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SHORT COMMUNICATION

Alien aquatic vascular plants in the in Hungary (Pannonian Ecoregion): historical aspects, dataset and trends

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Abstract

Estimating the extent of biological invasions is critical in predicting the effect of exotic species. We investigated the occurrence and number of alien freshwater plants and give information on the composition of alien aquatic flora, their trend in time, invasion pathway and their invasive character.

Keywords

Exotic, Macrophyte, Neophyte, Non-indigenous, Hungary

Introduction

Macrophytes play a key role in maintaining functioning aquatic ecosystems as primary producers, habitat maintenance, food for aquatic animals and strong influence on the chemical and physical properties of water (Santos et al. 2011). They are used as bioindicators (Demars & Edwards 2009) and in habitat rehabilitation (Lorenz et al. 2012). These properties have special importance in a landscape dominated by human activity where the management, protection and assessment of freshwater vegetation receive special attention because of the continuous decline of macrophytes (Sand-Jensen et al. 2000).

The decline of some indigenous species allows alien plant species to potentially establish where their niches are heterogeneous, generating serious ecological problems (D'Antonio & Meyerson 2002). Vegetation shifts in freshwater ecosystems from human influences can cause biodiversity loss, decreasing floristic quality and the expansion of alien species (Richardson 2006; Aguiar & Ferreira 2013; Liendo et al 2013). Freshwater biodiversity is one of the most vulnerable ecosystems (Dudgeon et al. 2006) threatened by biological invasions (Thiébaut 2007, Brundu et al. 2013). The impacts of invasive plant species are unclear in freshwater ecosystems, but are known to effect the macroinvertebrate community (Stiers et al. 2011).

To preserve biodiversity using conservation measures requires an extensive knowledge on rare and/or alien plant species populations (Duncan & Young 2000; Iberite et al. 2011). Therefore, estimating the extent of biological invasions is a key issue for predicting the effect of exotic species..

The first reports of alien aquatic vascular plant species in this ecoregion originate in the late 18th century, followed by scattered floristic surveys of aquatic alien species (Boros

1937; Gombocz 1945; Szabó 2002; Király et al. 2007). However due to aquatic habitats are very sensitive for disturbance and rapid invasion of aliens with large biomass are forecasted for the future due to e.g. climate change, there has been no information of the aquatic alien flora as well as there is no extensive impact evaluation of their effect in the Pannonian Ecoregion. Moreover a European review of alien aquatic plants (Hussner 2012) refers to fewer species for Hungary than what is actually true. In this paper we report the occurrence and number of exotic freshwater plants and the consequences of their presence on the native flora.

Materials and Methods

Study region

The study was carried out in Hungary, Central Europe (Fig. 1). Hungary lies in the Pannonian Ecoregion which is isolated by mountain ranges, with a heterogeneous climate and distinct geography, resulting in one of the most diverse ecoregions in Europe. Geographically, this ecoregion covers seven countries with 90% of the area in Hungary. However, several large rivers (e.g., Danube and Tisza) flow through this ecoregion and are known to be the major corridor for plant species invasion (Török et al. 2003). The ecoregion has a continental climate with a sub-Mediterranean influence in the western region, characterized by long dry hot summers, an ideal habitat for exotic plant growth (Hawkins et al. 2007). The area is geologically active, resulting in an abundance of thermal springs and streams.

Sampled biota

We focused on the aquatic alien plant species. We followed Blackburn et al. (2011) definition of alien species and den Hartog & Segal (1964) definition of aquatic species with the exception that we include pleustohelophytes (aquatic plant drift on the water table except for their submerged root system) and exclude amphyphytes (i.e. mudflat species) not to distort the overall picture of aquatic alien plants due they often colonize non-aquatic habitats.

.. We established a database of alien aquatic plant species. We conducted a field survey between 2007 and 2013, examining all hot springs, thermal creeks and aquatic habitats where occurrences of alien aquatic vascular plants had been reported. Other aquatic habitats and localities were checked at random. We checked and summarized 25 vascular plant species from the ecoregion, including herbarium specimens from major Hungarian and regional herbaria (BP, BPU, DE, JPU, SAMU, W and GJO – herbarium acronyms according toThiers (2014)).

In the database, the species frequency referred to the number of grid cells (approx. 35 km^2/unit) according to the Central European flora mapping system (Niklfeld 1971). We determined the first occurrence of a species so the data would be consistent with other international databases (e.g., Verloove 2006). For categorical predictors we evaluated four factors that are used to discuss database information: geographic origin; introduction pathway using the categories of Hulme et al. (2008); temperature demands (thermal, cold, both) and the invasive traits of alien aquatic vascular species using the categories of Richardson (2000).

Statistical analyses

We used one-way analysis of variance (ANOVA) to test the frequency of categorical predictors and two-way ANOVA to test the combined effect of temperature and invasive predictors on frequency. Where the main effects showed a significant difference we used Tukey's *post hoc* pairwise comparison test to determine where the differences occurred. All statistical analyses were carried out using STATISTICA 7.0 (Stat Soft Inc).

Results and Discussion

In total, 48 alien aquatic vascular plants were recorded as established in Hungarian inland waters (Table 1). 7 species (*Bacopa caroliniana, Houttuynia cordata, Hygrophila corymbosa, H. difformis, Limnophila sessiliflora, Rotala rotundifolia, Vallisneria gigantea*) are new to the DAISIE list (DAISIE 2009). These 48 species represent a significant proportion of the aquatic plant flora compared with the 79 native aquatic vascular plant species (Király 2011). This represents one of the highest numbers of alien aquatic vascular plant species in Europe with the exception of Italy, the United Kingdom, Portugal, Germany and Belgium (Lansdown unpublished data; Hussner 2012). The highest numbers of alien aquatic species are find in Hydrocharitaceae family (9 alien representatives), Nymphaeaceae (5); Pontederiaceae (4). 3-3 species are found in Acanthaceae, Lemnaceae, Onagraceae and Scrophulariaceae families. Apiaceae, Asteraceae, Haloragaceae and Saururaceae families have 2-2 alien representatives, while Araceae, Azollacea, Cabombaceae, Lentibulariaceae, Lythraceae, Nelumbonaceae, Pteridaceae and Salviniaceae contain 1-1 alien species. In total, alien aquatic species are form 20 families (Table 1). The majority of aquatic alien species recorded (from most to less abundant) were native to North America, Southeast Asia, Central America, South America and Africa (Fig. 2). The remaining species were from Europe and Australia. Our results support the findings of García-Berthou et al. (2005) with many of the non-indigenous species originated from North America came via independent pathways similar to other European countries, such as France, the United Kingdom and Germany.

The first record of alien aquatic species in the Ecoregion is questionable. As far as can reasonably determine the first record of *Vallisneria spiralis* at 1808 was the first certain record of alien species in the Ecoregion. Nevertheless *Nymphaea lotus* has been known from

Nagyvárad (Oradea, Romania) since 1798 but the status of the population is controversial. Recent molecular phylogenetic studies revealed that this population is not a tercier relict (Lukács et al. unpublished data) but it is still questionable whether this population is native or alien. The first documented intentional release of *Nymphaea lotus* to Lake Hévíz is happened at 1842. There was an increase in number of alien aquatic vascular plant species from 1808 to 2005 (Fig. 3). Many alien aquatic vascular plants were introduced more than 100 years ago, while others are more recent arrivals. Figure 2 shows that approximately half of the alien species in Hungary were recorded after the 1960s. Hence, half of the established alien species have been introduced in the last 50 years. However, consideration should be given to the increasing rate of floristic research, starting in the early 1990s, influencing this result.

Our results suggest that invasive species showed a significantly higher frequency compared with non-invasive species ($F_{1,46}$= 17.27, p=0.0001). We found that approximately 80% of the alien species were recorded only in thermal waters. In contrast, if we considered species frequency with its temperature demands, cold water habitat species showed a significantly higher frequency compared with species prefers thermal water ($F_{2,45}$=10.3, p=0.002). Furthermore, cold-water invasive species showed a significantly higher frequency than thermal-invasive species ($F_{2,42}$=2.14, p=0.04). This implies that species that are likely to occur in cold water habitats (e.g., *Azolla filiculoides, Cabomba caroliniana, Elodea canadensis, E. nutallii, Hydrocotyle ranunculoides, Lemna minuta*) have a higher potential for invasiveness compared with thermal-invasive species (e.g., *Hydrilla verticillata, Pistia stratiotes*).

Most of the alien aquatic species arrived in Hungary via intentional (release, escape, contaminant) and unintentional (unaided dispersal) pathways. Of all the plant species, 79% were escaped from horticulture, which is the most dominant vector for introduced plants. For most species the introduction pathway is unclear, thus we can only speculate for species such as *Elodea canadensis, E. nutallii, Lemna minuta,* and *L. turionifera*. This possibility exists that *L. minuta* and *L. turionifera* arrived in this region by waterfowls (Keddy 1976), while *Elodea* species arrived from traders in the 20th century. However, in some cases such as *Monochoria korsakowii*, there are documented reports (Bartha et al. 2000) indicating that this species arrived in Hungary in shipments of contaminated wild rice (*Zizania aquatica*). We have evidence concerning the introduction pathway of ornamental species (e.g., *Gymnocoronis spilanthoides, Houttuynia cordata*, *Hygrophila corymbosa, H. difformis, Vallisneria gigantea, V. spiralis*) showing that they were deliberately introduced to thermal areas for breeding/propagation purposes then sold to western markets. These species are the largest threat to native aquatic flora because of their rapid growth, production of large dense stands overgrowing and displacing native species. However, these alien species have limited spread and overwintering capacity because of the temperature gradient of thermal waterways (i.e., thermal waterways show a decrease in temperature from the point source).

The discovery of alien aquatic species is usually positively correlated with shipping activity, tourism and the human population size (Panov et al. 2009; Leuven et al. 2009). Our results show that approximately 80% of alien aquatic vascular plants occurred in thermal waters. We suggest that other metrics, (with a similar pattern of increase since the 1960s) such as horticulture are significantly correlated with the number of alien aquatic vascular plants. The cultivation and trade of ornamental aquatic plants is a major threat to freshwater biodiversity, supporting the findings of Duggan (2010).

Plant invasions of alien species from human activity are among the most significant components of global change. However the rate of plant invasion assessed separately from climate change, there are obvious evidence for their strong interaction. The survival of alien species introduced from a warmer region to colder conditions mainly depend on locally heated 'islands' (Walther et al. 2009). Due to great majority of invasive species are found in thermal waters in the Pannon Ecoregion, thermal springs and waters as well as thermal effluents works as islands with suitable habitats for alien aquatic species colonization. Our results suggest that the invasion rate of alien aquatic vascular plants in Hungary is one of the largest in Europe, more serious than previously reported in a recent review of European alien aquatic vascular plants (Hussner 2012). Furthermore, Hungary lies in the center of the 'Southern main invasion corridor' of Europe (Panov et al. 2009). Therefore, the assessment of invasive species in this area was timely. Future monitoring will be critical for obtaining information about the population dynamics of alien aquatic vascular plants and their interactions with native plant and animal species.

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Tables and Figures

Table 1. List of alien aquatic vascular plants of the Hungarian flora. Taxa are arranged alphabetically. The total number of records referring the number of grid cells according to the system of Mapping of the Central European flora (Niklfeld 1971). Species new to the DAISIE (2009) list is marked. Citation refers to publication or herbarium specimens (collector, herbarium code and year). Family codes are formed by initial letters of the family name. Invasion status notations: cas-casual, nat-natural, inv-invasive. Pathway notations: esc-escape, unaid-unaided (with natural agents).

New to DAISIE list	Species name	Family	First observation	Citation	Total No. records	Invasion (Richardson 2000)	Temperature demand	Pathway (Hulme et al. 2008)
	Azolla filiculoides Lam.	Salv	1940	Soó 1964-1980	20	cas	Both	Esc, una
	Bacopa caroliniana (Walt.) B.L. Robins	Scroph	2005	Lukács observed & photo	1	inv	Thermal	Esc
	Bacopa monnieri (L.) Wettst.	Scroph	2005	Király (ed.) 2009	1	nat	Thermal	Esc
	Cabomba caroliniana A.Gray	Cabom	1937	Király et al. 2007	50	nat	Both	Una
	Ceratopteris thalictroides (L.) Brongn.	Pterid	1968	Suba 1968	2	inv	Thermal	Esc
	Egeria densa Planch.	Hydro	1960	Jávorka, Csapody & Juhász, BP, 1960	5	nat	Thermal	Esc, una
	Eichhornia crassipes (Mart.) Solms	Pont	1950	Soó 1964-1980	1	nat	Thermal	Esc
	Eichhornia diversifolia (Vahl) Urb.	Pont	2005	Király (ed.) 2009	1	cas	Thermal	Esc
	Elodea canadensis Michx.	Hydro	1885	Király et al. 2007	140	cas	Cold	Esc, una
	Elodea nuttallii (Planch.) H.St.John	Hydro	1991	Király et al. 2007	35	inv	Cold	Esc, una
	Gymnocoronis spilanthoides DC.	Aster	1988	Szabó 2002	3	inv	Thermal	Esc
x	*Houttuynia cordata* Thumb.	Sauru	2005	Lukács et al. 2008	1	nat	Thermal	Esc

	Hydrilla verticillata (L.f.) Royle	Hydro	1980	Felföldy BP, 1980	3	cas	Thermal	Esc
	Hydrocotyle ranunculoides L. f.	Apia	2005	Király (ed.) 2009	5	inv	Both	Esc
x	*Hygrophila corymbosa* Lindau.	Acan	2005	Lukács et al. 2008	1	inv	Thermal	Esc
x	*Hygrophila difformis* Blume	Acan	2005	Lukács et al. 2008	1	cas	Thermal	Esc
	Hygrophila polysperma (Roxb.) T.Anderson	Acan	1958	Suba 1968	5	cas	Thermal	Esc
	Lagarosiphon major (Ridl.) Moss	Hydro	2005	Király (ed.) 2009	3	nat	Thermal	Esc
	Lemna aequinoctialis Welw.	Lemna	2005	Mesterházy et al. 2008	6	nat	Cold	Esc, una
	Lemna minuta Kunth in F.W.H.von Humboldt	Lemna	1984	Mesterházy et al. 2007	40	inv	Cold	Esc, una
	Lemna turionifera Landolt	Lemna	2005	Mesterházy et al. 2008	14	inv	Cold	Esc, una
x	*Limnophila sessiliflora* (Vahl) Blume	Plant	1940	Soó 1964-1980	5	nat	Thermal	Esc
	Ludwigia alternifolia L.	Onag	1940	Soó 1964-1980	1	cas	Thermal	Esc
	Ludwigia grandiflora (Michx.) Greuter & Burdet	Onag	2005	Király (ed.) 2009	2	nat	Thermal	Esc
	Ludwigia repens J.R.Forst.	Onag	1924	Soó 1964-1980	7	nat	Thermal	Esc
	Mimulus guttatus Fisch. ex DC.	Scroph	1994	Balogh et al. 2001	3	nat	Thermal	Una
	Monochoria korsakowii Regel & Maack	Pont	1988	Bartha et al. 2000	3	nat	Both	Esc
	Myriophyllum aquaticum (Vell.) Verdc.	Halora	1968	Suba 1968	3	nat	Thermal	Esc
	Myriophyllum heterophyllum Michx.	Halora	2006	Barina 2006	2	nat	Thermal	Esc
	Najas gracillima (A. Braun ex Engelm.) Magnus	Hydro	2012	Mesterházy et al. 2014	1	nat	Thermal	Una
	Najas guadalupensis (Spreng.) Magnus	Hydro	2005	Király (ed.) 2009	3	nat	Thermal	Esc
	Nelumbo nucifera Gaertn.	Nelumb	1955	Soó 1964-1980	2	cas	Thermal	Esc
	Nuphar advena (Aiton) W.T. Aiton	Nymph	1920	Soó 1964-1980	1	nat	Thermal	Esc
	Nymphaea 'Blue Bird' (N. micrantha x N. capensis)	Nymph	1900	Szabó 2002	1	cas	Thermal	Esc
	Nymphaea lotus var. *thermalis* L.	Nymph	(1798)1842	Soó 1964-1980	3	inv	Thermal	Esc
	Nymphaea rubra Roxb. ex Andrews	Nymph	1891	Szabó 2002	3	nat	Thermal	Esc
	Nymphaea nouchali var. *caerulea* (Savigny) Verdc.	Nymph	1891	Szabó 2002	6	nat	Thermal	Esc

	Pistia stratiotes L.	Arac	1966	Soó 1964-1980	15	nat	Both	Una
	*Pontederia cord*ata L.	Pont	2005	Lukács observed & photo	1	inv	Both	Esc
x	*Rotala rotundifolia* (Buch.-Ham. ex Roxb.) Koehne	Lythr	1998	Szabó 2002	7	nat	Thermal	Esc
	Sagittaria subulata (L.) Buchenau	Alism	1965	Suba 1968	3	nat	Thermal	Esc
	Salvinia auriculata Aubl.	Salv	1964	Soó 1964-1980	1	nat	Thermal	Esc
	Saurus cernuus L.	Sauru	2005	Lukács observed & photo	1	cas	Thermal	Esc
	Shinnersia rivularis (A.Gray) R.M.King & H.Rob.	Aster	1998	Szabó 2002	5	nat	Thermal	Esc
	Utricularia gibba L.	Lentib	1936	Szabó 2002	1	nat	Thermal	Esc
x	*Vallisneria gigantea* Graebn.	Hydro	1891	Simonkai BP, 1891	7	nat	Thermal	Esc
	Vallisneria spiralis L.	Hydro	1808	Soó 1964-1980	16	inv	Thermal	Esc

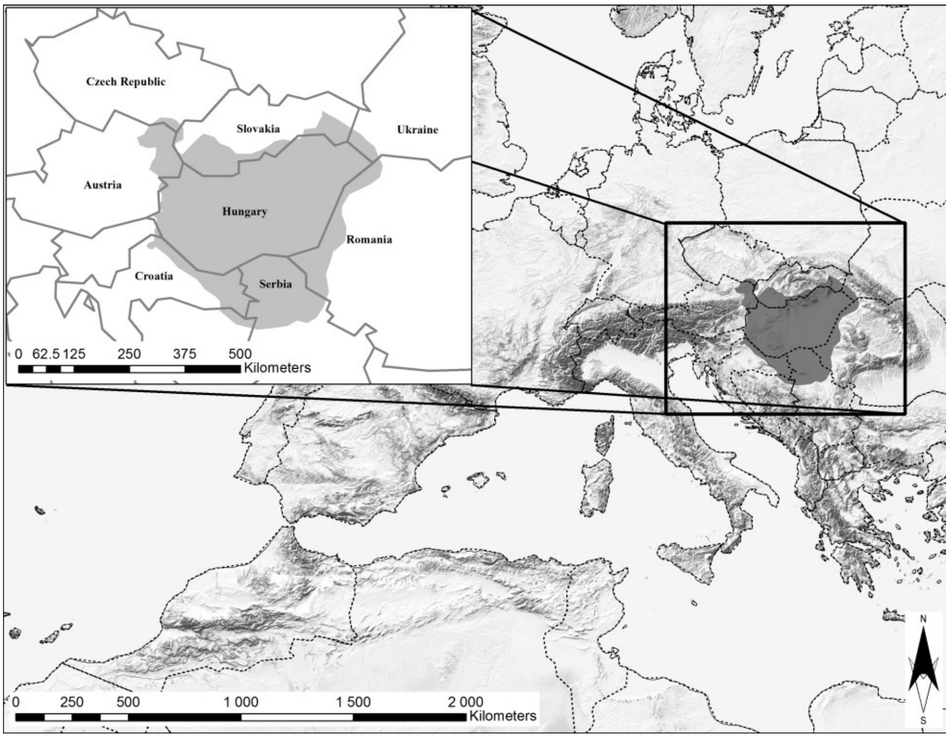

Figure 1. The location of the study area. Pannon Ecoregion is highlighted with grey.

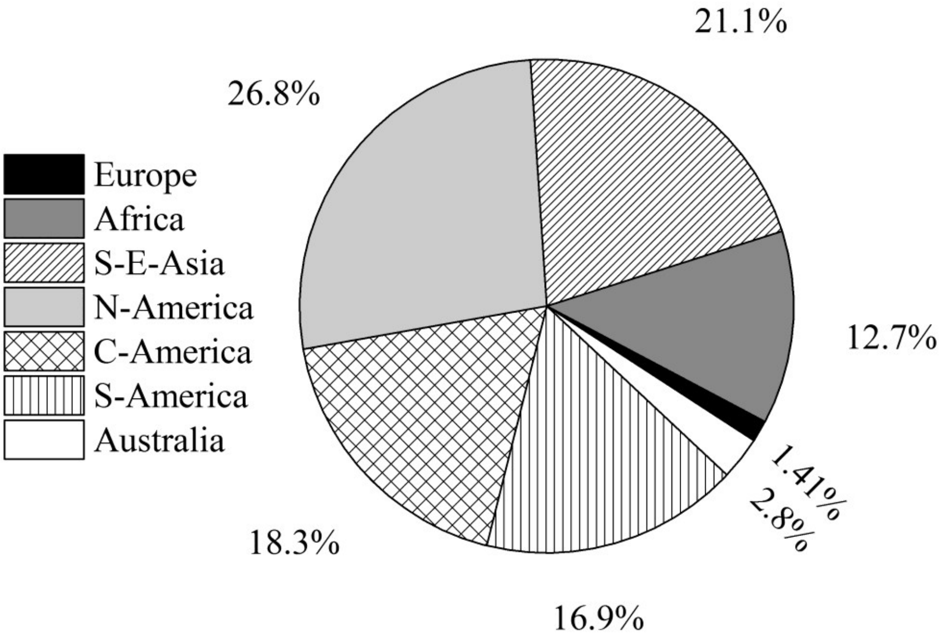

Figure 2. Native range of alien aquatic vascular plant species found in Hungary between 1808 and 2012.

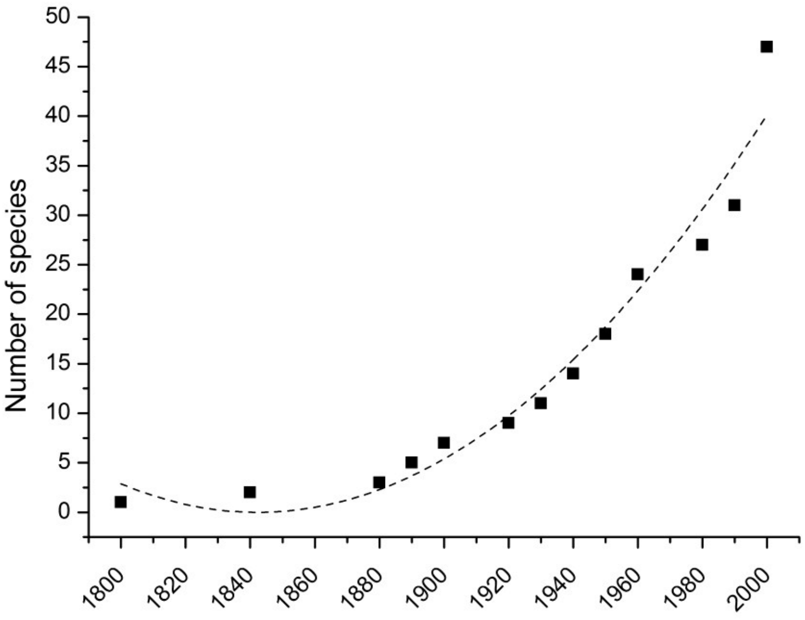

Figure 3. Historical trend of alien aquatic vascular plant species in Hungary from 1808 to 2012 (Dash line is polynomial regression: R^2=0.9474, $P < 0.001$).