The herbaceous tier analysis in protective forest plantations, Ukraine

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Abstract. The article analyses the five elements of vegetation: floristic and taxonomic composition, lifespan, life form, and species distribution in the Middle Pridneprovye Right Bank, Ukraine. Consequences of the anthropogenic impact on the grass cover of the forest shelterbelts in farmlands, located near the city Cherkasy, have been determined. Changes in the ecotope cause transformations of the grass tier due to alteration of the systematic structure, invasion of meadow species, heliophytization, mesophytization, synanthropization, expansion of alien plants and explerents, and inhibit natural regeneration and development of trees. Thirteen alien plants with high invasive ability have been defined.

Key words: ecomorphs, forest shelterbelts, life form, phytoindication, transformation

Introduction

No society can exist without natural resources. Intensive anthropogenic impact on the environment, however, causes significant alterations in the vegetation, due to cultivation and physical destruction, pollution, fragmentation of habitats, etc. As a result of introduction of alien species, floristic contamination of the environment leads to simplification and unification of vegetation, inevitably accompanied by a decrease in ecosystem stability in regards to negative external influences (Jenkins & Parker 2000; Kuhn & Klotz 2006; McKinney 2006; Burda & Petrovych 2012; Wojterska & al. 2016). These issues are particularly vital in the regions of intensive agriculture. One of the most difficult problems is optimization of structural and functional organization of the landscapes ratio in space and time, of lands, which have different functional purposes, modes of use, and preservation and restoration of the corresponding natural resources. Solution of this problem significantly affects the harmonization of such strategies as conservation of vegetation and improvement of land use in environmental terms. Agreement of economic and environmental interests will increase crop yields, decrease negative consequences of economic activity, improve ecological safety, protection of soils, waters and biota, and improve ecological conditions in the territories. In general, in Ukraine, it will promote coordinated implementation of a number of environmental, economic and social programs for sustainable development, with different levels of management. The urgency of these issues is pressing in industrial, urbanized, densely populated, and poorly forested agrarian regions of the country, as well as in the territories with conspicuous relief. Agroforestry, with its more than 200 years of experience, has shown that the most effective way of ecosystem solution of these issues is to create protective forest plantations (PFP) as valid target systems of different plantation types and categories, depending on their functional purpose and location, relief structure, categories and status of lands, etc. (Stadnyk 2012). The PFP perform important functions for the natural environment (NE): buffer, barrier, protective, filtration, productive, recreational. They restrain winds, soil erosion, desertification; increase farmland yields, maintain landscapes stability, form a habitat for living organisms, support biodiversity, and serve as corridors for species migration (Jenkins & Parker 2000; Chirkova 2010; Burda & Petrovych 2012; Jose 2012; Stadnyk 2012; Livesley & al. 2016; Schindler & al. 2016; Decocq & al. 2016; Huse & al. 2016; Moon & al. 2017). A significant share of these tasks is also performed by the green areas around the cities and other settlements.

The modern agrolandscape science defines protective forest plantations (forest belts) as anthropogenic ecotones (Zaletaev 1997). Burda & Petrovych (2012) have described the ecotone effect of PFPs. Petrovych (2012) wrote about their ecosystem services. In relatively insignificant numbers, often with linear configuration, they are special, unstable ecosystems with a specific sub-canopy climate. They have high biological diversity, instability and dynamism, in contrast to the more static ecosystems, between which ecotones form (Tsaryk 2003; Jose 2012; Felipe-Lucia & Comín 2015). In the last two decades, prompted by disadvantages of the land reform in Ukraine and decline of the agroforestry service, there was no sylvicultural care for PFPs to maintain their condition and proper structure, to extend their age and improve the performance of environmental functions (Stadnyk 2012). Therefore, the PFPs are subject to constant rapid changes during their development, directed at the indigenous type of the zonal elementary ecosystem, or undergo transformation as a result of the introduction and naturalization of non-characteristic plant species (Zaletaev 1997; Jose 2012; Loeb 2012; Gunnarsson & al. 2017), especially segetal and/or synanthropic species (Muratet & al. 2007; Knapp & al. 2010; Fagot & al. 2011; Burda & Petrovych 2012; Williams & al. 2015). Therefore, it is important to detect new adventitious species too (Protopopova & al. 2006; Burda 2007; Ricotta & al. 2009; Bomanowska & Kiedrzyński 2011; Lososova & al. 2011, 2012; Burda & Petrovych 2012; Trentanovi & al. 2013; Protopopova & Shevera 2014).

In our and in other studies (Pryhod'ko & Chirkova 2009; Chirkova 2010; Stadnyk 2012) of the poorly forested regions, the PFP system is often seen as the only set of corridors for fragments of natural ecosystems and separated biotope connections. Depending on the type, size, condition, and other forestry and taxation characteristics, PFPs keep up the necessary forest environment for conservation of various species and migration of wildlife. Owing to the formation of ecotone habitats, PFPs have a considerable potential for preservation of typical and rare species of the flora and fauna. Therefore, in man-transformed landscapes, the PFP system with its various functional purposes should be regarded not only as the main frame of agroforestry and protection of soils and waters (Stadnyk 2012), but also as important structural element of the ecological network, as component for restoration of the plant integrity coverage of the territories. It is relevant to analyse their status and to be able to connect the separate units of this network.

To accomplish these tasks, it is necessary to investigate the state of the green zones and PFPs, to find out their vulnerability and degree of degradation. The vegetation of the Cherkasy region is to some extent typical for study of its anthropogenic transformation. For 70 years, its territory was affected significantly by a number of negative factors: dehydration of land for peat development, cattle grazing, erosion of slopes due to deforestation and ploughing, construction of the Kremenchug Reservoir in 1961–1965, recreation (plants damage, trampling of soils, unauthorized felling of trees, forest fires, spontaneous landfills), and aerotechnogenic pollution with phytotoxic substances that damage and weaken the forest ecosystems. All this leads to the spread and development of pests and diseases, phytoinvasions and restructuring of ecosystems (Lavrov & Pahomov 1996; Lavrov & al. 2016).

Industrial and in particular aerotechnogenic pollution of the environment is one of the strongest factors inhibiting the development of forest ecosystems (Kandler & Innesb 1995; Lavrov & Pahomov 1996; Bussottia & Ferrettib 1998; Alexander 2000; Bondaruk & Lavrov 2000; Jenkins & Parker 2000; McKinney 2006; Bradley 2010; Knapp & al. 2010; Fuller & Quine 2016; Ziganshin & al. 2017). In the Cherkasy region, during the economic crisis of the 1990s, some reduction in industrial emissions has contributed to the restoration of forest ecosystems damaged by phytotoxicants. However, with the renewal of industry and its development, the technogenic load on the natural environment has significantly increased. Thus, in 2015, 120.3 thousand tons of harmful substances (about

20 % of all national emissions) were discharged into the air of the region from all anthropogenic sources. The annual load of harmful emissions on the natural ecosystems of the region was 5.8 t·km^{-2}. Sulphur compounds were emitted in the amount of 14.3, NO_x – 17.9, dust – 9.6 thousand tons (Environmental passport of Cherkasy region for 2015, published in 2016). These substances have inhibited the development of tree species-edificators, have transformed the structural and functional organization of forest ecosystems, including PFPs (Bondaruk & Lavrov 2000; Lavrov 2003; Miroshnyk 2016). Degradation of these ecosystems was further accelerated by unauthorized felling and building, unregulated recreation, and other violations of environmental regulations and of nature conservation. All this has led to a decrease in sustainability, productivity and ecological role of these ecosystems, to violation and fragmentation of habitats of the various species, their migration, etc. (Lavrov 2003; Lavrov & al. 2016).

The increase in anthropogenic impact, deterioration of its control and regulation insistently call for improvement of the system of indicators for the assessment of state of the changed environment, transformed ecosystems and natural resources, in order to regulate the trends and to forecast their dynamics (Alexander 2000; Bradley 2010; Lavrov & al. 2016). However, the role of PFPs is still insufficient in preserving biodiversity and in maintaining the stability of landscape ecosystems as an object of monitoring the anthropogenic changes. As a rule, the structural and functional organization of linear plantations, as relatively young ecotone ecosystems, is in the process of formation and does not have a system of close obligate connections and co-adaptations of organisms yet. Therefore, it is important to study the changes in environmental conditions of the subcanopy space, with the grassy tier as an indicator (Tsaryk 2003; Petrovich 2012; Potter & Woodall 2012). There are few studies into the structure and dynamics of the state of the grass cover in PFPs, depending on the complex anthropogenic impact. It is well known though that this tier of phytocoenoses is the first to react to changes in the environmental conditions under the tree canopy (Lavrov & Pahomov 1996; Bondaruk & Lavrov 2000; Jenkins & Parker 2000; Bomanowska & Kiedrzyński 2011; Fagot & al. 2011; Didukh 2012; Rahmonov 2014; Khannanova 2015; Lavrov & al. 2016). Monitoring of phytoindication of pollutants and other negative protracted anthropogenic impacts on the biosphere, and in particular the study of the ratio between ecotypes and biomorphs of plants in a cover structure, often reflects the environmental changes more precisely than any direct evaluation by various devices. This is due to the fact that certain taxonomic groups of plants react very quickly, variably and informatively (vegetation structure begins to change at small but chronic concentrations of pollutants or other minor anthropogenic factors). Moreover, they do it in an integrated manner: for the entire complex of different by nature and effect mechanisms and modes of action (Bondaruk & Lavrov 2000; Jenkins & Parker 2000; Mirkin & al. 2001; Jose 2012; Miroshnyk 2016; Lavrov & al. 2016; Huse & al. 2016; Vakhlamova & al. 2016). This allows us to draw conclusions about the integral response to complex ecosystem violations and to predict their changes (Lötscher & Köhm 1977; Lavrov 2003; Campione & al. 2012; Maltseva & al. 2017). Thus, the purpose of this study is to evaluate the structural changes in the grassy tier of protective forests, depending on the intensity of anthropogenic influence.

Material and methods

According to forestry zoning, the research area belongs to the second forest area of the southeastern part of the Right Bank Forest-Steppe Region of Ukraine and is located in the Forest-Steppe Forestry Region. Protective forest plantations grow on podzolic chernozem, typical chernozem low-humus, and meadow-chernozem soils, violated in different degree by urbanization (Lavrov & Pahomov 1996). According to geobotanical zoning of the territory of Ukraine (Geobotanical zoning ... 1977), Cherkasy region is part of the Euro-Siberian Forest-Steppe Region, East-European Province, Middle Pridneprovye and Left Bank Pridneprovye subprovinces. The region is one of the main ecocorridors of the National Ecological Network of Ukraine. The studies concentrated in the southeast direction of the prevailing winds, along the Cherkasy (49°25'13.4"N 32°03'12.1"E) – Chyhyrin (49°04'30.8"N 32°39'17.0"E) motorway, at a distance 0–25 km from the industrial zone of the city of Cherkasy, in the zone of intensive and average aerotechnogenic impact on forests (Miroshnyk 2010) (Fig. 1).

Seven field-protecting, wind-regulating forest belts, 50–85 years old, on unirrigated agricultural

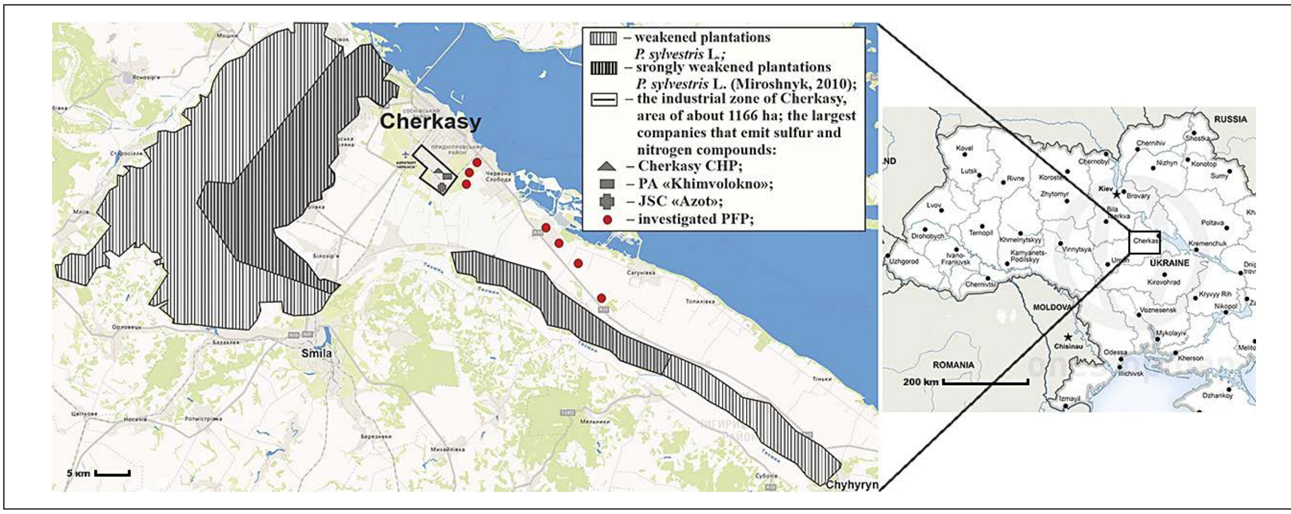

Fig. 1. Location map of Ukraine showing the Middle Pridneprovye Right Bank and distribution of seven studied forest stands.

land in the plain were the object of study. Their damage is seen visually, owing to the prolonged accumulation of negative impacts. According to the principles of comparative ecology and phytoindication, in 2013 we chose trial plots (TP; 0.20–0.25 ha each) at a different distance from the industrial zone of the city (2.0, 2.1, 2.3, 9.0, 12.5, 14.2, 25.0 km) (Table 1). More than 200 trees were examined in each plot. The five major PFPs of the eco-profile (TP 1, 4, 5, 6, 7) were most consistent with the principle of identity. They were similar in structure or construction (dense, 7–10 rows in the understorey) and in taxation (the same main species *Quercus robur* is part of the storey 3–6 units; *Sambucus nigra* and *Acer tataricum* dominate in the understorey). However, the associated species were different, especially in TP5 and TP6. In

Table 1. Characteristics of protective forest plantations in trial plots TP1 – TP7.

Indexes of evaluation	The value of PFP indexes depending on the distance (T) to the industrial zone of Cherkasy city, km						
	2.0 TP1	2.1 TP2	2.3 TP3	9.0 TP4	12.5 TP5	14.2 TP6	25.0 TP7
Number of rows, pcs	10	1	4	8	9	7	7
Species composition of the main canopy	3Qr4 Fe3 Ul	8Pn 2Aps	10Qr singleCb	5Qr3Fe1 Tc1Aps single Ul	6Qr3 Pa1 FesingleApS	6Qr2 Ul 2 Ma single Crb	5Qr4 Fe 1Aps singleMa
Species composition of the understorey	8Sr 2At	10Sn	–	5 At5Sn	10Sn singleEe Ps	5Sr5Snод. AvMsCa	10Sn
PFP height, m	23.4±1.2	28.3±1.5	21.4±1.9	21.3±1.4	18.5±1.1	16.2±1.2	17.2±1.4
PFP width, m	20.0±1.4	4.0±1.9	6.0±1.5	21.0±1.7	14.0±1.5	13.0±1.4	16.0±1.5
Canopy density* P	0.9	0.5	0.5	0.6	0.7	0.8	0.8
Construction	dense	openwork	wind-blown	dense	dense	dense	dense
Index of Sanitary Condition (ISC)	2.5	3.0	1.7	2.1	2.1	2.9	1.4
Sanitary condition of stands	weakened	strongly weakened	weakened	weakened	weakened	strongly weakened	healthy
Tree mortality, % Dd	41.3±0.1	20.2±0.1	58.5±0.2	8.2±0.1	36.8±0.1	27.4±0.1	25.8±0.2
Species saturation of the grassy tier, pcs Sg	32	19	19	28	26	29	35
Index of Adventization, % (I_{Adv})	28.1	31.6	31.6	21.4	26.9	34.5	25.7
TPC, %	94.7±0.3	72.7±0.4	100.0±0.2	100.0±0.2	100.0±0.3	98.3±0.3	100.0±0.4

Notes: * – for single-row PFP – the crown density in a row; «–» no plants. The names of tree and shrub species: Aps – *Acer pseudoplatanus*; Qr – *Quercus robur*; Ap – *Acer platanoides*; Crb – *Carpinus betulus*; Fe – *Fraxinus excelsior*; Tc – *Tilia cordata*; Ul – *Ulmus laevis*; Pc – *Pyrus communis*; Ms – *Malus sylvestris*; Pn – *Populus nigra*; Pa – *Prunus padus*; S – *Salix* spp.; Ma – *Morus alba*; Cb – *Catalpa bignonioides*; At – *Acer tataricum*; Sr – *Sambucus racemosa*; Sn – *S. nigra*; Ee – *Euonymus europaeus*; Av – *Prunus armeniaca*; Ps – *Prunus spinosa*; Ca – *Corylus avellana*; TPC – total projection cover of the grassy tier.

the zone of intense pollution and forest belt degradation (up to 9 km), in addition to the components of the general ecological profile TP1, some PFPs different in structure and species composition were analyzed: a 4-row belt, almost without additional oak species, wind-blown plantation TP2 (10 Qr single Cb) and 1-row wind-blown forest belt of *Populus nigra* (TP3 – 8Pn2Aps) (Table 1). The task was to compare the features of their technogenic changes against the same ecological background.

Field studies of the TP ecoprofile were conducted by commonly used methods in forestry, ecology and botany (Mirkin & al. 2001; Didukh 2004). The tree species composition, construction, structure, and sanitary condition of PFPs were evaluated, depending on the spatial location of the tree stands in relation to the industrial zone of the city, taking into account their characteristics. The degree of damage to tree stands was evaluated according to the scale of sanitary rules (Sanitary rules... 1995, Appendix 3), summarizing the information within certain tree species, under certain tiers of the tree stand. Information was summarized for the tree types at certain stand levels. Several categories of the tree states were distinguished: I – without signs of weakening, II – weakened, III – severely weakened, IV – dying, V – fresh dead wood, VI – old dead wood.

The sanitary state of the stands was calculated as a weighted average index (Index of Sanitary Condition – ISC), according to the categories of tree condition determined by the assessment of each tree.

For mixed forest stands:

$$ISC = \frac{k_1(n_a + n_b \ldots + n_i) + k_2(n_a + n_b + \ldots n_i) + \ldots k_6(n_a + n_b + \ldots n_i)}{N},$$

ISC – Index of Sanitary Condition,
k1 – k6 – categories of the tree state (I - VI, for Sanitary rules... 1995; Appendix 3),
na, nb ... ni – number of trees of different species for each state category,
N – total number of trees.

The level of damage to the stands was determined by the Index of Sanitary Condition (ISC) (Table 2).

The degree of recreational influence was determined visually by the degree of clogging, trampling of territory and mechanical damage to trees.

Taking into account the forestry and taxation characteristics and the integral index of the PFP state, we investigated the PFP grassy tiers. Across the entire site of TP, 100 m long (at both marginal forest edges and within the forest belt), the species composition and projection cover of the grass tier were studied. The height of PFP was measured by an altimeter IU-1 M along the top line of the wood canopy formed by Kraft class I trees. We identified the plant taxa after Mosyakin & Fedoronchuk (1999), biomorphological structure after Serebrjakov (1962), and ecomorphic analysis after Tarasov (2012), with further references to *Ecoflora of Ukraine* (Didukh 2004). The degree of anthropogenic transformation was estimated by the therophytes/geophytes ratio and the TG-index (ITG), which was defined as a normalized ratio of the number of geophytes (biomorphs, plants which are sensitive to anthropogenic impact) and therophytes in the species composition, within a range [-1; 1] (1).

Table 2. Sanitary condition of forest stands (Lavrov 2003).

Index of Sanitary Condition	Level of damage	Condition of forest stands
1.00–1.50	no damage	healthy
1.51–2.50	low	weakened
2.51–3.50	average	severely weakened
3.51–4.50	severe damage	dying
4.51–6.00	very severe damage	dead

$$ITG = (G - T) / (G + T), \quad (1),$$

where T, G is the proportion of therophytes and geophytes in the species composition (Goncharenko 2017). The value of the TG index for natural coenoses was positive, since the ratio of therophytes/geophytes exceeded 1, and, conversely, for synanthropic coenoses the TG index was negative.

The types of environmental strategies were described according to Ramensky-Grime (Grime 1977). The life forms of plants followed Raunkiaer (Raunkiaer 1934, Mirkin & al. 2001). The projection cover of species was assessed on the scale of Mirkin & al. (2001). The index of adventization was calculated as a share of alien species in the total number of species within a particular test plot (Burda 2007).

Statistical analyses

For the assessment of plant biodiversity, various methods and indexes have been available. In this study, the indexes of correlation, diversity, dominance, and equalisation were used for each trial plot (Magurran 2004) (2–7):

1. Relative abundance of species or guild
   $p_i = N_i / N$ (2)
2. Indexes of dominance:
   $Dm = (N - U) / (N - \sqrt{N})$; $U = \sqrt{\Sigma Ni^2}$ McIntosh (3)
3. Indexes of diversity
   $$H' = -\sum_{i=1}^{k} p_i \log_2 p_i \text{ Shannon} \quad (4)$$
   $DMn = S / \sqrt{N}$ Menchinick (5)
   $DMg = (S - 1) / \ln N$ Margalef (6)
4. Indexes of evenness
   $Ep = H' / \lg S$ Pielou, (7)

where Ni is density of the species in communities, N is the total number of individuals (the number of individuals per hectare), U is the McIntosh index of diversity, p_i is the ratio of each species, S is the total number of the species, and H' is Shannon's index of diversity.

The degree of phytocoenotical and floristic similarity of the grass layer of PFPs was determined by Glison and Jaccard coefficients. According to Koch's Biotic Dispersion Index (IBD), floristic similarity of a number of descriptions was evaluated, and the population homogeneity level, belonging to the same association, was ascertained according to (8):

$IBD = [(T - S) / (n - 1) S]\, 100$, (8)

where S is the total number of species in the descriptions; $T = S_1+S_2+S_3+\ldots+S_n$, where $S_1 - S_n$ is the number of species in each description (from 1 to n).

Results

Compared to massive forests, forest shelterbelts have a linear shape with relatively narrow plantations. Therefore, they differ significantly by the environmental factors that determine their development, and, accordingly, the species composition of the grassy tier. Specific features of the PFP construction, their microclimate and their proximity to other ecosystems (mainly agrarian and transport) explain the high species saturation and the total projection cover of the herbal species. During earlier studies (Lavrov & Pahomov 1996; Miroshnyk 2016), it was found that in the Cherkasy region, the aerotechnogenic effect of phytotoxicants on forest plantations extends in the south-east direction, at a distance of 25 km from the industrial zone.

The examined plantations were with or without understorey, weakened and strongly weakened, and with canopy density of 0.5–0.9 (Table 1). Tree mortality varied within 8–41 %. With the increase of distance from the industrial zone, tree mortality decreased 1.5 times, which reduced heliophilization under the canopy and increased mesophytisation.

Modern floristic researchers usually pay great attention to the 10 leading families, which reflect the main properties of the flora and represent most of the families' spectrum. In the herbal cover of the investigated PFPs, we have identified 76 vascular plants belonging to 27 families and 64 genera. In the distribution of species between the classes, *Liliopsida* accounted for 17.1 %, *Magnoliopsida* for 82.9 %, the total ratio of the species *Liliopsida* : *Magnoliopsida* was 1:5 and varied from 1:4 to 1:8. Representatives of *Polypodiopsida* and *Bryopsida* classes have not been detected during our PFP studies. *Asteraceae* (21 species or 27.6 % of all species) rated first among the 10 leading families of herbal plants, as in most Holarctic flora (Zaverukha 1985; Tarasov 2012) (Table 3).

Such a high position of the family is typical in almost all natural flora of the world, including the synanthropic flora of Ukraine (Protopopova & al. 2006; Protopopova & Shevera 2014). In the area of Cherkasy city, the species of this family dominated (14.5 %) in the plantation, which was 25 km off the industrial zone. Second rates *Poaceae* (10 species, 13.3 %), followed by *Brassicaceae* with 5 species, or 6.7 %; and *Geraniaceae*,

Table 3. Spectrum of the leading families and genera in the grassy tier of the protective forest plantations.

Place	Family	Genus		Species		Place	Genus	Number of species	%*
		Number	%*	Number	%*				
1	*Asteraceae*	17	27.0	21	28.0	1	*Viola*	3	4.0
2	*Poaceae*	9	14.3	10	13.3	1	*Urtica*	3	4.0
3	*Brassicaceae*	5	7.9	5	6.7	2	*Artemisia*	2	2.7
4	*Caryophyllaceae*	3	4.8	3	4.0	2	*Senecio*	2	2.7
5	*Apiaceae*	2	3.2	2	2.7	2	*Sonchus*	2	2.7
5	*Convolvulaceae*	2	3.2	2	2.7	2	*Taraxacum*	2	2.7
5	*Euphorbiaceae*	2	3.2	2	2.7	2	*Euphorbia*	2	2.7
5	*Geraniaceae*	2	3.2	3	4.0	2	*Geranium*	2	2.7
5	*Polygonaceae*	2	3.2	2	2.7	2	*Plantago*	2	2.7
6	*Urticaceae*	1	1.6	3	4.0	2	*Poa*	2	2.7
6	*Violaceae*	1	1.6	3	4.0				
7	*Plantaginaceae*	1	1.6	2	2.7				
7	*Lamiaceae*	2	3.2	2	2.7				
	Total	**63**		**75**					

Note: %* – share of the total number of taxonomic units.

Caryophyllaceae, *Urticaceae*, *Violaceae* with three species each, or 3.9 %. Five families comprised two species, or 2.6 % and 15 families had one species (1.3 %). Among them were: rare (*Apocynaceae*, *Vincetoxicum hirundinaria*), untypical (*Typhaceae*, *Typha latifolia*) and typical, especially *Rosaceae* (*Geum urbanum* L.), which is always a large family in the forest-meadow phytocoenoses. The first seven families with the highest number of species accounted for 56.6 % (43 species) of the total number of species. *Poaceae* and *Brassicaceae* rated second and third in the spectrum (total 13.2 %). The ratio of the families *Asteraceae*/*Brassicaceae* (4.2:1) indicated anthropogenic disturbance of the region. In the systematic structure of the flora of Cherkasy-Chyhyrin geobotanical region (Gajova 2015), ten leading families claimed different percentage in the phytocoenoses: *Asteraceae* – 11.5 %, *Poaceae* – 8.2 %, *Brassicaceae* – 5.4 %, *Caryophyllaceae* – 5.4 %, *Fabaceae* – 5.2 %, *Cyperaceae* – 4.7 %, *Lamiaceae* – 4.5 %, *Scrophulariaceae* – 4.5 %, *Rosaceae* – 4.4 %, and *Ranunculaceae* – 3.6 % (Table 4). The family *Fabaceae* was not represented in the studied ecological profile. Domination of the *Poaceae* family is typical for most of the Holarctic flora and the flora of Ukraine. The fourth place of *Caryophyllaceae* and the seventh place of *Lamiaceae* family testify to the links between the studied flora with ancient Mediterranean area. Ten of the leading families did not include *Ranunculaceae* and *Cyperaceae*, which are typical for the boreal flora (Shelyag-Sosonko & al. 2002). It indicates a significant anthropogenic disturbance of the systematic structure.

Table 4. Comparative spectra of the leading families from different floras.

Family name	Place of family in the flora							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Asteraceae	1	1	1	1	1	**1**	1	1
Poaceae	2	3	3	2	2	**2**	2	2
Fabaceae	3	2	4	4	5	–	3	3
Brassicaceae	9	5	2	6	3	**3**	5	4
Caryophyllaceae	18	6	9	5	4	**4**	4	6
Lamiaceae	6	8	5	7	7	**7**	2	5
Apiaceae	10	10	6	11	+	**5**	12	9
Cyperaceae	4	11	–	10	6	–	+	11
Rosaceae	8	4	–	3	9	–	11	7
Chenopodiaceae	19	–	7	18	+	+	+	12
Scorphulariaceae	5	7	8	9	8	+	4	10
Boraginaceae	16	–	10	12	+	–	–	13
Ranunculaceae	17	9	–	14	10	+	3	8
Polygonaceae	25	–	–	14	–	**5**	4	15
Euphorbiaceae	12	–	–	16	–	**5**	+	+
Convolvulaceae	+	–	+	–	–	**5**	–	-
Geraniaceae	+	+	+	–	+	**5**	–	-
Urticaceae	–	+	–	+	+	**6**	+	-
Violaceae	–	–	–	+	–	**6**	+	+
Plantaginaceae	–	–	–	–	–	**7**	+	14

Notes: Floras: 1 – Holarctic (Khokhryakov 2000); 2 – Ukraine (Didukh 2004); 3 – Synanthropic Ukraine (Protopopova & al. 2006); 4 – Northern Bukovina (Termena & al. 1992); 5 – Cherkasy-Chyhyrin geobotanical district (Gajova 2015); **6 – PFP in the district of Cherkasy city**; 7 – The valleys of the river Tyasmin (Lavrov & al. 2016); 8 – Left Bank Forest-Steppe of Ukraine (the regional Gadyatsky Landscape Park (Poltava region, Ukraine) (Khannanova 2015); "–" below the 20th place; "+" below the 15th place.

The phytocoenoses contained a few representatives of the family *Rosaceae*, which was not even in the spectrum of the leading families. Low presentation of this family was characteristic of the synanthropic flora of Ukraine. On the other hand, in the flora of the boreal region (Shelyag-Sosonko & al. 2002) and Ukraine, this family was among the first five leading families, which indicated violation of the environmental and plant cover of the protective plantations. *Urticaceae* and *Violaceae* rated sixth and *Plantaginaceae* seventh in the family spectrum of the studied PFPs. These families were not typical of the 10 leading families of comparable flora (Table 4). *Apiaceae* in the PFPs rated rather high, in the fifth place, which ran contrary to the listed flora and was close to the synanthropic flora of Ukraine. *Polygonaceae*, *Euphorbiaceae* and *Convolvulaceae* rated fifth in the PFPs, whereas in other floras they were not even listed among the first twenty families.

The spectrum of the taxonomic rank of families reflected the most important features of the flora, while the taxonomic units of the lower ranks were more relevant to the environment (Tolmachev 1974). In the spectrum of genera, the highest species diversity was exhibited by *Urtica* and *Viola* (three species, or 7.9 %). The other genera were represented by 1–2 species. This testified to changes in ecological conditions and an uncommon order spectrum of the plant cover (Table 3). The farther the industrial zone was, the higher the total projection cover and the species abundance were. This was probably due to reduction of aerotechnical contamination, as well as to changes in ecological conditions in the phytocoenoses, depending on the structure of PFP and/or unauthorized particular deforestation.

Taking into account that the systematic structure of the studied plantations was imbalanced, it was necessary to analyze the relationship between plant biomorphs, as a result of a complex set interaction of external environmental factors and the evolutional, physiological and biochemical adaptations of plants (Tsaryk 2003). The biomorphological spectrum of herbaceous plants indicated the adaptations of vegetation to anthropogenic changes in the investigated area (Table 5). We have found that annual species were the most common at a distance up to 2 km from the industrial zone (58 % of the total species), biennial plants constituted 10 % in all the PFPs on the average, and at a distance up to 25 km, abundance was reduced by 12 %. Analysis of the shoots structure was used as a characteristic of the habitats and generally showed that species without rosette dominated (*Artemisia absinthium*, *Achillea submillefolium*, *Sonchus oleraceus*). The rosette species accounted for about 10–26 % (*Lactuca serriola*, *Taraxacum officinale*, *T. serotinum*, *Geum urbanum*, *Erodium cicutarium*, etc.). Creeping species and species with creeping shoots similarly accounted for 5–10 % (*Apera spica-venti*, *Poa pratensis*, *Koeleria cristata* and *Convolvulus arvensis*, *Galium aparine*, *Glechoma hederacea*). Species without underground shoots dominated in number, second came species with long rhizomes (21–42 %; *Aristolochia clematitis*, *Chelidonium majus*, *Lycopus exaltatus*). This proportion indicated sufficient moisture in the upper root-bearing layer of soil under the PFP canopy.

We have evaluated the type of vegetative mobility of plants (the rate of vegetative reproduction) as an integral indicator of the species stability in the phytocoenoses, a background for its capability to capture and maintain a living space (Ramenskij 1971). In the PFP ecoprofile, dominated the vegetatively immobile species (42–69 %; *Thlaspi arvense*, *Agrostemma githago*, *Urtica*

Table 5. **Life forms structure of the grassy tier of the protective forests.**

Signs of life forms	Distance to industrial zone, km						
	2.0	2.1	2.3	9.0	12.5	14.2	25.0
	Sanitary condition of forest stands*						
	II	III	II	II	II	III	I
	Percentage of species, %						
Lifecycle duration							
Annuals	43.7	36.8	57.9	39.3	53.8	51.7	37.1
Biennials	6.3	15.8	0	10.7	7.7	10.4	8.6
Perennials	50.0	47.4	42.1	50.0	38.5	37.9	54.3
Structure of overground shoots							
Creeping	15.6	5.3	5.3	7.1	7.8	3.5	8.6
Rosellate	18.8	26.3	10.5	14.3	19.2	27.6	17.1
Unrosellate	59.3	57.9	78.9	71.4	69.2	58.6	65.7
Sod grass	6.3	10.5	5.3	7.2	3.8	10.3	8.6
Structure of underground shoots							
Long rhizome	34.4	42.1	21.1	35.7	23.1	24.1	34.3
Short rhizome	15.6	15.8	10.5	7.1	7.7	13.7	11.4
Roots sprouts	0	0	0	3.6	0	3.4	2.9
Without formations	50.0	42.1	68.4	53.6	69.2	58.6	51.4
Type of root system							
Taproot	75.0	73.7	73.7	67.9	73.1	75.9	71.4
Fibrous	25.0	26.3	26.3	32.1	26.9	24.1	28.6
Type of vegetative mobility							
Vegetative mobility	31.3	36.8	31.6	25.0	19.3	27.6	34.3
Vegetative semi-mobility	12.4	21.1	10.5	10.7	11.5	17.2	5.7
Vegetative immobility	56.3	42.1	57.9	64.3	69.2	55.2	60.0
Climamorphs (Raunkiær plant life-form)							
Therophytes	43.8	42.1	63.2	50.0	65.4	51.7	45.7
Chamaephytes	0	0	0	0	0	3.4	0
Hemicryptophytes	28.1	26.3	10.5	10.7	11.5	27.6	25.7
Hydrophytes	0	5.3	0	0	0	0	0
Gelophytes	3.1	0	0	0	0	0	0
Geophytes	25.0	26.3	26.3	39.3	23.1	17.3	28.6
Therophytes / Geophytes	1.8	1.6	2.4	1.3	2.8	3.0	1.6

Table 5. **Continuation.**

Signs of life forms	Distance to industrial zone, km						
	2.0	2.1	2.3	9.0	12.5	14.2	25.0
	Sanitary condition of forest stands*						
	II	III	II	II	II	III	I
	Percentage of species, %						
ITG	-0.3	-0.2	-0.4	-0.1	-0.5	-0.5	-0.2
Heliomorphs							
Heliophytes He	65.6	68.4	52.6	60.7	53.8	62.1	60.0
Sciophytes Sc	3.1	0	0	0	3.8	0	0
Heliosciophytes ScHe	31.3	31.6	47.4	39.3	42.4	37.9	40.0
Hygromorphs							
Xerophytes	12.4	10.4	10.5	10.6	7.8	6.9	11.4
Mesophytes	43.8	47.4	52.6	53.6	42.3	51.7	57.1
Higromosophytes	9.4	15.8	15.8	10.7	19.2	13.8	8.6
Mesogigrophytes	12.5	10.5	10.5	0	3.8	6.9	5.7
Xeromesophytes	9.4	5.3	5.3	17.9	15.4	6.9	11.4
Mesoxerophytes	3.1	5.3	0	3.6	7.7	10.3	2.9
Gigrophytes	9.4	0	5.3	3.6	3.8	3.5	2.9
Hydrophytes	0	5.3	0	0	0	0	0
Trophomorphs							
Oligotrophy	6.3	5.3	0	3.6	7.7	10.3	5.7
Mesotrophy	46.9	42.1	36.8	42.9	50.0	41.4	51.4
Megatrophy	46.8	52.6	63.2	53.5	42.3	48.3	42.9
Potassiumphiles	0	0	5.3	0	3.8	0	2.9
Nitrophiles Nt	43.8	42.1	42.1	28.6	38.5	31.0	25.7
Tsenomorphs (Belgard)							
Silvants Sil	12.5	10.5	10.6	14.3	11.6	3.5	22.8
Pratants	12.5	10.5	0	3.6	7.7	3.4	2.9
Steppants	6.3	5.3	10.5	7.1	11.5	10.3	14.3
Paludants	3.1	0	0	0	0	0	0
Ruderals Ru	65.6	73.7	78.9	75.0	69.2	82.8	60.0
Adventive Advt	28.1	31.6	31.6	21.4	26.9	34.5	25.7

Notes: * I – healthy, II – weakened, III – severely weakened forest stands.

urens, *Poa annua*, *etc*.). This means that the species have adapted to the existing ecological conditions and special microclimate under the tree canopy and the vector of plants migration from adjoining territories to places under the canopy. This also means that seeds spread from PFPs. Climamorphic analysis showed that therophytes (*Ambrosia artemisifolia*, *Arctium lappa*, *Galinsoga parviflora*, *Stenactis annua*, *Chenopodium album*, *Galium aparine*) predominated in the eco-profile (especially in the central part of the eco-profile TP4-TP6) and amounted to 42–65 %, which was almost twice higher if compared to hemicryptophytes. This contradicts the data about prevalence of hemicryptophytes in the Cherkasy-Chyhyrin geobotanical region (Gajova 2015; Lavrov & al. 2016).

Geophytes (*Elytrigia repens*, *Artemisia vulgaris*, *Lactuca serriola*, *Sonchus arvensis*) came second (17–29 %), hemicryptophytes (*Calystegia sepium*, *Juncus inflexus*, *Oenothera biennis*, etc.) third and their number slightly increased with the distance from the industrial zone. A significant prevalence of therophytes indicated anthropogenic intrusion in the habitats. The ratio of therophytes/geophytes was the highest within the ecological profile, the ITG was negative, which means that phytocoenoses were very synanthropic (Goncharenko 2017). The dynamics of the ITG (approximation to positive values at a distance of 25 km from the city's industrial zone) indicated a decrease of synanthropic processes. Distribution of heliomorphs has shown domination of heliophytes (*Polygonum aviculare*, *Elytrigia repens*, *Poa pratensis*, *Galium aparine*); in TP2 they were dominant (2.1 km from the industrial zone, 68.4 %). The number of heliophytes decreased with the distance from the industrial zone, which indicates an increase in the crown density of the PFP tree canopy and means that their condition has improved.

The percentage of heliosciophytes (*Oenothera biennis*, *Rumex acetosa*, *Urtica dioica*) varied between 31–47 %. A remarkable role in the distribution of hygromorphs belonged to mesophytes (*Plantago major*, *Urtica urens*, *Elytrigia repens*) (42–57 %) and to hygromesophytes (8–19 %) (*Lepidium ruderale*, *Stellaria media*). The number of mesophytes increased 1.3 times with the increase of distance from the industrial zone.

According to the ratio of trophomorphs, as characteristics of the edaphic mode, megatrophs substantially dominated in the suburban part of the eco-profile (up to 63 %) (*Artemisia absinthium*, *Senecio jacobaea*, *Chelidonium majus*, *Galium aparine*). Their numbers diminished 1.5 times with the distance from the city. The increase of nitrophiles (*Geum urbanum*, *Ranunculus repens*, *Rumex acetosa*, etc.) in the suburban PFPs (2–3 km) up to 26–44 % indicates significant enrichment of soils with technogenic nitrogen, which is explained by the emissions from industrial enterprises, primarily from the private Azot Joint Stock Company, and from the fertilizers on the adjacent territories. At the most remote TP7 (25 km from the Cherkasy Industrial Agglomeration), the number of nitrophiles decreased 1.7 times. Also, the mesotrophs *Plantago major*, *Stellaria media*, *Capsella bursa-pastoris* and *Erodium cicutarium* claimed a significant proportion of the herbal phytocoenoses of PFP. With the increase of distance from the city, the biomorph ratio became close to the natural one by the trophy of soil.

Analysis of cenomorphs has shown domination of ruderals (60–83 %) and alien species (21–35 %), namely, *Ambrosia artemisifolia*, *Lactuca serriola*, *Sonchus arvensis*, *Chelidonium majus*, *Galium aparine*, and *Capsella bursa–pastoris* in the ecoprofile. With the increase of distance from the industrial zone, the number of silvants and steppants has increased 1.8 and 2.3 times respectively, while the number of pratantes decreased 4.1 times. Typical silvants and silvant-pratants appeared in the remotest PFPs (14 and 25 km) from the enterprises: *Geranium sylvaticum*, *Hieracium pilosella*, *Viola mirabilis*, *V. canina*, and *V. hirundinaria* (projection cover is 0.5-2 %). In the forest strips separated from the industrial zone some 19–25 km, we have identified two species protected by the Bern Convention: *Dracocephalum ruyschiana* and *Jurinea cyanoides* (projection cover 0.5–3 %). The regionally rare species *Pyrola rotundifolia* occured singly.

Dominance of ruderal species in the structure of the herbaceous layer of PFP indicated a significant anthropogenic impact on the PFP of this zone. Amphibian plants were found only near the city (TP1-TP2): *Lycopus exaltatus*, *T. latifolia*. Significant development of the alien species in the ecoprofile (23 species, 30.3 %) indicated a secondary anthropogenic transformation of the ecotopes, which has notably increased as compared to 1994 data (Lavrov & Pahomov 1996). *Asteraceae* claimed the greatest share of the adventitious fraction: seven species (30.4 % of all alien species). Invasive North American species dominated among them: *Ambrosia artemisifolia*, *Erigeron canadensis*, *Galinsoga parviflora*, *S. annua*, *Cannabis ruderalis*, *Oenothera biennis,* etc. However, the Index of Adventization – the resistance index of the ecosystem to phyto invasions (Burda 2007) – of the surveyed plantations almost did not exceed the generalized data on the coenosis of the Dnieper Forest-Steppe Floodplain (29-33 %) (Protopopova & al. 2006) (Table 1).

Consequently, analysis of the biomorphological spectrum of the herbaceous cover of the investigated PFP in the district of Cherkasy has indicated high species diversity of this phytocoenotic tier. A significant proportion in its structure went to ruderals, especially alien species and damaged distributions by cenomorphs. That indicated a substantial spread of cultivated plant seeds (*Secale cereale*) and weeds (i.e. *Avena fatua*, *Apera spica-venti*, *Elytrigia repens* from agricultural lands, and silvantes (*Inula helenium*, *Angelica sylvestris*, *V. hirundinaria*, *Geranium sylvaticum*) from the closest forest areas. Plant attachment to a certain ecotope reflects the type of its ecological strategy in the phytocoenosis. As it is well known, the species strategy is variable within the ontogeny of the individual (Grime 1977; Mirkin & al. 2001). We have found that species of the transitional groups of the ecological strategy dominated the ecological profiles (Fig. 2). For instance, plants with CR-strategy (26–53 %) (i.e. *Ambrosia artemisiifolia*, *Artemisia vulgaris*, *Arctium lappa*, *Senecio jacobaea*, *Angelica sylvestris*). Plants with R-strategy (*Stenactis annua*, *Calystegia sepium*, *Cannabis ruderalis*, *Oenothera biennis*, *Polygonum aviculare*) came second in numbers. These numbers decreased 3.3 times with the increase of distance from the city, while the CS-strategists (*Rumex acetosa*, *Dactylis glomerata*, *Juncus inflexus*, *Geum urbanum*) increased 1.4 times. This tendency reflects a greater environmental disturbance under the canopy of trees near Cherkasy as a result of aerotechnogenic pollution and recreational impact (littering with household rubbish, network of trails), as well as the better condition of plantations with the increase of distance from the city.

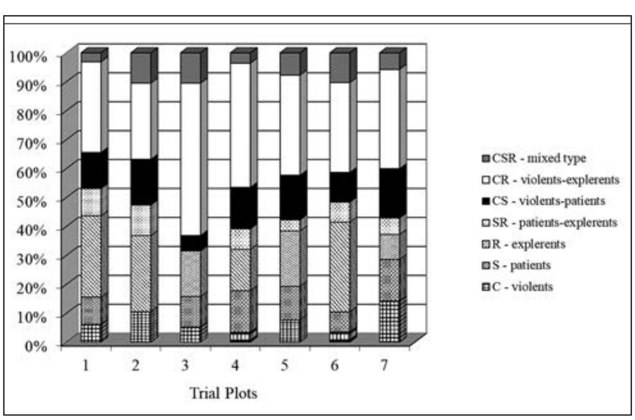

Fig. 2. Ecological profiles and types of strategies of the grassy tier species.

Dominance of explerents among the primary types indicated violation of the growth conditions of herbaceous species on the territory with industrial emissions (2–14.4 km from the industrial zone). The share of patients (*Aristolochia clematitis*, *Cynoglossum officinale*, *Capsella bursa-pastoris*, etc.) increased from 9.4 % to 14.3 % as a result of deterioration of their developmental conditions (variability of moisture, soil trophy, illumination), and intensification of interspecific competition with the increase of distance from the industrial zone. Around this zone, patients dominated over explerents in a fight for territory and other life resources. In more degraded areas (TP2-TP3), there was a tendency for increase from 3 % up to 10.5 % of the number of species with a mixed type of strategy (CRS) (*Achillea millefolium*, *Plantago major*, *Apera spica-venti*). The proportion of species in the eco-biomorph groups (phanerophytes + hamefites) / therophytes was 1.69 (Didukh 2012) in the cereal stage, which is closer to meadows. This is another indication of enormous grass transformation. Depending on the phytocoenosis violations (Didukh 2012), the ratio of patients/explerents, as different species strategy types in the grassy tier, was 0.42. This characterizes a motley-grass-pioneer stage of development closest to the urbosystems.

The number of sylvants, in turn, depended (r = –0.74) on the tree stand conditions index. They were displaced by heliophytes (r = 0.68), alien species (r = 0.52) and ruderals (r = 0.47). The share claimed by all mixed strategies, in turn, depended (r = –0.81) on the closeness of the tree canopy as a result of forest ecosystem destruction.

Diversity indexes of the grassy tier reflected the anthropogenic changes under the canopy of trees in PFPs (Fig. 3). According to Margalef, Menhinick and McIntosh indexes, phytodiversity directly depended on the distance from the industrial zone of Cherkasy (r = 0.67) and the closeness of the tree canopy (r = 0.88). Diversity of these plants was approaching its maximum in the most remote TP7 (25 km off the industrial zone). Furthermore, phytodiversity indexes

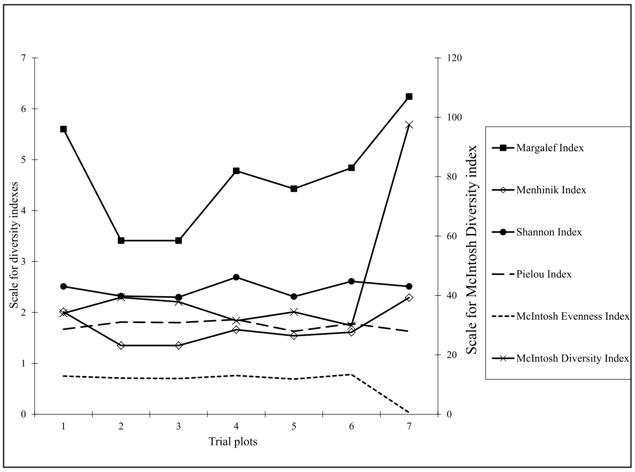

Fig. 3. The value of phytodiversity indexes in the trial plots.

rose with the increasing number of steppants and forest species and a significant decrease of ruderals and alien species in the herbaceous cover. Along with this, complexity of phytodiversity in the trial plots, as distribution of the individuals by species (McIntosh and Pielou indexes), showed opposite tendencies of certain species domination.

It was found out that the Shannon index reaches its maximum (2.6–2.7) at a distance of 9 to 14 km from the industrial zone, and its minimum (2.3) at a distance of 2.0 and 12.5 km. However, generally all TP showed high phytodiversity due to the ecotone effect. Koch's biotic dispersion index, which reflects the degree of homogeneity of the populations belonging to the same association, was 25.1 % and indicated slight similarity of herbaceous vegetation in the ecological profile.

Analysis of floristic and phytocoenotic similarity by the coefficients of Jaccard (KJ) and Glisone (KG) of the PFP grassland showed independence of general species saturation (Table 1) and floristic similarity (Table 6) with the increase of distance to the industrial zone, regardless of changes in the grass cover. Although representation of some species and families was notably different, certain equilibrium has been established at this stage of anthropogenic changes, when the loss of some species is offset by the invasion of others. The relatively low coefficients of Jaccard (2.0–24.1 %) in the upper line of the matrix apparently was a consequence of the ecosystem engineering effect of the tree canopy (Table 6). In the middle of the matrix, KJ was 30–45 % and increased with the distance from the industrial zone to an average of 7 %. Consequently, the similarity of the PFP grass covers increases with the higher numbers of identical types of ruderals. Rise of Glyson's coefficient with the increase of distance from the enterprises producing phytotoxic substances indicated increase of the projection cover and participation of silvants in the herbage.

Table 6. Changes of Jaccard (KJ) and Glisone (KG) coefficients in herbaceous PFPs depending on distance from industrial area.

Distance from the Cherkasy industrial area, km														
	KJ, %							KG, %						
km	2.0	2.1	2.3	9.0	12.5	14.2	25.0	2.0	2.1	2.3	9.0	12.5	14.2	25.0
2.0	×	24.4	31.8	15.9	33.3	32.6	24.1	×	0.2	0.3	3.4	0.3	0.3	0.3
2.1		×	28.6	31.0	30.6	43.1	17.4		×	1.0	5.0	2.2	0.2	5.7
2.3			×	36.4	38.5	41.0	24.5			×	1.1	0.3	0.2	0.3
9.0				×	34.3	45.5	31.7				×	0.2	0.2	0.3
12.5					×	32.6	43.2					×	0.5	0.2
14.2						×	28.0						×	0.2
25.0							×							×

Recently, the problem of floristic contamination has arisen sharply, as a result of the introduction and expansion of alien species. These plant 'pollutants' lead to simplification and unification of the floristic composition, which means reduction of the ecosystem's sustainability to negative external influences (Burda & Petrovych 2012). Anthropogenic transformation of the flora works as a catalyst for the process of synanthropy, adaptation of plants to the modified environment because of human activity. The process of anthropogenic changes is accompanied by many undesirable consequences: elimination of certain plants species, impoverishment of flora in general, reduction of genetic diversity of some species, simplification of structure, and unification of the flora, decrease of vegetation productivity and stability (Protopopova & al. 2006; Burda & Petrovych 2012).

In order to estimate the level of anthropogenic transformation of the flora in the investigated PFPs, we have analyzed the composition of the alien species, determined their typological characteristics and prevalence. We have identified 13 alien species with high invasive capacity (Dudkin & al. 2003: 366-372): archeophytes (*Artemisia absintium*, *Capsella bursa-pastoris*, *Conium maculatum*, *Descurainia sophia*, *Setaria glauca*, *Sonchus arvensis*, *S. oleraceus*, *Tripleurospermum inodorum*); and kenophytes (*Acer negundo*, *Ambrosia artemisifolia*, *Cannabis ruderalis*, *Galinosa parviflora*, *Sisimbrium loeselii*). *Asteraceae* and *Brassicaceae* were recorded as the leading families of anthropophytes; North American species dominated by origin, archeophytes by the time of skidding, and epicophytes (species that were naturalized in transformed ecotopes) by the degree of naturalization. The ration of archeophytes to kenofytes was 1/0.6, which indicated dominance of the ancient settler species and insignificant number of contemporary settlers. Analysis of correlation has confirmed a number of identified trends. Thus, with the increase of distance from the industrial zone, we have observed an improvement in the condition of the stands (r = –0.46) (Table 7). Also, the number of nitrophiles has reduced, indicating a decrease in aerotechnogenic emissions of nitrogen. The canopy and the number of sylvants have increased, and the number of ruderals decreased; the values of biodiversity coefficients went up (Margalef, Menchinick, Shannon). A decrease in value of the Index of Sanitary Condition (ISC), the number of nitrophiles and ruderals, and an increase in number of sylvants were due to augmentation of the McIntosh Dominance Index. The increasing number of violents (C – strategists, plants forming the subcanopy environment, mainly dominants) made the silvants increase in number, ruderals decrease, and the value of the dominance index go up. The increase in the number of explerents (R-strategists that spread rapidly in highly disturbed ecotopes), caused an increase in the number of alien species and heliophytes, while the number of sylvants and the dominance index decreased. As the sum of the share of species of all mixed strategies (S *) went up, the canopy density, species saturation, and the number of explerents went down, indicating that the structure of the phytocoenoses was disturbed by approaching closer the industrial agglomeration. The number of stepants increased with the increasing distance from the industrial zone (r = 0.81) and with the decrease in number of explerents (r = –0.57), heliophytes (r = –0.65), and pratants (r = –0.61). The number of pratants has increased with deterioration of plantations (r = 0.58), increase in the number of explerents (R; r = 0.56), and increase in the number of heliophytes (0.65) and nitrophiles (r = 0.54).

Conversely, the closer to the city, the worse the condition of the plantations was: their liquefaction was greater and there were more adventitious species and heliophytes in the grass tier (r = 0.68). With the increase in the proportion of dead trees in the main canopy, the number of nitrophiles increased. The more alien species there were, the less was the number of silvants. The higher was the number of ruderals, the lower was the species saturation of the grass tier; and the more alien species there were, the lower was the number of silvants. With the increase of the Index of Sanitary Condition (deterioration of the plantation state), penetration of the alien species was more

Table 7. Correlation of parameters in the protective forest plantations.

	T	P	ISC	Dd	Sg	IAdv	TPC	He	Nt	Pt	St	Sil	Ru	DMg	DMn	Í′	Dm	C	R	S*
T	1.00																			
P	0.44	1.00																		
ISC	-0.46	0.01	1.00																	
Dd	-0.32	0.01	-0.28	1.00																
Sg	0.67	0.88	-0.27	-0.27	1.00															
IAdv	-0.26	-0.07	0.52	0.45	-0.42	1.00														
TPC	0.46	0.39	-0.65	0.26	0.50	-0.34	1.00													
He	-0.21	0.20	0.68	-0.53	0.15	0.12	-0.71	1.00												
Nt	-0.85	-0.24	0.36	0.61	-0.60	0.42	-0.45	0.07	1.00											
Pt	-0.40	0.29	0.58	-0.13	0.06	0.00	-0.58	0.65	0.54	1.00										
St	0.81	0.26	-0.70	0.25	0.38	-0.04	0.64	-0.65	-0.53	-0.61	1.00									
Sil	0.49	0.13	-0.74	-0.18	0.47	-0.70	0.18	-0.07	-0.39	-0.08	0.38	1.00								
Ru	-0.40	-0.46	0.47	0.06	-0.59	0.54	-0.05	-0.11	0.12	-0.37	-0.27	-0.85	1.00							
DMg	0.67	0.86	-0.33	-0.24	0.99	-0.43	0.46	0.16	-0.57	0.07	0.39	0.55	-0.66	1.00						
DMn	0.62	0.78	-0.42	-0.16	0.93	-0.43	0.36	0.18	-0.49	0.08	0.40	0.69	-0.78	0.97	1.00					
Í′	0.34	0.45	0.07	-0.61	0.65	-0.38	0.36	0.31	-0.69	-0.16	-0.07	0.06	0.06	0.60	0.46	1.00				
Dm	0.73	0.23	-0.63	-0.09	0.49	-0.25	0.13	-0.03	-0.52	0.27	-0.70	0.83	-0.70	0.57	0.71	0.01	1.00			
C	0.46	0.06	-0.32	-0.09	0.20	-0.11	-0.32	0.17	-0.14	0.16	0.37	0.70	-0.74	0.29	0.46	-0.36	0.84	1.00		
R	-0.48	0.23	0.92	0.06	-0.17	0.66	-0.44	0.54	0.49	0.56	-0.57	-0.81	0.44	-0.22	-0.32	0.01	-0.65	-0.41	1.00	
S*	-0.09	-0.81	-0.49	-0.06	-0.50	-0.33	0.10	-0.47	-0.17	-0.29	0.12	0.24	0.25	-0.47	-0.40	-0.13	0.06	-0.07	-0.68	1.00

Notes: S * – Share of species of all mixed strategies, % (sum).

intense (r = 0.52). The Margalef coefficient went up with the increase of distance from the city, thus boosting the canopy density, decreasing the number of nitrophiles, increasing the number of silvants, and lowering the number of ruderals.

Discussion

Analysis of the scientific publications has shown that increasing anthropogenic influence, including aerotechnogenic contamination, violate the structure of forest ecosystems and fragment them, reduce their productivity and stability, shorten their period of existence, which results in a significant decrease of forests ability to perform ecosystem functions (Lavrov 2003; Pöykiö & al. 2005; McKinney 2006; Knapp & al. 2010; Hodgson & al. 2011; Nagaike 2012; Gamfeldt & al. 2013; Lavrov & al. 2016; Livesley & al. 2016; Simmons & al. 2016). Of all structural elements of the forest ecosystem, the grassy tier is the most sensitive indicator of environmental changes. Therefore, anthropogenic transformation of the grass cover has attracted the attention of the scientific community. Disappearance of species typical for certain ecosystems and appearance of alien and ruderal species, which reduce biodiversity in general and violate the grass layer structure, are very important problems (Jenkins & Parker 2000; Richardson & al. 2000; Godefroid & Koedam 2003; Kuhn & Klotz 2006; Hahs & McDonnell 2007; Bradley 2010; Knapp & al. 2010; Lososova & al. 2011, 2012; Campione & al. 2012; Loeb 2012; Beckline & Yujun 2014; Moszkowicz 2014; Rahmonov 2014; Felipe-Lucia & Comín 2015; Baranovskij 2016; Fuller & Quine 2016; Huse & al. 2016; Schindler & al. 2016; Maltseva & al. 2017; Rat & al. 2017).

We have found that biological contamination of the grassy tier in PFPs around the city of Cherkasy by alien and ruderal species has significantly increased, due to the considerable anthropogenic impact (nitrogen pollution from industrial emissions and agrarian soils). However, it did not depend on the distance from the industrial zone, which indicated a greater impact of the adjacent ecosystems (agroagents and transport network), as compared to aerotechnogenic pollution. A phytodynamic analysis of the grass cover in PFPs testified that the complex anthropogenic pressures pointedly violate the development stability of forest ecosystems due to changes in the environment (a significant proportion of dry trees in forest strips up to 2 km from the industrial zone causes heliophytization under the tree canopy; the proportion of heliophytes was up to 70 %). The number of shade-resistant species was rising with the increase of distance from the city.

Thus, there were changes in the ecological regimes under the canopy of forest plantations due to more light because of the aerotechnogenic thinning out and elimination of damaged trees, as well as to the nitrogen input from industrial emissions in the city of Cherkasy and fertilizers from the adjacent fields. Along with this, changes in the edaphotopes cause restructuring of the taxonomic and systematic structure of the herbage, transformation of the coenotic relations and relations of the eco- and biomorph. The biomorphological spectrum is characteristic with high participation of heliophytes, mesophytes, ruderal species, anthropophytes, damaged plants, distribution by cenomorphic categories, domination of transitional type strategies, and explerents. Alien species are common in the studied area, although the Index of Adventization did not exceed the level of the floodplain coenoses in the Forest-Steppe Pridnieprovie (29–33 %). The dominating life forms are therophytes, which testify to anthropogenic disturbance of the location, and geophytes (Richardson & al. 2000; Gonrad & Romane 2005; Schindler & al. 2016). Along with this, Goncharenko (2017) pointed out the sensitivity of geophytes to recreational impact. The therophytes/geophytes ratio was the highest in the ecological profile. A negative ITG indicated notable synanthropy of the phytocoenoses. Seamless plants dominated by the structure of the aboveground shoots and the placement of leaves, plants that did not have specialized modification dominated by underground shoots. The share of rhizomatous species grew in the anthropogenically stronger transformed areas. Megatrophs and nitrophiles predominated among the trophomorphs. Their number decreased with the increase of the distance from industrial zone, which pointed out to technogenic violation of the nitrogen regime.

Confinement of plants to a certain ecotope reflects the type of their environmental strategy (Grime 1977; Mirkin & al. 2001). In the last stages of anthropogenic transformation, the species with transitional and mixed types of strategies dominated regularly (Godefroid & Koedam 2003; Prevosto & al. 2011;

Huseinova & al. 2013; Lavrov & al. 2016). Explerents dominated among the species with the primary type of environmental strategy.

The maximum spatial diversity was typical for the most remote areas of the city. Due to the small width of the PFPs, their linear configuration and laziness of crowns of trees and canopies owing to the aerotechnogenic liquefaction of the stands, there was a mix of vegetation from the agrarian landscapes (field weeds and agricultural plants) and forestlands (forest grass species). Owing to this, the saturation, projection cover and the number of indigenous species were quite high. Along with this, the similarity index of vegetation was lower, which indicated an expressed disturbance and instability of these ecosystems. Results from the study of the PFP grassy tier structure make it possible to conclude that the degree of transformation of phytoremediation is closely connected with the qualitative and quantitative composition of the ecomorphs, and the indexes of biodiversity depend on the intensity of anthropogenic influence. Beckline & Yujun (2014) have found that, owing to the increased recreational impact, the generalized measure of phytopathogenicity was meaningfully reduced. According to our data, the same processes are typical of the forest ecosystems affected by aerotechnogenic contamination (Lavrov & al. 2016). All this requires further research into the issues of fluctuations and time dynamics of certain system-specific factors and forecasting of scenarios (directions, algorithms and mechanisms) for successional vegetation development under the conditions of system-based (determining) factors change. The applied synecological approaches permit integration of the effects of overlaying the properties and characteristics of anthropogenic limiting factors on the fluctuations and time dynamics of the ecological background of certain territories. This information will contribute to the aggregation and synecological determination of causal relationships during the diagnosis of the ecosystem condition as consequence of the anthropogenic environmental disruption.

Conclusions

Thus, violation of the ecological conditions of PFPs in agricultural landscapes around Cherkasy is due to human activity and leads to significant changes in the various structures of the phytocoenoses. The correlation of types and groups of grass species – as bioindicator of forest ecosystem violations – points out to a significant anthropogenic transformation. The main features of changes in the grassy tier are: restructuring of the taxonomic and systematic structures, heliophilization, mesophytisation, synanthropization, expansion of ruderals and alien species, explerents, displacement of species-patients, intense retention, suppression of the natural renewal and development of trees. The generalized measure of phytodiversity is maximum at the longest distance (25 km) from the emittant-enterprises of phytotoxic substances, which testifies to a greater influence of the adjacent agroagents and transport roads.

Our results indicate that it is necessary to carry out a study into the vegetation succession in the transformed territories, taking into account its natural features and dynamics of the environmental factors. Anthropogenically degraded protective forest belts could not perform properly the functions of ecological network corridors and fulfill promptly their main role as regulators of ecological factors, protectors and stabilizers of the landscape components. They would only partly ensure conservation of biodiversity. In order to preserve biodiversity, increase productivity and sustainability of the ecosystems, it will be necessary to prevent unjustified fragmentation of the habitats, degradation of the protective forest stands, which are important connecting elements of the local ecological network, especially in the less-forested landscapes. It will be important to predict scenarios (directions, algorithms and mechanisms) for successional vegetation development under the conditions of change of determining factors. In the future, it is recommendable to focus on the impact on fragmentation of the protective forests, on structure and composition of the grass cover.

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