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DISTRIBUTION PATTERNS OF HIMALAYAN BALSAM (IMPATIENS GLANDULIFERA ROYLE) IN AUSTRIA

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Abstract
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The distribution patterns of the highly invasive neophyte *Impatiens glandulifera* Royle in Austria are presented. The invasion dynamics of the species are characterised by historical reconstruction. The ecological preferences in altitude and habitat type are elucidated. The possible future expansion and the role of the different dispersal agents are discussed.
Key words: plant invasion, distribution patterns, mapping, dispersal agents, Impatiens glandulifera Royle, Austria
Nomenclature: Adler, Oswald & Fischer (1994)

Introduction

For thousands of years, people have introduced plant species, intentionally and unintentionally, into regions outside their original distribution area. Many of these species provide great benefit to society. Most of our major food crops have been introduced from other countries, and many other non-native species cause no problems in their new environment. However, the invasive alien species (including the so-called 'problem plants') cause big environmental problems world-wide (DI CASTRI & GROVES, 1990; DE WAAL & al., 1994; WADE & al., 1994; MOONEY & HOBBS, 2000). Many of them have become agricultural weeds, others have invaded native ecosystems by outcompeting native plants.

Himalayan balsam, *Impatiens glandulifera* Royle (Balsaminaceae), is one of these species. It is the tallest spontaneous annual plant in Europe, which makes it a strong competitor (GRIME, 1979). It is able to replace the native flora in invaded sites and may cause many problems for nature conservation along riversides (PERRINS & al., 1990).

Himalayan balsam was first introduced into Europe in 1839 when seeds from Kashmir (Western Himalayas) were sent to the Royal Botanic Gardens in Kew (England) by DR. ROYLE. The first records of naturalisation on the British Isles were noticed in 1855 (Middlesex and Hertfordshire) and 1859 (near Manchester). Up to now *I. glandulifera* spread throughout 26 countries of Europe between 40° and 65° N latitude, the Russian Far East, Japan (DRESCHER & PROTS, 2000; Fig. 1, improved), and the USA (RICE, 1998).

The rate of spread of *I. glandulifera* may be interpreted as very high throughout the major part of the present European distribution area. For example, the estimated and the observed rate of spread on the British Isles have been calculated as 2.6-38.0 and 9.4-32.9 km/year, respectively (TREWICK & WADE, 1986; PERRINS & al., 1993; GROSHOLZ, 1996). In some Central European countries *I. glandulifera* is distributed over a large part of the territory. In the Czech Republic it has spread into 47.7% of the mapping squares (PYŠEK & PRACH, 1995).

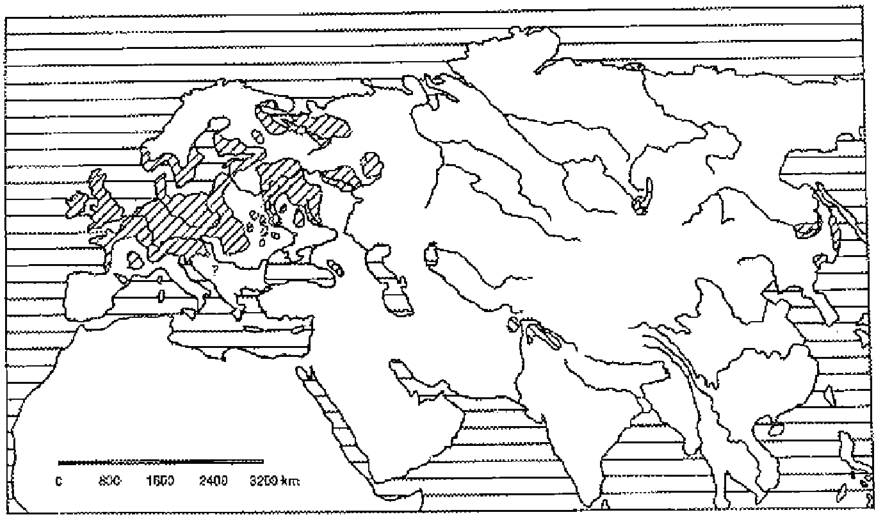


Fig. 1: Primary distribution range of Impatiens glandulifera in the Himalayas (\\\\\), and synanthropic distribution in Eurasia (/////).

In Austria this species has rapidly colonised many banks of rivers and streams, forests and roadsides, especially during the last 30-40 years (WITTMANN & al., 1987; HARTL & al., 1992; DRESCHER & PROTS, 1996; POLATSCHEK, 1997). Nevertheless, the distribution patterns and spread characteristics of *I. glandulifera* have not yet been discussed on an all-Austrian scale.

The present study addresses the following questions: (1) what are the distribution patterns of *I. glandulifera* on an all-Austrian scale? (2) what could we expect in the future? (3) what is the role of the different dispersal agents for the spread of *I. glandulifera?*

Methods

The distribution patterns have been recorded using the grid-map approach of the Central European Mapping Project (Niklfeld, 1971, 1994). The ecological demands have been studied with the usual field methods. The database has been compiled from the available field protocols of the floristic mapping, herbarium data [GJO, GZU (Styria), KL

(Carinthia), W, WU (Vienna), LI (Upper Austria), IB (Tyrol and Vorarlberg), SZU (Salzburg)], numerous literature resources (Drescher & Prots, 1996, 2000) and our field studies between 1991 and 2000. Analysis of variance (ANOVAR) and multiple regressions (Sokal & Rohlf, 1981) have been used for statistical purposes.

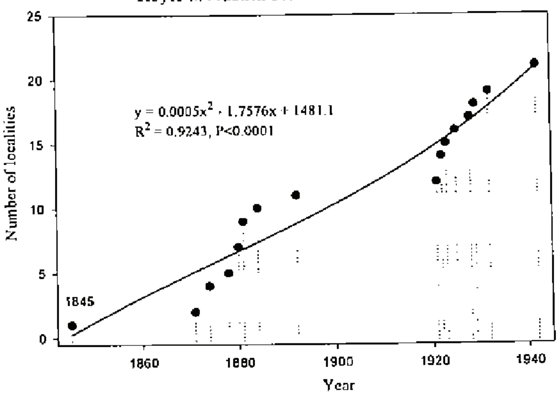
Result and discussion

The history of invasion in Austria

Impatiens glandulifera is unlikely to be overlooked, and as it is the only species of this taxonomic group in Europe it is easy to identify. Therefore it is a suitable subject for reconstructing the invasion process (Pyšek, 1991). Furthermore, Austria has a long botanical tradition, so that the information necessary for historical reconstruction is available.

The history of invasion of *I. glandulifera* in Austria started in the 1840s. The first location of Himalayan balsam as an ornamental plant was recorded by J. von Mor (LI) for the surroundings of Linz in 1845, only six years after the introduction to the RBG Kew. The invasion of the species started with cultivation, in the big botanical gardens of the universities of Vienna (first record dated 1871; GJO) and Innsbruck (1880; WU), as well as in small private gardens like in Obervellach (1874; KL) or in monastery gardens like in Kalksburg (1881; WU). Years later it appeared around farmhouses, for example in the Lavanttal (1892; KL). Seed exchange between universities and private gardens but also trading of seeds stimulated the spread of the species during that period. Very often river banks in the vicinity of gardens, nurseries and rarely cemeteries were the first habitats for its naturalisation. The first casual escape has been noticed by Pichler already in August 1884 (WU). The first spontaneous localities have been described along the Weidling river near Klosterneuburg (Lower Austria) in 1898 and 1902 by A. Ginzberger (WU) and along the Seltschach rivulet near the ruins of the castle of Arnoldstein (Carinthia) in 1899 by K. Prohaska (GJO).

Fig. 2. Records of localities of cultivated *Impatiens glandulifera* Royle in Austria between 1845 and 1945.



During three equal periods of one century (1845-1877, 1878-1911 and 1912-1945) the number of cultivation localities (observations) per period (Fig. 2) and the cumulative number of cultivation records over all three periods have increased. The increasing use of *I. glandulifera* as an ornamental decisevely supported the adaptation, establishment and expansion of this plant in Austria during that time.

Distribution maps of Himalayan Balsam have been presented for some of the Austrian provinces: Salzburg (WITTMANN & al., 1987), Carinthia (HARTL & al., 1992; DRESCHER & PROTS, 2000), Styria (DRESCHER & Prots, 1996), Tyrol and Voralberg (POLATSCHEK, 1997). According to these data, I. glandulifera has spread into 39.2% of all mapping squares in Styria, 47.8% in Carinthia, and 23.2% in Salzburg, which underlines a high colonisation activity of this alien.

Colonisation dynamics and ecological preferences

The spontaneous invasion in Austria may be divided into three separate phases (Fig. 3.), due to differences in the rate of spread.

The 'lag' phase (A) of the invasion process lasted 67 years (1898-1964) and can be described by the equation $y = 5E\text{-}41e^{0.0496x}$ ($R^2 = 0.9167$). During this phase the species occurred in a limited range of habitats, notably riparian habitats and settlements.

The 'exponential' phase (B) shows $y = 2E\text{-}57e^{0.0691x}$ ($R^2 = 0.9679$) over 29 years (1965-1993). This remarkable increase in the number of occupied mapping squares could be caused by (1) increased pollution (the deposition of organic sediments and debris) on river banks of Central European rivers as a result of the Second World War, (2) river corrections after the war, and (3) economic use of the plant by honey-bee keepers. However, it must be kept in mind that this exponential phase starts at the same time as the Central European mapping project which provided an enormous wealth of new records (NIKLFELd, 1971, 1994; WITTMANN & al., 1987; HARTL & al., 1992).

Fig. 3. Cumulative number of squares occupied by *Impatiens glandulifera* Royle in Austria (A - 'lag', B - 'exponential', ?C - 'sigmoidal' phases)

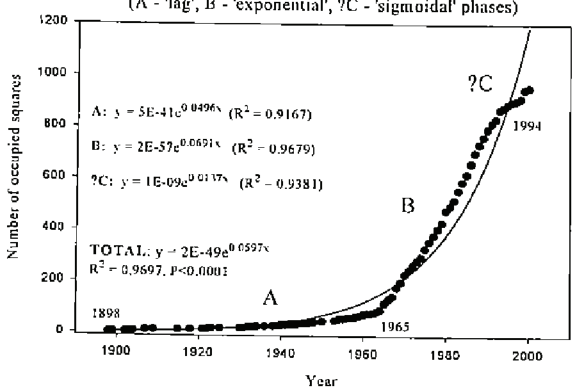
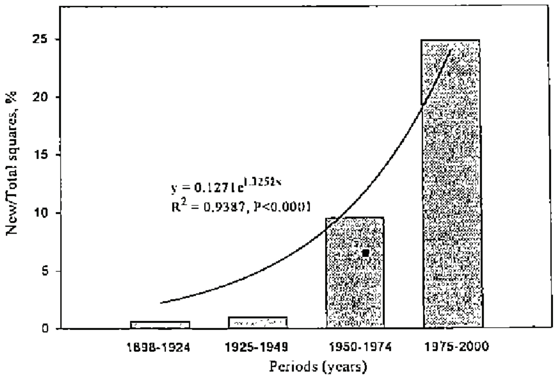


Fig. 4. Increase of the *Impatiens glandulifera* Royle invasion into the Austrian mapping squares



The last part of this graph can be interpreted as the 'sigmoidal' phase (C) of invasion which started in 1994 and presented as $y = 1E\text{-}09e^{0.0137x}$ ($R^2 = 0.9381$). Up to now the sigmoidal phase on an all-Austrian scale is less distinct than the one for Carinthia (Drescher & Prots, 2000). Of course we assume that under the present conditions the increase of the number of occupied squares will continue in accordance with that sigmoidal pattern.

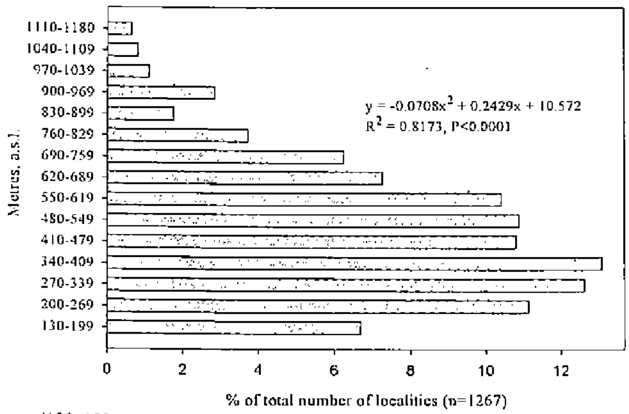
Another pattern could represent the dynamics of occupying of the species into mapping squares for the equal 25-year periods of the last century (Fig. 4). It proves a tremendous increase of the *I. glandulifera* invasion during the last decades.

The realised map (p. 93.) shows the present distribution of Himalayan Balsam in Austria, including the frequency of records per grid. Up to now *I. glandulifera* occupies 36% of the total number of mapping grid squares in Austria (Niklfeld, 1971, 1994). The frequency of records is very low in the mountainous areas above 1000 m, as well as in the Pannonian lowlands in eastern Austria. More than 2/3 of all grid squares, which could potentially be colonised are occupied. The grid squares showing the highest frequency of occurrence usually contain river courses.

The relation between altitude and number of squares containing spontaneous localities can be described by polynomial quadratic equation (Fig. 5). In general, the number of localities decreases with increasing elevation. The major number of records (about 69%) has been reported between 200 and 620 metres a.s.l. The high altitude localities (900-1180 m) amount to slightly more than 5%. Pannonian plain and other lowland records (130-199 m) are represented by 6.7%, almost exclusively along rivers.

The relation between altitude and number of squares containing casual localities shows a different pattern (Fig. 6). The correlation 'record vs. altitude' shows no significant result with the low value of determination coefficient. However, the two groups are possible to detect on the figure by aggregation. First, the larger one (55.8% of total) is ranged between 240 and 759 metres. Correlation of the shares of the spontaneous locali-

Fig. 5. Elevation and localities presence of *Impatiens glandulifera* Royle in Austria

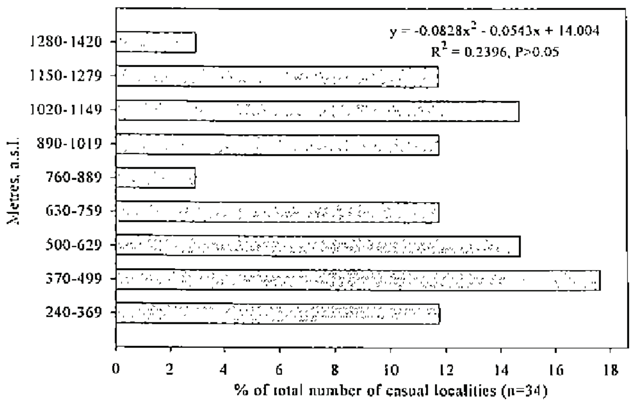


(130–199 m) are represented by 6.7%, almost exclusively along rivers.

ties to the casual consists of about 1.3 at the same altitudes (240-620 m). The records of the second casual group (38.2%) occur at high altitudes between 890 and 1279 metres. That group together with another one (2.9% of total; within 1280 and 1420 metres) prove a tendency of spread of *I. glandulifera* into the upper forest belt. Correlation of the shares of the spontaneous records to the casual consists of about 0.15 only at the same high altitudes (900-1180 m), which shows a high dispersal penetration of the species into upper altitudes and active attempts of naturalisation.

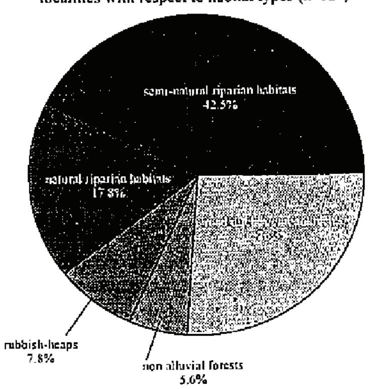
Spontaneous localities of *I. glandulifera* above 1180 m a.s.l. have not been observed up to now. However, a rise of temperature, CO_2 concentration, tourism and corrections of streams can contribute to increase the distribution range of this species towards higher altitudes.

Fig. 6. Elevation and casual localities presence of *Impatiens glandulifera* Royle in Austria



More than 60% of the total populations recorded were found in alluvial riparian habitats (Fig. 7). Moreover, the road ditches and embankments contain often a high amount of moisture and nitrogen persistently or periodically. The proportion between the number of records in natural riparian habitats (mixed forests with *Salix, Fraxinus, Alnus, Quercus* and tall herb vegetation with low human impact) and semi-natural riparian habitats (partly damaged forests, coppice or highly fertilised stands) is about 1:2.4. The autecological features (BEERLING & PERRINS, 1993; DRESCHER & PROTS, 1996, 2000) of the species strictly relate to synecological features. The *I. glandulifera* stands demand a high or moderate light intensity, nitrogen amount and moisture content. However, these stands can survive and produce seeds despite stress, direct human impact, very low amount of fertiliser and a strong competition of shrub and tree layers. The species shows a very high degree of plasticity and a ruderal strategy type even in changeable conditions of environment.

Fig. 7. Distribution of the *Impatiens glandulifera* Royle localities with respect to habitat types (n=320)



For the future an increase of the number of occupied habitats along riparian sites as well as on moist roadsides is expected at the local level, supported by further increase of nutrient pollution in riparian and roadside habitats. Human activity along river beds will stimulate the invasion by creating open microsites and eliminating riparian vegetation. A gradual expansion into damp forests without dense canopy is also highly probable, especially over nutrient-rich soils. The stands recorded in settlements, on compost hills, rubbish heaps and along the roads could vanish, especially due to reduced moisture or higher soil temperatures. The correction of alpine river systems will sharply increase the amount of fine sediment and nutrient deposition in the river beds further downstream. These changes of soil texture are very suitable for the establishment of the species and make even primary riparian habitats vulnerable to invasion.

Role of the different dispersal agents

The reproductive capabilities of *I. glandulifera* (size and weight of seeds, high fecundity rate; BEERLING & PERRINS, 1993; DRESCHER & PROTS, 2000) are important factors for the spread. The fruit of Himalayan Balsam is an explosive capsule which disperses the seeds up to 3-5 m, depending on the height of the plant and strength of prevailing wind during dehiscence. The seed rain peaks are 1-2 m from the parent stand. In a flat area the mean yearly rate of spread was estimated at 2.47 m/year (BEERLING & PERRINS, 1993). On steep slopes most seeds could be washed out of the stands by frequent or heavy rains at least few metres. Nevertheless, during the last decades the number of new localities at higher altitudes has increased.

Intentional ornamental and economic use of the species have been the most important causes of the invasion during the last decades. However, the unintentional way, like use of cars, trucks, caterpillars and excavators for house building and river canalisation or even human trecking plays the most important role today for the spread of the species, especially, at the local and regional level.

We found, that the time of first establishment of the species is not correlated to elevation (DRESCHER & PROTS, 2000). In addition, we have got plenty of evidences about using Himalayan balsam as a garden plant in the high mountainous settlements with a following escape. A long distance dispersion in the mountains is supported by inadvertent spread of the species, including transportation of top soil with the seed bank from the river site in the bottom of the valley to the upper part of the mountain. In general, man seems to be the most important dispersal agent for *I. glandulifera* against gravitation.

Small rodents are abundant in the settlements of the mountainous areas and may also support the dispersal of this species. Home ranges of small rodents like the wood mouse (Apodemus sylvaticus) are thought to include areas of up to 1 hectare (STODDART 1979). A dispersion of the seeds by birds is also probable.

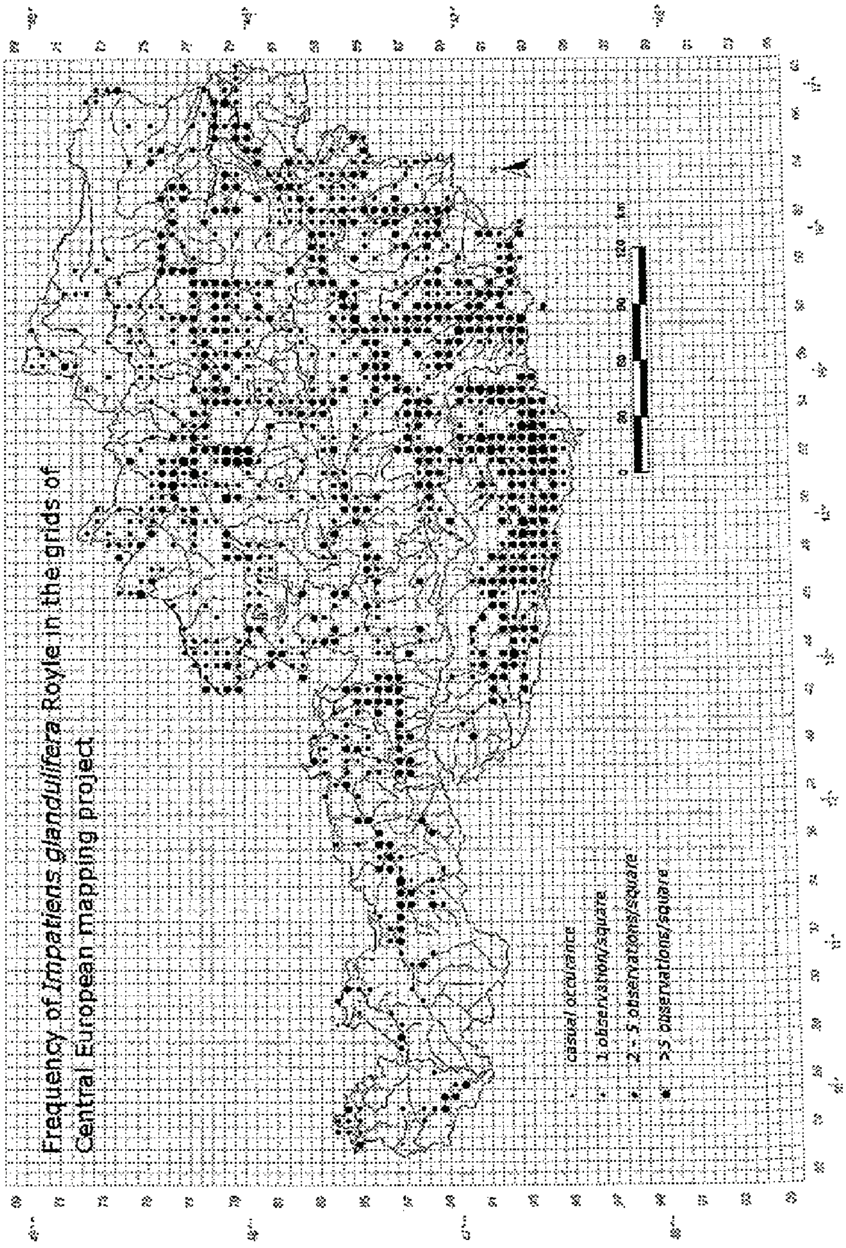
The spread of *I. glandulifera* downstream is obvious. However, dispersion and establishment of the species along watercourses will strictly depend on the geomorphology of river and bank, duration of flood, speed of water flow and type of sediment material. This issue needs further study. The persistent seed bank (DRESCHER & PROTS, 2000) could play a significant role for the spread of the species, especially, during heavy floods. The moist seeds are not buoyant. The rate of germination of seeds, which spent 6 months (autumn-spring) in the water (DRESCHER & PROTS, 2000), is only 10%. This means that the water course is not the most effective dispersal agent, as we thought before, but it is among others important for long distance transport.

Together with the attributes related to the dispersal and reproductive capabilities, the success of the *I. glandulifera* invasion is connected with: (1) the response of the species to various environmental parameters (heat sum and extreme temperature, water and nutrient availability, soil texture, CO_2 and oxygen concentrations); (2) the attributes related to the vegetative features (life span and biomass production) (LHOTSKÁ & KOPETSKÝ, 1966; MUMFORD, 1990; BEERLING, 1993; BEERLING & PERRINS, 1993; DRESCHER & PROTS, 2000).

Conclusions

1. The history of invasion of *I. glandulifera* in Austria consists of more than 150 years. The period of spontaneous invasion lasts already more than 100 years. The increase of the ornamental use of the plant is the main reason, which stimulated the escape, adaptation and establishment of the species during the initial period of invasion.

2. At the present moment *I. glandulifera* occupies 36% of the total number of Austrian grid squares. Three phases of invasion have been noted: 'lag', 'exponential' and, probably, 'sigmoidal'.


Frequency of Impatiens glandulifera Royle in the grids of
Central European mapping project
casual occurance
1 observation/square
2 - 5 observations/square
>5 observations/square
0 30 60 90 120 km

3. The increase of river corrections, pollution as well as military activities connected with the Second World War might have initiated the rapid increase of the number of reported localities. Reconstruction after the war and rising economic use of the plant could be the most important reasons for the exponential spread during the last decades.

4. The number of spontaneous localities decreases with altitude. The major part of them has been recorded between 200 and 620 metres a.s.l.

5.The number of casual records between 890 and 1420 metres a.s.l. amounts to 41.1% of the number of records at these higher altitudes, which underlines the high spreading activity of the plant at these altitudes.

6. The habitat preference for Himalayan Balsam is connected with the alluvial riparian ecosystems and nutrient-rich, moist, man-made habitats. I. glandulifera threatens even natural ecosystems.

7. The expansion of the species in Austria will probably proceed according to the 'sigmoidal' pattern. An increase of the number of occupied habitats along the riparian sites, moist roadsides and forests is expected at the local and regional level. The altitudinal distribution range of the species may rise, and some part of the lowland localities may vanish due to climatic changes.

8. Man is the most important dispersal agent for *I. glandulifera* against gravitation. Today the unintentional way of dispersal plays an important role for the spread of the species, especially at the local and regional level. The persistent seed bank of the species might be a significant help for its distribution, especially during heavy floods.

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A BÍBOR NEBÁNCSVIRÁG *(IMPATRIENS GLANDULIFERA ROYLE)* MINTÁZATÁNAK MEGOSZLÁSA AUSZTRIÁBAN

(Összefoglalás)

A dolgozat a neofita bíbor nebáncsvirág *(Impatiens glandulifera* Royle) mintázatának ausztriai megoszlását, a diszpergáló ágensek szerepét tárgyalja. A dolgozathoz az inváziós növénypopulációk megtelepedésének történeti bemutatása után szemlélteti az ausztriai populációk elterjedését a Közép Európai Flóratérképezési rendszer keretében (térkép) és vizsgálja az ökológiai tényezők valamint egyes terjesztési ágensek szerepét a kolonizációban. Az elért eredmények rögzitik azt, hogy Ausztriában a növény spontán terjedése az utobbi száz évben egyre növekszik, ma a növény a KEF mezők 36 százalékában van jelen, de a tszf. magassággal csökken az elterjedése. Az élőhelyek közül, a növény számára kedvező a folyóparti és ártéri ökoszisztémák, tápanyagban gazdag, ember által bolygatott területei. Az ember a legfontosabb közvetitő tényező ezen özönnövény további terjeszkedésében.