Journal of Mining and Mechanical Engineering
DOI: 10.32474/JOMME.2021.01.000118
ISSN: 2690-5779
Review Article

The Potential of Post-Excavation Novel Ecosystems of Enhancing Vegetation and Rare Plant Species Diversity, Influencing the Ecosystem Services Provision

Gabriela Wozniak*

Faculty of Natural Sciences Institute of Biology, Biotechnology and Environmental Protection, University of Silesia, Katowice, Poland

***Corresponding author:** Gabriela Wozniak, Faculty of Natural Sciences Institute of Biology, Biotechnology and Environmental Protection, University of Silesia, Katowice, Poland

Received: March 03, 2021 **Published:** March 15, 2021

Abstract

The pressure of human activity in the industrial centers all over the world has been growing over last centuries. In the urban–industrial sites the natural environment has been changed significantly. The vegetation cover of the previous ecosystems has disappeared or has been seriously altered.

Apart from intense environmental transformation some of the sites left after the mineral resources excavation are providing specific mineral oligotrophic habitats to the urban-industrial environmental ecosystem mosaic. There are some sites which fulfill the prerequisites of the novel ecosystems. This study conducted on the spontaneous vegetation of the post-excavation novel ecosystems revealed that the species composition of the spontaneous vegetation is very diverse. The dynamic processes of the spontaneous vegetation species composition development observed in time and between sites of different area is itself creating diversity. Vegetation patches are composed from many different plant species including those that are listed as rare or endangered. The results of analysis conducted for this group of species indicate that the high number habitats this species are derived from, both in terms of their social-ecological origin and the particular site condition (light, moisture, temperature, acidity), recorded species are preferring.

The presented high diversity of the recorded spontaneous species composition of vegetation and the diversity vegetation patches itself is providing the proof how important are the natural processes for enhancing vegetation and rare plant species diversity. The close relations between biodiversity and ecosystem services provision are already known. This natural process are particular important in the ecosystem mosaic in the urban–industrial landscape.

Keywords: Vegetation and rare plant species diversity; biodiversity; natural processes; post-excavation novel ecosystems; post-coal mine heaps; urban–industrial landscape

Introduction

The pressure of human industrial activity in the Upper Silesian Industrial District like in many European industrial centers has been growing over last centuries. Due to the long industrial development, the natural environment has been changed significantly. The exploitation of coal, sand, gravel, limestone and dolomites caused changes in the surface and landscape [1-5].

Apart from intense environmental transformation some of the side-products of the mineral resources excavation process, provide specific mineral oligotrophic habitats to the urban-industrial environmental mosaic. Such enrichment of the urban-industrial habitat mosaic has shown that biological systems developing spontaneously on such sites are assembled of unknown previously plant and animal species compositions [6-7]. It has been also revealed that these novel ecosystems are self-sustaining entities, that provide crucial ecosystem services in the urban–industrial landscape. The conducted study has shown that spontaneous flora and vegetation of *de novo* created habitats like quarries, sand and gravel pits, heaps and dumps or subsidence reservoirs, are outstanding due to their floristic richness and the participation of rare and endangered species [8].

Changes in the natural environment caused by industry influence on one hand the are connected with the negative social assessment of the importance of such areas in the landscape, while on the other hand it has been shown that the restoration of transformed and changed sites is very effective for the benefit of nature and economy when the natural processes, i.e. natural succession are involved [9-15]. For post-industrial, post-excavation sites, for which the ecological threshold has been crossed the effective restoration in its classical understanding is not possible any more[16-17]. Such sites are called novel ecosystems. The novel ecosystems are developing on unusual (often on *de novo* created) habitats. On such habitats, the vegetation and further on ecosystems are composed from plant and animal species assemblages linked by relations which have not been unknown previously from natural and semi-natural ecosystems [16-17].

The aim of this study was to present some the ecological characteristics and diversity of the spontaneous vegetation and of the recorded rare endangered and protected species which have spontaneously colonize, overgrow the vegetation of post coal mine and post-excavation habitats and discuss their importance for maintaining biodiversity in the aspect of ecosystem services provision in densely populated urban-industrial landscapes (environmental, habitat and ecosystem) mosaic.

The Study Site Area

Floristic and vegetation records have been conducted during the main stream study focused on the analysis of the conditions influencing of the diversity of spontaneous vegetation on post coal-mine heaps in Upper Silesia south Poland [18]. The Silesian Upland is a geographical region located in southern Poland and the largest industrial center in Poland. In south Poland the main branches of industry are the coal, sand, gravel, and limestone mining. The longtime of excavation has changed the landscape and the natural environment conditions including hydrology and water coursers on the surface [4, 19-22].

Results

The vegetation diversity and ecological spectrum of rare plant species

Post-industrial particular post-mineral exploitation sites, especially those subjected to spontaneous succession are characterized by specific habitat conditions, and thus unique biocoenoses arise on those habitats [18]. They are often characterized by a high number of species (biodiversity). Over 500 plant species were recorded on the post-coal mine heaps and sedimentation [18, 23-25]. Apart from the post-coal mine sites the vascular plant species flora of quarries, gravel and sand pits, post coal-mine heaps and dumps present high floristic richness, including the occurrence of rare and endangered species.

The long term study on the conditions influencing of the diversity of spontaneous vegetation on post coal-mine heaps in Upper Silesia have shown that vegetation diversity is changing in time. The spontaneous vegetation is most diverse in the initial stages of post-coal mine heaps ecosystem development (Figure 1).

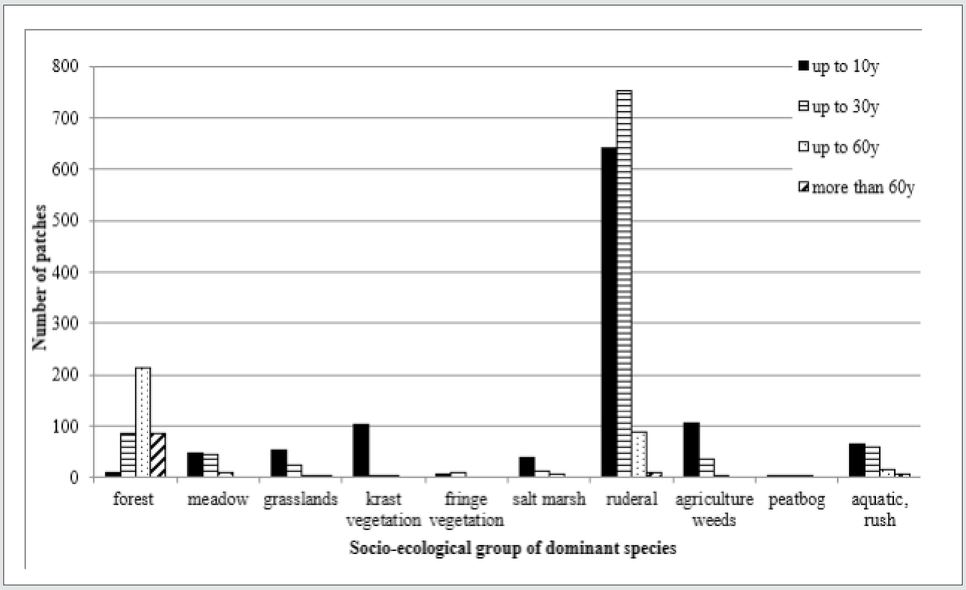

Figure 1: The changes in the spontaneous vegetation diversity on post-coal mine heaps of different age.
Explanations – socio-ecological groups: forest species **(Cl.** *Vaccinio-Piceetea*, *Querco-Fagetea*, *Alneteaglutinosae***)**; meadow species **(**Cl. *Molinio-Arrhenatheretea***)**; **grassland species (Cl.** *Festuco-Brometea*, *Sedo-Scleranthetea*, *Nardo-Callunetea***)**; karst species **(Cl.** *Asplenietea*, *Violeteacalaminariae*,*Thlaspietea***)**; fringe species **(Cl.** *Epilobieteaangustifolii*, *Trifolio-Geranietea***)**; ruderal species **(Cl.** *Artemisietea*, *Agropyretea*, *Plantaginetea*, *Agrostieteastoloniferae***)**; salt marsh species **(Cl.** *Zosteretea*,*Ruppietea*, *Astereteatripolii*, *Honckenyo-Elymetea*, *Cakiletea*,*Ammophiletea***)**; agriculture weeds **(Cl.** *Chenopodietea*, *Secalietea***)**; peatbog species **(Cl.** *Montio-Cardaminetea*, *Scheuchzerio-Caricetea*, *Oxycocco-Sphagnetea***)**; rush and aquatic species **(Cl.** *Phragmitetea*, *Isoëto-Nanojuncetea*, *Bidenteteatripartitae*, *Lemnetea*,*Utricularietea*, *Potamogetonetea***).**

The study conducted on heaps of different area has shown that the vegetation is the most diverse on the youngest heaps. On the coal mine heaps of the age up to 10 years the most commonly occurring patches have represented socio-ecological groups of the ruderal, segetal agricultural weeds and karst vegetation types. The coal mine heaps of the age up to 30 years were covered most often by patches that have represented the ruderal, wetland and woodland forest and aquatic vegetation (Figure 1).

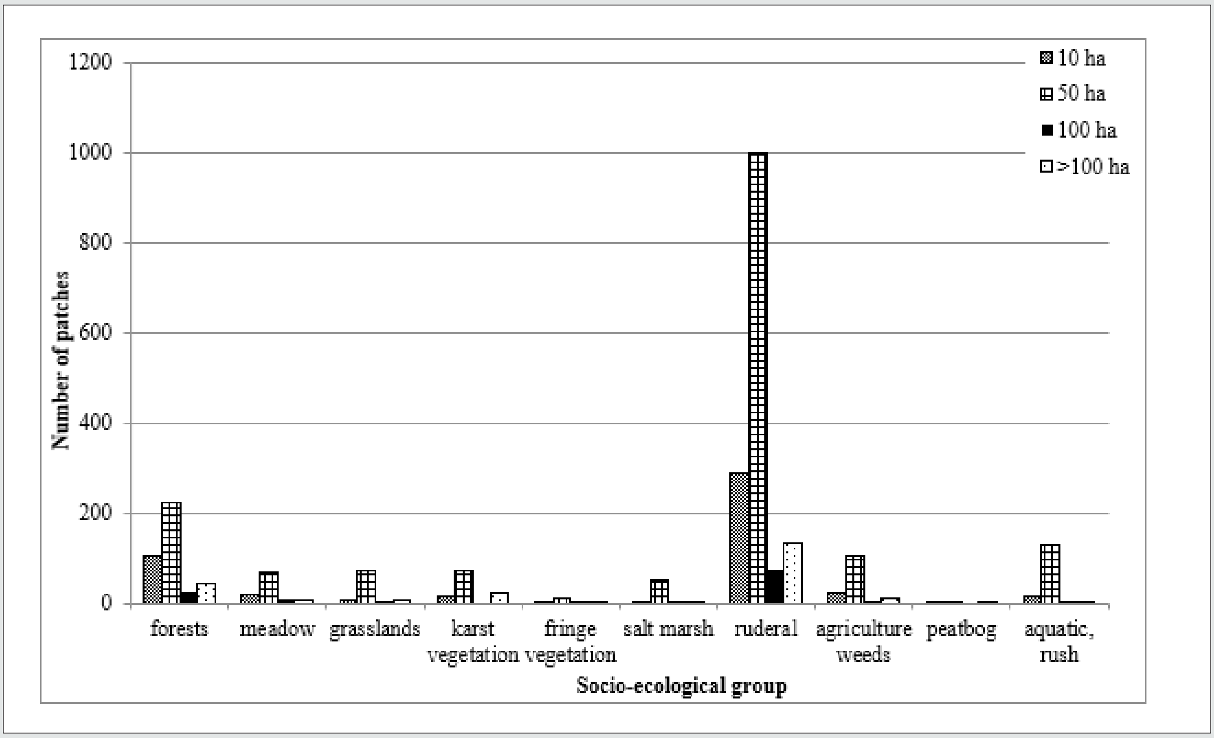

Figure 2: The changes in the spontaneous vegetation diversity on post-coal mine heaps of different area. Explanations – socio-ecological groups: forest species (Cl. *Vaccinio-Piceetea*, *Querco-Fagetea*, *Alneteaglutinosae*); meadow species (Cl. *Molinio-Arrhenatheretea*); grassland species (Cl. *Festuco-Brometea*, *Sedo-Scleranthetea*, *Nardo-Callunetea*); karst species (Cl. *Asplenietea*, *Violeteacalaminariae*, *Thlaspietea*); fringe species (Cl. *Epilobieteaangustifolii*, *Trifolio-Geranietea*); ruderal species (Cl. *Artemisietea*, *Agropyretea*, *Plantaginetea*, *Agrostieteastoloniferae*); salt marsh species (Cl. *Zosteretea*, *Ruppietea*, *Astereteatripolii*, *Honckenyo-Elymetea*, *Cakiletea*, *Ammophiletea*); agriculture weeds (Cl. *Chenopodietea*, *Secalietea*); peatbog species (Cl. *Montio-Cardaminetea*, *Scheuchzerio-Caricetea*, *Oxycocco-Sphagnetea*); rush and aquatic species (Cl. *Phragmitetea*, *Isoëto-Nanojuncetea*, *Bidenteteatripartitae*, *Lemnetea*, *Utricularietea*, *Potamogetonetea*).

Comparing the vegetation diversity on coal mine heaps of different area has shown that the heaps of the area up to 50 ha are the most diverse. The vegetation patches represented all ten main vegetation types (Figure 2). The most frequent were the patches of ruderal, woodland forest and aquatic, woodland vegetation. The patches of other vegetation types have been present but not the most frequent. All the analyzed vegetation types have been recorded on the smallest up the 10 ha studied heaps. However, the diversity has been mostly influenced by the presence of the salt marsh, fringe, peat bog, moores and grassland vegetation patches (Figure 2).

Recorded rare plant species occurring in the vegetation on the studied post-excavation sites have been divided into groups depending on the vegetation type they represent according to Oberdorfer et al. [26]. The most numerous recorded rare plant species represent deciduous beach forest of the *Querco-Fagetea* class. The second abundant group of recorded rare plant species represent the water (*Potametea*) and peat bog (*Scheuchzerio-Caricetaeanigrae*) class of vegetation type (Figure 3).

Among listed species there are some which were recorded on different types of objects. They were: *Centaurium erythraea* subsp. *erythraea*, *Epipactisatrorubens*, *E. palustris*, *Eriophorumlatifolium*, *Malaxismonophyllos*, *Melampyrumsylvaticum*, *Myricaria germanica*, *Najas marina*, *Neottia nidus-avis*, *Polypodium vulgare*, *Pyrola chlorantha*, *P. minor*, *Schoenoplectustabernaemontani* and *Utricularia australis.*

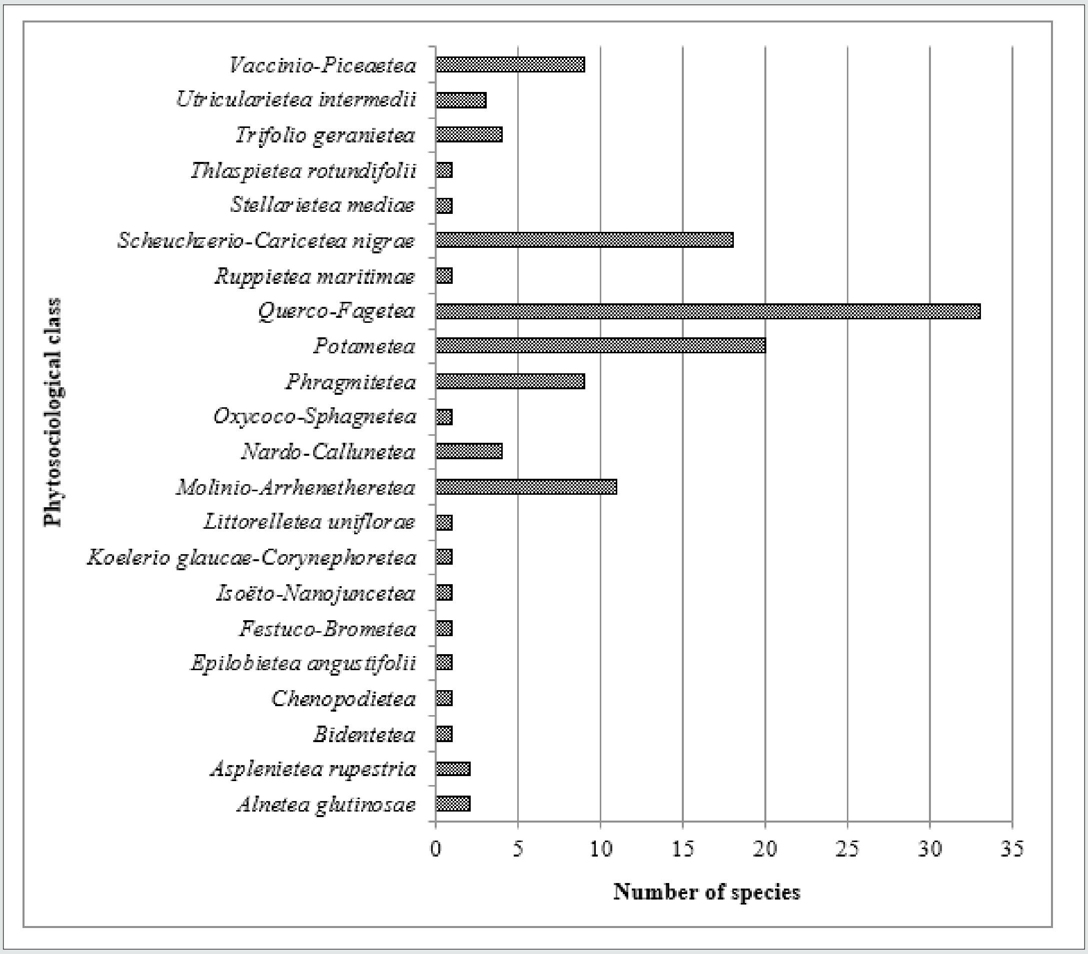

Figure 3: The number of rare plant species recorded in the vegetation patches on the studied post-excavation sites representing vegetation type groups depending on their classification in the natural and semi-natural ecosystems according to Oberdorfer et al. [26].

The analysis of abiotic habitat conditions where the recorded rare plant species occurring in the vegetation on the studied post-excavation sites, are coming from has been divided into groups depending on the preferred circumstances in terms of light, moistures, temperature and reaction parameters (Figure 4).

Most of rare plant species recorded in the vegetation patches on the studied post-excavation sites are known to occupy the places of moderate and full light conditions. Less of the analyzed plant species occupy the places of half shade and moderate shade light availability (Figure 4). In terms of temperature index requirements the most of the rare plant species are known to grow in moderately cold climatic conditions, lower regions, northern lowlands and special micro-habitats - raised bogs and moderately warm climatic conditions, mainly lowlands and lowlands. Less species has been recorded representing the warmest regions and micro-habitats, thermally advantaged areas and the coldest areas of the country, mainly the alpine and subalpine floors (Figure 4). Analyzing the habitat moisture value of the rare plant species recorded in the vegetation patches on the studied post-excavation sites the numerous group of species is representing habitats moderately moist and water conditions. The following groups represent dry habitats and very moist habitats. The differentiation of the trophism index among the analyzed species has shown that the highest number for plants are representing the moderately rich (mesophrophic) soils (water) - mixed forest, tall, acidophilous oak and beech forests and rich (eutrophic) soils (water) - lowland, fertile beech forests as well as poor (oligotrophic) soils (water) - fresh pine coniferous forests. Much less species represents the very rich (extremely fertile, over-fertilised) soils (water), (Figure 4). In terms of soil acidity index, the presence of species occurring on alkaline soils is justified by the presence of the largest number of the recorded species, followed by those that are known from the sub-neutral to neutral, 6≤pH<7 habitats. The least group of the recorded species represent the highly acidic soils, pH<4 site conditions.

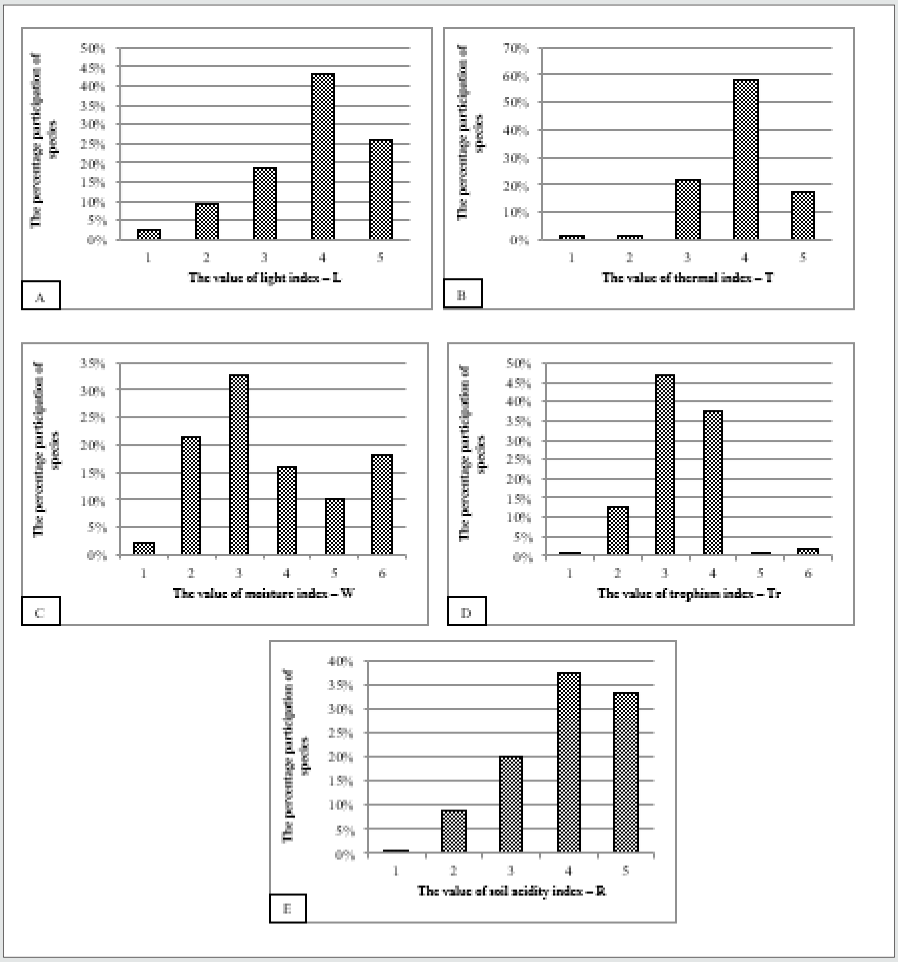

Figure 4: The participation of recorded rare species in relations to the value of selected ecological indicators: A – light index (L), B – thermal index (T), C – moisture index (W), D – trophism index (Tr), E – soil acidity index (R).

Explanations: Light index (L): 1 – deep shade, 2 – moderate shade, 3 – half shade, 4 – moderate light, 5 – full light. Thermal index (T): 1 – the coldest areas of the country, mainly the alpine and subalpine floors, 2 – moderately cold areas, mainly the subalpine and upper regions, 3 – moderately cold climatic conditions, lower regions, northern lowlands and special micro-habitats - raised bogs, 4 – moderately warm climatic conditions, mainly lowlands and lowlands, 5 – the warmest regions and micro-habitats, thermally advantaged areas. Moisture index (W): 1 – habitats very dry, 2 – habitats dry, 3 – habitats moderately moist, 4 – habitats very moist, 5 – habitats wet, 6 – water. Trophism index (Tr): 1 – extremely poor (extremely oligotrophic) soils (water) – raised bogs, loose sands, dry coniferous forests, 2 – poor (oligotrophic) soils (water) – fresh pine coniferous forests, 3 – moderately rich (mesophrophic) soils (water) – mixed forest, tall, acidophilous oak and beech forests, 4 – rich (eutrophic) soils (water) – lowland, fertile beech forests, 5 – very rich (extremely fertile,) soils (water), 6 – over-fertilised soils, water. Soil acidity index (R): 1 – highly acidic soils (pH<4), 2 – acidic soils (4≤pH<5), 3 – moderately acidic (5≤pH<6), 4 – subneutral to neutral (6≤pH<7), 5 – alkaline (pH>7).

The analysis of rare plant species recorded in the vegetation patches on the studied post-excavation sites presenting the participation of species with different threat categories. The largest group of species is vulnerable (V) and near threatened (NT) both in the regional and country scale. In the Europe and world scale most of recorded species are least concern (LC), (Figure 5).

Some of those objects have become included into the UNESCO World Heritage List [27]. The open cast sand pits in south Poland appear to be habitat that enables the development of numerous population of one of the representative of the orchid family – *Liparis loeselii*[28]. This species is included in Annex II of the Habitats Directive [29].

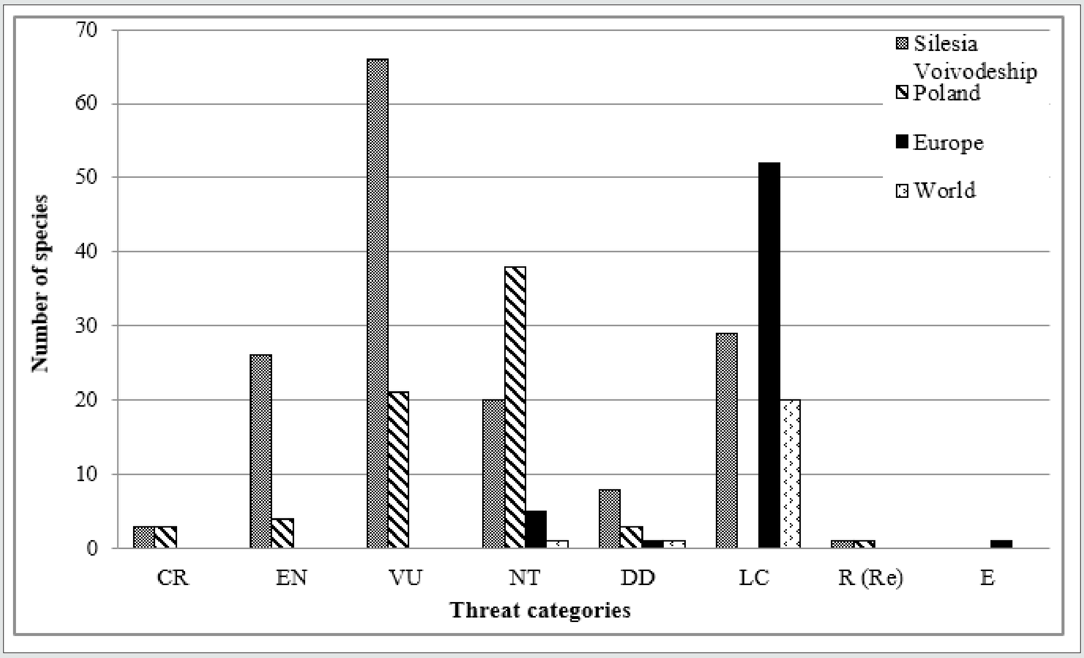

Figure 5: The participation of rare plant species recorded in the vegetation patches on the studied post-excavation sites in respect to different threat categories. Explanations: Threat categories:CR – critically endangered, EN – endangered, VU – vulnerable, NT – near threatened, DD – data deficient, LC – least concern, R (Re) – regionally extinct, E – extinct.

Discussion

Ecosystem services, vascular plant species and vegetation diversity

The relationship between habitat variability, species diversity, biodiversity, ecosystem functioning and ecosystem services is still discussed and intensely studied [30]. It is very often difficult to estimate what is the role of individual species in providing specific ecosystem services [31]. The role of the key note species has been proven to influence ecosystem services the up to now. Scientists undertake many projects regarding this issue. Species diversity plays vitally important role in increasing resistance to invasive species [32]. The long-term studies show that high species and / or functional diversity provides higher stability to the ecosystems, resulting in greater stability and ability to provide wider range of ecosystem services [33-34].

Vegetation and species diversity apart from physical, mental, spiritual and aesthetic benefits for health is influencing also the atmosphere regulation, pests or pollinators abundance, prevention of erosion and stimulation of soil-forming processes [30]. It has been proven that the increase and protection of biodiversity particular rare and endangered plant species and vegetation, causes an increase in other ecosystem services [3, 14, 35-37]. In recent years, there are more and more papers regarding the valuation of ecosystem services both in areas used by human and protected areas, e.g. [38]. The assessment of the costs necessary to preserve ecosystem services is met by Landscape Equivalency Analysis – ARK, which makes it possible to balance economic activities with ecosystem protection goals.

According to Bacler-Żbikowska and Nowak [39] the vascular plant species recorded in post-industrial sites of the Silesian Upland covers 7,4 % of the number of species listed in the flora of the Silesian Province. The plant species observed on post-industrial sites of the Silesian Upland are varied and represent different functional groups. Particularly valuable is the presence of species that represent the *Orchidaceae* family. The list of orchid species growing on Silesian post-industrial sites cover about 50% of all orchid species occurring in Poland. All the representatives of the *Orchidaceae* family are protected in Poland. Additionally the presence of endangered and rare species in the Silesian post-industrial sites provide the proof that the habitat conditions of post-industrial areas are suitable as secondary habitats for these species. The long term study suggests that the post-industrial areas support the spontaneous colonization, establishment and survival of rare, endangered and protected plant species as results these sites have become refugee for species which have been out competed and disappear from natural habitats. In the Olkusz Ore District more than 800 species of vascular plants have been recorded, what represent about 20% of Poland's flora [8]. In some European countries, specific forms of nature protection like SSSI are introduced for particularly valuable wild life post-industrial areas.

Many ecosystem functions of the biological systems that develop on post-industrial sites could provide ecosystem services in densely populated urban and industrialized lands [15]. In the urban-industrial space, the spontaneous development and constant evolution of new ecological systems in some of the post-industrial areas, directly contribute to biodiversity increase and in this way to the improvement of the ecosystem mosaic functioning and though the quality of human life condition. The recoded organisms' diversity results from the verity of specific micro-habitats of the post-industrial sites. In addition to plants, the primary producers, which are most often analyzed, both in Poland and other European countries, the biocenotic function for various animal groups is emphasized [40-43]. Due to the intense colonization and evolution process which take place spontaneously on the neglected post-industrial sites, a specific "network of life" is established increasing the cover of green areas. This network has also encouraged the flow of genes in areas which are known of significant habitats fragmentation.

Conclusion

The presence of high diversity of the recorded spontaneous species composition of vegetation and the diversity of vegetation patches itself growing on the post-coal mine and post-excavation has to be considered as a factor during environmental management projects, when the novel ecosystems habitats are considered. The presented study is providing the proof of how important are the natural processes for enhancing vegetation and rare plant species diversity. The vegetation species composition is governing the character of the following below and above ground ecosystem processes reflecting the close relations between biodiversity and ecosystem functioning and ecosystem services provision. This natural process are particular important in the ecosystem mosaic in the urban–industrial landscape. The natural processes are maintaining the ecosystem and environmental function lost because of human activity. The presented results show that only time must be given to get the ecological processes back.

The ecological features of the analyzed representatives present a wide spectrum, which is confirmed by the diversity of habitat conditions characterizing post-industrial areas. The post-industrial areas novel ecosystems habitat conditions help the rare and endangered plant species to survive in the urban–industrial landscape.

References

1. Dulias R, Hibszer A (2004) Województwo śląskie. Przyroda. Gospodarka. Dziedzictwo kulturowe. Wydawnictwo Kubajak. Kraków, Poland.
2. MEA – Millennium Ecosystem Assessment (2005) Ecosystems and Human Well-Being: Synthesis. Island Press. Washington DC, USA.
3. de Groot RS, Alkemade R, Braat L, Hein L, Willemen L (2010) Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecological Complexity 7(3): 260-272.
4. Dulias R (2018) Geografia fizyczna Wyżyny Śląskiej. Podręczniki i Skrypty Uniwersytetu Śląskiego w Katowicach nr 201. WydawnictwoUniwersytetuŚląskiego. Katowice. pp. 1-216.
5. Kompała-Bąba A, Sierka E, Dyderski MK, Bierza W, Magurno F, et.al. (2020) Do the dominant plant species impact the substrate and vegetation composition of post-coal mining spoil heaps? Ecological Engineering 143: 105685.
6. Błońska A, Kompała-Bąba A, Sierka E, Besenyei L, Magurno F, et.al. (2019) Impact of selected plant species on enzymatic activity of soil substratum on post-mining heaps. Journal of Ecological Engineering 20(1): 138-144.
7. Błońska A, Kompała-Bąba A, Sierka E, Bierza W, Magurno F, et.al.(2019) 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 20(2): 209-217.
8. Nowak T, Jędrzejczyk-Korycińska M, Kapusta P, Szarek-Łukaszewska G (2015) Characteristics in the vascular plant flora in the Olkusz Ore-bearing Region. In: Godzik B (ed) Natural and historical values of the Olkusz Ore-bearing Region. W. Szafer Institute of Botany. Polish Academy of Sciences. Kraków, poland pp. 147-166.
9. Woźniak G, Kompała A (2000) Gatunki chronione i rzadkie na nieużytkach poprzemysłowych. In: Nakonieczny M (ed.) Problemy środowiska i jego ochrony. Wydawnictwo Uniwersytetu Śląskiego 8: 101-109.
10. Woźniak G, Kompała A (2000) Rola procesów naturalnych w rekultywacji nieużytków poprzemysłowych. InżynieriaEkologiczna 1: 87-93.
11. Bruggeman DJ, Jones ML, Lupi F, Scribner KT (2005) Landscape Equivalency Analysis: Methodology for Estimating Spatially Explicit Biodiversity Credits. Environmental Management 36(4): 518-534.
12. Kremen C (2005) Managing ecosystem services: what do we need to know about their ecology? Ecology Letters 8(5): 468-479.
13. Woźniak G, Cohn EVJ (2007) Monitoring of spontaneous vegetation dynamics on post coal mining waste sites in Upper Silesia, Poland. In: Sarsby R, Felton A (eds) Geotechnical and Environmental Aspects of Waste Disposal Sites. Taylor and Francis Group, London pp. 289-294.
14. Larondelle N, Haase D (2012) Valuing post-mining landscapes using an ecosystem services approach – An example from Germany. Ecological Indicators 18: 567-574.
15. Woźniak G, Sierka E, Wheeler A (2018) Urban and Industrial Habitats: How Important They Are for Ecosystem Services. In: Hufnagel L (ed.) Ecosystem Services and Global Ecology pp. 169-194.
16. Hobbs RJ, Higgs E, Harris JA (2009) Novel ecosystems: implications for conservation and restoration. Trends in Ecology & Evolution 24(11): 599-605.
17. Hobbs RJ, Higgs ES, Hall CM (2013) Defining novel ecosystems. In: Hobbs RJ, Higgs ES, Hall CM (eds) Novel Ecosystems: Intervening in the New Ecological World Order. John Wiley & Sons, Ltd, USA.
18. Woźniak G (2010) Zróżnicowanie roślinności na zwałach pogórniczych Górnego Śląska. InstytutBotanikiim W Szafera PAN. Kraków, poland pp. 1-320.
19. Singh RS (2000) Revegetation of coal mine overburden dump (OBD) slopes by aromatic grasses. Journal of Medicinal and Aromatic Plant Sciences 22(1B): 506-509.
20. Pieczyrak J (2010) Characteristics and engineering usage of waste from coal mining. Architecture Civil Engineering Environment 3(1): 77-84.
21. Poros M, Sobczyk W (2013) Rewitalizacja terenu pogórniczego po kopalni surowców skalnych na przykładzie kamieniołomu Wietrznia w Kielcach. Rocznik Ochrona Środowiska 15(3): 2369-2380.

22. Poros M, Sobczyk W (2014) Kierunki rekultywacji terenów pogórniczych obszaru chęcińsko-kieleckiego w kontekście ich wykorzystania w aktywnej edukacji geologicznej. RocznikOchronaŚrodowiska 16(1): 386-403.

23. Woźniak G (1998) Primary succession on the sedimentation pools of coal mine. In: Faliński JB, Adamowski W, Jackowiak B (eds) Synanthropization of plant cover in new Polish research. Phytocoenosis Vol. 10 (N.S.) Supplementum Cartographiae Geo botanicae 9: 189-198.

24. Woźniak G (2006) Colonisation process on coal mine sedimentation pools (Upper Silesia, Poland). Polish Botanical Studies, Poland 22: 561-568.

25. Rostański A (2006) Spontaniczne kształtowanie się pokrywy roślinnej na zwałowiskach po górnictwie węgla kamiennego na Górnym Śląsku. Prace Naukowe Uniwersytetu Śląskiego w Katowicach. Nr 2410. Wydawnictwo Uniwersytetu Śląskiego. Katowice, poland.

26. Oberdorfer E, Müller T, Korneck D, Lippert W, Markgraf-Dannenberg I et.al. (1990) Pflanzensoziologische Excursionsflora. 6 Auflage. Ulmer, Stuttgart, Germany.

27. https://smzt.pl/2018/03/28/obiekt-unesco-w-trojwymiarze/

28. Błońska A (2010) Siedliska antropogeniczne na Wyżynie Śląskiej jako miejsca występowania rzadkich i zagrożonych gatunków torfowiskowych klasy Scheuchzerio-Caricetea nigrae (Nordh. 1937) R. Tx. 1937. Woda-Środowisko-Obszary Wiejskie 10(1): 7-19.

29. Habitats Directive (2019).

30. Balvanera P, Quijas S, Martín-López B, Barrios E, Dee L (2016) The links between biodiversity and ecosystem services. In: Potschin M, Haines-Young R, Fish R, Turner K (eds) Routledge Handbook of Ecosystem Services. Taylor & Francis Group p. 45-59.

31. de Groot R, Jax K, Harrison P (2016) Links between Biodiversity and Ecosystem Services. In: Potschin M, Jax K (eds) OpenNESS Ecosystem Services Reference Book. EC FP7 Grant Agreement no. 308428.

32. Wilsey BJ, Polley HW (2002) Reductions in grassland species evenness increase dicot seedling invasion and spittle bug infestation. Ecology Letters 5(5): 676-684.

33. Yachi S, Loreau M (1999) Biodiversity and ecosystem productivity in a fluctuating environment: the insurance hypothesis. Proceedings of the National Academy of Sciences of the United States of America 96(4): 1463-1468.

34. Chmura D, Molenda T (2007) Nowe stanowisko omiegu górskiego *Doronicum austriacum* Jacq. na Górnym Śląsku. Chrońmy przyrodę ojczystą 63(1): 20-24.

35. Hockings M (2003) Systems for assessing the effectiveness of management in protected areas. BioScience 53(9): 823-832.

36. Hockings M, Stolton S, Leverington F, Dudley N, Courrau J (2006) Evaluating Effectiveness: A framework for assessing management effectiveness of protected areas. 2nd edition. IUCN. Gland, Switzerland and Cambridge, UK.

37. Zipper CE, Burger JA, Skousen JG, Angel PN, Barton CD(2011) Restoring Forests and Associated Ecosystem Services on Appalachian Coal Surface Mines. Environmental Management 47: 751-765.

38. Wieliczko B (2016) Wykorzystanieusług ekosystemów w zarządzaniu zasobami naturalnymi w rolnictwie. Studia i Prace Wydziału Nauk Ekonomicznych i Zarządzania Uniwersytetu Śląskiego 46(2): 135-144.

39. Bacler-Żbikowska B, Nowak T (2021) The role of post-industrial sites in maintaining species diversity of rare, endangered and protected vascular plant species on the example of the Silesian Upland. In: Woźniak G, Dyczko A, Jagodziński AM (eds.) Mining industry responding to environmental challenges of the Anthropocene: Green Scenarios. Taylor & Francis Group, USA.

40. Tropek R, Konvicka M (2008) Can quarries supplement rare xeric habitats in a piedmont region? Spiders of the Blansky les Mts Czech Republic. Land Degradation and Development 19(1): 104-114.

41. Tropek R, Kadlec T, Karesova P, Spitzer L, Kocarek P, et.al.(2010) Spontaneous succession in limestone quarries as an effective restoration tool for endangered arthropods and plants. Journal of Applied Ecology 47(1): 139-147.

42. Tropek R, Kadlec T, Hejda M, Kocarek P, Skuhrovec J, Malenovsky I, et.al. (2012) Technical reclamations are wasting the conservation potential of post-mining sites. A case study of black coal spoil dumps. Ecological Engineering 43: 13-18.

43. Tropek R, Cerna I, Straka J, Cizek O, Konvicka M (2013) Is coal combustion the last chance for vanishing insects of inland drift sand dunes in Europe? Biological Conservation 162: 60-64.

DOI: 10.32474/JOMME.2021.01.000118