i>Conyza canadensis</i>	Common in fields, woodlands, ruderal habitats, sandy riparian habitats and railway embankments (K, P).
<i>Cynodon dactylon</i>	Rare in grasslands and settlements, in sand habitats and near railways (K, P).
<i>Datura stramonium</i>	Common in gardens and ruderal sites, rare in the North (K).
<i>Echinops sphaerocephalus</i>	In stony habitats, rare in ecotone of grasslands, fields and ruderal habitats (K, P).
<i>Geranium pyrenaicum</i>	Rare in grasslands and pastures, sometimes in xeric habitats in the South (K, P).
<i>Isatis tinctoria</i>	Rare in field margins, gardens and xeric habitats (K, P).
<i>Puccinellia distans</i>	Rare in wet grasslands (K).
<i>Ranunculus repens</i>	In riparian habitats, wet road-sides and grasslands (K).
<i>Rapistrum perenne</i>	In fields, road-sides and xeric habitats (K, P).
<i>Sisymbrium loeselii</i>	In ruderal habitats and fallows (K, P).
<i>Solidago canadensis</i>	In riparian habitats (P).
<i>Veronica persica</i>	In the South (P).

The neophytic period - phase 2

In the 20th century the river regulation was performed in several phases. It began in 1928 and the last phase was completed by building a big cylindrical flood-gate in Nitra, in 1937 (GERGELYI 1969). In 1935 the existing inundation dikes were elevated (KOŠOVAN 1975) and within the years 1942-1949 a water power station was built in Nitra (GERGELYI 1969). The river-banks of the rivulet Cetínka were modified in 1947-1948 and

the rivulet was regulated and widened in 1967. It gave rise to two parallel tributaries of the main flow of the Nitra: Stará Nitra and Nová Nitra (the Old Nitra and the New Nitra, PRESINSZKY 2002). Within the riparian plant communities as a result of greater and greater human influences (channel regulations, more intense ranging, greater migration of people, etc.) the proportion of the non-native species was gradually increased (Fig. 2).

Tab. 3. List of aliens in the riparian habitats of the Nitra District
(data resource: PANTOCSEK 1898, classified according to the classification of HALADA 1997)

Archeophytes	Archeophytes or apophytes	Archeophytes or neophytes	Apophytes, archeophytes or neophytes
<i>Aethusa cynapium</i>	<i>Arctium minus</i>	<i>Chenopodium botrys</i>	<i>Cucubalus baccifer</i>
<i>Anthemis cotula</i>	<i>Arctium tomentosum</i>		<i>Echinops sphaerocephalus</i>
<i>Artemisia scoparia</i>	<i>Artemisia vulgaris</i>		<i>Oenothera biennis</i>
<i>Conium maculatum</i>	<i>Atriplex patula</i>		
<i>Cynodon dactylon</i>	<i>Chenopodium album</i>		
<i>Diplotaxis muralis</i>	<i>Chenopodium glaucum</i>		
<i>Euphorbia helioscopia</i>	<i>Chenopodium hybridum</i>		
<i>Chenopodium opulifolium</i>	<i>Chenopodium polyspermum</i>		
<i>Melilotus albus</i>	<i>Dipsacus laciniatus</i>		
<i>Melilotus officinalis</i>	<i>Erysimum cheiranthoides</i>		
	<i>Linaria vulgaris</i>		
	<i>Saponaria officinalis</i>		
	<i>Verbena officinalis</i>		
	<i>Xanthium strumarium</i>		

In the first half of the 20th century in the Nitra catchment area new alien plant species appeared introduced from North America. The most significant among them were the expansive weed species of farmlands, balks and abandoned sites: *Iva xanthiifolia* (in 1934 at Šurany - WEBER PR) and *Ambrosia artemisiifolia* (1949 at Vrable - FUTÁK, HEJNÁ, RU I KA SLO), while they are among the first records about their occurrence on the territory of Slovakia. These species were later found in riparian habitats as well (FEHÉR 2001a). In the first or second half of the 20th century other new field weeds appeared gradually which were introduced mainly from North America: *Alopecurus myosuroides* (1991), *Amaranthus albus* (?), *A. blitoides* (1951), *A. powellii* (?), *Artemisia annua* (1933), *Bunias orientalis* (?), *Cannabis ruderalis* (1980), *Commelina communis* (1970), *Consolida orientalis* (1954), *Cuscuta campestris* (1951), *Kochia scoparia* (?), *Oxalis debilis* (1986), *O. latifolia* (1986), *Oxybaphus nyctagineus* (1973), *Panicum capillare* (1973), *P. dichotomiflorum* (1982), *Phelipanche ramosa* (1948), *Rumex patientia* (1933), *Sorghum halepense* (?), *Stenactis annua* (?) etc. (the first records in the Nitra River Basin: JELNIK 1998). The greatest growth in the number of sites was recorded in the last decades of the 20th century (Fig. 3).

Present day the most important river-side invasive plant species are: *Aster lanceolatus* (1971), *A. novi-belgii* (1998), *A. x salignus* (1865), *Bidens frondosa* (1989), *Echinocystis lobata* (1971), *Fallopia japonica* (1975), *F. x bohemica* (1994), *Helianthus tuberosus* (1978), *Heracleum mantegazzianum* (1982?), *Impatiens glandulifera* (1984), *I. parviflora* (1981), *Lycium barbarum* (1975), *Negundo aceroides* (1978), *Oenothera biennis* agg. (1865), *Rudbeckia laciniata* (1994), *Solidago canadensis* (1962) and *S. gigantea* (1972) (the first records in the Nitra River Basin: FEHÉR 2001b).

Aster novi-belgii agg. is expanded along the whole length of the Nitra River (36 localities), its abundant occurrence is most probably related to the Danube where this species is even massively expanded. It is a species growing in riparian phytocoenoses (50% of sites) but in some short sections of the river it is completely missing. Along the roads it is expanded unevenly and it is only scattered along the railway. Within the Nitra catchment area 74 localities of invasive plant species of the genus *Fallopia* (most expanded is *F. x bohemica*, less *F. japonica* and there are only 2 localities of *F. sachalinensis*) were found. Only 25% of riparian localities were registered but at the upstream of the Nitra *Fallopia* species create continuous mono-dominant riparian stands. From among the invasive plant species it has the lowest occurrence on the river-banks. Along the roads there were found 40% of sites and along the railway one tenth of all populations. Other sites were in ruderal habitats in urban areas or in the vicinity of settlements. Their escaped stands from the original decorative planting are quite often. *Helianthus tuberosus* is the most widespread invading plant species in the alluvium of the Nitra River (100 localities). It grows especially along the middle and downstream of the river and is almost missing at the Stará Nitra, it does not grow in riparian plant communities along the old channel of the downstream but appears again on the bank of the river Váh below the confluence of the Váh and the old main flow of the Nitra River. The species is most expanded in nitrophilous riparian phytocoenoses (61%), less along the roads and railways. From among other sites it prefers ruderal sites, dumps, deserted sites and hedgerows especially in urban areas. During the research in the Nitra catchment area 32 sites of *Impatiens glandulifera* were registered. It is mainly spread in the northern part of the catchment area and southwards up to Luianky. To the south of Nitra only two isolated sites were found near each other in 1999, which were still not there in 1998. It is a species with most of its localities in riparian associations (94%), 2 localities were along the railway on wet sites not far from each other. The species did not occur along the roads or any other sites. In the catchment area of the Nitra 35 localities of *Impatiens parviflora* have been found, it was expanded almost exclusively at the upstream and middle stream from the site close to the springs up to the city of Nitra (south of Nitra there is only one remote site). It prefers riparian

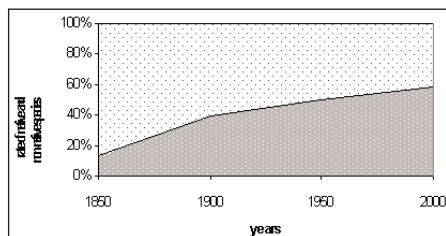


Fig. 2. Share of native and non-native plant species in riparian phytocoenoses of the Nitra River (+/- 10 years)

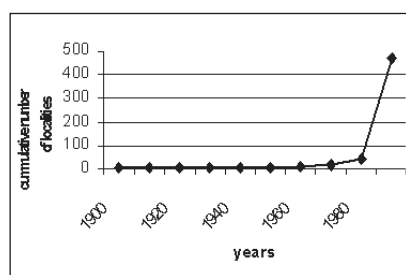


Fig. 3. Cumulative number of localities of the 16 most distributed neophytes in the Nitra River catchment area

(in the 20th century, after 2000: uncountable). Considered species: *Aster lanceolatus*, *A. novi-belgii*, *A. x salignus*, *Bidens frondosa*, *Echinocystis lobata*, *Fallopia x bohemica*, *F. japonica*, *Helianthus tuberosus*, *Heracleum mantegazzianum*, *Impatiens glandulifera*, *I. parviflora*, *Lycium barbarum*, *Negundo aceroides*, *Oenothera biennis* agg., *Solidago canadensis*, *S. gigantea*

habitats along the main stream and its affluents (77%) and after *I. glandulifera* it is the truest mate of a water flow. There are only few sites along the roads and only 1 locality was found at the railway. From among other localities they are in parks and forests. Within the overall catchment area of the Nitra River, 45 localities have been found of which 31 *Solidago canadensis* and 14 localities of *Solidago gigantea*. There is a great difference in the expansion of these two species and their sites almost do not lap. *S. canadensis* grows at the upstream of the catchment area, *S. gigantea* in the south. Both invasive species of the *Solidago* genus prefer riparian plant associations (more *S. gigantea*). They are less frequent along the roads and railways, they prefer ruderal sites.

Along the downstream of the Nitra River, according to dominant plant species and the degree of their invasiveness, 4 (generalized) transversal model zones can be differentiated (cf. FEHÉR, KON EKOVA 2001):

Zone 1. Cunette and the river bank edge - riparian reed associations on the river alluviums, by turns flooded clay and sandy (singly stony) soils and semi-ruderal associations of bare river banks (especially the alliance *Phalaridion arundinaceae* Kopecký 1961 and different non-defined transient plant communities). It is a zone of often disturbing and degradation, in places with a changing species composition and structure. The species *Phalaroides arundinacea* dominates here and *Urtica dioica* can be a subdominant. From among the neophytes *Bidens frondosa* can be found quite often, *Impatiens parviflora*, *Iva xanthiifolia* and others less often. *Helianthus tuberosus* and *Aster novi-belgii* agg. occur only singly and this zone is used as a transient to other zones on higher banks.

Zone 2. An artificial river terrace above the bank edge - associations of willows, poplars, alders and elms, in not canopied stands and in the open areas are mainly the invaded nitrophilous tall herb phytocoenoses [*Salicion albae* (Tüx.) Müller et Görs 1958, *Senectionion fluviatilis* Tüx. (1947) 1950, *Aegopodion podagrariae* Tüx. 1967 em. Hilbig, Heinrich et Niemann 1972]. The tree canopy is formed mainly by the species of *Salix* and *Populus* genera. In the open, herb associations dominate nitrophilous species as *Urtica dioica*, *Atriplex sagittata*, *Chenopodium album*, *Lamium maculatum*, *Chaerophyllum bulbosum*, *Galium aparine* etc. This zone, and especially its edge plant communities are mostly invaded by *Helianthus tuberosus* together with *Impatiens glandulifera*, *I. parviflora*, *Aster novi-belgii* agg., *Galinsoga urticifolia*, *Solidago canadensis* and *S. gigantea*.

Zone 3. Wide floodplain (berm) - associations of mesophytous, twice mown meadows, accompanying and protective tree planting [*Arrhenatherion* W. Koch 1926, on unhardened field paths also *Matricario matricarioidis-Polygonion arenastri* Rivas-Martínez 1975 corr. Rivas-Martínez et al. 1991 (syn.: *Polygonion avicularis* Br.-Bl. 1931)]. Associations of mesophytous, twice mown oat grass meadows, on nutritive, occasionally flooded soils that are relatively stable, with the dominant species of *Arrhenatherum elatius* and occurrence of grasses *Dactylis glomerata*, *Elytrigia repens*, *Poa angustifolia*, *Calamagrostis epigeios* etc. The invasion of non-native plant species is little successful because meadows are regulated and managed by men (a single occurrence of *Helianthus tuberosus*, *Aster novi-belgii* agg., *Fallopia japonica* and *Solidago canadensis* have been recorded). This meadow is often traversed by field paths with the dominant species of *Lolium perenne*. At some sections of the regulated water flow there is an accompanying tree stand formed of hybridogenic taxa of the *Populus* genus. Invasive species (such as *Helianthus tuberosus*, *Solidago canadensis*) can be found very

rarely here and form little numerous populations, after floods there is a temporary (but only a mass) occurrence of *Impatiens parviflora* (e.g. in 1999).

Zone 4: A flood-protection dike (waterward dike slope, dike top, outer dike slope). Associations are the same as in Zone 3. On the flood protection dikes more xerophilous types of meadows grow which are degraded on the top dikes by treading down. In comparison with Zone 3 subxerophilous meadows and ruderal species are found more often. The occurrence of *Helianthus tuberosus*, *Fallopia japonica* and *Solidago canadensis* has been recorded only singly in this zone, other invasive species are missing completely. In the neighbourhood of gardens and tilled fields ruderal herb associations are on rich soils, especially of the *Arction lappae* Tüx. 1937 alliance, which can also appear on a not mown outer dike slope of a protective dike. From the invading species *Aster novi-belgii* agg., *Galinsoga parviflora*, *Helianthus tuberosus* and *Solidago canadensis* are found there. From the newest R-strategy neophytes *Iva xanthiifolia* and *Ambrosia artemisiifolia* are often represented here (mainly at the downstream of the river).

Conclusions

The course of invasions is very dynamic and therefore its research seems to be a long-term process. It follows from the found-out data that the invasion process is in a direct correlation with the changes in the landscape which are most often induced by man (Tab. 4). A man created landscape, in various time and space horizons, modified or new types of habitats, enable penetration of new alien plant species into new areas and also ensure their transport in the landscape (or at least create new corridors for their further expansion). These facts ought to be taken into account both qualitatively and quantitatively in models of biological invasions, that are very mechanical at present.

Tab. 4. Phases of alien plants expansion in the Nitra River Basin.

Phases Historic age			Habitat	
Main	Side		Man-made habitat (fields and settlements)	Semi-natural riparian habitats
Archeo- phytic period	1 st phase	Neolithic	Expanding apophytes and first archeophytes	No or minimum change
	2 nd phase	Bronze Age - Middle Age	Further deforestation, new land use measures, more archeophytes	Wider alluvium with clay sediments (water run-off from deforested archaic agricultural landscape), further expansion of archeophytes (incl. subxeric species)
Neo- phytic period	1 st phase	16.-19. cent.	Introduction of new species (from	River channel regulations, North America and Asia) expansion of new aliens from agri-ecosystems
	2 nd phase	20. cent.	Intensive transport systems, exponential spreading of well established (naturalized) neophytes (weeds etc.)	Development of mono-dominant nitrophilous tall-herb plant communities with dominant aliens

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