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Spontaneous spread of the alien species *Nepeta racemosa* (Lamiaceae) in Ukraine

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Spontaneous spread of the alien species *Nepeta racemosa* (Lamiaceae) in Ukraine

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Running title: *NEPETA RACEMOSA* IN UKRAINE

Abstract – In the flora of Ukraine, 48 findings of the spontaneous spread of the alien species *Nepeta racemosa* Lam. were recorded: 30 records within the introduction centers and 18 outside the boundaries of cultivation. A brief morphological description of the plants is provided, and their ecological and biological features are investigated. It was found that all the habitats of this species in Ukraine were confined to synanthropic biotopes: decorative cultivated biotopes (parks, squares, lawns, flower gardens), residential and technotopes (biotope complexes of built-up areas, garbage and solid waste landfills). Most often, the plants grow in cracks in sidewalks and asphalt. According to time of introduction, *N. racemosa* belongs to neophytes, and according to method of introduction to ergasiophytes. The species requires further monitoring to assess the likelihood of its further spread within and beyond urban environments.

Keywords: alien species, flora, introduction, ornamental plants, ruderal vegetation

Introduction

The leading role in the processes of anthropogenic transformation of the urban environment's vegetation cover is played by non-native species, the appearance of which is due to many factors: transport flows, significant concentration of people, increase in built-up areas, infrastructure development and so on (Arianoutsou et al. 2021, Haubrock et al. 2021, Rodríguez et al. 2024). A separate factor is the purposeful or spontaneous introduction of plants which not only contributes to the preservation of plant diversity and the selection of promising species to replenish plant resources (decorative, medicinal, food, fodder, etc.) but can also become a source of phytoinvasions. Recent observations of new alien species growing spontaneously in Europe have revealed a current trend for them to emerge in consequence of their use in ornamental horticulture and commerce via the Internet, retail outlets, specialist nurseries, etc. (Ööpik et al. 2013, Hulme et al. 2017, Arianoutsou et al. 2021). Introductions often escape from their cultivation sites and become wild in a new region, achieve varying degrees of naturalization, and contribute to the replenishment of the spontaneous flora with alien plant species (Pyšek et al. 2022, Iamonico and Nicolella 2024, Koniakin et al. 2024).

Climate change will only exacerbate the problem of biological invasions, which will damage the environment and bring about undesirable economic and social consequences. Therefore, the European Union and Ukraine have adopted a strategy for biodiversity conservation, where special attention is focused on limiting the introduction of alien plant species with uncertain adaptive potential; ongoing monitoring studies of the adventitious fraction of the flora are being conducted (Burda and Ignatyuk 2011, Genovesi et al. 2015, European Commission 2022).

During floristic surveys of Kyiv, we recorded for the first time outside the place of cultivation the foci of the alien species *Nepeta racemosa* Lam. (Lamiaceae), which has not been previously reported by previous researchers into this area (Mosyakin and Yavorska 2002,

Yavorska 2004). This species belongs to the genus *Nepeta* L. (subfamily Nepetoideae (Dumort.) Luerss.), which has 295 accepted species, common in Southwest and Central Asia, North and Central America, North Africa, Southeastern Europe, Korea, Japan (POWO 2024). Representatives of this genus are characterized by high decorative qualities and valuable economic properties due to the presence of various bioactive compounds. For practical use, they are grown in many countries around the world – Great Britain, Netherlands, Romania, Czech Republic, USA, Argentina, New Zealand and others (Salehi et al. 2018, POWO 2024).

There are four taxa of the genus *Nepeta* growing in Ukraine: two native species – *N. nuda* L. subsp. *nuda* (syn. *N. pannonica* L.), *N. ucranica* L. subsp. *parviflora* (M. Bieb.) M. Masclans (syn. *N. parviflora* M. Bieb.) and two alien species – *N. cataria* L., *N. grandiflora* M. Bieb. (Klokov 1960, GBIF 2025, POWO 2024). There are 14 taxa of this genus that have been introduced in the botanical gardens and arboretums of Ukraine (Mashkovskaya 2015).

Nepeta racemosa is an ornamental, medicinal, melliferous, food, and essential oil species (Hawke 2007, Baser et al. 2011, Lungoci et al. 2023). According to time of introduction, it is a neophyte, and to method of introduction an ergasiophyte (species that are wild near their cultivation). The plant is entomophilous and it spreads anemochorically. Branched stems with fruiting inflorescences easily break off at their base and are rolled by the wind, gradually scattering seeds (Takhtadzhyan 1981). The aerial parts of *N. racemosa* secrete essential oil, the main components of which are biologically active substances – monoterpenoids (non-petalactones), which have a wide range of uses. It is used as an antibacterial, antifungal, antitumor, antiviral, antioxidant, sedative, and insecticidal agent (Baser et al. 2011, Salehi et al. 2018). This species is considered to have a potential for improving the structure of saline soils while obtaining higher concentrations of bioactive substances (Lungoci et al. 2023). It is also used in the food industry as a powerful preservative and a source of aromatic raw materials for winemaking. In the world, according to the needs of society, varieties have been invented for various applications (phytodesign, pharmaceutical, medicinal, in food, etc.) *N. racemosa* – ‘Walker's Low’, ‘Blue Ice’, ‘Grog’, ‘Superba’, ‘Posvyata Meysu’ and others (Hawke 2007, Kovtun-Vodyanitska and Rakhmetov 2018). The species has a wide ecological range of growth, easily adapts to new conditions, is resistant to frost and drought, and can also be self-seeding in culture (Bojňanský and Fargašová 2007, Hawke 2007, Rigó et al. 2023).

The native range of *N. racemosa* includes the mountainous regions of Turkey, Iran, Iraq, and Transcaucasia (Azerbaijan, Armenia, and Georgia), where it grows as part of the composition of upland xerophytic and mountain meadow-steppe vegetation (POWO 2024). Due to its valuable economic qualities, it is cultivated outside its native range – Austria, Switzerland, Czech Republic, Hungary, Spain, Great Britain, Finland, Australia, New Zealand South, USA (POWO 2024, GBIF 2025). As a result of introduction, it has been naturalized in temperate countries – the United States of America (states Wyoming, Wisconsin, New York), Canada and Europe (Kartesz 2015, Pyšek et al. 2022, GBIF 2025).

In Ukraine, *N. racemosa* was introduced in 12 research centers with various natural and climatic conditions (in the zone of Mixed Forests, Forest-Steppe and Steppe, Ukrainian Carpathians) (Mashkovskaya 2015). This species is also used in the phytodesign of cities and towns, and is grown in nurseries and on homestead plots.

Recently, according to various information sources and our own observations, the escape of this species from cultivation sites has been recorded (Shynder et al. 2018, Chorna et al. 2021, iNaturalist 2025). In view of this, there is a need to study the foci of spontaneous spread of *N. racemosa* in Ukraine, as well as to investigate its ecological and biological traits and biotope location to assess the further spread of the species in the urban environment.

Material and methods

Data on the spontaneous spread of *Nepeta racemosa* were collected during field surveys in Kyiv, a review of literary sources and from Internet open access resources – iNaturalist, GBIF and UkrBIN. The nomenclature follows Plants of the World Online (POWO 2024). Morphometric measurements of *Nepeta racemosa* were conducted in Kyiv. A total of 20 plant specimens from different localities were examined. Descriptive statistics (mean ± standard deviation) were calculated. The P values were considered significant at < 0.05. Statistical analyses were performed using Microsoft Excel 2016. The seeds of the local reproduction were photographed with a Canon EOS600D digital camera mounted on an Olympus SZX 12. Biotopes are defined according to the European Nature Information System (EUNIS) (Chytrý et al. 2020). Naturalization status was assessed and defined according to Pyšek et al. (2022). The research was conducted during 2021 – 2024. Own findings are uploaded to the iNaturalist database.

Results

According to our observations, scientific publications, and Internet resources, 48 occurrences of the spontaneous spread of *Nepeta racemosa* have been identified in Ukraine (Shynder et al. 2018, Chorna et al. 2021, iNaturalist 2025, UkrBIN 2025). Depending on their habitat, these occurrences can be conditionally divided into two groups: those resulting from escape from the initial point of introduction within the introduction centers – 30 localities and those that emerged as a result of leaving cultivation sites and settled outside cultivation in various anthropogenic places – 18 localities.

The spontaneous spread of *N. racemosa* in Ukraine within the introduction centers began in 2011 in Kyiv (Kyiv region), where the largest number of localities is currently located – 24. Subsequently, *N. racemosa* has continue to spread spontaneously in introduction institutions of the central, eastern, and southern regions of Ukraine. During the period from 2021 to 2024, its settlement was observed in the following locations: National Dendrological Park "Sofiivka" (Uman, Cherkasy region, 2021 – 2023); Botanical Garden of the Mechnikov National University of Ukraine (Odesa, Odesa region, 2022); Kryvyi Rih Botanical Garden of the National Academy of Sciences of Ukraine (Kryvyi Rih, Dnipropetrovsk region, 2024); Children's Botanical Garden (Zaporizhzhia, Zaporizhzhia region, 2024) (Figs. 1, 2).

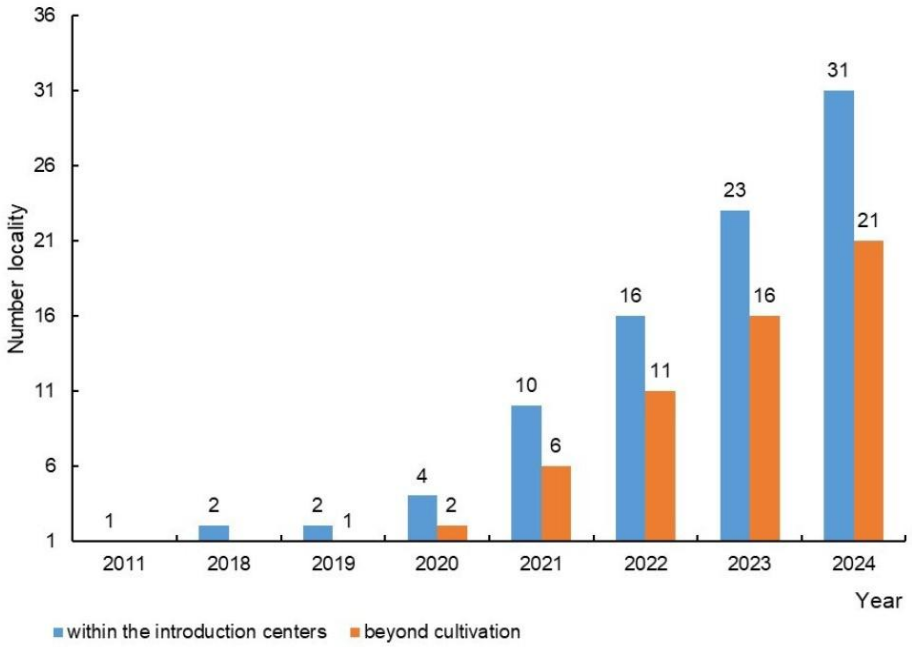

Fig. 1. Temporal dynamics (2011 – 2024) of recorded localities of spontaneous spread of *Nepeta racemosa* in Ukraine, showing cumulative numbers within cultivation sites (introduction centres) and outside cultivation.

Fig. 2. Occurrence of *Nepeta racemosa* in Ukraine: records from cultivation (red) and records outside cultivation (blue); numbers indicate the number of localities.

Eight years after the first settlement of *N. racemosa* within the boundaries of introductory institutions, in 2019, the species was first observed wild, outside of cultivation (Dnipro city). In the future, the number of such finds in Ukraine will increase annually. The largest number of spontaneous growths of this alien species is currently recorded in Kyiv and the Kyiv region – 14. In addition, in 2023 – 2024, *N. racemosa* was noted wild and outside cultivation in the

central (Smila city, Cherkasy region) and southern regions of Ukraine (in Odesa and Odesa region) (Figs. 2, 3).

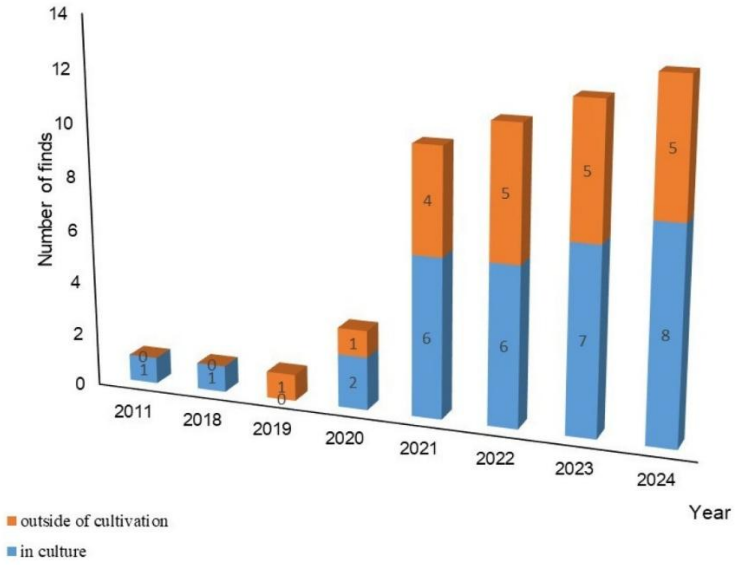

Fig. 3. Annual records of spontaneous spread of *Nepeta racemosa* in culture and outside cultivation for the period 2011 – 2024 in Ukraine.

An analysis of the nature of the spontaneous spread of *N. racemosa* in Ukraine outside the boundaries of culture found that all the finds are located near introduction centers or places of cultivation – cultural phytocenoses of various types. It was established that the spread of *N. racemosa* outside cultivation is closely related to its spontaneous growth in centers of introduction ($r = 0.84$, $P < 0.05$).

Most localities in both cases were found at the side of paths, in cracks in the pavement and asphalt, less often – in grass and lawns (Fig. 4).

Fig. 4. Habitat of *Nepeta racemosa*: A – a crack in an asphalt path (Children's Botanical Garden, Zaporizhzhia, photo O. Shynder); B – a crack in a curb, Bastionna Street, Kyiv, photo A. Levon; C – gap between stone fence and paving slabs (Sadovo-Botanichna Street, Kyiv) (photo: S. Koniakin).

Also, outside the cultivation area, we found *N. racemosa* in a natural dump of solid construction materials (crushed concrete, bricks, glass, asphalt residues, etc.; 50°22'01.4" N, 30°28'04.1" E, Kyiv, 2021) and the remains of garden waste near the fallow of the archaeological site "Khotiv hillfort" (50°20'00.2" N 30°29'34.3" E; Khotiv village, Kyiv region, 2024). To determine the invasive potential of this alien species in our conditions, we investigated its ecological and biological features.

Plant habit: 42 – 48 cm in height and 70 – 90 cm in diameter (Fig. 5A). Leaves are short-petiolate, ovate, heart-shaped at the base, and bluntly toothed. The length of the leaf blade of the average formation is 1.9 – 3.4 (2.6 ± 0.9) cm, width 1.5 – 3.1 (2.1 ± 0.1) cm. Flowers are lilac, 1.2 – 1.7 (1.5 ± 0.01) cm long, collected in 6 – 8 (12) verticils that form spike-shaped inflorescences (Fig. 5B). Inflorescence length 8 – 31 (23.7 ± 1.2) cm, number of flowers per inflorescence 34 – 42. Fruit four-nut, 4.6 – 8.2 (6.5 ± 0.2) mm long, 2.1 – 3.0 (2.3 ± 0.1) mm wide. Nuts are dark brown, broadly elliptical, slightly flattened, 1.8 – 2.0 (1.7 ± 0.1) mm long, 0.9 – 1.5 (1.3 ± 0.01) mm wide (Fig. 5C).

Fig. 5. *Nepeta racemosa* outside the place of cultivation ("Expocenter of Ukraine", Kyiv): A – habit, B – inflorescence and flowers (photo O. Leshcheniuk, S. Koniakin), C – seeds (photo: O. Bidzilya).

Phenological observations of *N. racemosa* individuals in Kyiv during 2021 – 2024 revealed that their annual development cycle was consistent with the weather and climatic conditions of a particular year. The beginning of regrowth occurred in the second–third decade of March. The budding phase occurred in the second decade of April–first decade of May. The duration of this phase was 6 – 8 days. Flowering began in the second decade of April–second decade of May and ended in the first – second decade of July. The flowering period lasted 54 – 70 days and was limited by dry and hot conditions. This phase was resumed each time after precipitation. Regular fruiting of *N. racemosa* individuals was noted in the third decade of May - the second decade of June. The end of the growing season was noted in the third decade of October – the second – third decade of November. The duration of the growing season was 224 – 246 days.

We investigated the quality indicators of local reproduction seeds – germination energy, dormancy period and seed germination (laboratory and soil), since seed characteristics are directly related to the preservation and growth of plant populations, and each seed is of great importance in the restoration and spread of the species (Misnik 1976, Baskin and Baskin 2014). The specific state of seed dormancy depends on genetics, growth pattern, and environmental conditions (Kildisheva et al. 2020). It was established that in laboratory conditions at a temperature of +25°C, seed germination began on the 6^{th} – 8^{th} day and ended on the 19^{th} – 21^{st} day from the beginning of the emergence of shoots. The germination energy, which characterizes the simultaneous germination of seeds, is 9.3%. Seed dormancy lasted

approximately 13.5 days; laboratory seed germination was 36 – 44%. In the soil, seedlings appeared on the 12^{th} –15^{th} day after sowing. Soil seed germination is much lower, at 8 – 12%. In addition, we investigated the features of ontogenesis of *N. racemosa* in culture. It was found that in one year the plants go through all phases of ontogenetic development – from seed to fruiting with the formation of viable seeds.

The plasticity of the phenorhythm, the completeness of all phenological phases of development, the rate of ontogenesis, and the viability of seeds of local reproduction confirmed the high adaptive potential of this alien species in our conditions.

Based on the analysis of our own observations, literary sources, and Internet resources, it was determined that all findings of spontaneous growth of *N. racemosa* in Ukraine, according to the European Nature Information System, are confined to synanthropic biotopes: decorative cultivated biotopes (parks, squares, lawns, flower beds), residential and technotopes (biotope complexes of built-up areas, garbage and solid waste landfills).

Discussion

The spread of this species in Ukraine is most facilitated by the presence of a significant number of introduction centers from which alien species most often escape and by their use in phytodesign. For example, the locality of *N. racemosa* studied in Kyiv and the region could have appeared as a result of escape from flower and decorative exhibitions, or as a result of their reconstruction, or due to accidental introduction of seeds or parts of plants by people or the wind. We also believe that the emergence of such habitats is facilitated by non-compliance with the rules and regulations for the storage and disposal of plant waste.

It should be noted that in the urban flora of other European countries, *N. racemosa* is distributed in biotopes and habitats similar to ours. For example, in Budapest (Hungary) this species is reported as naturalized, mostly growing in pavement cracks and along roadsides (Rigó et al. 2023). Pyšek et al. (2022) report on the naturalization of this neophyte in the Czech Republic, where its spontaneous growth was recorded in the cracks of sidewalks and asphalt pavements, near the foundations of buildings, etc. in Prague, Borno, Kutná Hora, Kyjov and other cities (Pyšek et al. 2022, iNaturalist 2025). In Finland, as in our country, *N. racemosa* has been found in garden waste dumps and landfills (Kurtto et al. 2019). In general, currently the largest number of findings has been recorded in Sweden (1446 finds), Belgium (661), Austria (187), and the Czech Republic (172) (Kartesz 2015, Pyšek et al. 2022, GBIF 2025).

Predicting the further spread of introduced species beyond their primary cultivation areas is an important contemporary task. Based on the dynamics of newly recorded localities of *N. racemosa* in Ukraine, we estimated the potential future spread of this species in urban environments over the next 20 years. An annual increase in cases of spontaneous spread is expected, from 7 in 2025 to 17 in 2045 under conditions of introduction, and from 5 to 12, respectively, outside cultivation. We believe that the spontaneous spread of this alien species in Ukraine is not yet of a threatening nature. But the high adaptive potential of *N. racemosa* and its wide involvement in landscape design may provoke an increase in the number of spontaneous localities of the species in anthropogenically transformed territories in the near future, because in cultural phytocenoses, self-seeding is observed in many cases, and plants are able to go through all phases of ontogenetic development with the formation of viable seeds in one growing season. Also, climate warming will contribute to the further spread of this species, since weather and climatic conditions will likely approach those of the original range, which will increase the competitiveness of the species.

Therefore, the species studied has a wide ecological amplitude of growth in the secondary range and is gradually increasing its presence in the urban environment of many European countries, including Ukraine, where it is naturalizing in synanthropic biotopes. *N. racemosa* requires ongoing monitoring and control of its spread to prevent possible invasion into new

territories. If the species shows signs of becoming invasive, its use in ornamental gardening should be limited.

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Author contribution statement

Both authors conducted the study, analyzed the statistical data, worked on the manuscript, and approved the submitted version of the manuscript.

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