Thaiszia - J. Bot., Košice, 34: 103–123, 2024
https://doi.org/10.33542/TJB2024-2-02

THAISZIA
JOURNAL OF BOTANY

Euphorbia maculata (Euphorbiaceae) in the flora of Ukraine: introduction history and current distribution

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Shevera M. M., Shynder O. I., Kolomiychuk V. P., Protopopova V. V., Miskova O. V., Lyubinska L. G., Kalashnik K. S. & Karmyzova L. O. (2024): *Euphorbia maculata* (Euphorbiaceae) in the flora of Ukraine: introduction history and current distribution. – Thaiszia – J. Bot. 34: 103–123.

Abstract: The study presents findings on *Euphorbia maculata* L. (Euphorbiaceae) in Ukraine, summarizing its introduction history, current distribution, and ecological characteristics. This alien species of North American origin exhibits progressive expansion. First recorded in 1931 in Lviv it has been documented later in the Crimea (1954) and Odesa (1980). Most known locations (94.5%) were identified after 2017, with over 93 sites within 19 administrative regions. Distribution mapping was based on herbarium data, online citizen-science platforms, and literature sources. In Ukraine, *E*. *maculata* is associated with plant communities of the *Stellarietea mediae* class, typically found in cracks of concrete and pavements at railway stations, walls, parks, and highways. Its colonization is patchy, with populations forming

narrow, ribbon-like communities. The species' naturalization varies regionally. For example, *E. maculata* did not establish in Lviv, where it was first recorded. In Odesa and in the Crimea, however, it has become an epoecophyte, forming persistent local populations. Population studies showed that colonysizes ranges from a few individuals to over 1,000 in optimal conditions. The largest population was found in Diukivskyi Park in Odesa, covering more than 0.5 hectares. Population density varies from 2-9 individuals per square meter in compact spaces to 46 individuals in optimal watered areas. Overall, this species is steadily expanding its range in Ukraine.

Keywords: alien plant, biodiversity, geography, naturalization, plant communities, Ukraine.

Introduction

Currently there is an increase in the rate of spread of many alien plant species in Ukraine (Protopopova & Shevera 2019; Koniakin et al. 2023; Mamchur et al. 2023; Shevera et al. 2023, etc.). Spotted spurge (*Euphorbia maculata* L.), from the family Euphorbiaceae, is a species that is characterized by accelerated rates of dispersal, expansion of the spectrum of habitats, and inclusion in various synanthropic plant communities (Moysiyenko et al. 2020, 2023; Shynder et al. 2018; Vasylyeva et al. 2019). The same case can be observed for other morphologically similar species of the subgenus *Chamaesyce* Raf. of the genus *Euphorbia* L., in particular *E. glyptosperma* Engelm., *E. prostrata* Aiton and *E. serpens* Kunth (Bátori et al. 2012; Wolf & Király 2014; Izverscaia & Ghendov 2017; Sîrbu & Șușnia 2018; Ryff 2019; Moysiyenko et al. 2023, 2024). This situation causes some confusion in the determination of the above species. Therefore, the identification of *E. maculata* and its monitoring are relevant.

Biology and morphology. *Euphorbia maculata* is a uniformly short-pubescent annual plant. The main shoot does not stand out, individual stems are rarely greater than 30 cm long. The leaves are oval or elongated up to 0.3–1 cm long and arranged in opposite pairs, often with a reddish spot in the center. Cyathias are bisexual, small and have four leaf-like appendages which are sometimes pink in color (Steinmann et al. 2016). *E. maculata* is morphologically similar to other prostrate native and alien species from the subgenus *Chamaesyce* of the genus *Euphorbia* in the flora of Ukraine, but it differs from them in several features: the fruits are evenly pubescent, the hairs are appressed, are stems pubescent with grayish protruding hairs, seeds with 3–4(–6) prominent transverse ridges, anthocyanin spots or stripes are sometimes visible on leaves (Gleason & Cronquist 1991; Steinmann et al. 2016; Sîrbu & Șușnia 2018).

Native range. The species has North American origin, naturally distributed from the northeastern part of Canada to the southern regions of the United States (Gleason & Cronquist 1991). According to more recent data it is presumed to be native to eastern and central North America, but it is difficult to be sure, based on

extremely weedy tendencies of its dispersal (Steinmann et al. 2016). In the native range, the species is limited to disturbed habitats, and grows in gardens, cracks on the hard substrate of pavements, along railway tracks, and on roadsides, at altitudes from 0 to 1500 m above sea level (Steinmann et al. 2016).

Introduced range in culture. First confirmed data about the cultivation of this plant in Europe: in the London Botanical Gardens from 1660 (Hegi 1975) and in Amsterdam (Ascherson & Graebner 1917; Galera & Sudnik-Wójcikowska 2004). The presence of the species was indicated in other botanical gardens, for example, in France, Italy, Hungary, Poland, and other countries. However, it is not reliably known whether this plant was specially cultivated or was introduced with other plant species.

Secondary spontaneous range. *Euphorbia maculata* is a widespread weed in temperate latitudes, and it also occurs in cool climates at higher elevations in the tropics regions. It spreads readily with greenhouse plants and earth-moving activities (Steinmann et al. 2016). The secondary range of *E. maculata* covers all inhabited continents. The species is spontaneously distributed in the western part of North America (outside the native range), in Central and South America, Western, Central and Southern Europe, Asia (the Middle East, Caucasus, Central Asia, South-Eastern Asia), North Africa, Australia, and New Zealand (Smith &Tutin 1968; Holm et al. 1979; Esler & Astridge 1987; Hügin 1998; Karzon & Böcker 2006; Steinmann et al. 2016; POWO (https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:347236-1).

Secondary habitats of the *E. maculata* are mainly artificial rocky places: in the cracks of slabs or asphalt on streets, parks, squares, and on railway embankments. Sometimes this plant grows on lawns, in agricultural nurseries, and as a weed in gardens and on fields. The optimal conditions for *E. maculata* are open sunny locations and mostly loamy neutral and weakly alkaline dry soils moderately enriched with minerals; it does not tolerate a salinity (Smith &Tutin 1968; Uva et al. 1997).

In Western Europe the beginning of the spontaneous distribution of *E. maculata* was associated with the Royal Botanical Gardens in Kew near London, from where the species distributed to southern regions of England. Escaped plants on the territory of modern Croatia (Dalmatia) were first recorded in 1826 (Ilijanić 1957; Frajman & Jogan 2007); in Switzerland (Geneva) this species was found in 1848 (Lányi 1906; Somlyay 2009), in Germany – in 1857 in Berlin, and 1877 in Baden, and later it was noticed in many other locations (Hegi 1975). Later the species was found in several other countries: in Hungary – in 1906 (Lányi 1906; Somlyay 2009), in Austria – in 1912 (Hegi 1975), in Slovenia and Poland – in 1917 (Frajman & Jogan 2007; Raciborski 1921), in Czech Republic – in the 1940s (Dostál 1948–1950), in Serbia – in Posavina near Kupinovo – at the same time (Slavnić 1953), and in Vojvodina – in 1986 (Janković 1986; Đurović et al. 2022), in Bulgaria – in 1959 (Kuzmanov 1961), in Albania – in 1976 (Seebens et al. 2017), in Slovakia – in 2007 (Eliáš 2009), in Moldova – in 2018 (Molnár et al. 2019). Currently, the range of *E. maculata* is expanding in the surrounding to Ukraine territories, especially in Poland (Urbisz 2019) and Slovakia (Dudáš et al. 2021).

It is believed that the spontaneous spread of *E. maculata* plants in Europe was facilitated by human activities in botanical gardens (Galera & Sudnik-Wójcikowska 2004). For example, in the botanical garden of Jena (Germany) the species was listed as a weed with seedlings of *Vaccinium macrocarpon* Aiton (Hegi 1975), and in Poland, where these plants grew as a weed in the Botanical Garden of Kraków (Raciborski 1921). Closer to our time, *E. maculata* was found in Kraków Botanical Garden on areas with cultivation of *Eremurus* sp. and *Polygonatum odoratum* (Mill.) Druce; and in the botanical garden of Poznań, where it arrived with planting material of *Opuntia* sp., brought from Wrocław in 1993 (Galera & Sudnik-Wójcikowska 2004).

Tourism and railways are also accesory for the distribution of *E. maculata*, since its plants are often noticed at railway stations and between tracks (Brandes 1993). Now this species is considered among the most common types of alien plants in the flora of Europe, it was recorded from 34 out of 48 regions of the European continent (Lambdon et al. 2008). Another way for the transferring of diaspores of *E. maculata* is construction material. Its colonies between pavement slabs were repeatedly noted in Ukraine, which was associated with the introduction of diaspores of this plant with a construction sand (Vasylyeva et al. 2012; Yena 2012).

Ecological and coenotic peculiarities. Euphorbia maculata occurs as a part of communities of segetal and ruderal vegetation. Timár (1950) singled out phytocoenoses with the dominantion of *E. maculata* in the composition of the association *Polygonetum avicularis* Gams 1927 (now traditionally treated within the class *Polygono-Poetea annuae* Rivas-Mart. 1975). Oberdorfer (1954) described the new association *Eragrostis minor-Polygonum aviculare* (*Eragrostio-Polygonum avicularis*) from Southeast Europe, which includes xenophytes of American origin: *E*. *maculata* and *Lepidium didymum* L. (ut *Coronopus didymus* (L.) Sm.). In his opinion, these could be characteristic types of associations, which he also indicated in the published table. However, they were so rare that he could not give them much diagnostic value. Poldini (1989) described the association of *Euphorbietum maculatae* from the vicinity of Terst (Eliáš 2019). Brandes (1993) described the community *Euphorbia maculata–Portulaca oleracea* from Germany. Later Čarni & Mucina (1998) identified a separate association *Portulaco-Euphorbietum maculatae* (Brandes 1993) Čarni & Mucina 1998, belonging to the class *Stellarietea mediae* (Br.-Bl.) Tx., Lohm. & Prsg. in Tx. 1950. This association is typical for trampled areas with compacted soil within cities and widely distributed in many countries of Mediterranean region (Eliáš 2009; Eliáš 2019).

Impact and properties. E. maculata can colonize pavement cracks in the summer; it is a segetal weed, for example, with a species density of 5–10 to 50 plants per square meter in cotton plantations, it dejects the growth of the last one, and a decrease in its yield on 47.6–85.0% (Bararpour et al. 1994). Modern scientists study *E. maculata* as a segetal weed and develop chemical methods of controlling its spread (Bararpour et al. 1994; Cheng et al. 2009). The species is considered as invasive, for example, in Romania, Croatia, and Greece (EPPO,

https://gd.eppo.int/taxon/EPHMA), included in the WSSA list of weeds in North America (WSSA, https://wssa.net/weed/composite-list-of-weeds/).

The plants of this species, as other representatives of Euphorbiaceae, are poisonous, the juice contains substances that cause allergic reactions, and the raw plant materials of *E. maculata* have a long history of use in traditional medicine as a laxative (Zollickoffer 1842). The chemical composition of *E. maculata* (Elmore & Paul 1983; Matsunaga et al. 1998; Agata et al. 1991; Runhui & Lingyi 2001), its physiological features (Kim et al. 2000), and allelopathic activity of the species (Cheng et al. 2009) were the objects of research at the end of the 20th and beginning of the 21st centuries.

Taxonomy. Traditionally, *E. maculata* was considered as a member of the subgenus *Chamaesyce* of the genus *Euphorbia* L. Based on new molecular phylogenetic data, it was found out, that species belongs to the section *Anisophyllum* Roeper (Yang et al. 2012; Steinmann et al. 2016). During a long time, this taxonomic group was repeatedly treated into separate genera, which led to the appearance of several synonyms: *Anisophyllum maculatum* (L.) Haw., *Chamaesyce maculata* (L.) Small, *Tithymalus maculatus* (L.) Moench, *Xamesike maculata* (L.) Raf. In addition, several species were described as separated from *E. maculata*, which now are considered as a heterotypic synonyms: *Chamaesyce jovetii* (Huguet) Holub, *Ch. mathewsii* Small, *Ch. pseudonutans* Thell., *Ch. supina* (Raf.) Moldenke, *Ch. tracyi* Small, *Euphorbia supina* Raf., *E. depressa* Torr. ex Spreng., *Xamesike littoralis* Raf. etc. (Yang et al. 2012; Nasseh et al. 2017, etc.).

Two varieties were described as part of the species: *E. maculata* var. *dentosa* Engelm. ex Boiss. and *E. maculata* var. *parvula* (Huquet) Holub, which indicates a certain variability of its morphological features (Nasseh et al. 2017). However, these varieties are not clear based on their morphological characteristics, so it is not customary to distinguish them now (Steinmann et al. 2016).

The aim of this study was to summarize information about (i) the stages and ways of introduction of the species *Euphorbia maculata*, (ii) the current distribution, and (iii) forecasting the further spreading of the species in Ukraine since an analysis of the distribution of the species has not been carried out until now.

Material and Methods

The object of our study is *E. maculata* in the flora of Ukraine. The work based on the comparative morphological and geographical methods and results of field expeditions (2021-2024) by authors of this paper. Literature data, herbarium collections (KW, KWHA, MELIT, PTR), and information from opened citizen science resources iNaturalist (https://www.inaturalist.org) and UkrBIN (https://ukrbin.com) were analyzed. Based on the analysis, a list of known locations was compiled and a map of the distribution of the species in Ukraine was created. Vascular plant names and their authors were accepted in according to POWO (https://powo.science.kew.org/).

For the identification of *E. maculata* by morphological features we used primarily the determination key (Sîrbu & Șușnia 2018), and other materials. The population density of *E. maculata* in individual studied habitats is given as a number of individuals per square meter. Individuals were counted in the second half of the vegetative season (August and later), on 10 randomly located transects measuring 1 × 5 m. In some cases, for small populations, the measuring plots had fewer repetitions.

The physical and geographical zones of Ukraine were indicated according to Marynych et al. (2003).

Results and Discussion

A brief overview of the distribution of E. maculata in Ukraine.

In Ukraine, the first specimen of *E. maculata* is known from Lviv (at that time as a part of the Polish Republic), from the territory of the Botanical Garden of the Lviv University ("Lwów – 1930, naścieżce, leg. J. Mądalski", KRA). Another specimen from this location, which was collected two years later, is preserved in Kyiv: *Euphorbia maculata* L., path in the Botanical Garden at the Dlugosza Street 4 … 10–11.VII.1932. J. Mądalski (KW s.n.) ["Lwów, naśceieźce w Ogrodzie Botanicznym przy ul. Dlugosza 4 … 10–11.VII.1932. J. Mądalski"].; at this time, the label states that in 1931–1932 it was included in the "Ogrod Flory Polskiej", located on 54 Tsetnerivska Street. To date, the species has not been found at the place of primary introduction.

An. Yena (2012) noticed that D. Geltman in 2001 informed him about a specimen of the species from the Crimea, collected in 1954 with this label: "Nikitsky Botanical Garden, on the flowerbed near the main building 12.X.1954, S. Kozhevnikova", which now is kept in the Herbarium YALT. In 2009 An. Yena confirmed the finding of the species in the same location and it was discovered by S. Svirin in Sevastopol, and five years before (2004) – in Simferopol by An. Yena: on the embankment of Salgir River, along the street Kyivska and Children's Park (Yena 2012). Now the species is widely distributed in many other settlements of the Crimea.

From the mid-80s of the 20th century *E. maculata* was dispersed in the Steppe zone of Ukraine. In 1984, this species was found in the Odesa Oblast: in Vylkove, on the sand spit of Kuban Island in the Kili Danube Delta (Dubyna & Protopopova 1984; Dubyna & Shelyag-Sosonko 1989; Shelyag-Sosonko 1999; Popova 2003). However, there is no corresponding herbarium specimen in the KW. In 2003, the species was collected later in the port of Reni (16.09.2003, M.V. Shevera, KW 025540), and 2009 – in the Primorsky Raion of Odesa, in the yard of the administrative institution, in the gaps between slabs (Vasylyeva et al. 2012). Nowadays, this species is not rare in Odesa and its surroundings.

At the beginning of the 21st century, the species actively invaded in the northern and eastern directions across the Steppe zone. In 2010, it was found in Dnipropetrovsk Oblast: in Kamianske (Lisovets 2016), later (2018) – in Kryvyi Rih (Moysiyenko et al. 2020), and Dnipro ("Dnipro, central railway station, on platforms, between tiles, 01.07.2023, M. Shevera, KW 162250)". Since 2017, *E. maculata* has

been recorded in Kherson Oblast: in Skadovsk (2017) on the territory of a seaport (Moysiyenko et al. 2020); in Kherson (2019) on the territory of a former cotton mill (Moysiyenko et al. 2021); in the vicinity of Oleshky (2019, I. Moysiyenko, N. Skobel, KHER 10363); and in several other settlements. In Zaporizhzhia Oblast, the species was firstly found by V. P. Kolomiychuk in 2018 in Pology, and in 2020 it was recorded by O. Levon in Zaporizhzhia. In 2024 O. Shynder discovered it in the Mykolaiv.

Recently, *E. maculata* was discovered in the capital of the country, located on the border between the Forest Steppe and Forest (Polissia) border. In Kyiv City, the species was recorded for the first time in 2017 in the Syretsky Dendrological Park, as a greenhouse weed and in open soil plant collections. It was preliminary identified as *E. humifusa* Willd. ex Schlecht. This species probably has got to the park with the collection of indoor succulents transferred by the agricultural company "Flowers of Ukraine" in 2007–2008. On the first stage, it spreads in greenhouses, becoming a characteristic weed of closed soils, and then – in a nursery and along cracks in asphalt near greenhouses. In open soil, individuals of *E. maculata* die during the first frosts, but its seeds successfully overwinter on the soil surface and new generations of the species are formed in spring (Shynder et al. 2018). Later, in 2020, the species was recorded by O. Shynder in the forest-steppe part of Kyiv City: "Southern Zvirynets, a lawn near a flower garden on Zvyrinetska Street, abundantly, 50.4080°, 30.5544°, 16.10.2020, O. Shynder" (KW 161379), and in the next years in other places. In October 2024, the species was found in the Mezhihirya National Park in Novi Petrivtsi village, Vyshhorod Raion, Kyiv Oblast.

During 2021–2023, the species has also been found in other regions of the Forest-Steppe zone of Ukraine: Cherkasy, Kharkiv, Khmelnytskyi, Sumy and Vinnytsia (Moysiyenko et al. 2023; materials of herbariums KW and KWHA; data of iNaturalist), and in 2023 – in the Volyn Forest-Steppe in Rivne Oblast, which indicates the penetration of the species into the northern regions of the country.

In the Carpathian region, *E. maculata* was firstly noticed by M. Peregrym in Chop, Zakarpattia Oblast (Májeková et al. 2021), and later this species was found by V. Hleba at the railway station in Koroleve village of Berehove Raion (Moysiyenko et al. 2023). In 2021–2023, the species was repeatedly recorded in various settlements, particularly in Berehove and Uzhhorod.

The last meeting of the species in one of the central squares of the Ivano-Frankivsk city, near the market, dates from October 2024.

Present information about all currently known locations of *E. maculata* in Ukraine, indicating the settlement, year of collection, collector or author of the photo observation (if it is reliably known) are summarized below.

Autonomous Republic of Crimea

Bakhchysarai Raion: eastern outskirts of Bakhchysarai, on the mountain road, 44.72846°N, 33.94449°E, 13.07.2022 (iNaturalist ID 126215799); the surroundings of Mostove village, roadside, 12.09.2021, K. Kashirina (iNaturalist ID 94610970).

Yalta Raion: Nikitsky Botanical Garden, on the flowerbed near the main building 12.X.1954, S. Kozhevnikova (YALT; Yena 2012); at the arboretum entrance of the Nikitsky Botanical Garden, 2009, An. Yena (Yena 2012); Sanatorne village, on the side of the Yuzhnoberezhne highway, 23.08.2021, K. Kashirina (iNaturalist ID 92373764); Krasnokamyanka village, roadside, 18.08.2020, V. Anvarov (iNaturalist ID 83138350); Alushta, on the park path, 44.676047°N, 34.418161°E, 24.06.2022, S. Bohdanovich (iNaturalist ID 123428899); Koreiz village, roadside of Koreizke highway, 44.430075°N, 34.073742°E, 03.12.2021, S. Bohdanovich (iNaturalist ID 102415532); Partenit village, on the path edge, 16.08.2021, S. Bohdanovich (iNaturalist ID 91429212); Sotera village, in the park, seashore, 44.734764°N, 34.510503°E, 30.08.2021, S. Bohdanovich (iNaturalist ID 93124345).

Simferopol city, on the embankment of Salghir River, along Kyivska Street, Children's Park, between concrete slabs were laid in the 1980s, 2004, An. Yena (Yena 2012).

Sevastopol, 2004, S. Svirin (Yena 2012); Senna Street, at the bus stop, 27.08.2022, S. Svirin (iNaturalist ID 133382053).

Yevpatoria Raion: Saki, Vokzalna Street, 16.10.2020, D. Safina (iNaturalist ID 62713949); *Yevpatoria*, eastern outskirts, on the square near the memorial, 12.09.2021, K. Kashirina (iNaturalist ID 94840377).

Feodosia Raion: the surroundings of Vladyslavivka village, near the railway, 45.165587°N, 35.380456°E, 13.09.2021, Ye. Razina (iNaturalist ID 94809083); Feodosia, quay, 25.09.2020, Ye. Razina (iNaturalist ID 60709342); Gallerina Street, in a yard, 08.08.2023, K. Kashirina (iNaturalist ID 181393818).

Cherkasy Oblast

Uman city: the quay of Ostashivskyi Pond, on a flowerbed among gravel, locally, 48.740283°N, 30.215526°E, 29.07.2023, O. Shynder (KWHA 103176) (iNaturalist ID 178819302).

Dnipropetrovsk Oblast

Dnipro city: railway station, on the platforms between the slabs, many, 48.477459°N, 35.010468°E, 02.07.2023, M. Shevera, O. Shynder, L. Karmyzova (KWHA 103174; KW 162251); Chechelivsky rayon of Dnipro city, Podmohilnoho Street, near the bus stop, 48.397917°N, 34.9845°E, 01.07.2020, V. Roi (UkrBIN.com ID 164716).

Kamianske city: near-by a recreation center “Himik”, 2010 (Lisovets 2016).

Kryvyi Rih city: the railway station, several individuals in the asphalt cracks and between the curbs, 47.91272°N 33.45164°E, 06.06.2018, I. Moysiyenko (Moysiyenko et al. 2020).

Ivano-Frankivsk Oblast

Ivano-Frankivsk city: on the sidewalk along the edge of the square, between Shpytalna Street and Dniesterska Street, scattered, about 30-40 plants, 48.92455°N, 24.71238°E, 30.09.2024, O. Shynder (iNaturalist ID 245562116).

Kharkiv Oblast

Kharkiv Raion: Vysokyi settlement, roadside, 49.883816°N, 36.103604°E, 10.07.2021, Yu. Bengus (iNaturalist ID 97534969).

Kherson Oblast

Kherson city: the territory of the former cotton mill, 18.10.2019, I. Moysiyenko (Moysiyenko et al. 2020); the railway station, between pavement tiles of the platforms and along railway tracks, 46.65588°N, 32.60311°E, 03.11.2019, I. Moysiyenko, N. Skobel (KHER 10364) (Moysiyenko et al. 2020); 15 Naftovykiv Street, along the street, 47.91272°N 33.45164°E, 15.07.2020, I. Moysiyenko (Moysiyenko et al. 2020).

Kherson Raion: Chornobayivka village, Airport "Kherson", 46.671957°N, 32.508972°E, 20.07.2019, I. Moysiyenko (Moysiyenko et al. 2020).

Oleshky Raion: Sahy village, at the gas station, along 2 Shliakhova Street, (north side), 46.61486111°N, 32.79445833°E, 18.10.2019, I. Moysiyenko, N. Skobel (KHER 10363) (Moysiyenko et al. 2020).

Skadovsk, a territory of the Skadovsk seaport, 06.10.2017, I. Moysiyenko (Moysiyenko et al. 2020).

Khmelnytskyi Region

Kamianets-Podilskyi city: on the platform near the railway station, 48.68799°N, 26.6019°E, 08.07.2022, I. Moysiyenko (Moysiyenko et al. 2023); ibid., 48.690185°N, 26.602241°E, 07.08.2022, O. Shynder (KWHA 102425; iNaturalist ID 153018176), 2023, M. Shevera, 2023, L. Liubinska (KW 162244; PTR s.n.).

Kamianets-Podilskyi Raion: Zhvanets village, between the cobblestones, in front of the hotel and restaurant complex "Dniester", 27.07.2023, M. Shevera (KW 162243; KWHA 103175).

Kirovohrad Oblast

Novoukrainka Raion: Voynivka village – the northern outskirts, along the railway track near the stone quarry, between the railways, locally, abundantly, 48.4089°N, 31.5072°E, 19.08.2019, O. Shynder (KWHA 103318; Moysiyenko et al. 2023).

Kyiv City

Syrets: Syretsky Dendrological Park, *E. maculata* was listed with a collection of indoor succulents in 2007–2008, 2017 (sub *E. humifusa*) (Shynder et al. 2018); Syretsky Dendrological Park, nursery, as a weed, 11.09.2017, O. Shynder (sub *E. humifusa*, det. 20.12.2023 by O. Shynder as *E. maculata*) (KWHA 103452); Syretsky Dendrological Park, near the greenhouses in asphalt cracks, 50.48165°N, 30.42333°E, 06.08.2018, O. Shynder (KWHA 102924); Syrets, Tyraspolska Street, on the square in front of the supermarket, several dozen, scattered, 50.48026°N, 30.41449°E, 07.08.2024, O. Shynder (iNaturalist ID 234320493);

Southern Zvirynets: lawn near the flower garden on Zvyrinetska Street, abundantly, 50.4080°N, 30.5544°E, 16.10.2020, O. Shynder (KW 161379; Shynder et al. 2022); the

side of the Zaliznychne Highway, abundantly, 01.07.2021, O. Shynder (iNaturalist ID 101758178);

Pechersk: Museum of the Second World War, on the square between slabs, little population, 50.42986°N, 30.56059°E, 19.09.2022, O. Shynder (iNaturalist ID 136942075);

Shulavka: near the metro station "Shulyavska", between slabs, abundantly, 50.45542°N, 30.4424°E, 17.06.2024, O. Miskova (iNaturalist ID 223291225).

Kyiv Oblast

Vyshhorod Raion: Novi Petrivtsi village, "Mezhyhirya Residence", colony on the sidewalk in front of the palace not far from the central entrance, several hundred plants, abundant but local, 50.61329°N, 30.47369°E, 20.10.2024, O. Shynder (iNaturalist ID 248490856); ibid., 50.61335°N, 30.47372°E, 20.10.2024, O. Shynder (iNaturalist ID 248558594).

Luhansk Oblast

Luhansk city: Pavlivska Street, on the roadside, near the gas station, 48.551944°N, 39.258071°E, 14.09.2017, T. Sova (UkrBIN.com ID 102563), 48.551978°N, 39.257908°E, 14.09.2017, T. Sova (UkrBIN.com ID 50311); on the railway, 48.57751°N, 39.29008°E, T. Sova (iNaturalist ID 195547596).

Lviv Oblast

Lviv city: Plantae Poloniae Exicatae. Lwów, na ściezce w Ogrodzie Botanicznym przy ul. Długosza 4, 10-11.07.1932, N116, J. Madalski (KW s.n.).

Mykolaiv Oblast

Mykolaiv city: on the side of the Odesa Highway, near a gas station, abundantly, 46.98528°N, 31.90323°E, 31.08.2024, O. Shynder (KWHA; iNaturalist ID 239730011).

Odesa Oblast

Odesa city: in the yard of an administrative building, in the gaps between the stacked slabs, 2009 (Vasylyeva et al. 2012); Fontanskaya Road, quay – upper terrace, as a weed on the sidewalk, in cracks between slabs, locally, 46.400937°N, 30.75451°E, 26.09.2022, O.Shynder (KW 161318), 06.10.2023, K. Kalashnik, O. Koshelev (iNaturalist ID 151810055; iNaturalist ID 187149113); Shampanskyi Lane, as a weed in the flowerbed, locally, 29.09.2022, O. Shynder, 46.452317°N, 30.758983°E, 07.10.2023, K. Kalashnik, O. Koshelev (iNaturalist ID 146513937); North Odesa Cape, the territory of the yacht club, in a crack in the cement coating, one plant, 46.54907°N, 30.820021°E, 24.07.2023, K. Kalashnik (iNaturalist ID 174681336); between Kanatna Street and Italiysky Boulevard, in front of the "Spartak" stadium entrance, in cracks between slabs on steps, 28 individuals per square meter (locality area about 250 square meters), 46.468046°N, 30.746939°E, 28.06.2023, 11.08.2023, K. Kalashnik, (iNaturalist ID 169936286, iNaturalist ID 177820362); Seventh Peresypska Street, between the tram tracks at the bus stop, 12 individuals per square meter (locality area about 300 square meters), 46.531746°N, 30.732563°E, 01.08.2023, 31.08.2023, K. Kalashnik (KWHA 103246; iNaturalist ID

176128918); Kovalevskoho Dacha Street, near the building, 46.370237°N, 30.72737°E, 10.09.2023, V. Kolomiychuk (iNaturalist ID 182665925), 46.370183°N, 30.727522°E, 10.09.2023, V. Kolomiychuk (iNaturalist ID 182666304); Bazarna Street, near the building, in cracks between slabs, 46.473453°N, 30.750433°E, 10.09.2023, K. Kalashnik, O. Koshelev (iNaturalist ID 182642335); Uspenska Street, on the flowerbed, in cracks between slabs, 46.474702°N, 30.754218°E, 22.09.2023, K. Kalashnik, O. Koshelev (iNaturalist ID 216179598); Hretska Ploshcha, in cracks between slabs, 46.48226°N, 30.735004°E, 29.09.2023, K. Kalashnik, O. Koshelev (iNaturalist ID 187652432); Kerchenska Street, in front of a private garage, in cracks between slabs, two plants, 46.56794°N, 30.78434°E, 05.10.2023, K. Kalashnik (iNaturalist ID 186292630); 9th station of the Great Fountain, in cracks between slabs, 46.420763°N, 30.764569°E, 06.10.2023, K. Kalashnik, O. Koshelev (iNaturalist ID 215790626); Genuezka Street, between crushed stone, 46.436271°N, 30.759207°E, 06.10.2023, K. Kalashnik, O. Koshelev (iNaturalist ID 215791716); near the tram tracks at the transport stop “Ploscha Desiatoho Kvitnia”, between crushed stone, in cracks between slabs, 46.439293°N, 30.757443°E, 06.10.2023, K. Kalashnik, O. Koshelev (iNaturalist ID 215792387); Ploschaesiatoho Kvitnia, in cracks between slabs, a lot of plants, 46.440304°N, 30.757191°E, 06.10.2023, K. Kalashnik, O. Koshelev, 22.05.2024, O. Koshelev (iNaturalist ID 215792806); Diukivsky Park, near the administrative building in cracks between slabs, a lot of plants, 46.482857°N, 30.703671°E, 21.10.2023, K. Kalashnik, O. Koshelev (iNaturalist ID 188387473), on the square and the stairs, to 0.5 ha, abundant in some places, 18.08.2024, O. Shynder (iNaturalist ID 238288237) (Fig. 2); Literaturna Street, in cracks between slabs, 46.419618°N, 30.760224°E, 28.10.2023, K. Kalashnik, O. Koshelev (iNaturalist ID 189337445); Harshina Street, on the sidewalk, in cracks between slabs, a lot of plants, 46.404814°N, 30.752892°E, 28.10.2023, K. Kalashnik, O. Koshelev (iNaturalist ID 216170369); Shevchenko Avenue, in cracks between slabs, 46.449077°N, 30.756494°E, 04.11.2023, K. Kalashnik, O. Koshelev (iNaturalist ID 189977519); Taras Shevchenko Central Park, in cracks between slabs, 46.483447°N, 30.751046°E, 02.12.2023, K. Kalashnik, O. Koshelev (iNaturalist ID 192841228); Fontanska Doroha Street, in cracks between slabs, 46.44202°N, 30.743988°E, 04.11.2023, K. Kalashnik, O. Koshelev (iNaturalist ID 189978541); Fontanska Doroha Street, 12th station of the Great Fountain, in cracks between slabs, 46.405089°N, 30.754879°E, 28.10.2023, K. Kalashnik, O. Koshelev (iNaturalist ID 216171528); Fontanska Doroha Street, 11th station of the Great Fountain, in cracks between slabs, 46.410818°N, 30.755709°E, 28.10.2023, K. Kalashnik, O. Koshelev (iNaturalist ID 216169405); Fontanska Doroha Street, embankment, as a weed on the sidewalk, in cracks between slabs, many plants, 46.400426°N, 30.754605°E, 06.10.2023, K. Kalashnik, O. Koshelev (iNaturalist ID 188296951); Railway station, on the track, 55 individuals per 20 square meters, the average density is seven individuals per square meter, 46.4646653257°N, 30.7401273027°E, 30.08.2024, K. Kalashnik, K. Lavrinenko (iNaturalist ID 238986559).

Odesa Raion: Kryzhanivka, in front of the village council building, in the cracks between the slabs, a lot of plants, 46.560146°N, 30.790037°E, 25.10.2022, 04.10.2023, 25.05.2024, K. Kalashnik (iNaturalist ID 140884295, iNaturalist ID 218117555); Kryzhanivka, central square, in cracks between slabs, in the flowerbed, very abundant, 46.559794°N, 30.789288°E, 04.10.2023, 25.05.2024, K. Kalashnik (iNaturalist ID 186294621, iNaturalist ID 218109221); Fontanka Village Community, Southern road, in the cracks between the slabs, the one plant, 46.554826°N, 30.839476°E, 17.11.2023, K. Kalashnik (iNaturalist ID 191359813); the same, descent to the sea, in the gaps between the concrete slabs, 20 individuals per square meter (locality area about 500 square meters), 46.55483°N, 30.83948°E, 17.11.2023, K. Kalashnik (iNaturalist ID 191360035).

Izmail Raion: Vylkove, on the sand spit of the Kuban Island of the Kiliya Danube Delta, 26.09.1981, D. Dubyna (Dubyna & Protopopova 1984); between Prymorske village and the mouth of Danube Delta, 1980–1981 (Dubyna & Protopopova 1984); Reni, in the port, 16.09.2003, M. Shevera (KW 025540).

Rivne Oblast

Rivne city: the local colony on the square near the railway station platforms, about 250–300 individuals, 50.628084°N, 26.238512°E, 02.09.2023, O. Shynder (KWHA 103496; iNaturalist ID 181432552).

Sumy Oblast

Konotop Raion: Putyvl, in the yard of Movchanskyi Monastery, between slabs, 51.326959°N, 33.874557°E, 18.07.2023, O. Miskova (KW 162245; iNaturalist ID 173609241).

Vinnytsia Oblast

Haisyn city: in the yard of the Protestant church, on gravel, very abundantly, 48.809321°N, 29.385801°E, 06.08.2023, O. Shynder (KWHA 103177; iNaturalist ID 177395750).

Zakarpattia Oblast

Uzhhorod city: in the courtyard of the Tyvodar Legotskyi Transcarpathian Museum of Local History (Uzhhorod castle), 26.10.2021, O. Shynder (iNaturalist ID 134463842), the same, 48.62170°N, 22.30657°E, 02.09.2022, O. Shynder, M. Shevera (Moysiyenko et al. 2018), the same, in cracks between slabs, 48.621286°N, 22.30642°E, 02.09.2022, M. Bilanych (UkrBIN.com ID 263437); the school No. 4, front garden, 48.62635°N, 22.29683°E, 03.09.2022, M. Shevera, O. Shynder (KW; Moysiyenko et al. 2023); Studentska embankment, near Palace of Children and Youth, between slabs, a lot of plants, 09.11.2024, M. Shevera (KW 166128).

Uzhhorod Raion: Chop, railway station, 48.43253°N, 22.21032°E, 23.06.2018, M. Peregrym (Moysiyenko et al. 2023; iNaturalist ID 48562240).

Berehove Raion: Berehove, 42 Bohdana Khmelnytskoho Street, 21.08.2022, M. Shevera, O. Shynder (KW 162248), the same, at the base of the foundation of a private building, 27.08.2022, O. Shynder, M. Shevera (KWHA 102581; Moysiyenko et

al. 2018), the same, a colony near a private estate on the sidewalk, 48.202278°N, 22.638618°E, 27.08.2022, O. Shynder, M. Shevera (KWHA 102605); Ferenc Rákóczi II Transcarpathian Hungarian College of Higher Education, the courtyard, 48.20709°N, 22.64340°E, 29.08.2022, M. Shevera, O. Shynder (Moysiyenko et al. 2018); platform near the railway station, one individual, 11.09.2023, M. Shevera, O. Shynder (iNaturalist ID 217517285); Velyka Kopanya station, 48.193403°N, 23.163429°E, 01.08.2021, V. Hleba (UkrBIN.com ID 213511); Koroleve village, near the railway station, 2021, V. Hleba (non coll.).

Khust city: in the park of culture and recreation "Heroiv Maidanu", 04.06.2023, M. Shevera, O. Shynder, V. Kolomiychuk (iNaturalist ID 165508111).

Mukachevo city: on the sidewalk near the city pool, 48.44835°N, 22.72489°E, 20.08.2024, R. Kish (iNaturalist ID 236869760).

Zaporizhzhia Oblast

Zaporizhzhia city: on the square near the railway station, 29.09.2020, O. Levon (iNaturalist ID 61221041); A Children's botanical garden, a colony on paths, in one place, abundantly, 01.07.2023, O. Shynder (iNaturalist ID 206912784), 47.837037°N, 35.197545°E, 01.07.2023, V. Kolomiychuk (iNaturalist ID 170421687).

Pology town: 47.476908°N, 36.257694°E, 02.09.2018, V. Kolomiychuk (MELIT; iNaturalist ID 68370584).

In total, more than 93 locations of *E. maculata* in 45 settlements of 19 administrative regions have been recorded in Ukraine now, in all botanical-geographical regions. Based on summarized chorological data the map of the current distribution of this species in Ukraine was compiled (Fig. 1). The majority of locations (94.5%) were discovered after 2017, which demonstrates the expansive nature of the distribution of *E. maculata* in Ukraine.

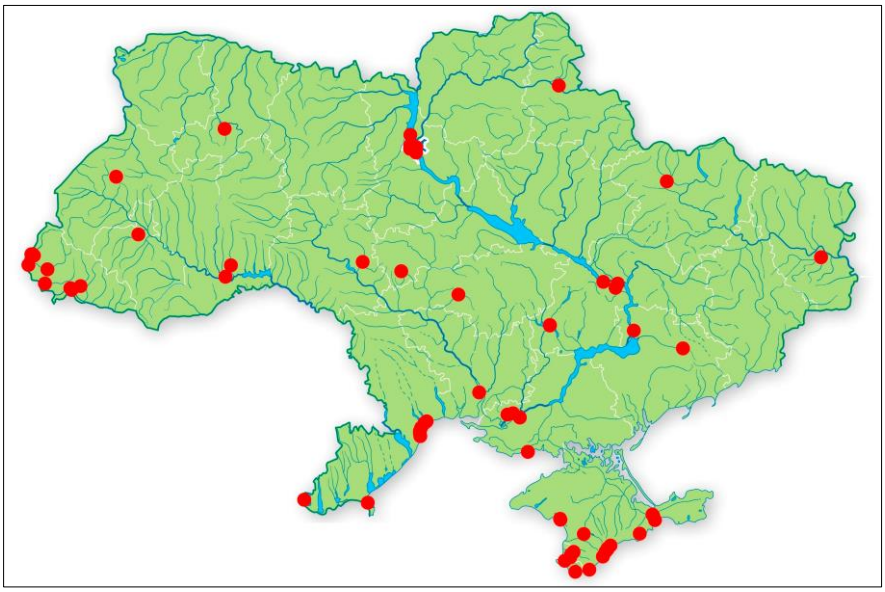

Fig. 1 Distribution map of *Euphorbia maculata* in Ukraine.

Dispersal of plants of the species is carried out by several ways. As a result of summarizing information on the distribution of *E. maculata* in Ukraine, it was found that the first findings were associated with their cultivation or the importation of seeds with other plants. Subsequently, the railway dispersal became the main factor in its distribution and remains it currently. Based on the nature of the modern spread of the species along railways (mainly in the form of colonies on platforms and station areas), it seems that the agents of *E. maculata* diaspore transferring are passengers who relocates seeds (fruits) between railway stations. But on the other hand, some individuals were found by authors outside of railway ecotopes. Thus, in Kyiv, Lviv, Uman, and other cities, the appearance of *E. maculata* was associated with the transport of greenhouse and ornamental flower plants. Also, many colonies of *E. maculata* are formed in places of construction of sidewalks, squares, paths, etc., and are probably associated with the accidental transfer of diaspores of the species in sandy or gravelly substrates. In the Crimea and the Steppe Zone, the active spread of this species along highways was noticed, and in the Odesa Oblast, the species was recorded for the first time on a sand spit in Vylkove and the port of Reni. Some individuals were found on agricultural land, which may be observed in the future.

Ecological and phytocoenotic features of E. maculata in Ukraine. In Ukraine, as well as in European countries, *E. maculata* plants are confined to unformed plant communities of the class *Stellarietea mediae* Tx. et al. in Tx. 1950 (Dubyna et al. 2022). They are spread sporadically, in the cracks of concrete and tile pavements of railway stations (Dnipro, Kamianets-Podilskyi, Chop, Pology, etc.), walls and stairs of buildings (Uzhhorod, Berehove), paths in city parks (Khust), front gardens (Uzhhorod), along city highways (Zaporizhzhia), in concrete cracks within garden centers (Odesa). Ribbon plant communities with individuals, tens or hundreds of meters in length, sometimes they are monodominant.

The degree of naturalization of *E. maculata* is different depending on the geographical area. It should be noted that in the place of the first recorded finding (botanical garden in Lviv), the species probably could not become naturalized, since there was no other evidence of the fixation of *E. maculata* in the city. This is typical for ephemerophytes and indicates the lowest degree of naturalization of the species at the time of observation. Currently, in most other regions, *E. maculata* has features of a typical colonophyte, which forms local populations in places of introduction. In Odesa and many settlements in the Crimea, *E. maculata* is an epecophyte.

The current state of populations of Euphorbia maculata in Ukraine. A local spatial type of population is charactered for *E. maculata* in Ukraine. In places where the species was introduced, it forms colonies, establishing itself and gradually increasing in number, and with favourable conditions the area of the population increases (mainly along highways, sidewalks, and railway platforms). In 2023 one adult plant was noted on the territory of the railway station in Berehove. Presumably, a significant number of invasive colonies of *E. maculata* detected now in this region were formed from one or more alien individuals of the species. The authors studied colonies of the species and found that their numbers ranged from 15-20 to several

hundred individuals. This is related to the penetration time of the species in habitats and environmental conditions. The number of populations of the species studied in 2017-2019 in the Kherson Oblast varied from 21 to more than 100 individuals (Moysiyenko et al. 2020). When *E. maculata* was introduced relatively long ago to the ecotopes with optimal conditions and a free large area, the species forms populations with more than 1000 individuals. The colonies on the territory of the railway station in Koroleve village and Ferenc Rákóczi II Transcarpathian Hungarian College of Higher Education in Berehove (Berehove Raion, Zakarpattia Oblast) are examples of such large populations.

The area of the studied populations of *E. maculata* varried from less than a square meter (in places of recent introduction) to 0.1–0.2 ha (on the railway territories in Koroleve village of Zakarpattia Oblast, and Kamianets-Podilskyi of Khmelnytskyi Oblast), but most of them have areas of six to 300 square meters. The largest population was noted in Diukivskyi Park (Odesa city), its size is more than 0.5 ha. Often, populations of *E. maculata*, that are located along transport routes, are narrow long ribbons in shape, up to several tens of meters long. Their actual area is relatively small.

The population density of *E. maculata* ranges from a few to several tens of individuals per square meter and depends on the free area of the open substrate which is suitable for the emergence of seedlings and the development of adult plants. Mainly they belong to spaces between concrete or stone slabs. On the platform of the railway station in Rivne city in 2023, we recorded a colony with a total number of more than 250 individuals, but population density in these conditions was low – from two to nine individuals per square meter. On the other hand, on the territory of Ferenc Rákóczi II Transcarpathian Hungarian College of Higher Education the density reached 46 individuals (Fig. 2). In the latter case, the

Fig. 2 A fragment of the population of *Euphorbia maculata* on the territory of Ferenc Rákóczi II Transcarpathian Hungarian College of Higher Education, Berehove, Zakarpattia Oblast (Photo by O. Shynder).

Fig. 3 A fragment of the population of *Euphorbia maculata* in Diukivsky Park, Odesa, Odesa Oblast (Photo by O. Shynder).

core of the population of *E. maculata* was formed in optimal conditions on a light nutrient substrate with constant watering and low plant competition (Fig. 2). These circumstances are typical for areas associated with ornamental gardening. The species grows abundantly in Diukivskyi Park, where the population density reaches up to 39 individuals in asphalt cracks (Fig. 3). From 11 to 140 individuals of studied species were recorded in the analysed areas on the platforms of the Central Railway Station in Dnipro (Fig. 4).

Factors for the forming of colonies of *E. maculata* on the territories of railway stations (platforms, station areas, etc.) are different. Xerophytic conditions (which do not exclude periodic water supply) and a compacted substrate are typical for this location. We observed population density of the species near the railway station in Kamianets-Podilskyi (Khmelnytskyi Oblast) varies from 2 to 16 individuals in a linear colony (235 m length, 0.5–1.6 m width). Approximately the same population density of the species was recorded in Zhvanets village in the same region.

Forecast of further spread of the species in Ukraine. Considering the feature of the modern distribution and the ecological and coenotic limitation of *E. maculata*, and the results of the analysis of the current state of its populations in different regions of the country, we can predict a further increase in the number of localities of the species, expansion, and densification of its range in anthropogenic places, especially in the northern direction.

Fig. 4 A fragment of the population of *Euphorbia maculata* in Central Railway Station in Dnipro, Dnipropetrovsk Oblast (Photo by L. Karmyzova).

The species may penetrate new ecotopes in connection with the warming and xerophytization of the climate since *E. maculata* is viable in the country's southern regions of Ukraine. The species can successfully naturalize as an agriophyte in many areas here. Therefore, the distribution of *E. maculata* needs monitoring, and it is necessary to record new local growth.

Conclusions

Based on the analysis of literature data, herbarium specimens, available information in online-resources, and the results of our research, information of the current distribution of *E. maculata* in Ukraine was summarized. The locations of the species were recorded in all geographical zones of the country (in 19 administrative regions), and it indicates its wide phytogeographical amplitude and the expansion of the spectrum of its ecological and coenotic characteristics. The main ways of the spread of *E. maculata* are railway, ornamental gardening, and transport of building materials. Most of the studied populations of *E. maculata* have sizes from 6 to 300 square meters, and numbers from several dozen to several hundred individuals. In several cases, the population area reaches up to 0.5 ha. Constant self-renewal of populations was observed. It was noticed up to 46 individuals per square meter in places of greatest density. The obtained data indicated that according to the degree of naturalization, this species belongs to the group of colonophytes or hemiepecophytes. Therefore, the modern trends in the distribution of the species in Ukraine require monitoring and the development of effective control measures.

Acknowledgement

The authors are sincerely grateful to the Editorial board of Thiaszia – Journal of Botany and the anonymous reviewers for their valuable advice and suggestions on the manuscript and improving the English style of the first draft of manuscript.

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Received: September 27th 2024
Revised: October 29th 2024
Accepted: November 20th 2024