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SPATIO-TEMPORAL DYNAMICS OF *AMBROSIA ARTEMISIIFOLIA* L. IN RURAL SETTLEMENTS AND SMALL TOWNS OF NORTHERN UKRAINE (2023–2026) AND INTEGRATION OF MONITORING INTO GEOGRAPHY EDUCATION

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ABSTRACT

The northward range expansion of the invasive quarantine weed *Ambrosia artemisiifolia* L. poses growing ecological, agricultural, and public health threats in Northern Ukraine. While large urban centers are well studied, small towns and rural settlements remain under-investigated stepping stones for invasion. This study aimed to assess the four-year (2023–2026) spatio-temporal dynamics, ecotope preferences, and management outcomes of *A. artemisiifolia* across two rural settlements (Kovpyta, Vybli) and two small towns (Slavutych, Bakhmach) in the Chernihiv Polissya region, as well as to evaluate the pedagogical integration of field monitoring into secondary school geography education. Field surveys were conducted annually in July – August using GPS tracking and 1×1 m geobotanical quadrats across 25 habitat types grouped into five ecotope categories. Results revealed a three-order-of-magnitude variation in infestation governed by landscape structure rather than administrative status. Compact, forest-buffered Slavutych maintained minimal occurrences (13–33 m²), whereas railway-hub Bakhmach exhibited entrenched infestation (3.53–3.59 ha) comparable to Kovpyta (2.57–3.87 ha) and Vybli (1.64–2.28 ha). Unmanaged agricultural fallows (*perelohy*, up to 73.9% of infested area), landfills (up to 40 ind./m²), and transport

corridors served as primary seed reservoirs. Continuous integrated control – combining pre-flowering multi-seasonal mowing, railway herbicide treatments, and perennial grass overseeding – successfully reduced stand area and density, whereas relaxing management in Vybli in 2026 triggered a 38.8% rebound from persistent soil seed banks. Furthermore, comparative curriculum analysis confirmed that adapting this monitoring protocol into Grade 6–9 Geography projects (particularly in Grade 8) fosters students' spatial competencies while establishing a sustainable community early-warning network.

KEYWORDS: *Ambrosia artemisiifolia*, biological invasion, spatio-temporal monitoring, rural and urban ecotopes, weed management, Northern Ukraine, geography education, citizen science.

1. INTRODUCTION

Biological invasions represent one of the primary drivers of biodiversity loss, ecosystem degradation, and socio-economic damage worldwide (Schaffner et al., 2020; Udzhmadzhuridze & Lisovets, 2025). Among invasive alien plant species in Europe, common ragweed (*Ambrosia artemisiifolia* L., Asteraceae), native to North America, poses a particularly severe threat due to its high ecological and genomic plasticity, rapid adaptive evolution, massive production of long-lived seeds, and potent allergenic pollen (Bieker et al., 2022; Hall et al., 2021; Knolmajer et al., 2024). Once introduced, *A. artemisiifolia* rapidly colonizes disturbed habitats, outcompeting native flora through resource competition and allelopathic suppression via sesquiterpenes, thereby simplifying plant communities and reducing agricultural yields (Hammad et al., 2026; Liu et al., 2022; Udzhmadzhuridze & Lisovets, 2025). Furthermore, its flowers exhibit specialized photoprotective mechanisms mediated by UV-absorbing flavonoids, enhancing reproductive resilience under high irradiance (Fedenko, 2025).

In Ukraine, *A. artemisiifolia* is officially listed as a quarantine weed, historically concentrated in the Steppe and Forest-Steppe zones (Udzhmadzhuridze & Lisovets, 2025). However, ongoing climate change – characterized by rising temperatures and prolonged frost-free periods – alters plant phenology, increases pollen allergenicity, and facilitates the northward range expansion of this thermophilic species into cooler regions, including Northern Ukraine (Gentili et al., 2019; Hrabovský et al., 2024). In addition, anthropogenic disturbances, intensive transport networks, and land-use changes act as critical drivers for seedling establishment and population growth in previously unaffected landscapes (Zhao et al., 2023).

While numerous studies have investigated ragweed distribution, phytocenotic impacts, and remote sensing monitoring within large urban agglomerations and major agricultural hubs (Hammad et al., 2026; Udzhmadzhuridze & Lisovets, 2025), small towns and rural settlements remain significantly understudied. Yet, these smaller residential areas act as vital ecological corridors and stepping stones for invasion. In rural and semi-urban communities, residential zones directly border agricultural fields, abandoned homesteads, roadsides, and unmanaged ruderal lands. Insufficient municipal resources for systematic weed control allow local populations of *A. artemisiifolia* to replenish persistent soil seed banks (Hall et al., 2021), creating chronic sources of re-infestation for surrounding agroecosystems and posing direct public health risks to local residents (Schaffner et al., 2020).

Therefore, multi-year field monitoring is essential to track population dynamics, identify primary invasion pathways, and evaluate the effectiveness of local containment measures. The aim of this study was to assess the spatio-temporal distribution, habitat preferences, and population dynamics of *Ambrosia artemisiifolia* across two rural settlements and two small towns in Northern Ukraine over a four-year period (2023–2026).

2. RESEARCH METHODOLOGY

2.1. Study area and natural conditions

The research was conducted in Northern Ukraine within the Chernihiv Polissya physico-geographical region and its southern transition zone toward the Forest-Steppe (encompassing Chernihiv Oblast and the northern enclave of Kyiv Oblast). The region is characterized by a temperate continental climate with moderately warm summers (mean July temperatures of 19.5–21.0 °C) and mild, unstable winters, with annual precipitation averaging 550–620 mm. Over recent decades, rising summer temperatures and an extended frost-free period have increasingly favored the northward establishment of thermophilic alien plants. The predominant soil cover consists of sod-podzolic, meadow, and gray forest soils, supporting mixed coniferous-deciduous forests interspersed with river floodplains and agricultural lands.

To evaluate the spatial dynamics of *Ambrosia artemisiifolia* L. across a gradient of settlement size and landscape structure, four residential settlements were selected for multi-year monitoring.

Kovpyta (Chernihiv Raion, Chernihiv Oblast; 51°26′ N, 30°51′ E): A rural settlement situated within a forest-agrarian Polissya landscape, surrounded by mixed forest massifs, arable fields, and extensive fallow lands (*perelohy*), without railway infrastructure within village boundaries.

Vybli (Kulykivka Settlement Hromada, Chernihiv Raion, Chernihiv Oblast; 51°27′ N, 31°34′ E): A rural settlement located adjacent to the Desna River floodplain, characterized by a mosaic of agricultural lands, pastures, drainage canals, and active transport exposure via the R-67 regional highway.

Slavutych (Vyshhorod Raion, Kyiv Oblast, geographically located within Chernihiv Polissya; 51°31′ N, 30°45′ E): A compact, modern planned small town (established in 1986) completely surrounded by intact pine-deciduous forest massifs. It features strict municipal zoning, a railway line, and a complete absence of peri-urban agricultural fallows or open landfills within administrative limits.

Bakhmach (Bakhmach Urban Hromada, Nizhyn Raion, Chernihiv Oblast; 51°11′ N, 32°49′ E): A small town and major regional railway junction situated in the southern Polissya / northern Forest-Steppe transition zone, embedded within an intensive agricultural matrix with dense railway, highway, and industrial corridors.

2.2. Field monitoring protocol

Field surveys were carried out annually over a four-year period (2023–2026) during the peak vegetative growth and onset of flowering of *A. artemisiifolia* (July–August). Monitoring followed the route-reconnaissance method combined with stationary sample plot assessments in accordance with classical geobotanical research methodologies (Yakubenko et al., 2018).

Within each settlement, all accessible habitats were systematically surveyed and categorized into five standardized ecotope groups comprising 25 specific habitat types.

Transport corridors and linear objects: field roadsides, highway roadsides, railway embankments and rights-of-way, power line corridors, and riverbanks/drainage canals:

- urbanized ecotopes – construction sites and excavations, wastelands, industrial zones, residential yards, lawns and flowerbeds, urbanized beaches/embankments, and high-traffic public areas (stations, markets, bus stops);
- agricultural lands – row crop fields (maize, sunflower), unmanaged fallow lands (*perelohy*) and pastures, farmyards/silos/warehouses, field margins, grain and machinery storage sites, and household vegetable gardens;
- anthropogenically disturbed natural ecotopes: sandy spits and waterbody shores, forest edges and shelterbelts, logging sites and burned areas, and eroded slopes of ravines and gullies;
- waste and raw material handling sites: official and illegal landfills, construction waste dumps, temporary piles of sand/gravel/screenings, and grain cleaning facilities/elevators.

The boundaries of each identified *A. artemisiifolia* focus were delineated in the field using GPS tracking via mobile GIS applications (QField / Locus Map) to calculate the total infested area (expressed in m² or ha); for micro-occurrences (<1 m²), areas were recorded as sub-square-meter patches (standardized as 0.5 m² for total area summation). To quantify stand density, standard 1×1 m geobotanical sample plots (quadrats) were established within representative sections of each focus (Yakubenko et al., 2021). Based on individual counts per square meter, infestation density was classified using a three-tier scale: sporadic / single plants: <5 ind./m²; moderate density: 5–20 ind./m²; continuous dense thickets: >20 ind./m². Concurrently, at every surveyed location, the presence, timing, and type of local weed management interventions (single or multi-seasonal mechanical mowing, plowing/disking, herbicide application, biopreparations, perennial grass overseeding, or manual weeding) were documented through direct field observation and verification with local municipal or land-use records.

2.3. Comparative curriculum analysis for educational integration

To evaluate the pedagogical applicability of the field monitoring protocol in secondary school geography education, a qualitative comparative curriculum analysis was conducted following methodological frameworks in comparative education research (Bray et al., 2014). Two official Ukrainian Model Curricula in Geography for Grades 6–9 approved under the New Ukrainian School reform (Kobernik et al., 2022; Zapototskyi et al., 2022) were systematically juxtaposed. The analysis focused on identifying thematic alignment, expected learning outcomes, and competency progression across grade levels to adapt scientific geobotanical monitoring tasks (species identification, GPS spatial mapping, quadrat density estimation, and human-environment impact assessment) into age-appropriate practical and project-based citizen science activities.

3. RESULTS AND DISCUSSION

3.1. Spatio-temporal dynamics and management outcomes in rural settlements

Field monitoring conducted between 2023 and 2026 revealed substantial differences in both the scale and multi-year trajectories of *Ambrosia artemisiifolia* infestation between the two studied rural settlements of the Chernihiv Polissya region: Kovpyta and Vybli (Table 1). Across both villages, agricultural lands constituted the primary reservoir of common ragweed, accounting for 57.0%–59.2% of the total infested area in Kovpyta and 72.4%–73.9% in Vybli throughout the observation period. Within this category, unmanaged fallow

lands and pastures (*perelohy*) were the most heavily colonized habitats, followed by row crops (maize and sunflower).

Table 1. Spatio-temporal dynamics of *Ambrosia artemisiifolia* L. infested areas (m²) across ecotope groups in the rural settlements of Kovpyta and Vybli (2023–2026).

Ecotope category	Kovpyta (2023)	Kovpyta (2024)	Kovpyta (2025)	Kovpyta (2026)	Vybli (2023)	Vybli (2024)	Vybli (2025)	Vybli (2026)
Transport corridors & linear objects	4,900	6,100	3,900	3,900	1,560	1,590	1,460	1,975
Urbanized ecotopes	4,300	6,160	4,390	4,390	1,555	1,430	1,225	1,750
Agricultural lands	15,800	22,700	15,200	15,200	13,770	13,435	11,880	16,630
Disturbed natural ecotopes	1,750	2,350	1,450	1,450	720	805	860	1,115
Waste & raw material sites	950	1,350	750	750	1,035	1,055	975	1,290
Total infested area (m²)	27,700	38,660	25,690	25,690	18,640	18,315	16,400	22,760
Total infested area (ha)	2.77	3.87	2.57	2.57	1.86	1.83	1.64	2.28

In Kovpyta, the total infested area initially expanded by 39.6%, increasing from 27,700 m² in 2023 to a peak of 38,660 m² in 2024. This surge was accompanied by a sharp rise in population density, with continuous dense thickets (>20 ind./m²) forming on unmanaged fallow lands (30 ind./m²), landfills (32 ind./m²), wastelands (28 ind./m²), construction sites (25 ind./m²), and highway roadsides (22 ind./m²). In 2025, the introduction of comprehensive municipal and agricultural control measures – including biannual mowing of field roadsides, plowing and mowing of wastelands, mowing of fallow lands, and partial cleanup of illegal dumps – led to a 33.5% reduction in total infested area (down to 25,690 m²) and the complete elimination of dense thickets across all ecotopes (maximum density dropped to 19 ind./m²). Continued adherence to these management practices maintained population stabilization at the same level in 2026.

Conversely, Vybli exhibited a biphasic trajectory characterized by steady suppression followed by a sharp resurgence. Between 2023 and 2025, systematic integrated management reduced the total infested area by 12.0% (from 18,640 m² to 16,400 m²). Particularly effective was the combination of regular mowing with the overseeding of competitive perennial grasses on wastelands and pastures implemented in 2025, as well as maintaining black fallow around farmyards, which reduced ragweed density on wastelands from 28 ind./m² (2023) to

15 ind./m² (2025). However, in 2026, a relaxation of containment efforts – specifically the cessation of mowing on fallow lands, landfills, and construction sites, alongside delayed single mowing of field roadsides in August – triggered a 38.8% rebound in total infested area (reaching 22,760 m², exceeding the 2023 baseline by 22.1%). Dense thickets re-established on landfills (38 ind./m²), fallow lands (31 ind./m²), wastelands (26 ind./m²), and highway roadsides (22 ind./m²).

These contrasting dynamics highlight several critical ecological and management mechanisms governing *A. artemisiifolia* invasion in rural landscapes.

The rapid resurgence observed in Vybli in 2026 demonstrates that even three consecutive years of suppression are insufficient to exhaust local populations if control is relaxed for a single season. Because *A. artemisiifolia* produces abundant seeds capable of remaining viable in the soil for decades (Hall et al., 2021; Knolmajer et al., 2024), any cessation of management allows dormant seeds to germinate immediately on disturbed substrates. Furthermore, delayed mowing in August – as recorded on Vybli field roadsides in 2026 – fails to prevent seed rain and pollen release, as northern populations accelerate their phenological development under warm summer conditions (Gentili et al., 2019).

As an early-successional ruderal species, *A. artemisiifolia* thrives on bare or disturbed soils where it outcompetes native flora and simplifies plant community structure (Udzhmadzhuridze & Lisovets, 2025). The marked decline in ragweed area and density on Vybli wastelands and pastures in 2025 confirms that mechanical mowing alone is significantly enhanced when paired with phytocenotic replacement – specifically overseeding perennial grass mixtures – which restricts light availability at the soil surface and suppresses seedling establishment (Knolmajer et al., 2024; Zhao et al., 2023).

In both settlements, anthropogenically disturbed natural ecotopes (riverbanks and drainage canals of the Desna floodplain, forest edges, logging sites, burned areas, and eroded ravines) received zero management interventions across all four years. While overall control in Kovpyta indirectly curbed expansion into adjacent natural sites in 2025–2026, Vybli experienced a continuous, uninterrupted 54.9% increase in infested natural ecotopes (from 720 m² in 2023 to 1,115 m² in 2026). This confirms that unmanaged ruderal hotspots – such as rural landfills (where densities consistently reached 25–38 ind./m²) and transport corridors – act as chronic propagule sources facilitating ragweed penetration into native northern ecosystems (Hammad et al., 2026; Zhao et al., 2023). In contrast, residential yards, flowerbeds, and household gardens consistently maintained the lowest infestation levels (only 1–4 ind./m²) due to regular manual weeding by homeowners.

Field phenological observations confirmed that *A. artemisiifolia* successfully completes its full reproductive cycle under the current climatic conditions of Northern Ukraine (Fig. 1).



Figure 1. Seasonal phenological development of *Ambrosia artemisiifolia* L. in Northern Ukraine (Chernihiv Oblast), from left to right: vegetative growth stage in May (optimal window for early mechanical and manual eradication); late flowering and onset of seed maturation in July (critical threshold after which mowing fails to prevent pollen release and seed set); and full fruiting and seed dispersal stage in November, confirming complete reproductive cycle realization in northern latitudes.

Following spring emergence and active vegetative growth in May (Fig. 1, left), plants enter late flowering and early seed maturation by July (Fig. 1, center), reaching full fruiting and seed dispersal in November prior to severe frosts (Fig. 1, right). This compressed phenological timeline underscores why control interventions must be strictly synchronized with early vegetative stages (May–June), whereas delayed mowing in late July or August – as observed on Vybli field roadsides – merely stimulates lateral branching and fails to prevent soil seed bank replenishment (Gentili et al., 2019; Hall et al., 2021)

3.2. Spatio-temporal dynamics and management outcomes in small towns

Comparative monitoring across the two small towns of Northern Ukraine – Slavutych and Bakhmach – revealed a striking contrast in infestation intensity, driven by differences in urban planning, municipal management rigor, and proximity to agricultural and railway infrastructure (Table 2).

Table 2. Spatio-temporal dynamics of *Ambrosia artemisiifolia* L. infested areas (m²) across ecotope groups in the small towns of Slavutych and Bakhmach (2023–2026).

Ecotope category	Slavutych (2023)	Slavutych (2024)	Slavutych (2025)	Slavutych (2026)	Bakhmach (2023–2024)*	Bakhmach (2025)	Bakhmach (2026)
Transport corridors & linear objects	9	19	9	11	4,630	4,420	4,120
Urbanized ecotopes	1	3	1	1	3,275	3,015	2,580
Agricultural lands	0	0	0	0	24,560	25,210	25,920
Disturbed natural ecotopes	3	6	3	4	890	990	1,080
Waste & raw material sites	3	5	0	1	1,970	2,120	2,220
Total infested area (m²)	16	33	13	17	35,325	35,755	35,920
Total infested area (ha)	0.0016	0.0033	0.0013	0.0017	3.53	3.58	3.59

**Note: Baseline data recorded in Bakhmach in 2024 represent the 2023–2024 observation period; sub-square-meter occurrences (<1 m²) in Slavutych were calculated as 0.5 m² for total area summation.*

In Slavutych, *A. artemisiifolia* exhibited an incipient, strictly localized invasion pattern, with total infested areas remaining negligible throughout the four-year period (fluctuating between 13 m² and 33 m²). The species was completely absent from agricultural ecotopes, landfills, wastelands, and high-traffic public spaces. Occurrences were restricted to sporadic individuals (<5 ind./m²) or small, moderate-density patches (5–20 ind./m²) along railway embankments (5–10 m²), utility corridors, temporary sand/gravel piles, and forest edges. Following a minor peak in 2024 (33 m²), consistent mechanized mowing by municipal services reduced the infested area by 60.6% in 2025 (down to 13 m²), maintaining effective suppression in 2026 (17 m²). Notably, the only persistent unmanaged micro-habitats were forest edges and eroded ravine slopes (1–3 m²), where absence of mowing allowed moderate densities to re-appear in 2026.

In contrast, Bakhmach demonstrated a large-scale, entrenched infestation exceeding 3.5 ha annually (35,325 m² in 2023–2024; 35,755 m² in 2025; and 35,920 m² in 2026). While the total infested area remained relatively stable (+1.7% over the study period), internal structural shifts occurred across ecotopes depending on management intensity.

Systematic herbicide treatments along railway embankments reduced ragweed area from 2,500 m² to 2,100 m² and downgraded population density from dense thickets (25–35 ind./m²) to moderate stands (16–20 ind./m²). Similarly, triseasonal mowing along highways, combined with mowing, perennial grass overseeding, and biopreparation treatments on urban wastelands, decreased urbanized ecotope infestation by 21.2% (from 3,275 m² to 2,580 m²).

Conversely, infested areas steadily expanded on unmanaged fallow lands and pastures (increasing from 15,000 m² to 19,000 m², with densities reaching 25–34 ind./m²), municipal and illegal landfills (from 1,100 m² to 1,400 m², up to 40 ind./m²), and disturbed natural habitats such as eroded ravines and forest edges (from 890 m² to 1,080 m²).

Integrating data from all four settlements (two villages and two towns) reveals three key ecological drivers shaping *A. artemisiifolia* distribution in Northern Ukraine.

The three-order-of-magnitude difference between Slavutych (~13–33 m²) and Bakhmach (~35,300–35,900 m²) underscores the role of urban morphology and surrounding land use. Slavutych is a compact, planned city surrounded by intact forest massifs, lacking peri-urban agricultural fallows and open landfills within city limits, which restricts propagule pressure primarily to railway corridors. Conversely, Bakhmach is a major railway junction embedded within an intensive agricultural matrix, mirroring the rural settlements of Kovpyta and Vybli, where unmanaged fallow lands (52.9% of total infested area in Bakhmach by 2026) and landfills act as massive, self-sustaining seed reservoirs (Hall et al., 2021; Zhao et al., 2023).

Across all settlements with rail infrastructure (Slavutych and Bakhmach), railway embankments and rights-of-way served as the most persistent linear entry points and high-density hotspots (up to 35 ind./m² in Bakhmach). Disturbance of gravel substrates, microclimatic warming, and long-distance seed transport by freight trains facilitate rapid establishment and genetic admixture of northern populations (Bieker et al., 2022; Hrabovský et al., 2024).

While mechanical mowing alone (when performed once or late in the season) merely slows population growth, integrated approaches – combining chemical control on railways, multi-seasonal mowing before flowering, biopreparations, and phytocenotic replacement via perennial grass overseeding – successfully reduced both area and stand density in Bakhmach's urban core and Vybli's wastelands. However, without extending containment policies to peri-urban fallows, landfills, and adjacent forest-ravine ecosystems, local eradication remains unattainable, highlighting the need for precision spatial monitoring (such as UAV-based mapping) to target hidden rural and peri-urban seed sources (Hammad et al., 2026; Udzhmadzhuridze & Lisovets, 2025).

3.3. Integration of ragweed monitoring into secondary school geography education

Beyond its ecological and municipal management value, the simplified field monitoring protocol developed in this study offers high pedagogical potential as a citizen science and project-based learning tool in secondary school geography education. An analysis of the current model curricula for basic secondary education in Ukraine (Grades 6–9) developed under the New Ukrainian School reform – specifically the curricula by Kobernik et al. (2022) and Zapototskyi et al. (2022) – demonstrates multiple curricular entry points where student-led monitoring of *Ambrosia artemisiifolia* directly supports the development of spatial, environmental, and research competencies (Table 3).

Table 3. Alignment of *Ambrosia artemisiifolia* L. field monitoring tasks with the Ukrainian Model Curricula in Geography for Grades 6–9 (Kobernik et al., 2022; Zapototskyi et al., 2022).

Grade & Curriculum Section	Relevant Topics in Model Curricula	Proposed Student Practical / Project Tasks	Core Competencies & Outcomes
Grade 6 Biosphere & Local Environment	• Biosphere and human impact on ecosystems • Orientation and terrain mapping (Kobernik et al., 2022; Zapototskyi et al., 2022)	• Field excursion around the schoolyard and adjacent streets to identify *A. artemisiifolia* using visual keys. • Plotting single occurrences (<5 ind./m²) on a schematic local plan.	• Basic species recognition. • Primary spatial orientation and map-making skills.
Grade 8 Nature of Ukraine, Nature Management & Local Lore (*Krainoznavstvo*)	• Vegetation, soils, and anthropogenic landscapes of Ukraine • Geoecological problems and nature management • Nature and population of the native region (Kobernik et al., 2022; Zapototskyi et al., 2022)	• Mini-project: *"Mapping quarantine weed hotspots in our settlement."* • Assessing stand density across ecotopes (roadsides, wastelands, parks) using 1×1 m quadrats and GPS smartphones. • Comparing infested areas before and after municipal mowing.	• Understanding anthropogenic transformation of local landscapes. • Data tabulation, GIS visualization, and formulating local management proposals.
Grade 9 National Economy & Sustainable Development	• Agricultural production and land use • Environmental consequences of economic activity (Zapototskyi et al., 2022)	• Analytical case study: Assessing ragweed infestation risks on fallow lands (*perelohy*) vs. cultivated fields. • Evaluating socio-economic and public health impacts (pollinosis risks) in rural vs. urban communities.	• Linking land-use practices with biological invasions. • Critical thinking and civic responsibility in community environmental safety.

The most comprehensive integration is achieved in Grade 8, where both model curricula include dedicated modules on Ukrainian landscapes, rational nature management, and regional geography (*Nature and Population of the Native Region* in Kobernik et al., 2022; *Nature Management* in Zapototskyi et al., 2022). Executing a local ragweed mapping project allows students to move beyond abstract textbook examples of environmental degradation to investigate a tangible, locally relevant biological invasion. Using accessible tools – such as smartphone GPS applications, simple 1×1 m counting frames, and a three-tier density scale – students can generate reliable primary spatial datasets for their village or town. Furthermore, involving schoolchildren and local communities in early-summer detection (prior to flowering in July) creates a sustainable, low-cost early-warning network that complements municipal weed control and fosters environmental stewardship.

4. CONCLUSIONS

Four-year field monitoring (2023–2026) across two rural settlements and two small towns in Northern Ukraine demonstrated that *Ambrosia artemisiifolia* L. has transitioned from sporadic occurrences to entrenched, self-sustaining populations in northern residential landscapes, with its spatial distribution governed by surrounding land-use matrices and the continuity of local management.

Infestation intensity varied by three orders of magnitude not along a simple rural–urban gradient, but according to urban morphology and proximity to agricultural and transport infrastructure. Compact, forest-buffered Slavutych maintained negligible, strictly localized occurrences (13–33 m²), whereas Bakhmach – a major railway junction embedded within an intensive agricultural landscape – exhibited large-scale infestation (3.53–3.59 ha) comparable to the rural settlements of Kovpyta (2.57–3.87 ha) and Vybli (1.64–2.28 ha).

Across infested communities, unmanaged agricultural fallows (*perelohy*) and pastures (accounting for up to 52.9%–73.9% of total infested area), illegal landfills (densities reaching 32–40 ind./m²), and railway/highway corridors acted as the primary seed reservoirs and entry gateways. Absence of control in adjacent disturbed natural habitats – such as riverbanks, forest edges, and eroded ravines – enabled progressive spillover into semi-natural Polissya ecosystems.

Single or late-season mowing proved insufficient to curb population growth. Effective suppression was achieved only through continuous, multi-year integrated management combining pre-flowering multi-seasonal mowing, targeted herbicide application along railways, biopreparations, and phytocenotic replacement via perennial grass overseeding. As

demonstrated in Vybli in 2026, relaxing control measures for even a single season triggers rapid resurgence (+38.8% area rebound) from persistent soil seed banks.

Adapting this standardized field monitoring protocol into project-based and practical tasks within the Ukrainian Model Curricula in Geography for Grades 6–9 (most notably in Grade 8 modules on local landscapes and nature management) offers a dual benefit: it develops students' spatial and environmental competencies while establishing a sustainable, low-cost community early-warning network for quarantine weed detection.

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