# SYN-ECOLOGICAL CONNECTIONS AND COMPARISON OF Α-DIVERSITY INDICES OF PLANT AND BIRD COMMUNITIES ON CULTIVATED COENOSISES

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## ABSTRACT

Changes in the ecological conditions of the cultivated coenosises caused by anthropogenic load have been shown by the example of several of the largest botanical gardens in Ukraine. That complex influence leads to the transformation of coenosises at stages II and III of anthropogenic degression. Changes in phyto- and avidiversity compositions have been shown using a transformation gradient. Positive correlations between compositions and diversity indices of bird communities and vegetation composition (diversity indices, dominance indices, evenness indices) have been detected. The values of the phytodiversity indices showed greater deviation from the normal conditions.

**Keywords:** phytobiota, avifauna, anthropogenic impact, indices of diversity, dominance indices and evenness indices.

## INTRODUCTION

Botanic gardens are one of the man-made centers of conservation and enrichment of plant diversity. Not only the autochthonous flora but also the introduced plants from the flora of different geo-botanical regions and provinces grow in botanical gardens. In such phytodiversity centers under urban conditions of cultivated coenosises is significantly represented. The major ecological threats to biodiversity in urban terrain are driven by anthropogenic activity, which involves the transformation and degradation of habitats, ecosystem resources overexploitation, the spread of alien species, pests and diseases, etc. Aerial technogenic pollution of settlements is caused by emissions of stationary and mobile sources, which supply the most dangerous substances for green planting, 85 % of which contributes to the urban airshed pollution by vehicle emissions (Akimov *et al*., 2006). Recreational activities in botanical gardens due to the large stream of holidaymakers are also one of the main anthropogenic factors. In order for studying biodiversity, it is relevant to research on consortium linkages as specific ecological phenomena (Lavrov & Blinkova, 2018; Blinkova & Ivanenko, 2018). Consideration of the transformation of 'tree–birds' consortium linkages in increasing insight on anthropogenic changes in the condition, productivity and development of tree stands as well as the fulfillment of their target functions is at an early stage (Chaplygina *et al*., 2016). In order to evaluate the anthropogenic impact effects on botanical gardens, it is advisable to carry out an analysis on a syn-ecological basis with the linkage between phyto- and zoological components (Blinkova & Shupova, 2017, 2018). In assessing the biodiversity of the area, birds are a particularly beneficial taxonomic group as they perform a variety of important functions in the urban ecosystem (Browder *et al*., 2002; Sekercioğlu, 2006; Fischer *et al*., 2007; Everard, 2008; Gardner *et al*., 2008; Robledano *et al*., 2010). In an urbanized environment, they easily inhabit transformed biotopes (Kurosawa, 2009; Shupova, 2014, 2017) and adapt themselves to the residence under permanent anthropogenic load. Variations in the composition of bird groups formed under the influence of anthropogenic load make it possible to identify the ecosystem balance degree (Chaplygina *et al*., 2016). Due to recreational effect, terrestrial microstations for birds disappear in biotopes. Variations of certain characteristics of forest stands formed under recreational influence make it possible to identify relationships between phytocoenotic and bird community parameters (Conner & Dikson, 1997; Chaplygina *et al*., 2016; Blinkova & Shupova, 2017). The structural complexity degree of the phytocoenosis is a major indicator of the links between bird and plant communities. The main approaches to above-mentioned issues are based on the measuring of phytocoenotic parameters and species diversity, bird nesting density (Fuller & Moreton, 1987; Catsadorakis, 1997; Walther, 2002) or a generalized measure that combines several measurement values, including vertical and horizontal heterogeneity indices (MacArthur R. & MacArthur, 1961; O'Connor, 1981). On the other hand, the links between phytocoenotic parameters and ornithological diversity in urban settings have not been fully analyzed. Therefore, the relevance of the study is beyond any doubt. The aim of the study was to evaluate the correlations and α-diversity indices of bird communities and plant communities of urban botanical gardens under anthropogenic conditions.

## MATERIAL AND METHODS

The study area covers the botanical gardens of Kyiv and Vinnytsia. Kyiv is located at the border between the Forest-Steppe zone and the Polissya on the right and left banks of the Dnipro River. The area of the city is 835.6 km$^2$. Podzolic sandy, sandy-loam, gray, light gray bleached, dark gray bleached and low-humic chernozem soils dominate the area. The Vinnytsia city is a regional center located in the Forest-Steppe zone of Ukraine. The city of 60.94 km$^2$ stretches along both banks of the middle reaches of the Southern Bug River. The climate is a semi-continental. According to the geo-botanical division of Ukraine, this territory belongs to the Lityn geo-botanical region of the Central-Podilsk district, the Podil-Bessarabian sub-province of the Eastern European province, the European broadleaf area (Biluk, 1977). The research was carried out on the territory of three botanical gardens in their exposition of plants of natural flora and arboretum during 2016-2018. Two botanical gardens, namely the Botanical Garden of the National University of Life and Environmental Sciences of Ukraine (EP3) and the Acad. O.V. Fomin Botanical Garden of the Taras Shevchenko National University of Kyiv (EP1) are located in Kyiv and the third one is in Vinnytsia – the 'Podillia' Botanical Garden of the Vinnytsia National Agrarian University (EP2). EP3 is located in the southern part of Kyiv and has an area of 53 hectares. EP1 is located in the center of Kyiv (22.5 ha). EP2 (70 ha) is located in the southwestern part of Vinnytsia on the north and south slopes of the Vyshnia River. The coordinates of the botanical gardens' center points are as follows: EP1 –50°26'35.0"N 30°30'19.1"E, EP2 – 49°12'46.4"N 28°24'46.3"E, EP3 – 50°22'55.5"N 30°30'06.9"E. The level of anthropogenic load on the ornithocomplex was evaluated in points according to the author's method with additions, based on data on air pollution, recreational load, urbanization level, noise factor, population density, etc.

**Analysis of plant communities**

Field studies were conducted using standard ecological and botanical methods (Mirkin *et al*., 2002). Taxa nomenclature was given after S.L. Mosyakin and M.M. Fedoronchuk (1999). Environmental strategies types were described according to the J.P. Grime (Grime, 1977). The ecological valence of the species was established after L.N. Zhukova (Zhukova, 2010). The health condition of trees (category of trees' state) was appraised following the Sanitary Forest Regulation in Ukraine (2016). The stand state index was calculated:

$$I_c = \frac{\sum k_i n_i}{N},$$

where ki is the category of tree state (I–VI); ni is the number of trees in a certain category of tree state and N is the total number of trees.

The stands with index values ranging from 1 to 1.5 are considered as healthy (I), 1.51−2.50 as weaker ones (II), 2.51−3.50 as heavily weakened ones (III), 3.51−4.50 as wilting ones (IV), 4.51−5.50 as recently dead (V) and 5.51−6.50 old dead stands (VI). In order to avoid the influence of the irregular intensity of sylvicultural practice upon the index of stand state, for each category of states, the weighted average Kraft classes (WAKC; vitality composition of tree vegetation) was calculated:

$$WAKC = \frac{\sum k_{kc} l_C}{n_i},$$

where $k_c$ is the number of trees in each Kraft class; $I_c$ is the stand state index and $n_i$ is the number of trees in a certain state category.

Indices of horizontal heterogeneity of vegetation and vertical heterogeneity of vegetation (IHH and IVH, respectively) were calculated to describe the vegetation composition as the feeding and breeding stations of birds (Sekercioğlu, 2002a, 2002b):

$$IHH = \frac{S.D.AD}{AD_{ave}},$$

where AD is the distance between the trees; ADave is the average distance between trees.

IVH is the Shannon-Weaver diversity index for vertical vegetation distribution. The condition of the soil surface layer was described after A.F. Polyakov (Polyakov, 2009). The recreational transformation stages of phytocoenosis were established according to L.P. Rysin (Rysin, 2003).

**Birds surveys**

Bird surveys were conducted using the standard transect method (Novikov, 1953; Bibby *et. al*., 2000). As the botanical gardens are fragmented into local biotopes, the area of the arboretum was measured and for that obtained value the bird density was calculated. Along the stands of each botanical garden, 2 routes with a length limited by the length of the garden and the available transect width of 100 m have been established. A standard deviation was calculated to determine the average nesting density of birds. The ecological composition of bird communities was assessed depending on biotopes (Belik, 2006), the selection of nesting microstations (Camprodon & Brotons, 2006; Shupova, 2017) and the proportion of protected bird species in accordance with the Lists of international conventions. The distribution of bird communities was carried out according to the feeding type: birds feeding on invertebrates, phytophages, birds with a mixed feeding type and polyphages (Camprodon & Brotons, 2006). The synantropization index of nesting bird communities was calculated after Jedryczkowski (Klausnitzer, 1990):

$$Ws = {}^{Ls}/_{Lo},$$

where Ls is the number of synanthropic species and Lo is a total number of species.

Species of birds forming both synanthropic and natural populations were isolated into the group of hemysynanthropes and those that nest only in urban habitat – into the group of obligate synanthropes (Klausnitzer, 1990).

**Statistical analyses**

Mathematical processing of the research results was carried out following the recommendations (Magurran, 1998) according to the estimation of relevant indicators of plants and birds' biodiversity. To compare the bird and plant species diversity of different EPs, some commonly accepted indices that express the correlation between the number and density of species were calculated. Since none of the currently developed indices is universal, several commonly accepted indices have been analyzed:

1) the relative abundance of species in communities

$$P_i = \frac{N_i}{N},$$

2) dominance indices:

$$d = \frac{N_{i_{max}}}{N} \text{ Berger–Parker}; \quad U = \sqrt{\sum N_i^{\,2}}, \text{ McIntosh}$$

3) diversity indexes:

$$H = -\sum p_i \log_2 \rho_i \text{ ...Shannon}, \quad D_{Mn} = \frac{S}{\sqrt{N}} \text{ Menchinick}, \quad D_{Mg} = \frac{(S-1)}{\ln N} \text{ Margalef}$$

4) evenness indices:

$$E = \frac{H^i}{\ln S} \text{ } Pielou, \; Us = \frac{N-U}{N-\frac{N}{\sqrt{S}}} \text{ McIntosh}$$

where Ni is the density of the species in communities, N is the total number of individuals, S is the total number of the species, ρi is the ratio of each species, U is the McIntosh diversity index, H' is Shannon’s diversity index.

The Principal Component Analysis was performed using the software Origin Pro 9.0.

## RESULTS

**Analysis of vegetation**

The stand in EP1 is two-storeyed of two age classes (40-60 years; 60-80 years). The first storey is composed of *Magnolia grandiflora* L., *Quercus robur* L., *Quercus rubra* L., and other spp. The second storey is composed of *Betula pendula* Roth, *Fagus sylvatica* L., *Tilia cordata* Mill., and other species. The understorey is represented by *Crataegus laevigata* (Poir.) DC., *Sorbus auccuparia* L., *Syringa vulgaris* L., etc. The stand in EP2 is also two-storeyed of two age classes (40-60 years; 60-80 years). The first storey is composed of *Q. robur*, *Q. rubra*, *A. hippocastanum*, *C. betulus*, *T. cordata*, *A. platanoides* etc. The second storey is composed of *A. campestre*, *A. negundo*, *B. pendula*, *B. pubescens*. The understorey is composed of *S. aucuparia* and *S. nigra*. The stand in EP3 is two-storeyed as well and consists of trees of 40-60 years. The first storey is composed of *Q. robur*, *Q. rubra*, *A. hippocastanum*, *T. cordata*, *A. platanoides*, etc. The second storey: *R. pseudoacacia*, *A. negundo*, *A. campestre*. The understorey is composed *Amorpha fruticosa* L., *E. verrucose*, *Sambucus nigra* L., *Corylus avellana* L., etc. The studied stands in all EP were weakened. The largest proportion of healthy trees was recorded in EP2 (47.1 %), which might be caused by less influence of the Vinnytsia transport network. On the other hand, the largest proportion of category IV trees was in EP1 (2.2 %). The proportion of weakened trees in EP1 and EP3 was the same, and the lowest number of weakened trees was on EP2 (31.8 %). The proportion of heavily weakened trees in EP1 was the smallest, but in EP2 and EP3 this category takes a larger percentage of trees. The proportion of wilting trees was approximately the same for all EPs (1.8-2.2 %). The overall stand state index was 1.77, 1.69 and 1.74 for EP1, EP2, and EP3, respectively. IVH are almost the same for all EPs: 3.13 (EP1); 3.12 (EP2); 3.16 (EP3). Meanwhile, IHH varies depending on the anthropogenic load: 0.61, 0.79 and 0.80 for EP1, EP2 and EP3, respectively. Since people tend plants in the botanical gardens, no changes in the typical forest parameters have been detected. For instance, the distance between trees does not change (302.4±15.1, EP1; 305.6±15.3, EP2; 299.3±15.0, EP3) and natural stand regeneration is unreliable, regardless of the intensity of anthropogenic impact. The analysis of the vitality composition has shown that the trees of II and III classes Kraft prevail. WAKC values for all EPs indicates the presence of pathological processes in the stands of botanical gardens since the drying of trees here is not a natural loss. It was found that in EP1 the trees of II-III classes Kraft drying. WAKC was 2.0 and 2.3 for weakened and heavily weakened trees, respectively. WAKC of wilting trees was 3.3, indicating that not only trees of IV class Kraft but even of III class Kraft can suffer from wilting. Such vitality distribution for EP1 indicates a significant anthropogenic impact on the stands. The analysis of generalized vitality composition as an integrated indicator of the population status of the dominant *Q. robur*, *Q. rubra*, *A. hippocastanum*, *C. betulus*, *T. cordata* in EP2 indicates less transformation of these tree species compared to EP1 data. WAKC for weakened and heavily weakened trees was 2.8 and 3.4, respectively. WAKC for trees of V category was 4.9, which indicates that the trees of lower classes are wilting. Meanwhile, WAKC of healthy trees was 1.9. An evaluation of the vitality composition of trees in EP3, which has the lowest phytocoenosis transformation rates, showed that, based upon the WAKC distribution for trees of different stand state, tree drying is closer to natural loss compared to EP1 and EP2. In particular, WAKC of weakened and heavily weakened trees was 2.9 and 3.5, which proves that the system of cultivated coenosises is balanced. At the same time, WAKC of wilting trees was 4.5. The assessment of the vitality and sanitary compositions of stands in EPs showed that trees adapt to different levels of anthropogenic ecological transformation according to the composition of their biomorphological features and vitality status.

**Assessment of herbaceous and soil surface layers**

The floristic list of nonspecific herbaceous vegetation in EP1 comprised 65 species of vascular plants of 59 genera and 18 families. The dominant herbaceous families were *Asteraceae* – 17 spp. (28.9 %), *Poaceae* – 12 (20.5 %), *Lamiaceae* – 6 (10.3 %), *Rosaceae* – 4 (6.7 %), *Fabaceae* and *Ranunculaceae* – 3 (5.3 %). The total projective cover in EP1 was 53.0 %. Forest species such as *Asarum europaeum* L., *Geranium sylvaticum* L. and *Galium aparine* L. can also be found in some places. The most common were ruderal and adventitious species (*Chelidonium majus* L., *Malva sylvestris* L., *Polygonum aviculare* L., *Stenactis annua* L., *Urtica dioica* L., etc.), the proportion of which was 59.7 %. The soil state was evaluated as stage IV of degradation. The total projective cover in EP2 was 68.5 % with 44.5 % of non-forest species. The floristic list of nonspecific herbaceous vegetation in EP1 comprised 71 species of vascular plants of 62 genera and 29 families. The dominant herbaceous families were *Poaceae* – 16 spp. (22.6 %), *Asteraceae* – 11 (15.6 %), *Rosaceae* – 6 (8.6 %), *Ranunculaceae* – 5 (7.0 %), *Lamiaceae* and *Fabaceae* – 4 (5.7 %). Among forest species *A. nemorosa*, *A. europaeum*, *G. sanguineum*, etc. were found. *Aegopodium podagraria* L., *Chenopodium album* L., *Dactylis glomerata* L., *Geum urbanum* L., etc. dominate among non-forest species. The soil state of EP2 was evaluated as stage III of degradation. The total projective cover in EP3 was 78.5 %. The floristic list of vascular plants in EP1 comprised 62 species of 55 genera and 27 families. The dominant herbaceous families were *Asteraceae* – 14 spp. (22,6 %), *Poaceae* – 12 (9,4 %), *Brassicaceae* – 5 (8,1 %), *Lamiaceae* – 4 (6,4 %), and *Fabaceae* – 3 (4,9 %). The dominant non-forest species are *D. glomerata*, *P. aviculare*, *P. major*, *Solidago canadensis* L., *U. dioica*, etc. In some places, biogroups of *A. europaeum*, *G. sylvaticum*, and *G. aparine* can be found. The soil surface was in stage III of degradation. In terms of ecological tolerance, species of wide ecological valence in relation to edaphic and climatic ecological factors dominate all EPs. In particular, in relation to the limiting ecological factor soil moisture, mesobionts, hemieurybionts, and eurybionts were representative groups. The proportion of stenobionts varied from 2.9 % to 4.9 %. Hemistenobionts and mesobionts were dominant in relation to soil aeration. Eurybionts were found only in EP1. In relation to climatic factors, mesobionts, eurybionts, and hemieurybionts dominated. The assessment of the ecological strategy of the species showed that the species with the secondary type of ecological strategy are the most represented in all EPs due to the different levels of recreational transformation. CSR-strategy species (29-33.8 %) were the most represented, the proportion of S-species (12.9 %) was the highest on EP3, while R-species were the most represented on EP1 (18.5 %). The proportions of SR-, CR- and CS- spp. are approximately the same in all EPs. The generalized stages of the recreational transformation were as follows: EP1 – IV; EP2 – III and EP1 – II.

**Analysis of nesting bird communities**

*Species composition*

Altogether, 33 bird species have been observed in all EPs, 31 of them were nesters. 20 spp. (60.6 %) are in the Bonn Convention list, 7 (21.2%) are in the lists of both the Berne and the Bonn Conventions. The avifauna of botanical gardens was rather poor and covered 4 orders: *Columbiformes*, *Apodiformes*, *Piciformes*, and *Passeriformes*. 25 spp. with an average density of 0.26 ± 0.06 pairs/ha nest in EP1, 1 spp. feeds here but does not nest. In EP2, all the identified spp. (n=20) were nesters (0.39 ± 0.09 pairs/ha). There are approximately 9-10 bird species in different areas of mixed park stands. In EP3 16 of 19 registered bird species were nesters (0.24 ± 0.04 pairs/ha), 3 species visit the botanical garden just for feeding. In terms of quantity, *Turdus merula* and *Parus major* are dominant in EP3 and EP2. That list is supplemented by *Ficedula albicollis* and *Erithacus rubecula* for EP3 and *by Fringilla coelebs* for EP2. In EP1 *Columba livia* and *Passer domesticus* supplant *T. merula* and *P. major*, leveling them down to the subdominant status.

*Ecological composition*

Nesting avifauna was represented mainly by woody nesters (21 species) of different nesting types. A small number of sclerophylla species (*C. livia*, *Sturnus vulgaris*, *Passer montanus*, *P. domesticus*) have been found only on EP1, where they use hollow nesting gilds.

Woody nesters use 3 nesting gilds: 12 species nest in a tree hollow and tree canopies, 2 (*Luscinia luscinia*, *Phylloscopus collybita*) were ground nesters, 1 (*Erithacus rubecula*) was polystation nester, which naturally captures several nesting gilds. The proportion of tree canopy nesters was approximately 40 % in all bird communities. In EP2 and EP3 the ratio of other nesting gilds use by birds is similar. The proportion of polystation nesters was significantly higher in the EP1 bird community (25.2 %). That means that in case of the absence of species-specific nesting gilds eurytopic species switch to using all possible nesting sites of both natural and anthropogenic origin. In EP1, some tree hollow nesters nest, apart from to cavities, in artificial nests of anthropogenic origin (8.2 %), which resulted in an additional cavity source for stenotopic tree hollow nesters. On the EP1 – EP3 gradient, the number of potent tree hollow nesters decreased from 3 to 1, and their density doubled (0.27; 0.23; 0.13), which could be explained by the immediate vicinity of the woodlands. The density of passive tree hollow nesters (10 spp.) was approximately the same (1.72; 2.14; 1.73). All species of bird communities were obligate synanthropes or hemisynanthropes, so the synanthropy index for all groups was 1.19. 61.3 % of species nest even in the outer courts of continuous multi-storey developments, but only 12.9 % have switched to an obligately synanthropic lifestyle. Therefore, a comparison of the synanthropyization of bird communities has been shown based on the obligate synanthropes proportion both in species composition and in partial numbers of nesting pairs. These characteristic values increased significantly on EP1 (0.43; 16.0 %). Bird communities of EP2 and EP3 close to natural biotopes are characterized by fewer obligate synanthropes, the smaller proportion of those in species composition as well as the lower relative abundance of breeding pairs of these species. Thus, on the EP1-EP3 gradient, the relative abundance of obligate synanthropes formed following descensive series: 0.434–0.210–0.100, and their proportion in the species composition of the group was 16.0–5.0–6.3.

*Trophic composition*

The bird communities were divided into 4 groups by feeding type. The most numerous were birds with a mixed feeding type (18 spp., 58,1 %). Second in number were birds that feed on invertebrates (7 spp., 22,5 %). Such phytophages as granivorous (*Columbiformes* and *Passeriformes*, 2 spp. each, 12,8 %) and polyphages (*Corvidae*, 2 spp., 9,6 %) numerically insignificant. Based on the birds' behavior, an interesting feature of EP2 is that there are no birds visiting this botanical garden from neighboring biotopes to feed. *Garrulus glandarius*, *Pica pica*, and *P. domesticus* were noted in EP3, they feed here but do not nest. *P. pica* visits EP1 for feeding but does not nest here. However, interestingly for *C. livia*, *Corvus cornix*, *S. vulgaris*, *P. domesticus*, not only individuals of the nesting community feed in residental area but also those who have settled in the blocks of multi-storey buildings. Generalized levels of species spectrum of plants and birds in the transformation gradient of EPs differ. Thus, the largest species richness in bird and plant communities (0.57 and 0.50, respectively) was recorded for EP3. However, the largest numbers of nesting birds were found in the most transformed section of the EP1 in the city center. This indicates that, wherever possible, most bird species for nesting choose the biotopes the most similar to the natural ones.

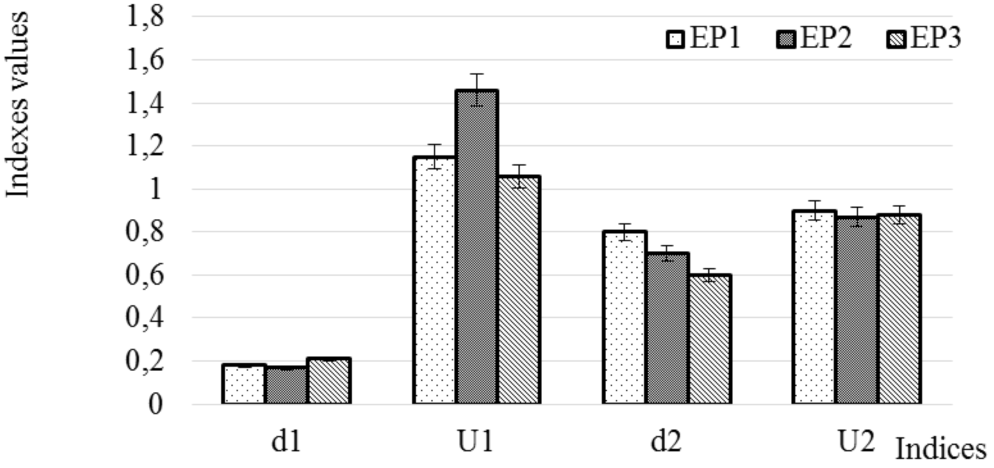
**Diversity indices**

The diversity indices for vegetation and avifauna indicate anthropogenic changes in complex ecological conditions. The values of plant diversity indices (DMn2, DMg2, H2, U2) vary depending on the level of anthropogenic load on the EP. In particular, the evaluation of phytodiversity indices showed that the highest values of the DMn2, DMg2 and H2 were for

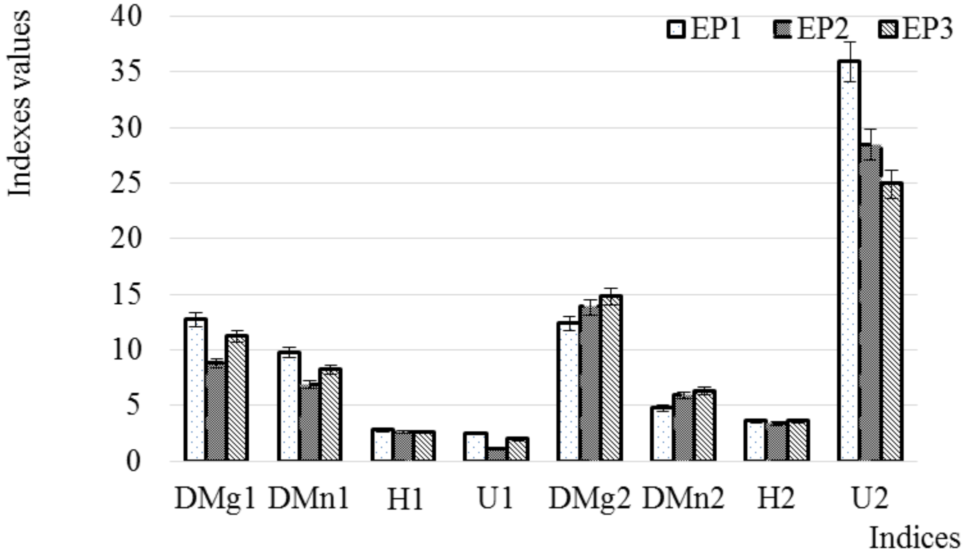
EP3 (Fig. 1, a). The values of the corresponding index for EP2 were similar to EP1. The lowest values were recorded for EP1, which has the highest anthropogenic load.

**Fig. 1: Diversity (a) and dominance (b) indices indices for plant and bird communities: 1 – ornithodiversity; 2 – phytodiversity**

**a)**




b)




At the same time, there is no clear dependence of McIntosh indices on anthropogenic load. Diversity indices for bird species communities do not show a clear general pattern of fluctuations. Most indices show an increase in species richness in EP1 and EP3. H2 is pretty much the same for all EPs. McIntosh index reveals a trend opposite to the general pattern of other indices. Thus, McIntosh index value was the lowest (1.1) for EP3. Comparative evaluation of the diversity indices for the phyto- and ornithocomplexes of the botanical gardens has shown that human activity equally leads to the transformation of both plant and bird communities. However, there are no trends for diversity indices in the avifauna. This could be explained by the fact that under the of significant anthropogenic load on bird community of small tree stands, which are additionally fragmented by lawns and alleys, the community shows a balance shift towards a decrease in species composition, with the simultaneous increase of the nesting species number in a forest.

*Dominance indices*

The dominance indices of McIntosh and Berger–Parker were the highest for plant communities on the most transformed EP1 (Fig. 1, b). This indicates that in areas with a corresponding transformation level the created ecological conditions are favorable only for ruderal and adventitious plant species, while other species were more depressed. The values of dominance indices for bird communities did not reveal any general fluctuation pattern. This is because, in a small fragmented area of forest stands, which is under load from the surroundings, few-species bird communities have been formed, from fifth to third part of which is represented by numerically dominant species.

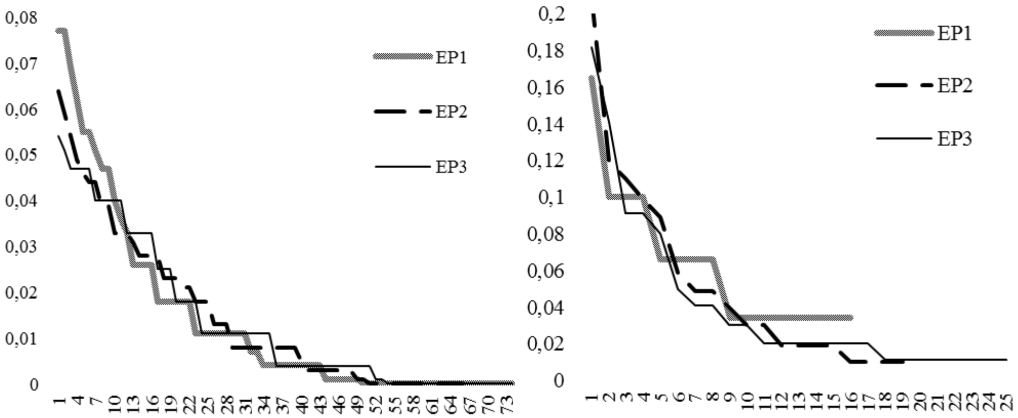
*Evenness indices*

Evenness indices for plant communities indicated the anthropogenic transformation level increase in all EPs. Evenness indices for bird communities were maximal for EP2 (UsEP1=0.95; EEP1=2.18), but for EP1 and EP3 they were almost the same (UsEP2=0.88, UsEP3=0.89; EEP1=1.99, EEP1=2.01). The distribution curves of bird species composition by quantity confirmed the values of α-diversity indices and showed a decrease in range of species with increasing of dominant species proportion, as well as the absence of rare species in all EPs. Bird composition in EP2 was the most balanced. In EP3, bird community which inhabits the smallest arboretum of all targeted botanical gardens, was the least balanced, even though it was under the least anthropogenic load (Fig. 2, a). The result of the analysis of the curves showed that, under conditions of substantial anthropogenic load in the urban landscape, the balance degree of the bird community was most significantly influenced by the tree stands area inhabited by this community. The evenness of plant species was balanced. The plant distribution by a relative number of species was similar for all EPs (Fig. 2, b).

The ranked curves illustrated the best state of numerical dominance for the EP2 and EP3 plant communities where the highest number of species was found. Thus, the analysis of biodiversity indices revealed a discrepancy between the responses of phytodiversity and ornithodiversity of urban botanical gardens to anthropogenic transformation. The indices of diversity, dominance and evenness of species communities showed synchronicity in terms of anthropogenic load solely for vegetation. In summary, it can be said that the response of bird communities' indicators to plant compositions changes in targeted EPs amid the intense anthropogenic influence of cities is subject to the additive effect with the response to the disturbance factor, which aggravates the negative load of ambient environment.

**Fig. 2: Distribution of plant (a) and bird (b) species composition in communities by relative abundance rank (Pi)**

a) b)




The assessment of correlation between parameters of plant and bird communities confirmed a significant direct correlation between IVH and the density of birds nesting (r=0,96, p<0,005). Meanwhile, no high association was found between the number of bird species (r=0,59) (Table 1). The relationship between IVH and U index for birds has also been established (r=0,94, p<0,005)

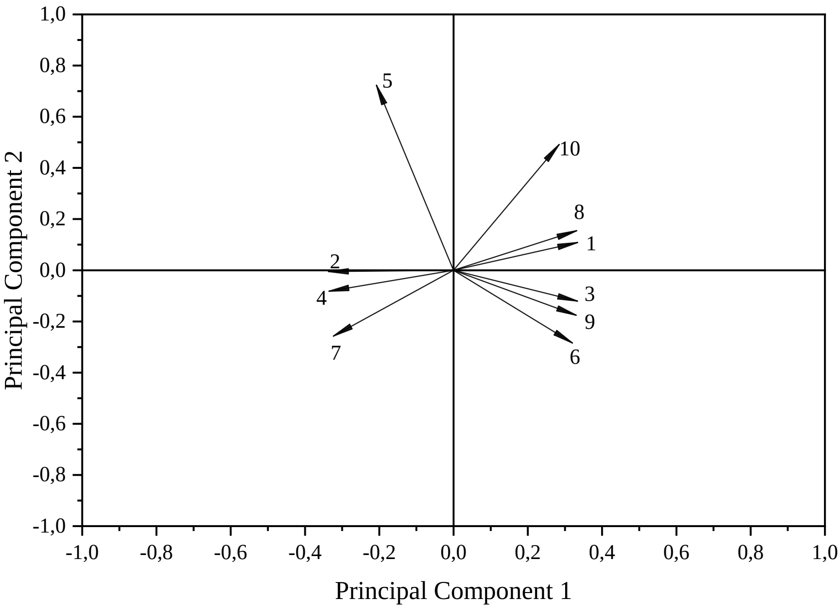
**Table 1: The correlation between parameters of plant and bird communities**

| **Indices** | **$N_1$** | **$P_1$** | **$DMr_1$** | **$DMn_1$** | **$H_1$** | **$d_1$** | **$U_1$** | **$E_1$** | **$Us_1$** | **$N_2$** | **$P_2$** | **$DMr_2$** | **$DMn_2$** | **$H_2$** | **$d_2$** | **$U_2$** | **$E_2$** | **$Us_2$** | **IVH** | **IHH** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **$N_1$** | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| **$P_1$** | 0,52 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| **$DMr_1$** | 0,56 | 0,35 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| **$DMn_1$** | 0,67 | 0,21 | **0,98** | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| **$H_1$** | **0,83** | 0,02 | **0,89** | **0,91** | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| **$d_1$** | 0,67 | 0,82 | -0,77 | -0,68 | -0,52 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| **$U_1$** | 0,58 | **0,93** | -0,51 | -0,34 | -0,28 | **0,78** | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| **$E_1$** | 0,11 | **-0,92** | 0,01 | -0,15 | -0,32 | -0,58 | **-0,80** | - | - | - | - | - | - | - | - | - | - | - | - | - |
| **$Us_1$** | -0,54 | **-0,88** | 0,15 | -0,03 | -0,03 | -0,53 | **-0,92** | **0,90** | - | - | - | - | - | - | - | - | - | - | - | - |
| **$N_2$** | 0,44 | 0,02 | 0,68 | **0,76** | 0,49 | -0,55 | 0,06 | -0,25 | -0,40 | - | - | - | - | - | - | - | - | - | - | - |
| **$P_2$** | -0,25 | 0,68 | **-0,89** | **-0,79** | **-0,75** | **0,84** | **0,82** | -0,38 | -0,57 | -0,34 | - | - | - | - | - | - | - | - | - | - |
| **$DMr_2$** | 0,58 | -0,35 | **0,99** | **0,97** | **0,90** | **-0,76** | -0,49 | -0,01 | 0,13 | 0,68 | **-0,88** | - | - | - | - | - | - | - | - | - |
| **$DMn_2$** | 0,47 | -0,49 | **0,98** | **0,93** | **0,86** | **-0,82** | -0,64 | 0,14 | 0,31 | 0,56 | **-0,95** | **0,98** | - | - | - | - | - | - | - | - |
| **$H_2$** | **0,89** | **0,85** | 0,14 | 0,29 | 0,50 | 0,48 | 0,66 | **-0,97** | **-0,79** | 0,25 | 0,19 | 0,17 | 0,03 | - | - | - | - | - | | - |
| **$d_2$** | -0,53 | 0,42 | **-0,96** | **-0,92** | **-0,91** | 0,73 | 0,62 | -0,08 | -0,31 | -0,47 | **0,95** | **-0,96** | **-0,98** | -0,11 | - | - | - | - | - | - |
| **$U_2$** | 0,58 | 0,10 | 0,33 | 0,30 | 0,65 | 0,10 | -0,25 | -0,24 | 0,19 | -0,32 | -0,43 | 0,35 | 0,39 | 0,43 | -0,53 | - | - | - | - | - |
| **$E_2$** | 0,77 | **0,87** | -0,06 | 0,05 | 0,35 | 0,68 | 0,64 | **-0,91** | -0,67 | -0,08 | 0,30 | -0,04 | -0,15 | **0,94** | 0,03 | 0,56 | - | - | - | - |
| **$Us_2$** | 0,66 | **0,86** | -0,20 | -0,09 | 0,24 | **0,77** | 0,63 | **-0,84** | -0,58 | -0,25 | 0,37 | -0,18 | -0,26 | **0,86** | 0,13 | 0,58 | **0,99** | - | - | - |
| **IVH** | 0,59 | **0,96** | -0,21 | -0,03 | 0,05 | 0,66 | **0,94** | **-0,95** | **-0,97** | 0,24 | 0,60 | -0,19 | -0,36 | **0,86** | 0,33 | -0,03 | 0,80 | 0,74 | - | - |
| **IHH** | **0,83** | -0,02 | **-0,91** | **-0,96** | **-0,94** | 0,48 | 0,13 | 0,39 | 0,23 | **-0,74** | 0,66 | **-0,92** | **-0,84** | **0,92** | **0,84** | -0,38 | -0,29 | -0,14 | - | - |

Notes: 1 - ornithodiversity; 2- phytodiversity

There was no correlation between IVH and d index (r=0.66), unlike the data for natural and semi-natural forests of Kyiv (Blinkova & Shupova, 2018). The relationship between IVH and diversity indices proved to be weak (r=-0,21, DMr1; r=-0,03, DMr1; r=0,05, H1). There was an inverse correlation between IVH and evenness indices for birds (r=-0,95; r=-0,97). The findings indicate both positive and negative correlations between the multi-storeyed vertical composition of the botanical garden and the diversity of birds. IHH was proved to be closely linked to the number of bird species (r=0,83, p<0,01). On the other hand, unlike for IVH, there was no close correlation between IHH and nesting density. Besides that, it should be noted that the inverse correlation between IHH and bird diversity indices has been established. The data obtained indicated coherence between the birds' distribution and the horizontal heterogeneity of the botanical gardens. It is interesting to note that close links between almost all bird and plant diversity indices have been established. In particular, it was 0.99 between DMg, 0.93 between indices of DMn, etc. H1 index was highly correlated with DMn2 and DMg2 for vegetation (r=0,86, p<0,01; r=0,91, p<0,005, respectively). The d1 dominance index for birds has a negative correlation with phytodiversity indices (r=-0,76, DMg2, and r=-0,82, DMn2). The d2 dominance index for plants also has a negative correlation with the bird diversity indices (r=-0,96, DMg1; r=-0,92, DMn1; r=-0,91, H1). The H2 index for phytodiversity was closely associated with the number of bird species (r = 0.89, p <0.005) and nesting density (r=0,85, p<0,01). The correlation between nesting density and evenness indices for plants was also recorded (r=0,87, p<0,01, E2; r=0,86, p<0,01, Us2). According to PCA, the variables in the same quadrant are directly proportional and in opposite are inversely proportional, and the line length indicates the variable strength in relation to the other ones (Fig. 3).

**Fig. 3: PCA ordination plots of phyto- and ornithodiversity parameters**
(1 – ground nesters; 2 – birds with a mixed feeding type; 3 – Pi of passive hollow nesters; 4 – Pi of obligate synanthropes; 5 – Is of tree stand; 6 –the relationship between Have and Dave tree morphometric parameters; 7 – soil state degradation; 8 – a total projective cover of an herbaceous layer; 9 – IHH; 10 – IVH)



For the first time ever we found the direct dependence between $P_i$ of passive hollow nesters, the determination coefficient of $H_{ave}$ and $D_{ave}$ and the IHH. We also found a relationship between the proportion of ground nesters and the total projective cover of the herbaceous layer, IVH, etc. An interesting link is the one between $P_i$ of the obligate synanthropes and the soil state degradation. Inverse proportionality between many parameters of ornitho- and phytodiversity was also found.

## DISCUSSION

In our work, we have shown that the vegetation of botanical gardens plays a significant role in the formation of different ornithocomplex compositions. It stands to mention that the native phanerophytes are characterized by a connection with native bird species. In other works, it is shown that the phytocoenosis composition is not so much important factor as the forest stand parameters (White *et. al*., 2009). Scientists have stated that the impact of anthropogenic activity on avifauna depends on the intensity of tree transformation (Gabbe *et. al*., 2002; Šalek *et. al*., 2010; Pereira *et. al*., 2014; Bergner *et. al*., 2015). In our work we also showed the relationship between ecological, trophic, species compositions of birds and the vitality and sanitary compositions of tree stands. In particular, it has been found that under the condition of intensive complex anthropogenic transformation, which includes recreational factor, noise pollution, air pollution, and disturbing factor, stand state deteriorates to heavily weakened, the relationship between tree vitality classes decreases, and as a consequence of this species decreases. On the other hand, anthropogenic disturbance of the understory and herbaceous layer caused a decrease in the forage resources and nesting sites for avifauna. Similar conclusions can be also found in the other authors' works. Transformation trends of the herbaceous layer in botanical gardens are similar to the corresponding degradation of natural and artificial forests stands: an increase in the proportion of adventitious and ruderal species, emerging role of species with wide ecological valence, and species with the secondary types of ecological strategies. R. Milne and L. Benett (2013) proved that bird populations are more associated with the tree layer, and they are associated with other vegetation tiers only under conditions of the most intense ecological transformation. Considering the fact that in the botanical gardens density of canopy ranges from 0.4 to 0.6, the relative abundance of tree feeding birds is higher than in natural forests where the density of canopy exceeds 0.8 (Shirihai *et. al*., 2001). In our previous work, we have shown the relationship between distance into trees, the development, and condition of undergrowth and bird community compositions. We have proved the cumulative impact of these factors on the avifauna of both the urban green zone and natural forests (Blinkova & Shupova, 2017; 2018). Herein that relationship was not established due to the regular handling of plants in the botanical gardens. Our study fully confirms the previous findings that a highly fragmented environment leads to a decrease in populations of limited species and species with large nesting areas and increases the extinction hazard for these populations (Sekercioğlu, 2006; Moreno-Rueda & Pizzaro, 2009; Šalek *et. al*, 2010; Robles *et. al*., 2012; Domokos & Domokos, 2016). Stated increase in the proportion of numerically dominant species in bird communities is representative of persistent negative pressure of the urbanized habitat. Under these conditions, most native species of the region disappear from the transformed territory, leaving only species that, firstly, are incline to synanthropization, and, secondly, have nesting biology genetically protected from ecological threats related to mechanical tree trunk damage as well as herbaceous layer and leaf-litter. The analysis of botanical garden bird communities, unlike of those in natural forests and urban forest stands

(Blinkova & Shupova, 2017; 2018), did not reveal any increase in the species composition of passive hollow nesters and their density depending on a number of species and density of woodpeckers. That is the conclusion about the limitation of secondary hollow nesters by the number of suitable nesting gilds in case if the number of woodpeckers in nesting bird community is insufficient is true only for forest biotopes where human activity is minimized (Woodley *et. al*., 2006; Virkkala, 2006; Carlson *et. al*., 1998; Mikusinski *et. al*., 2001; Robles *et. al*., 2012; Blinkova & Shupova, 2017). In our studies, we found a decrease in Pi of passive hollow nesters in communities in the midst of increasing their species number under the most significant anthropogenic load on biotopes. In the natural and semi-natural urban forests, the proportion of synanthropic species in bird composition increases by 1.5 times by the transformation gradient of the plant composition (the synanthropization index is 0.46-0.67 %) (Blinkova & Shupova, 2018). In terms of the trophic composition, the bird communities of the botanical gardens do not differ significantly from those of urban forests and the natural biotopes of city surroundings (Blinkova & Shupova, 2017; 2018).

## CONCLUSSIONS

The values of the phytodiversity indices showed greater deviation from the normal conditions. Comparative evaluation of the correlation between the parameters of plant and bird communities shows that in botanical gardens, the complex layering and vertical heterogeneity of the phytocoenosis inferior in value to horizontal heterogeneity. In this study, both positive and negative correlations between the layering and vertical heterogeneity cultivated coenosises and the several ornithodiversity indices have been revealed. The high correlation between almost all the indices of bird and plant diversity in botanical gardens, unlike natural forests, can be explained by the size of the targeted loci, the specific composition of the stand and herbaceous layer, and the urban impact of human and domestic animals. Established indicators of the syn-ecological characteristic of recreational disturbance of cultivated coenosises are recommended to be included in the ecological monitoring system.

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