https://doi.org/10.32056/KOMAG2023.1.7

The diversity and plant species composition of the spontaneous vegetation on coal mine spoil heaps in relation to the area size

Received: 13.03.2023

Accepted: 03.04.2023

Published online: 03.04.2023

Gabriela WOŹNIAK [1], **Jawdat BAKR** [2*], **Artur DYCZKO** [3], **Jacek JAROSZ** [3], **Karolina RYŚ** [1], **Łukasz RADOSZ** [1], **Szymon KAUL** [1], **Kamila ADAMIK** [1], **Lynn BESENYEI** [4], **Dariusz PROSTAŃSKI** [5]

Author's affiliations and addresses:

[1] Institute of Biology, Biotechnology and Environmental Protection, Faculty of Natural Sciences, University of Silesia in Katowice; Jagiellońska 28, 40-032 Katowice, Poland

[2] Technical Institute of Bakrajo, Sulaimani Polytechnic University SPU Qrga Wrme Street-327/76 46001-Sulaymaniyah, Kurdistan Region, Iraq

[3] Mineral and Energy Economy Research Institute, Polish Academy of Sciences; J. Wybickiego 7A, 31-261 Kraków, Poland

[4] Faculty of Science & Engineering, University of Wolverhampton; Wulfruna Str., Wolverhampton WV1 1LY, United Kingdom

[5] KOMAG Institute of Mining Technology, Pszczyńska 37, 44-101 Gliwice, Poland

*** Correspondence: Jawdat Bakr**
e-mail: jawdat.bakr@spu.edu.iq

Abstract:

Any newly created area includes human-created habitats such as the mineral material of post-coal mining spoil heaps undergoing natural colonization and ecosystem development during the succession processes of vegetation colonization. The study of the factors that influence the succession dynamics, and the mechanisms behind this, have a long history (including the species-area relationship or Arrhenius equation). Nevertheless, the list of scientific questions is increasing. One of the significant issues in the study of these processes is the relationship between factors influencing the Biodiversity–Ecosystem Functioning (BEF) relationships. The main prerequisite is the relationships between the plant species' assemblage mechanisms including diversity and the variety of assembly rules concerning the environmental abiotic habitat processes and these properties are not straightforward. At the large scale, parameters such as age and area of the colonized sites are considered to be important. These relationships are more complicated in newly established post-mineral excavation habitats where novel ecosystems are developing. Regardless of the degree of disturbances, vegetation re-establishes in such environments, as a result of spontaneous succession, by the colonization and establishment of the best-adapted organisms. In the habitats of post-coal mining spoil heaps with pure oligotrophic mineral conditions, the non-analogous, newly formed composition of flora, fauna, and saprophytes has been stated in many previous field studies. This study aimed to explore the biodiversity *versus* area size relationships, in particular, it investigated the species composition and diversity found in the development of the spontaneous vegetation formed during primary succession on mineral substrate habitats of post-coal mining spoil heaps of different area sizes. We tested the hypothesis: species diversity of the vegetation patches on coal mine spoil heaps becomes more diverse on larger sites over time. These results indicate that the area size of the spoil heap significantly affects the diversity of the vegetation. Regardless of which of the characteristics of the vegetation type (dominant species) is compared, the vegetation on the heaps differs depending on its area size.

Keywords: species-area relationship, Arrhenius equation, spontaneous succession, biodiversity–ecosystem functioning, non-analogous species composition, novel ecosystems.

Publisher: **KOMAG Institute of Mining Technology, Poland**

1. Introduction

In the urban-industrial landscape, it is possible to observe diverse natural, semi-natural and anthropogenic habitats that are undergoing natural ecosystem successional processes (Fig. 1). The change in plant species composition of spontaneous vegetation is a process which depends on many factors. The successional development is indicated by the sequential appearance and replacement of plant species assemblages that follow a disturbance event or the establishment of new land. The new habitat, and new area, can be the consequence of natural, or human, activity [1-4]. The biomass established as a result of primary production is the prerequisite of a heterotroph's (all grazing animals) survival. While the biochemistry of the organic matter of autotrophs and heterotrophs is the factor that shapes the saprophytic species composition and the process associated with the decomposition of organic matter e.g., bacteria, fungi, and mesiofauna assemblage that are consequently causing environmental changes in the substrate [5]. The feedback changes in biotic and abiotic environmental parameters induce the change in matter and energy flow during an ecosystem's successful development. These dynamic processes have led to intense discussion and to further studies on biodiversity–ecosystem functioning (BEF) relationships [6], which have now focused on a wide range of ecosystem functions (e.g. biomass production, carbon sequestration, litter decomposition, water retention, nutrient cycling, global change resistance) [7,8]. Clarifying the causality that is underlying the relationships between the plant species assemblage's mechanisms including diversity and the variety of possible assembly rules and environmental abiotic habitat processes and properties is not straightforward [9]. This is because synergetic influences and inherent feedback mechanisms between species assemblages, the structure of communities and the environment's biotic and abiotic parameters are all involved [10].

Human activity, mostly urbanization and industrialization, affects a vast area of the Earth's surface [11-13]. Many of Earth's landscapes, existing vegetation and the abiotic and biotic soil components have been disturbed or destroyed [14]. Frequently the resulting anthropogenic habitats provide unique conditions such as no soil profile, inadequate water conditions in the soil substrate, high salinity, lack of nutrients and diasporas, and a unique microclimate [15-20].

The plant species compositions and spatial distribution of the vegetation of novel ecosystems of post-industrial areas (e.g. coal mine spoil heaps) are usually different from that of plant communities known from natural and semi-natural habitats which makes it difficult to classify them using the accepted phytosociological (socio-ecological) which describe naturally occurring plant communities. Regardless of the degree of the disturbance, plants return to such habitats as a result of spontaneous succession that enhances the colonization and establishment of the best-adapted organisms. In these unusual habitats of pure oligotrophic mineral conditions, the non-analogous newly formed flora, fauna, and saprophytes has been described from many previous empirical studies [1,21-24]. The novel ecosystems which establish on these *de novo* sites differ significantly from the original and surrounding habitats [25-27]. These novel ecosystems become established as a consequence of differences in the physical and chemical properties of the primary substrate and thus the new soil substrate parameters [20,28,29].

This fact makes it difficult to assign them to commonly known phytosociological units of Braun-Blanquet system. A characteristic feature of the vegetation growing on coal mine spoil heaps is the mosaic of different vegetation patches which are dominated by various species confined to a variety of microhabitats [30-32]. The abundance of the dominant plant species causes the distinctiveness of each particular vegetation patch. The dominant species originate from a wide range of habitats, including aquatic, swamp, mire and marsh, as well as those from dry meadows and other grassland communities, stony gravel communities, and ruderal habitats. For the vegetation growing on the studied areas of post-coal mine spoil heaps, the most precise diagnosis is the identification of the dominant plant species, which determines the physiognomy of each distinctive vegetation patch. The dominant plant species (in terms of their percentage cover abundance) can be accompanied by numerous other species with varied abundances [32,33].

Fig. 1. The mineral materials of coal mine spoil heaps provide an environmental island within the urban-industrial landscape. The human-created habitats undergoing natural ecosystem succession and developing into novel ecosystems (Photo: G. Woźniak)

Natural succession is the process of gradual change within plant species assemblages and the associated organisms that are best adapted to the current biotic and abiotic habitat conditions. In natural and semi-natural conditions, the mechanisms of primary and secondary succession are relatively well understood [4]. At the large scale, time and area significantly influence the vegetation and species composition during the development of succession. There have been many studies focused on time as an important factor. There are fewer studies which consider the size of the area of a site that is undergoing colonization and succession as a significant factor influencing the colonization, establishment and persistence of species. In natural and semi-natural habitats, the dependence of the number of species on the size of the study area has long been known as the species – area relationship (SAR) [34]. Succession processes take place on all types of habitats and in all types of ecosystems, from water and wetland habitats, oceans, deserts, salt marshes to tundra, and rainforests. During succession, a pattern of changes is expected and appropriate for a particular habitat and ecosystem type whenever a new habitat becomes available or whenever an environment is disturbed.

For habitats developing on the sites of post-mineral excavation and other man-made sites, less research has been done to specify the Species – Area Relationship (SAR) and more studies are needed to address such relationships.

The aim of this study was to explore the composition of the vegetation and species composition diversity of the spontaneously developing *de novo* habitats on post coal mine spoil heaps of different heap areas and to investigate some aspects of their functional diversity during the primary succession process.

We tested the hypothesis on coal mining heap sites in Upper Silesia that species diversity of the vegetation patches will become more diverse on larger sites as the SAR Arrhenius concept suggested.

2. Methods

2.1. Study area

The study was conducted on one type of post-industrial mineral excavation site: coal mine spoil heaps, located in the Upper Silesia coal mining district (Poland) (Fig. 2). The study area lies in the transitional climate zone between a temperate oceanic climate in the west and a temperate continental climate in the east. The mean annual temperature fluctuates between 7 and 9°C and precipitation varies between 700 and 900 mm. The vegetation season (days with average temperature > 5°C) is between 210 and 220 days [33].

A total of 112 post-coal mining sites were studied in the area. The studied heaps were of carboniferous rock and were composed mainly of claystone, siltstone, sandstone, conglomerate, coal shale, and small quantities of coal [33,35]. The surface of most of the heaps was characterized by longitudinal elevations and depressions established by the heaping process. The resulting vegetation had developed spontaneously since heaping and there were no subsequent manipulations of the heap substrates at the studied.

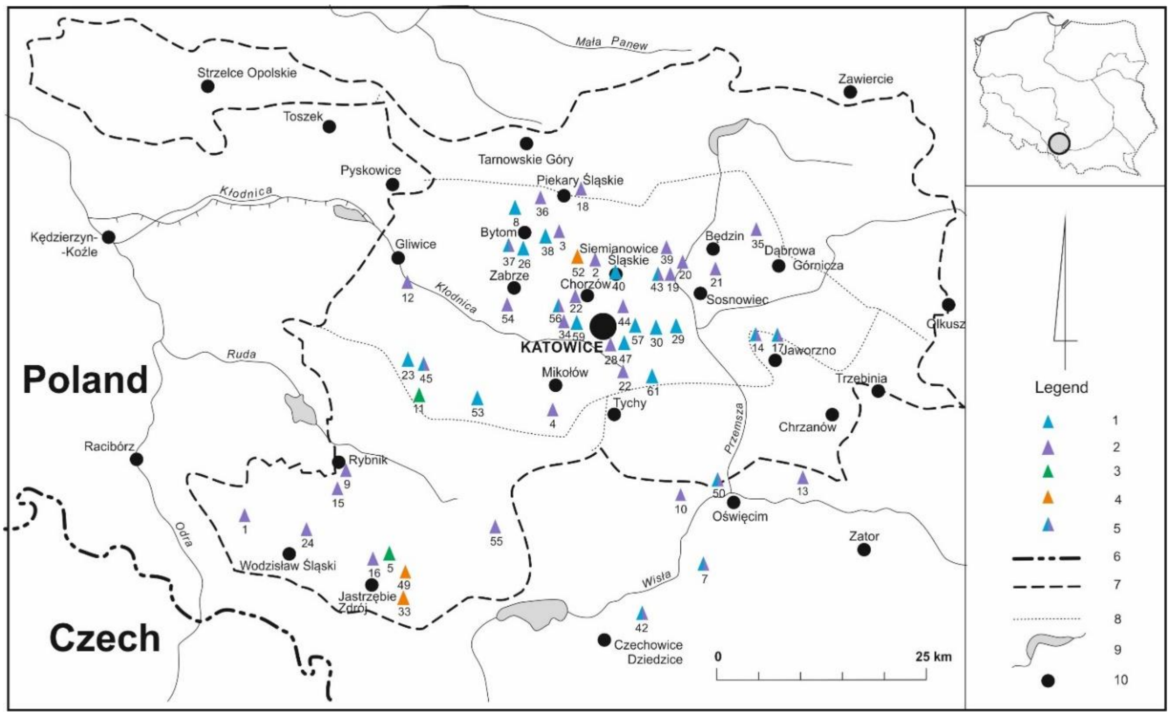

Fig. 2. The distribution of the coal mines of the Silesia Upland and heaps belonging to them: 1–5 – area size categories of heaps: blue triangle – up to 10 ha; purple triangle – up to 50 ha; green triangle – up to 100 ha; orange triangle – more than 100 ha; purple-blue triangle – area size of heap up to 10 ha and 50 ha; 6 – state border; 7 – borders of the Silesia Upland; 8 – minor geographical borders; 9 – rivers and lakes; 10 – towns and cities [33 – changed]

Coal mine spoil heaps are habitats that are difficult for plant colonization, establishment, and development. They are characterized by extreme abiotic conditions, e.g., large variations in humidity and daily temperatures (often reaching 50°C), high salinity, lack of soil, susceptibility to wind and water erosion, substrate instability, dusting, chemical, and thermal activity, and also biotic parameters such as lack of a seed bank and a deficiency of nutrients in the substrate. All of these determine the specificity of the flora and vegetation types which can tolerate the conditions found on these post-industrial areas [1,16,29,36-40]. These abiotic conditions are variable both in time and space, as well as are changing with the depth of the substrate. All these factors combine to present the environment of unmanaged coal

Publisher: **KOMAG Institute of Mining Technology, Poland**

mine spoil heaps and these are model examples of a novel ecosystem. Despite the harsh environmental conditions, including long periods of drought, and the high levels of compaction of spoil material [33], these heaps can be spontaneously colonized by herbaceous vegetation.

2.2. Vegetation sampling

Before starting field studies, the selected heaps have been divided into four area size categories (A – up to 10 ha; B – up to 50 ha; C – up to 100 ha; D – more than 100 ha). The vegetation sampling was conducted in randomly chosen patches on coal mine spoil heaps of different area sizes. The vegetation samples were collected in different environmental conditions in order to cover all the available habitat conditions occurring on unmanaged coal mine spoil heaps which were independent of the studied heap size. For each studied vegetation patch, a homogenous study plot was selected. The species composition and abundance (expressed as percentage coverage) of all species present were visually estimated. The cover abundance of species was estimated on a 12-point scale according to the rules (<1%, 1-5%, 5-10%, 10-20%, and then every 10%). The distribution of the studied heaps on the local map is shown in Fig. 2.

2.3. Measure of vegetation diversity

On the basis of species composition and abundance for each recorded vegetation patch, the following metrics were determined: the species richness, affinity of species to socio-ecological groups. The study covered vegetation patches consisting of species identified as typical of e.g. meadow, grassland rush and species without preferences to certain ecosystems and vegetation types.

Some of the analyses focused on dominant plant species according to the mass ratio hypothesis [41]. The identified dominant plant species were characterized by their socio-ecological origin, according to Oberdorfer et al. [42]. The analyzed species represented the following habitats: forest species: (Cl. *Vaccinio-Piceetea*) and (Cl. *Ouerco-Fagetea*, *Alnetea glutinosae*) and other species associated with forest habitats; meadow species (Cl. *Molinio-Arrhenatheretea*); broadly defined grassland species: (Cl. *Festuco-Brometea*) and (Cl. *Sedo-Scleranthetea*, *Nardo-Callunetea*); species of rock habitats, rock rubble – karst species (Cl. *Asplenietea rupestria*, *Violetea calaminariae*, *Thlaspietea rotundifolii*), species of clearings and fringes (Cl. *Epilobietea angustifolii*, *Trifolio-Geranietea*); ruderal species (Cl. *Artemisietea vulgaris*, *Agropyretea intermedio-repentis*, *Plantaginetea majoris*, *Agrostietea stoloniferae-Potentilla anserina*); salt marsh species (Cl. *Zosteretea marinae*, *Ruppietea maritimae*, *Asteretea tripolium*, *Honckenyo-Agropyretum juncei*, *Cakiletea maritimae*, *Ammophiletea*); segetal species (Cl. *Chenopodietea*, *Secalietea*); peatbog species (Cl. *Montio-Cardaminetea*, *Scheuchzerio-Caricetea*, *Oxycocco-Sphagnetea*); rush and aquatic species: (Cl. *Phragmitetea*, *Isoëto-Nanojuncetea*, *Bidentetea tripartiti*) and (Cl. *Lemnetea*, *Utricularietea*, *Potametea*).

The identified dominant species have also been analyzed in terms of geographical-historical groups, the alien and native plant species represent [43]: K – kenophytes (neophytes), A – apophytes.

2.4. Data analysis

The recorded vegetation patches were divided into four groups in terms of the coal mine spoil heap size area. Each group of records gathered data about vegetation patches growing on heaps with the same area. The vegetation taxonomic diversity (TD) was measured using several approaches and indices. For each vegetation patch, the dominant plant species were identified, the number of species were recorded, and the diversity metric such as Shannon-Wiener diversity index was calculated.

Based on the calculated species richness and the diversity index for each spoil heap area size group, the mean value, standard deviation, minimum and maximum were calculated. The list and frequency of vegetation patches dominated by particular species was prepared for each of the four spoil heap area sizes. The dominant plant species were categorized into socio-ecological and geographical-historical groups.

3. Results

3.1. Species richness, and diversity of vegetation patches on heaps of various area sizes

The lowest number (124) of patches was recorded on spoil heaps (of up to 100 ha), followed by 236 patches on the largest heaps (>100 ha), 475 patches were found on the smallest heaps up to 10 ha, and the highest number (1732) were found in those patches from heaps (up to 50 ha).

Species richness was highest on spoil heaps of up to 100 ha (4.17), and smallest (3.43) on heaps of up to 50 ha. However, differences found in species richness did not reach statistically significant level (H (3.2567) = 2.34, p = 0.5043) (Table 1).

Table 1. Species richness in patches in relation to the heap size area

Species richness	Heap size area			
	10 ha n =475	**50 ha** n =1732	**100 ha** n =124	**>100 ha** n =236
Mean	3.62	3.43	4.17	3.48
SD	2.31	2.23	3.44	2.03
Min.	1.12	1.00	1.25	1.15
Max.	12.88	17.11	16.62	1.15

n – the number of vegetation patches on each of the heap size area of the studied heaps

The highest number of different dominant plant species was recorded in vegetation patches growing spontaneously on heaps, with an area size up to 50 ha. In the vegetation patches present on the heaps of up to 100 ha, 29 different dominant plant species were identified, followed by 40 dominants in patches of more than 100 ha and 49 dominant species in patches up to 10 hectares of area. Eight of all dominant species were the most common (Table 2).

Table 2. Number of patches dominated by the most common dominant species in relation to area of the heap

The most common dominant plant species	The area of the heaps				
	10 ha	**50 ha**	**100 ha**	**>100 ha**	**TOTAL**
Betula pendula a	41	98	15	15	169
Betula pendula b	24	46		9	79
Betula pendula c	4	8			12
Calamagrostis epigejos (Fig. 3)	59	170	13	15	257
Chamaenerion palustre	13	64		17	94
Daucus carota	31	74	3	6	114
Melilotus alba	9	98	6	10	123
Phragmites australis (Fig. 4)	8	86	4	3	101
Poa compressa	46	82	5	6	139
Tussilago farfara (Fig. 5)	54	142	5	21	222

Betula pendula (as a tree) (present in 41 patches), *Calamagrostis epigejos* (59) (Fig. 3), *Poa compressa* (46) and *Tussilago farfara* (54) (Fig. 5) were the dominant species in more than 40 patches

Publisher: **KOMAG Institute of Mining Technology, Poland**

on the smallest spoil heaps (area up to 10 ha). On heaps with an area of 50 ha, 101 dominant plant species were observed. There were, on average, 17 patches per dominant species. In this area group, two dominant plant species such as *Calamagrostis epigejos* and *Tussilago farfara* were present in over 100, 170 and 142 vegetation patches respectively. On heaps with an area of up to 100 ha, 29 dominant species were found, with, on average, only 4 patches per dominant plant. On heaps with an area of more than 100 ha, 40 dominant species were found, with almost 6 vegetation patches per dominant plant species.

Fig. 3. Spontaneous vegetation type with dominance of *Calamagrostis epigejos* (Mysłowice site, Upper Silesia, Poland) (Photo: G. Woźniak)

Fig. 4. Patches with *Phragmites australis* in Sosnowiec (Upper Silesia, Poland) (Photo: G. Woźniak)

Fig. 5. Spontaneously occurring common patches of *Tussilago farfara* on coal mine heaps (Mysłowice site, Upper Silesia, Poland) (Photo: G. Woźniak)

Publisher: **KOMAG Institute of Mining Technology, Poland**

3.2. The socio-ecological groups of dominant species on heaps of various sizes

The number of recorded patches of spontaneously developed vegetation dominated by species representing different socio-ecological groups is unequal on heaps of different area size. The largest number of vegetation patches dominated by ruderal, forests as well as segetal species was recorded on heaps with an area of up to 50 ha. In this group of heaps worth underlying are also patches dominated by aquatic or rush species. In contrast, the least number of vegetation patches was recorded on heaps with an area up to 100 ha. They were dominated mainly by ruderal species (Fig. 6).

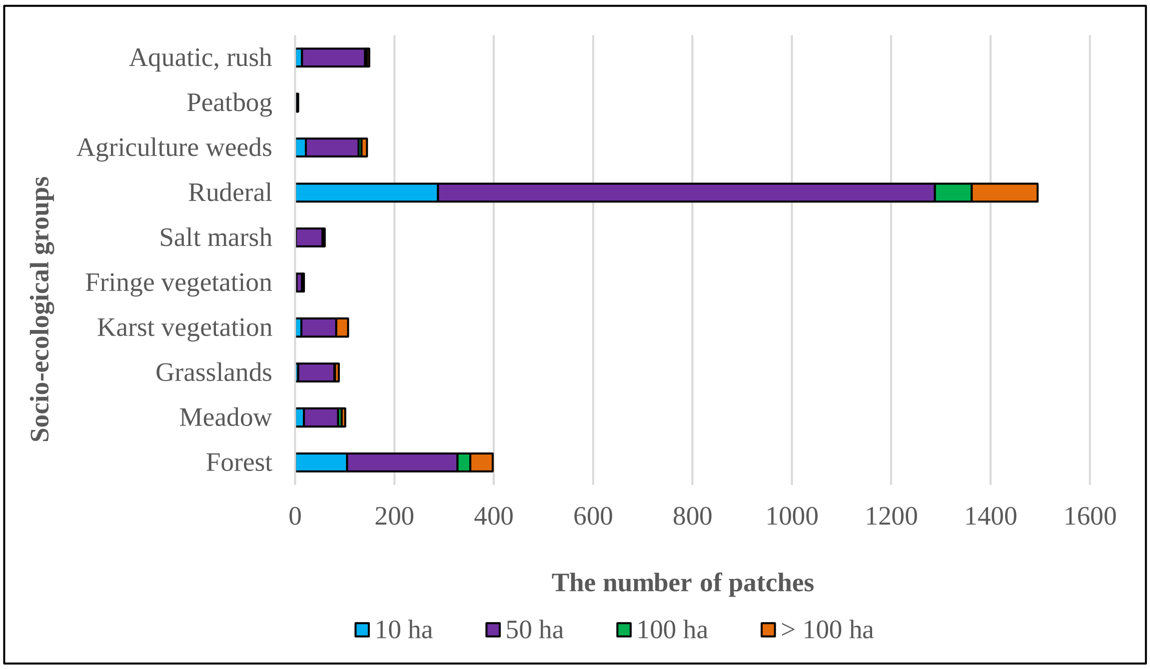

Fig. 6. Distribution of the number of patches in relation to heap area and the socio-ecological group of the dominant species in the patch

The distribution (percentage participation) of the number of patches dominated by particular socio-ecological groups, depending on the heap area size, is presented in Table 3.

Table. 3. Percentage participation of vegetation patches dominated by plant species representing particular socio-ecological groups in relation to spoil heap area and socio-ecological groups of the dominant species in the patch

Socio-ecological groups	The area of the heaps			
	10 ha	50 ha	100 ha	> 100 ha
Rushes and aquatic species	9	85	3	3
Peatbog species	71	15	0	14
Segetal species	15	73	4	8
Ruderal species	19	67	5	9
Salt marsh species	3	88	6	3
Species of clearings and fringes	17	61	16	6
Species of rock habitats, rock rubble – karst species	12	66	0	22
Broadly defined grassland species	7	83	1	9
Meadow species	18	68	7	7
Forest species (deciduous and coniferous)	26	56	7	11

The observed distribution of the number of vegetation patches on heaps of varied area sizes reveals significant differences and relationships (G=118.60; p <0.001) between the frequency of patches dominated by species representing particular socio-ecological groups and the area size of the spoil heaps.

3.3. The origin of dominant species in patches on heaps that differ in terms of size

Among the varied plant species characteristics that could be applied, the division between the alien (kenophytes =neophytes – neophytes recently introduced alien plants; archaeophytes – older alien plant species), and native plant (apophytes) species is very important, as alien plants threaten some ecosystems.

The distribution of the number of patches depending on the area of the spoil heap and the geographical-historical group represented by the dominant species in a given patch is shown in Fig. 7.

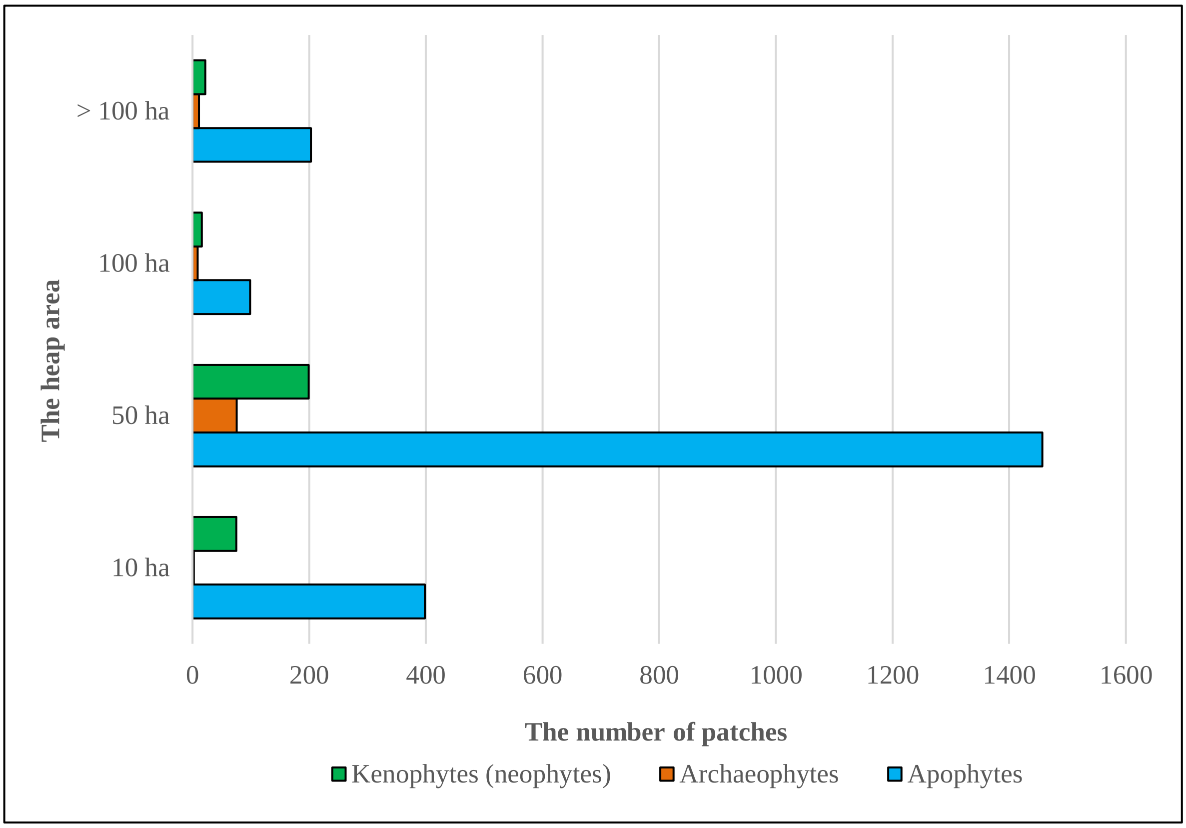

Fig. 7. The number of patches in relation to heap area and geographical-historical group of the dominant in the patch

It is worth underlying that apophytes predominate in patches developing on coal mine spoil heaps regardless their size area.

Kenophytes and apophytes occur more often than archaeophytes (older alien plant species), on heaps with an area of up to 10 ha. The highest number of patches with archaeophytes as well as apophytes as dominance were found on heaps up to 50 ha (Fig. 7).

As many as 199 patches dominated by kenophytes were recorded on heaps up to 50 ha. Among them are such species as *Conyza canadensis*, *Datura stramonium*, *Helianthus tuberosus* or *Robinia pseudoacacia*. Archeophytes such as *Lactuca serriola*, *Matricaria maritimia* subsp. *inodora* or *Lepidium ruderale* were found on coal mine spoil heaps. The observed regularities in patch proportions reflect the covariation ($G = 35.785$; $p < 0.001$) of the heap area and the geographical-historical groups of the dominant species.

4. Discussion

The relations between size of the spoil heap area and the diversity of the spontaneous vegetation

The species richness and species diversity of the vegetation patches recorded on the post-coal mine heaps of various sizes differed insignificantly. However, a comparison of the number of dominant species representing particular socio-ecological groups showed a dependence in terms of the area size of the post-coal mining heaps, however, not all the differences were significant. The species-area relationship [34] provided the theoretical background to formulate predictions regarding the results of this relationship between the size of the heap and the plant species diversity of the vegetation. The species-area relationship, or species-area curve expresses the relationship between the area of a habitat, or part of a habitat, and the number of species recorded within the studied area. Larger areas can contain more species, and empirically, the relative numbers seem to follow systematic mathematical relationships [44].

Connor and McCoy [45] discussed two main hypotheses to explain the increase of the number of species along with increasing area size. One is the habitat diversity hypothesis, and the other is a hypothesis based on demographic processes. The first assumes that the regularities resulting from the SAR are the result of the fact that there is a larger mosaic of habitats over a larger area and the increase in habitat diversity generates a SAR dependency. The demographic explanation, on the other hand, takes into account the dynamics of the spread and colonization process. Larger areas will be more intensively colonized, and in addition, larger heaps similar to large islands, reduce the probability that a given species will disappear [46,47]. The theory of island biogeography by MacArthur and Wilson in 1967 [46] predicted that, small populations in habitat patches are more likely to disappear than populations in large patches of habitat and that patches of habitat more isolated from the source of diaspores are less likely to be recolonized than patches closer together. Considering the diversity of dominant species on coal mine spoil heaps in terms of their life forms, it was found to be size dependent. The vegetation (dominant structure) of heaps with an area of up to 100 ha differs the most from that in the other three area size classes, due to the participation of patches dominated by species representing particular life forms. Among patches of vegetation occurring on heaps of this size class, no dominant plant species were found that represented the chamaephyte and nanophanerophyte life forms.

The species-area relationship is usually completed for one type of organism, e.g., in this study for the plant species composition of the vegetation. In a different approach, all species of a specific trophic level can be analyzed within a particular site. Rosenzweig [48] found that, a wide range of factors specifying the slope and elevation of the species-area relationship. The discussed factors enclose the proximate equilibrium between colonization, immigration and extinction, the number, rate and extent of disturbance in small vs. large areas, and the grouping of individuals of the same species as an effect of habitat heterogeneity or dispersal limitation [46,49]. However, the SAR was formulated as the consequence and to follow the second law of thermodynamics in ecology, the environmental scientific requirements have to be fulfilled [50]. The attractive-"mechanistic" explanation of the SAR observation in some studies needs to be tested as to whether the outcome is only the result of an accident, or whether it follows the rules of the environmental pattern and requirements.

To prove that the SAR observed in the field is genuine the results should be tested against the same data set randomized by permutation tests [45]. The rules concluded from the SAR are often considered in conservation science to forecast extinction rates in the case of habitat loss or habitat fragmentation [51]. Scientists have classified the SAR according to the type of habitats and ecosystems being tested and the census (period) procedure used. Preston [44], who investigated the theory of the SAR, divided the studied issue into two types: samples (contiguous habitat types that grow in the extended area), called "mainland" species-area relationships the isolates (discontiguous habitats, such as islands), also called "island" species-area relationships. Rosenzweig [48] emphasized those SARs for large areas, (those containing various biogeographic provinces or continents), present different patterns from those SAR from islands or smaller neighboring areas. The differences mentioned by Rosenzweig [48] are reflected by the presumed "island"-like SARs, which have steeper slopes in the log-transformed relationship than the "mainland" SARs [48,52]. Regardless of the time scale and habitat type, SARs are often suited to a simple function. Preston [44] supported the function based on his investigation of the relative species abundance distribution (RAD) or species abundance distribution. The -RAD defines the relationship between the number of species recorded in a field investigation as a function of their observed quantity or amount. The result of which performs as an index of biodiversity in the ecosystem that is studied [53].

Conversely, SARs for contiguous habitats will invariably rise as areas increase, provided that the sample plots are nested within one another [34]. The SAR for mainland areas (contiguous habitats) will differ according to the sampling design used [54]. A common method is to use quadrats of successively larger size so that the area enclosed by each one includes the area enclosed by the smaller one (i.e. sampling areas are nested). At the beginning of the 20th century, the species-area curve was used to estimate the minimum size of a quadrat necessary to sufficiently characterize a community. This is done by plotting the curve (usually on arithmetic axes) and assessing the area under it after which the use of the larger quadrats results in finding only a few additional species. This is the way to assess the minimal sampling area to be used. A quadrat that encloses the minimal area is called a vegetation record, and the use of species-area curves in this way is called the relevé method and was largely developed by Braun-Blanquet [55]. To avoid subjectiveness, some ecologists like to define the minimal sampling area as the area has at least 95 per cent (or some other large proportion) of the total species recorded. The species-area curve does not usually reach an asymptote, so it is not apparent what number of species is the total. The number of species grows with the size of the area. It is not feasible during fieldwork to achieve the point where the area accumulating all the species will be covered by the study [56].

The tests performed (G test to check the frequency differences between the groups for qualitative data) revealed that for the spontaneous vegetation developed on spoil heaps of different area sizes the number and diversity of identified vegetation types (dominant plant species) differs significantly. However, when considering the dependence of diversity on the size of the heap, it is necessary to refer to the concept of SAR (dependence of the number of species on the size of the area studied). This concept assumes that the number of species increases as the area increases. The concept of SAR was created as a result of searching for regularity in patterns of diversity. The assumption that the number of species increases with an increase in the area has been recognized as a regularity since Arrhenius [34] described this relationship. However, some researchers believe that the Arrhenius equation is not universally applicable [46,48]. A slightly different mathematical description of the relationship between the number of species and the size of the area was proposed by Gleason [57]. His studies have shown that the equation does not apply to large and small areas [47,48]. Pueyo [58] believes that there is a fundamental relationship between the SAR (increase in the number of species with an increase in the size of the study area) and the patterns of SAD (species abundance distribution) with a small group of dominant species and a large group of low-abundance species.

The number of vegetation patches diversity estimated by the different dominant plant species representing particular geographical-historical groups reflects a dependence on the area size of the heap. The participation of vegetation patches dominated by kenophyte (neophytes) plant species decreases with increasing area. On the largest heaps, the participation of kenophytes (newcomers) is the smallest and the participation of native plant species (vegetation patches dominated by apophytes) is the largest.

The results obtained from research on the factors determining the vegetation diversity on spoil heaps differ from those results obtained from previous research e.g., in forest size as the analyzed factor is taken into account. A study conducted in secondary forests revealed that the only variable affecting the total number of species was the area [59]. Recent studies indicate that in many types of communities, species richness, apart from the size of the study area, is strongly influenced by other factors. Differences in the species richness is strongly influenced by other factors apart from the size of the study area. Differences in the species richness of a site during the initial stages of succession are associated less with competition, animal interactions and population dynamics, but the importance of differences in the number of species on a larger regional spatial scale is increasingly being [52,60].

Researchers testing the metacommunity theory [61-63] and the experiments of Cadotte & Fukami [64] have also shown that the patterns of species coexistence should be seen in a spatial and area size context. They emphasize the importance of connections and exchanges between local habitats and the wider environment for maintaining regional species richness.

5. Conclusion

The natural processes observed, and recorded, in the novel ecosystems that are established based on the analogous plant species composition of the primary producers need to be tested against the theories and concepts formulated for undisturbed natural and semi-natural ecosystems. The novel ecosystems, such as those developing on the mineral oligotrophic habitats of post-coal mining spoil heaps, can present different organismal adaptations and solutions in the living organisms and the colonized habitats relations due to the ecological threshold crossed.

The species-area relationship (SAR) is among the most fundamental of described relationships. The results presented in the article indicate that the differences in the size of the area of the spoil heap affects (significantly for some aspects) the diversity of plant species composition of the colonizing vegetation. Regardless of which of the characteristics of the dominant species is compared, the vegetation on the spoil heaps differs depending on their area size.

Despite differences in the proportions of the recorded number of vegetation patches, it is difficult to indicate a pattern that would reflect the SAR of the colonizing vegetation. The results of this preliminary study which explored the vegetation and species composition diversity of the spontaneous vegetation development during the primary succession processes on mineral substrate habitats on post coal mining spoil heaps of different area sizes, revealed that diversity is not greater on the larger heaps.

It is concluded that the species diversity of the vegetation patches is not more diverse on larger sites. The development of the spontaneous vegetation in the novel ecosystems of the mineral oligotrophic habitats of post-coal mining spoil heaps does not follow the species area relationship (SAR) of Arrhenius.

References

[1] Rahmonov O., Oleś W.: Vegetation succession over an area of a medieval ecological disaster. The case of the Błędów Desert, Poland. Erdkunde 2010. 64(3), pp. 241–255. doi 10.3112/erdkunde.2010.03.03

[2] Meiners S.J., Cadotte M.W., Fridley J.D., Pickett S.T.A., Walker L.R.: Is successional research nearing its climax? New approaches for understanding dynamic communities. Funct. Ecol. 2015. 29(2), pp. 154–164. doi 10.1111/1365-2435.12391

[3] Bierza W., Bierza K., Trzebny A., Greń I., Dabert M., Ciepał R., Trocha L.K.: The communities of ectomycorrhizal fungal species associated with *Betula pendula* Roth and *Pinus sylvestris* L. growing in heavy-metal contaminated soils. Plant Soil 2020. 457, pp. 321–338. doi 10.1007/s11104-020-04737-4

[4] Prach K., Walker L.R.: Comparative plant succession among terrestrial biomes of the world. Cambridge: Cambridge University Press 2020. ISBN 9781108561167

[5] Naeem S., Bunker D.E., Hector A., Loreau M., Perrings C.: Biodiversity, Ecosystem Functioning, and Human Wellbeing An Ecological and Economic Perspective. Oxford: Oxford University Press 2009. ISBN 9780191720345

[6] Reiss J., Bridle J.R., Montoya J.M., Woodward, G.: Emerging horizons in biodiversity and ecosystem functioning research. Trends Ecol. Evol. 2009. 24(9), pp. 505–514. doi 10.1016/j.tree.2009.03.018

[7] Cardinale B.J., Duffy J.E., Gonzalez A., Hooper D.U., Perrings C., Venail P., Narwani A., Mace G.M., Tilman D., Wardle D.A., Kinzig A.P., Daily G.C., Loreau M., Grace J.B., Larigauderie A., Srivastava D.S., Naeem S.: Biodiversity loss and its impact on humanity. Nature 2012. 486(7401), pp. 59–67. doi 10.1038/nature11148

[8] Tilman D., Isbell F., Cowles J.M.: Biodiversity and Ecosystem Functioning. Annu. Rev. Ecol. Evol. S. 2014. 45, pp.471–493. doi 10.1146/annurev-ecolsys-120213-091917

[9] Grace J.B., Anderson T.M., Seabloom E.W., Borer E.T., Adler P.B., Harpole W.S., Hautier Y., Hillebrand H., Lind E.M., Pärtel M., Bakker J.D., Buckley Y.M., Crawley M.J., Damschen E.I., Davies K.F., Fay P.A., Firn J., Gruner D.S., Hector A., Knops J.M.H., MacDougall A.S., Melbourne B.A., Morgan J.W., Orrock J.L., Prober S.M., Smith M.D.: Integrative modelling reveals mechanisms linking productivity and plant species richness. Nature 2016. 529(7586), pp. 390–393. doi 10.1038/nature16524

[10] Van der Putten W.H., Bardgett R.D., Bever J.D., Bezemer T.M., Casper B.B., Fukami T., Kardol P., Klironomos J.N., Kulmatiski A., Schweitzer J.A., Suding K.N., Van de Voorde T.F.J., Wardle D.A.: Plant–soil feedbacks: the past, the present and future challenges. J. Ecol. 2013. 101(2), pp. 265–276. doi 10.1111/1365-2745.12054

[11] Alberti M., Marzluff J.M., Shulenberger E., Bradley G., Ryan C., Zumbrunnen C.: Integrating Humans into Ecology: Opportunities and Challenges for Studying Urban Ecosystems. BioScience 2003. 53(12), pp. 1169–1179. doi 10.1641/0006-3568(2003)053[1169:IHIEOA]2.0.CO;2

[12] MEA—Millennium Ecosystem Assessment. Ecosystems and Human Well-Being: Biodiversity Synthesis. World Resources Institute. Washington, DC. 2005 https://www.millenniumassessment.org/documents/document.354.aspx.pdf [accessed: 09.03.2023]

[13] Walker L.R.: The Biology of Disturbed Habitats. Oxford: Oxford University Press 2012. eBook ISBN 9780199575299

[14] Milgrom T.: Environmental aspects of rehabilitating abandoned quarries: Israel as a case study. Landscape Urban. Plan. 2008. 87(3), pp. 172–179. doi 10.1016/j.landurbplan.2008.06.007

[15] Woźniak G., Chmura D., Błońska A., Tokarska-Guzik B., Sierka E.: Applicability of functional groups concept in analysis of spatiotemporal vegetation changes on man made habitats. Pol. J. Environ. Stud. 2011. 20, pp. 623–631. ISSN 1230-1485

[16] Woźniak G., Markowicz A., Borymski S., Piotrowska-Seget Z., Chmura D., Besenyei L.: The relationship between successional vascular plant assemblages and associated microbial communities on coal mine spoil heaps. Community Ecol. 2015. 16(1), pp. 23–32. doi 10.1556/168.2015.16.1.3

[17] Woźniak G., Sierka E., Wheeler A.: Urban and Industrial Habitats: How Important They Are for Ecosystem Services. In: Ecosystem Services and Global Ecology. Hufnagel L.(Ed.) IntechOpen 2018. pp. 169–194. doi 10.5772/intechopen.75723

[18] Woźniak G., Dyderski M.K., Kompała-Bąba A., Jagodziński A.M., Pasierbiński A., Błońska A., Bierza W., Magurno F., Sierka E.: Use of Remote Sensing to track post-industrial vegetation development. Land Degrad. Dev. 2020. 32(3), pp. 1426–1439. doi 10.1002/ldr.3789

[19] Horodecki P., Jagodziński A.M.: Tree species effects on litter decomposition in pure stands on afforested post-mining sites. Forest Ecol. Manag. 2017. 406, pp. 1–11. doi 10.1016/j.foreco.2017.09.059

[20] Frouz J., Moradi J., Püschel D., Rydlová J.: Earthworms affect growth and competition between ectomycorrhizal and arbuscular mycorrhizal plants. Ecosphere 2019. 10(5), e02736. doi 10.1002/ecs2.2736

[21] Frouz J.: The effect of litter type and macrofauna community on litter decomposition and organic matter accumulation in post-mining sites. Biologia 2008. 63(2), pp. 249–253. doi 10.2478/s11756-008-0031-1

[22] Tropek R., Kadlec T., Hejda M., Kocarek P., Skuhrovec J., Malenovsky I., Vodka S., Spitzer L., Banar P., Konvicka M.: Technical reclamations are wasting the conservation potential of post-mining sites. A case study of black coal spoil dumps. Ecol. Eng. 2012. 43, pp. 13–18. doi 10.1016/j.ecoleng.2011.10.010

Publisher: **KOMAG Institute of Mining Technology, Poland**

[23] Błońska A., Kompała-Bąba A., Sierka E., Besenyei L., Magurno F., Frydecka K., Bierza W., Woźniak, G.: Impact of selected plant species on enzymatic activity of soil substratum on post-mining heaps. Journal of Ecological Engineering 2019a. 20, pp. 138–144. doi 10.12911/22998993/93867

[24] Błońska A., Kompała-Bąba A., Sierka E., Bierza W., Magurno F., Besenyei L., Ryś K., Woźniak G.: Diversity of vegetation dominated by selected grass species on coal-mine spoil heaps in terms of reclamation of post-industrial areas. Journal of Ecological Engineering 2019b. 20, pp. 209–217. doi 10.12911/22998993/93870

[25] Hobbs R.J., Arico S., Aronson J., Baron J.S., Bridgewater P., Cramer V.A., Epstein P.R., Ewel J.J., Klink C.A., Lugo A.E., Norton D., Ojima D., Richardson D.M., Sanderson E.W., Valladares F., Vilà M., Zamora R., Zobel M.: Novel ecosystems: theoretical and management aspects of the new ecological world order. Global Ecol. Biogeogr. 2006. 15(1), pp. 1–7. doi 10.1111/j.1466-822X.2006.00212.x

[26] Hobbs R.J., Higgs E.S., Hall C.M.: Defining novel ecosystems. In: Novel Ecosystems: Intervening in the New Ecological World Order. New Jersey: John Wiley & Sons, Ltd 2013. pp. 58–60. ISBN 9781118354186

[27] Milewska-Hendel A., Chmura D., Wyrwał K., Kurczyńska E.U., Kompała-Bąba A., Jagodziński A.M., Woźniak G.: Cell wall epitopes in grasses of different novel ecosystem habitats on post-industrial sites. Land Degrad. Dev. 2020. 32(4), pp. 1680–1694. doi 10.1002/ldr.3786

[28] Chmura D., Rozkowski Z., Guzicka M., Dorobek K.: Variation in aboveground biomass carbon accumulation in Scots pine seed orchards progeny. Ann. For Res. 2022. 64(2), pp. 139–148. doi 10.15287/afr.2021.2062

[29] Dyczko A., Ryś K., Radosz Ł., Woźniak G. Current Reclamation Practices and Their Successfulness. In: Green Scenarios: Mining Industry Responses to Environmental Challenges of the Anthropocene Epoch – International Mining Forum, Dyczko, A., Jagodziński, A.M., Woźniak, G. Eds.; CRC Press Balkema, Taylor & Francis Group: United States, 2022; 12 pp 375–385. ISBN 9781003271604

[30] Rawlik M., Kasprowicz M., Jagodzinski A.M.: Differentiation of herb layer vascular flora in reclaimed areas depends on the species composition of forest stands. Forest Ecol. Manag. 2018a. 409, pp. 541–551. doi 10.1016/j.foreco.2017.11.055

[31] Rawlik M., Kasprowicz M., Jagodzinski A.M., Kaźmierowski C., Łukowiak R., Grzebisz W.: Canopy tree species determine herb layer biomass and species composition on a reclaimed mine spoil heap. Sci. Total. Environ. 2018b. 635, pp. 1205–1214. doi 10.1016/j.scitotenv.2018.04.133

[32] Kompała-Bąba A., Sierka E., Dyderski M.K., Bierza W., Magurno F., Besenyei L., Błońska A., Ryś K., Jagodziński A.M., Woźniak G.: Do the dominant plant species impact the substrate and vegetation composition of post-coal mining spoil heaps? Ecol. Eng. 2020. 143, 105685, pp. 1–8. doi 10.1016/j.ecoleng.2019.105685

[33] Woźniak G.: Zróżnicowanie Roślinności na Zwałach Pogórniczych Górnego Śląska. Kraków. Instytut Botaniki im. W. Szafera PAN 2010. ISBN 9788389648884. [In Polish]

[34] Arrhenius O.: Species and area. J. Ecol. 1921. 9(1), pp. 95–99. doi 10.2307/2255763

[35] Cabała J., Teper E., Teper L., Małkowski E., Rostański A.: Mineral composition in rhizosphere of plants grown in the vicinity of a Zn-Pb ore flotation tailings pond. Acta Biol. Cracov. Bot. 2004. 46, pp. 65–74

[36] Woźniak G. Primary succession on the sedimentation pools of coal mine. In: Synanthropization of Plant Cover in New Polish Research; Faliński, J.B., Adamowski, W., Jackowiak, B. (Eds.): Phytocoenosis 10 (N.S.) Supplementum Cartographiae Geobotanicae 1998. 10(9), pp. 189–198

[37] Box J.: Nature Conservation and Post-Industrial Landscapes. Industrial Archaeology Review 1999. 21(2), pp. 137–146. doi 10.1179/iar.1999.21.2.137

[38] Bradshaw A.: The use of natural processes in reclamation – Advantages and difficulties. Landscape Urban Plan. 2000. 51(2–4), pp 89–100. doi 10.1016/S0169-2046(00)00099-2

[39] Kompała-Bąba A., Bąba W.: The spontaneous succession in a sand-pit – the role of life history traits and species habitat preferences. Pol. J. Ecol. 2013. 61(1), pp. 13–22

[40] Jagodziński A.M., Woźniak, G.: Environmental Knowledge and Understanding: an Important and Necessary Aspect of Corporate Social Responsibility. In Green Scenarios: Mining Industry Responses to Environmental Challenges of the Anthropocene Epoch – International Mining Forum 2021; Dyczko, A., Jagodziński, A.M., Woźniak, G. Eds.; CRC Press Balkema, Taylor & Francis Group: United States, 2022 pp. 317–325. ISBN 9781003271604

[41] Grime J.P.: Benefits of plant diversity to ecosystems: immediate, filter and founder effects. J. Ecol. 1998. 86(6), pp. 902–910. doi 10.1046/j.1365-2745.1998.00306.x

[42] Oberdorfer E., Müller T., Korneck D., Lippert W., Markgraf-Dannenberg I., Patzke E., Weber H.E.: Pflanzensoziologische Exkursionsflora. Stuttgart: Ulmer 1990. ISBN 9783800131310 [In German]

[43] Zarzycki K., Trzcińska-Tacik H., Różański W., Szeląg Z., Wołek J., Korzeniak U.: Ecological Indicator Values of Vascular Plants of Poland. Kraków: W. Szafer Institute of Botany, Polish Academy of Sciences 2002

[44] Preston F.W.: The Canonical Distribution of Commonness and Rarity: Part I. Spring 1962. 43(2), pp. 185–215. doi:10.2307/1931976

[45] Connor E.F., McCoy E.D.: The statistics and biology of the species-area relationship. Am. Nat. 1979. 113(6), pp. 791–833. doi 10.1086/283438

[46] Macarthur R.H., Wilson E.O.: The theory of island biogeography. Princeton: Princeton University Press 1967. ISBN 9780691088365

[47] Hubbell S.P.: The Unified Neutral Theory of Biodiversity and Biogeography. Princeton: Princeton University Press 2001. ISBN 9780691021287

[48] Rosenzweig M.L.: Species diversity in space and time. New York: Cambridge University Press 1995. ISBN 9780511623387

[49] Brose U., Williams R.J., Martinez N.D.: Allometric scaling enhances stability in complex food webs. Ecol. Lett. 2006. 9(11), pp. 1228–1236. doi 10.1111/j.1461-0248.2006.00978.x

[50] Würtz P., Annila A.: Roots of diversity relations. J Biophys. 2008. 2008(1267):654672, pp. 1–8. doi 10.1155/2008/654672

[51] Matthews T.J., Cottee-Jones H.E., Whittaker R.J.: Habitat fragmentation and the species–area relationship: A focus on total species richness obscures the impact of habitat loss on habitat specialists. Diversity Distrib. 2014. 20, pp. 1136–1146. doi 10.1111/ddi.12227

[52] Drakare S., Lennon J.J., Hillebrand H.: The imprint of the geographical, evolutionary and ecological context on species – area relationship. Ecol. Lett. 2006. 9(2), pp. 215–227. doi 10.1111/j.1461-0248.2005.00848.x

[53] Mouillot D., Lepretre A.: Introduction of Relative Abundance Distribution (RAD) Indices, Estimated from the Rank-Frequency Diagrams (RFD), to Assess Changes in Community Diversity. Environ. Monit. Asses. 2000. 63, pp 279–295. doi 10.1023/A:1006297211561

[54] Scheiner S.M.: Six types of species-area curves Six types of species-area curves. Global. Ecol. Biogeogr. 2003. 12(6), pp. 441-447. doi 10.1046/j.1466-822X.2003.00061.x

[55] Barbour M.G., Keeler-Wolf T., Allan A., Schoenherr A.A.: Terrestrial Vegetation of California 3th edition. California: The University of California Press 2007. EISBN 978-0-520-93336-1

[56] Williamson M., Gaston K.J., Lonsdale W.M.: The species-area relationship does not have an asymptot! J. Biogeogr. 2001. 28(7), pp. 827–830. doi 10.1046/j.1365-2699.2001.00603.x93336-1

[57] Gleason H.A.: On the relation between species and area. Ecology 1922. 3(2), pp. 158–162. doi 10.2307/1929150

[58] Pueyo S.: Self-similarity species – area relationships and in species abundance distribution. Oikos 2006. 112(1), pp. 156–162. doi 10.1111/j.0030-1299.2006.14184.x

[59] Dzwonko Z., Loster S.: Species richness and seed dispersal to secondary woods in southern Poland. J. Biogeogr. 1992. 19(2), pp. 195–204. doi 10.2307/2845505

[60] Zobel K.: On the species-pool hypothesis and on the Quasi-neutral concept of plant community diversity. Folia Geobot. 2001. 36, pp. 3–8

[61] Amarasekare P., Nisbet R.M.: Spatial heterogeneity, source-sink dynamics, and the local coexistence of competing species. Am. Nat. 2001. 158(6), pp. 572–584. doi 10.1086/323586

[62] Mouquet N., Loreau M.: Coexistence in meta-communities: the regional similarity hypothesis. Am. Nat. 2002. 159(4), pp. 420–426. doi 10.1086/338996

[63] Leibold M.A., Holyoak M., Mouquet N., Amarasekare P., Chase J.M., Hoopes M.F., Holt R.D., Shurin J.B., Law R., Tilman D., Loreau M., Gonzalez A.: The metacommunity concept: a framework for multi-scale community ecology. Ecol. Lett. 2004. 7(7), pp. 601–613. doi 10.1111/j.1461-0248.2004.00608.x

[64] Cadotte M.W., Fukami T.: Dispersal, spatial scale, and species diversity in a hierarchically structured experimental landscape. Ecol. Lett. 2005. 8(5), pp. 548–557. doi 10.1111/j.1461-0248.2005.00750.x

Publisher: **KOMAG Institute of Mining Technology, Poland**