Differential ecomorphic analysis of urban park vegetation

To cite this article: O Zhukov *et al* 2023 *IOP Conf. Ser.: Earth Environ. Sci.* **1254** 012023

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Abstract. The ecomorphic approach was developed to analyze the structure of natural plant communities. This method was applied to analyze the ecological structure of an artificial park plantation in an urban environment. Urban parks perform important and diverse functions in the urban environment. As anthropogenic objects, urban parks should be subject to adequate and effective management that can increase the functional value of forest plantations in the city and ensure their sustainability. In this regard, the choice of the quantitative parameters of the park plantation to be managed is crucial. We hypothesize that ecomorphic analysis can be the basis for selecting optimal quantitative criteria for parkland management. Therefore, the goal of our study was to assess the informational value of ecomorphic analysis for characterizing park plantation in urban environments. In the park, 166 species of vascular plants were found, which are represented by phanerophytes (19.9%), nannophanerophytes (8.4%), hemicryptophytes (40.4%), geophytes (11.4%), theorophytes (18.7%) and geolophytes (1.2%). Sylvants (35.5%) predominate among the coenomorphs, with slightly less pratants (22.3%), ruderants (18.7%) and stepants (14.5%). Cultivants (3.0%), psammophytes (3.0%) and paludants (3.0%) were occasionally found. The proportion of xeromesophytes and mesophytes was the highest (32.5 and 31.3% respectively). The proportion of mesoxerophytes was also relatively high (28.3%). The proportion of other hygromorphs was relatively low. The trophomorphs were represented mainly by mesotrophs (71.1%) and a slightly smaller proportion of megatrophs (22.3%). The oligotrophs were found occasionally (6.6%). Sciogeophytes (57.2%) and heliophytes (30.1%) prevailed among heliomorphs. The proportion of sciophytes and heliosciophytes was much lower (3.6 and 9.0 %, respectively). Entomophilous plant species were the most common among the vegetation cover of the park (71.7%). Anemophilous plants were significantly inferior to them (26.5%). Autogamous and hydrophilous plants were found occasionally (1.2 and 0.6% respectively). Ballistic diasporeochores prevailed among diasporeochores (39.8%). The proportion of anemochores and endozoochores was somewhat lower (27.7 and 12.0% respectively). The results obtained allow to discover the essential ecological features of the park plantation. The park plantation has many features that bring it closer to natural forests. The similarity consists in a significant proportion of silvants, shade-loving species, and mesotrophs. A significant level of anthropogenic impact can be diagnosed on the basis of information about the increased proportion of ruderants in the plant community. The differential analysis of the ecomorphic structure in the section by climorphs is of considerable value. This approach allowed to detect an increased role of the zoogenic factor in the distribution of diaspores of phanerophytes and nannophanerophytes and an increased role of wind in the dispersal of geophytes and therophytes. The role of wind is reduced in the dispersion of hemicryptophytes in the urban environment.

1. Introduction

The urban environment indirectly affects the formation of flora by changing the living conditions. There is also a direct impact through the physical destruction of plants, turning the flora into a variegated conglomerate of elements of both local and alien origin [1, 2]. Urban flora is a set of species that exist independently in the urban area. From the point of view of modern floristics it is a local flora or elementary flora of the regional level [3]. Hemeroby is the resilience of plants and their response to anthropogenic impact. From this point of view, there are two main categories [4–6]. Hemerophiles are species that respond positively to anthropogenic interference and increase their number in its presence [7]. Hemerophobes are species with a strongly negative reaction to anthropogenic factors [8–11]. A more detailed classification is also used [12], which includes the following categories. Agemerobic species are unstable to the impact of urbanization. Frequently these are forest and marsh species, which for various reasons are not adapted to life in urban conditions. Oligogemerobic species are weakly resistant. Mesohemerobic species are moderately resistant, withstand extensive anthropogenic impact. Intensive anthropogenic impact can be withstood by β-euhemerobic species. In turn, α-euhemerobic species inhabit meadows that are fertilized or in highly degraded forests and field weeds. Polyhemerobic species are typical ruderal plants, and metahemerobic species live in completely disturbed habitats [13, 14].

There are four most important types of factors of anthropogenic impact on the living ground cover in recreational forests. Mechanical damage (up to complete destruction) when trampling the ground organs of plants, including renewal buds. The least protected plants with tall succulent shoots and renewal buds located above the soil surface or at its surface suffer the most. Relatively more resistant are species with rosette arrangement of leaves, low elastic shoots, with sufficiently protected buds of renewal. Changes in physical parameters of the soil – moisture, aeration, density, temperature, etc. [15]. As a result, the normal functioning of underground plant organ systems is disrupted. In this case, the nature of underground organs is of great importance: the depth of their penetration and distribution in the soil profile, strength, etc. Cutting off ground shoots and digging up plants that attract the attention of recreationists with their decorative effect. At the same time, generative shoots of flowering plants are particularly affected, which inhibits the process of natural reproduction of the species' cenopopulation. Berry picking, harvesting of food or medicinal raw materials. Obviously, the last type of anthropogenic impact with rare exceptions (for example, mass harvesting of cranberries) does not have a decisive impact on forest ecosystems of urbanized areas. However, it is impossible not to take into account the existence of this factor.

Stress is a process of internal changes in the body systems in response to any strong or prolonged environmental impact [16, 17]. There is a broader interpretation of this term. Stress is a nonspecific response of the organism to any requirement presented to it, accompanied by the restructuring of protective forces [18]. From the point of view of this concept, the change in the nature of plant growth and development can be considered as an adaptation syndrome, which characterizes the degree of restructuring of the plant organism under the influence of anthropogenic pressure, as a compensatory reaction, on the one hand, to the deterioration of living conditions, and on the other hand, to reduce the intensity of competitive relations. The adaptation syndrome is a combination of three phases [19]. The phase of the primary stress reaction is a signal to activate the body's defenses. The phase of adaptation, or resistance, occurs during prolonged exposure to a factor that can cause stress. The degree of stress effect is determined by the level of restructuring of the organism – the more significant the impact, the more the organism changes. At this stage, plants show different forms of growth, can increase the intensity of growth and reproduction. The phase of exhaustion, which occurs after prolonged exposure to the stimulus, when the body loses the achieved adaptation. Reduction of resistance to the source of stress is expressed in a decrease in the size of individuals, in reducing the intensity of their growth and reproduction. Ultimately, the plant may die. The duration of a particular phase is determined by the adaptive capabilities of the species. In some species the stage of depletion occurs quite quickly, in others the phase of adaptation is relatively long. Species with greater plasticity are more stable. An expressive indicator of the state of a species is the type of its cenopopulation in a particular community, determined by the ratio of individuals of different age groups – the age spectrum [20].

Woody plants in urban areas can grow in various kinds of green spaces (in yards among residential buildings, on streets and highways, in squares, gardens and parks, in forest parks and in so-called urban forests) [21–24]. Forests in urbanized areas perform a variety of functions: environmental, sanitary and recreational [25–28]. The forest plantations have a positive impact on the atmosphere and climate of the city. They are able to change air temperature, illumination, wind speed, etc. Of course, this impact is more significant, the better the preservation of plantations [25, 29]. The forest transforms various climatic components while changing the radiation regime to the greatest extent [30–32]. Under the forest canopy, the illumination is much less, and in different types and in different parts of the forest it is different, because the composition of the rocks, the light permeability of the canopy, and the completeness of the stand differ. The total radiation is sharply reduced, because a significant part of it is intercepted by the crowns of trees and shrubs [33, 34]. The lighting becomes very variegated, which depends not only on the tree and shrub canopy, but also on the movement of the sun during the day, on the swaying of trees by the wind, on cloudiness [35]. The changes occur throughout the growing season due to the onset of different phenological phases [36]. At the same time, each type of forest has its own specifics, primarily due to the unifier species and the structure of the ecosystem. In artificial plantations (forest crops), the main species and planting density have a decisive influence on the light regime [37,38]. Wind speed is decreasing in the forest [39]. Inside the forest, at a distance of 30–50 m from the edge of the forest, the wind speed decreases to 30–40%, at a distance of 120–240 m, there is complete calm, especially if there is undergrowth in the plantation [40]. In summer, in cloudless and calm weather, in the contact zone between the city and neighboring green spaces, there is often a so-called breeze is a local breeze directed from the forest towards the city buildings during the day, and at night it blows in the opposite direction [41]. It is able to reduce the air temperature by several degrees. The reason for its occurrence is the difference in the thermal regime of the forest and urban development. As a result of this movement, the air in the city is cleaned and humidified, which also contributes to the improvement of the ecological situation [42,43].

Urban green spaces and suburban forests play an important, though not decisive role in maintaining the stability of the atmospheric gas composition [44]. The amount of carbon monoxide absorbed by the green mass and the amount of oxygen released by it depend on the condition of the plantation, its age, species composition, completeness and a number of other factors [45]. Green spaces serve as a reliable filter that cleans the air from dust [46]. In the forest, dust particles settle on trunks and branches, on the surface of leaves, stick to resinous secretions. The efficiency of dust collection is determined by the structure of plantations and their species composition [47]. The leaf surface is of great importance. Dust is retained more on rough, pubescent or sticky leaves than on smooth leaves, and even more so on needles. Small leaves usually trap dust better than large ones. Leaves of complex configuration clean the air more efficiently. On average, 1 hectare of forest can retain from 30 to 70 tons of dust. Multi-tiered plantations are more effective than single-tiered ones, deciduous forests are more effective than coniferous ones, but conifers retain their dust trapping functions all year round [48].

Forests clean the air from industrial and transport emissions, which are often toxicants [49]. Among them is sulfur dioxide, which can cause serious damage to the human respiratory system. On average, 1 hectare of forest can annually retain up to 400 kg of this compound. Lead emissions contained in exhaust gases are very dangerous for human health. Lead in particularly large quantities accumulates in plants growing in the immediate vicinity of transport routes. Sharp-leaved maple and small-leaved linden are among the tree species that accumulate toxic substances in the largest quantities. Coniferous species such as pine, spruce and larch are highly sensitive to toxicants [50–52].

Noise is a negative factor in a big city [53, 54]. The constant exposure to noise can lead to the development of neuroses, insomnia, hypertension, reduced performance, especially in older people. Forest plantations dampen sound waves, eliminate the most harmful high-frequency sounds and reduce noise levels. The level of noise pollution reduction depends on the density of crowns, the structure of plantations, their species composition. The most effective in noise absorption are sharp-leaved maple, poplar, linden, oak, elm, birch; a little less effective are coniferous stands. Mixed plantations with shrubs growing under the trees have the best screening properties. The loose soil surface also increases the noise absorption potential of the forest [55, 56]. Plants secrete phytoncides – volatile or water-soluble substances that can destroy pathogens or delay their development. The activity of phytoncides is closely connected with the species composition and age of plantations, with the physiological state of trees, with the season, time of day and many other factors. It is established that for most people, 5–7-hour stay in the forest improves tone and well-being. However, negative feelings may also appear. For example, a high content of turpentine vapors in a coniferous forest on a hot sunny day can worsen the condition of people suffering from cardiovascular diseases; it is better for them to rest in oak forests [57]. Recreation is one of the factors of forest formation, which often has a rather negative impact on forest ecosystems [58, 59].

2. Research aim and objectives

Thus, urban parks perform important and diverse functions in the urban environment. As anthropogenic objects, urban parks should be subject to adequate and effective management that can increase the functional value of forest plantations in the city and ensure their sustainability. In this regard, the choice of the quantitative parameters of the park plantation to be managed is crucial. We hypothesize that ecomorphic analysis can be the basis for selecting optimal quantitative criteria for parkland management. Therefore, the goal of our study was to assess the informational value of ecomorphic analysis for characterizing park plantation in urban environments.

3. Material and methods

3.1. Data collection

The study was carried out in the recreational zone of the Botanical Garden of Dnipro National University named after Oles Gonchar, Dnipro City, Ukraine (48.43°N 35.05°E). The urban park was created after World War II on the site of a natural thermophilous oak forest [60,61]. Vascular plant species lists were recorded for 3×3 m sampling point, along with a visual assessment of species coverage using a Braun-Blanquet scale [62]. The projective cover of plant species was measured at soil level, understory (up to 2 m in height), and canopy (above 2 m in height). All species were identified to species level at all sites. Plant taxonomy is based on Euro+Med Plantbase (https://europlusmed.org/).

3.2. Ecomorphes

Belgard [63] created a typology of forests of the steppe zone of Ukraine in the late 40s of the last century, which is a vivid example of the effectiveness of the application of the principles of biogeocenology and in this sense, this concept should certainly be recognized as structuralist. The typology was supplemented by the system of plant ecomorphs. According to the ideas of Belgard, the ecomorph reveals the relationship between organisms and the environment and reflects the adaptation of individual plant species to the most important elements of biogeocenosis: to the phytocenosis as a whole and to each of the structural elements of the ecotope (thermotope, heliotope, trophotope, hygrotope, thermotope) separately. Any system of life forms (biomorph, ecomorph) has the following broad philosophical basis [64]: a) plants have different ecological amplitudes, i.e. they are more or less limited in their ability to tolerate different environmental conditions; b) there is often a correlation between morphology and adaptation; c) a plant in its successful existence represents what can be called an automatic physiological integration of all factors of its environment. The term ecomorph is preferred because the life form usually refers to adaptations that are expressed in the appearance of the plant, while adaptations not to all structural elements of the biogeocenosis have physiognomic manifestation. Belgard considered ecotope as a combination of climatope and edatope (or edaphotope). He divided climatop into thermotop and heliotop (space factors), edatop (or edaphotop) is divided into trophotop and hygrotop (terrestrial factors).

3.3. Coenomorphes

The plant coenomorph characterizes the adaptation of a living organism to the biogeocenosis as a whole. The plants of the steppe zone of Ukraine are represented by the following coenomorphs:

1) stepants (St) are steppe plants;
2) sylvants (Sil) are forest plants;
3) ruderants (Ru) are plants of weed communities;
4) psammophytes (Ps) are plants of sandy communities;
5) pratants (Pr) are meadow plants;
6) paludants (Pal) are plants of marsh plants;
7) petrophytes (Ptr) are rock plants;
8) halophytoids (Hald) are plants of salt marshes;
9) halophytes (Hal) are plants of salt marshes;
10) calcophytes (Clc) are plants of communities of chalk outcrops;
11) chasmophytes (Chs) are plants of communities of gravelly outcrops;
12) aquants (Aq) are aquatic plants
13) culturants (Cul) are cultivated plants.

In other geographical zones, such coenomorphs as tundrants (Tn) are tundra plants, montants (Mont) are mountain plants, littorants (Lit) are littoral plants on the sea coasts, desert plants (Ds) are desert plants can also be distinguished.

The forest species include the most typical species that make up forest communities. In addition to woody and shrubby plants, sylvants also include grasses, mosses and lichens, which are closely related to the forest environment. Stepants are represented mainly by herbaceous species, as well as some shrubs, mosses and lichens. The vast majority of steppe species are drought-resistant and light-loving, preferring soils with neutral or slightly alkaline reaction. The meadow species (pratans) are herbaceous perennial mesophytes. Pratants differ from forest species by their light ecology. The forest grasses also disappear after the destruction of the forest canopy, and meadow grasses, on the contrary, develop more rapidly. Paludants include mainly herbaceous and moss species that grow in conditions of excessive moisture. Halophytes include semi-shrubs and herbaceous species that live on saline soils and are characterized by light-loving and, as a rule, significant osmotic pressure of cell sap. Ruderants are weeds with diverse ecological properties and usually gravitate to soils with high nitrogen content.

IOP Conf. Series: Earth and Environmental Science 1254 (2023) 012023 doi:10.1088/1755-1315/1254/1/012023

3.4. Terrestrial and cosmic factors
Along with coenomorphs, other ecomorphs are distinguished by the criterion of adaptation to the most essential environmental factors. According to Williams [65], the factors of life of green plants should be divided into two groups:

1) cosmic factors are light and heat;
2) terrestrial factors are water and food.

Therefore, Belgard's system distinguishes ecological groups of plants similar in adaptation to certain cosmic factors:

1) climamorphs are adaptations to climate conditions in general;
2) heliomorphs are adaptations to lighting conditions;
3) thermomorphs are adaptations to the conditions of thermal climate regime.

And ecological groups of plants are similar in adaptation to certain terrestrial factors:

1) trophomorphs are adaptations to soil fertility conditions
2) hygromorphs are adapted to the conditions of humidity regime.

3.5. Climamorphs
Belgard used Raunkiaer life forms [66, 67] as climamorphs: phanerophytes, chameophytes, hemicryptophytes, cryptophytes (geophytes, hydrophytes), therophytes, epiphytes. When choosing the features of life forms for recognition and classification of relationships between plant life and climate, Raunkiaer was guided by three basic rules: a) the feature must be structural and essential; it must represent an important morphological adaptation; b) the trait must be obvious enough to be easily seen in nature to which life form the plant belongs; c) all the life forms used must be of such a nature that they constitute a homogeneous system; they must represent a single viewpoint or aspect of the plants and thus enable comparative statistical treatment of the vegetation of different regions.

Considering these requirements, Raunkiaer differentiated life forms according to the type and degree of protection provided to the growth points of perennial buds, which are responsible for recovery after an unfavorable season. With the exception of some tropical climates that are constantly warm and humid, all of them show a certain seasonal rhythm with alternating periods that are favorable or unfavorable for growth. When comparing two climates, the difference between them in the favorable season may be relatively small, while the differences in the unfavorable season can be significant and of great importance. The unfavorable seasons may be caused by cold or drought, or both, they may be short or long, they may be one or two per year, but it is likely that those structural differences between plants that allow them to survive the unfavorable seasons are a good indicator of the plant climate. Based on these facts, Raunkiaer developed his classification of life forms, which depends primarily on the degree of protection provided to the perennial bud. The system consists of the following five main classes, arranged in accordance with the increased protection of the buds: phanerophytes, chameophytes, hemicryptophytes, cryptophytes and therophytes. Raunkiaer believed that life forms are formed historically as a result of adaptation of plants to climatic conditions of the environment. The percentage distribution of species by life forms in plant communities in the study area is called the biological spectrum. Biological spectra for different physiographic zones and countries serve as indicators of climatic conditions. Raunkiaer classified plants according to where the growing point is located in less favorable seasons, provided that the plant retains the ability to survive these difficult conditions. Depending on the place on Earth, this unfavorable period can be, for example, in the cold winter period or in the dry summer time. In temperate regions, the growth point during the unfavorable season corresponds mainly to winter buds.

3.6. Trophomorphs

Among trophomorphs are distinguished:

1) oligotrophs (OgTr) are adapted to poor soils;
2) mesotrophs (MsTr) are adapted to moderately rich soils;
3) megatrophs (MgTr) are adapted to rich soils;
4) alkalitrophs (AlkTr) are plants of saline physiologically poor soils;
5) parasitic plants (Par), semiparasitic plants (S/par), saprophytes (Sapr) and calciphiles (Ca).

3.7. Hygromorphs

Among hygromorphs are distinguished:

1) euxerophytes (EuKs) are highly drought-resistant species;
2) xerophytes (Ks) are drought-resistant species;
3) mesophytes (Ms) are plants of moderate moisture environment;
4) hygrophytes (Hg) are amphibious species;
5) pleistophytes (Pl) are aquatic plants with floating leaves;
6) hydatophytes (Hy) are plants completely immersed in water.

The transitional forms can be named through the combination of two hygromorphs that are located next to each other. In this case, the leading mode is denoted by the second one, and the auxiliary mode is denoted by a prefix, for example: xeromesophytes – mesophytes that are more drought-resistant than ordinary mesophytes, or: mesohygrophytes – hygrophytes that are able to exist in more arid conditions.

3.8. Moisture variability

The ecological analysis of floodplain ecosystems cannot be complete without taking into account the floodplain factor. Therefore, it is necessary to distinguish between floodplain ecomorphs, namely:

1) extra-floodplain species – occur mainly outside the floodplain;
2) short floodplain – characteristic of floodplains where the flood lasts no more than 10 days
3) medium floodplain – species can withstand floods that last no more than 40 days;
4) long floodplain – withstand floods that last more than 40 days.

The duration of the flood depends on the size of the river: in small rivers it lasts no more than 10 days, in large rivers the flood can last more than 40 days. The number of species that are able to adapt to flooding decreases in proportion to its intensity. Therefore, the species diversity of floodplain communities decreases from short floodplain ecosystems to long floodplain ecosystems. Therefore, the diversity of plant communities in short floodplain ecosystems of small rivers is higher than in long floodplain ecosystems of large rivers.

3.9. Heliomorphs

Among heliomorphs are distinguished:

1) heliophytes (He) are light-loving species;
2) scioheliophytes (ScHe) are light-tolerant species;
3) heliosciophytes (HeSc) are shade-tolerant species;
4) sciophytes (Sc) are shade-loving species.

3.10. Thermomorphs
Among thermomorphs are distinguished:

1) microtherms (MT°) are species originating from the polar geographical climatic zone;
2) mesotherms (MsT°) are species originating from the temperate zone;
3) megatherms (MgT°) are species originate from subtropical or tropical zones;
4) eurytherms (EuT°) are species that can grow in almost all climatic zones of the Earth.

3.11. Generative ecomorphs
These ecomorphs mainly reflect adaptation to growth conditions, so they can be called vegetative. Along with vegetative ecomorphs, there are generative ecomorphs, which characterize the attitude of species to pollination and spread of diasporas. The problem of creating a system of generative ecomorphs was solved by Tarasov [68].

Pollenochores are groups of plants that are distinguished by the type of pollination (for spore plants – by the type of gamete transfer). Among them are distinguished:

1) autogamy plants (Ah) – self-pollinated;
2) hydrophilous plants (Hdph) – pollination is carried out with the help of water;
3) gametohydrophilous plants (Hdgph) – gamete transfer occurs in the aquatic environment;
4) anemophilous plants (Anph) – pollen is distributed by wind;
5) entomophilous plants (Ent) – pollen is distributed by insects;
6) protandrous plants (Pa) – earlier maturation of pollen compared to the stigmas of pistils in plant flowers. It is an adaptation to cross-pollination.
7) protogynous plants (Pg) – earlier maturation of stigmas in the flowers of plants compared to pollen.

Diasporochores (ecobiochores) is a group of plants that are distinguished by the types of plant diaspora dispersal. According to the ways of diaspore dispersal, they are distinguished:

1) endozoochory (EndZ) – transfer of seeds by animals after eating and defecation;
2) synzoochory (SynZ) – transfer of plant fruits by animals when they harvest stocks.
3) myrmekochory (Myrm) – transfer is carried out by ants;
4) epizoochory (EpZ) – transfer on the surface of animals, diaspores are tenacious;
5) anemochory (Anch) – spreading of seeds, fruits and plant spores by air;
6) hydrochory (Hdch) – diaspores are transported by water;
7) autochory (Ach) – self-dispersing plants spread fruits, seeds, spores and vegetative parts of the plant organism with the help of the plant itself without the action of external agents; distinguish between active seed dispersal from a cracked ripe fruit (mechanochory), burying of fruits in the soil (geocarpy), shedding of fruits and seeds only under the influence of gravity (barochory);
8) barochory (Bar) – a kind of autochorus, shedding of fruits and seeds only under the influence of gravity;
9) ballistochory (Bal) – diaspores are scattered by elastic stalks when shocked;
10) geochory (Gch) – diaspores crawl and burrow into the ground, changing their shape;
11) cryptogeochory (KrGch) – hidden geochorus;
12) pervolvent (Perv) – movement of a plant under the influence of wind due to its rolling (tumble-field);
13) anthropochory (Antrch) – spreading of seeds, fruits and plant spores by humans.

4. Results

4.1. Climamorphs

In the park, 166 species of vascular plants were found, which are represented by phanerophytes (19.9%), nannophanerophytes (8.4%), hemicryptophytes (40.4%), geophytes (11.4%), theorophytes (18.7%) and geolophytes (1.2%) (figure 1). *Acer negundo* L., *Acer platanoides* L., and *Robinia pseudoacacia* L. were the most common among phanerophytes. Among nannophanerophytes, *Parthenocissus quinquefolia* (L.) Planch. and *Sambucus nigra* L. were the most common. The most numerous among hemicryptophytes were *Alliaria petiolate* (M.Bieb.) Cavara et Grande, *Anthriscus sylvestris* (L.) Hoffm., *Chelidonium majus* L., *Geum urbanum* L., and *Viola odorata* L.. Among therophytes the most numerous were *Galium aparine* L., *Impatiens parviflora* DC., *Stellaria media* (L.) Vill. Among geophytes the most numerous were *Cirsium arvense* (L.) Scop. and *Humulus lupulus* L. Helophytes were represented by only two species – *Phragmites australis* (Cav.) Trin. ex Steud. and *Sium latifolium* L..

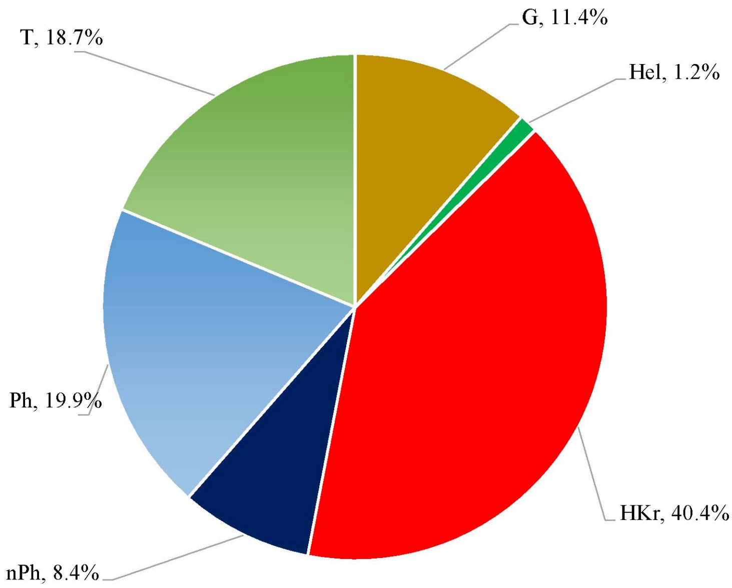

Figure 1. Structure of life forms according to Raunkier (climamorphs): Ph is phanerophyte; nPh is nannophanerophyte; Ch is chameophyte; HKr is hemicryptophyte; T is therophyte; G is geophyte, Hel is helophyte.

4.2. Coenomorphs

Sylvants (35.5%) predominate among the coenomorphs, with slightly less pratants (22.3%), ruderants (18.7%) and stepants (14.5%). Cultivants (3.0%), psammophytes (3.0%) and paludants (3.0%) were occasionally found. Sylvants prevail among phanerophytes (figure 2). The proportion of sylvants among nannophanerophytes was also high. The proportion of stepants, which varied in the range of 12.9–21.4% was established for nannophanerophytes, hemicryptophytes, geophytes and therophytes. The pratants dominated among hemicryptophytes (35.8%). The ruderants dominated among therophytes and geophytes (31.6 and 45.2% respectively). Helophytes were represented by paludants. The highest coenomorphic diversity was found for hemicryptophytes (2.24), with a slightly lower diversity for therophytes and geophytes (2.02 and 2.26, respectively). The lowest coenomorphic diversity was characteristic of phanerophytes and nannophanerophytes. Naturally, the diversity of helophytes,

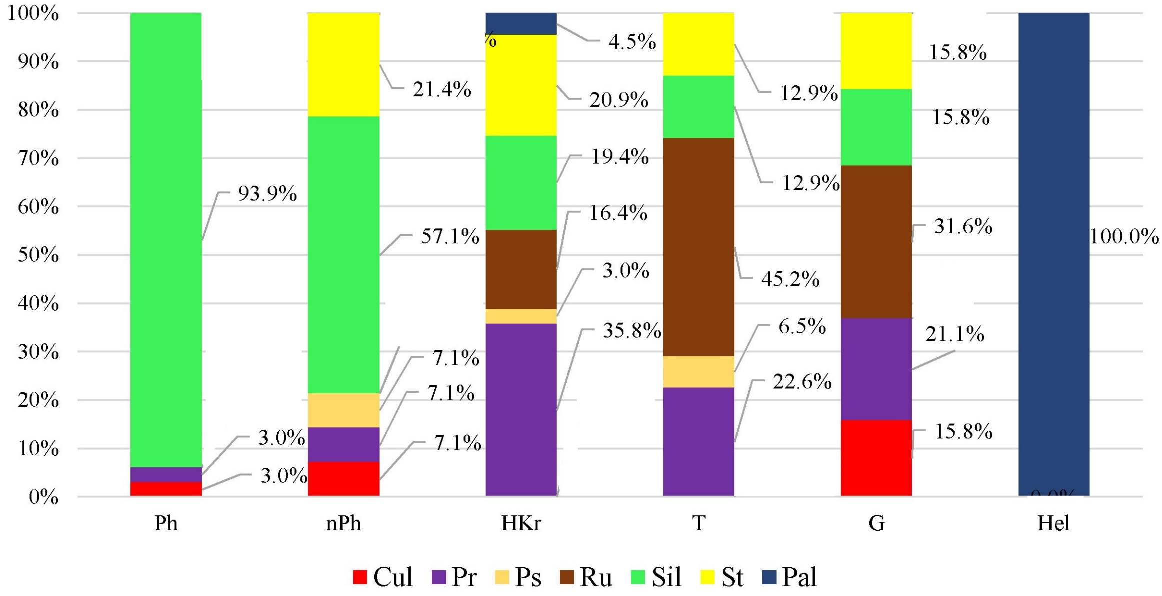

Figure 2. Structure of coenomorphs: Cul are culturants; Pr are pratants; Pal are paludants; Ps are psammophytes (psamants); Ru are ruderals; Sil are silvants; St are stepants. Ceonomorphic diversity: Ph – 0.39, nPh – 1.75, HKr – 2.24, T – 2.02, G – 2.26, Hel – 0. Specific diversity: Ph – 0.08, nPh – 0.46, HKr – 0.37, T – 0.41, G – 0.53, Hel – 0.

which are represented by only two species, was equal to zero. The lowest specific diversity was characteristic of phanerophytes, and the highest was characteristic of geophytes.

4.3. Hygromorphs

The proportion of xeromesophytes and mesophytes was the highest (32.5 and 31.3% respectively). The proportion of mesoxerophytes was also relatively high (28.3%). The proportion of other hygromorphs was relatively low. The hygromorphic structure of phanerophytes and nannophanenophytes was almost identical. These climamorphs were represented mainly by the mesophytes. The hygromesophytes were represented among hemicryptophytes and geophytes (6.0 and 10.5 % respectively). The therophytes were characterized by a low proportion of mesophytes due to the increase in the proportion of xeromesophytes. The helophytes were represented by the hygrophytes and mesohygrophytes. The hygromorphic diversity was the highest among hemicryptophytes, and the lowest among therophytes and helophytes. The lowest specific diversity was typical for phanerophytes, and the highest was typical for geophytes. The specific diversity of climamorphs showed no significant differences.

4.4. Trophomorphs

The trophomorphs were represented mainly by mesotrophs (71.1%) and a slightly smaller proportion of megatrophs (22.3%). The oligotrophs were found occasionally (6.6%). The proportion of megatrophs was the highest among phanerophytes (30.3%) and hemicryptophytes (26.9%) (figure 4). Accordingly, these climamorphs were the most demanding to soil fertility. The proportion of oligotrophs was the highest in nannophanerophytes (14.3%). The helophytes were represented exclusively by the mesotrophs. The level of trophomorph diversity was at the same level for all climamorphs, except for helophytes.

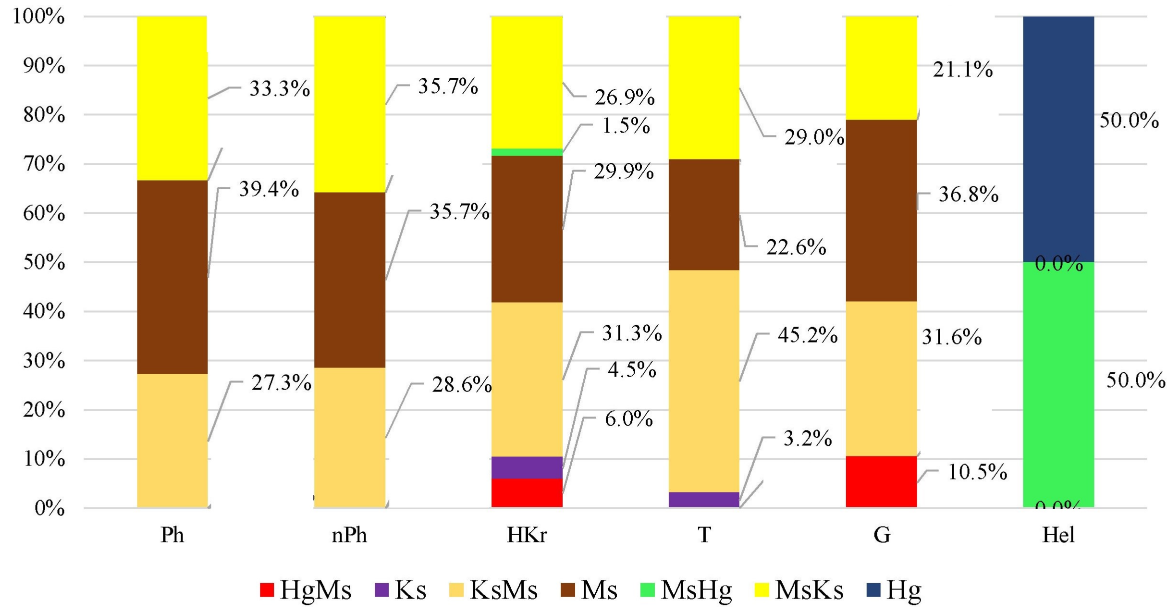

Figure 3. Structure of hygromorphs: Ks are xerophytes; MsKs are mesoxerophytes; KsMs are xeromesophytes; Ms are mesophytes; HgMs are hygromesophytes, MsHg are mesohygrophytes. Hygromorphic diversity: Ph – 1.57, nPh – 1.58, HKr – 2.09, T – 1.68, G – 1.87, Hel – 1. Specific diversity: Ph – 0.31, nPh – 0.41, HKr – 0.34, T – 0.34, G – 0.44, Hel – 1.

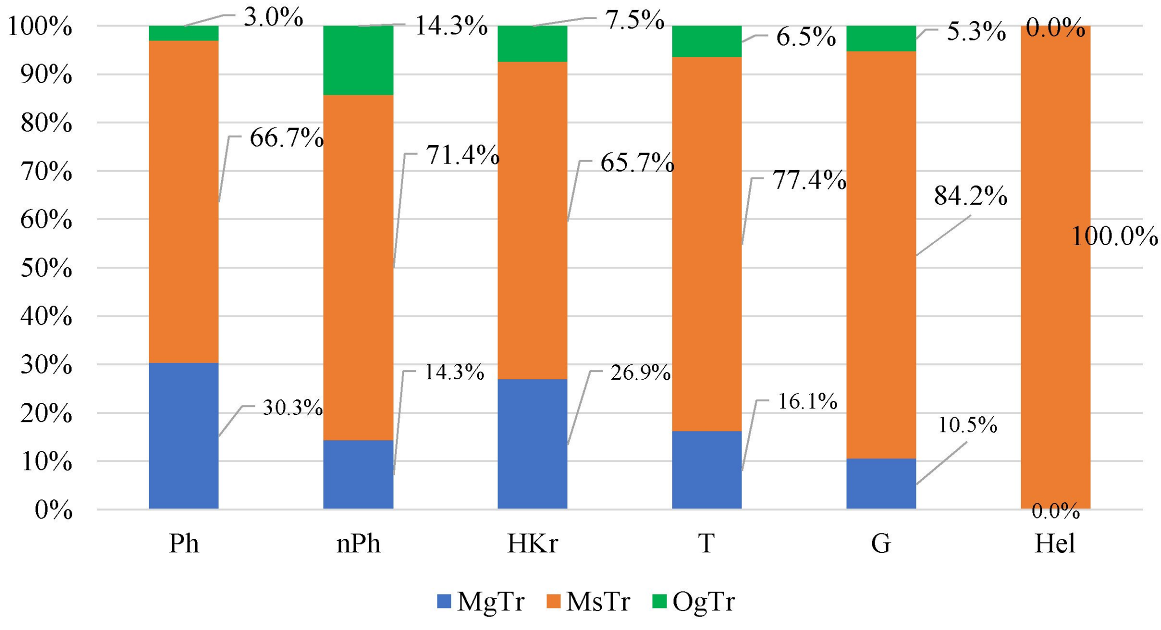

Figure 4. Structure of trophomorphs: MgTr are megatrophs; MsTr are mesotrophs; OgTr are oligotrophs. Trophomorphic diversity: Ph – 1.06, nPh – 1.15, HKr – 1.19, T – 0.97, G – 0.77, Hel – 0. Specific diversity: Ph – 0.21, nPh – 0.3, HKr – 0.2, T – 0.19, G – 0.18, Hel – 0.

The greatest diversity was typical for the hemicryptophytes. The lowest specific diversity was characteristic of the geophytes, and the highest was characteristic of the nannophanerophytes.

4.5. Heliomorphs
Sciogeophytes (57.2%) and heliophytes (30.1%) prevailed among heliomorphs. The proportion of sciophytes and heliosciophytes was much lower (3.6 and 9.0 %, respectively). The proportion of heliophytes was the highest among terophytes, geophytes and helophytes (figure 5). The proportion of heliophytes was lowest for nannophanerophytes. The highest proportion of sciophytes was found for hemicryptophytes. Sciophytes should be noted to be also found among the therophytes and geophytes. The highest proportion of heliosciophytes was among phanerophytes. The greatest heliomorphic diversity was typical for the hemicryptophytes. This diversity was also quite high for therophytes and geophytes. Nannophanerophytes were the least diverse in terms of light level preferences. The lowest specific diversity was typical for nannophanerophytes, and the highest was typical for geophytes.

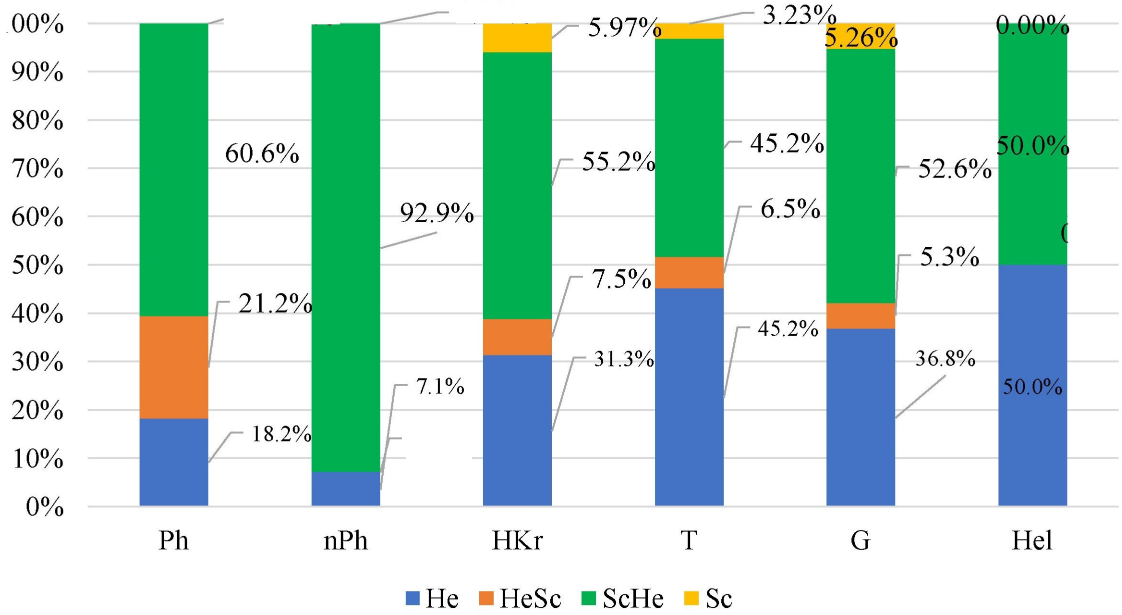

Figure 5. Structure of heliomorphs: HeSc are heliosciophytes; ScHe are scioheliophytes; He are heliophytes, Sc are scioheliophytes. Heliomorphic diversity: Ph – 1.36, nPh – 0.37, HKr – 1.52, T – 1.45, G – 1.47, Hel – 1. Specific diversity: Ph – 0.27, nPh – 0.10, HKr – 0.25, T – 0.29, G – 0.34, Hel – 1.

4.6. Pollenochores
Entomophilous plant species were the most common among the vegetation cover of the park (71.7%). Anemophilous plants were significantly inferior to them (26.5%). Autogamous and hydrophilous plants were found occasionally (1.2 and 0.6% respectively). The entomophilous species were most common among nannophanerophytes (92.9%) (figure 6). The anemophilous species were most commonly found among phanerophytes and helophytes (39.4 and 50.0%, respectively). The hydrophilous species were found among geophytes. The autogamous species were found among therophytes. Pollenochoric diversity was the highest among geophytes. The lowest specific diversity was characteristic of nannophanerophytes, and the highest was characteristic of geophytes.

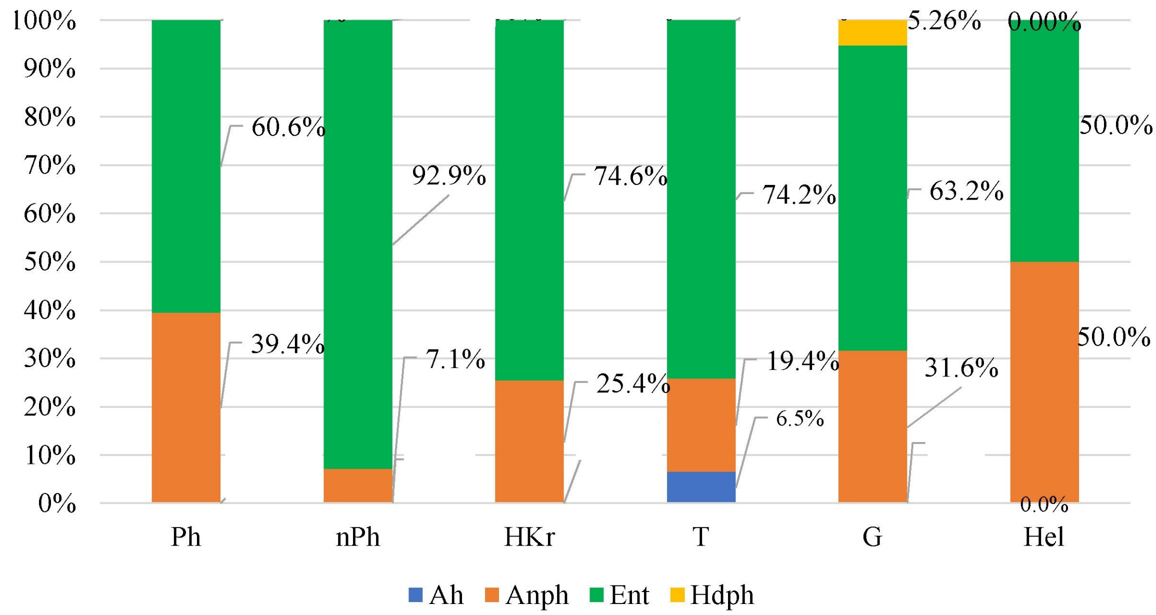

Figure 6. Structure of pollenochorus: Ah are autogamous plants; Anph are anemophiles; Ent are entomophiles, Hdph are hydrophilus plants. Pollenchoric diversity: Ph – 0.97, nPh – 0.37, HKr – 0.82, T – 1.03, G – 1.17, Hel – 1. Specific diversity: Ph – 0.19, nPh – 0.1, HKr – 0.13, T – 0.21, G – 0.27, Hel – 1.

4.7. Diasporochores

Ballistic diasporeochores prevailed among diasporeochores (39.8%). The proportion of anemochores and endozoochores was somewhat lower (27.7 and 12.0% respectively). Other diasproochores accounted for 0.6–4.8 of the total number of species. Endozoochores were mainly found among nannophanerophytes (78.6%). Among phanerophytes, anemochores were mainly found (60.6%). Among herbaceous species, ballistic species prevailed (47.4–56.7%). The highest diasporechoric diversity was found for hemicryptophytes. The lowest specific diversity was characteristic of nannophanerophytes, and the highest was characteristic of geophytes.

5. Discussion

In ecology, there are two alternative perspectives on the nature of ecological communities: continualism and structuralism [69].

Continualism considers the response of an organism to the effects of environmental factors as a species-specific property, which is generally described by a bell-shaped curve [70–72]. Hence, it is natural to conclude about living organisms as indicators of environmental properties, which became the basis for the creation of many indicator scales [73]. One of the first such scales was created by Ramenskiy, the founder of continualism [74]. Other phytoindicator scales differ in their resolution, the list of environmental properties indicated, and the aspect of the species response curve to an environmental factor: whether it is an optimum zone based on which Ellenberg scales are indicated [75–77], or whether it is the range of the factor within which the species can exist, as provided in the range scales of Tsyganov [78] or Didukh [79]. The principles of phytoindication are a practical consequence of biotope theory [80–82] according to which biocenosis [83,84] depends on the observed physical properties of the environment [85–87]. And an ecosystem, in turn, is a combination of biotope and biocenosis. Within the framework of structuralism, environmental factors take a second place and the intrasystem interactions

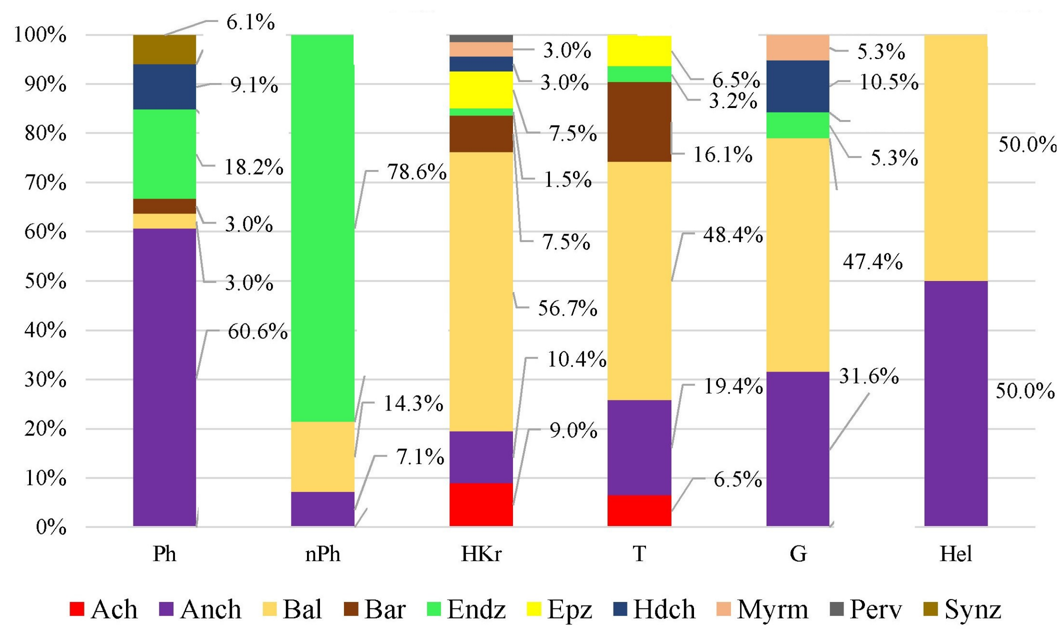

Figure 7. Structure of diasporochores: Ach are autochores; Anch are anemochores; Bal are ballistae; Bar are barochores; Endz are endozoochores; Epz are epizoochores; Hdch are hydrochores; Myrm are myrmecochores; Synz are synzoochores. Diasporochorous diversity: Ph – 1.75, nPh – 0.95, HKr – 2.16, T – 2.06, G – 1.82, Hel – 1. Specific diversity: Ph – 0.35, nPh – 0.25, HKr – 0.36, T – 0.42, G – 0.43, Hel – 1.

are advanced, which leads to explaining the observed boundaries of plant communities as those of an endogenous nature [88]. The most orthodox branch of structuralism is Sukachev's biogeocenology [89–91].

More recently, the conflict between continuism and structuralism has taken the form of a competition between ecological niche theory [92] and neutral diversity theory [93]. The constructive position of this confrontation is to soften the problem, namely, which of the alternative representations is the only true and which is false [94]. The solution moves to the question of under what circumstances one of the views explains a greater range of observable facts than the other, and under what circumstances the priority goes to the competing viewpoint.

Biogeocenosis is a combination of biocenosis and ecotope [91]. The term ecotope was coined by Vysotsky [95], but in English-language literature Sørensen [67] or Tansley [96] are considered as its authors. An ecotope is the smallest unit of the Earth's surface that possesses homogeneity of at least one property of the geosphere: atmosphere, vegetation, soil cover, rocks, water, etc., with a non-extreme variation of other properties [97]. Ramensky [98], along with ecotope (habitat), which is determined by direct acting factors (heat, light, aeration, nutrient, soil reaction, salinity), distinguishes entopia (location), which is determined by the indirect topological conditions. In the tradition of biogeocenology, an ecotope includes a climatope and an edaphotope. The climatotope, in turn, consists of a heliotope and a thermotope, and the edaphotope consists of a hygrotop and a trophotope [89]. Sukachev [90] considers a biotope as the zoological equivalent of the botanical term ecotope. However, the history and practice of using these terms allow them to be interpreted as the equivalent of abiotic properties of the environment within the framework of continuism (biotope is a component part of the dimensionless concept of ecosystem) and abiotic properties of the environment transformed by biota (ecotope is a component part of biogeocenosis as ecosystem within the boundaries of phytocenosis) within structuralism. In the late forties of the last century, Belgard [63] created the typology of the forests of the steppe zone of Ukraine, which is a bright example of the effectiveness of the principles of biogeocenology and in this sense this concept should certainly be recognized as structuralist. The typology was supplemented by the system of plant ecomorphs.

According to Belgard's ideas, an ecomorph reveals the relationship between organisms and the environment and reflects the degree of their adaptation to the most important elements of the biogeocenosis. The term ecomorph is preferred because the life form usually refers to adaptations that are expressed in the external form of the plant, whereas adaptations to all structural elements of the biogeocenosis do not have a physiognomic manifestation. The key feature of the Belgrad system of ecomorphs is the coenomorph which is the adaptation of plant species to the phytocoenosis as a whole [99]. The ecomorph system has been extended to other components of the biogeocenosis [100–103], which allows us to interpret coenomorph as adaptation of biotic and bioinert component of biogeocenosis to the biogeocoenosis as a whole. In turn, the adaptivity is defined as the responses of various objects to the environmental factors, which manifests itself in changes in the structure and functions of responding objects and their groups in response to various changing conditions, resulting in the maintenance of their existence [104]. Coenomorphs are distinguished along with adaptations to the most essential environmental factors such as climate (climomorphs), light regime (heliomorphs), thermal regime (thermomorphs), soil fertility (trophomorphs), and moisture regime (hygromorphs) [105]. The boundaries of the gradations of the corresponding factors are determined by the internal integrity of such categories as forest type, which in essence is equivalent to the concept of biogeocenosis type [106]. These gradations were proposed by Matveev [107] to represent in a score form and use for the purpose of phytoindication of the corresponding environmental factors. However, Belgard developed a system of ecomorphs primarily to assess the condition of the biogeocenosis as a whole. The spectra of hygromorphs, trophomorphs, climomorphs, thermomorphs, heliomorphs within a particular coenomorph illustrate the idea that under conditions of varying environmental properties a biogeocenosis can preserve its integrity and identity [108, 109]. Therefore, attempts to interpret coenomorphs as a tool for phytoindication of biotopes [110] are somewhat inconsistent with the purpose of this concept and the nature of ecological groups that are denoted by this term. Assuming that coenomorphs are discrete representations of the ecological continuum of plant organisms, this concept carries no additional information and is therefore degenerate for indicating biotope properties. In such a case, there is no objective criterion for distinguishing coenomorphs and, ultimately, their number and quality can be arbitrary. Often, a concept such as an ecological and cenotic group is used as an equivalent of the term coenomorph, or they refer to the ecological and cenotic relationship of a species. However, such a position is subject to criticism on the basis of the conceptual essence of the term, which implies the conditions of existence of biological objects, rather than their association with something [111]. Therefore, it is critically noted that the floristic studies should either abandon the use of community names to denote the habitat of individuals or their populations at all, or justify the possibility of their use in an ecological sense [112, 113]. If coenomorphs are discrete classes of plant species that are separated from each other to a greater extent than can be assumed based only on the continuum nature of ecological differences between species, then information on the coenomorphic membership of a species and, consequently, the coenomorphic structure of a community, can carry additional information for indicating the properties of an ecotope [114, 115].

Our results indicate a high level of plant community diversity within the city park. The plant community is represented by the different ecological groups. The tree layer is represented by phanerophytes, in the undergrowth predominantly nannophanerophytes are represented. The grass stand is represented by hemicryptophytes, geophytes, therophytes and helophytes. The wide ecological diversity of plant climomorphs in the park plantation indicates a potential for sustainability of this plant complex. On the other hand, the climomorphic structure indicates the presence of a permanent disturbance regime in the park plantation, which manifests itself in an increase in geophytes and thermophytes. It should be noted that the helophytes are represented by only two plant species. In the natural state along the thalweg of the gully, on the basis of which the city park was formed, a stream flowed, so the diversity of helophytes could be much higher. The low diversity of helophytes indicates a significant transformation of the landscape cover of the urban environment.

The ecomorphic analysis is applied to analyze the plant community as a whole. We applied the ecomorphic approach to the differential analysis of plant community climomorphs. The climomorphs were found to differ significantly in their ecomorphic structure. Thus, phanerophytes and nannophanerophytes differ from herbaceous layer plants in their coenomorphic structure. The phanerophytes are expectedly represented by the silvants. The diversity of coenomorphic structure of nannophanerophytes increases due to the growing proportion of steppants. The steppe shrubs usually form marginal complexes of forest communities in steppe, which ensures their ecological stability. An increase in the proportion of steppes among nannophanerophytes can be regarded as an element of maintaining the sustainability of artificial forest plantations in urban environments. Among herbaceous plants, the proportion of steppe and meadow species is systematically high, while the proportion of forest species is insignificant. This structure emphasizes the amphicenotic nature of the plant community structure. The cenotic elements of different nature have priority in different horizontal layers of the community. Among the therophytes, the ruderants predominate. This advantage is carried out against the background of a decrease in the proportion of silvants. Thus, the disturbance of ecological regimes, which provide the forest type of the cycle of substances and energy flow, leads to ruderalization of the ecological environment of the park plantation.

Phanerophytes and nannophanerophytes are represented by the mesoxerophytes, xeromesophytes and mesophytes. In plant layers the proportion of both mesoxerophytic and mesophytic hygromorphs decreases, but the proportion of xeromesophytic hygromorphs increases. This trend should be regarded as a decrease in the tolerance of herbaceous cover to the moisture conditions. The structure of trophomorphs is rather stable in the section of climomorphs. The plant community of the park plantation is mesotrophic.

The plant community is dominated by sociogeliophytes and the highest proportion of this heliomorph is characteristic of nannophanerophytes. The diversity of phanerophytes in comparison with nannophanerophytes increases at the expense of heliophytes, and the diversity of the herbaceous layer increases at the expense of both heliophytes and sociophytes. It is obvious that the forest stand of park plantation forms a wide variety of crown architectonics, which creates conditions for life of both light-loving and shade-loving species of herbaceous plants. A competitive strategy for the tree species is to adapt to the deficit of light under the canopy of other tree species. Obviously, a mosaic of light conditions is a characteristic of park plantings. Continuous park plantation management procedures prevent the development of a dense canopy of woody species that is observed in natural forests.

The predominance of entomophilous plant species in park plantations raises the problem of comprehensive protection of the animal component in urban forests. It is also important to note the potential of the plant community as a factor supporting animal diversity in the urban environment. Significant differences are observed between phanerophytes and nannophanerophytes with respect to diaspore structure. The diaspores of park plantation phanerophytes are distributed predominantly by wind, while the diaspores of nannophanerophytes are distributed predominantly by animals. The phanerophytes of the regional flora are represented by anemochores in 59.6% of cases and by endozoochores in 19.2% of cases, which is fully consistent with the values found in the park plantation. In turn, among phanerophytes in the park, there are almost twice as many synzoochores as in the regional flora (6.1% vs. 3.85%). The endozoochores are also more typical for the park plantation nannophanerophytes than for this climomorph in the regional flora as a whole (78.6% vs. 66.67%). At the same time, the nannophanerophytes of the park plantation are twice as rarely represented by the anomochores as is observed in the regional flora (7.1% vs. 14.6% in the regional flora). Among the hemicryptophytes, the anemochores occur much less frequently than in the regional flora (10.4% vs. 20.8% in the regional flora), whereas among the park's therophytes and geophytes, the anemochores occur more frequently than in the regional flora (19.4% vs. 9.9% in the regional flora for therophytes and 31.6% vs. 20.8% in the regional flora for geophytes). Thus, the park plantation has a specificity of its diaspore structure. It consists in the increased role of zoogenic factor for diaspore dispersal for phanerophytes and nannophanerophytes, the increased role of wind in geophyte and terrorophyte dispersal and the decreased role of wind in hemicryptophyte dispersal.

6. Conclusion

The ecomorphic approach was developed to analyze the structure of natural plant communities. This method was applied to analyze the ecological structure of an artificial park plantation in an urban environment. The results obtained allow to discover the essential ecological features of the park plantation. The park plantation has many features that bring it closer to natural forests. The similarity consists in a significant proportion of silvants, shade-loving species, and mesotrophs. A significant level of anthropogenic impact can be diagnosed on the basis of information about the increased proportion of ruderants in the plant community. The differential analysis of the ecomorphic structure in the section by climorphs is of considerable value. This approach allowed to detect an increased role of the zoogenic factor in the distribution of diaspores of phanerophytes and nannophanerophytes and an increased role of wind in the dispersal of geophytes and therophytes. The role of wind is reduced in the dispersion of hemicryptophytes in the urban environment.

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4th International Conference on Sustainable Futures: Environmental, Technological, Social and Economic Matters

To cite this article: S O Semerikov *et al* 2023 *IOP Conf. Ser.: Earth Environ. Sci.* **1254** 011001

Innovations in energy systems and sustainable technologies