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Analysis of the Distribution of Invasive Plant Species on Agricultural Lands in the Carpathian Region

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SUMMARY

Invasive plant species are among the major drivers of agroecosystem degradation, as they adversely affect biodiversity, agricultural land productivity, and the ecological stability of landscapes. This study examines the spatial distribution of invasive plant species on agricultural lands in the Carpathian region. The current distribution patterns of the most hazardous invasive species are analyzed, and the main natural and anthropogenic factors contributing to their spread are identified. Particular attention is paid to the application of Geographic Information Systems (GIS) and Remote Sensing (RS) technologies for the detection, mapping, and monitoring of invasive plant populations. The findings can be used to assess environmental risks, support the planning of invasive species management measures, and facilitate informed decision-making for the sustainable use of agricultural lands in the Carpathian region.

Keywords: Invasive plant species; Agricultural lands; Carpathian region; GIS; Remote Sensing; Spatial analysis; Mapping; Monitoring; Agroecosystems; Environmental risks.

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Introduction

The rapid spread of invasive plant species has become one of the most significant environmental challenges affecting natural and agricultural ecosystems worldwide. Biological invasions threaten biodiversity, reduce agricultural productivity, alter ecosystem functions, and cause substantial economic losses (Lipińska et al., 2023). Agricultural lands are particularly vulnerable to invasive species due to intensive land use, frequent soil disturbance, and the continuous movement of agricultural machinery, seeds, and other vectors that facilitate plant dispersal (Lipińska et al., 2023).

The Carpathian region represents a unique area characterized by high biological diversity, diverse climatic conditions, and extensive agricultural landscapes. In recent decades, both climate change and increasing anthropogenic pressure have accelerated the establishment and expansion of invasive plant species throughout the region. Species such as Solidago canadensis, Ambrosia artemisiifolia, Heracleum sosnowskyi, and Impatiens glandulifera have demonstrated a remarkable ability to colonize agricultural fields, abandoned lands, roadsides, and riparian zones, posing serious ecological and economic concerns (Lipińska et al., 2023).

Recent advances in Geographic Information Systems (GIS), remote sensing, and spatial analysis have significantly improved the ability to detect, monitor, and assess the distribution of invasive plant species over large areas. Satellite imagery, unmanned aerial vehicles (UAVs), and geospatial modelling provide efficient tools for mapping invasion hotspots, analysing spatial patterns, and supporting evidence-based management decisions (Nininahazwe et al., 2023; Zaka et al., 2024; Chetverikov et al., 2024).

The aim of this study is to analyze the distribution of invasive plant species on agricultural lands in the Carpathian region using geospatial technologies. The research focuses on identifying spatial distribution patterns, assessing the factors influencing the spread of invasive species, and demonstrating the potential of GIS and remote sensing techniques for monitoring invasive vegetation and supporting sustainable agricultural land management.

Method and Theory

The study of the distribution of invasive plant species on agricultural lands in the Carpathian region was conducted using modern GIS, Remote Sensing techniques, and spatial analysis methods. The research methodology included the collection of geospatial data, data preprocessing, invasive vegetation mapping, and the analysis of spatial distribution patterns. The primary data sources included Sentinel-2 satellite imagery, the State Land Cadastre of Ukraine, open geospatial databases (OpenStreetMap and the Copernicus Land Monitoring Service), as well as field survey data and published scientific literature on the distribution of invasive plant species.

Satellite image processing was performed using QGIS and Google Earth Engine. To improve image interpretation accuracy, atmospheric correction was applied, multispectral composite images were generated, and vegetation indices, including the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI), were calculated. These procedures enabled the identification of vegetation communities with spectral characteristics typical of invasive plant species and facilitated the assessment of their spatial distribution (Helber et al., 2019; Xing et al., 2024).

Subsequent analysis included land cover classification, identification of areas potentially affected by invasive plant species, and the preparation of thematic maps. Spatial analyses were performed using buffer analysis, Kernel Density Estimation (KDE), and statistical methods to evaluate the relationships between invasive species occurrence and selected environmental and anthropogenic factors (Nininahazwe et al., 2023; Zaka et al., 2024).

The density of invasive plant occurrence was calculated using the following equation:

$$\boldsymbol{D} = \frac{\boldsymbol{N}}{\boldsymbol{A}} \tag{1}$$

where D is the density of invasive plant occurrence (hotspots km^2); N is the number of identified invasion hotspots; and A is the area of the study region (km^2).

The spatial variables considered in the analysis included: distance to roads; distance to rivers and streams; land-use type; elevation above sea level; slope; slope aspect; mean annual air temperature; annual precipitation. The processed datasets were integrated into a GIS database, enabling the spatial assessment of the most affected agricultural areas and the development of invasion risk maps for the Carpathian region. The resulting geospatial database provides a basis for monitoring invasive plant species, assessing environmental risks, and supporting sustainable agricultural land management. The study was conducted within the Ukrainian Carpathian region, encompassing four administrative regions: Zakarpattia, Lviv, Ivano-Frankivsk, and Chernivtsi oblasts (Figure 1). The study area covers approximately 56,600 km² and represents one of the most ecologically diverse regions of Ukraine. It is characterized by a mountain landscapes, foothill zones, river valleys, forests, grasslands, and extensive agricultural lands.

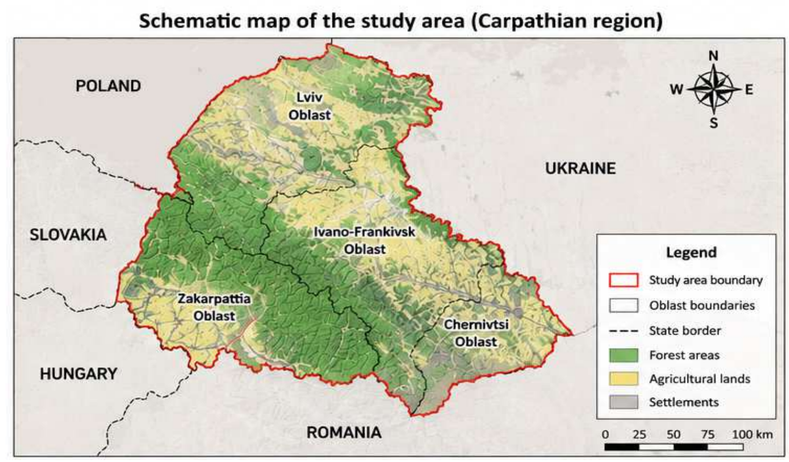

Figure 1. *Location of the study area within the Ukrainian Carpathian region*

The Ukrainian Carpathians elevation ranges from approx. 100 m in the lowland areas more than 2 km above sea level in the Chornohora mountain range. Such pronounced topographic variation creates diverse climatic and environmental conditions that influence vegetation distribution and the spread of invasive plant species.

Agricultural lands occupy a substantial proportion of the study area and include arable fields, hayfields, pastures, orchards, and abandoned agricultural lands. These landscapes are highly heterogeneous and are intersected by a dense network of roads, rivers, and settlements, which facilitate the dispersal of invasive plant species. River valleys of the Tysa, Dniester, Prut, and their tributaries are considered major ecological corridors promoting the expansion of invasive vegetation.

The study focused on four widespread invasive plant species that pose significant ecological and agricultural threats within the Carpathian region: Canada goldenrod (Solidago canadensis), common ragweed (Ambrosia artemisiifolia), giant hogweed (Heracleum sosnowskyi), and Himalayan balsam (Impatiens glandulifera). These species frequently colonize agricultural fields, abandoned farmlands, road verges, riparian habitats, and disturbed areas, reducing biodiversity and negatively affecting agricultural productivity.

Results

The processing of Sentinel-2 satellite imagery and subsequent land cover classification using Geographic Information Systems (GIS) enabled the identification of the main hotspots of invasive plant species occurring on agricultural lands within the Carpathian region. Spatial analysis revealed that the distribution of invasive vegetation is highly heterogeneous and is primarily associated with anthropogenically disturbed areas, river valleys, roadside corridors, abandoned agricultural lands, and low-productivity areas.

Figure 2 presents the classified Sentinel-2 satellite image, where the distribution hotspots of the four investigated invasive plant species are highlighted using different colours. The spatial distribution of the classified areas indicates that the highest concentration of invasive vegetation occurs in the foothill zones and along major transportation and river corridors. These areas are characterized by intensive human activity and environmental conditions that facilitate the establishment and further spread of invasive plant species.

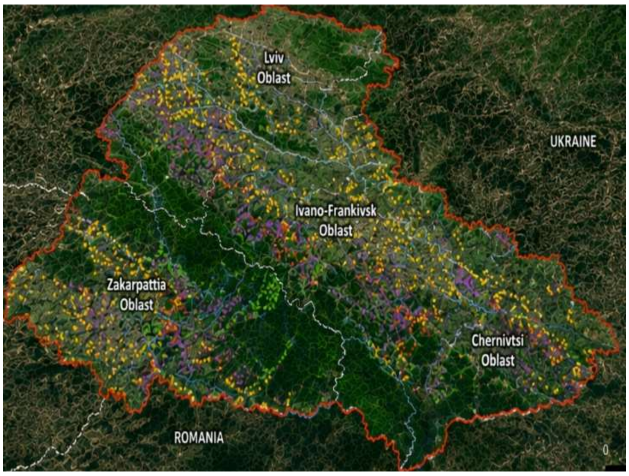

Figure 2. *Distribution of invasive plant species hotspots identified from Sentinel-2 satellite imagery in the Ukrainian Carpathian region*

The classification results indicate that Solidago canadensis occupies the largest area among the investigated species. Its extensive distribution is associated with high ecological adaptability and the ability to rapidly colonize disturbed habitats. Large populations were identified on abandoned agricultural lands, hayfields, and fallow fields. Ambrosia artemisiifolia is distributed mainly within lowland and foothill areas, particularly near roads, settlements, and cultivated agricultural fields. Its occurrence is closely related to intensive agricultural activities and a dense transportation network, which contribute to seed dispersal.

The identified populations of Heracleum sosnowskyi are concentrated primarily along river channels, drainage canals, and moist meadows. Spatial analysis confirms the important role of river systems as natural dispersal corridors facilitating the expansion of this invasive species. Impatiens glandulifera occurs predominantly within river floodplains, stream valleys, and other moist habitats with dense herbaceous vegetation. Although its occupied area is smaller than that of the other investigated species, the results indicate a gradual expansion along riparian ecosystems. The reported distribution areas should therefore be regarded as approximate, since the use of freely available Sentinel-2 satellite imagery with a spatial resolution of 10 m does not provide sufficient accuracy for precise delineation of individual invasive plant populations, particularly within fragmented agricultural landscapes. The quantitative characteristics of the identified invasive plant species are presented in Table 1.

Table 1. *Approximate distribution area of invasive plant species on agricultural lands in the Carpathian region*

Invasive plant species	Share of the total identified invaded area (%)	Total
Solidago canadensis	39.8	100
Ambrosia artemisiifolia	29.4	
Heracleum sosnowskyi	17.5	
Impatiens glandulifera	13.3	

Consequently, the relative distribution of invasive species expressed as percentages represents the most reliable indicator at this stage of the research. Future work will focus on refining the estimated distribution areas through the integration of very high spatial resolution commercial satellite imagery and unmanned aerial vehicle (UAV) imagery. The combination of these datasets with field validation is expected to significantly improve the accuracy of invasive vegetation mapping, the delineation of individual infestation boundaries, and the assessment of the spatial dynamics of invasive plant species across agricultural lands in the Carpathian region.

Conclusions

The present study demonstrated the potential of integrating Sentinel-2 satellite imagery, GIS and spatial analysis techniques for identifying and assessing the distribution of invasive plant species on agricultural lands in the Carpathian region. The obtained results revealed that the distribution of invasive vegetation is spatially heterogeneous and is primarily associated with anthropogenically disturbed areas, river valleys, transportation corridors, and abandoned agricultural lands. Among the investigated species, Solidago canadensis and Ambrosia artemisiifolia exhibited the widest distribution, indicating their dominant role in the transformation of agricultural landscapes. Although the current assessment provides a reliable overview of the relative spatial distribution of invasive species, the limited spatial resolution of freely available satellite imagery restricts the precise estimation of infestation areas. Therefore, future research will focus on integrating very high-resolution commercial satellite imagery, UAV-based aerial surveys, and field observations to improve the accuracy of invasive species mapping, quantify their actual distribution areas, and develop more effective monitoring and management strategies for sustainable agricultural land use in the Carpathian region.

References

Chetverikov, B., Trevoho, I., Prokhorchuk, O., Vladimirov, S., & Herasymchuk, P. (2024). Synergy of UAV Aerial Survey Methods and LiDAR Scanning for the Study of Planar Objects of Historical and Cultural Heritage. International Journal of Geoinformatics, 20(9), 98–111. https://doi.org/10.52939/ijg.v20i9.3551

Lipińska, H., Lipiński, W., Shuvar, I., Korpita, H., & Shuvar, A. (2023). Invasive plant species and their threat to biodiversity. Plant and Soil Science, 14(1), 51-65. https://doi.org/10.31548/plant1.2023.51

Helber, P., Bischke, B., Dengel, A., & Borth, D. (2019). EuroSAT: A novel dataset and deep learning benchmark for land use and land cover classification. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 12(7), 2217–2226. https://doi.org/10.1109/JSTARS.2019.2918242

Xing, F., Peters, D. P. C., Villarreal, M., et al. (2024). Mapping the continuous cover of invasive noxious weed species using Sentinel-2 imagery and machine learning. Remote Sensing, 16(9), 1648. https://doi.org/10.3390/rs16091648

Kobyrenko, Y., Panasiuk, R., Sydorak, I., & Vavrynovych, O. (2024). SOYBEAN AND ITS ADAPTIVE PROPERTIES AS A WAY TO SOLVE THE GLOBAL FOOD CRISIS. Bulletin of Lviv National Environmental University. Series Agronomy, (28), 89–93. https://doi.org/10.31734/agronomy2024.28.089

Nininahazwe, F., Guo, X., & Wang, J. (2023). Mapping invasive alien plant species with very high spatial resolution imagery using machine learning and deep learning approaches. GIScience & Remote Sensing, 60(1). https://doi.org/10.1080/15481603.2023.2190203

Sevruk A., Babiy L., Babushka A.,& Chetverikov B. (2021). Study of forest fires according to remote sensing data (on the example of the Chornobyl exclusion zone), International Conference of Young Professionals «GeoTerrace-2021», Oct 2021, 1 - 5. https://doi.org/10.3997/2214-4609.20215K3010

Zaka, M. M., Avtar, R., Yunus, A. P., & Ali, M. L. (2024). Advances in remote sensing and machine learning for invasive plant species detection, assessment, and management: A review. Remote Sensing, 16(20), 3781. https://doi.org/10.3390/rs16203781