УДК 581.55:58.072:582.747.1(476)

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Статья поступила 25 сентября 2019г.

THE COENOTIC ROLE OF *ACER NEGUNDO* IN FORESTS DOMINATED BY *SALIX ALBA* IN THE VALLEY OF PINA RIVER (BELARUS)

Objective *of the research was assessing the influence of A. negundo invasion on the coenotic structure of willow river valley forests in conditions of Belarusian Polesie.*
Materials and methods. *The structure and floristic composition of communities were studied by permanent sample plot, forest valuation, Ramensky and Raunkiaer methods, on 400 m^2 plots.*
Results. *All studied communities belong to Salix alba–Rubus caesius association, and had up to 33/100 m^2 trees of A. negundo older than 3 years, with the total trunk volume of A. negundo up to 4.75 m^3/100 m^2. With the increase of A. negundo projection coverage on a plot from 0–13% to 25–46%, Shannon diversity index (SDI) for vascular plants declined from 3.2–3.3 to 2.7–3.0. For the species of lower community level (living ground cover), SDI = 3.1 on the plot without A. negundo trees, and SDI = 2.6 on the plot with the highest A. negundo concentration. The light intensity under A. negundo crowns was 3–8 times lower, than under S. alba. On 5 sample plots 59 vascular plant species were recorded, of which 6 herbaceous species had various degree of gravitation or preference to the crown projections of A. negundo.*
Conclusion. *The communities of Salix alba–Rubus caesius association are favourable for the propagation and growth of A. negundo. Development of A. negundo simplifies the coenotic flora. Along with this negative effect, the possible positive effects of A. negundo growth are: saving soil humidity, prevention of soil erosion, accumulating humus, protecting the neighbouring water bodies.*

Keywords: *community cluster analysis, community mosaics, crown shadow effect, Drude abundance, Negundo aceroides, Pripyat' Polesie, tree stand formula.*

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ЦЕНОТИЧЕСКАЯ РОЛЬ *ACER NEGUNDO* В ЛЕСАХ С ПРЕОБЛАДАНИЕМ *SALIX ALBA* В ДОЛИНЕ РЕКИ ПИНА (БЕЛАРУСЬ)

Цель исследования *– оценка влияния инвазии Acer negundo на ценотическую структуру долинно-речных ивовых лесов в условиях Белорусского Полесья.*
Материалы и методы исследования. *Использованы: метод постоянных пробных площадей (по 400 $м^2$ каждая), методы лесной таксации, определение проективного покрытия и обилия видов по Раменскому, Раункиеру и Друде.*
Результаты. *Все изученные сообщества представляют ассоциацию Salix alba–Rubus caesius. Максимальная концентрация A. negundo в них достигала 33 дерева старше 3 лет на 100 $м^2$, с запасом древесины до 4.75 $м^3$/100 $м^2$. С увеличением проективного покрытия клена на площадках от*

0–13% до 25–46% индекс разнообразия Шеннона для ценофлоры сосудистых растений уменьшался с 3.2–3.3 до 2.7–3.0. Для живого напочвенного покрова этот индекс составлял от 2.6 (сообщество с максимальной концентрацией клена) до 3.1 (сообщество без деревьев A. negundo). Освещенность под кронами клена была в 3–8 раз меньше, чем под кронами ивы белой. Всего на 5-ти площадках отмечено 59 видов сосудистых растений, из которых 6 видов имели различную степень тяготения к проекциям крон A. negundo.

Заключение. *Сообщества ассоциации Salix alba–Rubus caesius благоприятны для размножения и развития A. negundo. Массовое развитие A. negundo в них упрощает ценотическую флору и создает мозаику. Наряду с негативным эффектом данной инвазии допускается, что существуют позитивные эффекты развития A. negundo: сохранение влаги в почве, накопление гумуса, предотвращение почвенной эрозии, водоохранная роль.*

Ключевые слова: *кластерный анализ сообществ, мозаичность структуры фитоценоза, Припятское Полесье, прирост деревьев, формула древостоя, эффект затенения, Negundo aceroides.*

What this paper adds

It was stated for *Salix alba* forest communities, that Shannon diversity index for vascular plant coenotic flora decreased with the increase of *A. negundo* tree concentration. The correlation between *A. negundo* projection coverage and number of vascular plant species in community was calculated (r = –0.81). The plants gravitating to *A. negundo* crown projections (6 species) and avoiding them (8 species) were stated by Raunkiaer 1 m^2 plot method.

Научная новизна статьи

Впервые количественно изучена связь между видовым разнообразием (индекс Шеннона) и видовым богатством сообществ с доминированием *Salix alba*, в зависимости от концентрации деревьев *Acer negundo* и их общего проективного покрытия. Методом Раункиера на 1 м^2 площадках установлены виды растений, которые в разной степени предпочитают проекцию кроны *A. negundo* (6 видов) или избегают *A. negundo* (8 видов).

Introduction. The vegetation cover, both vegetation and flora, are undergone strong changes in the areas of human agricultural and industrial activity. Such transformations are associated not only with the change in the abundances of indigenous species, but also with appearance and population progress (invasion) of alien species. There are the estimations that invasive plants development can lead to large economic losses [13]. One of such invasive species is boxelder maple – *Acer negundo* L. (*Negundo aceroides* Moench), indigenout to east-central parts of North America, but now known in Europe and northern Asia [2; 22]. It is remarkable that the species is classified as invasive in North America too [17]. It is a middle-sized dioecious tree with wide crown, which starts to fructify in age of 6 years, and has soft, easily broken wood [22]. It is anemophilous and anemochoric species [12], but hydrochoric manner of seed spreading is much more effective, where it occurs [2; 22]. The plant has the tendency to form bush-like trees or (in conditions of limited light) trees with strongly inclined and curved trunks [11]; the trunk has a tendency to develop burls [10]. In general the species has high phenotypic plasticity in physiologically beneficial foliage allocation [18]. The species prefers well-watered, but enough drained soils and it is of middle shadow-tolerance [9]. In wild state the tree lives usually 65–70 years [8]. The ability of *A. negundo* to form regular arbuscular mycorrhiza was communicated [21]. In Eurasia the plant is usually not attacked by any serious disease or pest [7]. Initially *A. negundo* was brought in Europe and Asia with the aim to create ornamental and protective plantations, but later it started to spread as naturalized one [23]. In Belarus the species was brought to culture in XIX century [14]. Today, the activity on introduction of *A. negundo* in Belarus is prohibited on the legal base (the decree by the Ministry of Natural Resources and Environmental Protection of the Republic of Belarus No. 106 of 28 November 2008, with modifications according to the decree No. 35 of 28 October 2016).

More than 4000 populations (localities) are estimated to grow in Belarus, with the occupied area of more than 300 ha [15]. There were a special research devoted to geography and ecology of *A. negundo* near Dobrush, in southeast Belarus [3], showed the diversity of life forms of this species depending on the conditions of juvenile development, and the differences in ontogenetic structure of populations grown in different environmental conditions.

The aim of this work was assessing of the influence of *A. negundo* invasion on the coenotic structure of *Salix*-dominated river valley forests in conditions of Belarusian Polesie.

Material and methods. The field research was carried out in 2017–2018. Five permanent sample plots, 400 m^2 each, sized 15 × 27 m, were put along the Pina river, south of Pinsk town (Table 1). The area of research belongs to Polesie Lowland, Pina-Prypyats' valley; the plots were situated on flat, occasionally or never flooded (but with high ground water level during high flooding) river terrace, with old alluvial soils. Selecting the size of plots we followed the recommendations [1; 6]. We were guided by the principle of physiographical and ecological identity of all sample plots, i.e. they have similar position in landscape above the water level of the river, similar micro-relief, soil and watering conditions. Before fixing the plots, the general distribution of *A. negundo* in the Pina rivel valley (both banks) south of Pinsk was studied by route method. Plots were selected using the principle to create a gradient of density of *A. negundo* plants from zero (*A. negundo* absent) to high density, typical to this area, but keeping similar physiognomy of the main tree level of *Salix alba*. The presence of the set of characteristic plant species in lower levels of all communities was also taken into account.

Sample plot corners were fixed by pegs and also bound on a paper sketch to small local objects (e.g. forest roads). Plot sides were kept using a compass. During the total tree inventory the trees were marked by paper patches with numbers. For the measurements of annual growth sampled trees were marked by color threads; three occasional lower branches were taken for the measurements on each sample tree. Vascular plants were identified directly in field, or using the detailed photographs or temporary herbarium.

Tree level was studied according to the methods of forest inventory, or forest valuation [6]. Tree diameters were measured 1.3 m above the ground; tree heights were determined by altimeter. Tree crown projections were accepted as elliptical and determined from the length of these projections in directions north-south and west-east. Age of trees was determined on kerns after boring four different-aged sample trees by a trunk bore; then the diagram age/trunk diameter was built and the age of non-bored trees was determined.

Projection coverage of plant species was determined according to Ramensky and Raunkiaer methods [19; 24], on 1 m^2 subplots; 10 such subplots were put uniformly within each 400 m^2 plot. Within each 1 m^2 subplot, each species was measured in 9 smaller quadrates (for herbs), and in 5 smaller quadrates – 4 in corners and 1 in center (for *A. negundo* in upper level). For the estimation of species abundance, 6-grade scale of Drude [19] was used. Light intensity under crowns was determined by light meter Testo 545, in the conditions of clear heaven, between 12 and 14 h, in period 31 Jul – 23 Aug.

Cluster analysis of communities was carried out in STATISTICA 6.0, with unweighted pair-group average amalgamation rule. Correlation analysis was carried out in MS Excel. Shannon diversity index was calculated according the formula from [4]. For this index calculation, the shares of species were taken from their Drude abundances, which were summarized for the all species in community. Then the Drude abundance for each individual species was converted to the proportional fractional value, if accept the sum of all abundances = 1.

Results and discussion. After study the tree level (Tab. 1) and floristic composition on the plots (Tab. 2), it was confirmed that all sample plots belong to one community type, called here *Salix alba–Rubus caesius* association. The values of *A. negundo* concentration were obtained after total inventory of all trees on the plots and taking their biometric characteristics (Tab. 2). Regardless the community No.3 had no saplings or large *A. negundo* plants, several seedlings of this species were recorded there, which indicated a potential of future invasion of *A. negundo* on this plot too.

Table 1. – Position of plots and valuation characteristics for the tree level of sample communities

Characteristic	Sample plot No.				
	3	**5**	**4**	**2**	**1**
Geographical coordinates	52°06'02" N, 26°04'35" E	52°06'48" N, 26°07'10" E	52°07'15" N, 26°07'53" E	52°06'15" N, 26°05'24" E	52°06'12" N, 26°05'23" E
Average age, *Salix alba*, years*	12	38	12	27	28
Average age, *Acer negundo*, years	–	3	5	5	4
Number of trees on the plot, *Salix alba*	59	14	24	13	22
Number of trees on the plot, *Acer negundo***	0	26	29	52	131
Total volume of trunk wood, *Salix alba*, m^3	121	68	70	63	75
Total volume of trunk wood, *Acer negundo*, m^3	0	2	9	17	19
Stand formula (calculated from the number of trees)***	10**Sa**	6**An**4**Sa**	5**An**5**Sa**	8**An**2**Sa**	9**An**1**Sa**
Stand formula (calculated from the trunk wood volume)	10**Sa**	10**Sa**+**An**	9**Sa**1**An**	8**Sa**2**An**	8**Sa**2**An**
Stand density	0.7	0.7	0.7	0.7	0.8
Average height of *Salix alba*, m	10	18	9	13	12
Salix alba stand quality (productivity class)	II	IV	III	IV	IV

*Some individual trees of *S. alba* on the plots were from 55 to about 100 year old.
**excluding seedlings
***An – *Acer negundo*, **Sa** – *Salix alba*

A more exact characteristic that illustrates the abundance of *A. negundo* in community, and, consequently, the degree of its invasion, is trunk wood volume. It is seen (Tab. 1) that having bigger number of trees, *A. negundo* has lesser volume of wood, than *S. alba*. Thus the stand formulas, based on wood volume, are significantly different from those based on tree quantity. From the average age of *A. negundo* it is seen that the most of invasion began only about 3–5 year ago. Tree level of the communities contains uneven-aged plants of both *S. alba* and *A. negundo*. However, seldom trees of *A. negundo* on the plots were 10–18 years old. Since the fruiting of *A. negundo* begins on the 6th year, the most of plants in sample communities are not the source of seeds. The stand quality of *Salix alba*, as a feature illustrating its productivity (based on average age and height), was the highest in the community No.3 lacked the influence of *A. negundo* (Tab. 1). However, the relative decrease of stand quality in other plots, possibly associated with *A. negundo*, is not high.

The dependence was observed between the number of vascular plant species in community (species richness) and the concentration of *A. negundo* (Tab. 2). The number of species in tree and underbush levels clearly increases with the decrease of *A. negundo* concentration in the raw: plots 1–2–4–5. A reason may be the mutual concurrence between *A. negundo* and other tree species at earlier stages of their ontogeny. In respect to the plants of living ground cover, the richest list (24 species) was in community without perennial *A. negundo*, and the poorest list (15 species) – in community with the highest abundance of *A. negundo*. In respect to the diversity, estimated via Shannon index (SDI), the most diverse was the community without *A. negundo* trees, SDI=3.1; the least diverse was phytocoenoses with the highest abundance of *A. negundo*, SI=2.6 (Tab. 2). Also the plot with the highest concentration of *A. negundo* had the lowest average number of plant species in ground cover level per 1 m^2 (3.2 species). There is a strong inverse correlation between boxelder maple projection coverage and the number of ground cover plant species in community (r = –0,81).

Table 2. – Floristic composition and the abundance (Drude grades) of vascular plant species in sample communities

Species	Sample plot No.				
	3	**5**	**4**	**2**	**1**
wooden and semi-wooden (tree and bush level)					
Acer negundo (bush and trees)	–	5	6	6	6
Acer negundo (seedlings)	2	2	2	2	2
Acer platanoides	–	1	–	–	–
Betula pendula	2	2	–	–	–
Cornus sanguinea	2	1	–	–	–
Fraxinus excelsior	–	1	1	–	–
Parthenocissus quinquefolia	–	–	2	–	–
Populus alba	–	–	2	2	–
Populus tremula	2	2	–	–	–
Ribes nigrum	2	–	–	2	–
Rubus caesius	6	6	6	6	6
Salix alba	6	6	6	6	6
Salix caprea	–	1	–	–	–
Salix cf. *cinerea*	–	–	–	–	1
Salix cf. *pentandra*	–	–	–	1	–
Sorbus aucuparia	–	2	–	–	–
Tilia cordata	–	2	–	–	–
Ulmus glabra	–	2	–	–	–
Ulmus pumila	–	1	1	–	–
herbs (living ground cover)					
Agrostis gigantea	–	2	–	–	–
Bidens tripartita	2	–	–	–	–
Calamagrostis canescens	2	3	2	2	–
Calystegia sepium	5	3	3	2	4
Carex acutiformis	6	3	5	6	2
Chamaenerion angustifolium	–	–	2	–	–
Deschampsia caespitosa	–	–	–	2	–
Echinocystis lobata	–	–	–	–	2
Epilobium montanum	2	–	–	–	–
Epipactis palustris	–	1	–	1	1
Equisetum pratense	2	2	–	–	–
Eupatorium cannabinum	2	2	–	–	–
Filipendula denudata	2	2	–	–	–
Galeopsis tetrahit	1	–	–	1	–
Galium aparine	2	–	2	2	3
Galium palustre	–	–	2	–	–
Geranium robertianum	–	–	–	2	2
Glechoma hederacea	–	3	–	3	2
Humulus lupulus	–	2	2	2	–
Impatiens noli-tangere	–	6	2	2	2
Lathyrus pratensis	1	–	–	–	–
Lychnis flos-cuculi	1	–	–	–	–
Lysimachia nummularia	–	–	–	3	4
Lysimachia vulgaris	2	2	2	1	2

Table continuation 2.

Species	Sample plot No.				
	3	**5**	**4**	**2**	**1**
Mentha aquatica	2	–	–	–	–
Moehringia trinervia	–	1	2	–	–
Phragmites australis	5	4	5	–	4
Scirpus sylvaticus	–	1	–	–	–
Scutellaria galericulata	1	–	2	–	–
Solidago canadensis	–	2	–	–	–
Stachys palustris	1	–	2	1	–
Stellaria nemorum	–	–	–	–	1
Symphytum officinale	2	–	2	–	–
Trifolium repens	–	–	–	2	2
Valeriana officinalis	1	–	–	–	–
Veronica longifolia	–	–	–	1	–
Vicia cracca	1	2	–	2	–
Urtica dioica	2	2	6	5	6
Asteraceae indet.	1	–	–	–	–
Caryophyllaceae indet.	–	–	–	1	–
Acer negundo projection coverage on plot, %	**0**	**13**	**25**	**27**	**46**
Number of plant species of tree level and underbush	5	12	6	5	4
Number of plant species in living ground cover	24	19	16	20	15
Average number of plant species of ground cover level per 1 m^2 plot	4.8	5.5	4.7	4.4	3.2
Shannon diversity index (for living ground cover)	3.1	2.9	2.8	2.9	2.6
Shannon diversity index (for all species)	3.2	3.3	2.9	3.0	2.7

Cluster analysis of similarity between sample communities, based on vascular plant species lists with the values of their abundances, is illustrated by dendrogram (Fig.). The communities with the highest abundance of *A. negundo* (1, 2, 4) occurred to be the most similar. This analysis shows the clear increase in dissimilarity between communities along with the decrease of *A. negundo* concentration.

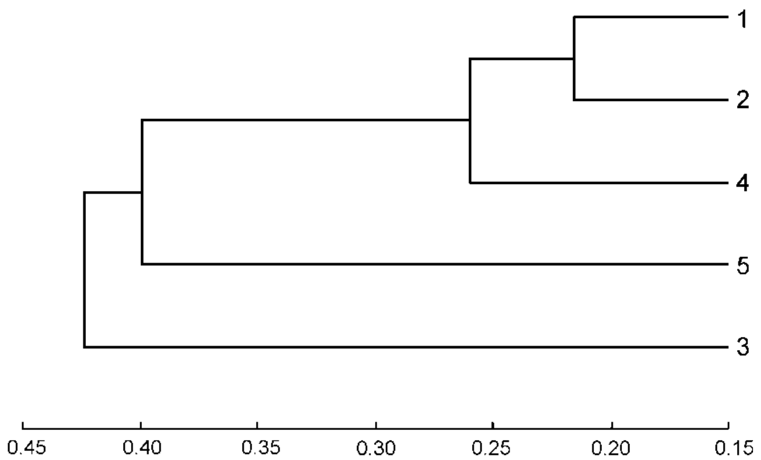

Figure – Dendrogram of similarity between coenotic floras of sample plots. Plots are numbered according to Tab. 1. Distance measure: 1–Pearson r

We have studied the changes in light regime under crowns of *A. negundo*. Shadow effect, provided by a plant species, is considered here as a part of its phytogenic field [5]. Depending on the complexity of tree level (number of tree species and their abundance), from 20 to 35 measurements of light intensity were done in different points on a plot. The change in light under *A. negundo* was compared with other tree species (Tab. 3). In the row plot 4–2–1 there is a distinct decrease of light under crowns of *A. negundo*, associated with the increase of this plant concentration. Each of sparsely distributed *A. negundo* trees gives less shadow, than those growing as closed groups. It is seen that *A. negundo* provides the greatest shadow effect among the trees, inhabiting studied phytocoenoses, except of *Ulmus scabra*. Light stream under *A. negundo* is in average 3.3 time less, than under denser part of *S. alba* crowns, and 8 times less, than under *S. alba* crown periphery. Consequently, shadow-preferring and shadow-tolerate herbaceous and bush species are able to develop under *A. negundo*, whereas more light-preferring plants gravitate to *Salix alba*, *Betula pendula*, and *Populus alba*.

Acer negundo changes the horizontal structure of communities by creating the mosaic. First of all, the higher diversity of ground cover was observed on the 1 m^2 subplots with zero or minimal coverage of *A. negundo*. Some subplots, which were 77–86% covered by *A. negundo* crown, contained a single lower level species (*Rubus caesius*), or even naked litter only. Contrary, some 1 m^2 subplots with zero coverage of *A. negundo* contained 10–12 species of living ground cover. The number of species in dense *A. negundo* groups (plot 1) did not exceed 5 per 1 m^2. The number of plant species of lower level were 0–7 per 1 m^2 subplots with presence of *A. negundo*, and 3–12 without *A. negundo*. A specific parcelles of *A. negundo* (covered 70–85% by this species) were observed on plots 1 and 2: they had 3–4 species in ground cover, with abundance 6 for *Glechoma hederacea* and *Geranium robertianum*. The preference of phytogenic field of *A. negundo* was observed for these two species. Other species, having gravitation to *A. negundo*, were *Lysimachia nummularia*, *Impatiens noli-tangere*, *Epipactis palustris*, *Trifolium repens*. They were recorded on subplots with *A. negundo* shadow only. Contrary, there were 8 species, recorded on plot 3 only, and thus avoiding boxelder maple. The abundance of *Carex acutifomis* decreased near *A. negundo*, whereas the abundance of *Urtica dioica* – increased. The horizontal structure of community No.3 looked uniform, almost lacked any mosaic. The herbaceous level here had dense, vigorous, and aesthetic appearance.

The growth dynamics of *A. negundo* in studied communities, determined after measurements at the end of vegetation seasons 2017–2018, is shown in Table 4. There are no a dependence between *A. negundo* plants concentration and growth of branches in length and trunks in diameter. The highest phytomass accumulation was observed on plot 4, where trunks become thicker and crown projection become broader about 1.5 times.

Table 3 – Values of light intensity under the crowns of tree species

Tree species	Sample plot No.					Average
	3	**5**	**4**	**2**	**1**	
Salix alba (10–20 cm from trunk of individual trees)	5440 (16)*	5030 (12)	2330 (11)	9090 (7)	3150 (14)	4680
Salix alba (under the crown periphery in *S. alba* parcelles)	–	25930 (1)	21560 (1)	4780 (1)	2130 (2)	11300
Betula pendula	6330 (3)	7390 (9)	–	–	520 (1)	6620
Populus alba	13640 (1)	–	900 (3)	6250 (4)	–	5170
Fraxinus excelsior	–	1940 (1)	–	–	–	1940
Acer negundo	**–**	**1430** (9)	**2760** (13)	**1310** (18)	**540** (18)	**1420**
Ulmus scabra	–	1300 (1)	610 (3)	–	–	780

*lc, average within the plot, rounded to 10 (in brackets: number of measurement points)

Table 4. – Annual enlargement in dimensions (%) of *A. negundo* in sample communities

Plot No. (number of trees sampled)	5 (2)	4 (2)	2 (3)	1 (3)	All plots (10)
Branch length, minimal–maximal / average	0–4.1 / 1.6	0–27 / 13	3.4–13.4 / 8.7	0–12.2 / 5.4	7
Average trunk diameter 1.3 m above the ground	11	41.7	24.9	15.3	23
Crown projection	3.7	56.5	21.4	17.4	24

Other workers described various negative effects of *A. negundo* on the communities, similar with those observed by us, e.g. stopping the renewal of *Salix* and *Populus* in river valley stands [22], the descrease of biometric characteristics of *Alnus glutinosa* of the main tree level [20], the release of allelopatic toxins by living shoots and roots [25].

We consider the spread of new plant species is various areas (including Belarus) as an element of evolution of plant cover. Because of too mass distribution of *A. negundo*, its full removal is economically and strategically impossible, but measures to reduce population growth rate are applicable. The measures that cause minimal damage to communities may be trunk girding [16] and arboricide infusion in trunk [7]; these actions must be applied first to the female individuals of *A. negundo*.

Conclusions. The communities belonged to *Salix alba–Rubus caesius* association are favourable for the development of *A. negundo* because of ecological requirements of the latter coincide well with those of *Salix alba* and the accompanying plants. The number of *A. negundo* trees older than 3 years in this association can reach 33/100 m^2, the total trunks volume – 4.75 m^3/100 m^2, projection coverage – up to 46%. In stands of *Salix alba* with average age 23 years, the average age of *A. negundo* is 4 years. The phytomass accumulation by *A. negundo* is classified as rapid and seen from the average annual enlargement in branch length (7%), trunk diameter 1.3 m above the ground (23%), and crown projection (24%). The shadow created by *A. negundo* crowns was about 3 times stronger, than by *Salix alba*. As a consequence, *A. negundo* development simplifies the coenotic flora: the species richness and species diversity were declined. It also creates certain mosaic, i.e. changes the horizontal structure of communities. The plant species, avoiding *A. negundo* and less frequent under it coverage, were recorded in lower level of *Salix alba–Rubus caesius* association. Besides, 6 herbaceous species (of 59 vascular plant species, recorded on all 5 plots) had various degree of gravitation to crown projections of *A. negundo*.

However, along with negative effect on the floristic diversity in river valley forests, we believe the growing of *A. negundo* has positive effects: saving soil humidity, prevention of soil erosion by root system, accumulating humus, protecting the neighbouring water bodies, i.e. the maple strengthens the environment-building functions of the phytocoenoses.

Acknowledgements. The authors are grateful to M.A. Dzhus (Minsk), G.Yu. Konechnaya (St-Petersburg), and N.N. Sychak (Lviv) for the help in identification of some plant species.

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Received 25 September 2019