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Research Article

CHORNOBYL'S CURRENT DENDROFLORA: ANALYSIS OF NATURAL SUCCESSIONS IN THE ABANDONED URBAN PHYTOCOENOSES

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Abstract: The research on the dendroflora of Chornobyl town 30 years after the accident at the Chornobyl nuclear power plant reveal that the taxonomic composition of the town green spaces comprises of 87 species and 8 decorative forms of 29 families, 26 orders, 2 divisions. The composition of plantations is dominated by trees (63%), bushes (30%) and winding plants (7%). Despite the natural succession processes over the past 30 years, the plantations of Chornobyl are dominated by introducers, which make up 57% of the total number of taxa. The study of test areas reveals successional changes in the abandoned phytocoenoses of the town, which led to the expansion of the alien invasive species *Acer negundo* L., *Robinia pseudoacacia* L., *Fraxinus pennsylvanica* L. and *Parthenocissus quinquefolia* (L.) Planch. The spread of alien invasive species is facilitated by droughts of long periods and the decrease in groundwater level. Climate change and the lack of proper agrotechnical care result in fungal diseases, damages caused by the semi-parasitic species *Viscum album* L. on decorative and fruit trees and bushes, both also leading to their expel from the town plantations.

Özet:
Çernobil Nükleer Santrali'nde meydana gelen kazadan 30 yıl sonra Çernobil kenti dendroflorası üzerine gerçekleştirilen araştırma kentin yeşil alanlarının 2 divizyo, 26 takım ve 29 familya içinde yer alan 87 tür ve 8 dekoratif formdan oluştuğunu ortaya koymuştur. Koruluk alanlar ağaçlar (%63), çalılıklar (%30) ve üzüm bağlarından (%7) oluşmaktadır. Geçen 30 yıllık süreçte yaşanan doğal süksesyona rağmen, Çernobil'deki dikili alanlar, tespit edilen toplam takson sayısının %57'sine karşılık gelen sonradan getirilmiş bitkiler oluşturmaktadır. Araştırmaya dahil edilen alanlardaki çalışmalar kentin terkedilmiş fitosenozunda, yabancı istilacı türler olan *Acer negundo* L., *Robinia pseudoacacia* L., *Fraxinus pennsylvanica* L. ve *Parthenocissus quinquefolia* (L.) Planch artışına neden olan süksesyonel değişimlerin görüldüğünü ortaya koymuştur. Uzun süren kuraklık ve yeraltı su seviyesindeki düşüş bu yabancı istilacı konusundaki eksiklik, dekoratif ve meyve ağaçlarında ve çalılarda fungal hastalıklara ve yarı parazitik bir tür olan *Viscum album* L. tarafından verilen hasarlara neden olmaktadır ki bu iki olumsuz durum zarar gören bitkilerin kent dikim alanlarından uzaklaştırılmasına yol açmaktadır.

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Introduction

The Chornobyl disaster and the resettlement of people from the city of Chornobyl took place over thirty years ago. However, the town has not completely died out, it is still the administrative center of the exclusion zone - hundreds of people live and work there, shops, hotels, and communal services are still operating. Despite the current situation, the town streets are well-kept, there are squares and parks while a significant area of the town is occupied by abandoned residential buildings that are collapsing. Since the plantations in these areas have not been cared for by anyone for a long time, natural successions are observed here. Considering that the dendroflora of the city of Chornobyl to be really unique, the study of natural successions of phytocoenoses is of important scientific and practical significance.

The first importance of such a study is that it aims to understand what changes occurred in the cultivated dendroflora after the human intervention cessation.

Secondly, such a study is important because it facilitates the assessment of the resistance of autochthonous and introduced species to recent rather sharp climate change in the absence of systematic care. Thirdly, the study of the current state of the dendroflora and directions of natural successions will be useful for future researchers in monitoring studies of the dendroflora state and composition.

The first scientific descriptions of the flora of Polissia, where the city of Chornobyl is located, were carried out by A. Rohovych in 1855 and 1869 (Rohovych 1855, 1869) and V. Montrezor in 1887 (Montrezor 1887). A thorough description of the flora of Polissia was carried out by J. Pachoskyj at the end of the 19th century after which the scientist published his findings with the name "Flora of Polessye and the adjacent areas" (Pachoskyj 1897, 1900). In the 20th century, thel flora of Polissia was studied by Povarnitsyn (1959), Miakushko (1978), Bradis & Andriienko (1977), Andriienko & Sheliah-Sosonko (1983) and Andriienko (2006). The analysis of the cultivated dendroflora of Polissia was carried out by Barbarych (1972) and Kokopo *et al.* (1980).

After the accident at the Chornobyl nuclear power plant in 1986, considerable attention was paid to the study of the effects of radiation on natural biocenoses, in particular on trees and shrubs (Davydchuk *et al.* 1990, Davydchuk *et al.* 1992). As these studies have revealed, the harmful effects of radiation occurred only in the first years after the accident in places with the greatest radioactive contamination, and in succeeding years, the trees resumed their normal growth. Basic studies of the effect of radiation on biocenoses in the exclusion zone were carried out by Belarusian scientists (Davydchuk *et al.* 1990, Davydchuk 1998, Veselov & Horodets'kyj 1998, Davydchuk & Sorokina 2003). These scientists stated that radiation does not affect phytocenoses, the radioactive exposure level decreases rather quickly, and radionuclides accumulate in the soil and forest floor. In Ukraine, a number of researchers published their data related to the effect of radiation on vegetation (Davydchuk *et al.* 1994, Matsala *et al.* 2021). With the exception of the "red forest" located not far from the accident power unit 4, woody plants died under the influence of radiation in very few areas. Morphological and anatomical tissue changes were observed in 1987 in some areas, but later on the radioactive influence decreased and noticeable changes in plant tissues and their reproductive capacity were no longer observed.

In recent decades, special attention has been paid to the spread of alien plant species and their impact on the natural biocenoses of the Ukrainian Polissia (Burda 2002, Burda & Kostenko 2007, Yavors'ka 2009, Tarasevych 2012, Baranskyj *et al*. 2016). The studies deal with both anthropogenic influence and changes in climatic conditions in the area. A number of studies revealed the self-seeding spread of some alien woody species such as *Acer negundo* L. and *Robinia pseudoacacia* L. in the cultivated phytocoenoses of Kyiv and Zhytomyr Polissia (Dzyba 2011, Yeremenko 2012, Spriahajlo 2013, Dojko *et al.* 2014).

Cultivated dendroflora of Chornobyl has never been the subject of scientific research. However, the issue of the composition and condition of the dendroflora in many settlements of Ukraine, including cities and towns located in the Polissia zone, is covered in the literature (Kokhno *et al.* 1980). According to Kokhno *et al*. (2001, 2002, 2005), the cultivated dendroflora in Ukraine includes about 1,700 species, more than 30 varieties and about 600 cultivars. Kalinichenko (2003) argues that about a third out of almost 2,500 taxa of woody plants concentrated in botanical gardens and arboretums is used for greening of settlements. Moreover, more than 200 taxa are used for landscaping in large cities, and up to 100 species, hybrids and cultivars of trees and shrubs are used for landscaping in district centers.

In recent years, the role of green spaces as a component of the urban natural infrastructure has been actively studied in different parts of the world (Alexandra & Norman 2020, Frantzeskaki & Bush 2021, Kirk *et al*. 2021, Oke *et al.* 2021). A number of researchers showed the positive impact of plantations on lowering the air temperature in the town (Frantzeskaki *et al.* 2019, Ossola *et al.* 2021, Ossola & Lin 2021.). In particular, Kendal *et al.* (2017) found out that the temperature under the canopy of trees on a sunny day drops by 4-6°C. Moreover, the average air temperature in areas covered with vegetation is 0.6-1.2°C lower than in those without vegetation (Eleftheria 2005). Some other researches also proved the positive role of urban natural infrastructure in biodiversity preservation (Ives *et al.* 2016, Threlfall *et al*. 2019, Frantzeskaki *et al.* 2020, United Nations Environment Programme 2021) as well as in absorbing moisture from natural precipitation and the formation of a microclimate (Lin *et al.* 2021, Moosavi *et al.* 2021), which has beneficial effects on the health and psychophysiological state of people (McDonald *et al.* 2018). Thus, the analysis of urban dendroflora carried out by Ossola *et al.* (2020) reveal the role of woody plants in preserving the biological diversity of modern cities.

The importance of these studies increases with regards to climate changes - uneven distribution of precipitation during the growing season in the study area since the reduction of anthropogenic influence makes it possible to monitor the natural processes (Burda 2002, Rogovskiy *et al.* 2019).

The purpose of this study was to analyze the structure, composition and dynamics of agrobiophytocoeoses and establish the directions and intensity of natural successions on the territory of the abandoned garden and park facilities of the city of Chornobyl 36 years after the nuclear accident at the Chornobyl nuclear power plant. The main task of the study was to examine the taxonomic composition, sanitary condition, age, trees and shrubs reproduction methods and intensity and the structure of phytocoenoses in the territory of the town of Chornobyl

Materials and Methods

The study was conducted during the period from 2012 to 2020 by the method of route surveys covering the central part of the city, its outskirts and the industrial zone. The taxonomic composition of trees and shrubs in the city's plantations were determined according to the multi-volume academic publications of the Dendroflora of Ukraine (Kokhno *et al.* 2001, 2002, 2005). The names of trees and shrubs are given in accordance with the World Flora Online Plant List (WOF Plant List 2022). To describe plantations of the town, six temporary test plots of 100 m^2 (10×10 m) were laid out in triplicate (Hryhora & Solomakha 2000). Square test plots were established in various locations in the central and peripheral parts of Chornobyl, including parks, near apartment buildings, on abandoned private estates, and on the territory of inactive enterprises (Fig. 1). All native and introduced trees and shrubs of each species between 1 and 10 years old were counted in the trial plots. The city's grass cover was not included in the study. The age class of trees and shrubs was estimated based on archival data and taxonomic indicators in accordance with the classes of 1-70 years. The age of the trees and bushes was estimated taking into account their size based on the analysis of the tables of the growth of the corresponding species and the period of establishment of the plantations in the city of Chornobyl.

The sanitary condition of plants was determined in accordance with the recommendations given in the Decree of the Cabinet of Ministers of Ukraine "On the approval of sanitary rules in the forests of Ukraine (Cabinet of Ministers of Ukraine 2020). The recommendations define plants of category I - healthy trees and bushes without signs of suppression, category II - trees and bushes weakened due to shading, competition with other species, and category III - trees and bushes have obvious signs of weakening and depression (dry branches, *Viscum album* L. and tinder fungi colonization, mechanical damage to the trunk bark *etc.*), category IV - severely weakened and dying trees and bushes (dry tops, total colonization of *Viscum album*, suppression due to mass reproduction of stem pests), category V - dead trees and bushes.

Temperature indicators and the amount of precipitation were analyzed according to the data of the Chornobyl meteorological station. The average monthly air temperature and precipitation in the study for 2012-2021 are based on data from the Chornobyl meteorological station (Chornobyl city weather station 2023). The average long-term temperature and precipitation by month over the past 140 years are shown by Chirkov (1986) and Adamenko (2016).

In 2016, the Chornobyl Radiation-Ecological Biosphere Reserve, which has the status of an international biosphere reserve, was established on the radioactively contaminated lands around the Chornobyl nuclear power plant within the territory of the Ivankivsky and Polisky districts of the Kyiv region on an area of 226,964.7 ha. In Ukraine, the Chornobyl Exclusion Zone is coordinated by the State Agency of Ukraine for the

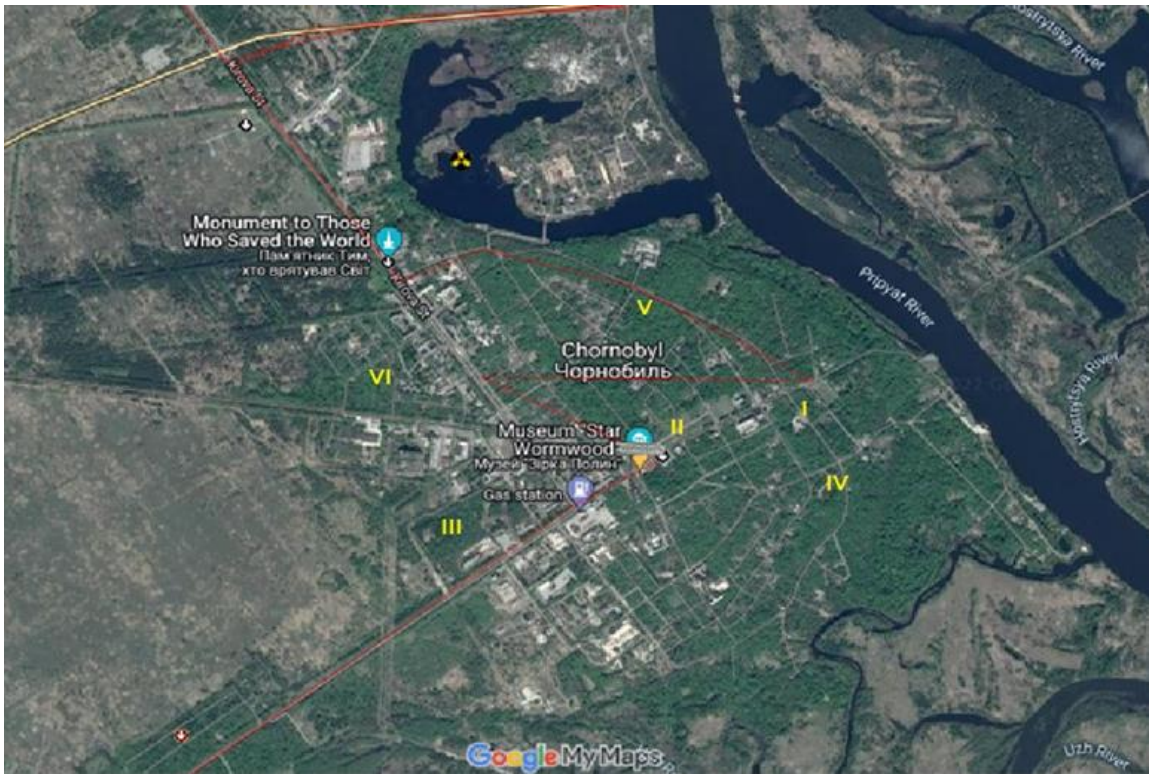

Fig. 1. Map of Chornobyl with trial areas (Google maps): I - Park of Glory, II - Park of Chornobyls, III - territory of an abandoned industrial enterprise, IV - territory of an abandoned kindergarten, V-VI – two areas on abandoned private homelands.

Management of the Exclusion Zone, which developed the Exclusion Zone Development Strategy for 2021-2030 (Strate Agency of Ukraine on Exclusion Zone Management 2021). The Strategy envisages scientific research in the territory of the exclusion zone through the creation of an international scientific hub in the city of Chornobyl.

The city of Chornobyl is located in the north of Kyiv Polissia on the right bank of the Prypiat River (a tributary of the Dnipro River) at the confluence of the Uzh River on an area of 4 km^2. Before the accident at the Chornobyl nuclear power plant in 1986, the city of Chornobyl was an administrative center of the district. After the accident, the town became the administrative center of the exclusion zone and the zone of unconditional (compulsory) resettlement of the local population. Currently, Chornobyl has the status of a shift village, where about 2,800 shift personnel and about 100 "self-immigrants" live. The northern part of the city is adjacent to the forest plantations of the Korohod Forestry, which in some places have merged with the plantations of the city of Chornobyl and form urban forests.

Results

The analysis of phytocoenoses in the central part of the town of Chornobyl (Glory Park and Memorial Park for the victims of the Chornobyl disaster, town squares, plantations near high-rise buildings) and in abandoned private estates reveal that the dendroflora of phytocoenoses in the territory of the city of Chornobyl comprises 95 taxa, including 87 species and 8 decorative forms (Table 1).

Table 1. Taxonomic composition of trees and shrubs in the city of Chornobyl.

No	Species name	Age groups	Reproduction mode: vegetative and generative	Sanitary condition	Growing locality	Note
1	*Acer campestre* L.	15-50	gen.	II	parks, squares	
2	*Acer negundo* L.	1-60	gen. and veg.	I-II	wastelands, abandoned biocenoses	
3	*Acer platanoides* L.	1-70	gen.	II-IV	parks, squares, street plantations, abandoned biocenoses	mass natural seeding
4	*Acer pseudoplatanus* L.	15-50	gen.	I-II	parks, squares	*Viscum album* affection
5	*Acer saccharinum* L.	15-50	gen.	II-III	parks, squares, street plantations	
6	*Aesculus hippocastanum* L.	15-60	gen.	II-III	parks, squares, street plantations	*Viscum album* affection
7	*Alnus glutinosa* (L.) Gaertn.	1-60	gen.	I-II	riverside	
8	*Amelanchier ovalis* (Willd.) Borkh.	35-45	gen.	I	town park, farmland	
9	*Amorpha fruticosa* L.	15-40	gen. i veg.	I	square	
10	*Aronia melanocarpa* (Machx) Eliot	35-45	gen.	II-III	self-settlers farmlands	
11	*Berberis thunbergii* DC.	30-45	gen.	I-II	forestry territory "Northern Pushcha"	
12	*Berberis thunbergii* f. *erecta* Rehder J. Arnold	25-30	veg.	I	forestry territory "Northern Pushcha"	
13	*Berberis vulgaris* L.	30-45	gen.	I-II	forestry territory "Northern Pushcha", squares	
14	*Betula pendula* Roth.	15-50	gen.	I-II-III	parks and squares, street plantations	
15	*Betula pubescens* Ehrh.	35-60	gen.	I-II	park, church territory	natural seeding
16	*Buxus sempervirens* L.	10-40	veg.	I	forestry territory "Northern Pushcha", church territory	
17	*Campsis radicans* (L.) Seem.	30-45	veg.	I	farmland of self-settlers	coppice shoot
18	*Caragana arborescens* Lam.	35-45	gen.	I-II	abandoned squares	
19	*Carpinus betulus* L.	35-45	gen.	I-II	abandoned squares, abandoned farmlands	natural seeding
20	*Carpinus betulus* L. 'Fastigiata'	10	gen.	I	Chornobyl victims park	
21	*Catalpa speciosa* (Ward. ex Bar.) Ward. ex Engelm.	10	gen.	I	Chornobyl victims park	
22	*Chaenomeles japonica* (Thunb.) Lindl.	3-30	gen.	I	abandoned farmlands	natural seeding
23	*Cornus alba* (L.) Opiz.	5-40	veg.	I-II	hedgerows, abandoned territories	natural seeding
24	*Cornus mas* L.	35-45	gen.	I-II	abandoned farmlands	

Table 1. Taxonomic composition of trees and shrubs in the city of Chornobyl (Continued).

No	Species name	Age groups	Reproduction mode: vegetative and generative	Sanitary condition	Growing locality	Note
25	*Crataegus monogyna* Jacq.	15-45	gen.	I-II	abandoned farmlands, squares	natural seeding
26	*Euonymus europaeus* L.	15-45	gen.	I-II	abandoned farmlands, squares	natural seeding
27	*Forsythia* × *intermedia* Zabel	10	gen.	I	Chornobyl victims park	
28	*Fraxinus excelsior* L.	5-70	gen.	I-IV	abandoned farmlands	natural seeding
29	*Fraxinus pennsylvanica* Marshall	5-50	gen.	I-IV	squares, abandoned farmlands	*Viscum album* affection
30	*Gleditsia triacanthos* L.	45-60	gen.	I-II	forestry territory "Northern Pushcha"	
31	*Hippophae rhamnoides* L.	35-50	gen.	I-II	forestry territory "Northern Pushcha"	
32	*Juglans cinerea* L.	20-40	gen.	I	territory of "Pivnichna pushcha" ent.	
33	*Juglans regia* L.	10-50	gen.	I-II	forestry, farmlands	natural seeding
34	*Juniperus communis* L.	20-30	veg.	II	territory of "Pivnichna pushcha" ent.	
35	*Juniperus* Lamb. *squmata* 'Blue Carpet'	5-12	veg.	I	Chornobyl victims park	
36	*Juniperus sabina* L.	10-30	veg.	II	forestry territory "Northern Pushcha"	
37	*Larix decidua* Mill.	20-40	gen.	I	forestry territory "Northern Pushcha"	
38	*Ligustrum vulgare* L.	35-45	veg.	II	square	root sprouts
39	*Lonicera tatarica* L.	25-40	gen.	I	square	
40	*Malus domestica* Borch.	34-45	veg.	II-V	abandoned farmlands	*Viscum album* affection
41	*Morus alba* L.	10-45	gen.	I-III	abandoned farmlands	natural seeding
42	*Parthenocíssus quinquefolia* (L.) Planch.	10-45	veg.	I-II	abandoned farmlands	natural seeding, root sprouts
43	*Persica vulgaris* Mill.	10-30	veg.	I-II	self-settlers farmland	
44	*Phellodendron amurense* Rupr.	10-30	gen.	I	forestry	
45	*Philadelphus coronarius* L.	30-40	veg.	II-III	abandoned square	
46	*Physocarpus opulifolium* (L.) Maxim.	35-45	veg.	I-II	abandoned hedgerow	
47	*Picea abies* (L.) Karst.	15-55	gen.	I-II	forestry, street plantations, forestry territory "Northern Pushcha"	
48	*Picea pungens* Enge	35-55	gen.	I-II	forestry, street plantations	
49	*Pinus sylvestris* L.	15-60	gen.	I-II	forestry, street plantations, squares and parks	
50	*Populus alba* L.	35-55	gen. and veg.	I-II	street plantations, town park	
51	*Populus balsamifera* (C. Koch.) Dipp.	35-60	gen. and veg.	I-II-III	street road plantations, town park	*Viscum album* affection
52	*Populus nigra* L.	35-65	gen. and veg.	I-II	abandoned territories	
53	*Populus nigra* var. *italica* Munchh.	35-55	veg.	I-II	street road plantations	
54	*Populus tremula* L.	35-55	gen. and veg.	I-II	abandoned territories	
55	*Prunus armeniaca* L.	30-45	gen.	I-II	farmlands, natural seeding in parks	
56	*Prunus avium* (L.) L.	5-50	gen.	I-II	abandoned farmlands	natural seeding
57	*Prunus cerasus* L.	5-50	gen.	I-IV	abandoned farmlands	natural seeding
58	*Prunus divaricata* Ledeb.	10-45	gen.	I-III	abandoned territories	
59	*Prunus domestica* L.	35-40	gen. and veg.	II-IV	abandoned farmlands	root sprouts
60	*Prunus serotina* Ehrh.	25-40	gen.	I	Chornobyl victims park, square	
61	*Prunus tomentosa* Thunb.	35-45	gen.	I-II	abandoned farmlands	
62	*Pyrus communis* L.	35-60	gen.	II-III	abandoned farmlands	
63	*Quercus palustris* Moench.	15	gen.	I	Chornobyl victims park	

Table 1. Taxonomic composition of trees and shrubs in the city of Chornobyl (Continued).

No	Species name	Age groups	Reproduction mode: vegetative and generative	Sanitary condition	Growing locality	Note
64	*Quercus robur* L.	10-70	gen.	I-II	forestry territory "Northern Pushcha", parks	
65	*Quercus rubra* Du Rei	15	gen.	I	Chornobyl victims park	
66	*Rhus typhina* L.	10-45	gen. and veg.	I-II	street plantations, forestry	root sprouts
67	*Ribes nigrum* L.	5-15	veg.	I-II	farmland of self-settlers	
68	*Robinia pseudoacacia* L.	5-60	gen. i veg.	I-II	abandoned territories, squares	root sprouts, natural seeding
69	*Rosa canina* L.	10-20	gen. and veg.	I-II	abandoned territories, squares	
70	*Rosa rugosa* Thunb.	10-20	veg.	I-II	street plantations near hostels and shops	
71	*Salix acutifolia* Willd.	10-45	gen. and veg.	I-II	riverbank plantations	
72	*Salix alba* L.	10-45	gen. and veg	I-II	riverbank plantations	
73	*Salix alba* f. *pendula* C.K.Schneid.	35-55	veg.	I-III	parks i squares	
74	*Salix cinerea* L.	10-45	gen. and veg.	I-II	riverbank plantations	
75	*Salix fragilis* L.	10-45	gen. and veg.	I-II	riverbank plantations	
76	*Salix babylonica* L.'Torturosa'	35-55	veg.	I-III	Chornobyl victims park	
77	*Salix caprea* L.	10-45	gen. and veg.	I-II	riverbank plantations	
78	*Sambucus nigra* L.	10-45	gen. and v eg.	I-II	abandoned territories	Natural seeding
79	*Schisandra chinensis* (Turez.) Bail.	10-25	gen. and veg.	I	self-settlers farmlands	
80	*Sorbus aucuparia* L.	5-40	gen.	II-III	road plantations, abandoned territories	*Viscum album* affection
81	*Spirea media* Franz Schmidt	5-30	veg.	I-II	curtilage	
82	*Spirea vanhouttei* (Briot) Zab.	5-30	veg.	I-II	curtilage, abandoned territories	
83	*Syringa vulgaris* L.	5-40	gen. and veg.	I-III	groups in a square, forestry territory "Northern Pushcha"	
84	*Thuja occidentalis* L.	12-45	gen.	I-II	forestry territory "Northern Pushcha"	
85	*Thuja occidentalis* L. 'Elvangera Aurea'	12-45	gen.	I-II	forestry territory "Northern Pushcha"	
86	*Thuja occidentalis* L. 'Fastigiata'	12-45	gen.	I-II	forestry territory "Northern Pushcha", abandoned territories of schools and kindergartens	
87	*Tilia cordata* Mill.	5-60	gen.	I-III	parks, squares, abandoned areas	
88	*Tilia plathyphyllos* Scop.	5-60	gen.	I-III	parks, squares, abandoned areas	
89	*Ulmus minor* Mill.	5-40	gen.	I-II	hedgerows, abandoned territories	
90	*Ulmus glabra* Huds.	15-60	gen.	I-II	parks, squares, abandoned areas	
91	*Ulmus laevis* Pall.	15-60	gen.	I-II	parks, squares, abandoned areas	
92	*Viburnum opulus* L.	15-35	gen.	I-II	parks, squares, abandoned areas	
93	*Vitis amurensis* Seeds	15-35	gen.	I-II	abandoned territories of private estates	
94	*Vitis vinifera* L.	25-45	gen.	I-II	abandoned territories of private estates	
95	*Viscum album* L.	4-12	gen.	I	parasitic on many types of trees	semiparasite

The analysis of the taxonomic composition of woody and shrubby plants found in the territory of the city of Chornobyl showed that the *Gymnospermae* section comprises 7 species and 3 cultivars combined into 2 orders and 2 families - *Pinaceae* (2 genera and 3 species) and *Cupresaceae* (2 genera, 4 types, 3 decorative forms). The *Magnoliophyta* section comprises 80 species and 5 decorative forms, which are grouped into 49 genera, 27 families, 24 orders, and 5 subclasses. The largest number of species and genera is represented by the family *Rosaceae* which comprises 11 genera and 22 species. The family *Betulaceae* is represented by 3 genera and 4 species, *Salicaceae* by 2 genera and 10 species, *Sapindaceae* by 1 genus and 6 species, *Oleaceae* by 4 genera and 5 species, *Juglandaceae*, *Malvaceae* by 1 genus and 2 species each, *Ulmaceae* and *Fagaceae* by 1 genus and 3 species for each, *Cornaceae*, *Vitaceae*, *Viburnaceae* and *Bignoniaceae* by 1 genus and 2 species for each. Flora of the remaining families of *Schizandraceae Berberidaceae*, *Buxaceae*, *Moraceae*, *Grossulariaceae*, *Hippocastanaceae*, *Celastraceae*, *Elaeagnaceae*, *Hydrangaceae*, *Sambucaceae Viscaceae* are represented by only one species for each (Fig. 2).

We determined, according to the classification of Serebriakov (1962), that 59 plant species have the life form of a tree, 29 species have the life form of a bush, and 7 species of the flora of Chornobyl belong to winding plants (Fig. 3).

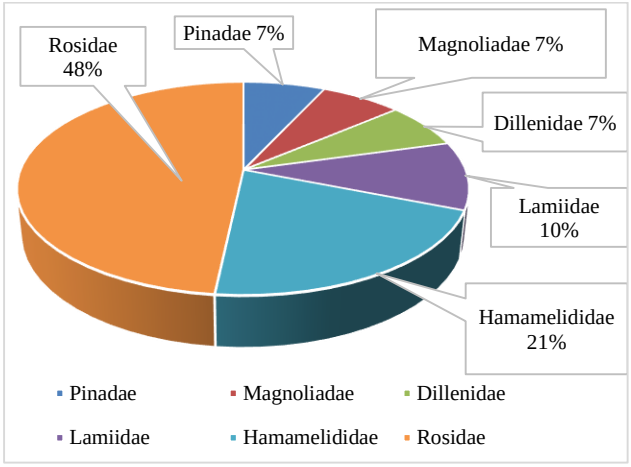

Fig. 2. Taxonomic composition of plantings in the city of Chornobyl according to their presence percentages (%).

The analysis of phytocoenoses in the territory of Chornobyl showed that the cultivated dendrophytocoenoses have undergone a significant transformation over the past 35 years. Cultivated garden-type phytocoenoses (gardens, berry orchards near private houses and garden-park phytocoenoses in parks, squares and on the territory of enterprises and institutions) prevailed on the territory of the city until 1986, while natural phytocoenoses were concentrated in the coastal part on the slopes of the Pripyat River.

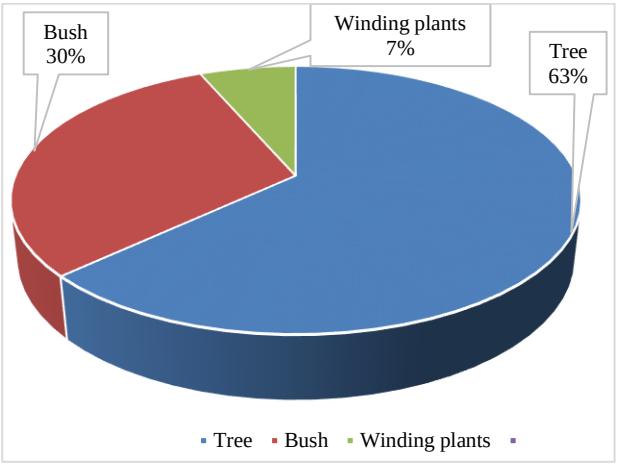

Fig. 3. Distribution of life forms (Serebriakov 1962) of the dendroflora of the city of Chornobyl.

According to K. Raunkiær classification of life forms (Raunkiær 1934), the species of Chornobyl dendroflora belong to phanerophytes and are divided into megaphanerophytes, mesophanerophytes, microphanerophytes and nanophanerophytes (Fig. 4).

Evergreen phanerophytes with unprotected buds comprise 6 species (*Pinus sylvestris*, *Picea abies*, *Picea pungens*, *Thuja occidentalis* L., *Juniperus communis* L., *J. sabina* L.*)* and 3 forms (*Juniperus squamata* Lamb. 'Blue Carpet', *Thuja occidentalis* 'Elvangera Aurea' and *Thuja occidentalis* 'Fastigiata'). Evergreen phanerophytes with protected buds comprise only 2 species: *Buxus sempervirens* L. and *Viscum album* L.. The remaining species belong to deciduous phanerophytes with protected buds. The Chornobyl dendroflora is dominated by introducers represented with 48 species and 6 decorative forms. Autochthonous dendroflora numbers 39 species and 2 decorative forms.

65 species originate from the Circumboreal Region, 15 species originate from the East Asian Region, 6 from the Atlantic-North American Region, 5 from the Irano-Turanian Region, and 1 species from the Rocky Mountains Region (Fig. 5).

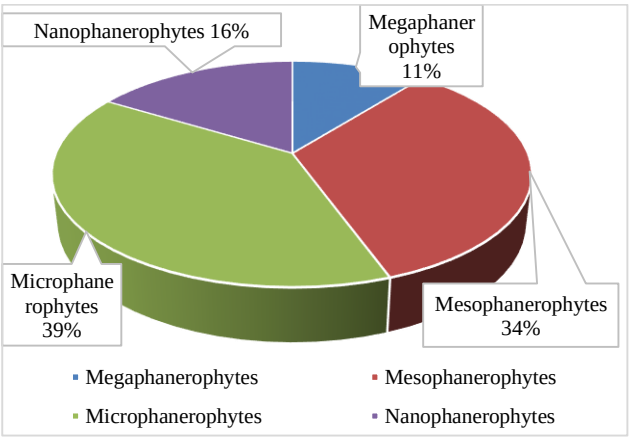

Fig. 4. Life form spectrum of phanerophytes according to K. Raunkier (Raunkier 1934) in the plantations of Chornobyl.

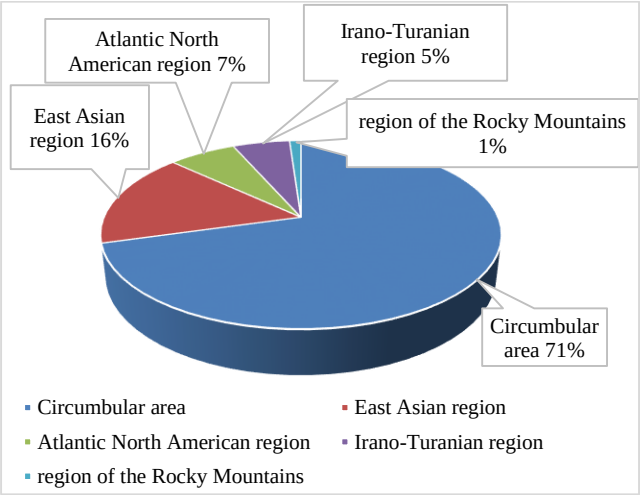

Fig. 5. Chorological spectrum of Chornobyl dendroflora.

Cultivated phytocoenoses have currently been preserved in a small area in the city. In the Glory park (Figs 6-7), in the recently established *Chornobyl victims park* (Fig. 8), in the territory of "Pivnichna pushcha" forestry enterprise of the Korohod Forestry and on some central streets (Fig. 9), where state institutions, shop and hotels operate, and on some private plots, where self-settlers people live. The rest of the territory Chornobyl is the abandoned territory of homesteads (Figs 10-13), the territories of institutions, enterprises and organizations (Figs 14-15), which are overgrown with self-sowing trees and bushes due to natural succession.

The largest number of species and form diversity are observed at the territories of operating enterprises, in particular, at the arboretum of *Pivnichna Puscha* forestry state enterprise located on an island of the Pripyat River, where 42 woody plant species are present. Many species grow in Chornobyl victims town park. Owing to systematic care, there is hardly any self-seeding on the territory of these locations, and the planted trees and bushes are in adequate condition.

The course of dendroflora transformation was significantly influenced by climate changes that took place in recent years. The average monthly temperature in April-August over the years of our research (2012-2021) according to the Chornobyl meteorological station is significantly higher than the long-term average of monthly temperature values over the past 140 years (1880-2020) (Fig. 16). Monthly precipitation over the years of the study also increased compared to the average long-term data, but it is unevenly distributed over the months (Fig. 17). Long-term droughts became more frequent, which led to the partial drying up of swamps and a decrease in the groundwater level by 1.6-2.1 m. Sandy soils filter rainwater quickly. All these processes affect the intensive self-renewal of a number of species such as *Acer platanoides, Acer negundo, Robinia pseudoacacia, Fraxinus excelsior, F. pennsylvanica, Ulmus glabra, Prunus divaricate* and *P. domestica.*

Fig. 6. Glory Park.

Fig. 7. Central Alley of the Glory Park with *Aesculus hippocastanum*, *Tilia cordata* with hedgerow of *Ligustrum vulgare.*

Fig. 8. Chornobyl victims park.

Fig. 9. Chornobyl town centre.

Fig. 10. An abandoned house overgrown with *Acer pseudoplatanus* and *Vitis amurensis* natural seedings.

Fig. 11. An abandoned house overgrown with *Acer platanoides*, *Ulmus laevis* and *Ribes nigrum* natural seedings.

Fig. 12. An abandoned house overgrown with *Acer pseudoplatanus* and *Vitis amurensis*, natural seedings.

Fig. 13. An abandoned house overgrown with *Betula pendula* and *Pinus sylvestris* natural seedings.

Fig. 14. The library house overgrown with *Acer platanoides, Fraxinus excelsior* and *Pyrus communis.*

Fig. 15. Enterprise territory is overgrown with *Robinia pseudoacacia* and *Phellodendron amurense.*

Table 2. Taxonomic composition and number of trees and bushes aged between 1-10 years and grown naturally on the test plots.

Number in order	Species name	Test plots in three replicates																Number of individuals, pieces
		No 1			No 2			No 3			No 4			No 5			No 6			
		I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	
1.	*Acer campestre*				2	3	6													11
2.	*Acer negundo*	5	4	7	2	-	3	18	25	14	10	16	8	12	20	15	13	8	9	189
3.	*Acer platanoides*	2	4	7	2	5	2	10	18	8	12	5	8	16	21	10	8	11	15	164
4.	*Acer pseudoplatanus*		1		5	2	4	2	6	7	2	1	4	5	10	8	3	5	4	69
5.	*Acer saccharinum*	2	1	3	2	4	1													13
6.	*Aesculus hippocastanum*	2	3	1	5	8	3	6	3	4	6		2							43
7.	*Alnus glutinosa*							2	4	1										7
8.	*Amorpha fruticosa*							2	4	5										11
9.	*Prunus armeniaca*										6	5	1	2	5	6	8	3	4	40
10.	*Berberis thunbergii*	4	2	1																7
11.	*Berberis vulgaris*				2	1	1													4
12.	*Betula pendula*							4	6	5	1	3	6	6	3	2				36
13.	*Caragana arborescens*							4	7	2	10	12	5							40
14.	*Carpinus betulus*	4	6	5	6	2	4							4	2	5	6	7	4	55
15.	*Prunus avium*													10	16	13	8	12	22	81
16.	*Prunus cerasus*													9	11	12	4	6	10	52
17.	*Crataegus monogyna*													4	8	3				15
18.	*Euonymus europaeus*				4		2	5												11
19.	*Forsythia × intermedia*	5	2	3																10
20.	*Fraxinus excelsior*							25	6	4	11	9	8	10	14	8	22	5	15	137
21.	*Fraxinus pennsylvanica*							12	18	11	9	13	17	23	28	11	6	14	10	172
22.	*Juglans cinerea*							7	5	4										16
23.	*Juglans regia*							11	9	16			5	7	15		12	8	10	93
24.	*Malus domestica*												3	7	6	14	8	5	12	55
25.	*Morus alba*												11	5	16					32
26.	*Parthenocissus quiquefolia*							12	8	6										26
27.	*Populus alba*				5	11	16													32
28.	*Populus balsamifera*	9	11	7																27
29.	*Populus nigra*				16	12	10													38
30.	*Populus nigra* var. *italica*				4	8	5													17
31.	*Populus tremula*							12	9	6										27
32.	*Prunus divaricata*													4	16	5	8	6	12	51
33.	*Prunus domestica*																6	3	11	20
34.	*Pyrus communis*							6	3	2							2	1	4	18
35.	*Quercus robur*										2	3	8							13
36.	*Rhus typhina*							8	5	6										19
37.	*Ribes nigrum*																7	2	2	11
38.	*Robinia pseudoacacia*													5	13	16	10	8	14	66
39.	*Rosa canina*							3	7	2										12
40.	*Salix alba*										5	7	5							17
41.	*Salix caprea*							4	6	2										12
42.	*Sambucus nigra*							3	11	5				5	7	4				35
43.	*Tilia cordata*	4	6	9	5	11	8													43
44.	*Ulmus minor*				6	5	5							2	7	4				29
45.	*Ulmus glabra*	12	6	3																21
46.	*Vitis vinifera*																1	2	3	6
In total		49	46	46	66	72	70	156	160	110	74	74	91	136	218	136	132	106	161	1903

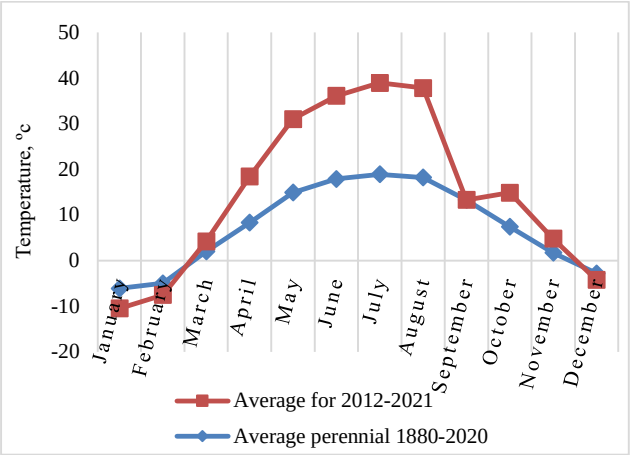

Fig. 16. Average monthly temperature data for 2012-2021 and average multi-year temperatures in Chornobyl.

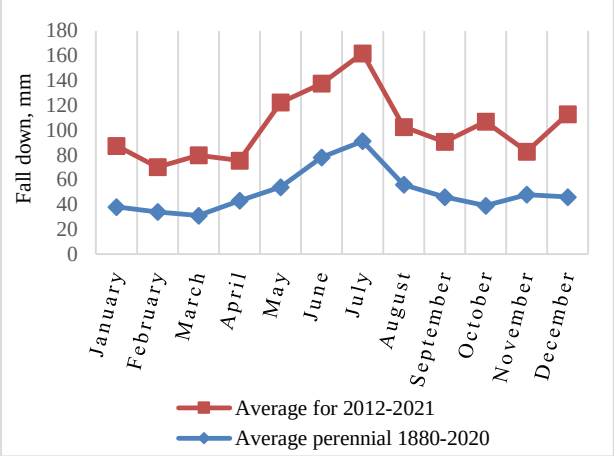

Fig. 17. Average monthly precipitation data for 2012-2021 and average multi-year precipitation in Chornobyl

We delineated six trial plots in order to analyze successional changes in the Chornobyl phytocenoses – in *Glory park* (trial plot No. 1), *Chornobyl victims park* (trial plot No. 2), on the territory of an abandoned industrial enterprise (trial plot No. 3), on the territory of an abandoned kindergarten (trial area No. 4) and two areas on abandoned private homelands (trial area No. 5 and 6). The lowest amount of natural regeneration was found in test areas in town parks (Fig. 19), where systematic maintenance of plantings was carried out. We found a large number of *Acer platanoides* and *A. negundo* natural regeneration in test plots No. 3-6. Abundant natural regeneration of *Prunus avium* and *Juglans regia* was observed on the abandoned private estates (test plots No. 5-6).

Discussion

The urban green spaces degradation is caused by a combination of legal, economic, ecological and biological factors (Rogovskiy 2014, Rogovskiy 2019). In the abandoned homelands, plant communities are dominated by adventitious invasive species of *Acer negundo, Robinia pseudoacacia, Fraxinus pennsylvanica* and *Parthenocissus quinquefolia*. Climatic change, in particular an increase in air temperature and a groundwater level decrease, accelerate the process of replacing native park-forming species with less valuable invasive adventive species (Rogovskiy *et al*. 2019, Ishchuk 2021). Regular abundant fruiting and the dispersion of seeds by wind and birds are the main reasons why these species have formed thickets on the territory of abandoned homeland gardens and kitchen gardens, as well as on the territories of enterprises and organizations. The rapid spread of these species in Polissia was confirmed by Burda (2002), Burda & Kostenko (2007) and Yavors'ka (2009). Some autochthonous species such as *Acer platanoides, Fraxinus excelsior, Tilia cordata, Betula pendula, Sambucus nigra, Ulmus minor, Carpinus betulus* and *Cornus alba* regenerate intensively and successfully get acclimated to new territories.

Homelands are closely related to the ethnic group mentality, to the traditions of landscape arrangement of homesteads and streets, the population well-being and culture (Rogovskiy 2013). Abandoned houses of Chornobyl indicate their multi-functional use in the past. Currently, derived phytocenoses usually have two or three tiers, the upper tier is dominated by *Fraxinus excelsior, Robinia pseudoacacia* and *Tilia cordata*. Fruit species (*Malus domestica, Pyrus communis, Prunus domestica*), which are the remains of orchards, as well as undergrowth of *Acer platanoides, Acer negundo* and *Ulmus minor* dominate in the second tier. The lower tier is occupied by seedlings of *A. negundo, Sambucus nigra, Euonymus europaeus*. *Acer negundo* has the highest abundance confirmed by satellite monitoring data (Matsala *et al*. 2021). The data reveal that over the past 34 years, the afforestation of the Chornobyl Exclusion Zone has increased from 41% in 1986 to 59% in 2020.

The species mentioned above make the basis of current phytocenoses in the abandoned territories of the town of Chornobyl. The fruit trees in the former orchards are derelict, a significant part of the apple trees is invaded *Viscum album*, the trunks of the fruit trees are often entwined with *Parthenocissus quinquefolia* vines. Natural regeneration is observed only in some varieties of *Prunus avium, P. divaricata* and *P. domestica* due to the formation of intensive root growth. Usually, in such phytocenoses, there is no grass cover due to significant shading and a large number of self-sowing trees and bushes.

On the territories of enterprises, institutions and organizations, where previously planted *Rhus typhina, Populus alba, Robinia pseudoacacia* grew, vegetative reproduction and expansion of the occupied territory caused by root growth are observed. *Populus alba, P. nigra* and *P. nigra* var. *italica* also occur in patches in the meadows of the coastal strip along the Pripyat River. The seeds of these species lose their germination relatively quickly, but they regenerate naturally in presence of sunlight and sufficient moist, (Ishchuk 2016a, Ishchuk 2016b). Seedlings of *Salix alba, S. fragilis* and *S.*

acutifolia are often found in large numbers in the floodplain of the Pripyat River. However, only single self-sown plants remain until autumn due to sharp fluctuations in the groundwater and the water level in the Pripyat River during the summer (Ishchuk *et al.* 2018). *Rhus typhina* has fully acclimatized in Polissia and Forest Steppe, and, in addition to spreading by root shoots, reproduces well by seeds (Kovalchuk *et al.* 2022).

In abandoned parks and squares after the regular care cessation, there are a lot of self-sown adventive species mentioned above. However, the upper tiers are dominated by park species, including *Fraxinus excelsior, Populus balsamifera, P. nigra, Quercus robur, Q. rubra, Tilia cordata, T. platyphyllos* and *Ulmus laevis* planted in the course of the park facilities creation. The second tier is formed by *Acer platanoides, A. pseudoplatanus, A. negundo, Betula pendula*. The third tier is dominated by self-sowing *Acer negundo* and *A. platanoides* maples. Shrubs are practically displaced from such phytocenoses – *Syringa vulgaris, Physocarpus opulifolium, Cornus alba, Sambucus nigra, Euonymus europaeus* are only found occasionally on the forest edges. However, native park-forming species contribute to the Chornobyl zone ecosystem fire resistance and its resilience increase (Lasko *et al.* 2020).

It should be noted that *Ulmus laevis* and *Ulmus glabra* have appeared in the city over the past 10-15 years. On the outskirts of the city of Chernobyl, we found *Ulmus laevis* and *Ulmus glabra* trees affected by the pathogen *Grapheme ulmi* Schwarz., which leads to their gradual extinction.

Some *Fraxinus excelsior* individuals with signs of drying caused the spread of the pathogenic fungi *Hysterographium fraxini* De Not and *Nectria cinnabarina* Tode Fr. The appearance of dry dead wood leads to the accumulation of biomass, which is a source of fires and makes it difficult to extinguish them. The risk of radionuclide spread during fires increases dramatically, especially in windy conditions. Evangeliou *et al.* (2015) found a positive correlation between droughts in the Chornobyl Exclusion Zone and fires. The risk of fires increases due to an increase in tree shrinkage and a decrease in the rate of dead wood decomposition which affects the redistribution of cesium (137Cs) radionuclides. In addition, climate change can lead to a high risk of radioactive contamination with characteristic fire peaks in the future. In this way, the preservation of healthy green areas in Chornobyl prevents the migration of radionuclides outside the radioactive zone.

It is worth noting that self-sowing *Pinus sylvestris* and *Picea abies* are rarely found on the territory of the town. This can be explained mainly by the limited number of individuals of these species in the town. However, literature data indicate the dependence of the morphometric dimensions of pine in the Chornobyl zone on the degree of contamination of the territory with radionuclides, in particular in the Red Forest (Ioshchenko & Bondar 2009, Kuchma 2010, Brown 2019). We discovered a 2-3-year-old self-seeding *Thuja occidentalis*, but no self-seeding of older trees of this species were found in Chornobyl. Single self-sowing plants of *Juglans cinerea* on the territory of the industrial zone were also found. The insignificant amount of self-sowing of this species is explained, in our opinion, by the limited number of generative trees, the frequency of their fruiting, the low average score of fruiting in urban conditions and the fruit consumption by wild mammals and birds (Ishchuk *et al.* 2021).

Populus balsamifera, Populus nigra var. *italica* and *Aesculus hippocastanum* make the basis of roadside plantings in the town. In many places with no roadside plantings care the *Prunus armeniaca* and *Juglans regia* self-sowing species added to the former ones. Particularly abundant along the roads are self-sowing *Acer negundo, Fraxinus pennsylvanica,* and *Robinia pseudoacacia* (Rogovsky 2013). Street and roadside plantings of *Populus balsamifera and Populus nigra* are heavily affected by *Viscum album*. *Aesculus hippocastanum* plants are affected by *Cameraria ohridella* Deschka & Dimic. The spread of *Viscum album* is facilitated by birds that feed on the seeds of this species and accelerate its spread in the town (Ishchuk 2013).

Conclusions

The taxonomic composition of the green spaces of Chornobyl city comprises 87 species and 8 decorative forms belonging to 29 families, 26 orders, 2 divisions. The *Rosaceae, Betulaceae, Salicaceae, Sapindaceae, Oleaceae* families are characterized by the greatest species diversity. Trees dominate in the plantations of Chornobyl and make up 63% of the total vegetation, followed by bushes (30%) and vines (7%), respectively. The largest share of species belongs to mesophanerophytes and microphanerophytes with 34% and 39% respectively. Due to natural succession and the lack of proper care over the past 30 years, the plantations of the city of Chornobyl are dominated by introducers, which make up 57%. Species from the Circumboreal region are better adapted to the soil and climatic conditions of Polissia and, therefore, are most widely represented in the dendroflora of the town of Chornobyl.

However, despite the high share of introducers in the park coenoses of Chornobyl, autochthonous park-forming species prevail in the upper tiers – *Acer platanoides, Fraxinus excelsior, Tilia cordata, Betula pendula, Ulmus minor, Carpinus betulus, Cornus alba* and *Sambucus nigra*, which form a lot of self-seeding. Considerable areas are occupied by phytocenoses of orchards with the participation of *Malus domestica, Pyrus communis* and *Prunus domestica*, which are in a depressed state due to the lack of proper agrotechnical care.

The transformation of cultural phytocoenoses in the soil and climatic conditions of the city of Chernobyl over the past 30 years has led to the expansion of *Acer negundo, Robinia pseudoacacia, Fraxinus pennsylvanica,*

Parthenocissus quinquefolia as invasive adventive species. Their spread is facilitated by climate change, in particular, long periodic droughts and a decrease in the level of groundwater. Self-sowing of these species, due to regular and abundant fruiting and the spread of seeds by wind and birds, occupies a dominant position in cultural phytocoenoses.

Climatic changes and the lack of proper agrotechnical care has led to decorative and fruit species being damaged by fungal infestations, in particular by *Graphium ulmi* Schwarz., *Hysterographium fraxini* De Not and *Nectria cinnabarina* Tode Fr. and by the semi-parasite *Viscum album*, which leads to their falling out of the plantations. This process contributes to the intensive spread of the adventitious species *Acer negundo, Robinia pseudoacacia, Fraxinus pennsylvanica, Parthenocissus quinquefolia* and *Rhus typhina* in cultural phytocoenoses.

The plantations in the central part of the town of Chornobyl and on the territory of "Pivnichna Pushcha" forestry enterprise, where systematic maintenance is carried out, are in a satisfactory condition, and there is no adventitious invasive species self-seeding and growth.

Ethics Committee Approval: Since the article does not contain any studies with human or animal subject, its approval to the ethics committee was not required.

Data Sharing Statement: All data are available within the study.

Author Contributions: Concept: S.R., Design: H.I., Execution: L.I., Material supplying: S.R., L.I., Data acquisition: S.R., H.I., Data analysis/interpretation: L.I., H.I., Writing: L.I., H.I., Critical review: S.R., L.I.

Conflict of Interest: The authors have no conflicts of interest to declare.

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