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Invasion of *Ambrosia artemisiifolia* L. (Compositae) in the Ukrainian Carpathians Mts. and the Transcarpathian Plain (Central Europe)

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The invasion of *Ambrosia artemisiifolia* in the Ukrainian Carpathians Mts. and the Transcarpathian Plain in Central Europe was reconstructed on the basis of floristic records. The first spontaneous occurrence was dated from the beginning of the 1940s. Within the next 55 year period, the distributional spread speed of the species was of 67.6 km^2/y (by the average data). The occupied area by *A. artemisiifolia* in the range of the studied areas is about 3716.5 km^2 now. The features of behavior of the invader and the habitat preference were determined. The frequency of occurrence by sociologic-ecological classification was carried out. The generalized model of correlations among the gravitation, the active temperature sum and the disturbance gradients and the frequency of occurrence of the species was presented. The scheme of the invasion stages of *A. artemisiifolia* is reflected in the population status changes of the species during the areal dynamics.

Plant invasions have drawn an increased attention from many regions of the globe (Protopopova, 1973; Holzner and Numata, 1982; Drake et al., 1989; De Waal et al., 1994; Pysek et al., 1995). As Harper (1977) noted, man has introduced a new order of magnitude into distances of dispersal, and through the transportation, by accident or design of seed or other propagules, through the disturbance of native plant communities and of the physical habitat, and by the creation of new habitats and niches, the invasion and colonization by adventive species is made possible.

Plant introduction induces naturalization and spread of aliens. These are the processes of establishing these species as components of the flora and nextly increasing their areas. These processes are accompanied by an increasing number and diversity of adventive taxa populations. Two hundred eighty three spontaneous (183 metaphytes - no aggressive plants, 93 contaminatiophytes - problem plants, 7 regresiophytes - declining plants) and 201 unspontaneous (171 ephemerophytes - no self-sustaining population plants, 30 premetaphytes - taxa with 1-3 self-sustaining populations) adventive taxa were found in the Latorytsya river basin (Prots, 1997) during the investigation period. This basin is the most representative territory of the Ukrainian Carpathians Mts. and the Transcarpathian Plain. It shows the high dynamics of invasion processes in these regions.

A. artemisiifolia is one of the most aggressive plant species of the plain part of studied areas during the last half of the 20th century. The movement of its invasion is now directed towards the hilly and mountainous parts. Chorological valuation, as a result of invasion dynamics investigation, makes it possible to understand the way and activity of invasion processes in these regions.

A. artemisiifolia occurs very often in all territories of Ukraine except for the western (north-western) regions, where it was found sporadically (Kozeko, 1988). The plant has been a problem plant (Crawley, 1997) in the southern, eastern and central regions (Burda, 1991; Protopopova, 1991) and is classified as a quarantine plant (Ustinov et al., 1995).

This study addresses the following questions: (1) What is the history of invasion, the borders of the present distribution area, and the invasion dynamics of the species? (2) What habitats and syntaxa are preferred? (3) What are the features of behavior of the invader? (4) What factors are important during the spreading? (5) What are the implications of the invasion of *A. artemisiifolia* for environmental management?

Study Areas

The invasion dynamics of *A. artemisiifolia* were explored in the Ukrainian Carpathians Mts. (Ukrainski Karpaty Hory) and the Transcarpathian Plain (Zakarpatska

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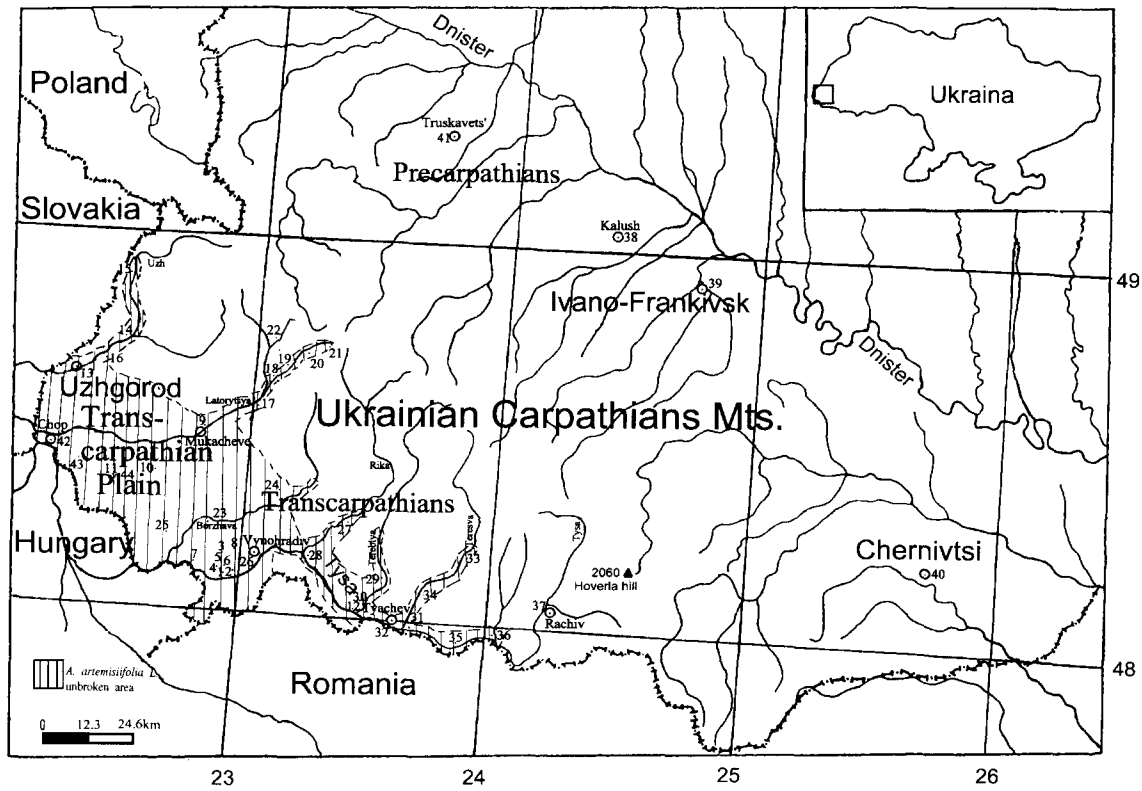

Fig. 1. The distribution of *Ambrosia artemisiifolia* in the Ukrainian Carpathians Mts. and the Transcarpathian Plain. Dots with the numbers NN1-12 represent previous researchers' findings and the numbers NN13-14 are our findings.

Rivnyna; Fig. 1).

The Ukrainian Carpathians Mts. and the Transcarpathian Plain are located in the western part of Ukraine, near the borders of four countries (Hungary, Slovakia, Romania and Poland). The Ukrainian Carpathians Mts. are also part of the East Carpathians Mts. The area of the Ukrainian Carpathians Mts. (including Precarpathians - Prykarpattya) and the Transcarpathian Plain consists of more than 37,000 km^2. These mountains are characterized by asymmetric ranges and longitude-zonal location of the main structure-orographical elements (Holubets et al., 1988). The Ukrainian Carpathians Mts. are divided into two parts: northeastern and southwestern. The altitude arrangement of studied areas changes from 106 m above sea level to 2,060 m. The studied territories are located in the zone of the continental European climate, the main features of which are formed by the domination of Atlantic and transformed continental air flows. The annual sum of precipitation distributes in limits of 500 to more than 1,400 mm. There are six climatic zones with the sum of active temperatures from less than 1,000 to 3,000℃. The process of soil creation is dependent on the presence of mountainous forest brown soil types. These soil types are presented by all subtypes and genera. Two vegetation zones (mountain and plain) and six vegetation belts (average data: the plain belt of oak forests - 103-110 m, the mountain belt of oak forests - 110-250 m, the belt of beech forests - 250-700 m, the belt of spruce forests - 700-1,300 m, subalpine belt - 1,300-1,800 m and alpine belt - 1,800-2,060 m a.s.l.) are in these areas (Holubets et al., 1988). As result of the barrier effect, the south western slopes' (macroslope) of the Ukrainian Carpathians Mts. are warmer than the northeastern slopes. The annual difference of these slopes' altitude temperature gradient consists of 0.31℃ per 100 meters elevation, and the difference of the radiation balance is around 10 kcal/y · cm^2 (Sakali, 1970). The flora have a Central-European character, with some influences from the Pannonian province of Ponticum-South-Siberian floristical region (Meusel et al., 1965-1978). Generally, the studied territories are a high heterogenic system, not only in geographical, climatic, soil, floristical and vegetation relations, but from hydrological and landscape points of view as well.

The human impact increases the diversity of secondary and artificial habitats and decreases the territory of natural and semi-natural forests. The forest territory consists of about 40%, the meadows, agricultural lands, gardens, and vineyards about 45% of the studied territory, and urban zones are in the range of 5-15%. They are concentrated dominantly in the low parts of Transcarpathians and Precarpathians. However, the structure of land categories depends on the

altitude level (Holubets et al., 1988). Dominantly, the human population density is no more than 100 people/km^2. The timber, mining, agricultural production and tourism are very important industries in the region. The automobile and railroad infrastructures are well-developed. These roads are part of the east-west European connection.

Materials, Methods, and Study History

The subject of investigation was the hemicryptophyte ragweed - *Ambrosia artemisiifolia* L. (Compositae, Angiospermae) of the North-American origin. Floristic research was carried out on the basis of detailed-itinerary, half-stationary and stationary methods (Simacheva, 1984; Yurtsev and Kamelin, 1987), and sometimes, including grid-coordinate methods (Helsinki University, 1972; Mirek and Piekos-Mirkowa, 1987) with usage of small scale mapping (Prots, 1997) during 1991-1997. The materials of Uzhhorod State University Herbarium (U), Lviv State University Herbarium (LW) and literature data were studied. Relevés were recorded and analyzed using methods of the Zürich-Montpellier school (Braun-Blanquet, 1964). The terminology was adopted from Schroeder (1969), Holub and Jirasek (1971), Kornas (1978), Sudnik-Wojcikowska and Kozniewska (1988), Pysek et al. (1995) and Prots (1997). The names of the species follow Flora Europaea (1964-1993). The geographical names were adopted from Today's world: A new world atlas from the cartographers of Rand McNally (1995).

The first data about the spreading of *A. artemisiifolia* in the Ukrainian Carpathians Mts. and the Transcarpathian Plain was collected in 1942 in the Vynohradivskyy district of the Transcarpathians (by the Transcarpathians Quarantine Inspection archive material). Mr. Lutsenko (personal commentary; Transcarpathians Quarantine Inspection) discovered 11 localities of *A. artemisiifolia* from the middle of the sixties onwards in the different districts of the studied territories. Its common area was 2,263.65 ha. Separately, in 1965 in the Vynohradivskyy district (Trostnyk, Drotyntsi, Verbovets, Ruska Dolyna, Matiyeve, Fanchykove, Nove Selo, Pidvynohradiv villages, NN1-8; Fig. 1) the common area of *A. artemisiifolia* localities consisted of 2,261 ha; in the Uzhhorodskyy district (Chop railway junction, Chop town surroundings) - 0.5 ha. The next findings were: in 1970 in the Mukachevskyy district ((Mukacheve, Kolchyne (N9), Strabychove (N10) railway stations)) - 2.5 ha; in 1979 in the Berehivskyy district (Batevo railway junction, N11) - 0.14 ha; in 1980 in the Tyachevskyy district (Bushtyn town, N12) - 0.01 ha. In addition, Tovt (1973) found two localities in the Vynohradivskyy district and Uzhhorod town surroundings. Fodor (1974) described the habitats of *A. artemisiifolia* in the Transcarpathian Plain. Protopopova (1991) presented the secondary areal expansion of the taxon for the studied regions (in the boundaries of the plain zone only). The findings of the taxon on the north-eastern slope of the Ukrainian Carpathians Mts. were absent in the literature before our investigation.

For identification of the secondary areal changes of the species in the Transcarpathians, the basin approach was used (Yurtsev and Kamelin, 1987).

Results and Discussion

In the limits of the Uzh river basin, the localities of *A. artemisiifolia* were found in the towns of Uzhhorod, Perechyn and Velykyy Bereznyy, and Nevytske village (NN13-16; Fig. 1). The next data were collected in the range of the Latorytsya river basin: the specimens separately occurred in the area of the town of Svalyava (N17). From the Svalyava to the Beskyd Pass by the elevation, the species occurred as small plant groups on the railway tracks and embankments (NN18-22). In the Borszava river basin *A. artemisiifolia* was discovered in the primary forests (N23) as well as in the devastated zones (NN24-26). The findings in the Horynchovo village (N27) and the town of Khust (N28) are represented by the spreading of the weed in the Rika river basin. In the Tereblya river basin this species was found in the village of Tereblya (N29) and the town of Bushtyno (N30). In the Teresva river basin the specimens of this taxon were discovered in the towns of Teresva (N31) and Tyachev (N32), and in the villages of Dubove (N33) and Ternovo (N34). In the Tysa river valley *A. artemisiifolia* was found in Solotvyno (N35) and Velykyy Bychkiv (N36). The separate locality of the species on this macroslope was discovered in Rachiv (N37).

On the northeastern macroslope of the Ukrainian Carpathians Mts. the specimens of *A. artemisiifolia* occurred in the range of the urboecosystems only. The first localities were discovered in the industrial and recreational zones, where human migration was very active (Kalush, Ivano-Frankivsk, Chernivtsi and Truskavets; NN38-41).

In addition, in the range of the Transcarpathian Plain *A. artemisiifolia* was found on pastures (10-20 specimens/m^2, N42), agricultural fields (*Nicotiana tabacum* plantation, 1 specimen/40-45 m^2, N43), in the natural 70-100-year-old oak communities (1 specimen/100-120 m^2, N44), as a result of the strong human impact and neighborhood of the transport junctions as the invasion source.

Based on our own field investigations (collected herbarium materials and floristical notes), previous explorations by botanists (herbarium collections and literature data) and naturalists' personal commentaries, we detected areal changes of *A. artemisiifolia* in the Ukrainian Carpathians Mts. and the Transcarpathian Plain (Fig. 1). In general, the occupied area by ragweed in the range of the studied territories consists of about 3716.5 km^2 now (it is about 30% of the Transcarpathians and 10% of all studied territories).

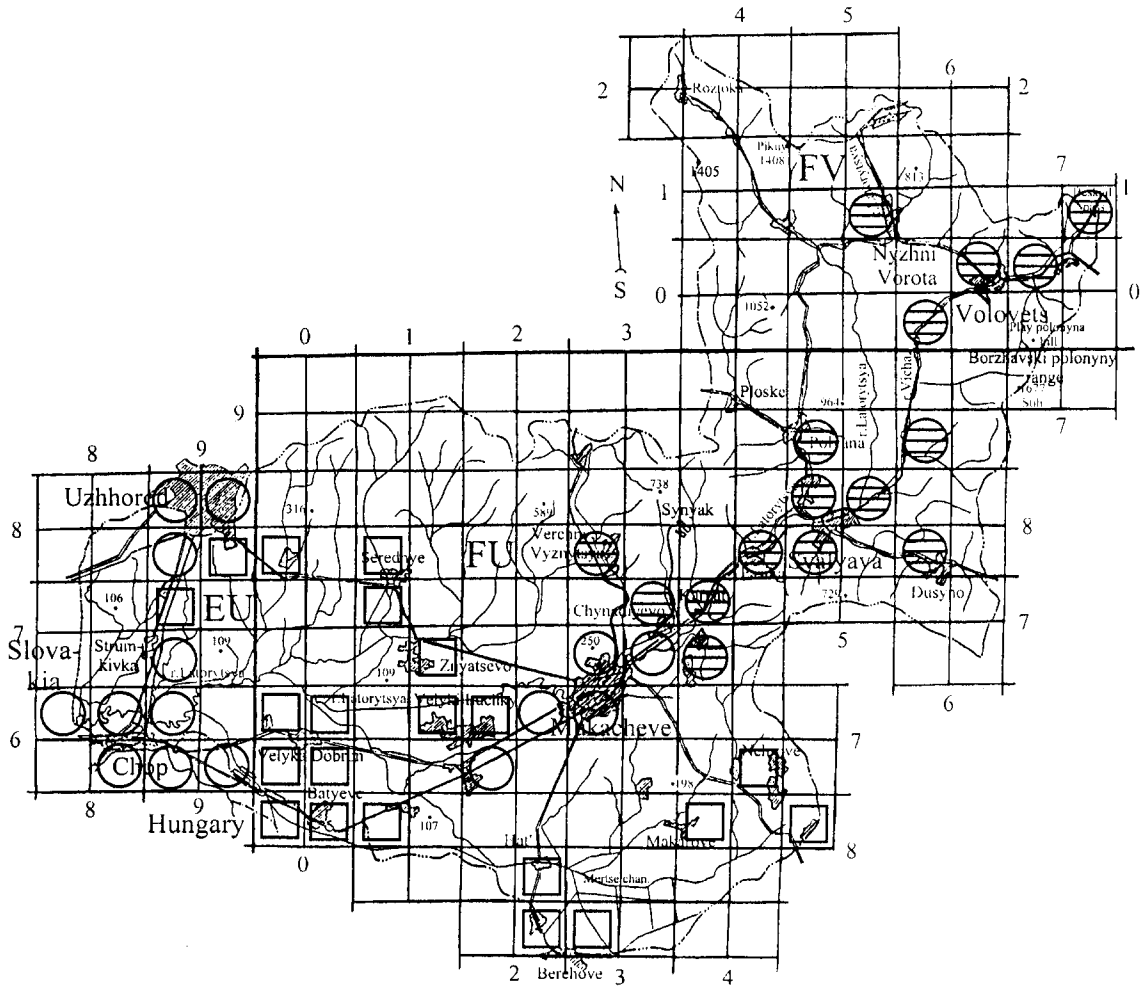

Fig. 2. *Ambrosia artemisiifolia* spreading in the Latorytsya river basin (in Ukrainian limits). ○, from 1965. □, from 1975. ⊖, from 1990.

The new distribution area of *A. artemisiifolia* increased by a ratio of 1.7 in comparison with the last data (Protopopova, 1991). However, with the connection of the common, not detailed character of the previous investigation, we cannot accept this result in the historical aspect. Taking into consideration that the invader spreads quite fast, the area of the Dnister-Prutskyy Bukovynskyy and Dnister-Prutskyy eastern climatic districts needs additional floristical investigations.

The detailed research of *A. artemisiifolia* spreading by the time gradient was carried out in the Latorytsya river basin only (Fig. 2). The cumulative number of invaded squares from 1965-1975 increased by 2.4 times compared with 1975-1990 period and by 3.5 times compared with 1990-1997 period.

On the whole, in the Ukrainian Carpathians Mts. *A. artemisiifolia* was found in 5 habitat types: on the roadside verges; railway tracks and embankments; building grounds and manufacturing zones; rubbish-heaps and garbage places; and pastures (Fig. 3). In the Transcarpathian Plain the specimens of this taxon were discovered in 7 habitat types (roadside verges; railway tracks and embankments; building grounds and manufacturing zones; rubbish-heaps and garbage places; pastures; crop fields; and forests). The number of *A. artemisiifolia* habitat types decreases with the

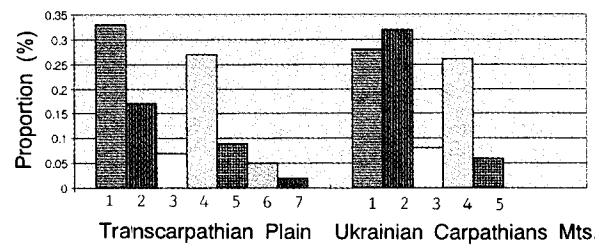

Fig. 3. Distribution of *Ambrosia artemisiifolia* with respect to habitat types: 1-roadside verges; 2-railway tracks and embankments; 3-building grounds and manufacturing zones; 4-rubbish heaps and garbage places; 5-pastures; 6-crop fields; 7-forests.

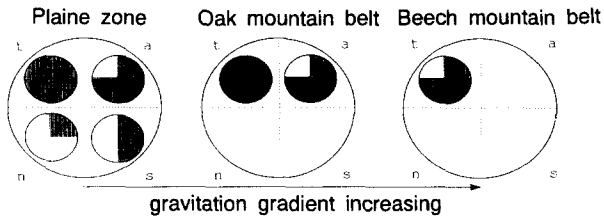

Fig. 4. Degrees of the naturalization and hemerobility of *Ambrosia artemisiifolia* in the Ukrainian Carpathians Mts. and the Transcarpathian Plain by elevation. Degree of naturalization: ●, contaminatiophyte. ◕, metaphyte. ◑, premetaphyte. ◔, ephemerophyte. t, technogenic ecosystems. a, agricultural ecosystems. s, semi-natural ecosystems. n, natural ecosystems.

elevation from 7 types (plain zone) to 2 types (low and middle parts of beech forest belt).

By the analysis of *A. artemisiifolia* distribution with respect to habitat types, we could determine that the specimens occur most often on the roadside verges in the range of Transcarpathian Plain, and on the railway tracks and embankments in the Ukrainian Carpathians Mts. (Fig. 3).

Using the integral classification of synanthropic plant species (Prots, 1997), the behavior of *A. artemiisifolia,* in the range of the studied areas, was shown to have the following statuses:

(a) the 1st criterion, by the time of invasion, is a kenophyte (neophyte sensu Meusel, 1943; newcomers, after A.D. 1500);

(b) the 2nd criterion, by the way of introduction, the taxon is characterized as a xenophyte (result of unintentional introduction);

(c) the 3rd criterion, by the degree of hemerobility (Blume and Sukopp, 1976): for the Transcarpathian Plain, it is often an epecophyte (occurs in limits of technogenic ecosystems), not often is it an ergasiophyte (occurs in agricultural ecosystems) and rare are hemi- and holoagriophyte (occurs in semi-natural and natural ecosystems), for the Ukrainian Carpathians Mts., it is often an epecophyte or rare ergasiophyte;

(d) the 4th criterion, by the degree of naturalization: for the Transcarpathian Plain - the taxon is often a contaminatiophyte (species with aggressive behavior, high degree of expansion, problem plant), rare a metaphyte (species that have no aggressive behavior, are not considered an immediate problem) and very rare a premetaphyte (creating equal to or less than three populations) and an ephemerophyte (introduced temporarily, creating invasion aggregations, not populations), for the Ukrainian Carpathians Mts., it is rare a contaminatiophyte and a metaphyte, and similarly rare a premetaphyte and ephemerophyte. The groups of plants with a disappearance tendency or with regressive populations (regresiophyte) of the species were not found in these regions.

Moreover, *A. artemisiifolia* has a different behavior on different parts of the studied areas when examined according to the elevation (Fig. 4) and on the different macroslopes (northeastern and southwestern) of the Ukrainian Carpathians Mts. (Fig. 5).

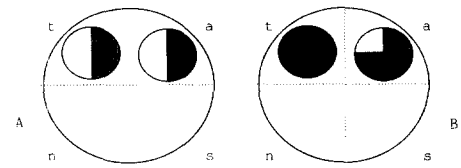

Fig. 5. Degrees of the naturalization and hemerobility of *Ambrosia artemisiifolia* on the northeastern (A) and southwestern (B) macroslopes of the Ukrainian Carpathians Mts. (refer to the legend in Fig. 4 for reference to this figure).

The frequency of occurrence of *A. artemisiifolia* in the most important syntaxa of the studied territories by sociologic-ecological classification (Jackowiak, 1993) shows that this taxon was found most often in *Polygono-Chenopodietalia* (Table 1). This datum is connected with the decreasing distribution of xerophytic type syntaxa in the mountainous region as well.

In general, the invasion of *A. artemisiifolia* has a high increasing dynamic tendencies in the range of the studied territories. Within the 55 year period (1942-1997), the distributional spread speed of the species was 67.6 km^2/y (by the average data). The process takes place not only through the invading and acclimating to new landscapes, but also through an increasing number of populations and population diversity, secondary areal compacting and uniting on local and regional levels.

The reason for such activity of the species can be explained by its strategy. *A. artemisiifolia* is a typical R group plant (Grime et al., 1986; Prots, 1993), that has a rich complex of adaptation properties. The main components of its properties are: 1) the possibility to oppress the species that have the expressive R-properties, for the high allelopatic potential assists it in comparison with weed species of aboriginal flora (Maryushkina, 1986); 2) the limitation of consortional connections (Kozeko, 1988); 3) the good adaptation to all kinds of anthropochoria, despite the fact that the primary method of spreading is avtobarochoria (Rice, 1984); 4) the high seed productivity (Protopopova, 1973); 5) the improvement of specimens' living state (lateral roots forming) by good substrate aeration (Vasilyev, 1959); 6) the wide temperature amplitude of seeds growing (Veselovskyy et al., 1988). In this meaning, *A. artemisiifolia* is very similar to Bakers (1965) description of the "ideal weed".

Generally, the spreading of *A. artemisiifolia* depends on the elevation, as it in turn affects environmental factors. The movement of the taxon invasion of the invader is directed towards the upper parts of the studied areas (Fig. 1; Appendix). High elevation localities in the Latorytsya river and Uzh river basins are present because of the existence of the railway tracks and the high commodity circulation degree between eastern and western parts of Europe. In this aspect,

Table 1. The frequency of occurrence of *Ambrosia artemisiifolia* in the most important syntaxa by sociologic-ecological classification (Jackowiak, 1993) in the Ukrainian Carpathians Mts. and the Transcarpathian Plain

Most important syntaxa	Frequency of occurrence (%)	
	Transcarpathian Plain	Ukrainian Carpathians Mts.
Quercion	1.7	-
Sambuco-Salicion, Alliarion	1.7	-
Festuco-Brometea	5.4	10.2
Sedo-Scleranthetea	3.4	2.5
Plantaginetea (incl. Agropyro-Rumicion crispi)	12.9	18.7
Arction, Convolvulion	13.7	15.1
Onopordion	14.5	9.5
Sisymbrion	15.7	13.6
Polygono-Chenopodietalia	22.4	21.2
Naturalized adventive species (anthropophytes) with undefined phytosociological attachment and ephemerophytes	8.6	9.2
Total	100	100

2.2-10.0% of imported grain from Hungary, Slovakia and the Czech Republic during 1986-1992 was polluted by *A. artemisiifolia* seeds (Transcarpathian Quarantine Inspection data). Such pollution has some influences on the distribution of the species in the studied areas. During the transportation period the escape of the seeds happens often.

In addition, such factors as the active temperatures sum, the amount of effective temperatures in the end of flowering period, the day length (Kozeko, 1988), human impact (Figs. 4, 5) and the presence of diaspore sources play a central role in the distribution of the invader as well. The model of correlation of these factors and the frequency of occurrence of the species is presented in Fig. 6.

In spite of the fact that *A. artemisiifolia* spreads in ranges of 1,800-3,000℃ active temperatures sum (the optimum is about 2,400-3,000℃) and in the belts of plain oak, mountain oak and beech forests (Fig. 1) of the studied territories, the environmental limitation is not absolute for the species. The gene pool of this taxon has the ability to adapt to new environments.

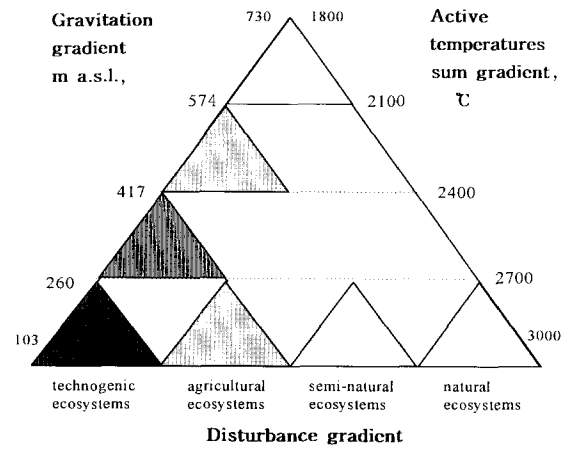

Fig. 6. The generalized model of correlation between the gravitation, the active temperatures sum, the disturbance gradients and the frequency of occurrence of *Ambrosia artemisiifolia*. The frequency of occurrence of *Ambrosia artemisiifolia*: ▭, 1.0-5.0%. ▭, 5.1-10.0%, ▭, 10.1-15.0%, ▭, 50.0-79.4%.

Furthermore, as a result of microevolutionary processes existing in the Latorytsya river basin (N21; Fig. 2) *A. artemisiifolia* var. *atropurpurea* (Priszter, 1960) was discovered at 730 m above sea level. It is a late-autumn variety and is stable in decreasing temperatures. Separate plants of this variety that had the viable appearance after the first frosts were also found in other parts of the studied territories. This is a typical example of man-induced evolutionary change of the populations. The process is displayed by technogenic varieties, ecotypes (anthropotolerable races) appearance, its spreading and hybridization (Burda, 1991). In this case, the future areal changes of the invader are unpredictable.

As a result of the above data analysis, we suggest the scheme of the invasion stages of *A. artemisiifolia* in the studied territories (Fig. 7) as part of the basic stages of plant invasions (Prots, 1997) that is reflected in the population status changes of the species during

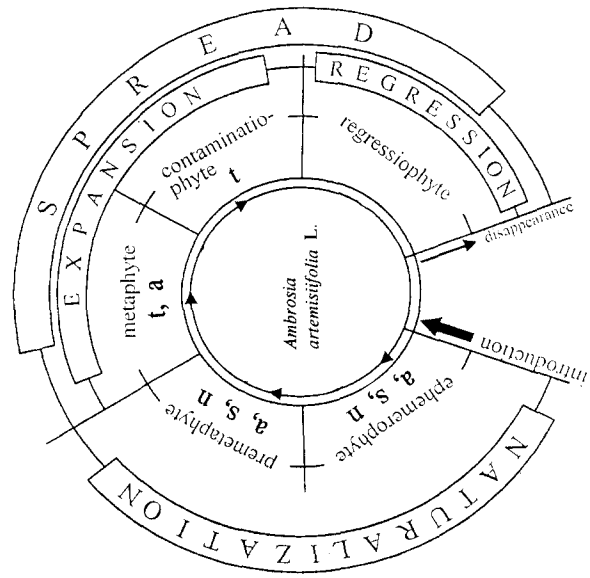

Fig. 7. The invasion stages of the *Ambrosia artemisiifolia* in the Ukrainian Carpathians. Mts. and the Transcarpathian Plain (modified after Prots, 1997) Explanation of the invasion stages is in the text. Refer to the legend about the degree of hemerobility in Fig. 4.

the areal dynamics (by average data).

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Appendix

Previous explorers data (NN1-12) are presented in the above text. Herbarium data collected during the exploration time (NN13-44; Fig. 1).

13. Town of Uzhhorod: railway station area, tracks, often, 11.09.91; central part of town, roadsides, sporadically, 12.09.91);
14. Town of Perechyn: railway station area, tracks, sporadically, 13.09.91;
15. Town of Velykyy Bereznyy: railway station area, track, about 40 specimens, 13.09.91;
16. Nevytske village: railway station area, track, not often, 14.09.91;
17. Town of Svalyava: railway station area, town rubbish-heap, in limits of manufacturing zones, near private buildings, not often, 3-6.09.91;
18. Vovchyy village: railway station area, track, 2 specimens, 5.09.91;

19. Zanka village: railway station area, track, 4 specimens, 18.08.92;
20. Volovets town surroundings: 4 km on east from Volovets railway station territory, track and embankment, 6 specimens, 29.09.91;
21. Skoratske village surroundings: 3, 5 km on east from Skotarske railway station territory, embankment, 730 m a.l.s., 2 specimens, 24.09.91;
22. Town of Nyzhni Vorota: west part, rubbish-heap, 2 specimens, 28.08.91;
23. Shalanky village: 1 km on west, Quercur robur L. flooded forests, on disturbed soil, 4 specimens, 10.07.1997;
24. Town of Irshava: center, roadsides, not often, 16.09.91;
25. Town of Berehovo: center, roadsides, sporadically, 16.09.1991;
26. Town of Vynohradiv: railway station area, tracks, often, 17.09.91;
27. Horynchovo village: central part, roadsides, rare, 25.08.93;
28. Town of Khust: south part, roadsides, often, 25.08.93;
29. Tereblya village: southern part, roadsides, not often, 26.08.93;
30. Town of Bushtyno: northern part, roadsides, often, 26.08.93;
31. Town of Teresva: southern part, roadsides, often, 28.08.93;
32. Town of Tyachev: northern part, roadsides and garbage places, often, 28.08.93;
33. Dubove village: southern part, roadsides, rare, 28.08.93;
34. Ternovo village: central part, roadsides, rare, 28.08.93;
35. Town of Solotvyno: southern part, roadsides, often, 28.08.93;
36. Town of Velykyy Bychkiv: central part, roadsides, often, 28.08.93;
37. Town of Rachiv: railway station area, tracks, rare, 19.09.91;
38. Town of Kalush: surroundings, pasture, 3 specimens, 17.08.94;
39. Town of Ivano-Frankivsk: railway station area, track, 8 specimens, 25.08.94;
40. Town of Chernivtsi: railway station area, track, rare, 10.09.92;
41. Town of Truskavets: center, roadside, 2 specimens; 29.09.95;
42. Town of Chop: surroundings, pasture, 4.09.91;
43. Petrivka village: surroundings, agricultural fields, Nicotiana tabacum L. plantation, 15.09.92;
44. Batevo railway junction: surroundings, oak forest, 10.08.92.