ECOLOGICAL DYNAMICS: THE SPREAD OF INVASIVE PLANT SPECIES IN HUNGARY'S ECOSYSTEM TYPES BETWEEN 2009-2018

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Abstract
Our research focuses on analyzing the spatiotemporal dynamics of five invasive plant species (Ailanthus altissima, Asclepias syriaca, Elaeagnus angustifolia, Robinia pseudoacacia, and Solidago spp.) in various ecosystem types in Hungary from 2009 to 2018.
Using the National Geospatial Database of Invasive Plants (NGDIP) and the Ecosystem Map of Hungary (EMH), we examine how these species' distribution and occurrence changed over time. Our methodology and findings offer valuable insights for invasive species research.
Our results indicate that Asclepias syriaca and Robinia pseudoacacia increasingly threaten grasslands and complex cultivated areas. Ailanthus altissima and Asclepias syriaca are declining in urban settings due to harsher environmental conditions, while Solidago spp. are expanding in wetlands, impacting riparian biodiversity."

Introduction
The dramatic spread of invasive plant species is a worldwide problem for nature conservation. In addition to causing the decline in the abundance of native species [1], invasive plants often pose a threat to human health due to their allergenic characteristics [2] and, in many cases, are reasons for soil degradation [3,4].

The extension of biological invasion can be extremely rapid, causing changes in ecosystem functions and conditions over a few years; this effect might fade with time in the long-term [1]. The maps of the National Geospatial Database of Invasive Plants (NGDIP) of Hungary, based on the Land Use and Coverage Area Frame Survey (LUCAS) point-cover photo data collections (2009, 2012, 2015, and 2018), showed significant changes in the extent of invasive plant distribution of Hungary [5]. Ecosystem types mean land cover and habitat types with functions related to ecosystem services.

The detailed thematic Ecosystem Map of Hungary (EMH), covering the whole territory of Hungary, has a high spatial resolution (20 × 20 m raster size as the minimal mapping unit). It offers a potential basis to evaluate the spreading trends in relation to ecosystem types when overlaid with the distribution of invasive plants of each type in Hungary [6-8].
In our research, we answered the following questions:
• What has been the trend in the level of invasion of different types of land cover (ecosystems) in Hungary between 2006 and 2018?

• Which types of ecosystems of conservation importance are most threatened by the biological invasion of the studied species?

To answer these questions, we calculated the proportions of invaded LUCAS points relative to the total LUCAS points for each year (2009, 2012, 2015, and 2018) and, then, determined the proportion in the distribution of invasion for each ecosystem type for 2009, 2012, 2015, and 2018, respectively. Based on the frequency of invasion of these four samplings in a ten-year period, we were able to identify those land-cover (ecosystem) types where the e occurrence of the species in question changed significantly between 2009 and 2018.

Materials and Methods

The first used database is the National Geospatial Database of Invasive Plants (NGDIP) of Hungary, which is part of the invasive plant monitoring initiative of the Department of Geoinformatics, Physical, and Environmental Geography at the University of Szeged, based on the LUCAS point dataset (survey of land use, land cover, and agricultural statistics for all EU member states. The investigated invasive plants were identified by the ecologists of the Department of Ecology of the University of Szeged through visual interpretation of more than 100,000 LUCAS photos from all the field observation points of 2009, 2012, 2015, and 2018 of LUCAS surveys in Hungary. The analysts aimed to identify invasive plants based on their phenological (morphological) characteristics.

Table 1. Occurrence of invasive species on the National Invasive Species Database (INOTA) of Hungary.

Invasive Species	Invaded LUCAS Points in 2009		Invaded LUCAS Points in 2012		Invaded LUCAS Points in 2015		Invaded LUCAS Points in 2018	
	(N)	Average Invasion	(N)	Average Invasion	(N)	Average Invasion	(N)	Average Invasion
Ailanthus altissima	86	1.64%	48	1.05%	71	1.56%	80	1.96%
Asclepias syriaca	250	4.92%	132	2.93%	195	4.40%	175	4.50%
Eleaeagnus angustifolia	251	4.94%	69	1.51%	168	3.77%	71	1.74%
Robinia pseudoacacia	1149	27.47%	714	18.20%	630	15.77%	695	20.08%
Solidago spp.	413	8.40%	299	6.89%	323	7.51%	297	7.70%
All LUCAS points in Hungary	LUCAS points in 2009		LUCAS points in 2012		LUCAS points in 2015		LUCAS points in 2018	
	5332 = 100%		4637 = 100%		4625 = 100%		4156 = 100%	

The other used database was the Ecosystem Map of Hungary (EMH) which was published in 2018 as an open-access land-cover database of Hungary. It shows the ecosystem types of Hungary in detail at a fine scale, providing an excellent tool for conservation biology, landscape ecology, and geographic research [9]. The 20 × 20 m raster resolution base map is a hierarchical system, corresponding to MAES Level 2 types of ecosystems or habitats

GIS and statistical methods. We conducted a spatial intersection between the polygons of EMH and the LUCAS points from the NGDIP dataset, then summed the number of points within each habitat type that were invaded and noninvaded with the given species. To allow time-series analysis, we had to treat the data separately by species and years. We subtracted this ratio from the national averages of invaded points for a given year per species. To determine the temporal changes in invasion of the ecosystem types, we subtracted the percentage of the national average invasion rate of each species from the infection percentage of the given ecosystem types in the examined year.

Using Microsoft Excel, we calculated the relative proportion of invaded versus noninvaded points per ecosystem type using the formula below:

$$PR_{(1-17)} = \left[\left(\frac{INV_{(1-17)}}{LUCAS_{(1-17)}}\right) \times 100\right] - \left[\left(\frac{INVH}{LH}\right) \times 100\right]$$

Number of Level 2 ecosystem types: 17
PR—invasion percentage of the ecosystem types; i.e., the proportion of LUCAS points invaded with the given species in the given year within the EMH ecosystem types (%).
INV—Total number of LUCAS points invaded with a given species within a given EMH ecosystem type in the survey year (2009, 2012, 2015, and 2018).
LUCAS—Total number of LUCAS points within a given EMH ecosystem type each year (2009, 2012, 2015, and 2018).
INVH—Total number of invaded LUCAS points in Hungary each year (2009, 2012, 2015, and 2018).
LH—Total number of LUCAS points in Hungary each year (2009, 2012, 2015, and 2018).

We calculated the percentage of LUCAS points invaded with the species each year within the EMH ecosystem types (Tables A3–A7). Using the PR values of the survey years (2009, 2012, 2015, and 2018), we calculated trends of change for each ecosystem type using linear, logarithmic, exponential, and power regression (R^2), and plotted the most significant changes on graphs. If the R2 value of the trend line for the study years was greater than or equal to 0.7 R^2 , then the change in invasion rate within the ecosystem type was considered a strong determination value. Although there is no definitive limit on what counts as a strong correlation, say $|r| > 0.70$, it is assumed to indicate a strong determination value. [10], The direction of change within the studied period (2009–2018) could decrease if the proportion of infection of an EMH ecosystem type with a given species decreased significantly. An increasing trend can also be distinguished if the proportion of invasion of an EMH ecosystem type with a given species increased significantly with a coefficient of determination above 0.7 R^2 .

Results and discussion

This study revealed the importance of ecosystem types regarding the level of invasion by the five investigated species based on a thorough, national-level analysis. It was already demonstrated in other studies that the invasibility (susceptibility to invasion), or the degree of invasion of habitat types can be very different [11], and mostly driven by human processes [12]. We have demonstrated these differences in the degree of invasion over a period of ten years.

This general picture shows that the studied species mainly invade intensively humanimpacted ecosystems (disturbed, cultivated, and urban); out of eleven types, only three are seminatural, native ecosystems. This demonstrates that if the structural stability ensured by species interactions (competitions and facilitations) is disturbed, newly arriving invasive species can more easily gain importance [13].

The type and intensity of land use have been recorded to influence the severity of invasion by different organisms [14]. In most studied cases, an increase in the frequency of invaded points was detected. This increase is most pronounced in the case of intensively used ecosystems, like arable land, roads and railways, other herbaceous vegetation, permanent crops, complex cultivation areas, and plantations. The higher invasibility of disturbed (mainly humanaffected) ecosystems was reported elsewhere [15,16].

This study has determined the level of invasion and its trends during ten years for five invasive species at a national level as a first survey. The data and the knowledge gained can improve awareness of the process of invasion, which has huge socioeconomic and health impacts [17]. Knowledge of the levels of invasion can help to explore how the abundance of invasive species affects species and communities and discover eventual saturation processes [1].

Shedding light on the invasibility of different ecosystems is also of great importance because it can help to identify the most vulnerable ecosystems for proactive management [18] and support further studies on which characteristics of communities influence the vulnerability against invaders [13]. As the level and the trend of invasion can vary among regions and might be different at finer scales that also influence the cost of invasion impact [17], the national-level survey must be complemented by further investigations.

Conclusion

We identified the main Ecosystem Map of Hungary (EMH) land-use (ecosystem) types within which the infestation rate of the five invasive species under study varied between
2009 and 2018 above a significant trend (R2 ≥ 0.7). We plotted significant decreasing or increasing changes on graphs.

After completing the analysis, we can state that Ailanthus altissima is spreading rapidly near roads and railways. Asclepias syriaca occurrence is increasing in diverse, mosaic, so called complex landscapes (where the land-cover heterogeneity is high), and in natural grassland habitats. It can be concluded that grasslands are the most threatened ecosystems by plant invasion in Hungary, as Asclepias syriaca and Robinia pseudoacacia are increasingly covered in these areas. It would be important to find the best conservation management technologies (for instance, an increase in grazing livestock) to reduce the spread of these plants. Wetlands are also prone to invasion by the investigated species, especially Solidago spp. and Robinia pseudoacacia. Solidago spp. species spread in wetlands, posing a growing threat to floodplain habitats around water bodies.
The results presented in our research can contribute to the conservation of biodiversity, to understanding the spread and geographical background of invasive plants, and to the development of appropriate conservation management methods.

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