PLANT ECOLOGY

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PLANT INVASIONS AND LANDCAPE ECOLOGICAL STATE INDICATION

SUMMARY. The purpose of the research is to study invasion processes in plant cover as a landscape state indicator (on the example of South-Eastern Belarus). Landscapes according to non-forest plant cover adventization are weakly differentiated. Considerable differences between landscapes appear in forest plant cover adventization. The correlation between plant invasions and the level of anthropogenic transformation landscape is revealed. The two most significant factors are the landscape ecological stability coefficient and the distance to the nearest climax ecosystem, which have substantial control over plant cover invasions. Thus, plant cover invasibility in the area depends on anthropogenic transformation of surrounding geosystems. The occurrence of 17 invasive species (Conyza canadensis (L.) Cronqist, Oenothera biennis L., Acer negundo L. and others) in natural and anthropogenic landscapes of South-East Belarus is studied. Invasion success in a forest land depends on its fragmentation. The highest invasive species occurrence is typical for forest lands with an area less than 0.1 km2. Some criteria of plant invasion risk assessment for natural-anthropogenic landscapes (anthropogenic transformation and fragmentation indicators) are suggested.

KEY WORDS. Landscape, plant cover, adventive species, invasion, anthropogenic transformation.

An adventive floral element (alien plants, exotic plants, introduced plants, non-native plants, non-indigenous plants) is mostly defined as a group of plant species not typical for local flora, which has been transported there owing to direct or indirect human activities. To identify the most aggressive alien plant species that can change the characteristics of ecosystems on a large territory, the term «transformer» is suggested [1].

Invasion of aggressive alien species is currently a significant part of global changes in the biosphere, and it often leads to a substantial loss of biological diversity. Sometimes, invasion causes significant economic damage, and even harm to human health [1-2]. Invasive species also cause serious ecological consequences by damaging ecosystems. They can be damaged and changed up to the complete disappearance of natural species, of which rare species and endemics suffer the most [3-4]. Invasive species also cause serious ecological consequences; ecosystems can be damaged and changed up to the complete extinction of natural species; rare species and endemics suffer the most [3-4].

The data analysis on consequences of plant and animal invasions indicates a possibility to block successional processes with alien species, which in a historically significant period may lead to the extinction of spatially dominating plant communities. Considerable differences in depth and mechanisms of invasional ecosystem transformations depend on nature landscape conditions. The most significant consequences, negative for natural successions, are observed on tropical and subtropical islands, the less significant ones are found in continental boreal communities [5]. Mass successful invasions are considered as a sign of ecological crisis. Wide-range blocking of successional landscape system is expected as a result of new species invasion into primary or secondary succession in an extreme situation [5-6].

Degradation of geosystem self-recovery potential leads to increasing invasion risks: the lower the geosystem's self-recovery potential, the higher the probability of mass invasion with alien species. Adventive species invasions are indicators of decreasing geosystem self-recovery potential [7].

Despite the importance of the problem, the criteria of plant invasion risk assessment for natural-anthropogenic landscapes are poorly developed. The purpose of the research is to study invasion processes in plant cover as a landscape state indicator (on the example of South-East Belarus). The following objectives have been solved: to study vegetation adventization in natural and natural-anthropogenic landscapes of South-East Belarus; to study the prevalence of the most aggressive invasive plant species; to find out the dependence of invasions on anthropogenic landscape alteration; to develop criteria of plant invasion risk assessment.

The methods of the research. The research was held on the territory of the south-east of Belarus (the eastern part of alluvial terraced, marsh and secondary fluvioglacial landscapes in the Polesskaya Province and secondary fluvioglacial and moraine-outwash landscapes in the Predpolesskaya Province). The model area includes the main kinds of natural landscapes: inundated (17.6% of the territory), secondary fluvioglacial (22.3%), moraine-outwash (22.4%) and alluvial terraced (37.7%).

Climatic features of the research area: the average temperature in the coldest month (January) is -7 °C; the average temperature in the warmest month (July) is +18.5 °C; the annual sum of temperatures above 10 °C is 2479; the annual amount of precipitation is 630 mm; the mixing ratio is 1.33. According to hydrothermal indicators, the territory belongs to subboreal damp (broad-leaved forest) landscapes.

The field work was carried out in key areas (a total of 582 areas in forest and non-forest geosystems). It involved geobotanical survey by standard methods [8]; defining anthropogenic influence indicators; stating natural-landscape conditions (type of soil, composition of soil-forming rocks, underground water bedding depth, modern geological processes). Geosystems with plant cover that has diverse successional status (from pioneer to late successional) were studied.

The following indicators were used to assess the anthropogenic transformation of geosystems: C_s is an ecological stability coefficient; D_s is a distance to the nearest climax ecosystems; S_l is an area of dense forest land.

Ecological stability coefficient (C_s) was identified in a sliding square sized 1x1 km (its central point is a key area) by equation: $C_s=\Sigma s_i*k_i*g$, where: s_i is a specific land-use area; k_i is the ecological importance of the land-use type; g is the coefficient of relief geological-geomorphological stability. Landscape stability is assessed with the following scale: C_s less than 0.33 is a landscape with very low ecological stability; C_s=0.34-50 is a landscape with low ecological stability; C_s=0.51-0.66 is a landscape with medium ecological stability; C_s=0.67-1 is a landscape with high ecological stability. When the value of C_s is negative, the geosystem is considered as a source of instability on larger territories [10].

The following indicators are suggested as the criteria of plant cover adventization:

AD_1 is a part of adventive species of the total number of species in flora (% of the total number of all species); it shows the degree of flora adventization;

AD_2 is a part of adventive species in a cover (% of the total projective cover); it shows the ecological-coenotic constructiveness of adventive species in a plant cover;

AD_3 is a part of adventive tree species of the total number of tree species;

AD_4 is a part of adventive tree species of the total amount of natural reforestation; it describes the ecological-coenotic constructiveness of adventive trees, adventive tree reproductivity.

Statistical data manipulation (non-parametric statistics method, multiple regression method) was carried out with the help of STATISTICA 6.0 program package.

Results and discussion. The indicators of plant cover adventization of landscapes in the south-east of Belarus were studied (Table 1). Table 1 shows that the landscapes are substantially different in the level of anthropogenic transformation. The least level of transformation is typical for the alluvial terraced landscape; the most one is for the moraine-outwash landscape.

Table 1

Indicators of anthropogenic transformation and plant cover adventization

Indicator	Landscape			
	ATL	SFL	IL	MOL
Ecological stability coefficient (C_{es})	0.43	0.39	0.34	-0.04
Average area of dense forest land, km^2	1.44	2.33	0.29	0.10
Amount of forests, %	52.1	39.6	9.5	4.9
Tillage, %	15.8	48.3	11.5	37.8
Built-up and disturbed land, %	15.6	6.7	8.9	47.3
Adventization of non-forest cover, %				
AD_1	16.9±1.3	29.5±3.9	21.5±2.2	20.1±1.1
AD_2	21.0±2.3	30.1±9.3	24.4±3.5	23.3±2.0
AD_3	19.5±4.9	12.5±3.3	15.4±6.1	35.6±7.1
AD_4	21.6±5.2	10.6±2.1	16.1±6.7	38.2±7.6
Adventization of forest cover, %				
AD_1	2.2±0.3	1.9±0.6	7.1±2.1	12.2±2.4
AD_2	2.2±0.6	1.2±0.7	6.1±2.1	8.1±2.8
AD_3	5.3±0.9	7.1±2.4	14.3±5.8	43.4±8.6
AD_4	6.5±1.3	9.6±3.5	16.6±7.1	40.0±9.0

ATL is alluvial terraced landscape; SFL is secondary fluvioglacial landscape; IL is inundated lanscape; MOL is moraine-outwash landscape.

The landscapes are weakly differentiated by adventization of non-forest plant cover. For example, the values of AD_1 and AD_2 are similar for all landscapes. A considerable increase of the values AD_3 and AD_4 is typical for the moraine-outwash landscape. There are substantial landscape differences in the adventization of forest plant cover. Apparently, the forest cover of the moraine-outwash landscape distinguishes itself in a sharp increase of adventization.

It has been established that plant cover adventization indicators are reliably correlated with the characteristics of anthropogenic transformation of geosystems (Table 2). The multiple regression method was used to establish the factors that determine adventization indicators. The following indicators were taken as independent factors: C_s, Sl, Dc, Ts (time from succession start, years), PI (pyrogenic influence indicator is the height of carbon on tree trunks, m).

Two factors have been stated to be the most significant, namely K_c and Pк, which to a considerable degree control the adventization of the plant cover. In the assumption of the results obtained, the plant cover adventization in this area mostly depends on anthropogenic transformation of surrounding geosystems.

Table 2

Correlation of adventization indicators with the characteristics of anthropogenic landscape transformation (Spearman's correlation coefficient, $p<0.05$)

Indicator	C_s	Sl	Dc	Ts
AD_1	-0.65	-0.48	0.51	-0.69
AD_2	-0.60	-0.42	0.47	-0.68
AD_3	-0.12	-0.39	0.19	iv
AD_4	-0.11	-0.39	0.19	iv

Note. C_s is the ecological stability coefficient; Sl is the size of the dense forest tract; Dc is the distance to the nearest climax ecosystems; Ts is the time since a succession started; iv is the invalid correlation coefficient value ($p>0.05$).

The distribution of 17 invasive species (a group of 13 species was North American by origin) on South-East Belarus landscapes was studied. The three most widely distributed species are *Conyza canadensis* (L.) Cronqist, *Oenothera biennis* L. and *Acer negundo* L (present on 10-30% of key areas). The occurrence of *Amaranthus retroflexus* L., *Robinia pseudoacacia* L., *Galinsoga parviflora* Cav., *Xanthoxalis stricta* (L.) Small, *Stenactis annua* (L.) Cass., *Echinocystis lobata* (Michx.) Torr. & A. Gray. is 5-10%. The occurrence of other species is less than 5%. Several of the species can be referred to as transformers, i.e. invasive plants that can influence the functioning and dynamics of an ecosystem. They are: *Acer negundo* L., *Robinia pseudoacacia* L., *Conyza canadensis* (L.) Cronqist, *Solidago canadensis* L., *Impatiens glandulifera* Royle, *Echinocystis lobata* (Michx.) Torr. & A. Gray. According to the degree of naturalization, 13 species are defined as agriophytes and 4 ones are epecophytes.

Early stages of succession are most susceptible to invasions. For example, at the pioneer stage the indicators of plant cover adventization have maximum values (AD_1=28.0%; AD_2=38.0%; AD_3=60.0%; AD_4=60.0%). In pioneer communities the occurrence of *Conyza canadensis* (L.) Cronqist is 72.2%, of *Amaranthus retroflexus* L. is 47.4%, of *Galinsoga parviflora* Cav. is 37.1%, of *Oenothera biennis* L. is 19.6% and so on. The following species are typical for communities in the tall grasses phase: *Oenothera biennis* L. (56.7%), *Conyza canadensis* (L.) Cronqist (51.1%), *Stenactis annua* (L.) Cass. (15.6%), *Echinocystis lobata* (Michx.) Torr. & A. Gray (12.2%), *Solidago canadensis* L. (10.3%). At the meadow stage the main characteristic species are: *Oenothera biennis* L. (49.4%), *Conyza canadensis* (L.) Cronqist (26.9%), *Stenactis annua* (L.) Cass. (14.6%), *Lupinus polyphyllus* Lindl. (9.0%) etc.

Despite the dynamic distribution of invasive species in non-forest communities, invasive species ability to block successive process in the landscapes of South-East Belarus is limited; it is occasionally observed. For example, summarizing the available data, the blocking of succession on non-forest stages is caused by the growth of *glandulifera* Royle and *Cyclachaena xanthiifolia* (Nutt.) Fresen thickets.

Plant cover adventization is considerably decreased in forest geosystems (on the early successive forest stage: AD_1=3.8%; AD_2=3.3%; AD_3=10.5; AD_4=12.0%); the number of invasive species is sharply reduced. The spreading of the following species is noticed in forest communities: *Acer negundo* L., *Physocarpus opulifolius* (L.) Maxim., *Robinia pseudoacacia* L., *Impatiens glandulifera* Royle, *Impatiens parviflora* DC. The following species are absent or isolated: *Amaranthus retroflexus* L., *Anisantha tectorum* (L.) Nevski, *Galinsoga parviflora* Cav., *Cyclachaena xanthiifolia* (Nutt.) Fresen., *Lepidotheca suaveolens* (Pursh) Nutt.

The adventization indicators in climax and sub-climax geosystems have minimum values (AD_1=0.8%; AD_2=0.5%; AD_3=1.7%; AD_4=1.6%), and invasive species are isolated.

The success of invasions in the forest landscape depends on its fragmentation. The highest occurrence of invasive species is typical for forest lands with an area less than 0.1 km^2. In the forest lands with an area more than 1 $km^{2,}$ the occurrence of invasive species decreases sharply (Table 3). Compared to the forest geosystems with the area less than 0.1 km^2 , in the forest lands with an area more than 10 km^2 the occurrence of *Impatiens parviflora* DC is decreased by 7 times,; the occurrence of *Conyza canadensis* (L.) Cronqist is decreased by 9.9 times; the occurrence of *Acer negundo* L. is decreased by 3.8 times; the occurrence of *Robinia pseudoacacia* L. is decreased by 14.9 times; the occurrence of *Physocarpus opulifolius* (L.) Maxim. is decreased by 6.3 times, etc. Many invasive species, present in badly fragmented forest geosystems, are absent in the lands with the area more than 10 km^2 (*Oenothera biennis* L., *Galinsoga parviflora* Cav., *Impatiens glandulifera* Royle, *Echinocystis lobata* (Michx.) Torr. & A. Gray, *Solidago canadensis* L.). Expansion of a forest land area to more than 1km^2 causes the most considerable changes in the occurrence of invasive species (Table 3). The occurrence of almost every species under study decreases by several times, some of the species disappear.

There is a reliable correlation between an invasive species projective cover and characteristics of an anthropogenic landscape transformation. The following covers correlate negatively with C_s value: *Conyza canadensis* (L.) Cronqist cover (Spearmen's correlation coefficient is -0.42), *Oenothera biennis* L. cover (-0.26), *Galinsoga parviflora* Cav. cover (-0.25), *Amaranthus retroflexus* L. cover (-0.25), *Lepidotheca suaveolens* (Pursh) Nutt. cover (-0.19). The following covers correlate negatively with the area of the forest land: *Conyza canadensis* (L.) Cronqist cover

(-0.24), *Oenothera biennis* L. cover (-0.24), *Galinsoga parviflora* Cav. cover (-0.12), *Impatiens parviflora* DC. cover (-0.17), *Impatiens glandulifera* Royle cover (-0.18), *Echinocystis lobata* (Michx.) Torr. & A. Gray cover (-0.23). With increase of the distance to hylion geosystems, the cover of the following species is reliably growing: *Conyza canadensis* (L.) Cronqist (0.20), *Oenothera biennis* L. (0.13), *Galinsoga parviflora* Cav. (0.21), *Solidago canadensis* L. (0.18), *Lupinus polyphyllus* Lindl. (0.24), *Echinocystis lobata* (Michx.) Torr. & A. Gray (0.14).

Table 3

Occurrence of invasive species in forest landscapes at different stages of anthropogenic transformation (% of the total amount of key areas)

Indicator	AN	RP	CC	OB	GP	EL	XS
Landscape ecological stability coefficient (C_s)							
>0.67 (n=182)	8.2	2.7	1.6	1.6	0	1.1	1.6
0.5-0.67 (n=43)	30.2	9.3	4.7	2.3	0	2.3	11.6
0.33-0.5 (n=33)	36.4	21.2	6.1	15.2	0	0	12.1
<0.33 (n=43)	30.2	23.3	25.6	14.0	7.0	14.0	7.0
Forest land area, km^2							
>10 (n=95)	10.5	2.1	2.1	0	0	0	4.2
1-10 (n=101)	8.9	2.0	1.0	2.0	0	1.0	0
0.1-1 (n=57)	26.3	12.3	8.8	12.2	1.8	0	10.5
<0.1 (n=48)	39.6	31.3	20.8	12.5	4.2	16.7	10.4

Note. AN — Acer negundo L.; RP — Robinia pseudoacacia L.; CC — Conyza canadensis (L.) Cronqist; OB — Oenothera biennis L.; GP — Galinsoga parviflora Cav.; EL — Echinocystis lobata (Michx.) Torr. & A. Gray; XS — Xanthoxalis stricta (L.) Small.

The cover of all invasive species under study correlates negatively with geosystem's age (with the exception of *Impatiens parviflora* DC. and *Impatiens glandulifera* Royle). For subboreal damp (deciduous forest) landscapes the risk of forest ecosystems disturbance is hardly probable, when connected with the invasions of adventive plant species. Successful invasions are possible under a significant degree of human pressure that causes the decrease of self-recovery potential in natural geosystems. In this case the invasion of some adventive species can have economical and sanitary-hygienic consequences.

The risk of invasion grows with the increasing fragmentation of a forest landscape (forest communities with the area less than 1km^2 are most susceptible to invasions). Under other equal circumstances the ability of natural communities to resist invasions depends on anthropogenic disturbance of surrounding geosystems: the more significant a disturbance is in its depth and area, the higher is the risk of invasions. The risk can be assessed with the help of the criteria given in Table 4.

Table 4

Criteria of invasion risk assessment

Indicator	Risk of invasions		
	High	Medium	Insignificant
C_s	<0.33	0.33-0.67	>0.67
Average area of a forest land, km^2	<1	1-10	>10

Thus, plant cover adventization can be an indicator of landscape ecological state: areas with high level of adventization and high concentration of invasive species indicate a sufficient decrease of natural geosystem stability, transformation of operation mode, and, are signs of ecological disbalance.

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