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Towards an Understanding of the Geographical Background of Plants Invasion as a Natural Hazard: a Case Study in Hungary

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Abstract

Biological invasion is a worldwide phenomenon that can be considered a natural hazard. Protection against invasive plant species can only be successful if we know the anthropogenic factors that influence their occurrence, such as changes in land cover. In our study, we investigated the LUCAS based spatial distribution of five common invasive plant species (2015) and its connections with the recent (2012-2018) land CORINE based cover changes. The LUCAS points infected with this species are much closer to the CORINE land cover change polygons than the non-infected points. Our results suggest that the occurrence of *Asclepias syriaca*, *Solidago* spp, *Ailanthus altissima* and *Robinia pseudoacacia* is significantly dependent on whether land use has changed in the vicinity of LUCAS points infected with these species. Only the occurrence of *Elaeagnus angustifolia* does not show any correlation with changes in land cover.

Keywords: land use change; biological invasion; natural risk; vegetation naturalness; anthropogenic processes

Introduction

Biological invasion is one of the greatest environmental challenges of our days and a geographical hazard with significant health and economic impacts (Kleinbauer et al., 2010; Genovesi & Monaco, 2014; Kézdy et al., 2018). Biological invasion is an environmental risk that has been accelerating in recent decades. Globalisation processes (e.g. international trade and transport of goods) allow plant and animal species to move easily from one continent to another. These moving species can be more successful than the native vegetation in the new geographical context. In addition to global market processes, climate change may also accelerate the spread of certain invasive plant species and the decline of biodiversity (Hulme, 2021; Manzoor et al., 2021). Biological invasion is therefore a spatial process that poses a significant environmental risk, and only a holistic approach, which is offered by geography can be successful to understand its consequences (Kitka & Szilassi, 2016; Szilassi et al., 2019; Szilassi et al., 2021). Exploring the causes of biological invasion using spatial methods (e.g. GIS-based spatial statistical analyses) can bring us closer to understanding the natural and anthropo-

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genic processes that drive the spread of invasive species worldwide (Mezősi et al., 2014; Mezősi, 2022).

The five invasive plant species- tree of heaven (*Ailanthus altissima*), common milkweed (*Asclepias syriaca*), Russian olive (*Elaeagnus angustifolia*), black locust (*Robinia pseudoacacia*), Goldenrods (*Solidago* spp.)- we have studied are spread extensively across the Eurasian continent (Pyšek et al., 2009).

Ailanthus altissima has been popularly planted in cities, but in addition to completely infesting cities and other degraded areas, it also infests natural communities. Many parts of *Ailanthus altissima* contain allelopathic substances that inhibit the growth of other plants (Mihály & Botta-Dukát, 2004).

Asclepias syriaca is a plant of disturbed habitats and can prevent the regeneration of semi-natural communities in the areas it occupies. The spread of *Asclepias syriaca* in sandy grasslands has resulted in a significant reduction in the cover of native species, especially those with low competitive ability (Kelemen et al., 2016).

Elaeagnus angustifolia prefers saline soils, so it was planted in Hungary to bind sandy areas and to cover saline soils. In addition, it was also planted along motorways and at the edge of forests (Bartha & Csiszár 2012; Lundgren et al., 2004). In the case of infestation of open habitats, it crowds out light-demanding species, thereby reducing species richness (Csiszár, 2012).

Robinia pseudoacacia has been planted for a long time in Hungary for a wide range of purposes almost everywhere. Where it has been planted or spontaneously established, it is quite difficult to remove, as it spreads well from rootstocks and its seeds germinate for a very long time. *Robinia pseudoacacia* induces nitrogen enrichment in the soil (as does Elaeagnus angustifolia), thus facilitating the establishment of nitrogen-favouring weeds, in addition, similar to *Ailanthus angustifolia*, it releases allelopathic substances (Kleinbauer et al., 2010).

Solidago spp. also spreads rapidly and aggressively and they produce pollen which is harmful to human health (Csiszár et al., 2020; Mihály & Botta-Dukát, 2004).

About 3% of the Hungarian flora (approximately 70 species) are invasive weed species (Mihály & Botta-Dukát, 2004). The European Union's list of the most dangerous invasive species with the highest risk of spreading includes 24 terrestrial plant species (DAISE, 2009).

Some of the geographic factors determining the occurrence of invasive plants are related to physical geography, while others are related to human activities. In our previous publications, we have shown that anthropogenic factors such as linear transport infrastructure (road and rail networks), surface water courses and ecological networks can facilitate the migration of some invasive plant species (Szilassi et al., 2021). In this paper, we investigate the relationship between the distribution data of five invasive plant species - widespread in Hungary and throughout the Eurasian continent - and changes in land cover within the whole territory of Hungary (another process of typically anthropogenic origin) (Csiszár et al., 2020). Our basic hypothesis is that land cover changes may facilitate the spread of many invasive plant species. In many cases, changes in land cover (e.g. deforestation, road construction) disturb natural and semi-natural ecosystems, and these disturbed - often barren - areas are more successfully and rapidly invaded by invasive species than by native plant species (Kálmán, 2014). In addition, changes in land cover are often associated with changes in soil characteristics, light conditions and microclimate (Csontos et al., 2009; DAISE, 2009; Dukes, 2004; Follak et al. 2021; Pyšek et al., 2009).

Here we compared the Euclidean distances between the invaded and uninvaded points of the five invasive plants and the nearest polygons of the land cover on a national-scale in Hungary. The aim of our research is to answer, how changes in land cover influence the occurrence of the five invasive species?

Materials and methods

Study area

Our investigations were conducted in Hungary. The country has a humid continental climate in Central Europe. The average annual temperature is 10.5 °C and the average annual precipitation is 550 mm. Climate change increases weather extremes, with a high probability of summer drought. The lowland areas of the Carpathian Basin are characterised by high soil fertility (mainly chernozem soils) (Dövényi et al., 2008). Arable land is the dominant land use type (about 50%). The proportion of the forested areas is 21% in Hungary, however, *Robinia pseudoacacia* has a considerable proportion, accounting for about 5% of the total area of the country. Biological invasions have severely damaged natural or semi-natural habitats about 13.1% of these habitats being invaded by alien species (Csiszár et al., 2020). In Hungary, the main types of land cover change are the loss of grassland due to the increase in artifical surfaces and forest cover, and the land abandonment in areas of lower soil fertility (Bíró et al., 2013,a,b).

Digital databases

Based on the 2015 field survey points for Hungary from the EUROSTAT Land Use and Coverage Area frame Survey (LUCAS) database, we produced a list of five invasive plant species -*Ailanthus altissima, Asclepias syriaca, Elaeagnus angustifolia, Robinia pseudoacacia* and *Solidago* spp. that are widespread in Europe and in Hungary (Fig1).

The spatial distribution of these invasive species shows large variation in Hungary, and the relationship of this spatial pattern with recent (2012-2018) land cover changes is not yet sufficiently clear (Fig1). The above species were mapped based on visual interpretation of more than 25 000 ground photographic images taken at 5169 field sites in about 5000 LUCAS surveys in Hungary. During the 2015 LUCAS survey, the predefined network of designated field survey points was surveyed based on visual interpretation of more than 25 000 ground photographs taken at 5169 field sites in about 5000 Hungarian LUCAS 2015 locations (Gallego et al., 2015; Szilassi et al., 2021). During the 2015 LUCAS survey, the predefined network of designated field survey points was located on average 3 km from each other. If we were able to identify at least one of the plant species we surveyed in one of the photographs taken at the points, we considered that LUCAS point is infected with that species (Szilassi et al., 2019). *Solidago canadensis* and *Solidago gigantea* were identified only at genus level as *Solidago* spp. (Szilassi et al., 2021).

The spatial patterns of land cover change between 2012-2018 were analysed using the CORINE digital map database. The CORINE Land Cover (CLC) database is a regional scale (1:100 0000) land cover database for the European Union, using a uniform mapping methodology, which describes land cover changes, including between 2012 and 2015, based on a consistent nomenclature (Büttner & Koszta, 2011).

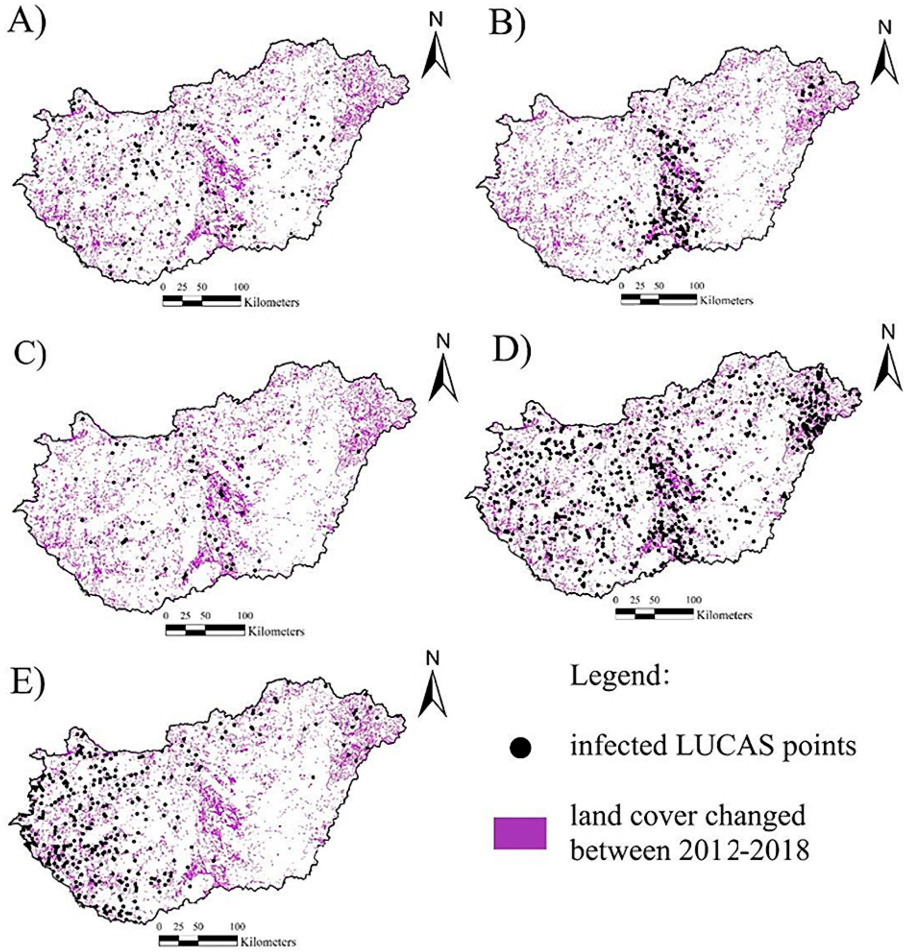

Figure 1. The areas with changed land cover, and the country-scale distribution of the investigated five invasive plants

2.3 GIS and statistical analysis

Using the spatial analysis tool of ArcGIS 10.7 software, we calculated the Euclidean distances between the LUCAS points of the five plant species (both infected and uninfected) and the nearest land cover change polygons. The resulting distance values were compared with each other using boxplot diagrams for each invasive plant, divided into infected and uninfected LUCAS point groups, using R-software. The average, median, and standard deviation of the distances of LUCAS points from CLC change polygons of LUCAS points for each investigated plant species were calculated separately for those infected by the plant (where the plant occurs) and those not infected by the plant (where the plant does not occur). We also calculated, for each of the five studied plants, how much closer the LUCAS points infected with a given species are to the CLC land cover change polygons than the LUCAS points not infected with a given species. We subtracted the mean distances, standard deviation and median values of the distances of the non-infected points to the CLC change polygons from the mean distances, standard deviation and median values of the infected LUCAS points. If the value of the difference thus obtained has a positive sign, it means that individuals of the species are located closer to the CLC change polygons than to the uninfected points, i.e. the occurrence of the species is dependent on the change in the surface cover.

Statistical analyses were carried out using R studio software. For statistical analysis, we used the one-way ANOVA model with the function *aov*() (Fisher, 1925). In the model, distances of infected LUCAS points was the dependent variable and species was the independent variable. The pairwise comparison of LUCAS points infected with each species was performed with a Tukey post-hoc test with the function *TukeyHSD*().

Results

In the distribution map produced from the 2015 LUCAS survey, there were significantly fewer LUCAS points infected with the species than uninfected points. *Robinia pseudoacacia* has the highest and *Ailanthus altissima* the lowest proportion of infected points. An intermediate value was obtained for *Asclepias syriaca, Elaeagnus angustifolia, Solidago* spp. (Table 1).

The means and medians of the Euclidean distances of non-invaded LUCAS points from areas of changed land cover show similar values for all plants. However, there is significant variation among the invasive species when comparing the means and medians of the distances of infected points from CLC change polygons (Table 1).

The most significant relationship between land use change and the presence or spread of the species was found for *Asclepias syriaca* (1214.5 m) and the LUCAS points infected with it were spatially closest on average to the land cover change polygons. The distribution of the other investigated invasive plant species (*Ailanthus altissima*, *Robinia pseudoacacia*, and *Soli-*

Table 1. Summary statistics of the Euclidean distances between the LUCAS survey (2015) points and the nearest CLC (2012-2018) polygons

Species name	LUCAS point type	Number of LUCAS points	Distance between the LUCAS survey (2015) points and the nearest CLC (2012-2018) polygons		
			Average (m)	Median (m)	SD
Ailanthus altissima	Uninfected	5098	2257.3	1747.5	1976.3
	Infected	71	1594.7	1155.4	1473.0
	Difference*	-	662.7	592.2	503.2
Asclepias syriaca	Uninfected	4974	2298.4	1793.8	1979.8
	Infected	195	1083.9	634.7	1305.3
	Difference*	-	1214.5	1159.1	674.4
Elaeagnus angustifolia	Uninfected	5001	2248.2	1739.1	1967.6
	Infected	168	2220.3	1661.2	2063.0
	Difference*	-	27.9	77.9	-95.3
Robinia pseudoacacia	Uninfected	4538	2342.9	1852.7	1995.9
	Infected	630	1639.7	1105.9	1684.6
	Difference*	-	703.2	746.8	311.2
Solidago spp.	Uninfected	4844	2290.8	1768.6	2005.2
	Infected	324	1670.2	1364.3	1321.5
	Difference*	-	620.6	404.3	683.7

**Distance of uninfected points: Euclidean distance from the land cover changed areas minus Euclidean distance of infected points from the land cover changed areas*

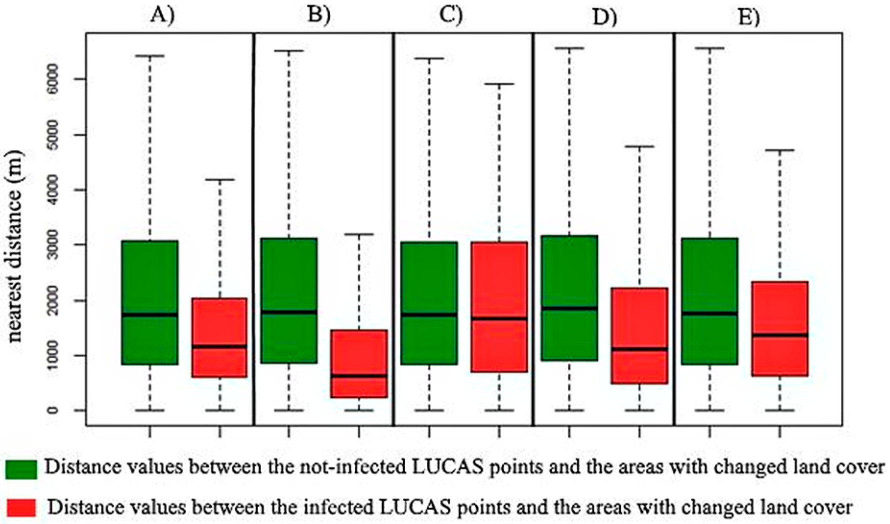

Figure 2. The distribution of Euclidean distances between the uninfected LUCAS points and the changed land cover areas. The distribution of Euclidean distances between the infected points and the changed land cover areas of the investigated invasive plants in a boxplot diagram

dago spp.) was also connected with land cover change. However, no relationship between landscape change and the distribution of the species was found for *Elaeagnus angustifolia*, as infected points were only marginally closer to CLC polygons, averaging only 27.90 m, compared to the average distances of LUCAS points uninfected with this species to CLC polygons (Table 1).

The distances of non-infected and infected LUCAS points from CLC polygons of the species studied differed in their median values to a similar extent as was seen for the mean values. Thus, it is clear from the differences in median values that while there is a significant difference in the Euclidean distances of infected and non-infected points from CLC polygons for the common milkweed (*Asclepias syriaca*), goldenrod (*Solidago* spp.), black locust (*Robinia pseudoacacia*), and tree of heaven (*Ailanthus altissima*). Nevertheless, the difference in both median and mean values for Russian olive (*Elaeagnus angustifolia*) is negligible, it is below 100 m (Table 1).

The fact that occurrence of *Elaeagnus angustifolia* is not related to changes in land use can also be concluded from the fact that the distance values of LUCAS points not infected with *Elaeagnus angustifolia* in 2015 show a much smaller spatial variance (spatial diversity) than those of the infected points compared to the areas with a change in land cover between 2012 and 2018. Therefore, the standard deviations of these distances is only negative for this species (Table 1, Fig 2).

Pairwise comparison of distances between infected LUCAS points show, a significant difference was obtained when Elaeagnus angustifolia and Asclepias syriaca (p< 0,001), *Robinia pseudoacacia* and *Asclepias syriaca* (p< 0,001), *Solidago* spp. and *Asclepias syriaca* (p<0,001), *Robinia pseudoacacia* and *Elaeagnus angustifolia* (p< 0,001) and *Solidago* spp. and *Elaeagnus angustifolia* (p= 0,003) pairs were compared (Table 2).

Table 2. Statistical analysis of the distances between LUCAS points infected with each species

Pairwise comparison of distances between infected LUCAS points for each species	p-value
Asclepias syriaca - Ailanthus altissima	0.146
Elaeagnus angustifolia - Ailanthus altissima	0.047
Robinia pseudoacacia - Ailanthus altissima	0.999
Solidago spp. - *Ailanthus altissima*	0.996
Elaeagnus angustifolia - Asclepias syriaca	< 0,001
Robinia pseudoacacia - Asclepias syriaca	< 0,001
Solidago spp. - *Asclepias syriaca*	< 0,001
Robinia pseudoacacia - Elaeagnus angustifolia	< 0,001
Solidago spp. - *Elaeagnus angustifolia*	0.003
Solidago spp. - *Robinia pseudoacacia*	0.999

Discussion

There is considerable variation between all investigated invasive species in relation to the type and weight of geographical factors influencing their occurrence. The presence or absence of a given invasive plant species is strongly related to different environmental (soil, climatic etc.) factors. One of these geographic and environmental factors is land cover, which is most often the result of anthropogenic processes. In our research, we found that changes in land cover may play different roles and have different importance in the distribution of the five studied invasive plant species.

The variation in adaptability of invasive plants may be related to the fact that the species studied are all broadly tolerant, occupying similar yet slightly different ecological niches in many aspects. For example, the tree of heaven is more commonly found in the urban environment around landfills and construction sites. The connection of the tree of heaven with land cover change, supported by our research results, is well explained, as its occurrence is linked to urbanisation and land cover changes in suburban areas (Knapp et al., 2000; Kowarik & Säumel, 2007; Kowarik, 2011).

The fact that *Elaeagnus angustifolia* does not show any relationship with land cover change has been confirmed in previous studies. The spread of *Elaeagnus angustifolia* is closely linked to urbanisation, water and cannel networks, and it prefers soils with salt accumulation. (Kitka & Szilassi, 2016; Szilassi et al., 2021).

Our results show that *Asclepias syriaca* is the most successful of the five invasive plants studied in colonising new habitats, such as open spaces, which are transformed by land cover change (Kitka & Szilassi, 2016; Bakacsy & Bagi, 2020). The occurrence of *Asclepias syriaca* mainly in disturbed habitats where natural competitors are absent. In these habitats, disturbance is a more important environmental factor than soil conditions (Mihály & Botta-Dukát, 2004). However, *Robinia pseudoacacia, Ailanthus altissima,* and *Solidago* spp. have the potential to easily conquer these new habitats as well (Török et al., 2003). The seeds of *Robinia pseudoacacia* can remain germinating for a very long time, for several decades. The initiation of germination is often triggered by human activities such as ploughing, burning or trampling, i.e. activities that lead to tangle. Land-use change is often accompanied by habitat disturbance, which favours the germination and spread of *Robinia pseudoacacia* (Csiszár, 2012).

As a result of land use change in many cases the agricultural fields turns into fallows. The best conditions for *Solidago* spp. and *Asclepias syriaca* seed germination are in abandoned agricultural fields, and it readily appears in fallow or neglected areas (Kitka & Szilassi, 2016; Szilassi et al., 2019).

The occurrence hotspots of *Ailanthus altissima* are located in cities, dumpsites, railway embankments and other devastated surfaces from here it spreads along road networks (Szilassi et al., 2019; Szilassi et al., 2021). To be able to settle, it needs soil disturbance and this often occurs as a result of land use change (Mihály & Botta-Dukát, 2004).

The barren surfaces created by construction sites are potential habitat for many pioneer weed species which are highly adapted to extreme environmental conditions (e.g. compact soil, drought, intense light). The impact of deforestation and plantations on biological invasion has been shown by several authors (Huebner, 2009; Warren et al., 2011). Our research has also shown that, in addition to common milkweed (*Asclepias syriaca*), the goldenrod (*Solidago* spp.) and black locust (*Robinia pseudoacacia*) also prefer spontaneously shrubby areas with changing land use (Csontos et al., 2009; Kelemen et al., 2016).

Deforestation and logging can also alter light, temperature and humidity conditions (Call and Nilsen, 2003), but can also significantly change the thickness of the topsoil layer. All of these factors result in changes in forest land cover that favour the occurrence of many invasive plant species (Webb et al., 2001). Our research supports Knapp & Canham's (2000) findings that clearcutting promotes the emergence and expansion of the tree of heaven.

Conclusions

For four of the five invasive plants studied in our research, we were able to show a strong correlation between changes in land cover and the distribution of the species. We have shown that land cover is one of the anthropogenic drivers of invasion and should be considered when invasion hazard maps are constructed. Our results can be used as input for land-use planning in protected areas, for the construction of distribution models for different invasive plants, and for a better understanding of the geographical background of biological invasion as an environmental risk (Genovesi et al., 2010).

The research methodology contributes to the understanding of the anthropogenic causes of biological invasions, and the relationship between land cover change and the distribution and spread of invasive plants. The results obtained can be used to model invasion risk and provide inputs for the assessment of invasion risk.

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