

Characterization of the Occurrence and Abundance of the Common Ragweed (*Ambrosia artemisiifolia* L.) with Regard to Assessment of Its Expansion Potential in European Russia

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Abstract—A field study of common ragweed (*Ambrosia artemisiifolia* L.) in European Russia provided information on the occurrence and abundance of the species and enabled a prediction of the possible boundaries of species naturalization. As a result, the understanding of the ecological limits of common ragweed distribution related to the limiting environmental factors was refined. Insufficient heat supply during the seed ripening period is the factor that determines the expansion of the species to the north in European Russia. The moisture deficit factor determines the eastern and southeastern boundaries of species expansion. Ecological maps based on MODIS data from the Terra satellite were used in the ecological analysis of geographical distribution of the common ragweed. As a result, the map of the distribution potential of the common ragweed in European Russia was refined and the possibility of species naturalization in the area was plotted on the map.

Keywords: *Ambrosia artemisiifolia*, range, occurrence, abundance, limiting environmental factors, ecological amplitudes, ecological and geographical analysis, expansion potential

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INTRODUCTION

The common ragweed (*Ambrosia artemisiifolia* L.) is an annual anemogamous short-day plant. It is a quarantine hazardous species characterized by restricted distribution on the territory of Russia (Rosselkhoznadzor..., 2019). The species causes harm to agriculture and poses a threat to human health due to the high allergenicity of the abundant pollen of the plants. The species invaded the territory of Russia from North America in the late 19th–early 20th century. The first invasion sites were found in the foothills of the Caucasus (Vasil'ev, 1958). The species spread in southern Russia and expanded to the north during a century-long invasion. The northern boundary of its range currently extends to Bryansk, Lipetsk, and Tambov oblasts. Some phytosanitary quarantine zones for the common ragweed have been established in even more northern areas, such as the Tula, Ryazan, and Moscow oblasts (Rosselkhoznadzor..., 2019), but the possibility of common ragweed naturalization in these areas requires more accurate analysis.

The modern methods of environmental niche modeling allow for highly precise assessment of the

expansion potential of biological objects (Nix, 1986; Afonin and Sokolova, 2018). The accuracy of identification of environmental niche boundaries depends on the accuracy of the ecological maps used in the analysis and modeling and on information concerning the distribution of the biological objects under consideration.

Information on the frequency of occurrence and abundance, which would provide a characteristic of object naturalization, is usually not available for the sighting points of biological objects used in the analysis, and this is one of the major problems in analysis and modeling. A model of the ecological niche of common ragweed with invasions taken into account and naturalization overlooked will obviously cause overestimation of its expansion potential. Therefore, the naturalization status of the biological object under consideration within its range should be assessed prior to the construction of the environmental niche model in order to make this model as informative as possible. For this purpose, we performed a dedicated route survey of the ecological limits of common ragweed distribution and its occurrence and abundance at the boundaries of the range in 2017. As a result, a refined

map for the expansion potential of this species in European Russia was constructed.

MATERIALS AND METHODS

Ecological geographic analysis of common ragweed distribution performed by us earlier showed that insufficient heat supply during the seed ripening and insufficient moisture supply during the vegetation period were the main environmental factors that restricted its expansion (Afonin et al., 2016). The common ragweed is a short-day species, and therefore the sum of temperatures required for seed ripening should be attained within a time interval from the beginning of blooming which coincides with the date when the threshold photoperiod value is attained (the threshold value somewhat varies for the populations of the species from different latitudes, but the average is close to 14 h), until the first autumn frosts.

We have constructed ecological maps for these parameters. The map of temperature sums within a time interval starting when the day's length exceeds 14 h and ending at first autumn frosts was constructed from the average monthly temperature layers according to the modified method of Kel'chevskaya (1971). We constructed the average monthly temperature layers according to the materials of remote temperature monitoring of the Earth's surface by the MODIS spectroradiometer of the Terra spacecraft (MODIS/Terra (Wan et al., 2015)). The temperature layers based on the data of remote monitoring are more detailed than the temperature maps based on data from meteorological stations, including the WorldClim maps most often used in ecological geographic modeling (Hijmans et al., 2005). The average temperature maps for each month were averaged over the period of temperature monitoring by the Terra spacecraft, from 2000 to 2014.

Vegetation indices can serve as the most accurate characteristic of water supply in arid territories. Projective vegetation cover, biomass, and photosynthetic activity decrease consistently upon the transition from humid to arid zones, and the vegetation index values, which reflect the values of these parameters, decrease accordingly. The normalized difference vegetation index (NDVI) was used in the present study to characterize the moisture supply to the area. The average monthly global NDVI layers can also be constructed from the MODIS/Terra data of remote monitoring of the Earth's surface (Didan, 2015). Moisture deficiency during the blooming period (in August) is the most critical for common ragweed, and therefore the map with NDVI values for August averaged over a similar 15-year observation period (2000–2014) was used to characterize the moisture supply.

Information on common ragweed distribution can be retrieved from diverse and rather numerous sources, including the GBIF (GBIF.org, 2019), Rosselkhoznadzor (*Rosselkhoznadzor...*, 2019), and

BONAP (Kartesz, 2015) databases and scientific publications (Basset and Crompton, 1975; Nadtochii and Budrevskaya, 2008). The information in these materials is presented both in point form and in the form of areas of ranges.

Data on the point location of a biological object only provide information on the presence of this object at a certain point. Range area maps provide information in terms of the presence or absence of an object without data on its abundance at specific points and the frequency of occurrence at a certain area within a region. Data on the geographic ranges of quarantine objects presented in terms of only presence or absence do not allow for a sufficiently accurate estimation of the invasion status or assessment of the expansion potential of the invasive objects. Information required for predictions that are more accurate should also include data on object abundance and frequency of occurrence, because plant abundance and frequency of occurrence combined can characterize the degree of plant naturalization within a certain zone.

The frequency of species occurrence in an area can be estimated as the number of points at which the object was found divided by the total number of points inspected. Abundance is characterized by the number of individuals of a certain species per unit area or unit length of the transect analyzed. We performed a dedicated field study in 2017 in order to assess the occurrence and abundance of the common ragweed within its secondary range.

The field study was performed in August 2017, and the frequency of occurrence and abundance of the species under consideration in European Russia were assessed during the study. The assumed boundaries of the range, that is, Kursk, Lipetsk, Voronezh, and Belgorod oblasts in the north and the Republic of Kalmykia and Volgograd oblast in the east, received special attention. The sites inspected along the route were located at a distance of approximately 10 km from each other, with the distances estimated according to the readings of a car speedometer. The number of sites inspected was 278 (Fig. 1); common ragweed abundance along the roads and in the fields, plant size, and life cycle phase were assessed at each site, the geographic coordinates and a brief description of the site were recorded, and the populations and habitat were photographed.

Occurrence in Regions (official administrative territorial unit in Russia) was inferred from the route survey materials as the ratio of the number of points at which common ragweed was found to the total number of points surveyed within a region. The abundance was assessed as the average abundance of common ragweed at points where the plant occurred within a region (oblast), whereas the sites at which the plant did not occur were not taken into account during the abundance assessment.

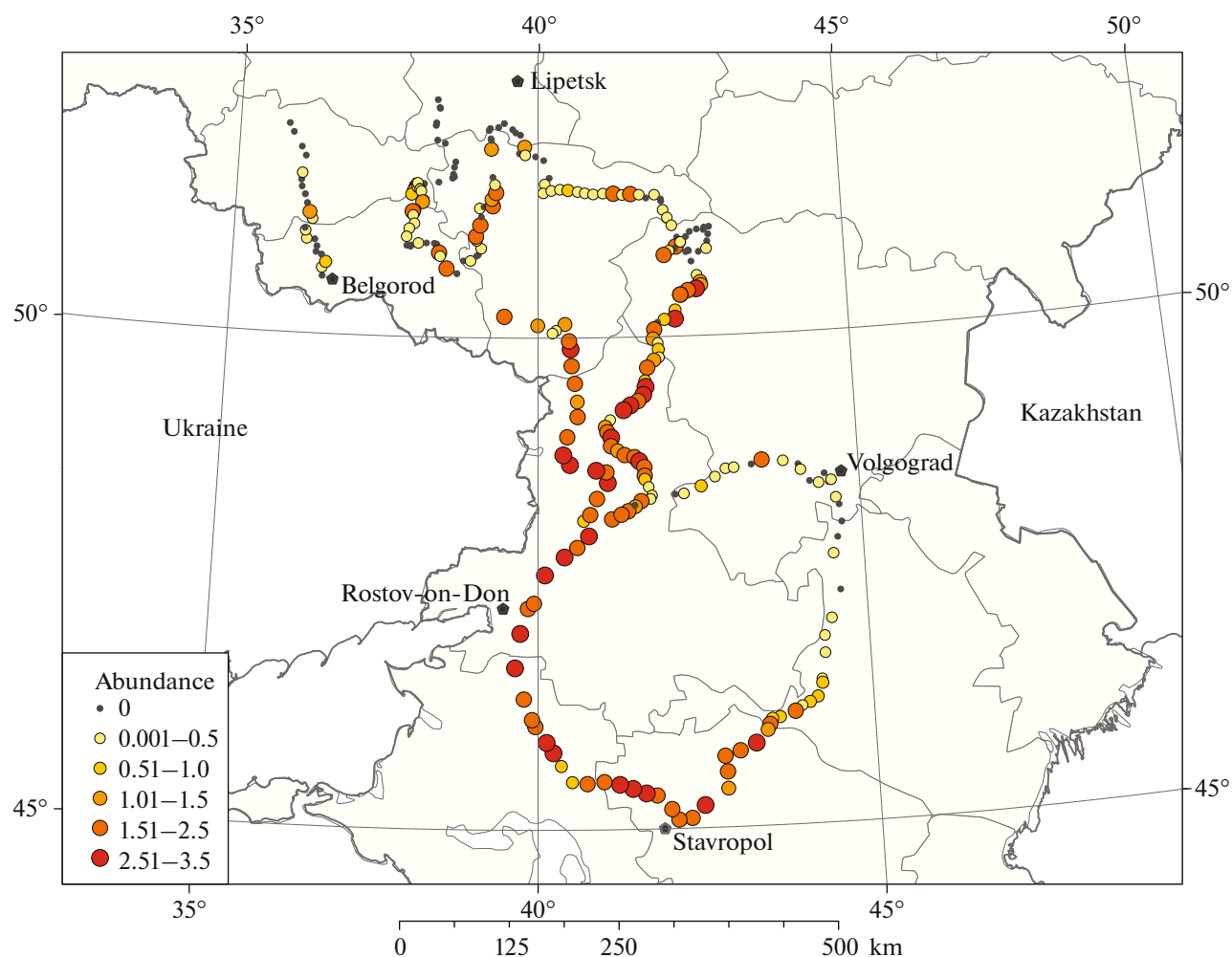


Fig. 1. The abundance of common ragweed within its range in European Russia according to the results of the 2017 route survey. The abundance is shown as the average score at the site according to the Drude scale, where 0 denotes the absence of the species, 1—*sol*, 2—*sp*, 3—*cop1*, 4—*cop2*, 5—*cop3*.

Areas 100 m wide adjacent to the road were surveyed at each site, and species abundance on the Drude scale was assessed individually for each 10-m interval. A numerical value of 0 to 5 was assigned to each grade on the Drude scale (Ponyatovskaya, 1964), so that 0 corresponded to the absence of the species at a point, 1 to *sol*, 2 to *sp*, 3 to *cop1*, 4 to *cop2*, and 5 to *cop3*. Thus, the abundance at the points inspected could be represented as an average value on a numerical scale.

RESULTS AND DISCUSSION

We have studied the common ragweed distribution in European Russia, developed a procedure for the assessment of the frequency of occurrence and abundance of the species, assessed these parameters in different geographical zones, and constructed a map to characterize the species occurrence and abundance and the possibility of species naturalization in Euro-

pean Russia. Species abundance at the study sites is shown on the map (Fig. 1); estimates of the frequency of occurrence and average abundance in individual regions (oblasts) are listed in Table 1.

The Northern Caucasus and the western territories of the Southern Federal District (Stavropol krai, Krasnodar krai, and Rostov oblast) belong to a zone characterized by ubiquitous occurrence and high abundance of common ragweed (Table 1). This is related to the environmental conditions of heat and moisture supply being optimal for the species and to the history of invasion in the area being the longest. Indeed, the first invasions by the species occurred in the Northern Caucasus, and spreading of the species over the territory of Russia started from here (Flyorov, 1938; Afonin et al., 2018). Volgograd oblast and Kalmykia, which are located to the east of the aforementioned areas, are characterized by a sharp gradient of moisture supply, and the eastern and southern part of the regions belong to the ecological pessimum zone of

Table 1. Common ragweed distribution and abundance in regions (oblasts) of European Russia

Occurrence	Number of sites inspected		Occurrence in the region, %	Average abundance in the region
	sites, total	sites with the species present		
Volgograd oblast—north	40	22	55	1.18
Volgograd oblast—south	18	11	61	0.31
Republic of Kalmykia	16	13	81	0.62
Stavropol krai	15	15	100	2.21
Krasnodar krai	9	9	100	1.92
Rostov oblast	50	48	96	1.7
Voronezh oblast—north	52	29	56	0.68
Voronezh oblast—south	8	8	100	1.46
Belgorod oblast	29	14	48	0.64
Kursk oblast	28	12	43	0.92
Lipetsk oblast	13	0	0	0

common ragweed with regard to moisture supply. The species is ubiquitous and abundant in the west of Volgograd oblast, but the frequency of occurrence and abundance decrease in the eastern and southern directions. Insufficient heat supply during the seed ripening period is an additional factor (along with low moisture supply) that acts on the species in the north of the Volgograd oblast and causes its elimination from a number of roadside communities. The heat supply conditions of Kalmykia are favorable for common ragweed, but insufficient moisture supply prevents the development and massive expansion of the species over almost the entire territory except for the easternmost part of the republic. The heat supply and moisture supply conditions of the southern part of Voronezh oblast are generally favorable for this plant. The plant is ubiquitous and abundant in the south of the Voronezh oblast, but the insufficiency of heat resources, which becomes more pronounced toward the north, leads to a decrease in the frequency of occurrence and abundance of the species. Nearly all of Belgorod oblast is located in the temperature pessimum zone. Therefore, common ragweed is not ubiquitous in the region, even though it is abundant at some sites. It is even less abundant in the south of the Kursk oblast, whereas the northern part of this region can be regarded as an intrazonal occurrence area, in which the ecological requirements of the species can be met only at small extrazonal patches. Tambov, Lipetsk, and Orel oblasts, the south of Bryansk oblast, and, possibly, the southernmost parts of Tula and Ryazan oblasts and a part of the Moscow oblast can also be regarded as intrazonal occurrence areas, since common ragweed was detected in these areas by phytosanitary authorities (Rosselkhoz nadzor..., 2019).

Superposition of points with known characteristics of species abundance on the ecological factor maps enabled us to trace the connections of abundance and frequency of occurrence to specific ranges of ecological factors and to assess these ranges quantitatively (Fig. 2).

The calculations were performed after superposition of points with known characteristics of species occurrence and abundance on the maps of ecological factors: (1) on the maps of effective temperature sums (ETS) during the seed ripening period; (2) on the maps of moisture supply characterized by the NDVI.

With the ecological limitations of the species known and maps of the corresponding limiting environmental factors available, it is possible to identify ecological optimum and pessimum zones in the range and to trace the connections between zone location and the patterns of occurrence and abundance. We performed an analysis and assessed the ecogeographic amplitudes of common ragweed, the boundaries of the ecological optimum and pessimum zones, and intrazonal occurrence.

The ecological optimum zone includes areas with effective temperature sums (ETS) > 900 and NDVI > 0.45. Common ragweed occurs ubiquitously in this zone and species abundance is at the *cop1* level or higher. The environmental pessimum zone includes areas with $700 < \text{ETS} < 900$ and $0.31 < \text{NDVI} < 0.45$. The species is not ubiquitous in this zone, and abundance is at the *sol-sp* level. The intrazonal occurrence area includes areas with $600 < \text{ETS} < 700$ and NDVI < 0.31. The species is very rare and its abundance is low in this zone.

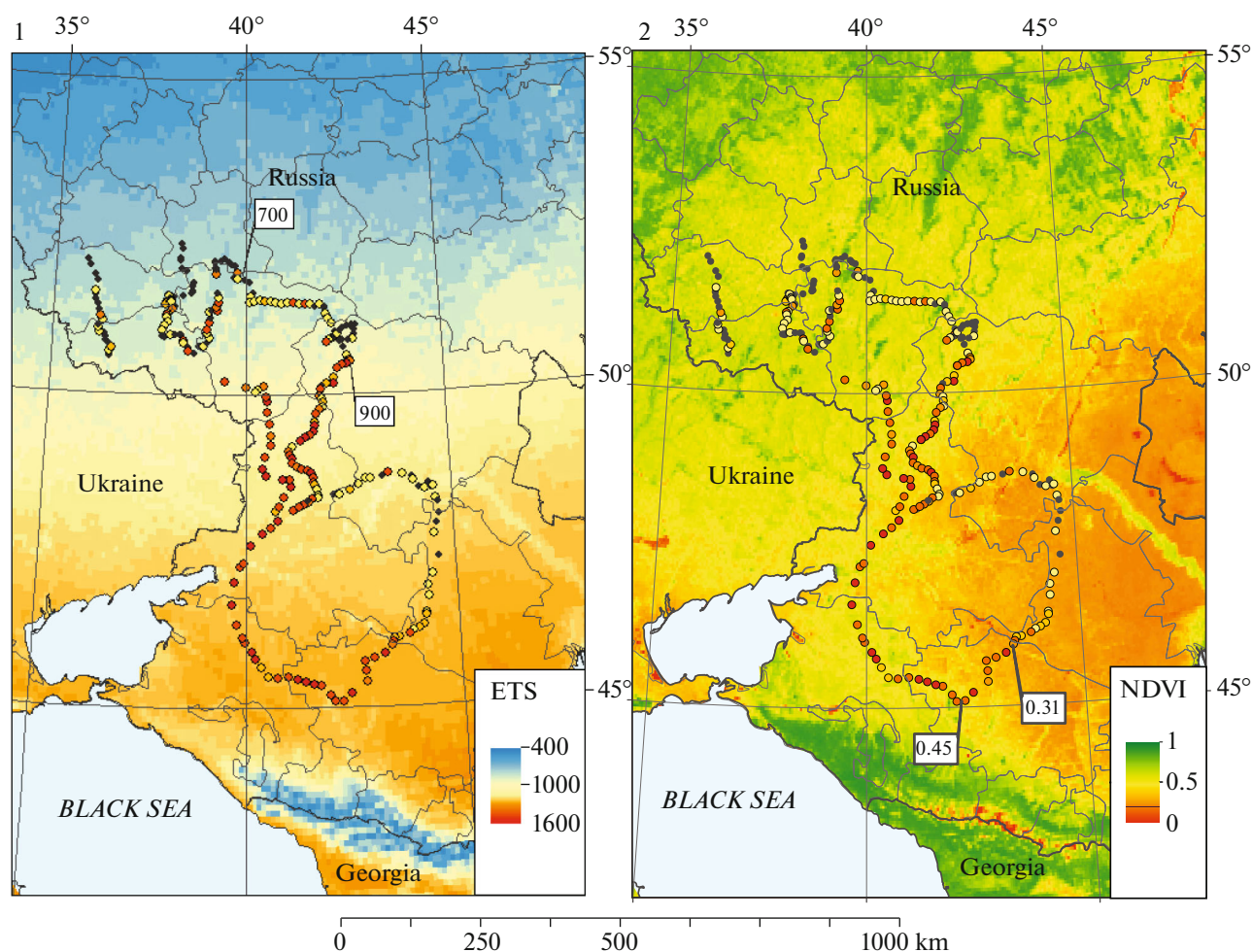


Fig. 2. Characterization of the ranges of ecological factor values at boundaries of zones with different values of occurrence and abundance of common ragweed.

The zone with optimal levels of the major environmental factors that limit the expansion of common ragweed is characterized by the highest occurrence and abundance of this plant. The species is nearly ubiquitous in this zone and its abundance is high. The species is less common in zones which are pessimal with regard to any of the two environmental factors analyzed. Occurrence becomes less common and abundance decreases as the limiting factor values approach the extremal level. Intrazonal occurrence areas, that is, small non-zonal fragments of territory suitable for common ragweed growth and development, regardless of the location in a zone that generally transcends ecological limitations of the species, can be identified at the boundaries of the range. Southern slopes can be fragments of this type in the north, where the possibility of species expansion is determined by the heat supply factor. Sufficiently humid habitats in the east, where plant expansion is limited by insufficient moisture supply, can be found

at sites with groundwater blowout, on northern slopes, and in the vicinity of water bodies.

Zones with different levels of ecological appropriateness of the area for common ragweed and the related levels of occurrence, abundance, and naturalization potential are shown on the map (Fig. 3).

CONCLUSIONS

Information on the occurrence and abundance of common ragweed within the secondary range and at its boundaries in European Russia was collected during the field trip. Superposition of the inspected points with known abundance characteristics onto ecological factor maps enabled the assessment of ecological amplitudes related to the factors that limit expansion of the species exactly within its naturalization zone. Abundance and occurrence zones for the common ragweed were marked on the ecological factor maps according to the values obtained (Fig. 3).

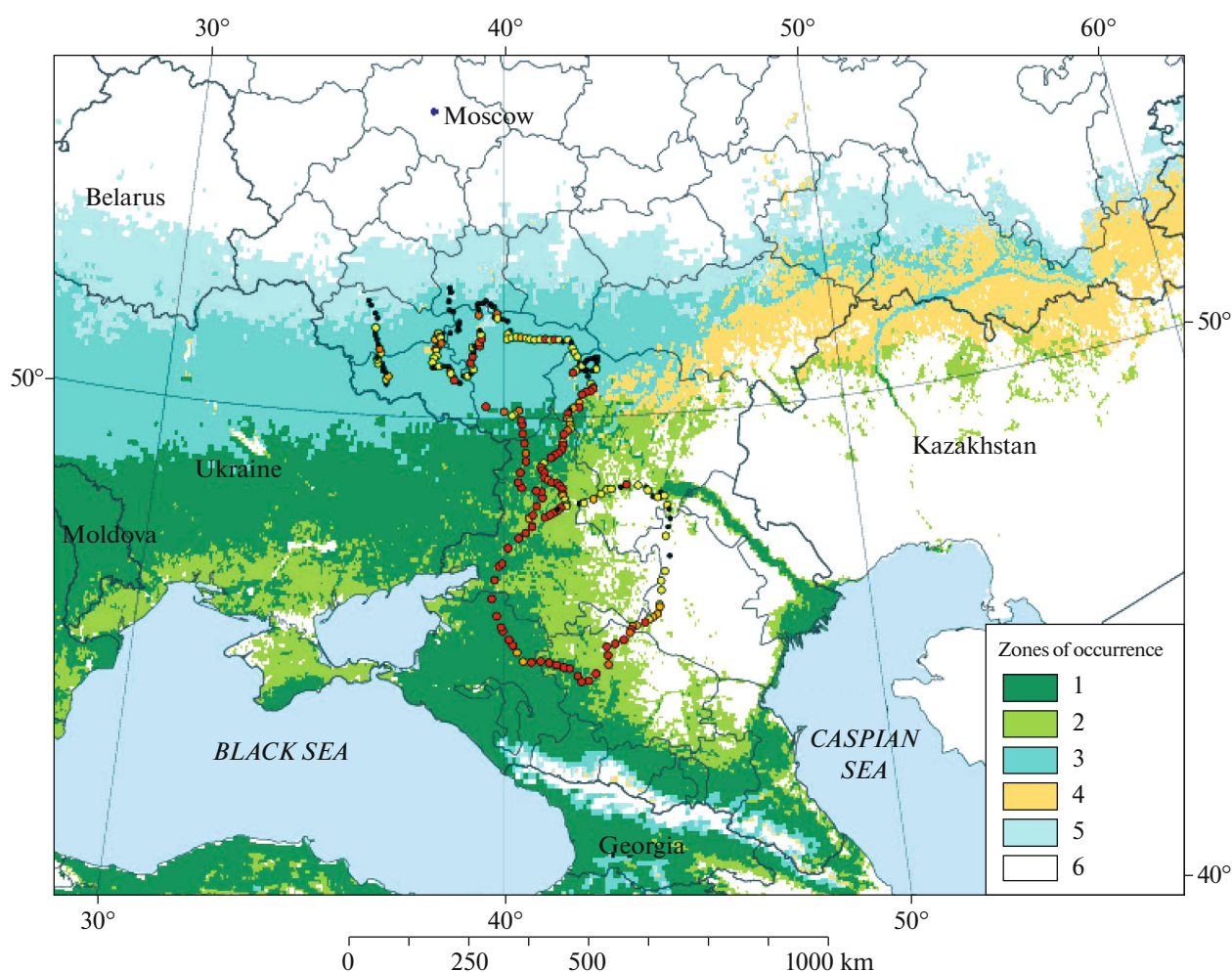


Fig. 3. Zones with varying degrees of ecological appropriateness of the territory for common ragweed in view of the possibility of species naturalization. (1) Optimum zone of heat and moisture supply with ubiquitous occurrence and high abundance. Naturalization is possible over the entire area. (2) Heat supply optimum and moisture supply pessimum zone with sporadic occurrence. Naturalization is possible at certain sites within the area. (3) Moisture supply optimum and heat supply pessimum zone characterized by sporadic occurrence. Naturalization is possible at isolated sites within the area. (4) Heat and moisture supply pessimum zone characterized by low frequency of occurrence. Naturalization is possible at a few sites within the area. (5) Intrazonal occurrence area with extreme conditions of heat supply; the species occurs sporadically. The possibility of naturalization requires additional analysis. (6) Zone with ecological characteristics unsuitable for the species. Species abundance is shown by the dots; the dot symbols are explained in the legend to Fig. 1.

European Russia at latitudes less than 48–50° N can be regarded as a zone of ubiquitous naturalization and occurrence of the species, provided that there is enough moisture. The temperature pessimum zone, in which the species occurs and naturalizes only at isolated sites, is located between the latitudes of approximately 50° and 52° N in European Russia. The existence of the species north of this boundary is possible on southern slopes and heat islets in urban areas, the intrazonal fragments of the territory characterized by elevated heat supply.

Parts of Tula, Ryazan, and Moscow oblasts in which phytosanitary quarantine zones for common ragweed have been established can presumably be

regarded as intrazonal occurrence areas, but non-naturalized plants can also occur in these areas.

Insufficient heat supply during the seed ripening period is the factor that limits the northward expansion of common ragweed in European Russia. The insufficient moisture supply factor determines the eastern and southeastern boundaries of its expansion in European Russia. The ecological amplitude for the heat supply factor is 600 degrees ETS or more during the period from the beginning of common ragweed pollen release until the end of the vegetation period according to the Earth's surface temperature measured by the MODIS spectroradiometer sensor. The ecological amplitude for moisture supply is 0.31 of the NDVI value for August or higher.

A map of common ragweed expansion potential in European Russia has been constructed as a result of the present work.

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CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

COMPLIANCE WITH ETHICAL STANDARDS

The article does not include any studies performed on living organisms in experiments carried out by any of the authors.

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