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Novel Ecosystem Development in Urban-Industry Areas as The Prerequisite of Modern Economy

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Contents

Introduction

Novel Ecosystem development in urban-industry areas as the prerequisite of modern economy is a thematically compact work on issues in the field of ecosystem functioning. The specificity of the reviewed work consists in applying the available knowledge and experience of researchers gained as a result of research conducted on natural and semi-natural habitats and ecosystems to the specific conditions of urban-industrial habitats. Characteristics and references to the Novel Ecosystem concept occupy an important place. This is crucial because more and more facts found during field studies prove that the processes taking place in the specific conditions of urban and industrial habitats differ from the previously known mechanisms of formation and functioning of natural and semi-natural ecosystems. The book presents an innovative approach to issues that have long been of interest to naturalists. The book presents how the processes and functioning of ecosystems, the relationship between abiotic and biotic parameters and colonization and development, association of living organisms, the formation of trophic chains, building biomass and ultimately fundamental and at the same time key decomposition processes in natural and semi-natural ecosystems are generally known in specific aspects. The authors also indicate in which areas there are many books that present the available scientific knowledge, explain theories, concepts, principles, regarding the modern understanding of the ecosystem functioning in natural and semi-natural systems.

Most post-mining areas meet the criteria of novel ecosystems. These proposals use the latest knowledge on the processes and functioning of ecosystems in areas transformed by man (novel ecosystems). There are few published results of interdisciplinary research on the mechanisms of ecosystem functioning. There are even fewer research results available for specific post-mining habitats. Therefore, it is not possible to provide ready-made rules of action, universal for all types of post-mining habitats and substrates. On the other hand, from the latest research of the world literature, it is known what certainly should not be done so as not to worsen the condition of the natural environment. With the current state of knowledge, it is possible to propose specific actions for specific fragments using an individual site-specific approach to a specific type of terrain. Given the need to limit and counteract global changes, each type of habitat and developing ecosystem that can contribute to increasing the natural capital is valuable. It has been shown that in post-mining areas there are many valuable habitats and developing ecosystems with significant natural potential. Both these habitats and ecosystems, in addition to their natural values and potential, are also a resource for the most important group of ecosystem services, supporting and

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auxiliary services. Unfortunately, many records and statements indicate that people responsible for developing innovative solutions for managing the natural environment of post-mining areas have a very general and superficial orientation in important issues of the latest concepts, they use non-existent names of categories of ecosystem services. Therefore, to organize the basic concepts and present complex interdisciplinary issues as well as the current state of knowledge regarding the relationship between processes taking place in the natural environment, the following text has been prepared. The book consists of six parts.

The first part of the book is a basic introduction to understanding the principles of ecosystem functioning. Concepts and definitions, essential concepts, connections between the basic elements of the ecosystem. The structure of an ecosystem and the structural relationships between the processes that underpin life on earth and most natural resources.

In the second part, abiotic and biotic parameters are characterized, which determine the structure of the ecosystem, processes and functioning. It is described in detail how dynamic changes caused by human activity, and carried out as habitat conditions, affect the course of ecosystem processes. With regard to habitats created as a result of the exploitation of mineral resources, the adaptation of organisms and processes in novel ecosystem systems in urban-industrial landscapes contributes to a significant increase in biodiversity.

The third part of the book deals with dynamic processes, changes in time and space, and partially understood temporal and spatial patterns in ecosystem processes. Particular attention is paid to the process of succession. Colonization of newly created open spaces by living organisms is a common and dynamic process. At the same time, the potential and importance of this process is underestimated in practical land development activities in urban and industrial areas.

The fourth part of the book characterizes the mechanisms by which the above-ground and underground parts of ecosystems operate and focus on the flow of water and energy as well as the circulation of micro and macro elements, including carbon, as a key element determining life on Earth. Cycles between terrestrial and aquatic ecosystems are compared. The importance of aquatic and aquatic ecosystems (Wetland ecosystems) for such global processes as water retention, carbon sequestration, and maintaining and increasing biodiversity is emphasized. It shows the role of individual groups of organisms in ecosystem processes through trophic interactions (nutrition relationships). With regard to the main goal of the book, it is important to refer in this part to changes that occur in ecosystems as a result of disturbances.

The fifth part presents the potential and documented possibilities of using the concept of natural capital in relation to environmental conditions that emerged along with the gradient of the subsoil structure and water conditions of habitats in contemporary urban and industrial landscapes. The following section presents the results of research on the species composition and diversity of communities in relation to various groups of organisms in various habitats of mineral substrates. The elements of functioning of novel ecosystems are characterized. They are presented taking into account the possibility of providing ecosystem services. Novel ecosystems are self-sufficient, and in the face of environmental changes introduced by humans, they become resistant to the influence of global change factors. Examples of post-industrial areas for which individual ecosystem services in the ecosystems of urban-industrial landscapes have been recognized and identified are presented.

The sixth part is focused on various aspects of the current and future possible and recommended understanding, education and application of the ideas of natural capital, new ecosystems and environmental health and ecosystem services inextricably linked to the conditions of human life. Novel ecosystems are particularly important for the regulation of ecosystem services. It was shown how the management of the transformed elements of the terrestrial, swamp and water environment, which were generated after the exploitation of mineral resources, is necessary for the social responsibility of business. The need to develop a new approach in post-mining land management practices is demonstrated.

The book is a summary and update of natural knowledge, which is very valuable in a dynamically changing environment. It will also enable a more conscious management of the natural environment while preserving its full potential.

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1. The principle of ecosystem functioning

The natural environment (environment) is the entirety of animate and inanimate elements of nature, remaining in mutual relations and closely related to each other. The following elements can be distinguished in the natural environment: geological structure, relief, climate, water relations, soil, living organisms. Each of these elements plays a significant role and influences, and at the same time remains under the influence of the other elements. The totality of these interactions determines the dynamic balance of the natural environment, as well as all the ecosystems that are part of it. One of the essential properties of the natural environment is the natural balance, which occurs when the outflow and inflow of energy and matter in nature are balanced. The dynamics and balance of processes determining the functioning of ecosystems and the environment remain entirely and exclusively in the field of natural sciences, as well as the search for ways to restore the balance of the functioning of the environment. Therefore, conducting a debate on the ways to restore the balance of the functioning of the environment, such as: preventing, stopping, counteracting and minimizing the effects of global changes (climate change) using only measures in the sphere of economics and social sciences cannot bring effective solutions.

1.1. Ecosystems: structure, concept, and functions

Biological processes, as well as broadly considered natural processes (i.e. biological-hydrological-geological-geographical), proceed according to the immutable laws of nature, independent of human activities and the legislative order. In the reality of changing as a result of human activity (the epoch of the Anthropocene), it is necessary to constantly update knowledge and track changes in the course of biological and natural processes underlying the functioning of the environment. One of the basic laws of nature has become the adaptation of living organisms and the relationships between them to the changing conditions of the abiotic environment. The harmonious coexistence of biotic and abiotic elements of nature determines the balance in the environment. If the goal is to limit and stop the effects of climate change, it is necessary to carefully track, learn, and understand the adaptation processes taking place in the environment. Failure to update the recommendations based on scientific knowledge of the bio-geo-chemical mechanisms of natural processes and the implementation of regulations, often based on the outdated (in many cases) state of (application) agricultural and engineering knowledge, instead of bringing benefits, may lead to an imbalance, and consequently to irreversible losses in the natural environment. Many catastrophic events (glacials, interglacials, earthquakes, volcanic eruptions)[1] in the geological history of the Earth indicate the emergence of adaptation mechanisms taking place in the natural environment.

The mechanisms developed so far suggest how to support the natural processes that appear in the newly created habitat and environmental conditions in the face of changes taking place in the environment in the Anthropocene epoch. In the face of the challenges of the new era of the Anthropocene and the changes that have already been proven in the form of new geological markers (concrete, plastic and radioactive fallout) and changes that have led to the so-called Global Change, appropriate conclusions should be drawn regarding the correct way of managing the natural environment (IPBES, 2012; IPCC, 2014). Changes caused by human activity have been taking place for a long time and are still progressing, despite the fact that for many years there have been regulations at the national and international level, which in their assumption should protect the environment against the changes that are currently observed. However, it can be seen that despite the efforts in a national and global scale this in no way improves the present condition of the environment. National and, to some extent, international regulations concerning environmental protection were (and are) created in isolation from the knowledge of the course of natural processes that underlie and regulate the functioning of the natural environment. These regulations were created and, to a large extent, are still being prepared from the perspective of usefulness, suitability of the environment for humans, and not in order to protect the natural basis for the environment functioning.

This approach is well reflected by an intensive use of the concept of waste in many documents on environmental protection. In no sense the areas are defined in this way and analyzed in terms of their role for the environment. The ever-developing knowledge resulting from research in the natural sciences was not used in the formulation of the regulations. A clear example of regulatory imperfections is, until recently, the classification of peat bogs, wet meadows and wetlands as wastelands that require reclamation to restore their economic value, completely disregarding their natural value. An essential requirement of the Anthropocene is the need to update and adjust the law in such a way that it reflects the state of natural knowledge on an ongoing basis. Therefore, the development of proposals for pro-environmental activities should be prepared in relation to the latest knowledge on the natural basis for the natural environment

[1] Glacials and interglacials are respectively alternating glacial and interglacial periods in the Holocene.

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functioning. Research in the biological and natural sciences has shown that plant communities and ecosystems of wetland habitats and wetlands, peat bogs are very important for limiting and preventing global changes. Preserving, protecting and restoring wetland habitats and wetlands, peat bogs can be fundamental to contain and counteract the effects of global changes.

There are many examples proving that human activities lasting for decades have been contrary to many basic natural laws of the environment functioning. A large part of the most spectacular examples concerns the lack of protection of water ecosystems (among others: reservoirs of watercourses, wetlands, floodplains of rivers and watercourses). Belonging to them does not in any way improve the present condition of the environment.

These include regulating rivers by building flood zones, transforming riverside riparian forests and partly alder forests into meadows and pastures.

Meeting the challenges related to limiting and mitigating the effects of changes caused by global climate change must be based on thorough knowledge of the biological and natural basis of the environment functioning. Activities should include several groups of tasks (Fisher et al., 2009; Kinzig et al., 2011; Costanza, Kubiszewski, 2012):

1. Understanding the mechanisms of resilience of individual elements of the environment and related ecosystem services (Ecosystem Services) mainly in industrial and urban landscapes.
2. Obtaining and developing knowledge on the formation, durability and value of Natural Capital in highly populated areas.
3. Understanding and determining the resources of ecosystem services based on knowledge about the course of biological processes of the ecosystem and of the natural environment functioning.
4. Based on the above task forces, developing principles for the management of natural capital and ecosystem services and continuously monitoring the effects of these activities.

For making the implementation of the above tasks possible, it is necessary to constantly develop knowledge using the latest available advanced methods in biological, biochemical, hydrobiological, hydrogeological, biophysical, and other natural sciences, which can significantly improve the ability to identify and assess the relationships between individual structural and functional elements of ecosystems in the modern world. The current situation of a multifaceted threat to the natural environment of our planet related to the so-called Global Change shows what leads to ignoring the laws of nature, unreflective pursuit of economic profit and unlimited use of environmental resources.

Information on the current state of the environment, and above all, the current state of global knowledge on the functioning of ecosystems emerging de novo on habitats transformed or created in connection with human activity, is crucial for making the right environmental decisions. Novel ecosystems are ecosystems created on habitats created or transformed in connection with human activity. Novel ecosystems were mostly formed in the Anthropocene. They now constitute a significant part of the environment and the available mosaic of niche habitats[2] in which humans live (including urban, suburban and rural ecosystems (Collier, 2012; Archibald et al., 2017)). Novel ecosystems have no natural counterparts and are now estimated to cover more than three-quarters of the Earth's surface. They exist in places that have been irreversibly changed due to the structure and function they have played in ecosystems so far. Spontaneous vegetation developing in emerging novel ecosystems includes, on a small scale, e.g. vegetation on old buildings, along stone boundary walls and fields, in old agricultural landscapes4[3]. Observations and measurements carried out in small-area habitats are examples of environments in which research is being developed to understand the functioning of ecosystems that have been destroyed for decades by chemicals called plant protection products. We are now beginning to understand the importance of plants and vegetation in habitats such as field margins and mid-field thickets together with the so-called field flower weeds in terms of functioning (maintaining balance) of ecosystems, as a base for pollinators and insect-eating birds. Novel ecosystems differ in composition and function from current and past systems (Ellis & Ramankutty, 2008; Hobbs et al., 2009). They are the determinants and hallmarks of the Anthropocene epoch. The lack of natural equivalents of novel ecosystems is due to unprecedented changes in global climate systems, the scale of the spread of invasive species, mass extinction of species and the disruption of the global nitrogen cycle (eutrophication) and carbon cycle (Seastedt et al., 2008; Hobbs et al., 2009; Jackson, Hobbs, 2009; Rockström et al., 2009). New ecosystems make it possible to study natural

[2] The ecological niche defines the relationship between habitat conditions and the species composition of organisms present in a given place, most often a microhabitat (synusium), (Grinnell, 1917; Hutchinson, 1957; MacArthur, 1968).

[3] The old agrocenoses are habitats enabling the survival of plants such as *Consolida regalis* (field larkspur) or *Agrostemma githago* (field cockle). Mentioned, as well as many other plants so-called. Field weeds, secretes substances that stimulate growth of other species, constituting a food base for pollinating insects and food for birds eating pests of crops.

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solutions that develop spontaneously after changes made by humans. They also provide an opportunity to study the history and dynamics of the relationship between biotic and abiotic elements in new systems (Hobbs et al., 2009; Jackson, Hobbs, 2009; Marris, 2009). Novel ecosystems present researchers with a number of dilemmas. Naturalists, researchers dealing with nature and environmental protection, face the challenge of searching for solutions consistent with the emerging new processes and relationships emerging and developing in the new reality of the Anthropocene (Lindenmayer et al., 2008; Rogers et al., 2014).

Most of the areas created as a result of the exploitation of mineral resources are habitats where ecological systems that meet the criteria of Novel Ecosystems develop (there is currently no Polish translation of the term, which reflects the essence of the phenomenon). Even the current, highly unsatisfactory and imperfect state of knowledge about the mechanisms of formation of natural systems in new mineral habitats that have not existed so far indicates that they can be centres of biodiversity, a place of shaping natural processes (proceeding in a modified way) and ecosystem services (e.g. in strongly transformed conditions of urban and industrial areas). According to the available publications, water, wetland, and non-eutrophic habitats, such as most mineral areas created as a result of the exploitation of mineral resources, are invaluable in actions aimed at limiting the effects of climate change.

References

[1] Archibald C.L., McKinney M., Mustin K., Shanahan D.F., & Possingham H.P. (2017). Assessing the impact of revegetation and weed control on urban sensitive bird species. Ecology and Evolution, 7(12): 4200-4208. https://doi.org/10.1002/ece3.2960.

[2] Collier M.J. (2012). Field boundary stone walls as exemplars of “novel” ecosystems. Landscape Research, 38(1): 1-10. https://doi.org/10.1080/01426397.2012.682567.

[3] Costanza R., & Kubiszewski I. (2012). The authorship structure of “ecosystem services” as a transdisciplinary field of scholarship. Ecosystem Services, 1(1): 16-25. https://doi.org/10.1016/j.ecoser.2012.06.002.

[4] Ellis E.C., & Ramankutty N. (2008). Putting people in the map: anthropogenic biomes of the world. Frontiers in Ecology and the Environment, 6(8): 439-447. https://doi.org/10.1890/070062.

[5] Fisher B., Turner R.K., & Morling P. (2009). Defining and classifying ecosystem services for decision making. Ecological Economics, 68(3): 643-653. https://doi.org/10.1016/j.ecolecon.2008.09.014.

[6] Grinnell J. (1917). The niche-relationships of the California Thrasher. The Auk, 34(4): 427-433. https://doi.org/10.2307/4072271.

[7] Hobbs R.J., Higgs E., & Harris J.A. (2009). Novel ecosystems: implications for conservation and restoration. Trends in Ecology & Evolution, 24(11): 599-605. https://doi.org/10.1016/j.tree.2009.05.012.

[8] Hutchinson G.E. (1957). Concluding remarks. Cold Spring Harbor Symposium on Quantitative Biology, 22: 415-427. http://dx.doi.org/10.1101/SQB.1957.022.01.039.

[9] IPBES – Intergovernmental Platform on Biodiversity and Ecosystem Services. (2012). Catalogue of Assessments on Biodiversity and Ecosystem Services. catalog.ipbes.net. (dostęp: 14.04.2021).

[10] IPCC – Intergovernmental Panel on Climate Change. (2014). Summary for policymakers. W: Field C.B., Barros V.R., Dokken D.J., Mach K.J., Mastrandrea M.D., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., & White L.L. (Eds). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, United Kingdom and New York. 1-32 p.

[11] Jackson S.T., & Hobbs R.J. (2009). Ecological restoration in the light of ecological history. Science, 325(5940): 567-569. DOI: 10.1126/science.1172977.

[12] Kinzig A.P., Perrings C., Chapin III F.S., Polasky S., Smith V.K., Tilman D., & Turner II B.L. (2011). Paying for ecosystem services – Promise and peril. Science, 334(6056): 603-604. DOI: 10.1126/science.1210297.

[13] Lindenmayer D.B., Fischer J., Felton A., Crane M., Michael D., Macgregor C., Montague-Drake R., Manning A., & Hobbs R.J. (2008). Novel ecosystems resulting from landscape transformation create dilemmas for modern conservation practice. Conservation Letters, 1(3): 129-135. https://doi.org/10.1111/j.1755-263X.2008.00021.x.

[14] MacArthur R.H. (1968). The theory of the niche. W: Lewontin R.C. (Ed.). Population biology and evolution. Syracuse University Press. Syracuse, New York. 159-176 p.

[15] Marris E. (2009). Ecology: Ragamuffin Earth. Nature, 460(7254): 450-453. DOI: 10.1038/460450a.

[16] Rockström J., Steffen W., Noone K., Persson C., Lambin E.F., Lenton T.M., Scheffer M., Folke C., Schellnhuber H.J., Nykvist B., de Wit C.A., Hughes T., van der Leeuw S., Rodhe H., Sörlin S., Snyder P.K., Costanza R., Svedin U., Falkenmark M., Karlberg L., Corell R.W., Fabry V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., & Foley J.A. (2009). A safe operating space for humanity. Nature, 461(7263): 472-475. https://doi.org/10.1038/461472a.

[17] Rogers A.M., & Chown S.L. (2014). Novel ecosystems support substantial avian assemblages: the case of invasive alien Acacia thickets. Diversity and Distributions, 20(1): 34-45. https://doi.org/10.1111/ddi.12123.

[18] Seastedt T.R., Hobbs R.J., & Suding K.N. (2008). Management of novel ecosystems: are novel approaches required? Frontiers in Ecology and the Environment, 6(10): 547-553. https://doi.org/10.1890/070046.

1.2. Methodology - the basis of knowledge

Cogito ergo sum (René Descartes: Discourses on Method, 1637)

How sure one can be about the statements written above? In Natural Sciences, the metodology and methods are the basic prerequisite of knowledge. Currently, the falsification of scientific hypothesis is the basis of any conducted study in biology and any natural sciences.

René Descartes delivered a sentence which was the conclusion of the argument in which he was looking for indisputable foundations of knowledge and cognition. He recognized that the fact of thinking is indisputable, and consequently the existence of a thinking subject is certain. On this thought process, Descartes bases his belief in the existence of "certain knowledge" (Popper, 1997, 2002).

Research methodology is the science of the principles and methods of research in order to obtain reliable knowledge about reality. The methodology of science develops on the borderline of ontology[4] and epistemology[5] and deals with the

[4] Ontology - theory of knowledge - a branch of philosophy that tries to study the structure of reality, dealing with issues related to, among others, notions of being.
[5] Epistemology - theory of cognition - a branch of philosophy dealing with the relationship between the process (subject and object) of cognition, cognition and reality.

method of measuring the occurring phenomena and the mechanisms of relations between them. The aim of research methodology is to develop and improve methods of measuring/studying phenomena and methods currently used (Szymanek, 2004; Wójtowicz, 2004; Olszewski, 2006). The better (more accurate) the testing method, the more faithful (closer to reality) results are obtained. The essence of reliable cognition - measurement of the studied phenomenon - is the appropriate selection of the research method or measurement technique. Each field and discipline of science has developed its own research methods (Levins, Lewontin, 1985; Metallmann, 2000; Murawski, 2003; Marczyk et al., 2005).

The philosophy of knowledge has been developed for many centuries. Currently, a theory commonly used in the methodology of the natural sciences is hypothetism (also called anti-inductivism[6]). It is a direction in the methodology of science indicating the importance of the decision regarding the formulation of research hypotheses. Contrary to inductivism, in which it is required that the acceptance of a hypothesis be the result of appropriate inductive procedures, hypothetism assumes that the criterion for accepting scientific statements and cognition is the principle of formulating the hypotheses that are the easiest to disprove experimentally (Adèr, Mallenbergh, 1999; Heller, 2005).

Hypothesis assumes that if a hypothesis stands up to serious refutation (testing), it deserves to be accepted, at least until further testing is undertaken. This is the essence of the principle of falsifiability as a criterion of the scientific approach, named after its creator Karl Popper (Popperism). The theory of knowledge proposed by Popper is easier understandable knowing that he is also the creator of a philosophical system which he calls critical rationalism. Popper considered himself a continuator of the philosophy of Immanuel Kant8[7]. Popper proposed a criterion of falsifiability that is very appropriate for the study of the functioning of the environment. This criterion allows for constant updating of knowledge about natural phenomena adequate to their dynamic nature. This criterion also makes it possible to track the adaptive processes of living

Epistemology considers: what is cognition. It explains the laws of both knowing and what is known.

[6] Anti-inductivism was created in opposition to the theory of inductivism - a theory that sees the real cognitive value in the methodology of science only in general statements formulated by induction. Induction is the observation of individual facts, which are described by sentences of the so-called perceptive. The observational statements are then generalized based on inductive reasoning.

[7] Immanuel Kant – founder of critical philosophy, an extensive research and philosophical project aimed at critical analysis of the possibilities of cognition. His main contribution to Western philosophy was the abolition of the opposition between rationalism (Descartes) and empiricism (Hume).

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organisms, which are a response to changes in the substrate and environment, which are constantly taking place in nature. Falsifiability lies in the fact that it should always be possible to propose such an experiment, the result of which unequivocally contradicts the validity of the theory and available knowledge. What matters is that the theory at all admits the possibility of disproving itself as a result of a designable experiment (Popper 1997, 2002).

According to Popper, the development of science does not consist in a gradual verification, as proposed by the logical positivists, but in the continuous falsification of existing scientific achievements (Popper, 1997, 2002; Habermas, 2003; Uebel, 2020). Popper rejects the empirical-logical theory (inductivism) and proposes a hypothetical-deductive one in its place. Thus, he replaces the idea of verification with the idea of falsification.

Rejecting hypotheses through falsification is the way to discover another theory closer to the truth. Thanks to the works of Karl Rajmund Popper, the ethos of critical thinking in philosophy has been appreciated again. The main goal of the philosopher's work is also to be a constant intellectual effort to separate science from pseudoscience (the problem of demarcation)9[8], (Levins, Lewontin, 1985; Herda, 2004; Heller, 2017). This approach is particularly justified in view of the changes and challenges of the Anthropocene that are taking place in the natural environment and must be known. It is also necessary to identify the underlying mechanisms of systems developing in changed or new conditions. All new phenomena and any significant changes in the course of widely understood natural processes, especially if they are related to social and economic phenomena and processes, require a new methodological approach. The phenomena and processes of the Anthropocene epoch require an appropriate methodological approach to certain phenomena, an approach not used so far. A development of the best methods for imaging processes and phenomena will make it possible to learn the mechanisms of de novo functioning of emerging ecosystems. Among the theory of knowledge and methodology, the theory of paradigms should also be considered10[9]. Changes in the natural environment

[8] The problem of demarcation was first formulated in antiquity. What science deals with fell within the scope of interests of philosophy (in particular, philosophy of nature). For Aristotle, knowledge was supposed to be completely certain, general or universal, and to have the character of cause-and-effect explanations.

[9] The paradigm is distinguished by several essential features: i.) the paradigm is adopted by consensus of the majority of researchers, it is not given once and for all; paradigm compliance with existing knowledge is important; ii. may periodically undergo fundamental changes leading to profound changes in science called the scientific revolution; iii.) according to Kuhn, a paradigm is a way of understanding scientific laws and the structure of the world, described by a matrix specifying exemplary solutions to theoretical and practical problems, valid for scientific disciplines.

brought about by the Anthropocene may require a completely new methodological approach. The concept of Kuhn's sense paradigm (The Structure of Scientific Revolutions) is a set of concepts and theories constituting the basis of the analysed science. The theories and concepts that make up the paradigm are generally not questioned, at least as long as the paradigm is cognitively creative, as long as it can be used to create detailed theories in accordance with the experimental data that a given science deals with (Lewontin et al., 1984; Metallmann, 2000; Szacki, 2002; Sierotowicz, 2003; Lewontin, Levins, 2007; The Internet Encyclopedia of Philosophy: https://www.iep.utm.edu/).

References

[1] Adèr H.J., & Mallenbergh G.J. (Eds). (1999). Research methodology in the social, behavioural & life sciences, SAGE Publications Ltd. London. 1-416 p. https://dx.doi.org/10.4135/9780857029027.

[2] Franciszek Ojciec Święty. (2015). Encyklika Laudato Si’. W trosce o wspólny dom. Libreria Editrice Vaticana. Watykan.

[3] Habermas J. (2003). Przyszłość natury ludzkiej. Czy zmierzamy do eugeniki liberalnej? Wydawnictwo Scholar. Warszawa. 1-115 p.

[4] Heller M. (2005). Filozofia przyrody Władysława Heinricha. Zagadnienia Filozoficzne w Nauce, 36: 31-44.

[5] Heller M. (2017). Jak być uczonym. Copernicus Center Press. Kraków. 1-72 p. ISBN: 978-83-7886-315-1.

[6] Herda J. (2004). Teoria ewolucji molekularnej w ujęciu Motoo Kimury. Zagadnienia Filozoficzne w Nauce, 35: 45-65.

[7] Levins R., & Lewontin R. (1985). The dialectical biologist. Harvard University Press. Cambridge. 1-336 p.

[8] Lewontin R., & Levins R. (2007). Biology under the influence. Dialectical essays on the coevolution of nature and society. New York Monthly Review Press. 1-304 p.

[9] Lewontin R., Rose S., & Kamin L.J. (1984). Not in our genes. Biology, ideology and human nature. New York Pantheon Books. 322 p. ISBN: 0394508173, 9780394508177.

[10] Metallmann J. (2000). Determinizm w biologii. Zagadnienia Filozoficzne w Nauce, 26: 91-99.

[11] Murawski R. (2003). Główne koncepcje i kierunki filozofii matematyki w XX wieku. Zagadnienia Filozoficzne w Nauce, 33: 74-92.

[12] Olszewski A. (2006). Kilka uwag o tezie Churcha i Aksjomacie Hilberta. Zagadnienia Filozoficzne w Nauce, 38: 114-126.

[13] Popper K.R. (2002). Logika odkrycia naukowego. Wydawnictwo Naukowe PWN. Warszawa. ISBN: 83-01-13870-X.

[14] Popper K.R. (1997). W poszukiwaniu lepszego świata. Wykłady i rozprawy z trzydziestu lat. Wydawnictwo Książka i Wiedza. Warszawa. 1-297 p.

[15] Sierotowicz T. (2003). Galileuszowskie perspektywy. Refleksje na marginesie Konferencji Eurosymposium Galileo 2001. Zagadnienia Filozoficzne w Nauce, 33: 137-149.

[16] Szacki J. (2002). Historia myśli socjologicznej. Wydawnictwo Naukowe PWN. Warszawa. ISBN: 83-01-13844-0.

[17] Butra J. 1981: Wpływ wybranych czynników i parametrów eksploatacji systemami komorowo-filarowymi na straty eksploatacyjne i zubożenie rudy - praca doktorska, Politechnika Wrocławska, Wrocław 1981 Szymanek, K. (2004). Sztuka argumentacji. Słownik terminologiczny. Wydawnictwo Naukowe PWN. Warszawa.

[18] The Internet Encyclopedia of Philosophy. "Vienna Circle" by Murzi M. ISSN: 2161-0002, https://www.iep.utm.edu/ (dostęp: 16.04.2021).

[19] Uebel T. (2020). Vienna Circle. Stanford Encyclopedia of Philosophy. Stanford University. https://plato.stanford.edu/entries/vienna-circle/ (dostęp: 15.04.2021).

[20] Wójtowicz K. (2004). Filozofia matematyki Gödla na tle neopozytywistycznej koncepcji matematyki. Zagadnienia Filozoficzne w Nauce, 34: 3-21.

"… We can therefore conclude that the source of many problems in today's world is primarily the not always conscious tendency to determine the methodology and goals of technical sciences according to the paradigm of reasoning that determines people's lives and the functioning of society. The effects of applying a technical and mechanistic approach to all reality, human and social, can be seen in the degradation of the environment. The use of the methodology and objectives of technical sciences is a symptom of reductionism, affecting human life and society in all their dimensions. It should be recognized that the objects produced by technology are not neutral because they influence lifestyles and direct social opportunities in accordance with the interests of specific power groups. Certain decisions that appear to be purely instrumental are in fact choices relating to the type of social life that is going to develop.

/Pope Francis (2015) "*Laudato Si*' Encyclical. Taking care of our common home"

1.3. The natural environment

The natural environment (environment) is the entirety of animate biotic and inanimate abiotic elements of nature, remaining in mutual relations and closely related to each other. The natural environment is a mosaic of ecosystems, each of which includes the atmosphere, biosphere, hydrosphere, pedosphere, and lithosphere (Fig. 1.3.1.). The natural environment distinguishes such elements as: geological structure, relief, climate, water conditions, soil, and living organisms. Each of these elements plays a significant role and influences (and at the same time remains) influenced by other factors. The totality of these interactions determines the dynamic balance of the natural environment, as well as all the ecosystems that are part of it. One of the essential properties of the natural environment is dynamic balance (a state that occurs when the outflow and inflow of energy and matter in the ecosystems that make up the natural environment are balanced). The dynamics and balance of processes determining the functioning of ecosystems and the environment remain entirely and exclusively in the field of natural sciences, as is the search for ways to restore the balance of the functioning of the natural environment (Solomon et al., 2000; Degórski, 2004; Łabno, 2006; Mackenzie et al., 2015).

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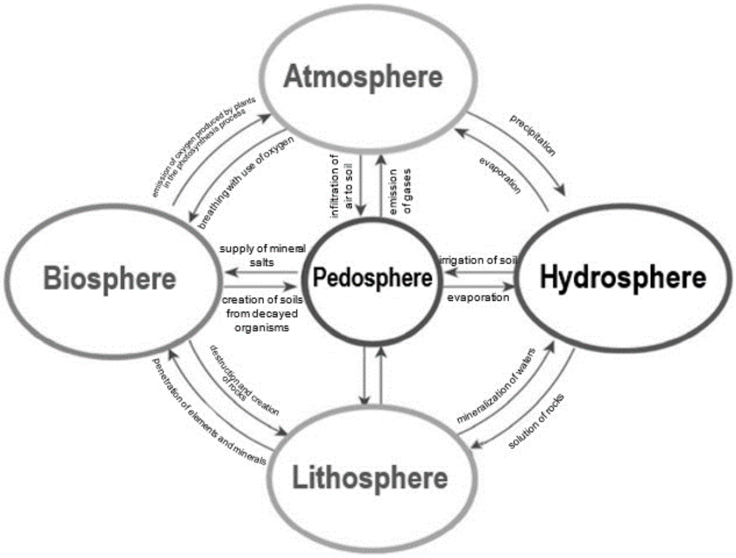

Figure. 1.3.1. The relations between the five spheres of the planet environment. All the elements are closely related. The changes in groundwater level caused by dewatering are changing the water level in rivers and are decreasing significantly the water retention of a bigger area. Functional relationships connecting individual elements of the natural environment: oxygen released by plants in the process of photosynthesis; breathing with oxygen; emitting gases; penetration of gases (air) into the soil or substrate; precipitation; evaporation; supply of mineral salts; soil irrigation; formation of soil from dead fragments of living organisms; soil hydration; evaporation; weathering and rock formation; penetration of elements and minerals; mineralization of waters; dissolving rocks; the formation of soil from rocks; soil-forming process; leaching of components from the soil into the rocks; mineralization of waters; rock solubility (changed and supplemented after Solomon et al., 2000; Degórski, 2004; Łabno, 2006; Mackenzie et al., 2015)

Therefore, conducting a debate on ways to restore balance in the functioning of the environment, such as: preventing, counteracting, and minimizing the effects of global changes (climate change) using only the way of seeing reality and activities in the sphere of economics and social sciences, cannot bring effective solutions (Helingerová et al., 2010; Józefaciuk et al., 2014). Living organisms together with the abiotic conditions of their occurrence, as inseparable elements of the environment functioning, are dynamic systems, closely interdependent and mutually influencing each other. The term "environment" etymologically means surroundings. Thus, the environment includes biotic as well as abiotic elements that surround living organisms. Any abiotic or biotic factor that affects the life of an organism is called an environmental factor, an ecological factor11, or an ecofactor. Abiotic factors include e.g. such elements of the environment as: ambient temperature, amount of sunlight, water pH, soil in which soil organisms are found, and others. Biotic factors include, among others: availability of food, presence and number of competitors, predators and parasites, and intensity of biochemical processes (Fotyma, Mercik, 1992; Helingerová et al., 2010; de Vries et al., 2013).

1.4. Soil and soil substratum (pedosphere)

Soil is the topmost layer of the earth's crust. It is a mixture of minerals of rock fragments formed in the weathering process. In addition to mineral elements, soil also consists of organic matter (i.e. living and dead), water, and air.

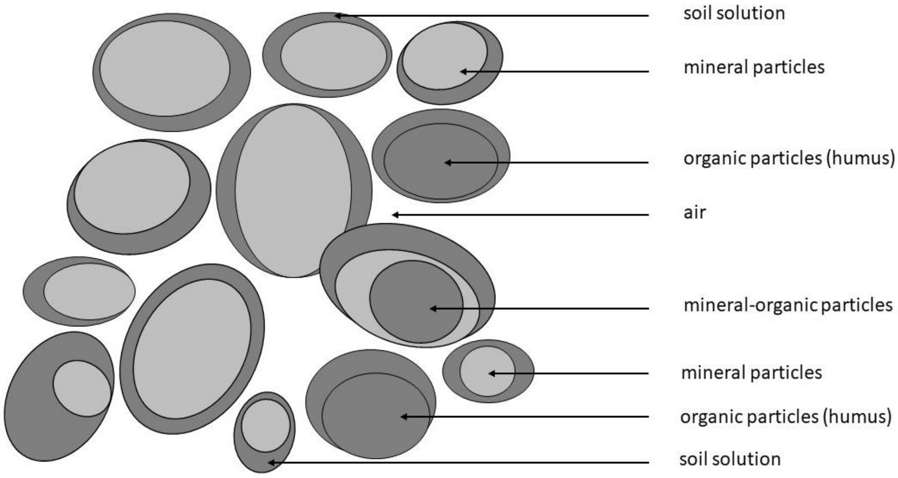

Figure 1.4.1. Scheme of the structure of the three-phase soil system created by mineral and organic compounds, water and air (changed and supplemented after: Musierowicz, Uggla H., 1967; Uggla H., Uggla Z., 1979; Uggla H., 1981)

Soil is a natural, three-phase (Fig. 1.4.1.), biologically active, surface layer of the earth's crust, formed through soil-forming processes from rock (rocks parent plant) as a result of the impact of weather conditions and living organisms, in specific relief conditions and in a specific time (Uggla H., 1981; Mocek, 2015; Uggla H., 1967; Uggla H., 1981; Fotyma, Mercik, 1992; Classification of Soil Resources of the World, 2014).

Soil is an integral component of terrestrial ecosystems and some shallow waters. Formed in the soil-forming process, it consists of structured (divided into clearly distinguishable layers) mineral and organic parts. Soil is biologically active and provides a living environment for a variety of organisms, creating a soil ecosystem (Solomon et al., 2000; Mackenzie et al., 2015). The science that studies the phenomena occurring in the soil is called pedology (Mocek, 2019).

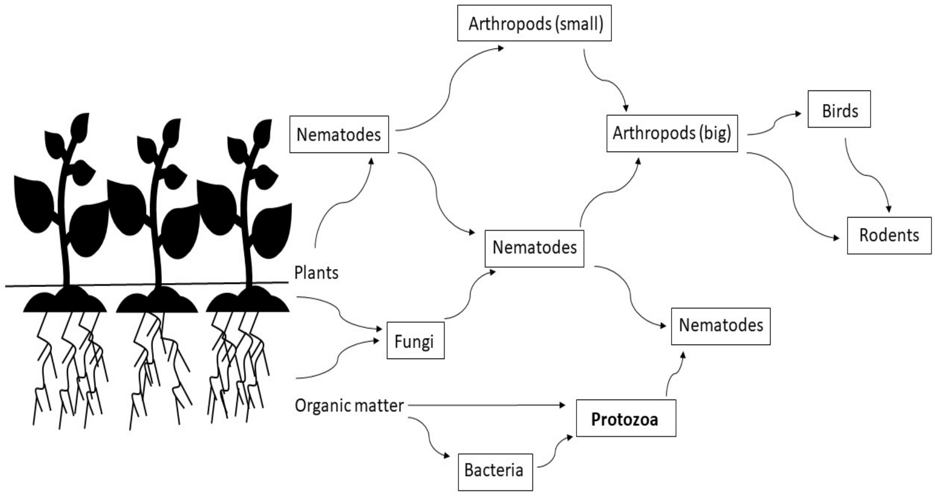

Figure 1.4.2. A simplified diagram of food webs in and above the soil. Soil as the exclusive or temporary place of life for many living organisms that together form the soil ecosystem. Soil is biologically active and is a living environment for various organisms and for the course of many processes in ecosystems (changed and supplemented after: Helingerová et al., 2010; de Vries et al., 2013)

Soil is of fundamental importance for the development of many organisms and for the course of a significant part of the processes determining the circulation of matter and energy in ecosystems. Mineral salts and water contained in the soil are the basis and are necessary for most primary producers, which are mainly plants. Mineral salts present in the soil are incorporated into plant tissues and thus reach a wide variety of food chains. Soil is a complex, structured, heterogeneous mixture of inorganic mineral compounds (in the first stages of the soil-forming process), and in later stages also organic elements. These compounds differ significantly in terms of particle size (granular structure). In addition to inorganic and organic compounds, water and gases are also present in the soil, (Solomon, 2000; Helingerová et al., 2010; de Vries et al., 2013). The composition of the soil depends on the nature of the parent rock constituting the substrate for the soil-forming process (Musierowicz, Uggla H., 1967; Kabała, 2015). The amount of humus and the diversity of organisms living in the emerging soil are related to the advancement of the physical and chemical aspects of the soil-forming process (Uggla H., 1981; Bednarek, Skiba, 2015).

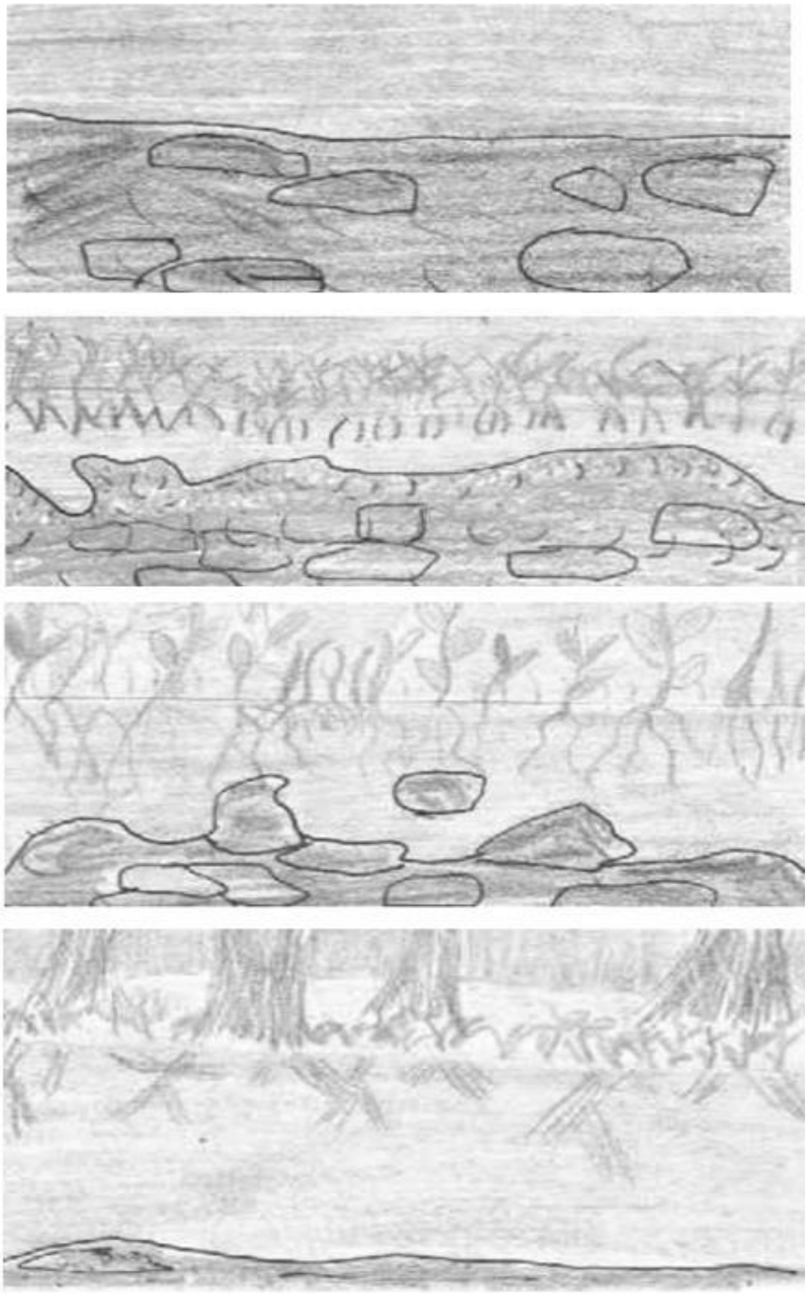

Figure 1.4.3. Diagram of the course of individual stages of the soil-forming process, starting from the bedrock, through the development of vegetation providing organic matter, to the developed soil profile (amended and supplemented after Uggla H., Uggla Z., 1979; Uggla H., 1981; Fotyma, Mercik, 1992; Bednarek, Skiba, 2015; Kabała, 2015)

It is estimated that approx. 45% of the soil volume is made up of mineral compounds, while approx. 25% are gases found in the spaces between the structural elements of the soil. The most common gases in the soil are CO_2, methane CH_4, hydrogen sulphide H_2S, ammonia NH_3, 25% - water, and 5% - gaseous organic substances (Uggla H., 1981). Quantitative and qualitative composition of gases in inter-soil spaces is determined by the intensity of processes, mostly associated with the activity of microorganisms, occurring in the soil. The characteristics, diversity, and abundance of the participation of individual groups of microorganisms depend primarily on whether the processes in the soil take place in anaerobic conditions or with access to oxygen (Zawadzki, 1999). Under anaerobic conditions, methane and hydrogen sulfide are present. The mixture of gases in the soil differs significantly from atmospheric air. The air in the soil contains a much higher (5-50 times) amount of carbon dioxide (CO_2). The humus in the soil is dominated by organic components, which are formed thanks to the microorganisms living in the soil and the dead remains of plants and animals (Uggla H., 1981; Kabała, 2015).

The elements that make up the soil are divided into two groups: macro- and micro-elements. The macroelements include 14 elements: potassium, sodium, calcium, magnesium, aluminum, iron, carbon, silicon, nitrogen, phosphorus, oxygen, sulfur, hydrogen, chlorine. In the top layer of the earth's crust, silicon and aluminum are particularly numerous, as well as oxygen, because these elements are part of the clay minerals, i.e. quartz SiO_2, aluminosilicates, and silicates of aluminum and magnesium. On the other hand, microelements include: boron, copper, zinc, manganese, iron, molybdenum. These micronutrients are part of minerals of various chemical composition: borosilicates, CuFe, S_2Cu, FeS_2 (chalcopyrite), $ZnCO_3$, $ZnCl_2$, $MnO_2(H_2O)$, $FeO(OH)$, $Fe(OH)_2$, $Fe(OH)_3$, MoS_2 (molybdenite), $CaMoO_4$ and humus.

1.4.1. Weathering and soil formation

Weathering is a process that leads to the formation of smaller rock and mineral fragments, which allows the formation of the soil and the development of the soil profile at a later stage. Weathering involves the physical fracture and chemical fracture of the rocks and minerals contained in the host rocks. Physical disintegration breaks rocks into smaller fragments, and finally into sand and silt particles, which are granulometrically part of the individual minerals. At the same time, minerals chemically decompose, releasing chemical compounds soluble in water (Uziak, Klimowicz, 2004). Other compounds can be formed from the resulting substrates. As a result, new minerals can form due to minor chemical changes or complete chemical fractures of the original mineral and the synthesis of new minerals. The soil may remain in place above the bedrock from which it was formed, or the mineral particles of the soil may be moved to another location by wind (aeolian soils), water (alluvial), gravity (colluvium), or ice (glacial soils).

1.4.2. Soil profile

The soil profile is a vertical section, a trench (150 cm deep) showing the soil layers (genetic horizons). The soil profile reveals the morphology (structure) of the soil. It allows for precise tracing of the type, volume, and mutual arrangement of genetic levels (Musierowicz, Uggla H., 1967; Uggla H., 1981; Mocek, 2015).

The soil profiles of individual soil types differ significantly. In each soil profile, layers of different compositions are distinguished. On this basis, soil classification is made. Different types of soils consist of layers of different thickness, because the composition and thickness of individual layers of the soil profile are determined by many factors, including type of substrate (parent rock), weather conditions, water content, presence of living organisms, advancement of soil-forming processes (Uggla H., 1981; Józefaciuk et al., 2014).

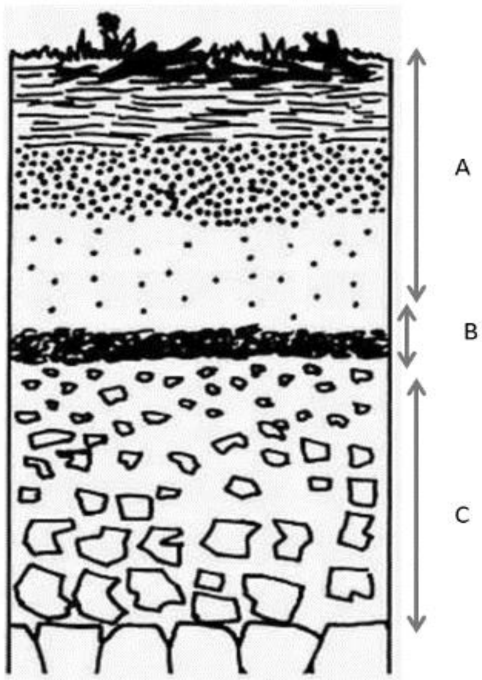

Figure 1.4.2.1. A simplified diagram of the arrangement of layers in a simple soil profile: A - mineral-humus horizon, B - illuvial horizon (wash-in, enrichment), C - bedrock horizon (changed and supplemented after Uggla H., Uggla Z., 1979; Uggla H., 1981; Fotyma, Mercik, 1992; Bednarek, Skiba, 2015; Kabała, 2015)

The following basic genetic soil horizons are distinguished in the systematics:

O - organic horizon. above the mineral part of the soil profile (e.g. forest litter level),

A - mineral and humus level, E - leaching and washing level, B - illuvial level (washing, enrichment), C - parent rock level, G - glial level (in soils with glazing coming from groundwater), M – decay level,

R - rocky substrate in incomplete soils (formed from heterogeneous parent rock), D – non-solid rock substrate in incomplete soils. The appearance and genetic properties of soil horizons are shaped as a result of the soil-forming process, which at the same time causes a soil-specific arrangement of genetic soil horizons, called soil structure (Systematyka soil Polski, 2011).

As a result of soil-forming processes, organic and mineral elements are moved and concentrated. The migration of particles of different sizes under specific conditions leads to the formation of specific soil levels, which enables the identification of clearly separated levels. During field research, when soil profiles are analyzed, a soil excavation is made. On the walls of the excavated soil profile, it is possible to observe the arrangement of individual genetic levels. A determination of the arrangement, thickness and colour of individual layers in the soil profile is one of the most important identifying features showing the stage of development of the tested soil. It also allows to determine the genesis and evolution of the soil. Based on the quantitative parameters and properties of individual layers of the soil profile, the soil type is determined. Each of the known types of soil is characterized by a specific arrangement of layers in the soil profile (Bednarek et al., 2004; Brożek, 2017).

Based on the structural elements of individual layers, soil profiles are distinguished:

- well-developed – consisting of specific and appropriately developed horizons, specific for each type of soil,
- uneducated - which is identified on the basis of small thickness or lack of certain levels appropriate for the middle or lower part of the profile.

In addition, soil profiles are distinguished:

- complete - in which mineral material from the same parent rock occurs along the entire depth of the profile (the depth of the profile cannot be less than 1.5 m),
- incomplete - formed from source rocks, the thickness of which is less than 1.5 m.

Hippocrates believed that the development of living organisms of plants and animals depends on the quality of the soil. The soil enables growth, food, retains and collects water, and thanks to the microorganisms living in it, it participates in the process of decomposition (mineralization) of dead organic remains, necessary for the continuity of life on Earth, thus affecting the circulation of elements in the environment.

References

[1] Bednarek R., Dziadowiec H., Pokojska U., & Prusinkiewicz Z. (2004). Ecological and soil science research. PWN Scientific Publishing House. Warsaw. 234-241 p. ISBN: 83-01-14216-2.

[2] Bednarek R., & Skiba S. (2015). Soil-forming factors and processes. In: Mocek A. (ed.). Soil science. PWN Scientific Publishing House. Warsaw. 68-98 p. ISBN: 978-83-01-17944-6.

[3] Brozek S. (2017). Forest soil science. Synthesis of knowledge about soils close to natural and their relations with vegetation in Polish forests. ed. University of Agriculture in Krakow. 1-410 p. ISBN: 978-83-64758-44-7.

[4] Degorski M. (2004). Soil geography as a physico-geographical discipline. Geographical Review, 3(76): 271-288.

[5] Fotyma M., & Mercik S. (1992). agricultural chemistry. PWN Scientific Publishing House. Warsaw. 32-38 p.

[6] Helingerová M., Frouz J., & Santrůčková H. (2010). Microbial activity in reclaimed and un-reclaimed post-mining sites near Sokolov (Czech Republic). Ecological Engineering, 36(6): 768-776. https://doi.org/10.1016/j.ecoleng.2010.01.007.

[7] Józefaciuk A., Nowocień E., & Wawer R. (2014). Soil erosion in Poland – environmental and economic effects, remedial actions. Monographs and Scientific Dissertations 44. IUNG-PIB. Pulawy. 1-261 p. DOI: 10.13140/RG.2.1.3432.0401.

[8] Kabbalah C. (2015). Soil morphology. In: Mocek A. (ed.). Soil science. PWN Scientific Publishing House. Warsaw. 99-130 p. ISBN: 978-83-01-17944-6.

[9] Classification of Soil Resources of the World - WRB. (2014). IUSS Working Group WRB: World reference base for soil resources 2014. International soil classification system for naming soils and creating legends for soil maps. http://web.archive.org/web/20170828204221; /http://www.fao. org: 80/3/a-i3794e.pdf (access: 23/12/2020).

https://doi.org/10.32056/KOMAG/Monograph2023.5

[10] Labno G. (2006). Ecology. Encyclopedic dictionary. Europa Publishing House. Wroclaw. 1- 472 p.

[11] Mackenzie A., Ball A.S., & Virdee S.R. (2015). Ecology. Short lectures. PWN Scientific Publishing House. Warsaw. 1-428 p.

[12] Mocek A. (ed.). (2015). Soil science. PWN Scientific Publishing House. Warsaw. 1-571 p. ISBN: 978-83-01-17944-6.

[13] Musierowicz A., & Uggla H. (1967). General forest soil science. National Agricultural and Forestry Publishing House. Warsaw. 1-303 p.

[14] Solomon E. P., Berg L. R., Martin D. W., & Villee CA (2000). Biology. Multico Publishing House. Warsaw. 1-1334 p. ISBN: 83-7073-090-6.

[15] Polish soil systematics. (2011). Soil Science Annals, 62(3): 1-195. Polish Society of Soil Science. ed. 5. The Village of Tomorrow Publishing House. Warsaw. http://ssa.ptg.sggw.pl/files/artykuly/2011_62/2011_tom_62_3/tom_62_3_calosc.pdf (accessed: December 23, 2020).

[16] Uggla H. (1981). Agricultural soil science. PWN Scientific Publishing House. Warsaw.

[17] Uggla H., & Uggla Z. (1979). Forest soil science. National Agricultural and Forestry Publishing House. Warsaw.

[18] Uziak S., & Klimowicz Z. (2004). Elements of soil geography and soil science. Maria Curie-Skłodowska University Publishing House. Lublin. 1-254 p. ISBN: 83-227-1671-0.

[19] de Vries F., Thébault E., Liiri M., Birkhofer K., Tsiafouli MA, Bjørnlund L., Jørgensen HB, Brady MV, Christensen S., de Ruiter PC, d 'Hertefeldt T., Frouz J., Hedlund K., Hemerik L., Gera Hol W. H., Hotes S., Mortimer S. R. Setälä.

[20] Sgardelis H., Uteseny S. P., van der Putten K., Wolters WH, Bardgett V., & RD (2013). Soil food web properties explain ecosystem services across European land use systems. Proceedings of the National Academy of Sciences of the United States of America, 110(35): 14296-14301. https://doi.org/10.1073/pnas.1305198110

[21] Zawadzki S. (ed.). (1999). Soil science. National Agricultural and Forestry Publishing House. Warsaw. 17-18 p. ISBN: 830901703-0.

1.5. Air and atmosphere

Another element of the natural environment is air and atmosphere. The earth is surrounded by an atmosphere, which we usually call air. Air contains oxygen, nitrogen, and a small amount of other gases, including such as greenhouse gases, which keep (should keep) the Earth naturally at the right temperature, making it a planet conducive to the development of life. The air also contains pollutants (Prentice, 2001a). Some of them (dust and gases from the fumes of volcanoes, geysers, and fumaroles) are of natural origin (Earth Fact Sheet: https://nssdc.gsfc.nasa.gov/planetary/factsheet/earthfact.html). However, many compounds and substances found in the atmosphere are man-made and come from e.g. burning fuels for energy, electricity, heat, and transport (Ruddiman, 2005; Tans, 2019; https://www.esrl.noaa.gov/gmd/ccgg/trends/).

The air also contains a lot of water in the form of water vapor. The moisture in the air is clearly visible when it rains. The rest of the time, water is present in the air as invisible vapor or visible clouds. The constant circulation of water takes place between the Earth's atmosphere, its biosphere, hydrosphere, and pedosphere. The presence of water in the atmosphere enables the occurrence of many weather phenomena that are crucial to sustaining and sustaining life on Earth.

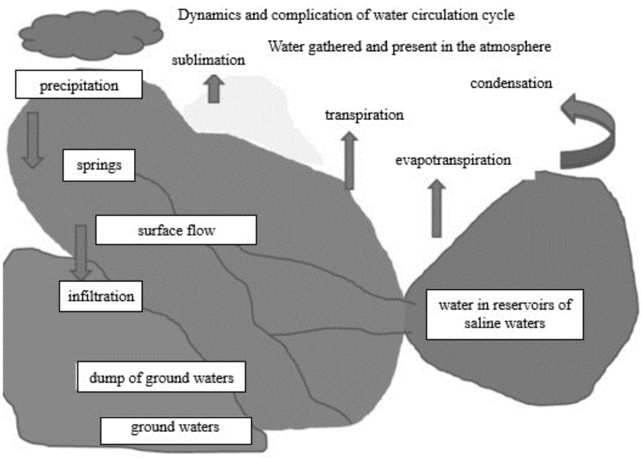

Figure 1.5.1. Scheme of the global water cycle between the atmosphere, biosphere, hydrosphere, pedosphere, and lithosphere

The largest volume of air is near the Earth's surface (in the lowest layer of the atmosphere called the troposphere). This layer is attracted to the Earth's surface by gravity. Weather phenomena occur in the troposphere within a distance of up to 10 km from the Earth's surface. First of all, they are caused by the movement of warm layers of air. Heat is exchanged between hot and cold places as a result of the movement of air that causes winds. They result from the difference in temperature and air pressure. The atmosphere extends far into space and is made up of various layers. For example, the stratosphere, which lies above the troposphere, contains the ozone layer, which protects life on Earth from the sun's harmful ultraviolet rays (Rybka, 1970). Even higher up, meteors burn up in the atmosphere and can be seen as shooting stars at night.

1.5.1. Light and temperature - factors determining the existence of living organisms

Sunlight is a major part of the abiotic conditions that determine the functioning of an ecosystem. The sun is the primary source of energy on our planet. Above the frequency of infrared waves, visible light appears. The sun emits its peak power in the visible region, although integrating the entire emission power spectrum at all wavelengths shows that the sun emits slightly more infrared than visible light. Visible light is the part of the electromagnetic (EM) spectrum to which the human eye is most sensitive. Visible light (and near-infrared light) is typically absorbed and emitted by electrons in molecules and atoms that move from one energy level to another. Electromagnetic radiation is an external (originating outside the ecosystem) source of energy, which is an essential abiotic factor enabling the course of all other biological and natural life processes in almost all ecosystems on Earth. Electromagnetic radiation with a wavelength between 380 nm. and 760 nm. (400-790 terahertz) is detected by the human eye and perceived as visible light. Other wavelengths, especially near infrared (longer than 760 nm) and ultraviolet (shorter than 380 nm), are also sometimes referred to as light. White light is a combination of lights of different wavelengths in the visible spectrum. Passing white light through a prism splits it into several colours of light observed in the visible spectrum between 400 nm. and 780 nm. Light energy (sunlight) is the primary source of energy in almost all ecosystems. This is the energy used by green plants (containing chlorophyll or another dye capable of changing the energy of electromagnetic radiation into the energy of chemical bonds) during the light phase of the photosynthesis process.

In the dark phase of the photosynthesis process, plants synthesize organic substances (mainly simple sugars, e.g. glucose) by combining inorganic substances (https://ocw.mit.edu/high-school/biology/exam-prep/cellular-energetics/photosynthesis/).

In the light phase (light-dependent), the assimilation force in the form of ATP and NADPH is generated, which is then used in the reactions of the dark phase.

Photosystem I (PSI) has an absorption maximum at 700 nm. and photosystem II (PSII) with a maximum absorption of about 680 nm. Then photolysis of water occurs. The assimilation force generated in the light phase and retained in high-energy chemical bonds is used to carry out the dark phase. The dark phase of photosynthesis is the Calvin cycle (supplemented and modified from: https://pl.khanacademy.org/science/ap-biology/cellular-energetics/photosynthesis/a/intro-to-photosynthesis).

Visible light is of the greatest importance to plants as it is essential for photosynthesis. Factors such as light quality, light intensity and length of light exposure (day length) play an important role in the life of primary producers (photosynthetic organisms) and thus in the functioning of the ecosystem (Ritchie et al., 2004).

Light quality (wavelength)

Terrestrial plants absorb (absorb) blue and red-light during photosynthesis. The quality of light in terrestrial ecosystems varies little. And in aquatic ecosystems, it may be a limiting factor. Both blue and red light are absorbed at the surface and as a result, do not penetrate deep into the water. To compensate for this, some algae have additional pigments that are able to absorb light of other electromagnetic wavelengths.

The intensity of light reaching the Earth varies depending on the latitude and season. The Southern Hemisphere receives less than 12 hours of sunlight from March 21 to September 23, and receives more than 12 hours of sunlight over the next six months. While much of the Northern Hemisphere receives sunlight, it is summer in regions north of the equator. In these places there is the longest day and the shortest night - June 21. At the same time, the winter season is underway in the Southern Hemisphere. The nights are longer than the days. The time of the year when the Earth's axis of rotation is maximally tilted towards the Sun (the North Pole is closer to the Sun than the South Pole) is called the summer solstice. The hemisphere of the Earth tilted in this way towards the sun has longer access to a certain amount of direct sunlight, which results in higher temperatures in these parts of the Earth (Seidel et al., 2008; http://www.biologydiscussion.com).

When the solar radiation reaching the Earth is almost perpendicular, it is concentrated on a smaller area, causing high temperatures (Hall, 2001a). At higher latitudes, the angle of solar radiation is smaller, so solar radiation spreads over a larger area, contributing to lower temperatures.

Many phenomena and processes occurring in the natural environment are related to the quantity and quality as well as the access time of solar radiation.

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One such phenomenon is phototropism. Phototropism is the directional growth of plants in response to access to light. The direction from which the light stimulus comes determines the direction of movement of the plant. Shoots show positive phototropism as they grow towards the light.

Sunlight and its angle of incidence and temperature are interrelated. Temperature is another important abiotic factor affecting the functioning of the natural environment (Hall, 2001b). The temperature of the air, soil, and top vegetation cover (e.g., tree crowns) affects the growth and course of processes determining the development of living organisms (especially plants and animals), (Shimwell, 1971; University of California: http://cottoninfo.ucdavis.edu). Individual plant species have minimum, optimal, and maximum temperature limits at which their growth and development are optimal or possible at all. Temperature limits vary depending on the stage and conditions of growth and development of a given plant species. Root and soil temperature is as important as air temperature, as the roots of most plants have lower optimal temperatures as well as resistance and are less adapted to extreme temperatures and/or sudden fluctuations.

1.5.2. Adaptations to periodically changing temperatures

Low winter temperatures in temperate climates and cold winters or dry summers in different parts of the planet have resulted in numerous adaptations in plants (Galán de Mera et al., 1999). Raunkiær (1934) classified plants according to where the buds are located during the least favorable seasons of the year, provided that the plant retains the ability to survive these harsh conditions (Ellenberg, Mueller-Dombois, 1967). Depending on the location, the unfavorable period may be, for example, during a cold winter or a dry summer (Raunkiær, 1905). Under temperate climate conditions, the form a plant takes to survive an unfavourable season mainly concerns the place of protection of the buds during the winter (Raunkiær, 1907).

Based on these criteria, Raunkiær distinguished the following types of plant life forms (morphological types of plants that reflect their adaptation to the environment) (Fig. 1.5.2.1.):

– Phanerophytes (F) – durable plants (manifest buds) with lignified shoots with winter-hardy renewing buds, which are placed more than 50 cm above the soil surface (substrate). Phanerophytes include megaphanerophytes (trees) and nanophanerophytes (shrubs less than 2 m high and green phanerophytes).

This group also includes epiphytes (self-sustaining plants, settling on other plants, which are only physical support for them) (Falińska, 2004).
- chamefits (CH) – shrubs (low buds) with woody shoots (woody chamefits) and durable herbaceous plants (herbaceous chamaphytes) with buds on shoots up to 50 cm above the ground, usually protected by snow cover.
- hemicryptophytes (H) - are mainly represented by perennials (ground-bud) in which overwintering buds are located on shoots located just at the soil surface, the substrate, and are protected by living or dead leaves and snow cover.
- cryptophytes (K) - cryptobud plants with renewing buds located on storage organs hidden in soil, mud or water, e.g., tubers, rhizomes, stolons, and bulbs. Plants forming underground organs (rhizomes, stolons, tubers or bulbs) are geophytes that can bloom very early before full shade is provided by trees. In this way, they contribute to the occurrence of various phenological phases in ecosystems, e.g., beech forests and some forms of oak-hornbeam forests. On the other hand, aquatic plants that are completely submerged in water are classified as hydrophytes (Hy). Perennial aquatic plants growing above the water represent the group of helophytes (He).
- therophytes (T) – are a group of annual plants that survive unfavourable seasons in the form of seeds. These plants complete their entire life cycle (ontogeny) in one growing season.

In different climatic zones, the proportions between life forms are different (Volovnik, 2013).

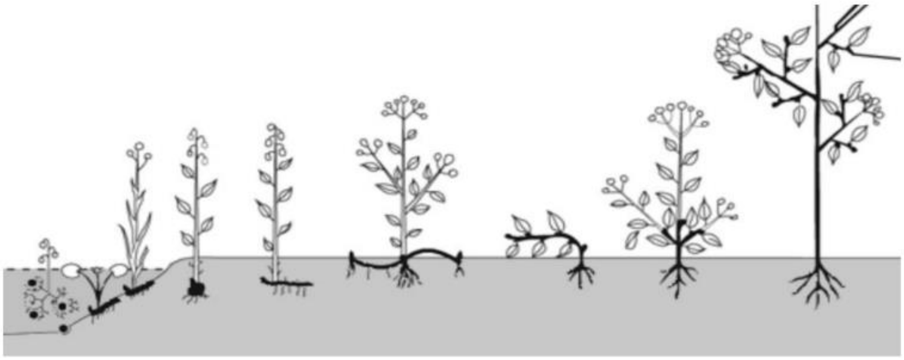

Figure 1.5.2.1. The scheme of location of surviving buds according to the concept of life forms by Raunkiær (1934). Schematic arrangement of life forms in the habitat humidity gradient (modified after: Mueller-Dombois, Ellenberg, 1974)

Animals also have a number of adaptations to periodically changing temperatures (Mowat, 1993). Poikilothermic organisms such as reptiles, fish, and

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amphibians are unable to maintain body temperature at a constant level. In these animals, body temperature changes with changes in the ambient temperature. Poikilothermic organisms (poikilotherms) are characterized by a low metabolic rate and high thermal conductivity. The metabolic rate of these organisms is controlled by the ambient temperature. Poikilotherms have an upper and lower limit on the temperatures they can tolerate. These limits are based on the body temperature range within which the poikilotherm can carry out daily essential activities. The upper and lower limits of temperature tolerance vary from species to species. In order to maintain a tolerable, relatively constant body temperature range during periods of activity, terrestrial and amphibious poikilotherms have the ability to perform various behaviours (behavioural thermoregulation), such as changing position or location. To survive the long and cold winters, many terrestrial poikilotherms go into a long, seasonal torpor called hibernation. Hibernation is manifested by the body's torpor and a state of reduced physiological activity of the animal. It is characterized by such physiological changes as slow breathing, slow heart rate, and low levels of metabolic processes.

References

[1] Earth Fact Sheet. https://nssdc.gsfc.nasa.gov/planetary/factsheet/earthfact.html (access: December 29, 2020).

[2] Ellenberg H., & Mueller-Dombois D. (1967). A key to Raunkiær plant life-forms with revised subdivisions. Berichte des Geobotanischen Institutes der Eidg. Tech. Hochschule, Stiftung Rübel, 37: 56-73. http://doi.org/10.5169/seals-377651.

[3] Falińska K. (2004). Plant ecology. PWN Scientific Publishing House. Warsaw. 141-144 p.

[4] Galán de Mera A., Hagen M. A., & Vicente Orellana J. A. (1999). Aerophyte, a New Life Form in Raunkiær's Classification? Journal of Vegetation Science, 10(1): 65-68. https://doi.org/10.2307/3237161.

[5] Hall A. E. (2001a). Crop developmental responses to temperature, photoperiod, and light quality. In: Hall, A. E. (Ed.). Crop Responses to Environment. CRC Press. Boca Raton. 83-95 p. https://doi.org/10.1201/9781420041088.

[6] Hall A. E. (2001b). Crop physiological responses to temperature and climatic zones.

[7] In: Hall A. E. (Ed.). Crop Responses to Environment. CRC Press. Boca Raton. 59-82 p. https://doi.org/10.1201/9781420041088.

[8] Mowat F. (1993). Never Cry Wolf. Amazon Kindle Edition (electronic): Open Road Media. 1- 220 p. https://www.amazon.com/Never-Cry-Wolf-Farley-Mowat-ebook/dp/B00ZJZGVXQ (accessed: December 29, 2020).

[9] Mueller-Dombois D., & Ellenberg H. (1974). Aims and methods in vegetation ecology. John Wiley & Sons. New York. Reprint 2003. Blackburn Press. ISBN: 1-930665-73-3.

[10] Prentice I. C. (2001a). Availability. In: Intergovernmental Panel on Climate Change IPCC Special Report on Emissions Scenarios

[11] Prentice I. C. (2001b). SRES scenarios and their implications for future CO_2 concentration. In: Houghton J.T., Ding Y., Griggs D.J., Noguer M., van der Linden P.J., Dai X., Maskell K., & Johnson CA (Eds). Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, United Kingdom and New York. 1-223 p. https://www.ipcc.ch/site/assets/uploads/2018/03/WGI_TAR_full_report.pdf (access: 28/12/2020).

[12] Raunkiær C. (1907). Planterigets Livsformer og deres Betydning for Geografien. Gyldendalske Boghandel. Nordisk Forlag. Kobenhavn and Kristiania. 1-132 p.

[13] Raunkiær C. (1934). The Life Forms of Plants and Statistical Plant Geography: being the collected papers of C. Raunkiær. Oxford University Press. Reprinted 1978.

[14] Egerton F. N. (Ed.). Ayer Co Pub. History of Ecology Series. ISBN: 0-405-10418-9.

[15] Raunkiær C. (1905). Types biologiques pour la géographie botanique. Oversign over Det Kongelige Danske Videnskabernes Selskabs Forhandlinger, 5: 347-438.

[16] Ritchie G. L., Bednarz C. W., Jost P. H., & Brown S. M. (2004). Cotton Growth and Development. Cooperative Extension Service. The University of Georgia College of Agricultural and Environmental Sciences. Bulletin, 1252: 1-16.

[17] Ruddiman W. F. (2005). Did Humans First Alter Global Climate? Scientific American, 292(3): 46-53.

[18] Rybka E. (1970). General astronomy. PWN Scientific Publishing House. Warsaw. 1-614 p.

[19] Seidel D. J., Fu Q., Randel W. J., & Reichler T. J. (2008). Widening of the tropical belt in a changing climate. Nature Geoscience, 1: 21-24. https://doi.org/10.1038/ngeo.2007.38.

[20] Shimwell D. W. (1971). The Description and Classification of Vegetation. Sidgwick & Jackson. London. 1-322 p. ISBN: 9780283980633.

[21] Tans P. (2019). Trends in Atmospheric Carbon Dioxide - Mauna Loa, Hawaii. National Oceanic and Atmospheric Administration. https://www.esrl.noaa.gov/gmd/ccgg/trends/ (accessed: December 28, 2020).

[22] University of California Cotton Web Site – Cotton guideline section. http://cottoninfo.ucdavis.edu (access: December 29, 2020).

[23] Volovnik S. (2013). On phylogenetic inertia: a case of Lixinae weevils. Annales de la Société Entomologique de France. Nouvelle Série, 49(3): 240-241. https://doi.org/10.1080/00379271.2013.854087.

[24] https://en.wikipedia.org/wiki/File:Atmosphere_gas_proportions.gif

[25] https://ocw.mit.edu/high-school/biology/exam-prep/cellular-energetics/photosynthesis/

[26] https://pl.khanacademy.org/science/ap-biology/cellular-energetics/photosynthesis/a/intro-to-photosynthesis

[27] http://www.biologydiscussion.com

[28] http://www.biologydiscussion.com/biologyarticles

[29] http://www.ecoca.ro/meteo/tutorial/Atmosphere/Younger/Atmosphere_Introduction.html

[30] https://www.esrl.noaa.gov/gmd/ccgg/trends/

[31] https://www.sciencelearn.org.nz

[32] https://www.sciencelearn.org.nz/image_maps/36-dynamic-and-complex-the-global-water-cycle

1.6. Hydrosphere

The hydrosphere is one of the geospheres. It is a term for the waters that are on, below, and above the surface of the planet. It is the totality of waters on Earth, including underground and surface waters: rivers, lakes, seas, oceans, glaciers, ice sheets, and swamps, as well as water contained in the atmosphere and biosphere. The hydrosphere can be divided into two parts: the oceanosphere and the land waters. The Earth's hydrosphere is estimated to have existed for about 4 billion years (Shiklomanov, 1998; de Villiers, 2003; World Water Resources, 2013), but the Earth's hydrosphere is still observed to change shape. This is due to the shifting of the seabed and continental drift, which is changing the arrangement of land and oceans (Mackenzie, 2011).

It is estimated that there are 1,386 million cubic kilometers (333,000,000 cubic miles) of water on Earth (Shiklomanov, 1998; World Water Resources, 2013). This includes water in liquid and frozen form in groundwater, oceans, lakes, and streams. Sea water makes up 97.5% of this amount, and freshwater only 2.5%. Of the freshwater resources, 68.9% is found in the form of ice and snow cover in the Arctic, Antarctica, and mountain glaciers. However, 30.8% of freshwater is groundwater, and only 0.3% of freshwater on Earth is found in easily accessible lakes, reservoirs, and river systems (Campbell, Norman, 1998; Shiklomanov, 1998; World Water Resources, 2013).

The total mass of the Earth's hydrosphere is about 1.4 × 1018 tonnes, which is about 0.023% of the total mass of the Earth. At any one time, approximately 20 × 1012 tonnes are found as water vapor in the Earth's atmosphere (for practical purposes, 1 cubic meter of water is assumed to weigh one ton). Oceans cover about 71% of the Earth's surface, which is about 361 million square kilometers (139.5 million square miles). The average salinity of the Earth's oceans is about 35 grams of salt per kilogram of seawater (3.5%) (Kennish, 2001).

The water cycle is the movement of water from one state or body to another. Reservoirs, streams, oceans, rivers, lakes, and groundwater are fed by precipitation (mainly rain and snow). Groundwater, aquifers, and polar caps also enter the water cycle. The sun's energy in the form of heat and light (insolation) and gravity causes the water to change from one state to another at various times, ranging from a few hours to thousands of years. Most of the water vapour in the atmosphere is produced by evaporation from the oceans and returns to Earth as snow or rain (de Villiers, 2003). Water vapour in the atmosphere is also produced by sublimation, evaporation from snow and ice, and transpiration releasing water vapour through the fine pores or stomata of plants. Evapotranspiration is a term used by hydrologists to refer to three processes

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combined: transpiration, sublimation, and evaporation (de Villiers, 2003). Marq de Villiers (2003) describing the hydrosphere as a closed system in which water cycles. The hydrosphere is an intricate, complex, interdependent, all-pervasive, and stable system. De Villiers (2003) claimed that: "the total amount of water on Earth has hardly changed with the changes of successive geological epochs. Water can be polluted, and misused, but it's not created, it just migrates".

About 0.3 km³ of water increases annually as a result of natural processes such as gaseous water synthesis and the release of juvenile waters. At the same time, a comparable amount of water undergoes photodissociation in the upper atmosphere or is chemically bound in rocks as a result of other processes (Monteith, Unsworth, 1990; Dawson, 1993; Czubla, 2007). It is estimated that the Earth's water cycle covers 577,000 km^3 of water each year, including water that evaporates from the ocean (502,800 km^3) and land (74,200 km^3). As precipitation, 458,000 km^3 of water falls into the ocean and 119,000 km^3 of water falls onto land. The difference between precipitation and evaporation from the land surface (119,000 - 74,200 = 44,800 km^3/year) represents the total runoff of the Earth's rivers (42,700 km 3 / year) and the direct runoff of groundwater into the ocean (2,100 km^3 / year). These are the main sources of freshwater that are necessary for life and human economic activity (Shiklomanov, 1998; World Water Resources, 2013).

Water is the basis of life on Earth. Almost 2/3 of the Earth's surface is covered with water. Earth is also called the blue planet and the water planet. The hydrosphere plays an important role in the existence of the atmosphere in its present form, mainly thanks to the oceans. When Earth formed, it had only a very thin atmosphere rich in hydrogen and helium, similar to Mercury's atmosphere today. Later, the gases hydrogen and helium were released from the atmosphere. However, gases and water vapour released as the Earth cooled became its current atmosphere. Other gases and water vapour released by volcanoes also enter the atmosphere. As the Earth cooled, water vapour in the atmosphere condensed and fell as rain. The atmosphere continued to cool, and carbon dioxide present in the atmosphere dissolved in rainwater. This, in turn, further caused water vapour to condense and fall as rain. Rainwater-filled depressions on the Earth's surface and formed oceans. It is estimated to have occurred around 4,000 million years ago. According to Igor A. Shiklomanov, the complete filling and replenishment of ocean waters took 2,500 years, permafrost and ice - 10,000 years, groundwater and mountain glaciers - 1,500 years, waters in lakes - 17 years and rivers - 16 days (Shiklomanov, 1998; World Water Resources, 2013; https://www.unwater.org/publications/world-water-development-report-2019/).

It is believed that the first forms of life appeared in the oceans. The first organisms did not breathe (they obtained energy) by using oxygen. Later, after the evolution of cyanobacteria, the process of converting (assimilation) carbon dioxide into food and releasing oxygen began. As a result, Earth's atmosphere has a different composition compared to other planets, which has enabled the evolution of life on Earth.

1.6.1. Availability of fresh water

Only 2.5% of the water in the hydrosphere is fresh water, and only 0.25% of this water is available for use. “Specified water availability” is defined as “the remaining (after use) amount of freshwater per capita” (Shiklomanov, 1998; World Water Resources, 2013). Freshwater resources are unevenly distributed in space and time and can go from flooding to water shortages within months in the same area. In 1998, 76% of the total population had water availability below 5,000. m^3 per capita per year. However, as early as 1998, 35% of the world's population suffered from "very low or catastrophically low access to water resources". Many researchers predicted that the situation would worsen in the 21st century, when "the majority of the Earth's population will live in conditions of low or catastrophically low levels of water supply" (https://www.unwater.org/publications/world-water-development-report 2019/).

1.6.2. Human influence

Human activity (especially nowadays) has a drastic impact on the hydrosphere. River regulation, reduction of peat bog, wetland, and floodplain habitats, water diversion, development of industrial human activity, and pollution affect the hydrosphere and the natural processes occurring within it. Humans are taking water from aquifers and changing riverbeds at an unprecedented rate. An example of the dependence of humans and their economy on rational management of water resources is the Ogallala aquifer, which is used in agriculture in large areas of the United States. If the aquifer dries up, more than $20 billion worth of food and fiber will disappear from global markets (Braxton, 2009). Recent observations indicate that the aquifer is being depleted much faster than it is being replenished and that unless appropriate action is taken, the aquifer will eventually dry up.

Moreover, only 1/3 of rivers are free-flowing, unregulated. Most rivers in the world have lost their natural character due to intensive use, including the construction of dams, flood embankments, and hydroelectric power plants. River regulation and hydrotechnical structures lead to the degradation of valuable

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waterside habitats, (Carrington, 2019). Human impact on the hydrosphere is manifested in a very serious way: through eutrophication of waters, acid rain, and acidification of the oceans.

Man influences changes in the amount of water in the hydrosphere, e.g., also in chemical and technological processes. The combustion of fossil fuels also plays an important role, resulting in the release of about 5 km^3 of water vapour per year. It is estimated that the share of water directly used by humans is only 0.4% of freshwater volume. The remaining part of freshwater is groundwater, some lakes, rivers, and swamps. The loss of surface retention wetlands influences the river depth and rainfall regularity and intensity.

1.6.3. The water cycle in nature

The hydrosphere is inseparably connected with the movement of water between it and individual elements of the natural environment: pedosphere, atmosphere, lithosphere, and biosphere. This movement is caused mainly by the energy of solar radiation and the force of gravity. It is estimated that water moves in space with a vertical range of several kilometers. Only approximately 525,000 people take part in the process each year, i.e., 0.038% of the total water in the hydrosphere. Solar radiation causes constant evaporation of water from the surface of water bodies, biosphere (transpiration), and soil (Jarvis, McNaughton, 1986; Schulze et al., 1994; Sperry, 1995). Water is also released as a result of volcanic processes (juvenile waters). Exceeding the condensation level causes water vapour to condense and form clouds. Air with water in gaseous, liquid or solid form can be transported over various distances. Depending on the temperature, rain, snow, hail or atmospheric sediments form in the lower layer of the troposphere. As much as 80% of rainfall occurs over the oceans, the rest on continents. On land, a large part of rainwater evaporates directly into the atmosphere and flows away via surface watercourses, often reaching the seas and oceans through rivers or to areas with no outflow, from where it evaporates. Some of it seeps into groundwater, which often feeds rivers and flows directly into the sea (underground runoff). A large part of water is also taken up by the biosphere, which then releases it back into the atmosphere in the process of transpiration. A certain amount of water can be removed from circulation through retention. It is assumed that the average amount of water involved in the annual circulation does not change, and the statement of water revenues and losses (water balance) for the Earth is zero.

1.6.4. The origin of water on Earth

Early on, the Earth had no water or water vapour on its surface. Explaining how water reached the Earth's surface is still a matter of considerable debate. Some scientists say that much of the planet's water was supplied by comet and meteor impacts. Both of these celestial bodies contain ice. Others argue that most of the water on Earth comes from chemical reactions taking place inside the planet. Once the planet's surface has cooled sufficiently, water contained in the minerals of the accumulated material and released at depth could rise to the surface and, instead of being lost to space, was cooled and condensed, forming the initial hydrosphere. The large, cool Earth served as a trap for water, because the lower the temperature and the greater the mass of the planet, the less likely it is for water vapour to escape and the stronger the gravitational pull of water vapour. Water loss in the upper atmosphere occurs as a result of photodissociation, the break of water vapour molecules into hydrogen and oxygen under the influence of ultraviolet light energy. About 4.8 × 10-4 cubic kilometers (about 0.0005 cubic miles) of water vapour are lost each year through photodissociation. The low temperatures in the upper atmosphere create a cold trap around 15 km in which most of the water vapour condenses and returns to lower altitudes, thus avoiding photodissociation. Since the early formation of the hydrosphere, the amount of water vapour in the atmosphere was regulated by the temperature of the Earth's surface - hence its radiation balance. Higher temperatures mean higher concentrations of atmospheric water vapour, while lower temperatures suggest lower levels in the atmosphere (www.britannica.com/science/hydrosphere/Origin-and-evolution-of-the-hydrosphere).

1.6.5. The water cycle in ecosystems

The water cycle in ecosystems is the matrix in which all other bio-geochemical cycles function. The mechanisms controlling hydrological cycles and the ecosystem energy balances that drive the hydrological cycle have been largely understood (Jones, 1992; Kelliher, 1995).

Water and solar energy are essential for the functioning of the Earth's ecosystem. As none of them are evenly distributed across the planet, redistribution mechanisms (global hydrological cycle and energy cycle) are important. These processes are so closely interconnected that they cannot be treated separately (Oke, 1987; Waring, Running, 1998). Solar energy drives the hydrological cycle by vertically transferring water from the Earth to the atmosphere through evapotranspiration, the sum of evaporation from the surface, and transpiration, which is the loss of water by plants. Evapotranspiration

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is responsible for 75% of energy transfer from the Earth to the atmosphere and is therefore a key process in the Earth's energy cycle. The hydrological cycle also controls the Earth's bio-geo-chemical cycles, influencing all biotic processes. Nutrients dissolved in water are transferred within and between ecosystems. Nutrients provide resources that support a range of organisms through the food chains that arise. The movement of chemical compounds dissolved in water as well as substances and materials suspended in water connects ecosystems that occur in a given fragment of the landscape.

The available knowledge on the level of complexity, numerous ecosystem connections, as well as the importance of the hydrological cycle for other elements of the natural environment, raises concerns about the extent to which the hydrosphere has been modified by human activity. Humans currently use half of the Earth's readily available freshwater, which is about half of the average annual runoff in regions accessible to humans. Water use is projected to increase to 70% of available resources by 2050. This level of human use of freshwater affects land and water management, the flow of pollutants between ecosystems and indirectly other ecosystem processes on a global scale. The changes that have taken place as a result of land use have significantly changed the water and energy cycles, which have led to climate modification on a regional and global scale. Human activities alter the ability of the atmosphere to hold water vapour. Water vapour is the main greenhouse gas. It is transparent to solar radiation but absorbs long-wave radiation from the Earth, thus providing an insulating thermal layer. Climate warming caused by emissions of other greenhouse gases increases the amount of water vapour in the atmosphere, and thus the efficiency of the atmosphere at stopping long-wave radiation.

This water vapour feedback explains why the climate is so sensitive to emissions of other greenhouse gases. Warming accelerates the hydrological cycle, increasing evaporation and precipitation on a global scale. Sea levels are also rising, mainly due to the thermal expansion of the oceans, and secondarily, the melting of glaciers and ice caps. Rising sea levels are threatening the coastal zone where most of the world's major cities are located. Given the crucial role of the water and energy cycle in ecosystem and global processes, it is of the utmost importance that the mechanisms that drive water and energy circulation and exchange and the extent to which they have been modified by human activities, are understood.

1.6.6. Water properties that combine the water and energy budget

The unique properties of water are crucial to understanding the links between energy and water cycles. Evapotranspiration is one of the largest ecosystem processes (both in the water and energy cycles). Factors governing the amount of evapotranspiration determine the strength of the link between water and energy cycles. How much energy does it take to melt the ice? How much energy does it take for the hot water to evaporate? What determines the amount of water vapour that the atmosphere can hold before it rains?

Due to the high specific heat (the energy needed to heat 1 g of a substance by 1°C), water changes its temperature relatively slowly. As a consequence, summer temperatures near large bodies of water fluctuate less and are cooler than inland. A wet surface heats up more slowly, but more water evaporates than a dry surface. Significant amounts of energy are absorbed or released when the water changes its state. The energy needed to change 1 g of ice into liquid water, i.e., the heat of fusion, is 0.33 MJ kg -1. More than seven times more energy (2.45 MJkg -1) is needed to change 1 g of liquid water into steam at 20°C, the heat of vaporization. Therefore, changes between liquid and vapour generally have a greater impact on ecosystem energy budgets than changes between liquid and solid. This property of water causes the water to change from liquid to vapour, causing the leaves to cool. Conversely, when clouds condense to form water droplets, energy is released as the water changes phase from a vapour to a liquid state. Water vapour density (or absolute humidity) is a measure of the mass of water per volume of dry air. The amount of water vapour that can be held in the air without saturating it increases significantly with increasing temperature.

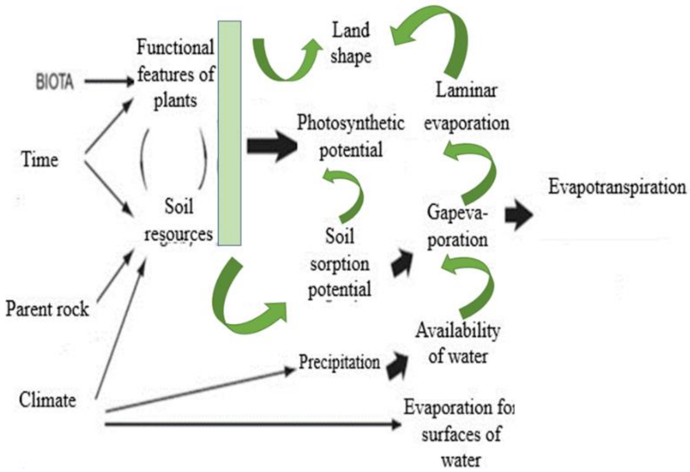

Figure 1.6.6.1. The relationship between the amount (pressure and density) of water vapor that can be held in the air without being saturated depends on the temperature (revised from Chapin III et al., 2002)

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Consequently, as the climate warms, the water-holding capacity of the atmosphere increases in a more than linear way. Relative humidity (RH) is the ratio of the actual amount of water held in the atmosphere to the maximum amount that can be retained at that temperature.

References

[1] Braxton J. (2009). The Ogallala Aquifer: Saving a Vital US Water Source. Scientific American. DOI: 10.1038/scientificamericanearth0309-32.

[2] Campbell G. S., & Norman J. M. (1998). An Introduction to Environmental Biophysics. Springer Verlag New York. 1-286 p. DOI: 10.1007/978-1-4612-1626-1.

[3] Carrington D. (2019). Only a third of the world's great rivers remain free flowing, analysis finds. The Guardian. https://www.theguardian.com/ environment/ 2019/may/08/only-a-third-of-worlds-great-rivers-remain-free-flowing-analysis-finds (accessed: 27/12/2020).

[4] Chapin III F.S., Matson P.A., & Mooney H.A. (2002). Principles of Terrestrial Ecosystem Ecology. Springer Verlag New York. 1-442 p. DOI: 10.1007/b97397.

[5] Czubla P. (2007). Hydrosphere. In: Czubla P., & Papińska E. Physical geography. Coursebook. PWN Scientific Publishing House. Warsaw. 1-344 p. ISBN: 978-83-7446-125-2.

[6] Dawson T. E. (1993). Water sources of plants as determined from xylem-water isotopic composition: Perspectives on plant competition, distribution, and water relations. In: Ehleringer, JR, Hall, AE, & Farquhar, GD (Eds). Stable Isotopes and Plant Carbon-Water Relations. Academic Press. San Diego. 465-496 p. https://doi.org/10.1016/B978-0-08-091801-3.50040-4.

[7] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (CELEX: 32000L0060).

[8] Jarvis P.G., & McNaughton K.G. (1986). Stomatal control of transpiration: Scaling up from leaf to region. Advances in Ecological Research, 15: 1-49. https://doi.org/10.1016/S0065-2504(08)60119-1.

[9] Jones H. G. (1992). Plants and Microclimate: A Quantitative Approach to Environmental Plant Physiology. Cambridge University Press. Cambridge. 1-452 p.

[10] Kelliher F.M., Leuning R., Raupach M.R., & Schulze E.-D. (1995). Maximum conductances for evaporation from global vegetation types. Agricultural and Forest Meteorology, 73(1-2): 1-16. https://doi.org/10.1016/0168-1923(94)02178-M.

[11] Kennish M. J. (2001). Practical Handbook of Marine Science. 3rd edition. CRC Press. 1-35 p. ISBN: 0-8493-2391-6.

[12] Mackenzie F.T. (2011). Our Changing Planet: An Introduction to Earth System Science and Global Environmental Change. 4th edition. Pearson Education. 88-91 p.

[13] Monteith J.L., & Unsworth M. H. (1990). Principles of Environmental Physics. 2nd edition. Arnold, London. 1-291 p. ISBN: 0 7131 2931 X. https://doi.org/10.1002/qj.49712052015.

[14] Okay T. R. (1987). Boundary Layer Climates. 2nd edition. Routledge. 464 p.

[15] Schulze E.-D., Kelliher F.M., Körner C., Lloyd J., & Leuning R. (1994). Relationship among maximum dental conductance, ecosystem surface conductance, carbon assimilation rate, and plant nitrogen nutrition: A global ecology scaling exercise. Annual Review of Ecology and Systematics, 25(1): 629-662. https://doi.org/10.1146/annurev.es.25.110194.003213.

[16] Shiklomanov I. A. (1998). World Water Resources: A New Appraisal and Assessment for the 21st Century. The United Nations Educational, Scientific and Cultural Organization. https://unesdoc.unesco.org/ark:/48223/pf0000112671 (access: 27/12/2020).

[17] Sperry J. S. (1995). Limitations on stem water transport and their consequences.

[18] In: Gartner B.L. (Ed.). Plant Stems: Physiology and Functional Morphology. Academic Press. San Diego. 105-124 p. de Villiers, M. (2003). Water: The Fate of Our Most Precious Resource. Houghton Mifflin Company. 1-368 p. ISBN: 0-618-12744-5.

[19] Waring R.H., & Running S.W. (1998). Forest Ecosystems: Analysis at Multiple Scales. Academic Press. New York. 1-370 p.

[20] World Water Resources. (2013). A New Appraisal and Assessment for the 21st Century. UNESCO. 1998.

[21] Origin and evolution of the hydrosphere: www.britannica.com/science/hydrosphere/Origin-and-evolution-of-the-hydrosphere

[22] UN World Water Development Report 2019: https://www.unwater.org/publications/world-water-development-report-2019/

[23] http://www. sciencelearn.org.nz

[24] https://www.sciencelearn.org.nz/image_maps/36-dynamic-and-complex-the-global-water-cycle

1.7. Lithosphere

The lithosphere is the rigid, outermost shell of the planet. The earth consists of a crust and part of the upper mantle. The crust and upper mantle are distinguished by rock chemistry and mineralogy. The earth's crust is made of rock masses. Some of them are solid and durable (granite), others - loose, loose (sands and gravels), and still others - plastic (clays). Visible elements can be separated from heterogeneous rocks, e.g., by mechanical crushing and selecting components. Quartz, feldspar, and mica grains can be separated from granite. These rock components are called minerals. Over 4,000 minerals are involved in the construction of the rocks of the earth's crust, and there are even more varieties and modifications (Melillo et al., 1993; Manecki, 2008; Miller, Spoolman, 2009).

The lithosphere, over timescales of thousands of years or more, behaves flexibly. The term "lithosphere" is sometimes used imprecisely as a substitute for the term "earth's crust". Lithosphere is a more extensive concept than the Earth's crust (Jaroszewski et al., 1985; Skinner, Porter, 1987). The lithosphere is closely related structurally and functionally to the pedosphere, biosphere, hydrosphere, and atmosphere (Field et al., 1998; Molles, 2010). The thickness of the lithosphere ranges from approximately 10 to over 100 km, and its temperature in the lower part reaches 700°C. The term lithosphere, sclerosphere, comes from the Greek word lithos ("stone, rock") or sklērós ("hard") and the word sphaîra ("sphere").

The Earth's lithosphere is divided into plates moving relatively to each other, the movement of which is described by the theory of plate tectonics derived from Wegener's theory. This theory allows for the explanation of most geological phenomena in the lithosphere.

The lithosphere is made up of tectonic plates. Beneath the lithosphere is the asthenosphere, which is the weaker, hotter, and deeper part of the upper mantle. The lithosphere-asthenosphere boundary is defined by the difference in stress response. The lithosphere remains rigid while the asthenosphere deforms plastically and adapts to the deformation. Lithospheric thickness is thought to be the depth of the isotherm associated with the transition between brittleness and viscosity (Macdonald, 2019). The temperature at which olivines become plastic (approximately 1,000°C) is used to establish this isotherm because olivine is generally the weakest mineral in the upper mantle (Skinner, Porter, 1987). These concepts of a strong lithosphere resting on a weak asthenosphere are central to the theory of plate tectonics.

The lithosphere can be divided into oceanic and continental lithosphere. The oceanic lithosphere is related to the oceanic crust (with an average density of about 2.9 g/cm^3) found in ocean basins. The continental lithosphere, on the other hand, is bound to the continental crust (with an average density of about 2.7 g/cm^3) and lies beneath the continents and the continental shelf. The oceanic lithosphere is denser than the continental lithosphere. The oldest oceanic lithosphere is typically about 140 km thick. The thickness of the continental lithosphere ranges from about 40 km to 280 km.

1.7.1. The lithosphere and the soil-forming process

There is a close relationship between the chemical composition and properties of the rocks that make up the lithosphere, and the course of the soil-forming process. The petrographic composition, properties, and chemical composition of minerals determine the course of the weathering process, which takes place under the influence of weathering factors, (Schlesinger 1997; Zawadzki, 1999; Bednarek *et al.,* 2004; Bednarek and Skiba, 2015; Styling, 2015). The nature of the host rock determines what soil, and with what parameters and properties, will be formed (Jørgensen, 1997; Knight *et al.,* 2005). The soil, in turn, determines which organisms will colonize it (Carpenter, Kitchell, 1988; Begon *et al.,* 2006). As a result of creating communities of various biotic elements, an ecosystem is created that is optimally adapted to the habitat conditions (Naveh, Lieberman, 1984; Saugier *et al.,* 2001; Barrett, Likens, 2002; Odum, Barrett, 2004; Blackburn *et al.,* 2006; Chapin III *et al.,* 2011).

Bedrock is the main substrate from which soil is formed (Chapman, Reiss, 2010). An important difference is whether the soil-forming process leading to the formation of soil takes place on solid rock (and the soil is formed from its weathering) or on loose rock. Loose rock is much easier to transform by soil-forming factors. In the soil-forming process, apart from the mineral composition (chemical composition) of the rock, compactness and susceptibility to weathering are also important. Granulometric composition (grain size) and erosion susceptibility are also important factors. They influence the pace and direction of the weathering and soil development process, especially during the formation of initial soils, rendzinas, lithogenic soils and peat soils.

Ventilation stands out:

- physical (mechanical) - rock breaks down without changing its chemical composition, occurs during frequent changes in temperature and humidity (in a temperate climate),
- chemical - rock decomposition as a result of changes in chemical composition in the presence of water, mainly rainwater, oxygen, nitrogen and carbon dioxide,
- biological - fracture and decomposition of the parent rock as a result of the action of living organisms.

1.7.2. Physical airing

Daily temperature changes cause slow rock bursting. The sun's rays heat and expand the outer, thin shell of the rocks. Under the influence of lower temperatures at night, the outer shell contracts, causing stresses between the outer part, exposed to direct temperature influence, and the rest of the rock.

High daily temperature changes lead to such high stresses that they cause cracks and the outer layers of the rock to fall off. The phenomenon of exfoliation can most often be observed in mountains, steppes, deserts and areas influenced by continental climates. Physical ventilation may include frost. Water freezing in rock cracks increases its volume by approximately 9%, bursting the rock. Insolation weathering is more intense when the rocks are darker. Insolation weathering occurs as granular disintegration, which occurs as a result of various thermal expansions, or as crustal weathering (flaking of the rock). As a result, the near-surface rock layer separates, which is most often exposed to temperature fluctuations. Exudation occurs when, as a result of physical weathering, salt crystallizes in the cracks of rocks, which, like water, increases in volume, and causes rocks to burst. Clay rocks have hygroscopic properties and as a result of physical weathering (deflocculation) under the influence of water (precipitation), the rocks swell and increase their volume. In conditions where water can evaporate, rocks (clay formations) crumble and crevices and cracks are formed.

1.7.3. Chemical weathering

A common method of chemical weathering is dissolution. Some minerals (such as dolomites, limestones, chlorides, gypsum) dissolve completely. Other minerals (such as marls, sandstones) undergo partial dissolution, during which the molecules of the solute combine with the solvent particles (solvation). Leaching also occurs during chemical weathering. Leaching involves washing and dissolving minerals. Calcium carbonate is an example of leaching. When combined with water containing carbon dioxide, it is easily converted into soluble bicarbonate that is washed away by the water.

As a result of hydrolysis, which occurs under the influence of water, minerals break down into alkaline and acidic parts, which are easier to erode. Mainly feldspars and silicates undergo hydrolysis. Chemical weathering is hydration, the conversion of anhydrous minerals into hydrated ones. Hydration changes the physical properties of minerals (Self-Taught Manual, 1925; Dodson *et al.,* 2000). In the case of compact, dry clays, moisture increases the volume and e.g., cohesiveness decrease. Anhydrous red hematite converts to less compact yellow limonite when hydrated. On the other hand, anhydrite turns into gypsum when water is added. Carbonization also occurs during chemical weathering (carbonation), which converts minerals (primarily silicates and aluminosilicates) into carbonates.

Oxidation, which takes place during chemical weathering, causes minerals to combine with oxygen and transform e.g., sulphides into sulphates. Chemical weathering also includes such chemical processes as: reduction (change of oxidation from a higher level to a lower one) and chelation (a process causing the decomposition of rocks that contain metals in their composition).

1.7.4. Biological ventilation

Biological weathering includes mechanical impact, such as: penetration of plant roots into rock crevices and their pushing and bursting. Organic substances contained in plant and animal tissues have a chemical effect on rocks (Bormann, Likens, 1967; Kormondy, 1996; Lidicker, 2008). Biological weathering is also caused by bacteria, e.g., anaerobic bacteria that convert gypsum into sulfur (Naveh, Lieberman, 1984; Krebs, 2009). In turn, the action of burrowing animals causes water to penetrate through burrows and corridors (Kenyon, 2010). Such conditions also contribute to the promotion of chemical weathering (Odum, 1969; Campbell, Reece, 2005).

The nature of the weathering products (waste rock) and the intensity of the process depend on the petrographic structure and mineralogical composition of the rock as well as conditions such as the amount of water and temperature. In dry desert climate conditions, physical weathering prevails. However, in humid and hot climates – chemical weathering. As a result of physical weathering, clastic rocks are formed, and chemical weathering causes the decomposition of

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some chemical rocks, such as bauxites or laterites. Weathering contributes to and facilitates soil formation, but also erosion.

1.7.5. Lithosphere, rocks and petrographic division

Petrography is the science of rocks. Petrography deals with the study of the chemical composition and physical properties of rocks. It is also sometimes referred to as the physiography of rocks. In some works, it is identified with petrology. Most often, however, petrography is considered a narrower concept, as an area of knowledge included in petrology.

The division of rocks most often used in petrography is based on their origin and includes three main groups: igneous rocks, sedimentary rocks, and metamorphic rocks (transformed rocks), (Bolewski 1965; Bolewski and Manecki 1993; Manecki, 2008; Medenbach, Sussieck-Fornefeld, 1996; Jaroszewski *et al.*, 1985; Bauer, 1997; Ryka, Maliszewska, 1991; Schumann, 2003; Żaba, 2014).

References

[1] Barrett G.W., & Likens G.E. (2002). AIBS news – Eugene P. Odum: Pioneer of Ecosystem Ecology. BioScience, 52(11): 1047-1048. https://doi.org/10.1641/0006-3568(2002)052[1047:AN]2.0.CO;2.

[2] Bauer J. (1997). Guide - Rocks and minerals. ed. Multico. Warsaw. 1-220 p. ISBN: 83-7073-050-7.

[3] Bednarek R., Dziadowiec H., Pokojska U., & Prusinkiewicz Z. (2004). Ecological and soil science research. PWN Scientific Publishing House. Warsaw. 1- 344 p. ISBN: 83-01-14216-2.

[4] Bednarek R., & Skiba S. (2015). Soil-forming factors and processes. In: Mocek A. (ed.). Soil science. PWN Scientific Publishing House. Warsaw. 68-98 p. ISBN: 978-83-01-17944-6.

[5] Begon M., Townsend C. R., Harper J. L. (2006). Ecology: From individuals to ecosystems. 4th ed. Wiley-Blackwell Publishing. 1-750 p. ISBN: 978-1-405-11117-1.

[6] Blackburn T. M., Cassey P., & Gaston K. J. (2006). Variations on a theme: Sources of heterogeneity in the form of the interspecific relationship between abundance and distribution. Journal of Animal Ecology, 75(6): 1426-1439. https://www.jstor.org/stable/4125084.

[7] Bolewski A. (1965). Detailed mineralogy. ed. Geological. Warsaw. 1-796 p.

[8] Bolewski A., & Manecki A. (1993). Detailed mineralogy. ed. Polish Ecological Agency. Warsaw. 1-663 p. ISBN: 83-85636-03-X.

[9] Bormann F.H., & Likens G.E. (1967). Nutrient cycling. Science, 155(3761): 424-429. DOI: 10.1126/science.155.3761.424.

[10] Campbell N.A., & Reece J.B. (2005). biology. 7th ed. Pearson Benjamin-Cummings. San Francisco, CA.

[11] Carpenter S. R., & Kitchell J. F. (1988). Consumer Control of Lake Productivity: Large-scale experimental manipulations reveal complex interactions among lake organisms. BioScience, 38(11): 764-769. https://doi.org/10.2307/1310785.

[12] Chapin III F.S., Matson P.A., & Vitousek P.M. (2011). Principles of Terrestrial Ecosystem Ecology. 2nd edition. Springer.

[13] Chapman J. L., & Reiss M. J. (2010). Ecology, Principles and Applications. 2nd edition. Cambridge University Press

[14] Dodson S.I., Arnott S.E., & Cottingham KL (2000). The relationship in lake communities between primary productivity and species richness. Ecology, 81(10): 2662-2679. https://doi.org/10.1890/0012-9658(2000)081[2662: TRILCB]2.0.CO;2.

[15] Einsele G. (2000). Sedimentary Basins: Evolution, Facies, and Sediment Budget. Springer-Verlag Berlin Heidelberg. 1-792 p. DOI: 10.1007/978-3-662-04029-4.

[16] Field C. B., Behrenfield M. J., Randerson J. T., & Falkowski P. (1998). Primary production of the biosphere: integrating terrestrial and oceanic components. Science, 281(5374): 237-240. DOI: 10.1126/science.281.5374.237.

[17] Hantschel T., & Kauerauf A. I. (2009). Fundamentals of basin and petroleum systems modelling. Springer-Verlag Berlin Heidelberg. https://doi.org/10.1007/978-3-540-72318-9.

[18] Jaroszewski W., Marks L., & Radomski A. (1985). Dictionary of dynamic geology. Geological Publishing House. Warsaw. 1-310 p. ISBN: 83-220-0196-7.

[19] Jørgensen S. E. (1997). Integration of ecosystem theories: A pattern. Springer, Dordrecht. Kluwer Academic Publishers. https://doi.org/10.1007/978-94-011-5748-3.

[20] Kenyon C. J. (2010). The genetics of aging. Nature, 464: 504-512. https://doi.org/10.1038/nature08980.

[21] Knight T. M., McCoy M. W., Chase J. M., McCoy K. A., & Holt R. D. (2005). Trophic cascades across ecosystems. Nature, 437(6): 880-883. DOI: 10.1038/nature03962.

[22] Kormondy E. J. (1996). Concepts of Ecology. 4th edition. WH Prentice-Hall. 1-559 p

[23] Krebs C. J. (2009). Ecology: the experimental analysis of distribution and abundance. 6th edition. San Francisco. PearsonBenjamin Cummings. 1-655 p.

[24] Lidicker W. Z. (2008). Levels of organization in biology: on the nature and nomenclature of ecology's fourth level. Biological Reviews, 83(1): 71-78. Cambridge Philosophical Society. https://doi.org/10.1111/j.1469-185X.2007.00032.x.

[25] Macdonald K. C. (2019). Mid-Ocean Ridge Tectonics, Volcanism and Geomorphology. Encyclopedia of Ocean Sciences. Elsevier. 405-419 p. DOI: 10.1016/b978-0-12-409548-9.11065-6.

[26] Manecki A. (2008). Minerals and rocks of the Earth - their importance for man. Planet Earth Committee of the Polish Academy of Sciences. Warsaw. 1-16 p.m.

[27] Medenbach O., & Sussieck-Fornefeld C. (1996). Minerals (Gypsum). Natural Lexicon. Book World. Warsaw. 162-163 p. ISBN: 83-7129-194-9.

[28] Melillo J.M., McGuire A.D., Kicklighter D.W., Moore B., Vorosmarty C.J., & Schloss A.L. (1993). Global climate-change and terrestrial net primary production. Nature, 363: 234-240. https://doi.org/10.1038/363234a0.

[29] Miller G. T., & Spoolman S. E. (2009). Essentials of Ecology. 5th edition. Brooks/Cole. Cengage Learning. https://sangu.ge/images/EssentialsofEcology.pdf (access: 30.12.2020).

[30] Molles Jr., M.C. (2010). Ecology: Concepts and Applications. 5th edition. McGraw-Hill Higher Education. NY.

[31] Naveh Z., & Lieberman A. S. (1984). Landscape ecology: Theory and applications. Springer Verlag. New York. 1-360 p. DOI: 10.1007/978-1-4757-2331-1.

[32] Odum E. P. (1969). The Strategy of Ecosystem Development. Science, 164(3877): 262-270. DOI: 10.1126/science.164.3877.262.

[33] Odum E. P., & Barrett G. W. (2004). Fundamentals of Ecology. 5th edition. Belmont, CA. Thomson Brooks/Cole. 1-598 p.

[34] Peters K. E., Walters C. C., & Moldowan J. M. (2005). The Biomarker Guide: Biomarkers and isotopes in the environment and human history. Vol. 1. Cambridge University Press. ISBN: 0 521 83763 4.

[35] Self-taught guide. TV (1925). Mineralogy and petrography - methodological tips for students. https://pbc.gda.pl/Content/72610/Mineralogja_i_petrografja.pdf (access: 31/12/2020).

[36] Ryka W., & Maliszewska A. (1991). Petrographic Dictionary. Geological Publishing House. Warsaw. 1-413 p.

[37] Saugier B., Roy J., & Mooney H. A. (2001). Terrestrial Global Productivity. Academic Press. London. 1-573 p.

[38] Schlesinger W. H. (1997). Biogeochemistry: An analysis of global change. San Diego. Academic Press. 1-588 p.

[39] Schumann W. (2003). Minerals of the world. ed. Alma-Press. 1-227 p.

[40] Skinner B. J., & Porter S. C. (1987). Physical Geology. The Earth: Inside and Out. John Wiley & Sons. New York. ISBNs: 0-471-05668-5.

[41] Styling P. (2015). Ecology: Global insights and investigations. 2nd edition. McGraw-Hill Education. 1-640 p. ISBN: 0073532509.

[42] Zawadzki S. (ed.). (1999). Soil science. National Agricultural and Forestry Publishing House. Warsaw. 23, 35-57 p. ISBN: 830901703-0.

[43] Frog J. (2014). Illustrated encyclopedia of rocks and minerals. ed. Videographer. 1-504 p. ISBN: 978-83-7835-297-6.

[44] https://pl.wikipedia.org/wiki/Litosfera#/media/Plik:Earth-crust-cutaway-polish.svg (access: 31/12/2020).

1.8. Biosphere

The biosphere is the sum of all ecosystems on our planet. It can also be called the zone of life on Earth. The biosphere is a closed system, excluding solar and cosmic radiation as well as heat from the Earth's interior, in which the circulation of matter and energy takes place in and between ecosystems. The biosphere under undisturbed conditions is also a self-regulating system (Campbell et al., 2006). According to the most general bio-physiological definition, the biosphere is a global ecological system integrating all living things and their relationships, including their interactions with the elements of the lithosphere, geosphere, hydrosphere and atmosphere. It is assumed that the biosphere has evolved from the process of biopoiesis (the origin of life on Earth - life arising naturally from non-living matter such as simple organic compounds) or biogenesis (life created from living matter). It is estimated that these processes took place at least around 3.5 billion years ago (Bell et al., 2015; Dodd et al., 2017).

Biosphere (terrestrial ecosystems) accumulate organic carbon (in all organisms living on land, both living and dead). Carbon is stored in the soil in the form of organic compounds. About 500 gigatonnes of carbon are stored on the Earth's surface in plants and other living organisms (Prentice et al., 2001). At the same time, there are about 1,500 gigatonnes of relatively fixed carbon in the soil (Rice 2001). Most of the carbon in terrestrial biosphere ecosystems is organic carbon (Mukhtar et al., 2016), while about 1/3 of soil carbon is stored as inorganic compounds (such as calcium carbonate), (Lal, 2008). Organic carbon is the main component of all living organisms on earth. Autotrophs (self-feeding organisms) obtain carbon from the air in the form of carbon dioxide, converting it to organic carbon, while heterotrophs complete the carbon cycle by eating other organisms.

Carbon leaves the biosphere's terrestrial ecosystems in several ways and on different time scales. Combustion (or respiration) of organic carbon causes its rapid release into the atmosphere. Ions of inorganic carbon compounds can also be transported with the waters of rivers flowing to the seas and oceans or remain in the soil or substrate (Li et al., 2017). Carbon stored in the soil can remain there for thousands of years before being washed into rivers by erosion or released into the atmosphere by soil respiration. Between 1989 and 2008, soil respiration is estimated to have increased by about 0.1% per year (Bond-Lamberty, Thomson, 2010). In 2008, the total amount of CO_2 released by soil respiration was around 98 billion tonnes. The amount of CO_2 released into the atmosphere from soil is about 10 times more in one year than the amount of carbon humans currently releases into the atmosphere as a result of burning fossil fuels (Bond-Lamberty, Thomson, 2010). Carbon dioxide introduced into the atmosphere as a result of soil respiration is not a net value, because this amount is largely compensated and introduced in biochemical processes secondarily as carbon compounds into the soil. There are several plausible explanations for this trend. It is most likely that the global increase in temperatures on Earth has increased the rate of decomposition of organic matter in the soil, which has increased the flow of CO_2 between elements of the environment. The length of time in which carbon remains unmineralized in the soil (sequestration) depends on local conditions (such as: vegetation composition, soil type, access to water, weather), as well as on current global climate changes (Bond-Lamberty and Thomson, 2010).

Ecosystems are systems of communities of different groups of organisms that coexist and interact with each other and often interdependent, along with their inanimate (abiotic) environment. The interactions of organisms and their environment are carried out in processes that are called ecosystem functions. The capture (absorption) of solar energy (photosynthesis), the circulation of matter and energy are fundamental functions of the ecosystem that enable the existence of life on Earth. Biodiversity has a great influence on the functioning of the ecosystem. Understanding how biodiversity and ecosystem functioning are interrelated is essential so that to determine how to ensure the future survival of human populations (Odum, 1969).

The concept of an ecosystem, as a functioning entity in the natural world, is relatively new. The term ecosystem was coined by the British ecologist Tansley et al., 1935 and has since become a popular concept among researchers. The ecosystem includes all organisms occurring in a given area and their mutual relations and relationships as well as their interdependencies with the abiotic environment (physico-geo-chemical). An ecosystem is a functional unit that includes dynamic relationships and interactions between living organisms and the non-living environment. Research and knowledge in the field of the functioning of ecosystems as a unit of science means a transition from learning about natural history (determining the state and behaviour of individual organisms and populations of various species) to studying the processes and understanding the mechanisms of how organisms affect or are influenced by an interaction with the environment.

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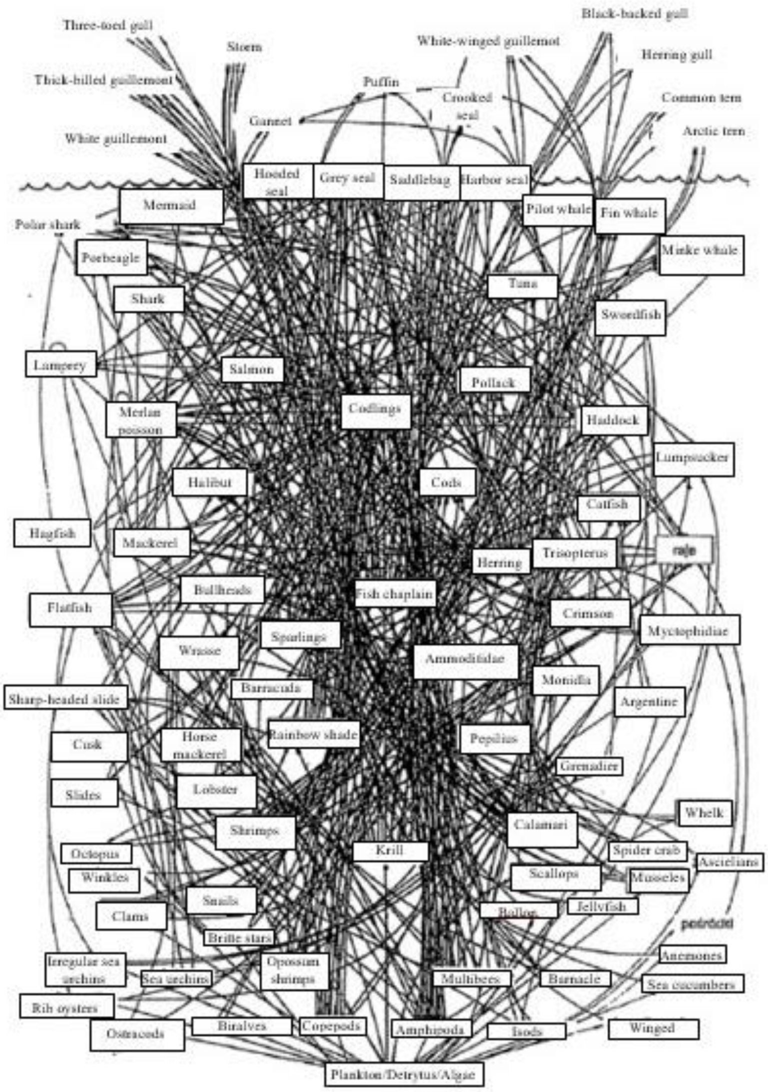

Figure 1.8.1. A detailed scheme of dependencies in the ecosystem on the example of food webs in the marine ecosystem (Weiner, 2003; after: Schmid et al., 1996)

Boundaries of Ecosystems. Dividing complex systems of nature (environment) into convenient units is necessary for cognitive purposes. Ecosystems can be organized in a hierarchy of increasing levels of organization and complexity: individual, population, species, community, ecosystem, landscape, and biome (Figure 1.8.1.).

Ecosystems may have clear boundaries, as in the case of a lake or a watershed. More often, the boundaries of one ecosystem (forest) gradually change into another ecosystem, e.g., grassland, peat bog or meadow. The area between the ecosystems is called an ecotone. An ecotone is often an area of greater diversity as it can be a suitable habitat for species from both neighbouring ecosystems (Weiner, 1999). Ecosystems exist on different (often extreme) scales. On the one hand, the Earth is sometimes treated as an ecosystem, and on the other hand, it has all its functional properties as an ecosystem, which is a community composed of symbiotic organisms living in the intestines of termites.

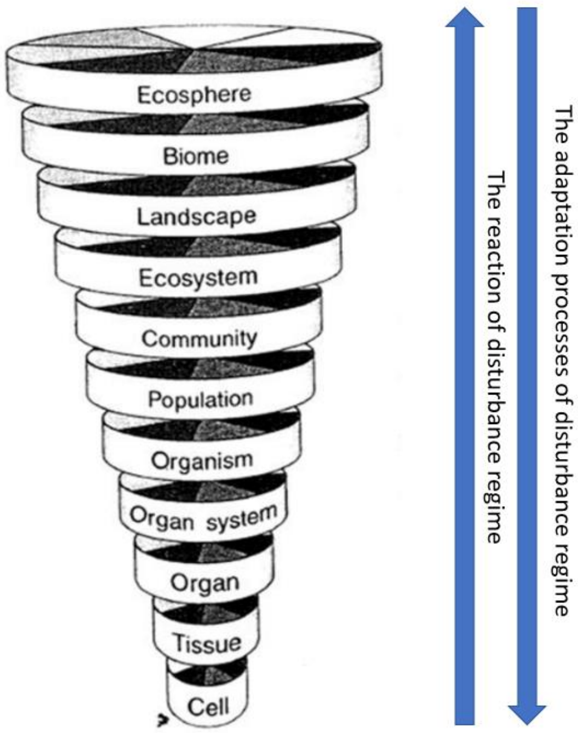

Fig. 1.8.2. Hierarchical organization of components and structural elements in an ecosystem from the global, landscape, biocenotic, population, organismal and molecular levels (Odum, 2004 - amended and supplemented)

Defining and setting the boundaries of ecosystems is of practical importance, because ecosystems are more and more often treated as functional units in the process of managing natural resources and in the process of setting nature conservation goals. It became obvious that responsible management of natural resources required an understanding of: i.) how ecosystems function; ii.) how they respond to disruptions. Managing nature resources also requires understanding of the biodiversity role in regulating the functioning of ecosystems and maintaining their dynamic balance as the only irreplaceable source of ecosystem services (necessary for the life of all organisms (including human beings - human well-being)).

Ecology is a science that studies the interactions between organisms and their environment, and between living organisms (Fig. 1.8.2.). It focuses on understanding the structure and functioning of nature, the structure and functioning of ecosystems. It studies the connections between living organisms and their inanimate, abiotic environment. Biological systems form a network of connections between themselves and the surrounding environment, based on many interactions. Ecology also provides a scientific basis for the relationship between nature and man. In common discussions, it is mistakenly identified with sozology and philosophy. The terms ecology or ecological are often used incorrectly in everyday language in a broad and sometimes imprecise sense, not always related to ecology as a science. The terms incorrectly refer to sozology or environmental protection as such, and even to ecological philosophy (ecosophy), social or artistic activities.

According to Krebs (1996), ecology is the study of relationships that determine the abundance and distribution of organisms:

– where do they occur?
– in what numbers?
– what is responsible for this?

Ecology is not:

– an ideology,
– a social movement,
– a way to increase sales.

Ecology does not say what is:

– good or bad,
– useful or harmful,
– right or wrong.

The term ecology (from the word oecologia) was introduced in 1866 by the German biologist and evolutionist Ernst Haeckel. He used this term to describe research on animals and their relations with the surrounding inorganic and organic world. He stated that organisms are affected by abiotic and biotic factors in the environment.

According to some authors, the subject of ecology should be the relationship between biotic and abiotic elements of nature. On the other hand, other researchers extend the scope of ecology to the so-called application dimension (so-called applied ecology). This makes it a biological or geographical science or even environmental science. There is also a duality in understanding the methodological dimension (reductionist concept or holistic concept). Due to such a variety of approaches and views on the scope of ecology, there are different definitions and theoretical models.

The following concepts are considered to be the most important in ecology: individual, population, biocenosis, ecosystem, landscape, and biosphere. Currently, two main branches of ecology are distinguished: autecology (species ecology) and synecology (ecology of multi-species communities). Autecology is the science of the functioning of individual organisms in their environment (similar to the ecophysiology of a species). Synecology, on the other hand, is the ecology of groups of individuals, plant populations and communities, animal assemblages, and ecosystems.

1.8.1. The functioning of ecosystems

The central process of ecosystems is photosynthesis, the capture of solar radiation and its conversion into the energy of chemical bonds, and the construction of plant cells and tissues (accumulation, formation of biomass). Plants require sunlight, water, and essential minerals for photosynthesis to germinate, grow, and develop. One of the important parameters characterizing the functioning of an ecosystem is its basic primary productivity, i.e., the amount of plant biomass produced per unit of area and time. Primary productivity (often referred to as ecosystem productivity) is related to the biodiversity of organisms, particularly the diversity of plant species. The productivity of plant biomass production is also the basis for such branches of the economy as agriculture, forestry, and fishing.

Therefore, the factors that change the efficiency of photosynthesis, the primary production of individual ecosystems (e.g., climate change and loss of biodiversity) also directly affect the economy that is responsible for these changes. Ecosystems with a high rate of primary productivity have the required amounts of resources for plant growth, including optimal climatic conditions. The highest rate of productivity and diversity among terrestrial ecosystems has been shown for ecosystems in tropical climate conditions, where temperature and humidity are favorable for plant growth throughout the year. On the other hand, systems with limited access to water and extreme daily hot and cold temperatures

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(eg. deserts) have much lower efficiency, on average less than 10% of the efficiency of tropical systems (Virginia, Wall, 1999).

1.8.2. Factors limiting the formation of biomass (productivity) in ecosystems

This raises the question of what causes the limitations in the productivity of ecosystems. The basic principle invoked to explain the differences between ecosystems in terms of the amount of biomass produced (primary productivity) is Liebig's Law of the Minimum.

Liebig's Law of the Minimum was originally reduced to chemical elements (oxygen, phosphorus, potassium, magnesium). Liebig studied the nutritional needs of plants.

The growth and development of an organism is limited by a component present in deficiency, when its deficiency is impossible to replace by another environmental factor.

Examples:

- Water scarcity in the soil that limits the growth of desert plants.
- Deficiency of nitrogen and phosphorus compounds, which limits the fertility of water reservoirs.
- A protein deficiency in the diet of animals that limits growth.
- A deficiency of one amino acid may limit the absorption of another amino acid taken from a given meal.

Figure 1.8.2.1. The principle of operation of Liebig's Law is graphically presented as 'Liebig's barrel'. The barrel shows that its value in use depends on the shortest element. Such graphics symbolize a situation in which, for example, the amount of assimilated protein is equal to the amount of the limiting amino acid, i.e., the one whose amount in the meal is the smallest (https://view.genial.ly/5e98436b63b9e50d80908d3f/interactive-image-interaktywna-lekcja-nawozy-mineral)

Justus Liebig, at the beginning of the 19th century, formulated this concept during pioneering research on mineral nutrition of plants. Liebig noticed that adding one "limiting element" to the soil increased plant growth. If this element were given in sufficient quantity, another mineral element would have to be supplied in increased amounts to stimulate further plant growth. Based on these observations, Liebig proposed the law that the limiting factor was responsible for limiting the growth or reproduction of an organism or population. The limiting factor may be an element or a chemical (growth-promoting nutrient such as nitrogen), a physical factor (such as moisture) or a biological factor (such as the presence of another species). Thus, any change in the limiting factor has a large impact on the functioning of the entire ecosystem.

There are many examples showing how changing the limiting factor modifies the functioning of the entire ecosystem. A large two-fold increase in the amount of nitrogen in the cycle of this element in the environment caused by the introduction of artificial fertilizers, burning fossil fuels, and a significant

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reduction in biodiversity have resulted in changes in the functioning of forests in many parts of the world (Virginia, Wall, 2001).

The diversity of organisms (mainly plant species) and the formation of biomass and (primary production) are linked. The theoretical background is about understanding how scarce resources (water and minerals) are distributed in ecosystems. The variety of functional (physiological) features allows organisms to intercept (assimilate and absorb) and use the resources present in the ecosystem in a more diverse, and thus more comprehensive and complete way. Differences between plant species due to differences in their rooting (the nature of the root system and rooting depth), phenology (seasonality of growth), photosynthesis parameters, and other physiological features allow multi-species communities to make fuller use of the resources available in the environment.

Many studies have demonstrated higher efficiency (the amount of biomass produced) in plant communities with greater biodiversity (Sarkar, Margules, 2002; Sarkar, 2005). There are numerous examples of the relationship between biodiversity and productivity in natural ecosystems. In the grassland ecosystem communities in California, Hooper and Vitousek (1997) in their experiment modified the number of functional groups of plants found in the studied communities. Species systems differing in phenology were studied: monocotyledonous and dicotyledonous plants, as well as plants that fix atmospheric nitrogen and those that do not, in combinations of one to four groups on a given plot. It was shown that the number of functional groups of plants was not the most important factor determining the amount of biomass produced. Primary production varied depending on the arrangement of functional characteristics of individual species within the functional group. It was shown that functional diversity contributed to the increase in ecosystem productivity to a greater extent than the overall species diversity of the examined patch of vegetation (Hooper, Vitousek, 1997). It can be seen that there is no simple relationship - the greater the biodiversity (species) - the greater the amount of biomass produced. Based on the results obtained by Hooper and Vitousek (1997), it can be concluded that the important fact is not so much the number of different organisms that are part of a community or ecosystem, but the functional features that plants possess or reveal in specific conditions of the natural environment. A particularly important role in regulating the functions of the ecosystem is played by such organisms that affect the course of the process of matter and energy circulation.

The knowledge obtained from understanding the relationships found in natural communities was also used in agriculture. It has been confirmed that multi-species crops have higher yields than single-species plantings (monocultures) (Gliessman, 1998). At the same density of corn (Zea mays), the yield is higher when vetch (Vicia spp.) is sown among the corn. Species of the genus Vicia have the ability to form symbiotic relationships with bacteria that have the ability to "absorb" inorganic atmospheric nitrogen (N 2), synthesizing nitrogen compounds (such as ammonia), making them available to plants. Nitrogen resources obtained by species of the genus Vicia are used in some crops instead of introducing artificial fertilizers. This method of supplying agricultural fields with nitrogen significantly reduces environmental costs (combustion of fossil fuels, fuels used for the production and transport of fertilizers). Excessive use of fertilizers is a major source of surface and groundwater pollution.

1.8.3. Keystone species, biodiversity and biomass

Some species are called keystone species. The importance of these species and their impact on the functioning of ecosystems is disproportionate to their biomass. The loss of key species triggers a cascade of processes in the ecosystem that affect the diversity and functions of the rest of the ecosystem (Bond, 1994). Identification of key species and understanding the mechanisms through which they control the diversity and functioning of the ecosystem is very important for the proper setting of priorities as regards the management and protection of the environment (communities of organisms and their habitats). There is well-documented research into the role of keystone species, and the ways in which they interact with other organisms and affect the functioning of the ecosystem. The classic example of a keystone species is the otter (Sea otter) living in the North Pacific. Otter (Sea otter) feeds, feeds on sea urchins (Urchins), which in turn feed on seaweed (Kelp). In the absence of the key predator, the otter, the sea urchin population grows and creates areas devoid of seaweed. No seaweed means no habitat for countless fish and other species that depend on where dense seaweed populations are found. This arrangement illustrates very close relationships between organisms in one of the foods (trophic) webs in the ecosystem.

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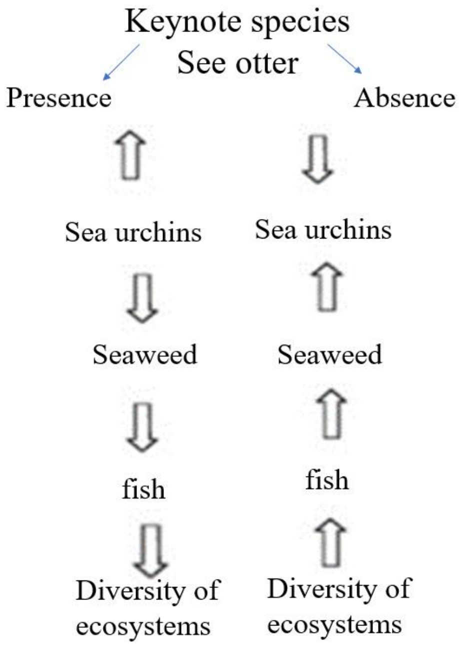

Figure 1.8.3.1. The impact of key species on the biodiversity of the entire ecosystem can be large. Arrows indicate an increase or decrease in population size or species diversity in response to the presence or absence of key species. The removal of the otter from the coastal ecosystems of the Pacific Ocean of California led to the disappearance of seaweed and many fish species (amended and supplemented after: Szpak et al., 2013)

Similar examples of keystone species have been found in terrestrial ecosystems (keystone species). The Central African savannah ecosystem is regulated by the abundance of the African elephant and the tsetse fly. A large change in the African elephant population causes dramatic changes in the biodiversity and structure of the dominant type of vegetation, which are savanna forests. A change in African elephant numbers changes the productivity of the savannah ecosystem. The cycle of the circulation of elements in the soil and the diversity of plant communities are modified. The much smaller tsetse fly generally occupies the same habitats as the African elephant. However, the high abundance of the tsetse fly in a particular area means that the area is avoided by both African elephants and humans. The tsetse fly is a carrier (so-called vector) of the human malaria disease and African trypanosomiasis, dangerous even for such large herbivores as elephants. In this way, this fly influences the behaviour of large herbivores that try to avoid heavily infested areas. Thanks to this mechanism, the fly affects the functioning of the savannah ecosystem by modifying the range of its occurrence areas (including the African elephant). This small insect may also control the biodiversity of large areas of Africa through another relationship. Many indigenous African ecosystems have been "protected" by the tsetse fly, because thanks to its presence there has been no development of agriculture and other human economic activities, and thus no loss of many species of plants and animals. People avoid regions where the tsetse fly is particularly abundant.

1.8.4. The cycle of elements

The sustainable functioning of any ecosystem requires the minimum number of species necessary to form the complex relationships between producers, consumers, and decomposers that break down dead organic matter. These three groups of organisms regulate the flow of energy and matter in every ecosystem.

The performance of all ecosystems depends on the circulation of essential elements. All organisms present in a given ecosystem participate in the circulation and biological transformation of energy and matter, especially those present in soil and sediments (Virginia, Wall, 1999). Therefore, along with changes in the biodiversity of ecosystems, basic bio-geo-chemical processes may change, which in extreme cases may lead to a permanent upset of the dynamic balance prevailing in every natural and anthropogenic ecosystem.

The carbon cycle

Carbon is the basic element of all organic life on Earth. Carbon is found in the geological substratum, oceans, and atmosphere. There is a rapid accumulation of carbon dioxide in the atmosphere. Its amount is growing at a rate of over 3 billion tonnes per year (https://cordis.europa.eu/article/id/29910-ten-billion-tonnes-of-carbon-released-in-2007/pl). Industrialization and the burning of fossil fuels (coal, oil, and natural gas) greatly accelerated this growth. Carbon dioxide is a gas that absorbs heat and thus contributes to the greenhouse effect.

The carbon cycle is the main bio-geo-chemical cycle in which carbon is exchanged between the biosphere, pedosphere, geosphere, hydrosphere, and Earth's atmosphere. Carbon is the main component of organic biological compounds, as well as many minerals, such as limestone. Along with the nitrogen and water cycles, the carbon cycle determines a sequence of processes that are crucial to making Earth a life-sustaining planet. In its cycle, carbon is recycled and reused many times in the biosphere. There are also long-term processes of carbon sequestration and release. The carbon cycle was described by Antoine Lavoisier and Joseph Priestley and popularized by Humphry Davy.

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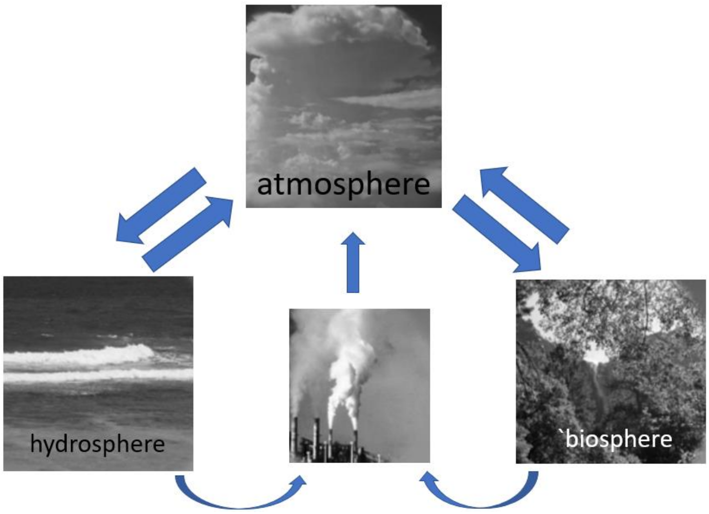

Figure 1.8.4. The ocean and land still absorb about half of all carbon dioxide emissions released into the atmosphere, even though anthropogenic emissions have increased dramatically in recent decades. It is unclear whether carbon uptake can and will continue to occur at this rate (GMS: Carbon and Climate Briefing – 12 November 2015, National Aeronautics and Space Administration – https://svs.gsfc.nasa.gov/12044)

In the Earth's atmosphere, carbon exists in the form of two main compounds: carbon dioxide and methane. Both of these gases absorb and retain heat in the atmosphere and are partly responsible for the greenhouse effect, (Falkowski et al., 2000). Compared to carbon dioxide, methane has a greater greenhouse effect on a volumetric basis. However, methane is present in much lower concentrations and is less persistent than carbon dioxide, making carbon dioxide the most important greenhouse gas.

Carbon dioxide is assimilated from the atmosphere by the ability of autotrophic (self-sustaining) organisms in the process of photosynthesis. Thanks to the assimilation of carbon dioxide by autotrophic (autotrophic) organisms (photo-autotrophs, mainly plants), carbon dioxide from the atmosphere penetrates into the biosphere (terrestrial ecosystems) and hydrosphere (water and oceanic ecosystems). Carbon dioxide also dissolves directly from the atmosphere in bodies of water (oceans, lakes, etc.). It also dissolves in precipitation as raindrops fall into the atmosphere. When dissolved in water, carbon dioxide reacts with water molecules to form carbonic acid, which contributes to the acidity of the ocean. It can then be absorbed by the rocks in the weathering process. Carbon dioxide can also cause acidification of other natural systems or be leached directly to inland or oceanic waters, (Pliński, 1995).

Human activities over the last two centuries have significantly increased the amount of carbon in the atmosphere, mainly in the form of carbon dioxide, both by modifying the capacity of ecosystems to extract carbon dioxide from the atmosphere and by releasing it directly, for example through the burning of fossil fuels, the mineralization of organic carbon (intensive drainage) and concrete production (Falkowski et al., 2000).

1.8.5. Succession

The process of succession is the process of changes that an ecosystem undergoes over time. It is a natural directional process, reflecting the gradual adaptation of organisms and their mutual relations to the changing conditions of the habitat. In the process of natural succession, changes in habitat conditions are caused by living organisms affecting the habitat. It is most often possible to observe the succession process when it occurs in response to disturbances that are often caused by humans (Falińska, 2003). Careful observation of natural systems at various stages of successive development contributes to the knowledge and understanding of the mechanisms that shape the relationships between biodiversity and individual ecosystem functions depending on the abiotic conditions in which a given stage of succession takes place (Woźniak, 2010). Succession is characterized as a directional process, but we are still unable to precisely predict the succession pathway in specific ecosystems. The examples of succession described by researchers follow one unchanging paradigm: the relationship between the diversity of organisms and the functioning of the ecosystem (Weiner, 2020). The succession processes often described include: secondary succession related to the return of the forest to a habitat created after felling the forest or after destruction caused by windthrows, the restoration of the so-called grassland or permanent grassland after a fire, and overgrowth of an unused field or other abandoned agricultural land.

During succession, ecosystems change as a result of the colonization of a given area by various organisms, among which plants are of major importance, because thanks to them, the amount of biomass accumulated increases. A transformed habitat of a disturbed ecosystem can regain structural complexity and recreate self-regulatory mechanisms. Odum (1969) proposed a model of ecological succession (development) which refers to ecosystem diversity, structure, and functioning as the recovery of ecosystems after moderate disturbance. The model proposed by Odum (1969) is related to the indication of the relationship between the stability of functions and the behaviour of nutrients in relation to increasing complexity and diversity.

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The relationship between ecosystem functioning and biodiversity presented in Odum's model (1969) was based on the results of the Hubbard Brook experiment (Likens, Bormann, 1995; https://hubbardbrook.org/about). This experiment was one of the first long-term ecosystem research programs, started at Hubbard Brook in 1963 in the White Mountains, New Hampshire. These studies were aimed at understanding the process of forest regeneration after tree felling, with particular emphasis on those ecosystem functions that are related to primary production, circulation and loss of matter from the ecosystem. A cycle of matter (inorganic and organic nutrients) where efficiency is low and internal nutrient circulation is high (loop from soil to vegetation and back to soil) is called a closed cycle of matter.

1.8.6. Ecosystem stability

Ecosystems are dynamic systems. There are changes in the species composition of plants, and changes in functioning, taking place in response to changes in habitat conditions, caused by natural factors or resulting from disturbances and disturbances introduced by man. Fire, flood, drought, frost and biological events (such as outbreaks of diseases caused by the emergence of pathogens and pests) can disrupt the functioning of an ecosystem and change its condition. Ecosystems vary greatly in their resilience and response to disturbances.

The ability of an ecosystem to survive a period of intense stress without loss of function (resistance) or to recover quickly from disturbance (resilience) is an important feature of an ecosystem (resistance and resilience). Some ecosystems, such as tropical forests, appear to be very stable (high resilience) and their functioning has little impact on changes in external factors of the system (e.g., weather). Highly resilient ecosystems are protected against disturbance. However, many ecosystems show significant declines in process efficiency and biodiversity in response to disturbances. The relationship between ecosystem stability and diversity has been the subject of many field studies and theoretical tests using mathematical modelling. Ecologists have hypothesized that ecosystems with high biodiversity are more resilient (will be less sensitive to changes due to disturbance) in response to a given level of disturbance and will also exhibit resilience - a high rate of return to previous functioning (Folke et al., 1996).

1.8.7. Does biodiversity affect the stability and functioning of an ecosystem?

There is experimental evidence that there is a relationship between biodiversity and ecosystem stability and functioning (Chapin III et al., 1998). Higher species diversity means that the trophic structure (relationships in the food chain of species) in a given ecosystem is more complex. Higher species diversity provides alternative pathways for energy flow within and between trophic levels (producers, consumers and saprophytic, decomposer organisms). Alternative energy transfer paths within the ecosystem may increase resistance to disturbances (it is possible to lose redundant species that perform the same or very similar functions in the ecosystem). Naeem and Li (1997) tested the hypothesis that redundancy (many species performing similar functions, the same functional group in the food web) will allow the functional stabilization of the ecosystem after a disturbance. Naeem and Li (1997) conducted research on experimental microcosms (synusia) with different numbers of species representing each functional group. Simple systems included producers (algae), decomposers (bacteria), and primary and secondary consumers at the trophic level, thus creating the trophic structure of a typical aquatic ecosystem. Nutrient levels, factors such as light and temperature, and the number of species at a given trophic level were varied depending on the experiment variant, and biomass density and other producer parameters were measured as an indicator of ecosystem functioning. It was shown that communities/ecosystems with more species were more predictable in terms of basic processes and functions (biomass production). They also showed higher reliability resulting in a return to the pre-disorder state (Naeem, Li, 1997).

Greater species diversity can ensure more reliable ecosystem functioning by reducing the risk of being affected by the entry or invasion of species that have the ability to alter the structure or function of the ecosystem. An example is the higher resistance of species-rich natural ecosystems to the gradation (mass multiplication) of pests compared to ecosystems with low diversity, such as agricultural agro-ecocenoses or tree plantations growing in the same natural environment conditions (Naeem, Li, 1997). The spatial arrangement of individuals of particular species in an ecosystem may influence the risk of disease spread, predation or consumption. In an ecosystem with higher diversity, the average distance between individuals of the same species is, on average, greater than in an ecosystem with low diversity. A larger distance between individuals slows down the movement of pathogenic organisms, which should reduce the occurrence of pest outbreaks that change the efficiency of processes and the functioning of the ecosystem. These and other observations lead to the conclusion

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that diversity increases the resilience of ecosystems to disturbances (Tilman et al., 1996; Naeem, Li, 1997; Tilman, 2007).

The benefits of biodiversity for the functioning of the ecosystem should be numerous, because production processes and the nutrient cycle are coupled with biological interactions between organisms. Intensive observations conducted in 1987 and 1988, when drought reduced the productivity of grasslands, allowed the formulation of further hypotheses. Comparison of the species diversity areas they represented before the drought with the effects of drought in individual experimental plots explained the differences in biomass production efficiency. Plots that had high diversity as a result of drought experienced an approximately 50% decline in biomass production efficiency, while biomass production efficiency in the least diverse plots decreased by over 90%. It was also shown that plots with less diverse species systems had lower root zone nitrate concentrations, indicating more efficient use of this limited resource in more species-diverse systems.

The experiment described above shows that species diversity influences the amount of biomass produced (productivity) and the circulation of nutrients in the ecosystem. However, we still lack a holistic understanding of the mechanisms that determine the relationships between the response patterns of various types of ecosystems to disturbances and changes in biodiversity (e.g., the number of plant species). It is estimated that diversity can increase the chance of surviving a single drought without compromising the functioning of the ecosystem. However, the number of species remaining in the community will ensure the course of basic bio-geo-processes, and thus a relatively high efficiency of biomass formation (productivity). Similarly, greater biodiversity can ensure more efficient use of limited resources. As shown by Folke et al. (1996), in plots with a more diverse species composition, lower levels of nitrates in the soil were found, which indicates that they are more efficiently obtained by living organisms.

Human activity has become the main factor in changing environments and modifying biodiversity and the structure of ecosystems in many ways (air pollution, removal of natural ecosystems, and gaining space for agriculture and forestry (tree plantations)). Moreover, the constant development of urban areas, the spread of exotic species, changes in the composition of the atmosphere, and other anthropogenic influences are changing the functioning of the ecosystem (Woźniak et al., 2018). By changing the biodiversity of ecosystems and changing the processes that determine the functioning of the ecosystem and the living organisms present in the ecosystem, the ability of ecosystems to provide ecosystem services (ecosystem services) and self-reproduction of natural capital (natural capital) is significantly reduced. Managing ecosystems for the sustainability of the level of ecosystem services and restoring the functioning of damaged ecosystems will require greater knowledge about the role played by living organisms in the processes and functions of ecosystems in the circulation of matter (nutrients) and energy. Although we cannot (with limited methodological capabilities) know the role of most species in ecosystems, it is reasonable to assume that all naturally occurring biodiversity is essential to the functioning and stability of ecosystems.

1.8.8. Terrestrial ecosystems

At the ecosystem level, nutrient cycling follows a common pattern. The general model of the circulation of nutrients, elements, and/or chemical compounds includes the main elements of the natural environment in which elements and/or chemical compounds are accumulated or transferred between these elements. Each element of the natural environment that accumulates elements and/or chemical compounds is determined by two parameters: i.) whether it contains organic or inorganic forms of a given element; ii.) whether these forms are directly available for use by living organisms. Nutrients in living organisms and their remains are available to other organisms directly in organic form or after their mineralization.

The efficiency of carbon fixation in terrestrial ecosystems depends on biotic factors that occur in daily and seasonal cycles. Carbon fixation is strongest in the Northern Hemisphere because this hemisphere has a larger land area than the Southern Hemisphere and therefore larger areas are occupied by ecosystems that absorb and circulate carbon.

1.8.9. Water ecosystems

In water reservoirs, there is a surface layer, in which the water borders the atmosphere, and a deep layer. The boundary between the layers is most often set below the typical depth of the mixed layer. This depth depends on the size of the reservoir. In the oceans it is usually several hundred meters. In the surface layer there is inorganic carbon (dissolved inorganic carbon – DIC) dissolved in water is quickly exchanged with the atmosphere. This exchange remains in a state of dynamic equilibrium. This is due to an approximately 15% higher concentration of inorganic carbon dissolved in the surface layer of water (Sarmiento, Gruber, 2006) and a larger volume. Globally, waters contain much more carbon. The oceans are the world's largest stores of cyclically activated carbon. Ocean waters contain 50 times more carbon than the atmosphere (Falkowski et al., 2000).

However, the time scale in which equilibrium between the hydrosphere and the atmosphere can be achieved is hundreds of years. The exchange of carbon between the two layers driven by circulation (thermohaline) is very slow (Falkowski et al., 2000).

Carbon enters the ocean mainly through the dissolution of atmospheric carbon dioxide, a small part of which is then converted to carbonates. It can also flow into the seas and oceans along with the waters of rivers that carry dissolved organic carbon with them. In aquatic ecosystems (hydrosphere), as in terrestrial ecosystems (biosphere), carbon is converted by autotrophic living organisms into organic carbon and can be exchanged throughout the food chain or precipitated in deeper, richer, carbon-saturated layers as dead tissue soft or as carbonates mainly of calcium. Carbon may circulate for a long time before being deposited, either as sediment, or eventually returned to surface waters via thermohaline circulation. The reaction of ocean waters is alkaline (~pH 8.2) therefore an increased amount of CO_2 may lead to acidification and changes in the pH value towards neutral reaction.

The absorption of CO_2 by ocean waters is one of the most important forms of carbon sequestration, limiting the human-caused increase in carbon dioxide in the atmosphere. However, this process is limited by many factors. Increased CO_2 absorption makes the water more acidic, which affects the dynamic balance of ocean biosystems. The projected rate of increase in ocean acidity may lead to a slowdown in the biological precipitation of calcium carbonates, which as a result of feedback will reduce the ability of the oceans to absorb carbon dioxide (Kleypas et al., 1999; Langdon et al., 2000).

1.8.10. Dictionary of selected terms

Ecosystem - all individuals, species and populations in a spatially defined area and interactions among them and their abiotic environment.

Ecosystem functioning - the sum of such processes as the working circulation of matter, energy and nutrients at the level of the ecosystem.

Functional group – a group of species that perform similar roles in an ecosystem process.

Nutrient cycle (or biogeochemical cycle) - The circulation of mineral elements such as carbon, nitrogen, phosphorus, and water from the environment through organisms and back to the environment.

Succession – predictable, directional changes in the occurrence of species in a given area over time, caused by changes in biotic relationships between organisms and/or caused by abiotic factors that are beneficial to some species but unfavorable to others.

References

[1] Ab Bell E. A., Boehnke P., Harrison T. M., & Mao W. L. (2015). Potentially biogenic carbon preserved in a 4.1 billion-year-old zircon. Proceedings of the National Academy of Sciences of the United States of America, 112(47): 14518-14521. https://doi.org/10.1073/pnas.1517557112.igmow J.M., Owobienko B.K. 1971: Osnowy ekonomiczeskoj ocenki potier rudy pri otkrytom sposobie razrabotki. Izd. „Nauka", Leningrad;

[2] Bond W. J. (1994). Keystone Species. In: Schulze E.-D., & Mooney H.A. (Eds). Biodiversity and Ecosystem Function. Praktische Zahnmedizin Odonto-Dentistry Pratique Practical Dental Medicine (Geology), 99: 237-253. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-58001-7_11.

[3] Bond-Lamberty B., & Thomson A. (2010). Temperature-associated increases in the global soil respiration record. Nature, 464(7288), 579-582. https://doi.org/10.1038/nature08930.

[4] Campbell N. A., Williamson B., & Heyden R. J. (2006). Biology: Exploring Life. Pearson Prentice Hall. Boston, Massachusetts. 1-864 p.

[5] Chapin, FS, Sala, OE, Burke, IC, Phillip Grime, J, Hooper, DU, Lauenroth, WK, Lombard, A, Mooney, HA, Mosier, AR, Naeem, S, Pacala, SW, Roy, J, Steffen, WL & Tilman, D 1998, 'Ecosystem consequences of changing biodiversity', BioScience, vol. 48, no. 1, pp. 45-52. https://doi.org/10.2307/1313227

[6] Steffen W. L., & Tilman D. (1998). Ecosystem consequences of changing biodiversity. Bio-Science, 48(1): 45-52. https://doi.org/10.2307/1313227.

[7] DeRose R. J., & Long J. N. (2014). Resistance and Resilience: A Conceptual Framework for Silviculture. Forest Science, 60(6): 1205-1212. https://doi.org/10.5849/forsci.13-507 .

[8] Dodd M. S., Papineau D., Grenne T., Slack J. F., Rittner M., Pirajno F., O'Neil J., & Little C. T. S. (2017). Evidence for early life in Earth's oldest hydrothermal vent precipitates. Nature, 543(7643): 60-64. https://doi.org/10.1038/nature21377.

[9] Falińska K. (2003). Alternative pathways of succession: species turnover patterns in meadows abandoned for 30 years. Białowieża

Geobotanical Station. Publishing House of the University of Warsaw. Phytocoenosis NS 15, Arch. Geobot., 9: 1-104 p.

[10] Falkowski P., Scholes R. J., Boyle E., Canadell J., Canfield D., Elser J., Gruber N., Hibbard K., Högberg P., Linder S., Mackenzie F.T., Moore III B., Pedersen, T., Rosenthal Y., Seitzinger S., Smetacek V. and Steffen W. (2000): The global carbon cycle: A test of our knowledge of earth as a system, Science, 290 (5490), pp. 291-296. doi: 10.1126/science.290.5490.291

[11] MacKenzie F. T., Moore III B., Pedersen T., Rosenthal Y., Seitzinger S., Smetacek V., & Steffen W. (2000). The Global Carbon Cycle: A Test of Our Knowledge of Earth as a System. Science, 290 (5490): 291-296. DOI: 10.1126/science.290.5490.291.

[12] Folke C., Hollings C. S., & Perrings C. (1996). Biological diversity, ecosystems, and the human scale. Ecological Applications, 6(4): 1018-1024. https://doi.org/10.2307/2269584.

[13] Gleissman S. R. (1998). Agroecology: Ecological Processes in Sustainable Agriculture. Ann Arbor Press, Chelsea, Michigan. 1-357 p. DOI: 10.1046/j.1526-100x.1999.72014.x.

[14] Hooper D.U., & Vitousek P.M. (1997). The effects of plant composition and diversity on ecosystem processes. Science, 277(5330): 1302-1305. DOI: 10.1126/science.277.5330.1302.

[15] Kleypas J. A., Buddemeier R. W., Archer D., Gattuso J.-P., Langdon C., & Opdyke B. N. (1999). Geochemical Consequences of Increased Atmospheric Carbon Dioxide on Coral Reefs. Science, 284(5411): 118-120. DOI: 10.1126/science.284.5411.118.

[16] Krebs C. (1996). Ecology. PWN Scientific Publishing House. Warsaw. 1- 495 p.

[17] Lal R. (2008). Carbon sequestration. Philosophical Transactions of the Royal Society B: Biological Sciences, 363(1492): 815-830. https://doi.org/10.1098/rstb.2007.2185.

[18] Langdon C., Takahashi T., Sweeney C., Chipman D., Goddard J., Marubini F., Aceves H., Barnett H., & Atkinson M. J. (2000). Effect of calcium carbonate saturation state on the calcification rate of an experimental coral reef. Global Biogeochemical Cycles, 14(2): 639-654. DOI: 10.1029/1999GB001195.

[19] Li M., Peng C., Wang M., Xue W., Zhang K., Wang K., Shi G., & Zhu Q. (2017). The carbon flux of global rivers: A re-evaluation of amount

and spatial patterns. Ecological Indicators, 80: 40-51. https://doi.org/10.1016/j.ecolind.2017.04.049.

[20] Likens G. E., & Bormann F. H. (1995). Biogeochemistry of a Forested Ecosystem, 2nd edition. Springer Verlag, New York. 1-159 p. DOI: 10.1007/978-1-4612-4232-1.

[21] Mukhtar I., Shahid M. A., Khan M. W., Balal R. M., Iqbal M. M., Naz T., Zubair M., & Ali H. H. (2016). Improving salinity tolerance in chili by exogenous application of calcium and sulfur. Soil & Environment, 35 (1):56-64.

[22] Naeem S., & Li S. (1997). Biodiversity enhances ecosystem reliability. Nature, 390(6659): 507-509. https://doi.org/10.1038/37348.

[23] Odum E. P. (2004). Fundamentals of ecology. National Agricultural and Forestry Publishing House. Warsaw. 1-660 p.

[24] Odum E. P. (1969). The strategy of ecosystem development. Science, 164(3877): 262-270. DOI: 10.1126/science.164.3877.262.

[25] Plinski M. (1995). Hydrobiology - basics. ed. Ocean. Sopot. http://plinski.pl/ podreczniki/ hydrobiologia -podstawy.html (access: December 18, 2020).

[26] Prentice I. C., Farquhar G. D., Fasham M. J. R., Goulden M. L., Heimann M., Jaramillo V. J., Kheshgi H. S., Le Quere C., Scholes R. J., & Wallace D. W. R. (2001). The carbon cycle and atmospheric carbon dioxide. In: Houghton J.T., Ding Y., Griggs D.J.

[27] Noguer M., van der Linden P.J., Dai X., Maskell K., & Johnson CA (Eds). Climate change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press.

[28] Rice C. W. (2001). Storing Carbon in soil: Why and how? Geotimes, 47(1): 14-17. http://www.geotimes.org/jan02/feature_carbon.html (access: 18/12/2020).

[29] Sarkar S. (2005). Biodiversity and Environmental Philosophy: An Introduction. Cambridge Studies in Philosophy and Biology. New York: Cambridge University Press. 1-278 p.

[30] Sarkar S., & Margules C. (2002). Operationalizing biodiversity for conservation planning. Journal of Biosciences, 27(4): 299-308. https://doi.org/10.1007/BF02704961.

[31] Sarmiento J.L., & Gruber N. (2006). Ocean Biogeochemical Dynamics. Princeton University Press. Princeton and Oxford. 1-503 p.

[32] Schmid B., Birrer A., & Lavigne C. (1996). Genetic variation in the response of plant populations to elevated CO 2 in a nutrient-poor, calcareous grassland. In: Körner, C., & Bazzaz, F. A. (Eds). Carbon Dioxide, Populations, and Communities. Academic Press, New York. 31-50 p.

[33] Szpak P., Orchard T. J., Salomon A. K., & Gröcke D. R. (2013). Regional ecological variability and impact of the maritime fur trade on nearshore ecosystems in southern Haida Gwaii (British Columbia, Canada): evidence from stable isotope analysis of rockfish (Sebastes spp.) bone collagen. Archaeological and Anthropological Sciences 5, 159-182. https://doi.org/10.1007/s12520-013-0122-y.

[34] Tilman D. (2007). Resource competition and plant traits: a response to Craine et al. 2005. Journal of Ecology, 95: 231-234.

[35] Tilman D., Wedin D., & Knops J. (1996). Productivity and sustainability influenced by biodiversity in grassland ecosystems. Nature, 379(6567): 718-720. https://doi.org/10.1038/379718a0.

[36] Virginia R. A., & Wall D. H. (2001). Ecosystem function, principles, Encyclopedia of Biodiversity, Volume 2. Academic Press. 345-352 p.

[37] Virginia R. A., & Wall D. H. (1999). How soils structure communities in the Antarctic Dry Valleys. BioScience, 49(12): 973-983. https://doi.org/10.1525/bisi.1999.49.12.973.

[38] Weiner J. (1999). The Life and Evolution of the Biosphere: A Manual of General Ecology. PWN Scientific Publishing House. Warsaw. 1-589 p.

[39] Weiner J. (2003). The Life and Evolution of the Biosphere: A Manual of General Ecology. ed. II corrected and modernized. PWN Scientific Publishing House. Warsaw. 1-609 p.

[40] Weiner J. (2020). The Life and Evolution of the Biosphere: A Manual of General Ecology. PWN Scientific Publishing House. Warsaw. 1-794 p.

[41] Dyczko A. 2014: Rola informatyki w inteligentnej głębokiej kopalni przyszłości. Szkoła Eksploatacji Podziemnej, Kraków – prezentacja;

[42] Wozniak, 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. intechOpen. DOI: 10.5772/intechopen.75723.

[43] Ecological Concept: Resilience and Resistance: https://naturalresources.anthro-seminars.net/concepts/ecological-concept-resilience-and-resistance/

[44] GMS: Carbon and Climate Briefing – 12 November 2015: https://svs.gsfc.nasa.gov/12044

[45] Hubbard Brook Ecosystem Study: Overview and Organization: https://hubbardbrook.org/about

[46] National Aeronautics and Space Administration: https://svs.gsfc.nasa.gov/12044

[47] Ten billion tonnes of carbon released in 2007: https://cordis.europa.eu/article/id/29910-ten-billion-tonnes-of-carbon-released-in-2007/en

[48] https://view.genial.ly/5e98436b63b9e50d80908d3f/interactive-image-interactive-lesson-mineral-fertilizers

2. The abiotic conditions influencing the ecosystem processes and functioning

The abiotic parameters, determining the ecosystem structure, processes, and functioning are described and characterized with respect to the dynamics of the transformation and focused on two crucial aspects of ecosystem functioning, and presented in this part of the book. The basis of each ecosystem is the primary production, and the biomass establishment. The biomass presence gives the beginning of matter and energy flow through all the ecosystem elements. On the other end, the decomposition of the biomass along with the soil respiration (CO_2 release) and the soil organic carbon are the prerequisite for the nutrients coming back to the soil or the soil substratum. These two processes are universal for all ecosystems, including the novel ecosystem established, e.g., in the urban-industry landscape. The factors causing soil transformation, are the biotic processes developing in the soil substratum, such as the post-mineral excavation material. The importance of relations of below and above-ground properties resulting in processes and ecosystem functioning are presented. This chapter focuses on abiotic habitat parameters. However, it has to be considered that it is impossible to separate strictly the impact of abiotic and biotic parameters as the two environmental elements are interrelated and dependent on each other.

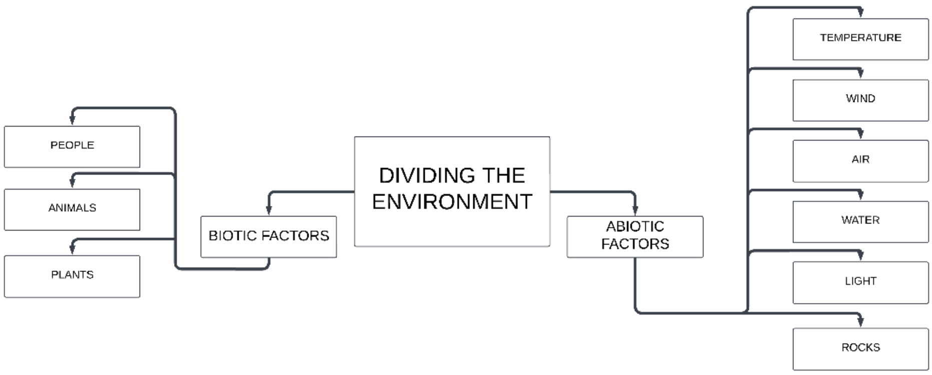

Figure 2.1. Scheme presenting the division of the factors influencing the ecosystem function

2.1. The abiotic habitat conditions and biomass amount in the spontaneous vegetation types of the novel ecosystem

Biomass amount is a crucial metric of vegetation and species abundance. Understanding how community assembly processes, such as environmental filtering and competitive exclusion, affect biomass establishment and distributions of coexisting species along different ecosystem gradients in time and space has proven logistically challenging (Colgan, Asner 2014). Biomass established by autotrophic, heterotrophic, and saprophytic organisms' abundance is usually used in the ecological study of different ecosystems for calculating the ecological indexes (Laux, Torgan 2015).

Trees, shrubs, herbs, and other autotrophic organisms are the only primary producers of biomass. Biomass amount established by trees and herbaceous plants is a crucial metric of plant species abundance, both in the scale of a patch of vegetation type and ecosystem level. The biomass amount is also one of the important ecosystem services metrics. The assembly of the trees and herbaceous plant species in a vegetation patch and the establishment of ecological communities reflect many ecological processes that influence the species' vegetation composition and biomass amount similarities and differences. The assembly process and the associated relationships maintain the dynamic ecosystem processes, each of which is crucial for different aspects of ecosystem services.

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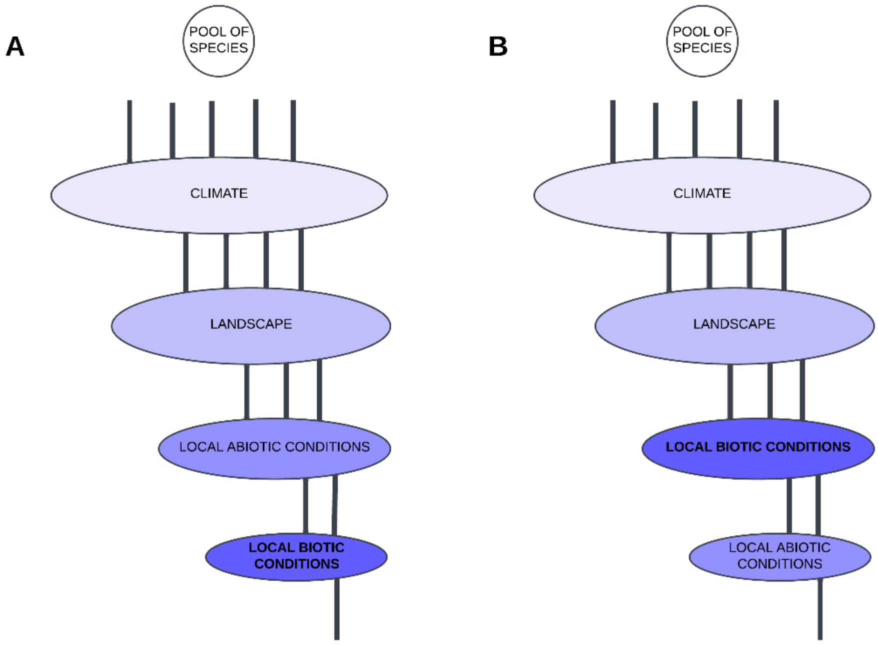

Figure 2.1.1. Schematic diagram of the effects of ecological filters on recruitment and colonization of species. The presence and abundance of species (represented by black lines) is determined by their ability to pass through multiple filters (represented by ovals). Filters are placed in a hierarchy based on the ability to limit recruitment; the upper filters (i.e., climate and landscape) limit recruitment more than the lower filters (i.e., local abiotic and biotic conditions). Any species that lacks traits which would allow it to pass through an upper filter will not be available to pass through the lower filters. Previous tropical coastal forest literature has argued that the upper diagram (A) is most representative of tree recruitment limitation. We argue that where crabs are present, the lower scheme (B) is more representative; crabs, as biotic filters, may limit tree recruitment as much or more than local abiotic conditions

In community ecology, the most accepted idea related to community and biomass assembly is that the communities' compositions are the results of species-sorting processes caused by environmental filtering and competitive exclusion (Silvertown, 2004). Understanding how community assembly processes, such as environmental filtering and competitive exclusion, affect the vegetation plant species composition biomass establishment and distributions of the coexisting species along different ecosystem gradients in time and space has been proved to be logistically challenging (Colgan and Asner, 2014). Biomass established by autotrophic, heterotrophic, and saprophytic organisms' abundance is usually used in the ecological study of different tree and herb plant ecosystems for calculating the ecological indexes that might be a proxy of ecosystem processes and services (Laux and Torgan, 2015). The ecosystem developmental processes influence the vegetation diversity, species composition, structural characteristics, and above-ground biomass (Looney et al., 2016; Lutz et al., 2018). Some studies showed that environmental filtering at a microscale determines biomass productivity, diversity, and species composition in a particular assembly. The understanding of these links is related to the decided approach being a current controversy in ecology (Castellanos et al., 2018; Gerhold et al., 2015; Goberna et al., 2014). The appearing question is related to the nature of biological communities. Are the biological communities discrete biological entities causing the existence of ecotone ecosystems or a continuity changing along gradients (Peralta-Maraver et al., 2018).

In the ecosystem, the vegetation species composition of plant individuals varies in growth type, growth rate, and size annually during the growing seasons. The developmental processes influence vegetation diversity, species composition, structural characteristics, and above ground biomass (Looney et al., 2016; Lutz et al., 2018). Some studies showed that environmental filtering at a microscale determines biomass productivity, diversity, and species composition of the whole assemblage. The understanding of these links is related to another current controversy in ecology (Castellanos et al., 2018). The appearing question is related to the nature of biological communities. Are the biological communities discrete biological entities causing the existence of ecotone ecosystems or a continuity changing along gradients.

In the natural and semi-natural ecosystems, there are several ideas of theories and conceptual approaches that try to explain the relations between the abiotic habitat conditions and the amount of biomass established by trees and herbaceous plants in particular vegetation communities. The niche theory suggests that different environmental conditions affect the species distribution and coexistence in established assemblages by different resource requirements along the environmental gradient in space and time. As a result, species may show different adaptations to a specific environment (Tilman, 2004; Weiser et al., 2018). The environmental conditions (light, water, texture, nutrients) influence species distributions, diversity, and coexistence. The abiotic factors' contributions to biotic conditions vary across space and time (Ali et al., 2019; Toledo et al., 2012). An important question in ecology is still open. The biomass amount and species composition depend on niche and environmental factors rather than biotic factors such as competitor traits (Ali et al., 2020; Tilman, 2004). The biomass establishment and species coexistence mechanism can be explained by fitness differences between species vs. stabilizing effects obtained via niche differentiation (Carroll et al., 2011; Kraft et al., 2008). There are also various concepts that attempt to explain the relations between higher plant (trees and

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herbs) species diversity and above-ground biomass. One concept assumes the positive correlation enhancement through resource-use partitioning amongst structurally complex compositions (e.g., herb plants, shrubs, trees) of plant species within a community (Ali and Yan, 2017; Poorter et al., 2015; Yachi and Loreau, 2007).

The concept of the mass ratio hypothesis and the scaling theory are very inspiring. The two approaches suggest that dominant species govern stand-level above-ground biomass through the continuous relationship between dominant, most abundant species and the spatial relationship within the group of strong and weak competitors (Enquist and Niklas, 2001; Grime, 1998). The competitive exclusion theory suggests that high biomass and structurally-complex vegetation exclude weak competitors. Hence, the negative relationships between species diversity and above-ground biomass are expected in natural forests (Ali et al., 2020; Carroll et al., 2012). Forests are climax succession stage in most climatic zones on the Earth. However, after disturbance, the tree seedlings first appear amongst the herbaceous vegetation.

The traditional niche-based theory is considered a deterministic process, including environmental filters and species interactions, governing community species composition and structure (Chase and Leibold, 2004; Gilbert, 2012). The biomass amount established in a given vegetation patch depends on habitat conditions. The abiotic mineral composition of the bedrock is the primary habitat condition that is determining all the following processes leading to community assembly processes across ecosystems. This relation is a crucial research objective in ecology (Hubbell, 2001; Martiny et al., 2006; McGill, 2010; Vellend, 2016). While the neutral theory considers the species as ecologically equivalent. In this respect, the structure of the community is a result of stochastic processes such as colonization, birth, death, immigration, and probabilistic dispersal (Bell, 2001; Hubbell, 2001; Rosindell et al., 2011). The discussion about the relative importance of different factors in shaping natural communities' ecology revealed that those two approaches are not mutually exclusive (Hubbell, 2001; Martiny et al., 2006; McGill, 2010; Vellend, 2016).

The metacommunity theory enables the identification of the processes, considering the observed phenomenon in multiple spatial scales (Chase and Leibold, 2004; Wilson, 1992). Vegetation community's species composition is spatially connected by, and related to the dispersal, and assembling as a result of the interplay between the dynamic regional and local factors. As of late, Vellend (2010) proposed a conceptual system in which the structure of communities can be clarified by taking after four “high-level processes” (Hubbell, 2001; Vellend, 2016, 2010). According to Vellend (2010) the processes include: dispersal, diversification selection, and ecological drift. These processes are universally shaping the low-level community assembly (such e.g., colonization, establishment, persistence (succession), competition, and local extinction (out-competing).

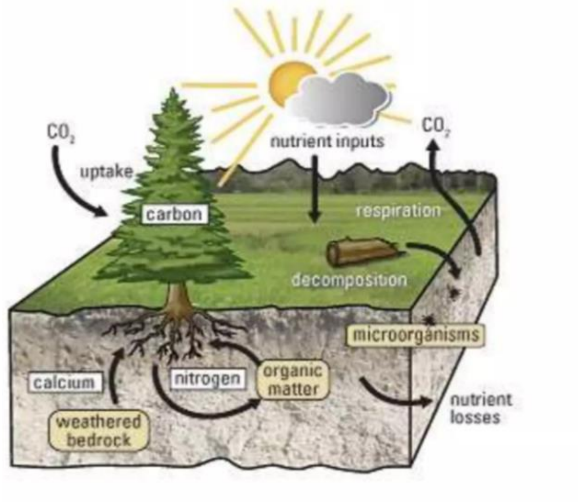

Figure 2.1.2. The scheme of the simplified relations between the above-ground and below-ground ecosystem elements changed and modified after the concept from www.slideshare.net/JuanCarlosValverde2/soil-and-ecosystems-slideshare

The selection process modifies the community assembly structure because the plant species individuals have differences in fitness to respond to heterogeneous environmental conditions. The level of a variety of environmental conditions leads to more similar or dissimilar structures among communities (MacArthur and Wilson, 2001; Stegen et al., 2013). In homogeneous environmental conditions, selection will not act intensively and will lead to similar communities (low community turnover), in terms of plant species composition, and the related heterotrophs and saprophytes' "homogeneous selection." In heterogeneous habitat conditions, selection enhances the increase in community turnover. Each part of the heterogeneous habitat mosaic is colonized by the best-adapted plant species of different taxa and is referred to as "heterogeneous selection" (Dini-Andreote et al., 2015; Hubbell, 2001; Lowe and McPeek, 2014; Vellend, 2010; Vellend et al., 2014). The diversity has been increased due to the generation of new species by genetic variation mainly due to stochastic factors, in response to habitat conditions on a larger temporal scale (Rundle and Nosil, 2005). The relative importance of selection compared with other processes may depend on the environmental heterogeneity and dispersion rates within the metacommunity (Östman et al., 2012).

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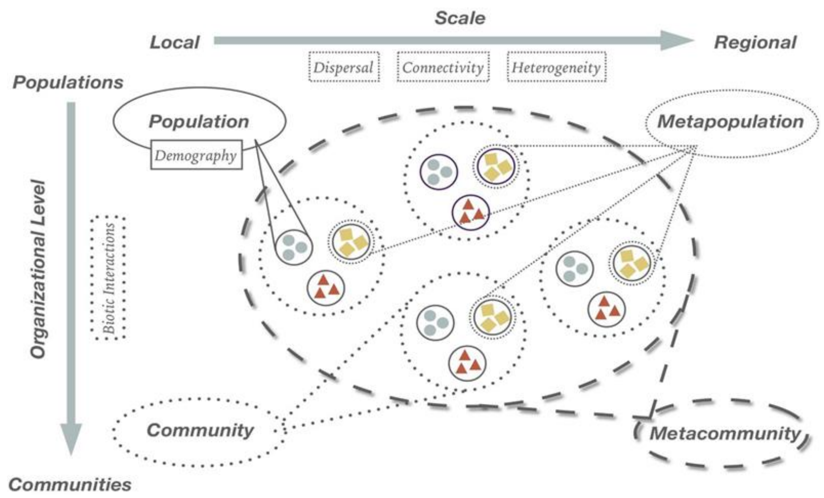

Figure 2.1.3. The conceptual scheme, presenting how varied levels of conservation are integrated within the metacommunity along two axes of organizational and scale level. Individuals and populations are presenting in the local communities level, the regional metapopulations and regional metacommunities. Population, the individual groups, based processes affect metapopulations and communities. Community and metapopulation processes both impact the metacommunities

The impact of the above theories and concepts has been considered concerning natural and semi natural habitat conditions. The impact of the abiotic factors of any aspect of biotic and further feedback relations become more complex when the spontaneous vegetation patches and the developing ecosystem start to cover habitats of novel ecosystems (Hobbs et al., 2006), e.g., post-mineral excavation sites. The de novo formed mineral habitats provide an opportunity to investigate the relationships between the plant species, particularly the dominant plant species, and the abiotic substrate parameters. The crucial observed process is the colonization of the best-adapted tree and herbaceous plant species individuals, influencing richness, and biomass amount of the developing vegetation and consequently ecosystem functioning and ecosystem services of novel ecosystems. In novel ecosystems, some of the relationships are developing as a result of previously unknown processes caused by the non-analogous species composition and the extreme human effect on the Earth's ecosystems during the Anthropocene (Zalasiewicz et al., 2016). Post-mineral excavation sites deliver an example of newly established habitats that differ from the natural ecosystems current in the surrounding landscape.

Many studies have indicated that, nevertheless, of the transformation caused by human activity, these sites have been intensively inhabited by living organisms through spontaneous succession, delivering novel non-analogous species compositions of flora and fauna (Frouz, 2018; Hobbs et al., 2006; Kowarik, 2011; Tropek et al., 2012). Differences in the chemical and physical properties of post-mineral excavation substrates have resulted in unknown, non-analogous species compositions of the vegetation and animal organisms (Helingerová et al., 2010; Keith et al., 2009; Novák and Prach, 2003; Woźniak, 2010). The vegetation growing on the mineral material of the post-coal mine heaps consists of a mosaic of patches dominated by various species assembled in a variety of microhabitats (Rawlik et al., 2018a, 2018b; Wozniak et al., 2015). This mosaic is reflecting the diversity of abiotic habitat conditions (Woźniak, 2010). Amongst the high variety of vegetation types observed at the early stages of successional development on coal mine spoil heaps, some of the vegetation types are particularly frequent, including *Calamagrostis epigejo*s and Poa compressa, and some herbaceous plants, including *Daucus carota* and Tussilago farfara, have been studied. The dominant plant species are accompanied sometimes by a high number of plant species both herbaceous and tree juveniles different in cover and abundance (Woźniak, 2010). The impacts of the plant species composition of the early-successional vegetation stages on mineral substrates of harsh site conditions are much less well-known (Emery, 2007; Lamošová et al., 2010; Orwin et al., 2014; Peltzer et al., 2009; Prach and Pyšek, 1999; Woźniak, 2010). Because of the extreme abiotic conditions of the mineral material of the coal mine heaps, it is intriguing how the abiotic habitat conditions influence the biomass amount of plant species composition of identified vegetation types in coal mine heaps novel ecosystem. The biomass production (amount) is a proxy for ecosystem functioning. The ecosystem functioning is the basis for the provision of each ecosystem service (Aragão et al., 2016; Baral et al., 2016; Bark et al., 2016; Jacobs et al., 2016; Washbourne et al., 2020). The initial successional stages determine the development forest type that will develop in the particular abiotic site conditions.

In this respect, there are questions about the relations between the abiotic mineral material of habitat conditions and biomass amount in the spontaneous vegetation type's novel ecosystem of coal mine heaps. The abiotic habitat conditions such as: the water holding capacity (WHC), texture of the soil substratum, acidity pH, EC, basic abiotic N, C, Mg, Na, exchangeable cations (acidity) might be important to understand the functioning of coal mine heaps novel ecosystem. It could be assumed that the nitrogen content in the heaps mineral material will influence the biomass amount in the most significant way. While the other abiotic coal mine heaps parameters such as acidity pH, EC, texture of the soil substratum, the water holding capacity (WHC), can also impact on the biomass amount in the identified spontaneous vegetation types. The number of studies conducted on spontaneous vegetation development on the pure mineral material of the post hard coal deep mining is very limited. There are scarcely any comprehensive studies conducted on ecosystem functioning of spontaneous development of the novel ecosystems in those specific habitats. Most of the study on such type of specific post-mining environment has been conducted by a limited group of experts.

Coal mine heaps model habitats for adaptation processes

As a model object, coal mine spoil heaps, mostly situated in the Upper Silesian Coal Basin are considered. The mineral materials deposited in the coal mine heaps originate from carboniferous gangue rock situated about 700 m below the surface (Kompała-Bąba et al., 2019). Due to the origin of these materials, the fresh heap mineral substrate is at the beginning free from organic matter, soil microorganisms, or plant propagules (Rahmonov et al., 2022; Woźniak et al., 2021) and does not possess any features to support biological life. The coal mine spoil heaps are open for the plant colonization, succession and diversity, soil formation, and the development of relationships between plants and the associated microorganisms (Frouz et al., 2008; Kompała-Bąba et al., 2019; Woźniak, 2010). Moreover, in terms of the theoretical approach, the physicochemical properties of post-mining mineral material are unfavourable for plant growth. They are characterized by acidic pH, locally very high salinity, and low nutrient availability as well as unfavourable soil texture (Błońska et al., 2019; Kompała-Bąba et al., 2019; Prach and Walker, 2020; Rahmonov et al., 2020; Bierza et al. 2023). On the other hand, mining mineral material, after being stored, is highly vulnerable to weathering, resulting in the rapid accumulation of a fine mineral soil fraction that retains soil nutrients and water, providing a substrate for seed germination (Błońska et al., 2019b; Kompała-Bąba et al., 2019; Rahmonov et al., 2022; Woźniak et al., 2021). The analysis of the data and visualization can be performed using R language and environment (R Core Team 2022).

The preliminary study conducted by Ryś et al. (2023 in press) to investigate the relation between the biomass amount of the spontaneous vegetation types and the mineral material habitat condition of the coal mine heaps revealed some impact.

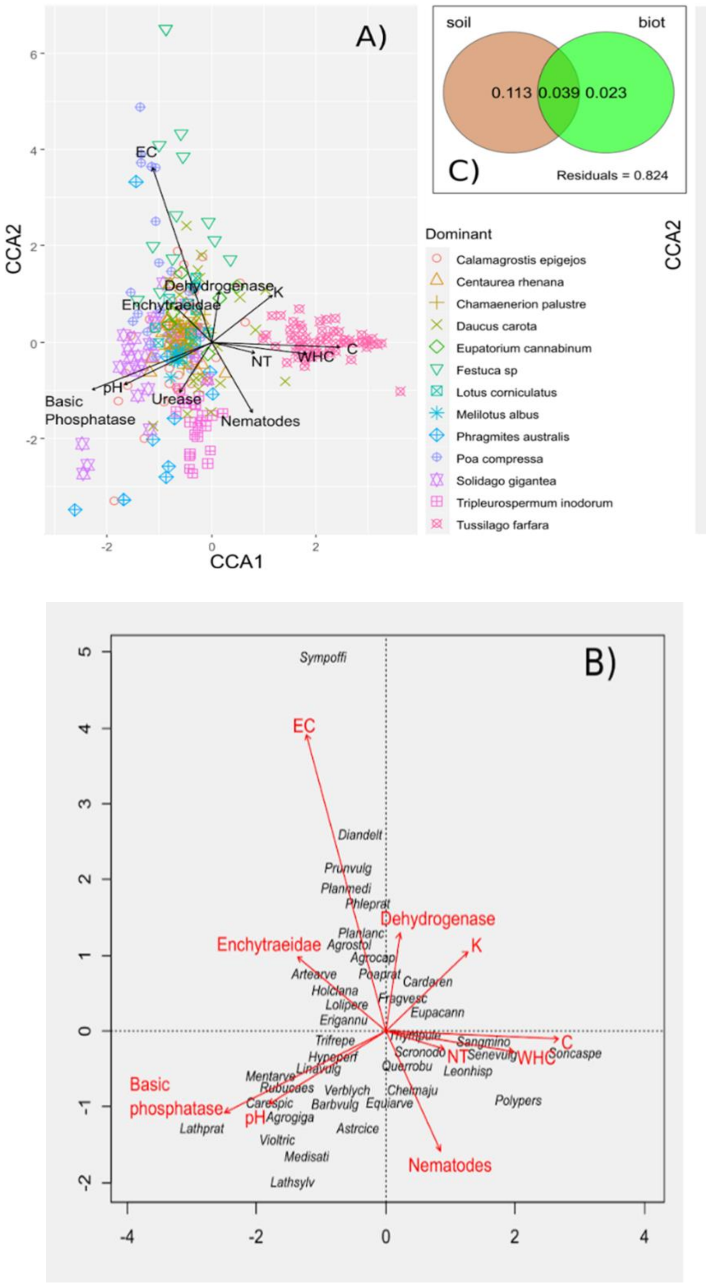

Figure 2.1.4. The biplot of CCA along the first two axes shows vegetation groups with particular dominants (A), relationship between significant environmental factors ($p<0.05$) and species scores (B), and variance partitioning between soil data (after Ryś at al. 2023 in press)

The soil substratum analysis has been performed in the distinguished (dissimilar) spontaneous vegetation type groups. Such arrangement of the samples enabled the categorization of the abiotic soil substratum parameters to the measured amount of biomass. The total nitrogen, water holding capacity and organic carbon revealed the relation to the biomass amount along the first axis of CCA (Figure 2.1.4. A). The high values of these variables characterize the *Tussilago farfara* group plots. Electrolytic conductivity is correlated with the second axis, and with the *Festuca* sp and *Poa compressa* group plots are assigned. High value of basic phosphatase and pH plot with *Solidago gigantea* are associated. The high value of urease and nematode ordinate plots with *Triplospermum inodorum* group plots (Ryś at al., 2023 in press).

The theoretical constraints concerning the factors influencing the biomass amount in respect to natural capital and ecosystem services

Biomass amount is a key metric of vegetation and species abundance. It is also the main ecosystem functioning and consequently ecosystem services. The understanding how community plant species assembly processes, such as environmental filtering and competitive exclusion, affect biomass establishment and distributions of coexisting species along different ecosystem gradients in time and space has proven logistically challenging (Colgan and Asner, 2014). Biomass and abundance estimates are metrics usually taken in ecological study in different ecosystems for calculating the ecological indexes (Laux and Torgan, 2015).

In the ecosystem, the vegetation species composition of plant individuals vary in growth type, growth rate and size annually during any growing season. The developmental processes influence the vegetation diversity, species composition, structural characteristics and above ground biomass (Looney et al., 2016; Lutz et al., 2018). Some studies showed that environmental filtering at a microscale is determining biomass productivity, diversity and species composition of the whole assemblage. The understanding of these links is related to another current controversy in ecology. The appearing question is related to the nature of biological communities. Are the biological communities discrete biological entities or a continuity changing along gradients. The existence of the ecotone ecosystem is discussed (Peralta-Maraver et al., 2018).

The niche theory suggests that different environmental conditions affect the species coexistence by using different resources along the environmental gradient in space and time. As a result, different species may show different adaptations to a specific environment (Tilman, 2004; Weiser et al., 2018). The environmental conditions (light, water, nutrients) influence species distributions, diversity and coexistence. The abiotic factors influencing biotic conditions vary across space and time (Ali et al., 2019; Toledo et al., 2012). In the previously conducted studies, it is not decided if the biomass amount and species composition are controlled by niche environmental factors or biotic factors such as competitor traits (Ali et al., 2019; Tilman, 2004). The biomass establishment and species coexistence mechanism can be explained with either fitness differences between species vs stabilizing effect via niche differentiation (Carroll et al., 2011; Kraft et al., 2008). There are also various concepts that are trying to explain the mechanisms of the relations between higher species diversity and above ground biomass. One concept assumes that the positive correlations are enhanced through resource-use partitioning in the multi level structure complexity of tree species within the species composition of the other layer shrub and herb in a community (Ali and Yan, 2017; Poorter et al., 2015; Yachi and Loreau, 2007). The mass ratio hypothesis and the scaling theory suggests that the dominant species govern stand-level aboveground biomass through the continuous relationship between dominant most abundant species and the spatial relationship between strong and weak competitors (Enquist and Niklas, 2001; Grime, 1998; West et al., 2009). The competitive exclusion theory suggests that high biomass, structurally-complex vegetation exclude weak competitors, and hence, the negative relationships amongst species diversity and aboveground biomass are predicted in natural forest (Ali et al., 2019; Carroll et al., 2011).

Environmental filtering is an important process that shapes vegetation communities in a range of habitats and time and space scales (Kraft and Ackerly, 2010; Rodrigues et al., 2020). For example, the regional-scale relationships amongst species diversity, and aboveground biomass can be directly influenced by abiotic factors (Ali et al., 2020; Poorter et al., 2015; Stegen et al., 2011). Although different abiotic factors influence species distribution patterns, precipitation and temperature controls regional-scale vegetation diversity, structure and aboveground biomass compared to inconstant impacts of soil fertility (Ali et al., 2020; Poorter et al., 2015; Prado-Junior et al., 2016; Stegen et al., 2011). Despite the direct importance of environmental filtering in shaping species biomass amount vs species richness and composition (Kraft and Ackerly, 2010; Toledo et al., 2012), the relative indirect importance of environmental filtering through different impacts of the competitor species is still poorly explored. The environmental filtering concept and niche theory are explaining the influence of abiotic habitat conditions on biomass amounts, including precipitation. The study conducted in forest communities revealed that reduced precipitation decreases plant biomass (Heisler-White et al., 2009), but increased precipitation variability and soil water content can promote plant diversity

(Knapp et al., 2002). The mass ratio hypothesis and biomass amount in relation to biodiversity are focused on the biotic vegetation and ecosystem parameters carried by the dominant plants (Grime, 1998). The random factors and differences in mechanisms dependent on-site specific conditions must be also considered. The ecological mechanisms underlying aboveground biomass and species diversity are not mutually exclusive (Ali et al., 2019; Poorter et al., 2015).

There is still low understanding of how the ecological processes influence the interactions between taxa and their biomass. The mechanisms can be different along the different groups of organisms. Particular groups are the vascular plants, the primary producers and saprophytes, e.g., bacteria and fungi. Co-occurrence networks are an increasingly useful tool to infer microbial interactions (Liu et al., 2020). Interactive relations between taxa are either positive or negative. These microbial taxa play a significant role within the community and confer stability due to their high connectivity with other members. Therefore, a better understanding of the processes and mechanisms that govern the highly influential connection taxa composition and structure may provide an insight into the underlying response of the modification in the whole community and ecosystem (Liu et al., 2020).

The carbon content in the soil and the biomass amount

The carbon (C) cycling gets much attention, particularly in relation to increased N deposition (Cusack et al., 2011; Sinsabaugh et al., 2005).

The carbon, nitrogen, and phosphorus cycles are closely related in soils of different ecosystems particularly in forest soil and participate in the cycles of other nutrients, which influence the vegetation composition and diversity (Fahey et al., 2013). The studies conducted in forests revealed the increase in soil carbon in plots with N additional (Tafazoli et al., 2019; Zarif et al., 2020). This suggests that forest ecosystems as well as probably in mineral coal mine novel ecosystems the soil (soil substartum) C:N ratio is governing the plant uptake of available N as it is made through the carbon compounds and soil microbial activities (Eberwein et al., 2017; Zarif et al., 2020). In the forest soils and probably also in the soil (mineral substratum), acidification is resulting in leaching down of base cations. The weathering of certain base cations like Ca > Na > Mg > K causes limitations in basic cation budgets and an imbalance of metal ions in soils (Lu et al., 2014; Lucas et al., 2011). In our study, the base cations are positively and significantly correlated with the established biomass amount of the dominant and non-dominant plant species.

The nitrogen content and the biomass amount

Nitrogen is considered to be a crucial nutrient for plant growth in terrestrial ecosystems particularly in temperate ecosystems, where the soil is regarded to be relatively younger (LeBauer and Treseder, 2008; Vitousek and Howarth, 1991). For a long time, nitrogen has been regarded as an important parameter influencing photosynthesis efficiency and consequently the biomass amount. Therefore, the additional input of nitrogen but also phosphorus and potassium has been introduced into the farmland soils and consequently into the environment. The high amount or addition of nitrogen limits the role of other important nutrients, like base cations and phosphorus (P) (Małek and Astel, 2009; Yang et al., 2015). The carbon (C) cycling gets much attention in particular in relation to increased N deposition (Cusack et al., 2011; Sinsabaugh et al., 2005).

The study conducted by Band et al., (2022) revealed that anthropogenic (mostly agriculture) eutrophication (over NPK fertilization) is a serious threat to global diversity (Bobbink et al., 2010; Sala et al., 2000; Stevens et al., 2010; Tilman et al., 2001). In the Band et al., (2022) study, it has been stated that eutrophication (mostly the increased nitrogen content) is the main driver of species loss in vegetation community patches worldwide (Berg et al., 2016). The mechanisms of this phenomenon are not clear. There might be three main explanations. One is that high soil resources increase the biomass amount, intensifying interactions of competitive character (the “biomass-driven competition hypothesis”). The other approach is related to the high levels of soil resources that reduce the potential for resource-based niche partitioning concept (the “niche dimension hypothesis'). The last concept suggests that the increase of soil nitrogen is causing stress by altering the abiotic or biotic conditions (the “nitrogen detriment hypothesis”). The mechanisms behind the three hypotheses are not independent. Band et al., (2022) conducted a test of the three concepts by integrating data from resource addition experiments sites worldwide. The obtained results revealed that the nitrogen detriment hypothesis got strong support. The biomass-driven competition hypothesis in the presented study received weaker support. The results presented by Band et al., (2022) provided less convincing proof for the niche dimension hypothesis. It has also been shown that the impact of nitrogen occurrence on the amount of biomass might be indirect. However, its effect on biomass is lower when compared to its direct effect and is much higher than that of all other resources (phosphorus, potassium, and water). The biodiversity has to be always considered as the fundamental ecosystem service. The nitrogen-specific mechanisms are more crucial for biodiversity than biomass or niche dimensionality as factors of species loss in the high levels of soil resources conditions. This conclusion is of high importance for

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future actions to reduce biodiversity loss caused by global change (Band et al., 2022). Moreover, the study conducted in forests revealed that the total nitrogen measurements do not give the insight into the NO^{3-}versus NH^{4+} ratio. It has been stated that the NO^{3-} -N is significantly increased while NH^{4+}-N remained stable in response to N additional input in the plots. The N's addition and its forms can lead to a modification of the balance between H^+ ion production and consumption and influences N mineralization with increased N application in soil. The decrease in ammonification and increase in nitrification indicates the N saturation state in the soil (Tafazoli et al., 2019; Yan et al., 2008). In the forest ecosystem, the long-term N addition increases the N mineralization rate in the soil due to microorganism adaptability to increased soil acidification and the N content (Falkengren-Grerup et al., 1998).

The mechanisms governing the levels of resources that are causing the decrease in species richness are not fully understood (Ceulemans et al., 2013; DeMalach and Kadmon, 2017; Dickson and Foster, 2011; Grace et al., 2016; Harpole et al., 2017; Lamb et al., 2009; Rajaniemi et al., 2003). Early the decrease of richness in habitats of high resource availability have been attributed to an increase in biomass that has caused the intensified interspecific competition (Grime, 1973; Newman, 1973). As a consequence, the biomass-driven competition hypothesis has been announced, explaining that the high level of nutrients in the habitat gives a competitive advantage for large and fast-growing species, excluding the slow-growing and smaller species from the community (Aerts, 1999; Rajaniemi, 2003). It has revealed that such competitive exclusion is primarily related to competition for light (Hautier et al., 2009). There are also studies showing that root competition may contribute to species loss in nutrient rich habitats (Rajaniemi et al., 2003).

The results opposite that expected might be also related to the fact that the studied sites are the isolated systems, a kind of **environmental islands** like the mineral constructions of post-coal mine heaps might be governed by special rules. In the isolated objects with lower environmental heterogeneity, the stochastic processes are more relevant. Due to the low environmental heterogeneity, the environmental filters are weak and cannot cause species sorting (Boet et al., 2020). Communities in isolated systems can be structured by dispersal limitation, (Evans et al., 2017; Fernandes et al., 2014; Ofiţeru et al., 2010).

Is the phosphorus content influencing the biomass amount?

According to De Groot et al., (2020) the phosphorus (P) availability is related to N dynamics, as the P cycle is strongly connected with the N cycle (De Groot et al., 2001). The availability of P is considered to be the second limiting factor in forest ecosystems to that of available N (Aber et al., 1989).

In our study, P is revealed to have a significantly positive influence on the biomass amount recorded in the different vegetation types identified on the mineral substratum of the coalmine heaps novel ecosystem. Consequently, the presence of soil enzymes base and acidic phosphatase is positively related to the biomass amount established in the spontaneous vegetation patches developed on the studied mineral material.

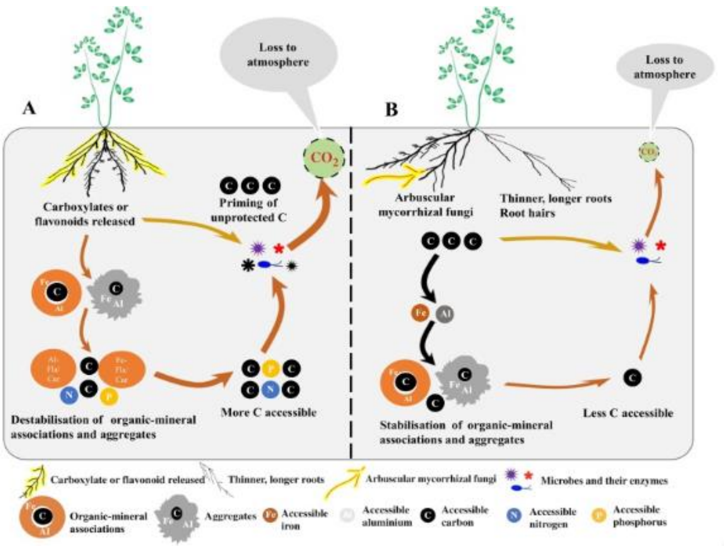

Figure 2.1.5. Plant phosphorus acquisition and use strategy affecting soil carbon cycling

Phosphorus is reported as a crucial but limiting abiotic factor related to exchangeable oxides promoting the release of hydroxyl ions in many ecosystems (Hou et al., 2020; Mao et al., 2016; Vitousek et al., 2010).

The phosphorus forms vary and change dynamically in their availability to different living organisms (microbes and plants) (Helfenstein et al., 2018; Zhang et al., 2020, 2016). The mineral inorganic phosphorus (Pi) may be released in organic phosphorus (Po), along with the secondary mineral P (i.e., NaOH Pi) in different forms and it can contribute to soil P bioavailability (Bünemann, 2015; Helfenstein et al., 2020, 2018a; Rosling et al., 2016; Oberson and Joner, 2005; Walker and Syers, 1976). The phosphorus occurrence significantly increased the litter nitrogen and microbial biomass and reduced the nitrogen mineralization (Chen et al., 2018). In this way the nitrate leach-down process and the release of nitrous oxide has been limited (Homeier et al., 2012). The study of Mao et al. (2016) also presented that the amount of total N was higher in the winter than summer. The continuous N deposition, e.g., from the atmosphere, is limiting the soil acidity, which would suggest that a buffering effect caused by the additional phosphorus keeps the soil pH stable (Mao et al., 2016; Yang et al., 2015; Zarif et al., 2020).

The texture impact on the abiotic parameters' availability on biomass amount

In our study, the texture of soil substratum parameter is not significant and is not presented in the result section. However, it is known that texture, in particular the finest material, can influence the soil processes. The leaching down of nitrate due to weak bind to soil particles (i.e., negative charge on clay particle) is resulting in a decrease in base cations and soil pH (Lu et al., 2009).

There are studies showing that the relationship between clay participation in the soil texture and the amount of SOC content is strong (Jenkinson, 1990). The study also revealed that SOM decomposition decreases as clay concentration increases, when all the other factors are the same. While the SOC accumulates faster along with the soil (soil substratum) clay participation increases.

Clay proportion in the soil texture may have different effects on the decomposition of varied SOC pools (Franzluebbers et al., 1996). The soil respiration during the early stages of a laboratory incubation the (labile SOC mineralization), according to Wang et al., (2003) was not influenced by clay participation (Wang et al., 2003). Later in the same incubation, when the recalcitrant SOC pools had been mineralized, it has been stated that the clay content slowed down the process of mineralization. The heterogeneous clay effect on C decomposition has been incorporated in SOM alternation dynamic models (Müller and Höper, 2004). The carbon C mineralization process generally decreases with increasing clay content (Hassink, 1997). The laboratory incubations do not always present this trend (Scott et al., 1996). These observations have led to the conclusion that clay-rich soils protect some portion of SOC from decomposition and cause SOC accumulation more rapidly than sandy soils. Two separate mechanisms are proposed to explain these mechanisms.

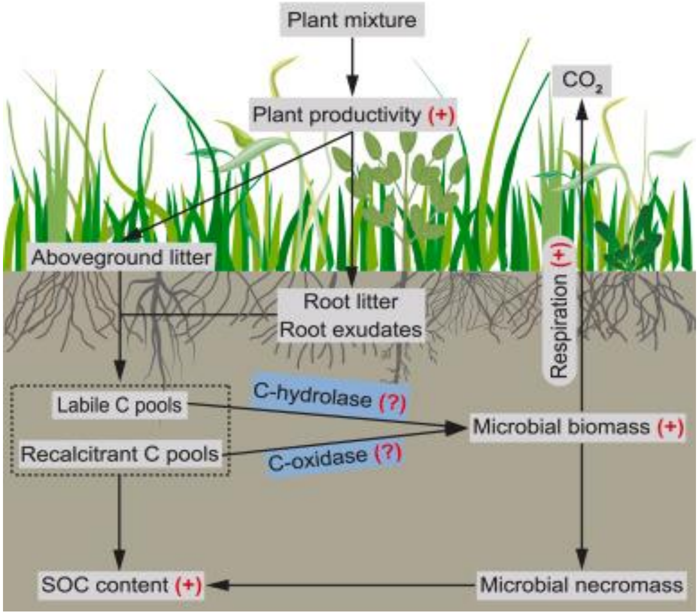

Figure 2.1.6. The scheme of carbon transformation of soil organic matter (SOM) and soil organic carbon (SOC) including the labile and recalcitrant carbon forms

One of them assumes that SOC becomes humified, and is adsorbed by the negatively charged clay minerals that are providing high surface area. A second explanation might be that SOC is physically isolated from microbial mineralization by the formation of soil aggregates. The process of aggregate formation often takes place in stages, and the occurrence of the first clay particles enables this process of aggregation of the others (Six et al., 2000). The clay aggregations may change the soil moisture parameters, which in turn affects the C inputs to soils through plant productivity and decomposition of SOC (Six et al., 2000).

The relations between the role of clay participation and soil nutrient cycling, particularly the key step of nitrogen (N) mineralization, are not straightforward. Some studies showed that the increase in clay content limits the N mineralization (Coã Teâ et al., 2000). The study conducted by (Giardina et al., 2001), revealed how different the results might be when the conditions (temperature and moisture) are controlled. In the Giardina et al., (2001) study, the clay content has little effect on the net N mineralization rate (Giardina et al., 2001). Regardless of soil texture, with increasing time since the effects of below-ground disturbance, the net N mineralization decreases, and soil C content increases (Schimel, 1986). The lack of significant relationships between the texture and biomass amount in the identified spontaneous vegetation on coal mine heaps novel ecosystems might be caused by the highly mineral stony soil substrate. The indirect relationship might be reflected in the significant relationship of the SOM and the biomass established by the *Melilotus alba* vegetation type.

The water soil content and the biomass amount

In the natural and semi-natural conditions, the rules governing plant species assemblages and the resulting ecosystem functions such as biomass amount, are different in the moisture gradient from water to terrestrial systems (Barberán and Casamayor, 2010; Fodelianakis et al., 2019; Graham et al., 2016; Grosberg et al., 2012; Huber et al., 2020; Isabwe et al., 2019; Jiao et al., 2020; Lindström and Langenheder, 2012; Nemergut et al., 2013; Ruiz-González et al., 2015; Wang et al., 2013; Widder et al., 2014; Zinger et al., 2011). It is known that the complex network systems under the influence of changing **moisture** conditions are undergoing important structuring ecological processes over time according to the hydrological conditions (Devercelli, 2009). It might be expected that biomass amount can be influenced by the water holding capacity (WHC) in the spontaneous vegetation type's novel ecosystem of coal mine heap. In our study, the biomass of the dominant species and the accompanying species that are not dominant ones, is negatively correlated with the water-holding capacity (WHC).

The observed limited precipitation has been stated to decrease plant biomass (Heisler-White et al., 2009). However, increased rain precipitation changeability and soil water-holding abilities can promote plant diversity (Knapp et al., 2002). It is expected that global climate changes along with anthropogenic disturbances including hay harvesting, will have repercussions for both primary producers and heterotrophs such as insects (Shi et al., 2016; Xu et al., 2013). This finding is especially true in grasslands, which are frequently covering stony slopes. Grasslands are herbaceous ecosystems covering ~37% what is a sufficient part of Earth’s terrestrial surface that provides many ecosystem services including livestock forage, slope stabilization, erosion protection and carbon sequestration (White et al., 2000).

Drought causes the reduction of primary production, the biomass amount (Heisler-White et al., 2009). The lack of water in an ecosystem is altering plant nutrient quality. The reduced precipitation, and lower water content in grasslands can increase the biomass amount of drought-resistant C4 grasses and reduce the biomass amount of C3 forbes (Heisler-White et al., 2009). This change is leading to ecosystem-level balance modification in plant quality via higher lignin and lower nitrogen content (Caswell et al., 1973; Tscharntke and Greiler, 1995).

Drought can increase the concentration of nutrients in individual plants that are experiencing water stress (Franzke and Reinhold, 2011; Grant et al., 2014). Parallely, the water stress is decreasing plant defenses abilities (Gutbrodt et al., 2011; Jamieson et al., 2012; Mattson and Haack, 1987).

Plant biomass amount can be affected by salinity stress EC

In natural and semi-natural ecosystems, plant biomass in vegetation community patches is primarily a product of photosynthesis. The process in which carbon dioxide, water with mineral nutrients, and light radiation as the energy source are the basics. Among the mentioned, only abiotic stresses like water deficit and soil salinity are very often the limit of the biomass production. Plant individuals' responses to abiotic factors including stress is of high researcher interest. It is one of the most active research topics in plant biology due to its importance for practical implications in agriculture, since abiotic stresses (mainly drought and high soil salinity).

The studied mineral material habitats of coal mine heaps are characterized both by salinity and drought stress. However, in our study of the spontaneous vegetation patches in novel ecosystem mineral coal mine heaps habitats, the water holding capacity in the soil substratum is significantly negatively related to the biomass amount of both the dominant species and the non-dominant plants. This might be explained by the fact that the structure of the minerals like, e.g., montmorillonite has the ability of storing water. The procedure of the water holding capacity measurement method because of the change in the minerals structure does not enable to measure the real water capacity potential. In our study, the Electrical Conductivity (EC) is not a significant factor for the biomass amount in the identified spontaneous vegetation types developing on mineral material of the post coal mine heaps novel ecosystem.

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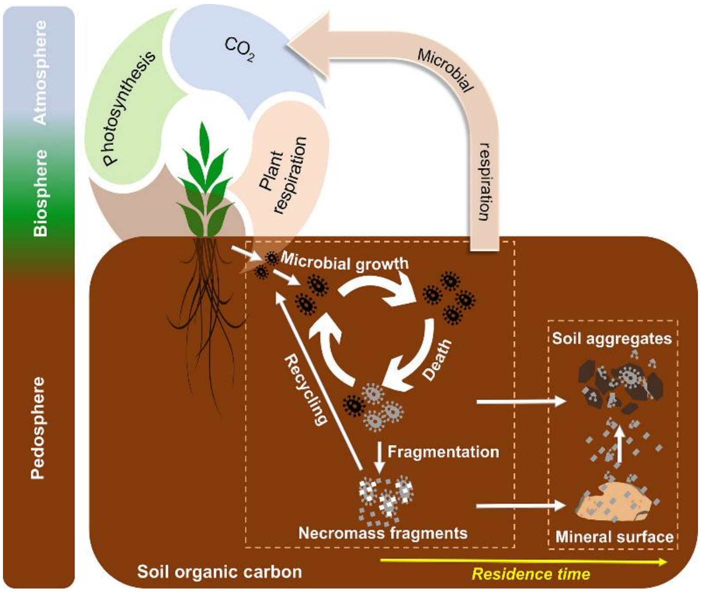

Figure 2.1.7. The relations between abiotic parameters stresses like water deficit, salinity EC electrical conductivity in the soil or soil substratum are very often the limit of the biomass production

Plants in natural and semi-natural ecosystems are susceptible to changes resulting from drought or salinity, and according to some researchers, do not generally adapt quickly (Lane and Jarvis, 2007). Plants adaptation processes range from morphology, anatomy to physiology and molecular processes. The adaptation processes are different among plants living in the same area. Each plant responded uniquely when various stress signals, such as drought or cold, prompted a group of different plant species. Hardly any of the responses were similar, even though the plants had become accustomed to the same home environment (Mittler, 2006). Abiotic stresses can impact the organisms in many forms. The occurrence of many of these abiotic stresses is unpredictable. However, drought and soil salinity are relatively more predictable in agricultural management and familiar with occurrences demanding focused research.

The studies focused on the factor influencing the biomass amount are conducted in different resolutions. In our study, we have focused on the vegetation patch scale. Colgan and Asner (2014) used airborne remote sensing to study the ecosystem-scale distribution of species-specific, woody plant biomass. They studied biomass and the relation to topographic and moisture gradients in the South African savannah. Colgan and Asner (2014) spatially analysed differences in biomass among species to reveal the patterns of coexistence, mapping the biomass and species covering of one million trees across 10500 ha (Colgan and Asner, 2014).

Plant biomass is the weight of plants above and / or below the ground. Assessed as the weight of biomass or organic matter assimilated by a community or species on an area of land in a particular unit of time. Primary production is expressed in two ways. Gross primary production (Pg) is the total amount of organic matter assimilated (including that lost in respiration). Net primary production (Pn) is the amount of organic matter assimilated less than lost due to respiration, i.e., the total production available to other trophic levels or remains as stored chemical energy. Although production is expressed here in terms of the dry weight of organic matter, it can be expressed as any conserved quantity, e.g., carbon or energy. Pn=Pg−R (Roberts et al., 1985).

Exchangeable cations play a significant role in the soil ecosystem functioning. They can be exchanged by a cation of an added salt solution (Ramos et al., 2018). The exchange of the basic cations Ca_2+, Mg_2+, K+, and Na+ and the altered acidity, is primarily caused by the cations AI_3+and H+. In habitat conditions where the absence of additional $CaCO_3$, the cations Ca_2+, Mg_2+, and Na+ are exchangeable by NH_4OAc. The important difference might take place in certain conditions in which the vermiculites are present.

In the studied coal mine heaps, it has been reported that the admixture of vermiculites and montmorillonite is recorded. Exchangeable acidity is a crucial part of four types of acidity. The first considered and most frequently measured type is the H ions obtained from the hydrolysis (Ramos et al., 2018). Cation exchange in fully developed soils is a reversible chemical reaction. There are many methods available for the determination of cation-exchange capacity (CEC). Most of them are indicating the order of magnitude of exchange capacity.

In our study, the content of the Na+ and Ca+ was positively correlated with biomass of the individuals of the dominant species. Similarly, the available phosphorus reveals even more significant correlation to the biomass of the individuals of the dominant species. The cycling of carbon (C) is carefully observed, particularly in relation to increased N deposition (Cusack et al., 2011; Sinsabaugh et al., 2005). The phosphorus P dynamics, base cations, and soil acidification related to increased N deposition is less frequently studied. This is surprising because these soil parameters are good eco-chemical indicators for soil health and can be used also to assess the damage from soil acidification (Binkley et al., 1999; Futa and Mocek-Płóciniak, 2016; Małek and Astel, 2009). The soil development, and the soil chemical properties, such as soil acidity and exchangeable cations are dependent on the herb and tree plant species

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composition in the vegetation communities (Binkley and Giardina, 1998; Rhoades, 1996), and vice versa the changes in the local and global environment and habitat conditions may significantly influence the composition and diversity of plants communities (Bardgett et al., 2005). The study conducted in frosts has revealed that the pH and basic cation saturation (BS%) can be significantly decreased as a result of the N addition. The effective acidity (EA; EA [mmol kg^{-1}] = Al_3+ + H+), is recorded to be increased with the N addition (Shi et al., 2016; Zarif et al., 2020). The study conducted in forests revealed that the exchangeable soil cations like K+, Ca_2+, and Mg_2+ were not significantly affected by the P additional input (Bolan, 1991). The increased P deposition significantly increased the total soil exchangeable base cations by 60% (Yang et al., 2015).

References

[1] Aber J.D., Nadelhoffer K.J., Steudler P., Melillo, J.M., 1989. Nitrogen Saturation in Northern Forest EcosystemsExcess nitrogen from fossil fuel combustion may stress the biosphere. Bioscience 39, 378–386. https://doi.org/10.2307/1311067

[2] Aerts R., 1999. Interspecific competition in natural plant communities: mechanisms, trade-offs and plant-soil feedbacks. J Exp Bot 50, 29–37. https://doi.org/10.1093/JXB/50.330.29

[3] Ali A., Lin S.L., He J.K., Kong F.M., Yu J.H., Jiang H.S., 2019. Tree crown complementarity links positive functional diversity and aboveground biomass along large-scale ecological gradients in tropical forests. Sci Total Environ 656, 45–54. https://doi.org/10.1016/J.SCITOTENV.2018.11.342

[4] Ali A., Sanaei A., Nalivan O.A., Ahmadaali K., Pour M.J., Valipour A., Karami J., Aminpour M., Kaboli H., Askari Y., 2020. Environmental filtering, predominance of strong competitor trees and exclusion of moderate-weak competitor trees shape species richness and biomass. Science of The Total Environment 723, 138105. https://doi.org/10.1016/J.SCITOTENV.2020.138105

[5] Ali A., Yan E.R., 2017. The forest strata-dependent relationship between biodiversity and aboveground biomass within a subtropical forest. For Ecol Manage 401, 125–134. https://doi.org/10.1016/J.FORECO.2017.06.056

[6] Aragão A., Jacobs S., Cliquet A., 2016. What's law got to do with it? Why environmental justice is essential to ecosystem service valuation. Ecosyst Serv 22, 221–227. https://doi.org/10.1016/J.ECOSER.2016.09.012

[7] Band N., Kadmon R., Mandel M., DeMalach N., 2022. Assessing the roles of nitrogen, biomass, and niche dimensionality as drivers of species loss in grassland communities. Proc Natl Acad Sci U S A 119, e2112010119. https://doi.org/10.1073/PNAS.2112010119/SUPPL_FILE/PNAS.2112010119.SAPP.PDF

[8] Baral H., Guariguata M.R., Keenan R.J., 2016. A proposed framework for assessing ecosystem goods and services from planted forests. Ecosyst Serv 22, 260–268. https://doi.org/10.1016/J.ECOSER.2016.10.002

[9] Barberán A., Casamayor E.O., 2010. Global phylogenetic community structure and β-diversity patterns in surface bacterioplankton metacommunities. Aquatic Microbial Ecology 59, 1–10. https://doi.org/10.3354/AME01389

[10] Bardgett R.D., Bowman W.D., Kaufmann R., Schmidt S.K., 2005. A temporal approach to linking aboveground and belowground ecology. Trends Ecol Evol 20, 634–641. https://doi.org/10.1016/J.TREE.2005.08.005

[11] Bark R.H., Colloff M.J., Hatton MacDonald, D., Pollino C.A., Jackson S., Crossman N.D., 2016. Integrated valuation of ecosystem services obtained from restoring water to the environment in a major regulated river basin. Ecosyst Serv 22, 381–391. https://doi.org/10.1016/j.ecoser.2016.08.002

[12] Bell G., 2001. Neutral Macroecology. Science (1979) 293, 2413–2418. https://doi.org/10.1126/SCIENCE.293.5539.2413

[13] Berg C.E., Mineau M.M., Rogers S.H., 2016. Examining the ecosystem service of nutrient removal in a coastal watershed. https://doi.org/10.1016/j.ecoser.2016.06.007

[14] Bierza W., Czarnecka J., Błońska A., Kompała-Bąba A., Hutniczak A., Jendrzejek B., Bakr J., Jagodziński A.M., Prostański D., Woźniak G., 2023. Plant Diversity and Species Composition in Relation to Soil Enzymatic Activity in the Novel Ecosystems of Urban–Industrial Landscapes. Sustainability 2023, Vol. 15, Page 7284 15, 7284. https://doi.org/10.3390/SU15097284

[15] Binkley D., Burnham H., Lee Allen H., 1999. Water quality impacts of forest fertilization with nitrogen and phosphorus. For Ecol Manage 121, 191–213. https://doi.org/10.1016/S0378-1127(98)00549-0

[16] Binkley D., Giardina C., 1998. Why do Tree Species Affect Soils? The Warp and Woof of Tree-soil Interactions. Biogeochemistry 1998 42:1 42, 89–106. https://doi.org/10.1023/A:1005948126251

[17] Błońska A., Kompałła-Baba A., Sierka E., Bierza W., Magurno F., Besenyei L., Ryś K., Woźniak G., 2019a. 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, 209–217. https://doi.org/10.12911/22998993/93870

[18] Błońska A., Kompałła-Baba A., Sierka E., Bierza W., Magurno F., Besenyei L., Ryś K., Woźniak G., 2019b. 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, 209–217. https://doi.org/10.12911/22998993/93870

[19] Bobbink R., Hicks K., Galloway J., Spranger T., Alkemade R., Ashmore M., Bustamante M., Cinderby S., Davidson E., Dentener F., Emmett B., Erisman J.-W., Fenn M., Gilliam F., Nordin A., Pardo L., De Vries, A.W., 2010. Global assessment of nitrogen deposition effects on terrestrial plant diversity: a synthesis. Ecological Applications 20, 30–59.

[20] Boet O., Arnan X., Retana J., 2020. The role of environmental vs. biotic filtering in the structure of European ant communities: A matter of trait type and spatial scale. PLoS One 15, e0228625. https://doi.org/10.1371/JOURNAL.PONE.0228625

[21] Bolan N.S., 1991. A critical review on the role of mycorrhizal fungi in the uptake of phosphorus by plants. Plant Soil 134, 189–207. https://doi.org/10.1007/BF00012037

[22] Bünemann E.K., 2015. Assessment of gross and net mineralization rates of soil organic phosphorus – A review. Soil Biol Biochem 89, 82–98. https://doi.org/10.1016/J.SOILBIO.2015.06.026

[23] Carroll I.T., Cardinale B.J., Nisbet R.M., 2012. Niche and fitness differences relate the maintenance of diversity to ecosystem function: reply. Ecology 93, 1487–1491. https://doi.org/10.1890/11-0792.1A

[24] Carroll I.T., Cardinale B.J., Nisbet R.M., 2011. Niche and fitness differences relate the maintenance of diversity to ecosystem function. Ecology 92, 1157–1165. https://doi.org/10.1890/10-0302.1

[25] Castellanos A.E., Llano-Sotelo J.M., Machado-Encinas L.I., López-Piña J.E., Romo-Leon J.R., Sardans J., Peñuelas J., 2018. Foliar C, N, and P stoichiometry characterize successful plant ecological strategies in the Sonoran Desert. Plant Ecol 219, 775–788. https://doi.org/10.1007/S11258-018-0833-3

[26] Caswell H., Reed F., Stephenson S.N., Werner P.A., 1973. Photosynthetic Pathways and Selective Herbivory: A Hypothesis. American Naturalist 107, 465–480. https://doi.org/10.1086/282851

[27] Ceulemans T., Merckx R., Hens M., Honnay O., 2013. Plant species loss from European semi-natural grasslands following nutrient enrichment –

is it nitrogen or is it phosphorus? Global Ecology and Biogeography 22, 73–82. https://doi.org/10.1111/J.1466-8238.2012.00771.X

[28] Chase J.M., Leibold M.A., 2004. Ecological Niches: Linking Classical and Contemporary Approaches. The University of Chicago Press, Chicago.

[29] Chen J., Bin Dong C.C., Yao X.D., Wang W., 2018. Effects of nitrogen addition on plant biomass and tissue elemental content in different degradation stages of temperate steppe in northern China. Journal of Plant Ecology 11, 730–739. https://doi.org/10.1093/JPE/RTX035

[30] Coã Teâ, L., Brown S., Pareâ D., Fyles J., Bauhus J., 2000. Dynamics of carbon and nitrogen mineralization in relation to stand type, stand age and soil texture in the boreal mixedwood. Soil Biol Biochem 32, 1079–1090.

[31] Colgan M.S., Asner G.P., 2014. Coexistence and environmental filtering of species-specific biomass in an African savanna. Ecology 95, 1579–1590. https://doi.org/10.1890/13-1160.1

[32] Cusack D.F., Silver W.L., Torn M.S., Burton S.D., Firestone M.K., 2011. Changes in microbial community characteristics and soil organic matter with nitrogen additions in two tropical forests. Ecology 92, 621–632. https://doi.org/10.1890/10-0459.1

[33] De Groot C.C., Marcelis L.F.M., Van Den Boogaard, R., Lambers, H., 2001. Growth and dry-mass partitioning in tomato as affected by phosphorus nutrition and light. Plant Cell Environ 24, 1309–1317. https://doi.org/10.1046/J.0016-8025.2001.00788.X

[34] DeMalach N., Kadmon R., 2017. Light competition explains diversity decline better than niche dimensionality. Funct Ecol 31, 1834–1838. https://doi.org/10.1111/1365-2435.12841

[35] Devercelli M., 2009. Changes in phytoplankton morpho-functional groups induced by extreme hydroclimatic events in the Middle Paraná River (Argentina). Hydrobiologia 639, 5–19.

[36] Dickson T.L., Foster B.L., 2011. Fertilization decreases plant biodiversity even when light is not limiting. Ecol Lett 14, 380–388. https://doi.org/10.1111/J.1461-0248.2011.01599.X

[37] Dini-Andreote F., Stegen J.C., Van Elsas J.D., Salles J.F., 2015. Disentangling mechanisms that mediate the balance between stochastic and deterministic processes in microbial succession. Proc Natl Acad Sci U S A 112, E1326–E1332. https://doi.org/10.1073/PNAS.1414261112

[38] Eberwein J., Shen W., Jenerette G.D., 2017. Michaelis-Menten kinetics of soil respiration feedbacks to nitrogen deposition and climate change in subtropical forests. Sci Rep 7. https://doi.org/10.1038/S41598-017-01941-8

[39] Emery S.M., 2007. Limiting similarity between invaders and dominant species in herbaceous plant communities? Journal of Ecology. https://doi.org/10.1111/j.1365-2745.2007.01274.x

[40] Enquist B.J., Niklas K.J., 2001. Invariant scaling relations across tree-dominated communities. Nature 410, 655–660.

[41] Fahey T.J., Yavitt J.B., Sherman R.E., Maerz J.C., Groffman P.M., Fisk M.C., Bohlen P.J., 2013. Earthworm effects on the incorporation of litter C and N into soil organic matter in a sugar maple forest. Ecological Applications 23, 1185–1201. https://doi.org/10.1890/12-1760.1

[42] Falkengren-Grerup U., Brunet J., Diekmann M., 1998. Nitrogen mineralisation in deciduous forest soils in south Sweden in gradients of soil acidity and deposition. Environmental Pollution 102, 415–420. https://doi.org/10.1016/S0269-7491(98)80062-6

[43] Fodelianakis S., Lorz A., Valenzuela-Cuevas A., Barozzi A., Booth J.M., Daffonchio D., 2019. Dispersal homogenizes communities via immigration even at low rates in a simplified synthetic bacterial metacommunity. Nat Commun 10, 1314–1314. https://doi.org/10.1038/S41467-019-09306-7

[44] Franzke A., Reinhold K., 2011. Stressing food plants by altering water availability affects grasshopper performance. Ecosphere 2, 1–13. https://doi.org/10.1890/ES11-00095.1

[45] Franzluebbers A.J., Haney R.L., Hons F.M., Zuberer D.A., 1996. Active fractions of organic matter in soils with different texture. Soil Biol Biochem 28, 1367–1372.

[46] Frouz J., 2018. Effects of soil macro- and mesofauna on litter decomposition and soil organic matter stabilization. Geoderma 332, 161–172. https://doi.org/10.1016/J.GEODERMA.2017.08.039

[47] Frouz J., Prach K., Pižl V., Háněl L., Starý J., Tajovský K., Materna J., Balík V., Kalčík J., Řehounková K., 2008. Interactions between soil development, vegetation and soil fauna during spontaneous succession in post mining sites. Eur J Soil Biol 44, 109–121. https://doi.org/10.1016/J.EJSOBI.2007.09.002

[48] Futa B., Mocek-Płóciniak A., 2016. The influence of uncontrolled grass burning on biochemical qualities of soil. Journal of Research and Applications in Agricultural Engineering Vol. 61.

[49] Gerhold P., Cahill J.F., Winter M., Bartish I. V., Prinzing A., 2015. Phylogenetic patterns are not proxies of community assembly mechanisms (they are far better). Funct Ecol 29, 600–614. https://doi.org/10.1111/1365-2435.12425

[50] Giardina C.P., Ryan M.G., Hubbard R.M., Binkley D., 2001. Tree Species and Soil Textural Controls on Carbon and Nitrogen Mineralization Rates. Soil Science Society of America Journal 65, 1272–1279. https://doi.org/10.2136/SSSAJ2001.6541272X

[51] Gilbert B., 2012. Joint consequences of dispersal and niche overlap on local diversity and resource use. Journal of Ecology 100, 287–296. https://doi.org/10.1111/J.1365-2745.2011.01908.X

[52] Goberna M., Navarro-Cano J.A., Valiente-Banuet A., García C., Verdú M., 2014. Abiotic stress tolerance and competition-related traits underlie phylogenetic clustering in soil bacterial communities. Ecol Lett 17, 1191–1201. https://doi.org/10.1111/ELE.12341

[53] 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., 2016. Integrative modelling reveals mechanisms linking productivity and plant species richness. Nature 529, 390–393. https://doi.org/10.1038/NATURE16524

[54] Graham E.B., Knelman J.E., Schindlbacher A., Siciliano S., Breulmann M., Yannarell A., Beman J.M., Abell G., Philippot L., Prosser J., Foulquier A., Yuste J.C., Glanville H.C., Jones D.L., Angel R., Salminen J., Newton R.J., Bürgmann H., Ingram L.J., Hamer U., Siljanen H.M.P., Peltoniemi K., Potthast K., Bañeras L., Hartmann M., Banerjee S., Yu R.Q., Nogaro G., Richter A., Koranda M., Castle S.C., Goberna M., Song B., Chatterjee A., Nunes O.C., Lopes A.R., Cao, Y., Kaisermann A., Hallin S., Strickland M.S., Garcia-Pausas J., Barba J., Kang H., Isobe K., Papaspyrou S., Pastorelli R., Lagomarsino A., Lindström E.S., Basiliko N., Nemergut D.R., 2016. Microbes as engines of ecosystem function: When does community structure enhance predictions of ecosystem processes? Front Microbiol 7, 181167. https://doi.org/10.3389/FMICB.2016.00214/BIBTEX

[55] Grant K., Kreyling J., Dienstbach L.F.H., Beierkuhnlein C., Jentsch A., 2014. Water stress due to increased intra-annual precipitation variability reduced forage yield but raised forage quality of a temperate grassland. Agric Ecosyst Environ 186, 11–22. https://doi.org/10.1016/J.AGEE.2014.01.013

[56] Grime J.P., 1998. Benefits of plant diversity to ecosystems: immediate, filter and founder effects. Journal of Ecology 86, 902–910. https://doi.org/10.1046/J.1365-2745.1998.00306.X

[57] Grime J.P., 1973. Competitive Exclusion in Herbaceous Vegetation. Nature 242, 344–347. https://doi.org/10.1038/242344A0

[58] Grosberg R.K., Vermeij G.J., Wainwright P.C., 2012. Biodiversity in water and on land. Current Biology 22, R900–R903. https://doi.org/10.1016/J.CUB.2012.09.050

[59] Gutbrodt B., Mody K., Dorn S., 2011. Drought changes plant chemistry and causes contrasting responses in lepidopteran herbivores. Oikos 120, 1732–1740. https://doi.org/10.1111/J.1600-0706.2011.19558.X

[60] Harpole W.S., Sullivan L.L., Lind E.M., Firn J., Adler P.B., Borer E.T., Chase J., Fay P.A., Hautier Y., Hillebrand H., MacDougall A.S., Seabloom E.W., Bakker J.D., Cadotte M.W., Chaneton E.J., Chu C., Hagenah N., Kirkman K., La Pierre K.J., Moore J.L., Morgan J.W., Prober S.M., Risch A.C., Schuetz M., Stevens C.J., 2017. Out of the shadows: multiple nutrient limitations drive relationships among biomass, light and plant diversity. Funct Ecol 31, 1839–1846. https://doi.org/10.1111/1365-2435.12967

[61] Hassink J., 1997. The capacity of soils to preserve organic C and N by their association with clay and silt particles. Plant Soil 191, 77–87. https://doi.org/10.1023/A:1004213929699/METRICS

[62] Hautier Y., Niklaus P.A., Hector A., 2009. Competition for light causes plant biodiversity loss after eutrophication. Science (1979) 324, 636–638. https://doi.org/10.1126/SCIENCE.1169640/SUPPL_FILE/HAUTIER.SOM.PDF

[63] Heisler-White J.L., Blair J.M., Kelly E.F., Harmoney K., Knapp A.K., 2009. Contingent productivity responses to more extreme rainfall regimes across a grassland biome. Glob Chang Biol 15, 2894–2904.

[64] Helfenstein J., Jegminat J., McLaren T.I., Frossard E., 2018a. Soil solution phosphorus turnover: Derivation, interpretation, and insights from a global compilation of isotope exchange kinetic studies. Biogeosciences 15, 105–114. https://doi.org/10.5194/BG-15-105-2018

[65] Helfenstein J., Pistocchi C., Oberson A., Tamburini F., Goll D.S., Frossard E., 2020. Estimates of mean residence times of phosphorus in commonly considered inorganic soil phosphorus pools. Biogeosciences 17, 441–454. https://doi.org/10.5194/BG-17-441-2020

[66] Helfenstein J., Tamburini F., von Sperber C., Massey M.S., Pistocchi C., Chadwick O.A., Vitousek P.M., Kretzschmar R., Frossard E., 2018b. Combining spectroscopic and isotopic techniques gives a dynamic view of phosphorus cycling in soil. Nature Communications 2018 9:1 9, 1–9. https://doi.org/10.1038/s41467-018-05731-2

[67] Helingerová M., Frouz J., Šantrůčková H., 2010. Microbial activity in reclaimed and unreclaimed post-mining sites near Sokolov (Czech Republic). Ecol Eng 36, 768–776. https://doi.org/10.1016/J.ECOLENG.2010.01.007

[68] 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., 2006. Novel ecosystems: Theoretical and management aspects of the new ecological world order. Global Ecology and Biogeography 15, 1–7. https://doi.org/10.1111/J.1466-822X.2006.00212.X

[69] Homeier J., Hertel D., Camenzind T., Cumbicus N.L., Maraun M., Martinson G.O., Poma L.N., Rillig M.C., Sandmann D., Scheu S., Veldkamp E., Wilcke W., Wullaert H., Leuschner C., 2012. Tropical Andean Forests Are Highly Susceptible to Nutrient Inputs—Rapid Effects of Experimental N and P Addition to an Ecuadorian Montane Forest. PLoS One 7, e47128. https://doi.org/10.1371/JOURNAL.PONE.0047128

[70] Hou E., Luo Y., Kuang Y., Chen C., Lu X., Jiang L., Luo X., Wen D., 2020. Global meta-analysis shows pervasive phosphorus limitation of aboveground plant production in natural terrestrial ecosystems. Nature Communications 2020 11:1 11, 1–9. https://doi.org/10.1038/s41467-020-14492-w

[71] Hubbell S.P., 2001. The Unified Neutral Theory of Biodiversity and Biogeography. Princeton University Press, Princeton.

[72] Huber P., Metz S., Unrein F., Mayora G., Sarmento H., Devercelli M., 2020. Environmental heterogeneity determines the ecological processes that govern bacterial metacommunity assembly in a floodplain river system. ISME J 14, 2951. https://doi.org/10.1038/S41396-020-0723-2

[73] Isabwe A., Ren K., Wang Y., Peng F., Chen H., Yang J., 2019. Community Assembly Mechanisms Underlying the Core and Random Bacterioplankton and Microeukaryotes in a River–Reservoir System. Water 2019, Vol. 11, Page 1127 11, 1127. https://doi.org/10.3390/W11061127

[74] Jacobs S., Dendoncker N., Martín-López B., Barton D.N., Gomez-Baggethun E., Boeraeve F., McGrath F.L., Vierikko K., Geneletti D., Sevecke K.J., Pipart N., Primmer E., Mederly P., Schmidt S., Aragão A., Baral H., Bark R.H., Briceno T., Brogna D., Cabral P., De Vreese R., Liquete C., Mueller H., Peh K.S.H., Phelan A., Rincón A.R.,

Rogers S.H., Turkelboom F., Van Reeth W., van Zanten B.T., Wam H.K., Washbourn C.L., 2016. A new valuation school: Integrating diverse values of nature in resource and land use decisions. Ecosyst Serv 22, 213–220. https://doi.org/10.1016/J.ECOSER.2016.11.007

[75] Jamieson M.A., Trowbridge A.M., Raffa K.F., Lindroth R.L., 2012. Consequences of climate warming and altered precipitation patterns for plant-insect and multitrophic interactions. Plant Physiol 160, 1719–1727. https://doi.org/10.1104/PP.112.206524

[76] Jenkinson D.S., 1990. The turnover of organic carbon and nitrogen in soil. Philos Trans R Soc Lond B Biol Sci 329, 361–368. https://doi.org/10.1098/RSTB.1990.0177

[77] Jiao S., Yang Y., Xu Y., Zhang J., Lu Y., 2020. Balance between community assembly processes mediates species coexistence in agricultural soil microbiomes across eastern China. ISME J 14, 202. https://doi.org/10.1038/S41396-019-0522-9

[78] Keith S.A., Newton A.C., Herbert R.J.H., Morecroft, M.D., Bealey, C.E., 2009. Non-analogous community formation in response to climate change. J Nat Conserv 17, 228–235.

[79] Knapp A.K., Fay P.A., Blair J.M., Collins S.L., Smith M.D., Carlisle J.D., Harper C.W., Danner B.T., Lett M.S., McCarron J.K., 2002. Rainfall variability, carbon cycling, and plant species diversity in a mesic grassland. Science 298, 2202–2205. https://doi.org/10.1126/SCIENCE.1076347

[80] Kompała-Bąba A., Bierza W., Błońska A., Sierka E., Magurno F., Chmura D., Besenyei L., Radosz Ł., Woźniak G., 2019. Vegetation diversity on coal mine spoil heaps – how important is the texture of the soil substrate? Biologia (Bratisl) 74, 419–436. https://doi.org/10.2478/S11756-019-00218-X/TABLES/3

[81] Kowarik I., 2011. Novel urban ecosystems, biodiversity, and conservation. Environ Pollut 159, 1974–1983. https://doi.org/10.1016/J.ENVPOL.2011.02.022

[82] Kraft N.J.B., Ackerly D.D., 2010. Functional trait and phylogenetic tests of community assembly across spatial scales in an Amazonian Forest. Ecol Monogr 80, 401–422. https://doi.org/10.1890/09-1672.1

[83] Kraft N.J.B., Valencia R., Ackerly D.D., 2008. Functional traits and niche-based tree community assembly in an Amazonian Forest. Science 322, 580–582. https://doi.org/10.1126/SCIENCE.1160662

[84] Lamb E.G., Kembel S.W., Cahill J.F., 2009. Shoot, but not root, competition reduces community diversity in experimental

mesocosms. Journal of Ecology 97, 155–163. https://doi.org/10.1111/J.1365-2745.2008.01454.X

[85] Lamošová T., Doležal J., Lanta V., Lepš J., Lamošová T., Doležal J., Lanta V., Lepš J., 2010. Spatial pattern affects diversity-productivity relationships in experimental meadow communities. Acta oecologica 36, 325–332. https://doi.org/10.1016/J.ACTAO.2010.02.005

[86] Lane A., Jarvis A., 2007. Changes in climate will modify the geography of crop suitability: agricultural biodiversity can help with adaptation. SAT eJournal.

[87] Laux M., Torgan L.C., 2015. Which metric to choose? Differences between abundance and biomass responses to environmental conditions in a planktonic diatom community. Hydrobiologia 744, 63–76. https://doi.org/10.1007/S10750-014-2056-5/METRICS

[88] LeBauer D.S., Treseder K.K., 2008. NITROGEN LIMITATION OF NET PRIMARY PRODUCTIVITY IN TERRESTRIAL ECOSYSTEMS IS GLOBALLY DISTRIBUTED. Ecology 89, 371–379. https://doi.org/10.1890/06-2057.1

[89] Lindström E.S., Langenheder S., 2012. Local and regional factors influencing bacterial community assembly. Environ Microbiol Rep 4, 1–9. https://doi.org/10.1111/J.1758-2229.2011.00257.X

[90] Liu J., Zhu S., Liu X., Yao P., Ge T., Zhang X.H., 2020. Spatiotemporal dynamics of the archaeal community in coastal sediments: assembly process and co-occurrence relationship. ISME J 14, 1463–1478. https://doi.org/10.1038/S41396-020-0621-7

[91] Looney C.E., D'amato A.W., Fraver S., Palik B.J., Reinikainen M.R., Looney C., 2016. Examining the influences of tree-to-tree competition and climate on size-growth relationships in hydric, multi-aged Fraxinus nigra stands.

[92] Lowe W.H., McPeek M.A., 2014. Is dispersal neutral? Trends Ecol Evol 29, 444–450. https://doi.org/10.1016/J.TREE.2014.05.009

[93] Lu X., Mao Q., Gilliam F.S., Luo Y., Mo J., 2014. Nitrogen deposition contributes to soil acidification in tropical ecosystems. Glob Chang Biol 20, 3790–3801. https://doi.org/10.1111/GCB.12665

[94] Lu X.K., Mo J.M., Gundersern P., Zhu W.X., Zhou, G.Y., Li D.J., Zhang X., 2009. Effect of Simulated N Deposition on Soil Exchangeable Cations in Three Forest Types of Subtropical China. Pedosphere 19, 189–198. https://doi.org/10.1016/S1002-0160(09)60108-9

[95] Lucas R.W., Klaminder J., Futter M.N., Bishop K.H., Egnell G., Laudon H., Högberg P., 2011. A meta-analysis of the effects of nitrogen additions on base cations: Implications for plants, soils, and streams. For Ecol Manage 262, 95–104. https://doi.org/10.1016/J.FORECO.2011.03.018

[96] Lutz J.A., Furniss T.J., Johnson D.J., Davies S.J., Allen D., Alonso A., Anderson-Teixeira K.J., Andrade A., Baltzer J., Becker K.M.L., Blomdahl E.M., Bourg N.A., Bunyavejchewin S., Burslem D.F.R.P., Cansler C.A., Cao K., Cao M., Cárdenas D., Chang L.W., Chao K.J., Chao W.C., Chiang J.M., Chu C., Chuyong G.B., Clay K., Condit R., Cordell S., Dattaraja H.S., Duque A., Ewango C.E.N., Fischer G.A., Fletcher C., Freund J.A., Giardina C., Germain S.J., Gilbert G.S., Hao Z., Hart T., Hau B.C.H., He F., Hector A., Howe R.W., Hsieh C.F., Hu Y.H., Hubbell S.P., Inman-Narahari F.M., Itoh A., Janík D., Kassim A.R., Kenfack D., Korte L., Král K., Larson A.J., Li Y., De Lin Y., Liu S., Lum S., Ma K., Makana J.R., Malhi Y., McMahon S.M., McShea W.J., Memiaghe H.R., Mi X., Morecroft M., Musili P.M., Myers J.A., Novotny V., de Oliveira A., Ong P., Orwig D.A., Ostertag R., Parker G.G., Patankar R., Phillips R.P., Reynolds G., Sack L., Song G.Z.M., Su S.H., Sukumar R., Sun I.F., Suresh H.S., Swanson M.E., Tan S., Thomas D.W., Thompson J., Uriarte M., Valencia R., Vicentini A., Vrška T., Wang X., Weiblen G.D., Wolf A., Wu S.H., Xu H., Yamakura T., Yap S., Zimmerman J.K., 2018. Global importance of large-diameter trees. Global Ecology and Biogeography 27, 849–864. https://doi.org/10.1111/GEB.12747

[97] MacArthur R.H., Wilson E.O., 2001. The Theory of Island Biogeography, Nature. Princeton University Press, Woodstock.

[98] Małek S., Astel A., 2009. Sustainability of Picea abies of Istebna provenance in Dupniański Stream catchment as dependent on stand age class. Dendrobiology 155, 517–527. https://doi.org/10.1016/J.ENVPOL.2008.01.031

[99] Mao Q., Lu X., Zhou K., Chen H., Zhu X., Mori T., Mo J., 2016. Effects of long-term nitrogen and phosphorus additions on soil acidification in an N-rich tropical forest. https://doi.org/10.1016/j.geoderma.2016.09.017

[100] Martiny J.B.H., Bohannan B.J.M., Brown J.H., Colwell R.K., Fuhrman J.A., Green J.L., Horner-Devine M.C., Kane M., Krumins J.A., Kuske C.R., Morin P.J., Naeem S., Øvreås L., Reysenbach A.L., Smith V.H., Staley J.T., 2006. Microbial biogeography: putting microorganisms on the map. Nat Rev Microbiol 4, 102–112. https://doi.org/10.1038/NRMICRO1341

[101] Mattson W.J., Haack R.A., 1987. The Role of Drought in Outbreaks of Plant-eating Insects. BioScience 37(2):110-118 37, 110–118.

[102] McGill B.J., 2010. Towards a unification of unified theories of biodiversity. Ecol Lett 13, 627–642. https://doi.org/10.1111/J.1461-0248.2010.01449.X

[103] Mittler R., 2006. Abiotic stress, the field environment and stress combination. Trends Plant Sci 11, 15–19. https://doi.org/10.1016/J.TPLANTS.2005.11.002

[104] Müller T., Höper H., 2004. Soil organic matter turnover as a function of the soil clay content: consequences for model applications. Soil Biol Biochem 36, 877–888. https://doi.org/10.1016/J.SOILBIO.2003.12.015

[105] Nemergut D.R., Schmidt S.K., Fukami T., O'Neill S.P., Bilinski T.M., Stanish L.F., Knelman J.E., Darcy J.L., Lynch R.C., Wickey P., Ferrenberg S., 2013. Patterns and processes of microbial community assembly. Microbiol Mol Biol Rev 77, 342–356. https://doi.org/10.1128/MMBR.00051-12

[106] Newman E.I., 1973. Competition and Diversity in Herbaceous Vegetation. Nature 244, 310. https://doi.org/10.1038/244310A0

[107] Novák J., Prach K., 2003. Vegetation succession in basalt quarries: Pattern on a landscape scale. Appl Veg Sci 6, 111–116. https://doi.org/10.1111/J.1654-109X.2003.TB00570.X

[108] Oberson A., Joner E.J., 2005. Microbial turnover of phosphorus in soil. Organic phosphorus in the environment 133–164. https://doi.org/10.1079/9780851998220.0133

[109] Orwin K.H., Ostle N., Wilby A., Bardgett R.D., 2014. Effects of species evenness and dominant species identity on multiple ecosystem functions in model grassland communities. Oecologia 174, 979–992. https://doi.org/10.1007/S00442-013-2814-5

[110] Östman Ö., Drakare S., Kritzberg E.S., Langenheder S., Logue J.B., Lindström E.S., 2012. Importance of space and the local environment for linking local and regional abundances of microbes. Aquatic Microbial Ecology 67, 35-U158. https://doi.org/10.3354/AME01581

[111] Peltzer D.A., Bellingham P.J., Kurokawa H., Walker L.R., Wardle D.A., Yeates G.W., 2009. Punching above their weight: low-biomass non-native plant species alter soil properties during primary succession. Oikos 118, 1001–1014. https://doi.org/10.1111/J.1600-0706.2009.17244.X

[112] Peralta-Maraver I., Galloway J., Posselt M., Arnon S., Reiss J., Lewandowski J., Robertson A.L., 2018. Environmental filtering and community delineation in the streambed ecotone. Scientific Reports 2018 8:1 8, 1–11. https://doi.org/10.1038/s41598-018-34206-z

[113] Poorter L., van der Sande M.T., Thompson J., Arets E.J.M.M., Alarcón A., Álvarez-Sánchez J., Ascarrunz N., Balvanera P., Barajas-Guzmán G., Boit A., Bongers F., Carvalho F.A., Casanoves F., Cornejo-Tenorio G., Costa F.R.C., de Castilho C. V., Duivenvoorden J.F., Dutrieux L.P., Enquist B.J., Fernández-Méndez F., Finegan B., Gormley L.H.L., Healey J.R., Hoosbeek M.R., Ibarra-Manríquez G., Junqueira A.B., Levis C., Licona J.C., Lisboa L.S., Magnusson W.E., Martínez-Ramos M., Martínez-Yrizar A., Martorano L.G., Maskell L.C., Mazzei L., Meave J.A., Mora F., Muñoz R., Nytch C., Pansonato M.P., Parr T.W., Paz H., Pérez-García E.A., Rentería L.Y., Rodríguez-Velazquez J., Rozendaal D.M.A., Ruschel A.R., Sakschewski B., Salgado-Negret B., Schietti J., Simões M., Sinclair F.L., Souza P.F., Souza F.C., Stropp J., ter Steege H., Swenson N.G., Thonicke K., Toledo M., Uriarte M., van der Hout P., Walker P., Zamora N., Peña-Claros M., 2015. Diversity enhances carbon storage in tropical forests. Global Ecology and Biogeography 24, 1314–1328. https://doi.org/10.1111/GEB.12364

[114] Prach K., Pyšek P., 1999. How do species dominating in succession differ from others? Journal of Vegetation Science 10, 383–392. https://doi.org/10.2307/3237067

[115] Prach K., Walker L.R., 2020. Comparative plant succession among terrestrial biomes of the world.

[116] Prado-Junior J.A., Schiavini I., Vale V.S., Arantes C.S., van der Sande M.T., Lohbeck M., Poorter L., 2016. Conservative species drive biomass productivity in tropical dry forests. Journal of Ecology 104, 817–827. https://doi.org/10.1111/1365-2745.12543

[117] Rahmonov O., Czajka A., Nádudvari Á., Fajer M., Spórna T., Szypuła B., 2022. Soil and Vegetation Development on Coal-Waste Dump in Southern Poland. Int J Environ Res Public Health 19, 9167. https://doi.org/10.3390/IJERPH19159167/S1

[118] Rahmonov O., Pukowiec-Kurda K., Banaszek J., Brom K., 2020. Floristic diversity in selected city parks in southern Poland. Ochrona Srodowiska i Zasobow Naturalnych 30, 8–17. https://doi.org/10.2478/OSZN-2019-0020

[119] Rajaniemi T.K., 2003. Explaining productivity-diversity relationships in plants. Oikos 101, 449–457. https://doi.org/10.1034/J.1600-0706.2003.12128.X

[120] Rajaniemi T.K., Allison V.J., Goldberg D.E., 2003. Root competition can cause a decline in diversity with increased productivity. Journal of Ecology 91, 407–416. https://doi.org/10.1046/J.1365-2745.2003.00768.X

[121] Ramos F.T., Dores E.F. de C., Weber O.L. dos S., Beber D.C., Campelo J.H., Maia J.C. de S., 2018. Soil organic matter doubles the cation exchange capacity of tropical soil under no-till farming in Brazil. J Sci Food Agric 98, 3595–3602. https://doi.org/10.1002/JSFA.8881

[122] Rawlik M., Kasprowicz M., Jagodziński A.M., 2018a. Differentiation of herb layer vascular flora in reclaimed areas depends on the species composition of forest stands. For Ecol Manage 409, 541–551. https://doi.org/10.1016/J.FORECO.2017.11.055

[123] Rawlik M., Kasprowicz M., Jagodziński A.M., Kaźmierowski C., Łukowiak R., Grzebisz W., 2018b. Canopy tree species determine herb layer biomass and species composition on a reclaimed mine spoil heap. Sci Total Environ 635, 1205–1214. https://doi.org/10.1016/J.SCITOTENV.2018.04.133

[124] Rhoades C.C., 1996. Single-tree influences on soil properties in agroforestry: Lessons from natural forest and savanna ecosystems. Agroforestry Systems 35, 71–94. https://doi.org/10.1007/BF02345330/METRICS

[125] Roberts M.J., Long S.P., Tieszen L.L., Beadle C.L., 1985. Measurement of plant biomass and net primary production. Techniques in Bioproductivity and Photosynthesis 1–19. https://doi.org/10.1016/B978-0-08-031999-5.50011-X

[126] Rodrigues A.C., Villa P.M., Ali A., Ferreira-Júnior W., Neri A.V., 2020. Fine-scale habitat differentiation shapes the composition, structure and aboveground biomass but not species richness of a tropical Atlantic Forest. J For Res (Harbin) 31, 1599–1611. https://doi.org/10.1007/S11676-019-00994-X/FIGURES/5

[127] Rosindell J., Hubbell S.P., Etienne R.S., 2011. The unified neutral theory of biodiversity and biogeography at age ten. Trends Ecol Evol 26, 340–348. https://doi.org/10.1016/J.TREE.2011.03.024

[128] Rosling A., Midgley M.G., Cheeke T., Urbina H., Fransson P., Phillips R.P., 2016. Phosphorus cycling in deciduous forest soil differs between stands dominated by ecto- and arbuscular mycorrhizal trees. New Phytologist 209, 1184–1195. https://doi.org/10.1111/NPH.13720

[129] Ruiz-González C., Niño-García J.P., del Giorgio P.A., 2015. Terrestrial origin of bacterial communities in complex boreal

freshwater networks. Ecol Lett 18, 1198–1206. https://doi.org/10.1111/ELE.12499

[130] Rundle, H.D., Nosil, P., 2005. Ecological speciation. Ecol Lett 8, 336–352. https://doi.org/10.1111/J.1461-0248.2004.00715.X

[131] Sala O.E., Chapin F.S., Armesto J.J., Berlow E., Bloomfield J., Dirzo R., Huber-Sanwald E., Huenneke L.F., Jackson R.B., Kinzig A., Leemans R., Lodge D.M., Mooney H.A., Oesterheld M., Poff N.L.R., Sykes M.T., Walker B.H., Walker M., Wall D.H., 2000. Global biodiversity scenarios for the year 2100. Science 287, 1770–1774. https://doi.org/10.1126/SCIENCE.287.5459.1770

[132] Schimel D.S., 1986. Carbon and nitrogen turnover in adjacent grassland and cropland ecosystems. Biogeochemistry 2, 345–357. https://doi.org/10.1007/BF02180325/METRICS

[133] Scott N.A., Cole C.V., Elliott E.T., Huffman S.A., 1996. Soil textural control on decomposition and soil organic matter dynamics. Soil Science Society of America Journal 60, 1102–1109. https://doi.org/10.2136/SSSAJ1996.03615995006000040020X

[134] Shi Z., Xu, X., Souza L., Wilcox K., Jiang L., Liang J., Xia J., Garciá-Palacios P., Luo Y., 2016. Dual mechanisms regulate ecosystem stability under decade-long warming and hay harvest. Nat Commun 7, 11973. https://doi.org/10.1038/NCOMMS11973

[135] Silvertown J., 2004. Plant coexistence and the niche. Trends Ecol Evol 19, 605–611. https://doi.org/10.1016/j.tree.2004.09.003

[136] Sinsabaugh R.L., Gallo M.E., Lauber C., Waldrop M.P., Zak D.R., 2005. Extracellular enzyme activities and soil organic matter dynamics for northern hardwood forests receiving simulated nitrogen deposition. Biogeochemistry 75, 201–215. https://doi.org/10.1007/S10533-004-7112-1/METRICS

[137] Six J., Elliott E.T., Paustian K., 2000. Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. Soil Biol Biochem 32, 2099–2103.

[138] Stegen J.C., Lin X., Fredrickson J.K., Chen X., Kennedy D.W., Murray, C.J., Rockhold, M.L., Konopka, A., 2013. Quantifying community assembly processes and identifying features that impose them. ISME J 7, 2069–2079. https://doi.org/10.1038/ISMEJ.2013.93

[139] Stegen J.C., Swenson N.G., Enquist B.J., White E.P., Phillips O.L., Jørgensen, P.M., Weiser, M.D., Monteagudo Mendoza, A., Núñez Vargas, P., 2011. Variation in above-ground forest biomass across

broad climatic gradients. Global Ecology and Biogeography 20, 744–754. https://doi.org/10.1111/J.1466-8238.2010.00645.X

[140] Stevens C.J., Duprè C., Dorland E., Gaudnik C., Gowing D.J.G., Bleeker, A., Diekmann, M., Alard, D., Bobbink, R., Fowler, D., Corcket, E., Mountford, J.O., Vandvik, V., Aarrestad, A., Muller, S., Dise, N.B., 2010. Nitrogen deposition threatens species richness of grasslands across Europe. Environmental Pollution 158, 2940–2945. https://doi.org/10.1016/j.envpol.2010.06.006

[141] Tafazoli M., Hojjati S.M., Jalilvand H., Lamersdorf N., 2019. Simulated Nitrogen Deposition Reduces the Concentration of Soil Base Cations in Acer velutinum Bioss. Plantation, North of Iran. J Soil Sci Plant Nutr 19, 440–449. https://doi.org/10.1007/S42729-019-00048-5

[142] Tilman D., 2004. Niche tradeoffs, neutrality, and community structure: a stochastic theory of resource competition, invasion, and community assembly. Proc Natl Acad Sci U S A 101, 10854–10861. https://doi.org/10.1073/PNAS.0403458101

[143] Tilman D., Reich P.B., Knops J., Wedin D., Mielke T., Lehman C., 2001. Diversity and productivity in a long-term grassland experiment. Science (1979) 294, 843–845. https://doi.org/10.1126/SCIENCE.1060391/SUPPL_FILE/1060391S2_THUMB.GIF

[144] Toledo D., Kreuter U.P., Sorice M.G., Taylor C.A., 2012. To Burn or Not to Burn: Ecological Restoration, Liability Concerns, and the Role of Prescribed Burning Associations. Rangelands 34, 18–23. https://doi.org/10.2111/RANGELANDS-D-11-00037.1

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

[146] Tscharntke T., Greiler H.J., 1995. Insect communities, grasses, and grasslands. Annu Rev Entomol 40, 535–558. https://doi.org/10.1146/ANNUREV.EN.40.010195.002535

[147] Vellend M., 2016. The Theory of Ecological Communities (MPB-57), The Theory of Ecological Communities (MPB-57). Princeton University Press, Princeton. https://doi.org/10.1515/9781400883790/HTML

[148] Vellend M., 2010. Conceptual synthesis in community ecology. Q Rev Biol 85, 183–206. https://doi.org/10.1086/652373

[149] Vellend Mark, Srivastava D.S., Anderson K.M., Brown C.D., Jankowski Jill E., Kleynhans Elizabeth J., Kraft Nathan J. B., Letaw Alathea D., Andrew A., Macdonald M., Maclean Janet E, Myers-Smith I.H., Norris A.R., Xue X., Vellend M, Anderson M., Jankowski J. E., Kleynhans E. J., Kraft N. J. B., Letaw A. D., Macdonald A.A.M., Maclean J. E., 2014. Assessing the relative importance of neutral stochasticity in ecological communities. Oikos 123, 1420–1430. https://doi.org/10.1111/oik.01493

[150] Vitousek P.M., Howarth R.W., 1991. Nitrogen limitation on land and in the sea: How can it occur? Biogeochemistry 13, 87–115. https://doi.org/10.1007/BF00002772/METRICS

[151] Vitousek P.M., Porder S., Houlton B.Z., Chadwick O.A., 2010. Terrestrial phosphorus limitation: Mechanisms, implications, and nitrogen-phosphorus interactions. Ecological Applications 20, 5–15. https://doi.org/10.1890/08-0127.1

[152] Walker T.W., Syers J.K., 1976. The fate of phosphorus during pedogenesis. Geoderma 15, 1–19. https://doi.org/10.1016/0016-7061(76)90066-5

[153] Wang J., Shen J., Wu Y., Tu C., Soininen J., Stegen J.C., He J., Liu X., Zhang L., Zhang E., 2013. Phylogenetic beta diversity in bacterial assemblages across ecosystems: deterministic versus stochastic processes. ISME J 7, 1310–1321. https://doi.org/10.1038/ISMEJ.2013.30

[154] Wang W.J., Dalal R.C., Moody P.W., Smith C.J., 2003. Relationships of soil respiration to microbial biomass, substrate availability and clay content. Soil Biol Biochem 2, 273–284.

[155] Washbourne C.L., Goddard M.A., Le Provost G., Manning D.A.C., Manning, P., 2020. Trade-offs and synergies in the ecosystem service demand of urban brownfield stakeholders. Ecosyst Serv 42, 101074. https://doi.org/10.1016/J.ECOSER.2020.101074

[156] Weiser J.N., Ferreira D.M., Paton J.C., 2018. Streptococcus pneumoniae: transmission, colonization and invasion. Nat Rev Microbiol 16, 355–367. https://doi.org/10.1038/S41579-018-0001-8

[157] West G.B., Enquist B.J., Brown J.H., 2009. A general quantitative theory of forest structure and dynamics. Proc Natl Acad Sci U S A 106, 7040–7045. https://doi.org/10.1073/PNAS.0812294106/SUPPL_FILE/0812294106SI.PDF

[158] White R., Murray S., Rohweder M., 2000. Pilot Analysis of global ecosystems: Grassland Ecosystems. World Resources InstituteWashington, DC.

[159] Widder S., Besemer K., Singer G.A., Ceola S., Bertuzzo E., Quince, C., Sloan, W.T., Rinaldo, A., Battin, T.J., 2014. Fluvial network organization imprints on microbial co-occurrence networks. Proc Natl Acad Sci U S A 111, 12799–12804. https://doi.org/10.1073/PNAS.1411723111

[160] Wilson D.S., 1992. Complex Interactions in Metacommunities, with Implications for Biodiversity and Higher Levels of Selection. Ecology 73, 1984–2000. https://doi.org/10.2307/1941449

[161] Woźniak G. (1964-)., 2010. Zróżnicowanie roślinności na zwałach pogórniczych Górnego Śląska = Diversity of vegetation on coal-mine heaps of the Upper Silesia (Poland). Instytut Botaniki im. W. Szafera. PAN. Dział Wydawnictw.

[162] Woźniak G., Chmura D., Małkowski E., Zieleźnik-Rusinowska P., Sitko K., Ziemer B., Błońska A., 2021. Is the Age of Novel Ecosystem the Factor Driving Arbuscular Mycorrhizal Colonization in Poa compressa and Calamagrostis epigejos? Plants (Basel) 10. https://doi.org/10.3390/PLANTS10050949

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

[164] Xu X., Sherry R.A., Niu S., Li D., Luo Y., 2013. Net primary productivity and rain-use efficiency as affected by warming, altered precipitation, and clipping in a mixed-grass prairie. Glob Chang Biol 19, 2753–2764. https://doi.org/10.1111/GCB.12248

[165] Yachi S., Loreau M., 2007. Does complementary resource use enhance ecosystem functioning? A model of light competition in plant communities. Ecol Lett 10, 54–62. https://doi.org/10.1111/J.1461-0248.2006.00994.X

[166] Yan E.-R., Yan E.-R., Wang X.-H., Wang X.-H., Huang J.-J., Huang J.-J., Li G.-Y., Li G.-Y., Zhou W., Zhou W., 2008. Decline of soil nitrogen mineralization and nitrification during forest conversion of evergreen broad-leaved forest to plantations in the subtropical area of Eastern China. Biogeochemistry 89, 239–251. https://doi.org/10.1007/S10533-008-9216-5

[167] Yang K., Zhu J., Gu J., Yu L., Wang, Z., 2015. Changes in soil phosphorus fractions after 9 years of continuous nitrogen addition in a Larix gmelinii plantation. Ann For Sci 72, 435–442. https://doi.org/10.1007/S13595-014-0444-7/TABLES/2

[168] Zalasiewicz J., Waters C.N., Ivar do Sul J.A., Corcoran P.L., Barnosky A.D., Cearreta A., Edgeworth M., Gałuszka A., Jeandel C., Leinfelder, R.,

McNeill J.R., Steffen W., Summerhayes C., Wagreich M., Williams M., Wolfe A.P., Yonan Y., 2016. The geological cycle of plastics and their use as a stratigraphic indicator of the Anthropocene. Anthropocene 13, 4–17. https://doi.org/10.1016/J.ANCENE.2016.01.002

[169] Zarif N., Khan A., Wang Q., 2020. Linking Soil Acidity to P Fractions and Exchangeable Base Cations under Increased N and P Fertilization of Mono and Mixed Plantations in Northeast China. Forests 2020, Vol. 11, Page 1274 11, 1274. https://doi.org/10.3390/F11121274

[170] Zhang H., Shi L., Fu S., 2020. Effects of nitrogen deposition and increased precipitation on soil phosphorus dynamics in a temperate forest. Geoderma 380, 114650. https://doi.org/10.1016/J.GEODERMA.2020.114650

[171] Zhang H., Shi L., Wen D., Yu K., 2016. Soil potential labile but not occluded phosphorus forms increase with forest succession. Biol Fertil Soils 52, 41–51. https://doi.org/10.1007/S00374-015-1053-9

[172] Zinger L., Amaral-Zettler L.A., Fuhrman J.A., Horner-Devine M.C., Huse S.M., Welch D.B.M., Martiny J.B.H., Sogin M., Boetius A., Ramette A., 2011. Global patterns of bacterial beta-diversity in seafloor and seawater ecosystems. PLoS One 6. https://doi.org/10.1371/JOURNAL.PONE.0024570

2.2. The relationship between abiotic conditions of the coal mine heaps and the soil respiration rates

The vegetation species composition including trees and herbaceous species along with the associated heterotroph species and saprotrophic organisms is strictly dependent on the habitat conditions. This general relationship is explained on the basis of ecology. The various factors that are responsible for the particular conditions in a habitat are characterized as environmental factors. One group of the biotic or living factors is related to other living organisms in the environment and include factors such as the symbiosis or competition between members of one or different species. In the other group, the abiotic conditions are non-living factors which are related to varied aspects of water, soil, light, texture, temperature etc. An intriguing approach is the concept of the niche, that refers to the “way of life as the role of a species in a community or the status or role of an organism in its habitat”. A niche can be explained using the example of a human population within a city. The niche can be identified in terms of the degree of use of resources, e.g., where the organism lives, what it eats, when it feeds.

In this way, the ecosystem process reflects the relations between the habitat conditions. In all the different ecosystem matter and energy flow functioning processes, soil respiration is a kind of proxy of various ecosystem processes that control terrestrial energy balance and element cycling (Chen and Chen, 2019; Luo and Zhou, 2006; Xiao et al., 2021). The soil respiration parameters are an integrated indicator of ecosystem functioning and consequently ecosystem services along all habitats. Soil respiration is one of the most important ecosystem processes responsible for carbon emissions in the form of CO_2. Carbon dioxide CO_2 is taken up by plants from the atmosphere and converted into organic compounds through photosynthesis. This process is an essential ecosystem service that is linked to natural processes in all ecosystems (Aragão et al., 2016; Baral et al., 2016; Bark et al., 2016; Washbourne et al., 2020).

Figure 2.2.1. The equipment used for the measurement of soil respiration and the assessment of the texture of soil or soil substrate

The release of CO_2 is one of the basic ecosystem functions. For the matter and energy flow, the organic matter transforms into the inorganic compounds. In this respect, soil respiration is a critical ecosystem process that releases carbon from the soil organic matter in the form of CO_2. Soil respiration is strictly related to the biochemistry of the vegetation species composition and later their biomass and the soil's physical-chemical parameters. The soil physical-chemical parameters influence the plants above and below the organ growth. In consequence, the microbial community is attracted by the plant root's exudates and the soil respiration components itself are dependent. In soil respiration, CO_2

release takes place due to the biological activity of soil organisms associated with the below-ground organs and the occurrence of soil organic matter (SOM). Soil respiration is a significant flux within the global carbon cycle process, releasing about ten times more carbon dioxide to the atmosphere annually than fossil fuel use for heating (Raich and Schlesinger, 1992; Bond-Lamberty and Thomson, 2010; Le Quéré et al., 2015).

Soil respiration is often affected by many factors. It is difficult to separate the interactions between the factors. Soil respiration, like many other physiological processes of plants and microbes, usually responds to the most limiting factor (Luo and Zhou, 2006). Soil respiration activity is defined as the process of carbon dioxide release by plant roots and microorganisms. The microorganisms are attracted by the particular plant species root exudates (Cerhanová and Nováková, 2006; Wolińska et al., 2014). It has been proven that the plant-microorganisms relation to be the most sensitive biological relation give response to anthropogenic intense activity like e.g., water regime change, agricultural practices, open-cast mining (Luo and Zhou, 2006; Wolińska, 2019; Wolińska et al., 2014). This is also the reason why soil respiration is a crucial ecosystem service, however not obvious at first glance.

Figure 2.2.2. The soil respiration chamber enables the measurement of the short-term value of the CO_2 release. Along with respiration rate, the measurement of temperature and moisture of the spot where the measurement has been taken. The respiration rate can be expected to be varied, in different vegetation communities assemblies

The impact of root respiration, soil water content, water uptake, and soil CO_2 concentrations on seedling's growth in varied soil mixtures in terms of their sand, silt, and clay ratios in controlled laboratory conditions in agriculture systems are subject to investigation. In strictly controlled agricultural experiments the crops (e.g., *Citrus*) are chosen for their root respiration rates which are relatively constant over a long period and not affected by short-term fluctuations in soil water content or soil CO_2 concentrations (Bouma et al., 1997a, 1997b; Bouma and Bryla, 2000) Several factors control the amount of soil respiration that occurs in an ecosystem. The moisture, temperature, nutrient content, and level of oxygen in the soil can result in different respiration rates. Human activity can primarily affect soil respiration rates, by changing the factors controlling soil respiration for numerous years. All of these factors can affect the rate of global soil respiration, such as increased nitrogen fertilization in agriculture, influencing the rates over large scales.

Among the respiration elements, the below-ground ones are more complicated. There are still many aspects unresolved (Bouma and Bryla, 2000). In the farmlands, the soil texture is reported to influence the soil respiration (Bouma et al., 1997a). The authors, studying agriculture lands, found that in fine sandy soil, changes in soil moisture could cause changes in present respiration rates. The soil CO_2 diffusion was reduced in wet conditions. This effect will be even greater in soils having finer texture and higher clay content, further complicating root respiration measurements. There is no detailed information available on how soil texture affects the estimates of root and soil respiration (Bouma and Bryla, 2000). Soil texture have effects on CO_2 in the soil. It is influenced by soil porosity. Small pores hold water well, while large interconnecting pores are needed for air and water to move between soil and atmosphere. Most research was focused on soil respiration in agriculture. Bouma and Bryla (2000) e.g., examined the dynamic relationship between CO_2 released during respiration and subsequent CO_2 flux from the soil surface for soils of different textures following wetting and drying cycles. An additional aim of Bouma and Bryla (2000) study was to examine the relationship between soil water content and soil CO_2 concentration in more detail because of growing interest in the effects of soil CO_2 concentration on root respiration. The other way round the soil CO_2 amount have been shown to affect microbial respiration rates (Koizumi et al., 1991) and the plant species root respiration rates (Bouma et al., 1997b, 1997a; Burton et al., 1997; Nobel and Palta, 1989; Palta and Nobel, 1989; QI et al., 1994; Scheurwater et al., 1998). As soil water relations are known to vary considerably depending on soil texture (Singer and Munns, 1991) the dynamics of CO_2 diffusion rates should also vary among different textured soils.

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Figure 2.2.3. The variety of abiotic conditions determines the spatiotemporal distribution of the spontaneous vegetation on the heap and in the surrounding

Among the abiotic conditions (e.g., micro-, macro-element, soil pH, nitrogen deposition soil texture, temperature, and moisture is considered to influence soil respiration, and interactively affect components of summarized total respiration R_{tot} (Fenn et al., 2010; Melillo et al., 2002; Mo et al., 2008; Xu and Qi, 2001; Heinemeyer et al., 2007). All the physiological processes, including soil respiration, usually respond most strongly to a few dominant environmental factors. Temperature affects almost every aspect of above and below-ground surface processes, including soil respiration (Atkin and Tjoelker, 2003; Moyano et al., 2008, 2007). Several types of models, including temperature-respiration models, are usually used to analyze the relationship between temperature and soil respiration (Davidson and Janssens, 2006; Zheng et al., 2009). Soil moisture in the extremes (low or high) also strongly influences soil respiration (Borken et al., 2003; Wang et al., 2003; Ilstedt et al., 2000). Abiotic factors, including soil pH, influence some aspects of the soil respiration parameters. The soil pH influences the activities of soil microorganisms, and later the RH (respiration of plant biomass, soil organic matter) (Ilstedt et al., 2000; Sitaula et al., 1995). SR affects soil respiration indirectly by influencing photosynthesis (Zhang et al., 2013). Most of the study are analyzing separately the role of abiotic environmental factors on soil respiration due to other factors. However, these factors do not act independently, may interact with each other and mutually affect soil respiration (Yu et al., 2015).

Figure 2.2.4. Apart from the commonly considered abiotic parameters, some less frequently analyzed can be very important. The AFM such as the new world fungi *Rhizoglomus silesianum* (the bottom picture), are dependent on the abiotic conditions and together with soil biotic parameters are influencing the above-ground part of the ecosystems

Novák and Prach, 2003). The vegetation growing on coal mine heaps consists of a mosaic of patches dominated by various species confined to a variety of microhabitats (Rawlik et al., 2018a, 2018b; Stefanowicz et al., 2015). This mosaic is reflecting the diversity of abiotic habitat conditions (Woźniak, 2010).

Figure 2.2.5. Apart from the vegetation patches dominated by the frequently occurring dominant species, sometimes less common species occur, colonizing the pure mineral material such as *Chenopodium boytrs*

Among the great diversity of vegetation types observed in early successional development in coalfields, some vegetation types are particularly common, including *Calamagrostis epigejos* and *Poa compressa*, and some very common grasses have been studied, including *Daucus carota* and *Tussilago farfara*. The dominant plant species are accompanied by high plant species richness with differences in cover and abundance (Woźniak, 2010). The impacts of early-successional vegetation stages on substrates of harsh site conditions are less well known (Emery and Kellogg, 2007; Woźniak, 2010; Lamošová et al., 2010; Orwin et al., 2014; Peltzer et al., 2009; Prach and Pyšek, 1999) and these studies have mostly been focused on the plant species composition that grows together with the dominant plants on a wide range of varied types of mineral material of post-industrial and post-mining sites.

Previous studies on factors regulating Rs and Q_{10} concentration mainly focused on soil temperature, humidity, root biomass and carbon and nitrogen nutrients (Arevalo et al., 2010; Wang et al., 2018). However, the relationships between R and soil microorganisms are poorly understood. Soil microorganisms are the main regulators of soil functions; thus, variations in soil microorganisms due to land use changes can have a significant impact on Rs (Xiao et al., 2021). Because of the extreme abiotic conditions of the mineral material of the coal mine heaps, it is intriguing how the abiotic habitat conditions influence the soil substrate respiration parameters in plant species composition of identified vegetation types in the coal mine heaps novel ecosystem. The soil respiration amount is a proxy for ecosystem functioning. While ecosystem functioning is the basis for the provision of each ecosystem service.

There are studies that aimed at analyzing the relationship between the abiotic conditions of the mineral material of coal mine heaps varied habitats, which are reflected by different spontaneous vegetation types, and the respiration rates of the soil substratum (Radosz et al., 2023 in press). The analysis of respiration rate of the soil substratum under different spontaneous vegetation types on coal mine heaps novel ecosystems in relation to the soil substratum parameters such as water content, the water holding capacity (WHC), texture of the soil substratum, acidity (pH), EC, basic abiotic - total nitrogen N_T, total carbon C_T, and exchangeable cations Mg, Ca, Na, K (acidity) has been performed (Radosz et al., 2023 in press).

In particular, in the study on the coal mine heaps (Radosz et al., 2023 in press) it has been tested which of the abiotic habitat parameters is influencing the soil substratum respiration amount most. The amount of C content has been expected to influence the soil substratum respiration on the coal mine heaps in the most significant way. While the other abiotic parameters such as texture of the soil substratum, the water holding capacity (WHC), pH, EC have been expected not to be significant factors influencing the biomass amount in the identified vegetation types (Radosz et al., (2023 in press).

Figure 2.2.6. Coal mine activity is transforming the landscape in the same way, providing many unusual habitats of a wide gradient of many different factors. At the very beginning, the environmental potential of those sites is not obvious and needs more detailed analysis

The coal mine heaps, or piles of Carboniferous waste rock, are areas with environmental conditions that are different from natural ones. They were created by man as a result of the exploitation of fossil fuels, and the dumped material comes from the depth of 0.5 to 1 km. The new anthropogenic forms are unique habitats because they are oligotrophic (very poor in nutrients, such as nitrogen, carbon, sulfur, and phosphorus, among others) mineral substrates, initially devoid of organic matter. This substrate has no developed soil profile, and the physical and chemical properties are significantly different from the surrounding environment. Due to difficult conditions, such heaps have been called biological deserts, where living organisms cannot develop. Over many years of research, it has been shown that despite unfavourable conditions, they are colonized by plants and animals (Woźniak, 2010; Radosz et al., 2019; Bierza et al., 2023).

For analyzing such complex filed work data, several methods can be used. Apart from the commonly used analysis in R language and environment ver. 4.2.2 (R Core Team 2022), the fuzzy set ordination (FSO; Boyce, 1998; Roberts, 1986; Ter Braak, 1987) to find environmental factors that are responsible for shaping vegetation is a good solution. The species individual responses to environmental factors are generally not limited to a certain function. The species individual responses can be, for example, nonlinear or discontinuous (Zaharescu et al., 2017). High correlation means effective ordination, in which environmental variables have a large effect on species composition (Roberts, 2008). The study was conducted by Radosz (et al., 2023 in press).

The SRL did not account for as much variation as those aforementioned ones. In the next analysis, acid phosphatase and pH in aqua were excluded because they are correlated with other variables. According to the Bioenv function the best model had 9 parameters (max. 13 allowed): pHKCl, NT, C, MgAV, Mg, K, WHC, Dehydrogenase, Urease and with correlation 0.20. The function excluded SRL either.

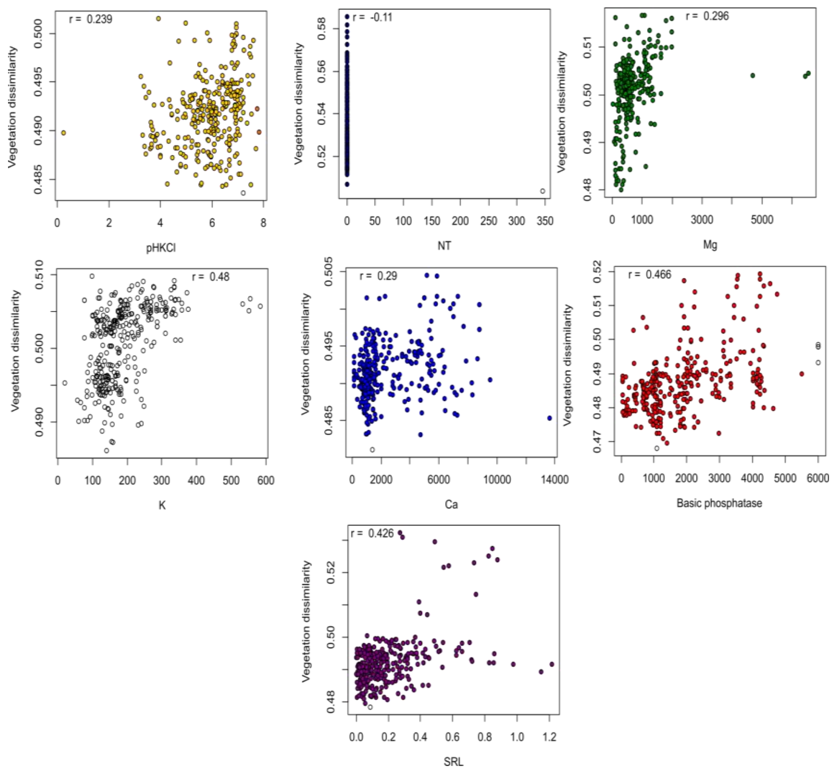

Figure 2.2.7. The relationship between SRL and particular soil variables and dissimilarity of vegetation based on fuzzy set ordination after Radosz (et al., 2023 in press)

In their study, Radosz (et al., 2023 in press) presented the relationship between biotic parameters of the soil substratum samples collected from dissimilar vegetation types. The FSO analysis revealed that all the studied environmental factors had a significantly different influence on the heap's soil substratum rate (p=0.001), except for total nitrogen, (p=0.893). The highest correlation was revealed by the content of potassium (K), basic phosphatase. The highest positive correlation was between SRL and total nitrogen, followed by pH while negative ones with magnesium and calcium Radosz (et al., 2023 in press).

In MFSO ordination between vegetation dissimilarity and ordination distance was relatively high, (r=0.748). According to the results of MFSO samples of vegetation, arranged by SRL, are mostly concentrated at lower values of soil respiration, but single vegetation plots are associated with higher values. In the case of pH, Ca and Mg samples are also arranged by another variable.

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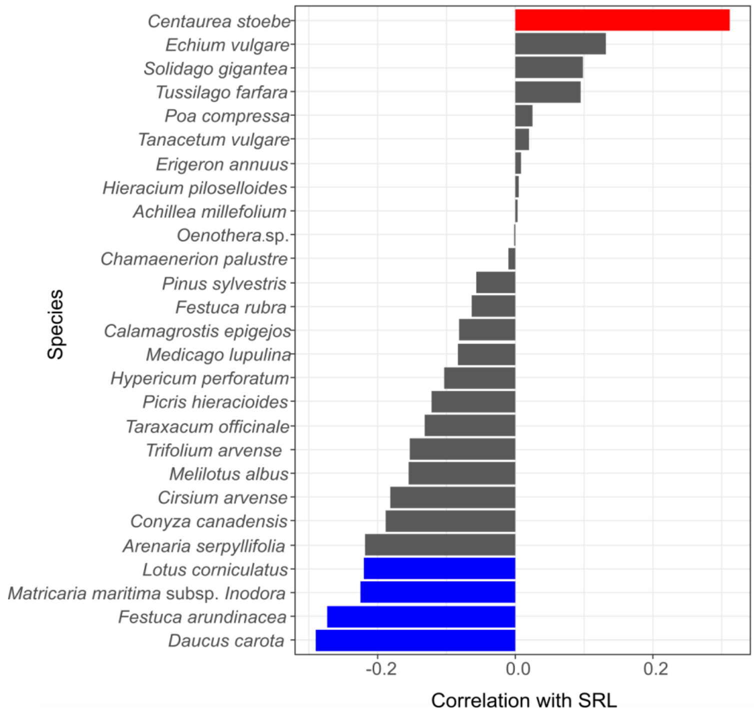

Figure 2.2.8. The Spearman correlation coefficient values on the basis of pairwise complete observations among most frequent species and soil respiration in coal mine heaps. Blue indicates significant negative correlations and red one – positive significant relationships after Radosz (et al., 2023 in press)

Among the spontaneous vegetation types dominated by 27 taxa, only the below-ground conditions provided by the vegetation communities dominated *Centaurea stoebe* were significantly correlated with the soil respiration level (SRL). The dominant plant species of three vegetation types caused the development of below-ground conditions that resulted in negative impact whereas the strongest negative correlation was demonstrated by abiotic below-ground conditions associated to the vegetation patches dominated by *Daucus carota* (Figure 2.2.8).

In the complex multi-spatial, vegetation, and environmental factors, data sets are necessary for explaining ecosystem functioning. Community ecology is interested in understanding the mechanisms ruling species spatial distribution patterns during community change. Ordination is used to quantify and study the species patterns in plant communities. Ordination methods use a set of multivariate techniques that reduce the multiple variables matrix in a community to a few dimensions. The reduced number of dimensions, preferably only three, reflect, hopefully, the most important patterns in the data set (Gauch, 1982;

Stöcker, 1990). In the direct gradient analysis (DGA) or constrained ordination, environmental gradients are recognized before the analysis is begun. These gradients are directly incorporated into the analyses (ter Braak and Verdonschot, 1995) and hypotheses can be precisely tested in the a priori manner (Legendre and Legendre, 2012). The most generally used DGA method is Canonical Correspondence Analysis (CCA) (ter Braak and Verdonschot, 1995).

The carbon (C) cycle rules the life

The carbon (C) cycle has received significant attention, but not always in relation and dependence on nitrogen, especially for increased N deposition (Cusack et al., 2011; Sinsabaugh et al., 2005). Carbon, nitrogen, and phosphorus cycles are closely linked in the soils of various ecosystems, especially in forest soils, and participate in the cycles of other nutrients that affect the composition and diversity of vegetation (Fahey et al., 2013). Forestry studies have shown the phenomenon of an increase in soil carbon content in plots with supplemental N (Zarif et al., 2020). This suggests that in forest ecosystems, and possibly in new mineral coal mine ecosystems in a similar way, the (subsoil) increases the uptake of available N by plants as carbon compounds and soil microbial activity produce it (Eberwein et al., 2017; Zarif et al., 2020).

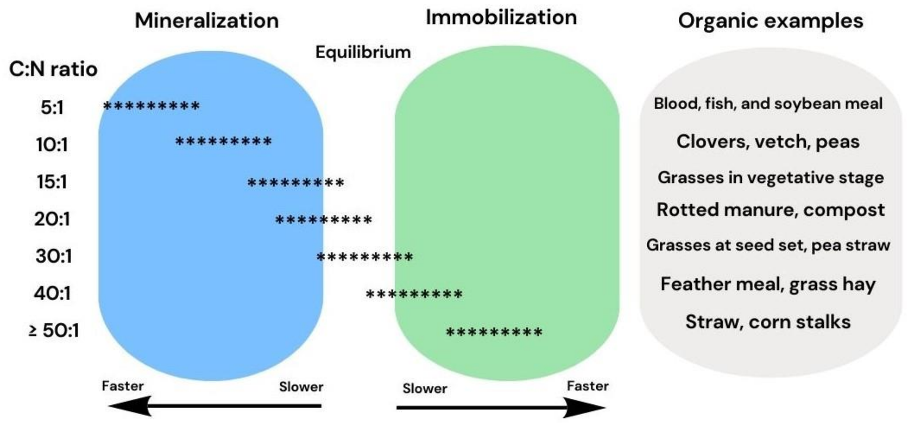

Figure 2.2.9. The C: N ratio in the soil vary over a range for any organic material and these values represent an average of the range. Mineralization: nitrogen is released for the plant uptake. Immobilisation: microbes utilise and reduce the nitrogen compounds amount in the soil or soil substratum

Additionally, the carbon content in our study has been assessed as the loss of ignition this might cause that the geogenic coal carbon could increase the real content of the carbon available for living organisms. The assumption that other

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abiotic factors will not be significant for the coal mine heaps respiration also appeared to be wrong. In our study some of the tested abiotic environmental factors were significant (p=0.001) except for total nitrogen (p=0.893) potassium (K), alkaline phosphatase, and SRL showed the highest correlation. The highest positive correlation was obtained between SRL and total nitrogen, followed by pH, while it was negative between magnesium and calcium.

The phosphorus content influencing the SRL

The phosphorus content in soil or soil substratum is to some extent related to the activity of the phosphatases. In our study, the alkaline phosphatase was related to the soil respiration amount. Phosphorus content in soil is known to primarily determine the proper development of the root system, and improve the rooting of plants and the biological activity of the soil, resulting in a better utilization of other soil abiotic mineral components. Chemically, phosphorus is a low-mobility element, available to plants only from the immediate vicinity of the roots, and its uptake is very dependent on soil pH and temperature. According to de Groot et al., (2020), the phosphorus (P) availability is related to N dynamics, as the P cycle is strongly connected with the N cycle (De Groot et al., 2001). The availability of P is considered to be a second limiting factor in forest ecosystems to that of available N (Aber et al., 1989). In our study, we chose the base phosphatase activity as a reference element for the analysed phosphorous soil content parameter. The study showed a positive correlation between base phosphatase activity and the amount of CO_2 released.

Nutrient availability is an important regulator of soil respiration. Human activity has significantly accelerated the supply of active nitrogen (N) and phosphorus (P), which increases the availability of nitrogen and phosphorus in the soils in general. However, most previous studies of soil respiration have focused on the effect of nitrogen rather than phosphorus or its interaction with nitrogen (Guo et al. 2016). The phosphorus forms vary and change dynamically in their availability to different living organisms (microbes and plants) (Helfenstein et al., 2020; Zhang and Zhang, 2016; Zhang et al., 2020). The mineral inorganic phosphorus (Pi) may be released in organic phosphorus (Po), along with the secondary mineral P (i.e., NaOH Pi) in different forms could contribute to soil P bioavailability (Helfenstein et al., 2020, 2018; Lambers et al., 2008; Oberson and Joner, 2004; Rosling et al., 2016). Along with these dynamics, the impact of the soil phosphorus on soil (or soil substratum) respiration will change. In the previous study, it has been shown that the phosphorus occurrence significantly increased the litter nitrogen and microbial biomass and reduced the nitrogen mineralization. In this way, the nitrate leach-down process and the release of nitrous oxide have been limited (Homeier et al., 2017). The study by Mao et al., (2017), also presented that the amount of total N was higher in the winter than summer in relation to the phosphorus soil content. The continuous N deposition e.g., from the atmosphere, is limiting the soil acidity, which would suggest that a buffering effect caused by the additional phosphorus keeps the soil pH stable (Mao et al., 2017; Yang et al., 2015; Zarif et al., 2020). What is a factor that stabilizes the soil respiration also in the developing ecosystems? What might be partially an explanation of the results obtained in our study on soil substratum respiration in different vegetation types?

Exchangeable cations and acidity in relation to SRLs

Exchangeable cations Ca^{2+} Mg^{2+} K^{+}, and Na^{+} play a significant role in the soil ecosystem functioning that can be exchanged by a cation of an added salt solution (Ramos et al., 2018). In our study the potassium K, magnesium Mg and calcium Ca content as well as the pH level in coal mine soil substratum are significantly related to the CO_2 release. The exchange of the basic cations $Ca^{2+,}$ $Mg^{2+,}$ K^{+}, and Na^{+} and the altered acidity is primarily caused by the cations AI^{3+} and H+. In the natural or seminatural habitat conditions without additional $CaCO_3$ addition, the cations Ca^{2+} Mg^{2+} and Na^{+} are exchangeable by NH_4O_{Ac}. The important difference might occur in certain conditions where the vermiculites minerals are present.

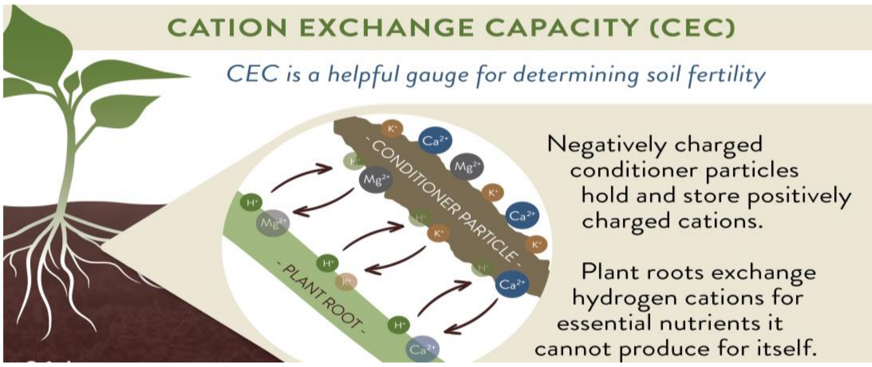

Figure 2.2.10. Exchange of the basic cations $Ca^{2+,}$ $Mg^{2+,}$ K^{+}, These colloid particles consist of flat, thin plates with a lot of negatively charged surface area to hold and store large quantities of cations. A plant can then trade for the nutrients it *can't* produce; with hydrogen cations it *can* produce. This exchange is continually taking place between the roots and the negatively charged particles in the soil. That means CEC is a very useful gauge for soil fertility, because if the soil is efficiently storing cations, plants have access to the nutrition they need

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In the studied coal mine heaps, it has been reported that the admixture of vermiculites and montmorillonite is recorded. Exchangeable acidity is a crucial part of the four types of acidity. The first considered and most frequently measured type is the H ions obtained from the hydrolysis (Ramos et al., 2018). Cation exchange in fully developed soils is a reversible chemical reaction. There are many methods available for the determination of cation-exchange capacity (CEC). Most of them are indicating the magnitude order of exchange capacity. Potassium (K), alkaline phosphatase, and SRL showed the highest correlation. The highest positive correlation was between SRL and total nitrogen, followed by pH, while the relation was negative with magnesium and calcium soil content.

The soil respiration as the crucial process in the carbon living cycle

The cycling of carbon (C) is carefully observed, particularly in relation to increased N deposition (Cusack et al., 2011; Sinsabaugh et al., 2005). The phosphorus P dynamics, base cations, and soil acidification related to increased N deposition are studied less frequently. This is surprising because these soil parameters are good eco-chemical indicators for soil health and can be used also to assess the damage from soil acidification (Futa and Mocek-Płóciniak, 2016; Małek, 2009). The soil development, the soil chemical properties, such as soil acidity and exchangeable cations are dependent on the herb and tree plant species composition in the vegetation communities (Binkley et al., 1999; Rhoades, 1996) and vice versa the changes in the local and global environment and habitat conditions may significantly influence the composition and diversity of plants communities (Bardgett, 2005). The study conducted in frosts has revealed that the pH and basic cation saturation (BS%) can be significantly decreased as result of the N addition. The effective acidity (EA; EA (m_{mol} kg^{-1}) = $Al^{3+} + H^{+}$), is recorded to be increased with the N addition (Zarif et al., 2020). The study conducted in forests revealed that the exchangeable soil cations like K^{+}, Ca^{2+}, and Mg^{2+} were not significantly affected by the P additional input (Bolan, 1991). The increased P deposition significantly increased the total soil exchangeable base cations by 60% ((Yang et al., 2015)). In forest soils, and probably also in soil (mineral soil substratum), acidification causes leaching of base cations. The weathering of some base cations, such as Ca > Na > Mg > K, would cause limitations in base cation budgets and metal ion imbalances in soils (Lucas et al., 2011).

The understanding of soil (or soil substratum) respiration rates and the abiotic habitat conditions connections along with the feedback relation with plant species composition is crucial for a range of reasons (Bouma and Bryla, 2000; Dugas, 1993; Dugas et al., 1997; Epron et al., 1999; Joon Kim et al., 1992; Linn and

Doran, 1984; Mielke et al., 1986; Norman et al., 1992; Šimůnek and Suarez, 1993; Skopp et al., 1990).

Most of the study on soil reparation parameters have been performed in agriculture, cropland, grasslands and managed forests. Much less attention has been focused on the study of soil reparation parameters in natural ecosystems and spontaneous ecosystem development in e.g., human created habitats such as mineral material of post coal mine heaps. According to Xiao et al., (2021) the soil organic carbon, total nitrogen, available nitrogen, dissolved organic carbon, and microbial biomass carbon decreased, in the managed vegetation types, by the following order: grassland > woodland > abandoned land > cropland > orchard. The plant residues together with human disturbance in grassland and managed woodland resulted in the higher soil carbon and nitrogen nutrient parameters in the above order of land-use types. In the previous study it has been presented that soil respiration Rs decreased from summer to December, showing that the soil temperature and moisture are the main explanatory factors. The mean soil respiration in grassland (3.68 μ_{mol} m^{-2} s^{-1}) and in tree stands or woodlands (3.81 μ_{mol} m^{-2} s^{-1}) was significantly higher than that in cropland, orchard, and agricultural abandoned land. The variable importance in the projection values from the partial least squares regression model showed that soil temperature, pH, microbial biomass nitrogen, microbial biomass carbon, bacterial abundance, available nitrogen, and soil moisture were the most important predictors of Rs in the studied habitats (Xiao et al., 2021). It has been underlined that it is important to consider root respiration, as roots can respire more than 50% of plant photosynthates produced daily (Lambers et al., 2002).

Soil respiration includes respiration RA of e.g., plant roots and microorganisms and respiration RH of e.g., plant biomass, soil organic matter, litter, and soil animals) (Scott-Denton et al., 2006; Bond-Lamberty et al., 2004; Hanson et al., 2000). The RA respiration is assessed in temperate forests as the main part (60%) of total respiration RT. In subtropical forests in contrast the significant component (75%) was RH as a key element of RT. Therefore, separating components of RT could contribute significantly to our understanding of C storage (Rodeghiero and Cescatti, 2006). However, it is a very limited number of studies, because the separated measurement of these two respiration components is very difficult. There are three techniques used to seperate the components of RT. The methods using root exclusion, direct measurement and isotope tracer. All of them are designed to use a feature of the soil respiration process to quantitatively define one or more components (Kelting et al., 1998; Vose and Ryan, 2002). The three techniques involve a compromise between low accuracy and inconvenient methods. Direct measurement and root exclusion have

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limited accuracy since data may contain components of RH (Butler et al., n.d.; Jiang et al., 2017). The isotope tracer methods are more accurate, but the related field techniques are quite difficult to perform. The techniques have been developed to measure root respiration and its components (e.g. (Bouma et al., 1996; Kooijman et al., 1988). Soil respiration is frequently assessed over limited areas (< 1 m^2). The equipment used is generally surface chambers or chambers buried with CO_2 sensors. Due to soil limited diffusivity, CO_2 is more concentrated compared to the atmosphere (Phillips, Nickerson 2015). In our study we have applied one of the commonly used measurements of soil respiration. We focused on the measurement of the joined RTtot CO_2 release both from RA and RH in respect of the habitat mosaic reflected by the vegetation type variety.

Soil respiration elements in initial succession and managed forests

The study conducted on soil respiration in two types of forests gave similar results. It has been found that the monthly mean components of soil respiration in central Brazil were all single-peaked curves. In particular, total soil respiration and heterotrophic respiration in the two forests showed similar trends, peaking at the same time (Butler et al., 2012; Yu et al., 2015). In these vegetation types the litter respiration was the main component of heterotrophic respiration (88%), suggesting that these heterotrophic respiration peaked later because soil C used in litter decomposition by microorganisms was not immediately absorbed. In this way, the combination of microbial C utilization and high C in litter organic matter respiration caused a hysteresis phenomenon (Yu et al., 2015). In the study conducted by Bond-Lamberty et al. (2010), they cut off the roots and found that the decomposition of dead roots in an excavated plot resulted in a 5% relative increase in heterotrophic respiration in Wayward Pines. Dead roots provide a new source of SOM for microorganisms and increase the rate of heterotrophic respiration (Bond-Lamberty et al., 2004). Lee et al., (2003) found that the effect of root pruning could be ignored later in the study because dead roots turned black after 2-3 months (Lee et al., 2003). The dead roots did not rot completely in the first year, and new roots grew into the plots even in the third year. Since changes in root activity cannot be directly detected, the effects of decaying and new roots in relative humidity have proven difficult to be detected, which can lead to a poor estimation of soil respiration (Yu et al., 2015).

Some studies have shown that extensive bamboo forest management leads to higher than average SOM content, which creates a rich source of C for soil microbes. At the same time, the complexity of the organic matter material composition leads to a low C/N ratio, resulting in the accelerating SOM cycling due to the decomposition of organic matter by soil microbe. This in turn is leading to higher heterotrophic respiration (Grant et al., 2001). Therefore, the intensive management may be another reason why the relative humidity in the studied forests was an important factor (Liu et al., 2011) although the age of the studied tree stand was also analyzed. The older tree stand compared with the younger ones from the previously studied sites revealed differences in the amount in soil respiration (Yang et al., 2015). Additionally, some of the previous study conducted in woodlands and tree stands have also revealed that soil respiration has a linear positive correlation with the content of organic matter, in old bamboo stands releasing more CO_2 than young stands (Chen et al., 2010; Franzluebbers et al., 2001) therefore, the combination of forest age and SOM content may also contribute to the matter and energy cycle processes.

The components of soil respiration to total soil respiration

Many studies have shown that heterotrophic and autotrophic respiration contributes to total soil respiration at different rates in different forests. Globally, root respiration accounts for 10–60% (–90%) of total soil respiration in most forest ecosystems (Kuzyakov, 2004). Different vegetation types and research methods can lead to a different assessment of effects of autotrophic respiration on total soil respiration between forest systems. The participation of RH in RT was more than 73% in the studied forests. However, unexpectedly the relative humidity apparently affected RT more than RA in the studied forests. These contributions are higher than those identified by Shen et al., (2011) for subtropical forests in the lower Yangtze River valley (Shen et al., 2011). The reason for the differences might be related to the fact that some of the study sites were located in the area of a current nature reserve. The stands here had a minimal human intervention, a thick litter layer, and abundant SOM, resulting in a relatively high proportion of relative humidity (Yang et al., 2015).

According to Subke et al., (2006) who performed a meta-analysis of the contribution of soil respiration components based on the last 30 years of literature, found that heterotrophic respiration accounted for 27-86% of total soil respiration in forest systems (Subke et al., 2006). In addition, Satomura et al., (2006) found that both autotrophic and heterotrophic respiration increased during the growing season in Japanese temperate forests, accounting for more than 50% of the carbon dioxide released annually by RT. During the growing season, the environmental conditions favour plant growth and the amount of CO_2 released during soil respiration increases. The results obtained during the study in forests (mostly managed forests) revealed that the contribution of soil respiration to total respiration itself was influenced not only by separation methods and stand structure, but also by forest types and environmental factors (Satomura et al.,

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2006). The above results are in agreement with the assumptions of our study. We have assumed that the total respiration amount will be related to the species composition of the spontaneous herbaceous vegetation type that has developed on the mineral material of the post coal mine heaps abiotic environmental factors.

The effect of texture on the availability of abiotic parameters on SRLs

The soil substrate texture parameter in our study is irrelevant and it is not presented in the section results, as only the significant parameters are analyzed in detail. However, based on the available literature, it is known that the finest material can affect soil processes. The soil texture can influence the nitrogen cycle in the ecosystem. Among others due to its weak binding to the soil particles, nitrate leaching can causes a decrease in base cations and soil pH (Araujo et al., 2017).

Studies show a strong relationship between the proportion of clay in the soil structure and SOC content (Jenkinson, 1990; Parton et al., 1987). The study also showed that the distribution of SOM decreases as clay concentration increases when all the other factors are the same. While SOC accumulates faster with soil (soil substrate), the proportion of clay increases. The proportion of clay in the soil structure can have different effects on the distribution of different pools of SOC (Franzluebbers et al., 2001). Soil respiration during the early stages of laboratory incubation (labile mineralization of SOC), according to Wang et al. (2003), was not dependent on the proportion of clay (Wang et al., 2003). In the later stages of the identical incubation, when the re-calcined SOC pools were mineralized, it was found that the clay content slowed the mineralization process. The heterogeneous effect of clay on carbon decomposition has been accounted for in dynamic models of SOM transformations (Müller and Höper, 2004). Carbon C mineralization generally decreases with increasing clay content (Hassink, 1997). Laboratory incubations do not always show this trend (Scott et al., 1996). These observations have led to a conclusion that clay-rich soils protect some SOC from decomposition and cause faster SOC accumulation than sandy soils. Two separate mechanisms have been proposed to explain this phenomenon (Scott et al., 1996; Hassink, 1997).

One assumes that SOC humifies and is adsorbed by negatively charged clay minerals, which provide a large surface area. A second explanation could be that SOC is physically isolated from microbial mineralization by forming soil aggregates. The process of aggregate formation often takes place in some stages. The appearance of the first clay particles enables the aggregation process of the remaining particles (Tisdall and Oades, 1982). Aggregations of clay can change soil moisture parameters, affecting the input of C into the soil through plant productivity and SOC distribution (McLauchlan, 2006; Six et al., 2000).

The relationship between the role of clay proportion and soil nutrient cycling, particularly the key step of nitrogen (N) mineralization, is unclear. Some studies have shown that increased clay content reduces N mineralization (Côté et al., 2000). A study conducted by Giardina et al., (2001) revealed how the results can vary when other conditions (temperature and humidity) are controlled. In the Giardina et al., (2001), study, clay content had little effect on the rate of net N mineralization (Giardina et al., 2001). Regardless of soil texture, as time increases from the effects of underground disturbance, net N mineralization decreases, and soil C content increases (McLauchlan, 2006; Schimel, 1995). According to our expectations no significant relation between the soil respiration parameters and the texture has been revealed. The reason for that might be the fact that in our study the mineral material of the soil substratum was rich in gravel and even more in stones.

Soil water content capacity and soil respiration

Identifying the environmental factors that control soil CO_2 release from the ecosystems is an essential step in assessing the potential effects of environmental changes. Soil respiration rates are primarily determined by soil temperature and moisture (Schlentner and Van Cleve, 1985; Singh and Gupta, 1977). The high-water level flooding in the habitat changes the conditions from the oxygen rich into anaerobic conditions. In anaerobic conditions the organic carbon cannot be oxidized and the carbon dioxide is not released. In this respect the seasonal changes in soil microclimate might play an essential role in determining seasonal differences in soil CO_2 within sites, and the climatic differences might generate different soil respiration rates at remote sites (Raich and Potter, 1995).

When modelling soil respiration (soil respiration, soil CO_2 release), it is almost universally accepted that the dependence of soil CO_2 release rates on temperature (soil and air, below and above ground). This relation is best described by an exponential equation (Borken et al., 1999; Kutsch et al., 2001; Rochette et al., 2013). Soil respiration models take into account moisture conditions (soil moisture or precipitation amount) in addition to temperature (Savage and Davidson, 2003; Tang et al., 2005; Tüfekçioğlu and Küçük, 2004). The formula for calculating soil CO_2 release vary, but these two features are repeated with almost all models. If they are applied to the scale of the whole year, this gives very good results. Sometimes other factors are additionally taken into account, such as carbon content (as it has been assumed in our study) (Kutsch et al., 2001;

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Rodeghiero and Cescatti, 2005) maximum leaf area index (Skopp et al., 1990) pH (Reth et al., 2005) land use (Ardö and Olsson, 2003).

Effect of salinity on SRL

One of the frequent characteristics of the mineral material of the coal mine heaps habitat conditions is high salinity. The salt or salty waters are excavated together with the hard coal and the associated geological layers. The habitats with salt are spontaneously colonized by different halophytes (obligatory and plant species communities characteristic for saltmarsh ecosystems. In agriculture and forestry salt is considered as significant threat to sustainable crop production in many arid and semi-arid regions of the world (Bossio et al., 2007). Low rainfall and high potential evapotranspiration in these regions promote the movement of salts upward in the soil solution, adversely affecting the soil physical, chemical and biological properties (Rengasamy, 2006). Worldwide, more than 831 million hectares of land are affected by salt (Beltrán and Manzur, 2005) and this area is likely to increase in the future due to secondary salinization caused by irrigation and removal of native vegetation (Pannell and Ewing, 2006). It is, therefore, important to understand the processes in salt-affected soils, especially those related to nutrient cycling in relation to soil respiration.

As indicated by Zeng et al., (2014), soil respiration and rates of nitrification and denitrification were dependent on soil salinity. In addition, they found that the effect of soil salinity level on nitrification and denitrification rates had a threshold value (EC1:5 = 1.13 dS/m). When the soil salinity level was less than this threshold value, the rates of nitrification and denitrification increased as the soil salinity increased. If soil salinity was higher than the threshold, these rates decreased. Moreover, the changes in the nature of the dependence of soil respiration rates on salinity were comparable with the rates of nitrification and denitrification, while the trend of changes was the opposite. Moreover, the transformation of urea to ammonia and nitrate nitrogen also decreased with increasing soil salinity, and an exponential function can express the effect of such a decrease.

Plants in natural and semi-natural ecosystems are susceptible to changes resulting from drought or salinity, and according to some researchers, do not generally adapt quickly (Jarvis et al., 2008). Plants adaptation processes to whole variety of stresses range from morphology, anatomy to physiology and molecular modifications. The adaptation processes are different among plants living in the same area. Each plant responded uniquely when various stress signals, such as drought or cold, prompted a group of different plant species. Hardly any of the responses were similar, even though the plants had become accustomed to the same home environment (Mittler, 2006). Abiotic stresses can impact the organisms in many forms. The presence of some of these abiotic stresses is unpredictable. However, drought and soil salinity are relatively more predictable in agricultural management and familiar with occurrences demanding focused research. It is less frequently considered that the adaptations cause differences in the biochemistry of the plants and consequently the SOM and the decomposition process which are directly related to the carbon dioxide release.

References

[1] Aber J.D., Nadelhoffer K.J., Steudler P., Melillo J.M., 1989. Nitrogen Saturation in Northern Forest EcosystemsExcess nitrogen from fossil fuel combustion may stress the biosphere. Bioscience 39, 378–386. https://doi.org/10.2307/1311067

[2] Aragão A., Jacobs S., Cliquet A., 2016. What's law got to do with it? Why environmental justice is essential to ecosystem service valuation. Ecosyst Serv 22, 221–227. https://doi.org/10.1016/J.ECOSER.2016.09.012

[3] Araujo M.A., Zinn Y.L., Lal R., 2017. Soil parent material, texture and oxide contents have little effect on soil organic carbon retention in tropical highlands. Geoderma 300, 1–10. https://doi.org/10.1016/J.GEODERMA.2017.04.006

[4] Ardö J., Olsson L., 2003. Assessment of soil organic carbon in semi-arid Sudan using GIS and the CENTURY model. J Arid Environ 54, 633–651. https://doi.org/10.1006/JARE.2002.1105

[5] Arevalo C.B.M., Bhatti J.S., Chang S.X., Jassal R.S., Sidders D., 2010. Soil respiration in four different land use systems in north central Alberta, Canada. J Geophys Res Biogeosci 115, 1003. https://doi.org/10.1029/2009JG001006

[6] Atkin O.K., Tjoelker M.G., 2003. Thermal acclimation and the dynamic response of plant respiration to temperature. Trends Plant Sci 8, 343–351. https://doi.org/10.1016/S1360-1385(03)00136-5

[7] Baral H., Guariguata M.R., Keenan R.J., 2016. A proposed framework for assessing ecosystem goods and services from planted forests. Ecosyst Serv 22, 260–268. https://doi.org/10.1016/J.ECOSER.2016.10.002

[8] Bardgett R., 2005. The Biology of Soil: A community and ecosystem approach. The Biology of Soil: A community and ecosystem approach 1–256. https://doi.org/10.1093/ACPROF:OSO/9780198525035.001.0001

[9] Bark R.H., Colloff M.J., Hatton MacDonald D., Pollino C.A., Jackson S., Crossman N.D., 2016. Integrated valuation of ecosystem services obtained from restoring water to the environment in a major regulated river basin. Ecosyst Serv 22, 381–391. https://doi.org/10.1016/J.ECOSER.2016.08.002

[10] Beltrán J., Manzur C., 2005. Overview of salinity problems in the world and FAO strategies to address the problem.

[11] Bierza W., Woźniak G., Kompała-Bąba A., Magurno F., Malicka M., Chmura D., Błońska A., Jagodziński A.M., Piotrowska-Seget Z., Bierza W., Woźniak G., Kompała-Bąba A., Magurno F., Malicka M., Chmura D., Błońska A., Jagodziński A.M., Piotrowska-Seget Z., 2023. The Effect of Plant Diversity and Soil Properties on Soil Microbial Biomass and Activity in a Novel Ecosystem. Sustainability 15, 1–18.

[12] Binkley D., Burnham H., Lee Allen H., 1999. Water quality impacts of forest fertilization with nitrogen and phosphorus. For Ecol Manage 121, 191–213. https://doi.org/10.1016/S0378-1127(98)00549-0

[13] Bolan N.S., 1991. A critical review on the role of mycorrhizal fungi in the uptake of phosphorus by plants. Plant Soil 134, 189–207. https://doi.org/10.1007/BF00012037/METRICS

[14] Bond-Lamberty B., Thomson A., 2010. Temperature-associated increases in the global soil respiration record. Nature 2010 464:7288 464, 579–582. https://doi.org/10.1038/nature08930

[15] Bond-Lamberty B., Wang C., Gower S.T., 2004. Contribution of root respiration to soil surface CO2 flux in a boreal black spruce chronosequence. Tree Physiol 24, 1387–1395. https://doi.org/10.1093/TREEPHYS/24.12.1387

[16] Borken W., Davidson E.A., Savage K., Gaudinski J., Trumbore S.E., 2003. Drying and Wetting Effects on Carbon Dioxide Release from Organic Horizons. Soil Science Society of America Journal 67, 1888–1896. https://doi.org/10.2136/SSSAJ2003.1888

[17] Borken W., Xu Y.-J., Brumme R., Lamersdorf N., Borken W., Xu Y.-J., Brumme R., Lamersdorf N., 1999. A Climate Change Scenario for Carbon Dioxide and Dissolved Organic Carbon Fluxes from a Temperate Forest Soil. SSASJ 63, 1848. https://doi.org/10.2136/SSSAJ1999.6361848X

[18] Bossio D., Critchley W., Geheb K., Lynden G.W.J. van, Mati B., Udas P.B., Hellin J., Jacks G., Kolff A., Nachtergaele F., Neely C., Peden D., Rubiano J., Shepherd G., Valentin C., Walsh M., 2007. Conserving land: protecting water.

[19] Bouma T., Broekhuysen A., Veen B.W., 1996. Analysis of root respiration of Solanum tuberosum as related to growth, ion uptake and maintenance of biomass. Plant Physiology and Biochemistry.

[20] Bouma T.J., Bryla D.R., 2000. On the assessment of root and soil respiration for soils of different textures: Interactions with soil moisture contents and soil CO2 concentrations. Plant Soil 227, 215–221. https://doi.org/10.1023/A:1026502414977/METRICS

[21] Bouma T.J., Nielsen K.L., Eissenstat D.M., Lynch J.P., 1997a. Soil CO2 concentration does not affect growth or root respiration in bean or citrus. Plant Cell Environ 20, 1495–1505. https://doi.org/10.1046/J.1365-3040.1997.D01-52.X

[22] Bouma T.J., Nielsen K.L., Eissenstat D.M., Lynch J.P., 1997b. Estimating respiration of roots in soil: Interactions with soil CO2, soil temperature and soil water content. Plant Soil 195, 221–232. https://doi.org/10.1023/A:1004278421334/METRICS

[23] Boyce R.L., 1998. Fuzzy set ordination along an elevation gradient on a mountain in Vermont, USA. Journal of Vegetation Science 9, 191–200. https://doi.org/10.2307/3237118

[24] Burton A.J., Zogg G.P., Pregitzer K.S., Zak D.R., 1997. Effect of measurement CO2 concentration on sugar maple root respiration. Tree Physiol 17, 421–427. https://doi.org/10.1093/TREEPHYS/17.7.421

[25] Butler A., Hur B., Junior M., Maracahipes L., Schwantes Marimon B., Silvério V., Almeida De Oliveira E., Lenza E., Feldpausch T.R., Meir P., Grace J., n.d. Absorbing roots areas and transpiring leaf areas at the tropical forest and savanna boundary in Brazil.

[26] Cerhanová D., Nováková J., 2006. Respiration activity of the soil samples from the long-term field experiments in Prague.

[27] Chen B., Liu S., Ge J., Chu J., 2010. Annual and seasonal variations of Q10 soil respiration in the sub-alpine forests of the Eastern Qinghai-Tibet Plateau, China. Soil Biol Biochem 42, 1735–1742. https://doi.org/10.1016/J.SOILBIO.2010.06.010

[28] Chen X., Chen H.Y.H., 2019. Plant diversity loss reduces soil respiration across terrestrial ecosystems. Glob Chang Biol 25, 1482–1492. https://doi.org/10.1111/GCB.14567

[29] Côté L., Brown S., Paré D., Fyles J., Bauhus J., 2000. Dynamics of carbon and nitrogen mineralization in relation to stand type, stand age and soil texture in the boreal mixedwood. Soil Biol Biochem 32, 1079–1090. https://doi.org/10.1016/S0038-0717(00)00017-1

[30] Cusack D.F., Silver W.L., Torn M.S., Burton S.D., Firestone M.K., 2011. Changes in microbial community characteristics and soil organic matter with nitrogen additions in two tropical forests. Ecology 92, 621–632. https://doi.org/10.1890/10-0459.1

[31] Davidson E.A., Janssens I.A., 2006. Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. Nature 2006 440:7081 440, 165–173. https://doi.org/10.1038/nature04514

[32] De Groot C.C., Marcelis L.F.M., Van Den Boogaard R., Lambers H., 2001. Growth and dry-mass partitioning in tomato as affected by phosphorus nutrition and light. Plant Cell Environ 24, 1309–1317. https://doi.org/10.1046/J.0016-8025.2001.00788.X

[33] Dugas W.A., 1993. Micrometeorological and chamber measurements of CO2 flux from bare soil. Agric For Meteorol 67, 115–128. https://doi.org/10.1016/0168-1923(93)90053-K

[34] Dugas W.A., Reicosky D.C., Kiniry J.R., 1997. Chamber and micrometeorological measurements of CO2 and H2O fluxes for three C4 grasses. Agric For Meteorol 83, 113–133. https://doi.org/10.1016/S0168-1923(96)02346-5

[35] Eberwein J., Shen W., Jenerette G.D., 2017. Michaelis-Menten kinetics of soil respiration feedbacks to nitrogen deposition and climate change in subtropical forests. Scientific Reports 2017 7:1 7, 1–9. https://doi.org/10.1038/s41598-017-01941-8

[36] Emery S.M., Kellogg W.K., 2007. Limiting similarity between invaders and dominant species in herbaceous plant communities? Journal of Ecology 95, 1027–1035. https://doi.org/10.1111/J.1365-2745.2007.01274.X

[37] Epron D., Farque L., Lucot E., Badot P.M., 1999. Soil CO_2 efflux in a beech forest: The contribution of root respiration. Ann For Sci 56, 289–295. https://doi.org/10.1051/FOREST:19990403

[38] Fahey T.J., Yavitt J.B., Sherman R.E., Maerz J.C., Groffman P.M., Fisk M.C., Bohlen P.J., 2013. Earthworm effects on the incorporation of litter C and N into soil organic matter in a sugar maple forest. Ecol Appl 23, 1185–1201. https://doi.org/10.1890/12-1760.1

[39] Fenn K.M., Malhi Y., Morecroft M.D., 2010. Soil CO_2 efflux in a temperate deciduous forest: Environmental drivers and component contributions. Soil Biol Biochem 42, 1685–1693. https://doi.org/10.1016/J.SOILBIO.2010.05.028

[40] Franzluebbers A.J., Haney R.L., Honeycutt C.W., Arshad M.A., Schomberg H.H., Hons F.M., 2001. Climatic influences on active

fractions of soil organic matter. Soil Biol Biochem 33, 1103–1111. https://doi.org/10.1016/S0038-0717(01)00016-5

[41] Frouz J., 2018. Effects of soil macro- and mesofauna on litter decomposition and soil organic matter stabilization. Geoderma 332, 161–172. https://doi.org/10.1016/J.GEODERMA.2017.08.039

[42] Futa B., Mocek-Płóciniak A., 2016. The influence of uncontrolled grass burning on biochemical qualities of soil. Journal of Research and Applications in Agricultural Engineering.

[43] Woźniak G., 2010. Zróżnicowanie roślinności na zwałach pogórniczych Górnego Śląska. Wydawnictwo Naukowe Scholar - Instytut Socjologii UW.

[44] Gauch H.G., 1982. Introduction. Multivariate Analysis in Community Ecology 1–42. https://doi.org/10.1017/CBO9780511623332.002

[45] Giardina C.P., Ryan M.G., Hubbard R.M., Binkley D., n.d. Tree Species and Soil Textural Controls on Carbon and Nitrogen Mineralization Rates.

[46] Grant R.F., Juma N.G., Robertson J.A., Izaurralde R.C., McGill W.B., Grant R.F., Juma N.G., Robertson J.A., Izaurralde R.C., McGill W.B., 2001. Long-Term Changes in Soil Carbon under Different Fertilizer, Manure, and Rotation. SSASJ 65, 205. https://doi.org/10.2136/SSSAJ2001.651205X

[47] Hanson P.J., Edwards N.T., Garten C.T., Andrews J.A., 2000. Separating root and soil microbial contributions to soil respiration: A review of methods and observations. Biogeochemistry 48, 115–146. https://doi.org/10.1023/A:1006244819642/METRICS

[48] Hassink J., 1997. The capacity of soils to preserve organic C and N by their association with clay and silt particles. Plant Soil 191, 77–87. https://doi.org/10.1023/A:1004213929699/METRICS

[49] Heinemeyer A., Hartley I.P., Evans S.P., Carreira De La Fuente J.A., Ineson P., 2007. Forest soil CO_2 flux: uncovering the contribution and environmental responses of ectomycorrhizas. Glob Chang Biol 13, 1786–1797. https://doi.org/10.1111/J.1365-2486.2007.01383.X

[50] Helfenstein J., Pistocchi C., Oberson A., Tamburini F., Goll D.S., Frossard E., 2020. Estimates of mean residence times of phosphorus in commonly considered inorganic soil phosphorus pools. Biogeosciences 17, 441–454. https://doi.org/10.5194/BG-17-441-2020

[51] Helfenstein J., Tamburini F., von Sperber C., Massey M.S., Pistocchi C., Chadwick O.A., Vitousek P.M., Kretzschmar R., Frossard E., 2018.

Combining spectroscopic and isotopic techniques gives a dynamic view of phosphorus cycling in soil. Nature Communications 2018 9:1 9, 1–9. https://doi.org/10.1038/s41467-018-05731-2

[52] Helingerová M., Frouz J., Šantrůčková H., 2010. Microbial activity in reclaimed and unreclaimed post-mining sites near Sokolov (Czech Republic). Ecol Eng 36, 768–776. https://doi.org/10.1016/J.ECOLENG.2010.01.007

[53] 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., 2006. Novel ecosystems: theoretical and management aspects of the new ecological world order. Global Ecology and Biogeography 15, 1–7. https://doi.org/10.1111/J.1466-822X.2006.00212.X

[54] Homeier J., Báez S., Hertel D., Leuschner C., 2017. Editorial: Tropical forest ecosystem responses to increasing nutrient availability. Front Earth Sci (Lausanne) 5, 255840. https://doi.org/10.3389/FEART.2017.00027/BIBTEX

[55] Ilstedt U., Nordgren A., Malmer A., 2000. Optimum soil water for soil respiration before and after amendment with glucose in humid tropical acrisols and a boreal mor layer. Soil Biol Biochem 32, 1591–1599. https://doi.org/10.1016/S0038-0717(00)00073-0

[56] Jarvis A., Lane A., Hijmans R.J., 2008. The effect of climate change on crop wild relatives. Agric Ecosyst Environ 126, 13–23. https://doi.org/10.1016/j.agee.2008.01.013

[57] Jenkinson D.S., 1990. The turnover of organic carbon and nitrogen in soil. Philos Trans R Soc Lond B Biol Sci 329, 361–368. https://doi.org/10.1098/RSTB.1990.0177

[58] Jiang L., Ma S., Zhou Z., Zheng T., Jiang X., Cai Q., Li P., Zhu J., Li Y., Fang J., 2017. Soil respiration and its partitioning in different components in tropical primary and secondary mountain rain forests in Hainan Island, China. Journal of Plant Ecology 10, 791–799. https://doi.org/10.1093/JPE/RTW080

[59] Joon Kim Verma S.B., Clement R.J., 1992. Carbon dioxide budget in a temperate grassland ecosystem. Journal of Geophysical Research: Atmospheres 97, 6057–6063. https://doi.org/10.1029/92JD00186

[60] Keith S.A., Newton A.C., Herbert R.J.H., Morecroft M.D., Bealey C.E., 2009. Non-analogous community formation in response to climate

change. J Nat Conserv 17, 228–235. https://doi.org/10.1016/J.JNC.2009.04.003

[61] Kelting D.L., Burger J.A., Edwards G.S., 1998. Estimating root respiration, microbial respiration in the rhizosphere, and root-free soil respiration in forest soils. Soil Biol Biochem 30, 961–968. https://doi.org/10.1016/S0038-0717(97)00186-7

[62] Koizumi H., Nakadai T., Usami Y., Satoh M., Shiyomi M., Oikawa T., 1991. Effect of carbon dioxide concentration on microbial respiration in soil. Ecol Res 6, 227–232. https://doi.org/10.1007/BF02347124

[63] Kooijman A., Welschen R., Lambers H., 1988. Respiratory energy costs for the maintenance of biomass, for growth and for ion uptake in roots of Carex diandra and Carex acutiformis. Physiol Plant 72, 483–491. https://doi.org/10.1111/J.1399-3054.1988.TB09155.X

[64] Kowarik I., Fischer L.K., Säumel I., von der Lippe M., Weber F., Westermann J.R., 2011. Plants in Urban Settings: From Patterns to Mechanisms and Ecosystem Services. Perspectives in Urban Ecology 135–166. https://doi.org/10.1007/978-3-642-17731-6_5

[65] Kutsch W.L., Staack A., Wötzel J., Middelhoff U., Kappen L., 2001. Field measurements of root respiration and total soil respiration in an alder forest. New Phytologist 150, 157–168. https://doi.org/10.1046/J.1469-8137.2001.00071.X

[66] Lambers H., Atkin O., Millenaar F., 2002. Respiratory Patterns in Roots in Relation to Their Functioning. Plant Roots 521–552. https://doi.org/10.1201/9780203909423.PT6

[67] Lambers H., Raven J.A., Shaver G.R., Smith S.E., 2008. Plant nutrient-acquisition strategies change with soil age. Trends Ecol Evol 23, 95–103. https://doi.org/10.1016/J.TREE.2007.10.008

[68] Lamošová T., Doležal J., Lanta V., Lepš J., 2010. Spatial pattern affects diversity–productivity relationships in experimental meadow communities. Acta Oecologica 36, 325–332. https://doi.org/10.1016/J.ACTAO.2010.02.005

[69] Le Quéré C., Moriarty R., Andrew R.M., Peters G.P., Ciais P., Friedlingstein P., Jones S.D., Sitch S., Tans P., Arneth A., Boden T.A., Bopp L., Bozec Y., Canadell J.G., Chini L.P., Chevallier F., Cosca C.E., Harris I., Hoppema M., Houghton R.A., House J.I., Jain A.K., Johannessen T., Kato E., Keeling R.F., Kitidis V., Klein Goldewijk K., Koven C., Landa C.S., Landschützer P., Lenton A., Lima I.D., Marland G., Mathis J.T., Metzl N., Nojiri Y., Olsen A., Ono T., Peng S., Peters W., Pfeil B., Poulter B., Raupach M.R., Regnier P.,

Rödenbeck C., Saito S., Salisbury J.E., Schuster U., Schwinger J., Séférian R., Segschneider J., Steinhoff T., Stocker B.D., Sutton A.J., Takahashi T., Tilbrook B., Van Der Werf G.R., Viovy N., Wang Y.P., Wanninkhof R., Wiltshire A., Zeng N., 2015. Global carbon budget 2014. Earth Syst Sci Data 7, 47–85. https://doi.org/10.5194/ESSD-7-47-2015

[70] Lee M.S., Nakane K., Nakatsubo T., Koizumi H., 2003. Seasonal changes in the contribution of root respiration to total soil respiration in a cool-temperate deciduous forest. Plant Soil 255, 311–318. https://doi.org/10.1023/A:1026192607512/METRICS

[71] Legendre P., Legendre L., 2012. Numerical Ecology Ch 6 - Multidimensional qualitative data. Developments in Environmental Modelling 24, 337–424.

[72] Linn D.M., Doran J.W., 1984. Effect of Water-Filled Pore Space on Carbon Dioxide and Nitrous Oxide Production in Tilled and Nontilled Soils. Soil Science Society of America Journal 48, 1267–1272. https://doi.org/10.2136/SSSAJ1984.03615995004800060013X

[73] Liu J., Jiang P., Wang H., Zhou G., Wu J., Yang F., Qian X., 2011. Seasonal soil CO_2 efflux dynamics after land use change from a natural forest to Moso bamboo plantations in subtropical China. For Ecol Manage 262, 1131–1137. https://doi.org/10.1016/J.FORECO.2011.06.015

[74] Lucas R.W., Klaminder J., Futter M.N., Bishop K.H., Egnell G., Laudon H., Högberg P., 2011. A meta-analysis of the effects of nitrogen additions on base cations: Implications for plants, soils, and streams. For Ecol Manage 262, 95–104. https://doi.org/10.1016/J.FORECO.2011.03.018

[75] Luo Y., Zhou X., 2006. Soil Respiration and the Environment. Soil Respiration and the Environment 1–316. https://doi.org/10.1016/B978-0-12-088782-8.X5000-1

[76] Małek S., 2009. Sustainability of Picea abies of Istebna provenance in Dupniański Stream catchment as dependent on stand age class. Dendrobiology.

[77] Mao Q., Lu X., Zhou K., Chen H., Zhu X., Mori T., Mo J., 2017. Effects of long-term nitrogen and phosphorus additions on soil acidification in an N-rich tropical forest. Geoderma 285, 57–63. https://doi.org/10.1016/J.GEODERMA.2016.09.017

[78] McLauchlan K.K., 2006. Effects of soil texture on soil carbon and nitrogen dynamics after cessation of agriculture. Geoderma 136, 289–299. https://doi.org/10.1016/J.GEODERMA.2006.03.053

[79] Melillo J.M., Steudler P.A., Aber J.D., Newkirk K., Lux H., Bowles F.P., Catricala C., Magill A., Ahrens T., Morrisseau S., 2002. Soil Warming and Carbon-Cycle Feedbacks to the Climate System. Science (1979) 298, 2173–2176. https://doi.org/10.1126/SCIENCE.1074153

[80] Mielke L.N., Doran J.W., Richards K.A., 1986. Physical environment near the surface of plowed and no-tilled soils. Soil Tillage Res 7, 355–366. https://doi.org/10.1016/0167-1987(86)90022-X

[81] Mittler R., 2006. Abiotic stress, the field environment and stress combination. Trends Plant Sci 11, 15–19. https://doi.org/10.1016/J.TPLANTS.2005.11.002

[82] Mo J., Zhang W., Zhu W., Gundersn P., Fang Y., Li D., Wang H., 2008. Nitrogen addition reduces soil respiration in a mature tropical forest in southern China. Glob Chang Biol 14, 403–412. https://doi.org/10.1111/J.1365-2486.2007.01503.X

[83] Moyano F.E., Kutsch W.L., Rebmann C., 2008. Soil respiration fluxes in relation to photosynthetic activity in broad-leaf and needle-leaf forest stands. Agric For Meteorol 148, 135–143. https://doi.org/10.1016/J.AGRFORMET.2007.09.006

[84] Moyano F.E., Kutsch W.L., Schulze E.D., 2007. Response of mycorrhizal, rhizosphere and soil basal respiration to temperature and photosynthesis in a barley field. Soil Biol Biochem 39, 843–853. https://doi.org/10.1016/J.SOILBIO.2006.10.001

[85] Müller T., Höper H., 2004. Soil organic matter turnover as a function of the soil clay content: consequences for model applications. Soil Biol Biochem 36, 877–888. https://doi.org/10.1016/J.SOILBIO.2003.12.015

[86] Nobel P.S., Palta J.A., 1989. Soil O_2 and CO_2 effects on root respiration of cacti. Plant Soil 120, 263–271. https://doi.org/10.1007/BF02377076/METRICS

[87] Norman J.M., Garcia R., Verma S.B., 1992. Soil surface CO_2 fluxes and the carbon budget of a grassland. Journal of Geophysical Research: Atmospheres 97, 18845–18853. https://doi.org/10.1029/92JD01348

[88] Novák J., Prach K., 2003. Vegetation succession in basalt quarries: Pattern on a landscape scale. Appl Veg Sci 6, 111–116. https://doi.org/10.1111/J.1654-109X.2003.TB00570.X

[89] Oberson A., Joner E.J., 2004. Microbial turnover of phosphorus in soil. Organic Phosphorus in the Environment 133–164. https://doi.org/10.1079/9780851998220.0133

[90] Orwin K.H., Ostle N., Wilby A., Bardgett R.D., 2014. Effects of species evenness and dominant species identity on multiple ecosystem functions in model grassland communities. Oecologia 174, 979–992. https://doi.org/10.1007/S00442-013-2814-5/METRICS

[91] Palta J.A., Nobel P.S., 1989. Influence of soil O2 and CO2 on root respiration for Agave deserti. Physiol Plant 76, 187–192. https://doi.org/10.1111/J.1399-3054.1989.TB05630.X

[92] Pannell D.J., Ewing M.A., 2006. Managing secondary dryland salinity: Options and challenges. Agric Water Manag 80, 41–56. https://doi.org/10.1016/J.AGWAT.2005.07.003

[93] Parton W.J., Schimel D.S., Cole C. V., Ojima D.S., 1987. Analysis of Factors Controlling Soil Organic Matter Levels in Great Plains Grasslands. Soil Science Society of America Journal 51, 1173–1179. https://doi.org/10.2136/SSSAJ1987.03615995005100050015X

[94] Peltzer D.A., Bellingham P.J., Kurokawa H., Walker L.R., Wardle D.A., Yeates G.W., 2009. Punching above their weight: low-biomass non-native plant species alter soil properties during primary succession. Oikos 118, 1001–1014. https://doi.org/10.1111/J.1600-0706.2009.17244.X

[95] Prach K., Pyšek P., 1999. How do species dominating in succession differ from others? Journal of Vegetation Science 10, 383–392. https://doi.org/10.2307/3237067

[96] QI J., Marshall J.D., Mattson K.G., 1994. High soil carbon dioxide concentrations inhibit root respiration of Douglas fir. New Phytologist 128, 435–442. https://doi.org/10.1111/J.1469-8137.1994.TB02989.X

[97] Radosz Ł., Ryś K., Chmura D., Hutniczak A., Woźniak G., Botaniki K., Przyrody O., Biologii W., Środowiska O., 2019. Rola fauny glebowej w zróżnicowaniu roślinności na zwałowisku karbońskiej skały płonnej. Inżynieria Ekologiczna Vol. 20, 21–28. https://doi.org/10.12912/23920629/113635

[98] Raich J.W., Potter C.S., 1995. Global patterns of carbon dioxide emissions from soils. Global Biogeochem Cycles 9, 23–36. https://doi.org/10.1029/94GB02723

[99] Raich J.W., Schlesinger W.H., 1992. The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate. Tellus B 44, 81–99. https://doi.org/10.1034/J.1600-0889.1992.T01-1-00001.X

[100] Ramos F.T., Dores E.F. de C., Weber O.L. dos S., Beber D.C., Campelo J.H., Maia J.C. de S., 2018. Soil organic matter doubles the cation

exchange capacity of tropical soil under no-till farming in Brazil. J Sci Food Agric 98, 3595–3602. https://doi.org/10.1002/JSFA.8881

[101] Rawlik M., Kasprowicz M., Jagodziński A.M., 2018a. Differentiation of herb layer vascular flora in reclaimed areas depends on the species composition of forest stands. For Ecol Manage 409, 541–551. https://doi.org/10.1016/J.FORECO.2017.11.055

[102] Rawlik M., Kasprowicz M., Jagodziński A.M., Kaźmierowski C., Łukowiak R., Grzebisz W., 2018b. Canopy tree species determine herb layer biomass and species composition on a reclaimed mine spoil heap. Science of The Total Environment 635, 1205–1214. https://doi.org/10.1016/J.SCITOTENV.2018.04.133

[103] Rengasamy P., 2006. World salinization with emphasis on Australia. J Exp Bot 57, 1017–1023. https://doi.org/10.1093/JXB/ERJ108

[104] Reth S., Reichstein M., Falge E., 2005. The effect of soil water content, soil temperature, soil pH-value and the root mass on soil CO_2 efflux - A modified model. Plant Soil 268, 21–33. https://doi.org/10.1007/S11104-005-0175-5/METRICS

[105] Rhoades C.C., 1996. Single-tree influences on soil properties in agroforestry: Lessons from natural forest and savanna ecosystems. Agroforestry Systems 35, 71–94. https://doi.org/10.1007/BF02345330/METRICS

[106] Roberts D.W., 2009. Comparison of multidimensional fuzzy set ordination with CCA and DB-RDA. Ecology 90, 2622–2634. https://doi.org/10.1890/07-1673.1

[107] Roberts D.W., 2008. Statistical analysis of multidimensional fuzzy set ordinations. Ecology 89, 1246–1260. https://doi.org/10.1890/07-0136.1

[108] Roberts D.W., 1986. Ordination on the basis of fuzzy set theory. Vegetatio 66, 123–132. https://doi.org/10.1007/BF00039905

[109] Rochette P., Angers D.A., Chantigny M.H., Gasser M.O., MacDonald J.D., Pelster D.E., Bertrand N., 2013. NH3 volatilization, soil NH4+concentration and soil pH following subsurface banding of urea at increasing rates. Can J Soil Sci 93, 261–268. https://doi.org/10.4141/CJSS2012-095

[110] Rodeghiero M., Cescatti A., 2006. Indirect partitioning of soil respiration in a series of evergreen forest ecosystems. Plant Soil 284, 7–22. https://doi.org/10.1007/S11104-005-5109-8/METRICS

[111] Rodeghiero M., Cescatti A., 2005. Main determinants of forest soil respiration along an elevation/temperature gradient in the Italian Alps.

Glob Chang Biol 11, 1024–1041. https://doi.org/10.1111/J.1365-2486.2005.00963.X

[112] Rosling A., Midgley M.G., Cheeke T., Urbina H., Fransson P., Phillips R.P., 2016. Phosphorus cycling in deciduous forest soil differs between stands dominated by ecto- and arbuscular mycorrhizal trees. New Phytologist 209, 1184–1195. https://doi.org/10.1111/NPH.13720

[113] Satomura T., Hashimoto Y., Koizumi H., Nakane K., Horikoshi T., 2006. Seasonal patterns of fine root demography in a cool-temperate deciduous forest in central Japan. Ecol Res 21, 741–753. https://doi.org/10.1007/S11284-006-0182-X/METRICS

[114] Savage K.E., Davidson E.A., 2003. A comparison of manual and automated systems for soil CO2 flux measurements: trade-offs between spatial and temporal resolution. J Exp Bot 54, 891–899. https://doi.org/10.1093/JXB/ERG121

[115] Scheurwater I., Cornelissen C., Dictus F., Welschen R., Lambers H., 1998. Why do fast- and slow-growing grass species differ so little in their rate of root respiration, considering the large differences in rate of growth and ion uptake? Plant Cell Environ 21, 995–1005. https://doi.org/10.1046/J.1365-3040.1998.00341.X

[116] Schimel D.S., 1995. Terrestrial ecosystems and the carbon cycle. Glob Chang Biol 1, 77–91. https://doi.org/10.1111/J.1365-2486.1995.TB00008.X

[117] Schlentner R.E., Van Cleve K., 1985. Relationships between CO_2 evolution from soil, substrate temperature, and substrate moisture in four mature forest types in interior Alaska. Canadian Journal of Forest Research 15, 97–106. https://doi.org/10.1139/X85-018

[118] Scott N.A., Cole C.V., Elliott E.T., Huffman S.A., 1996. Soil Textural Control on Decomposition and Soil Organic Matter Dynamics. Soil Science Society of America Journal 60, 1102–1109. https://doi.org/10.2136/SSSAJ1996.03615995006000040020X

[119] Scott-Denton L.E., Rosenstiel T.N., Monson R.K., 2006. Differential controls by climate and substrate over the heterotrophic and rhizospheric components of soil respiration. Glob Chang Biol 12, 205–216. https://doi.org/10.1111/J.1365-2486.2005.01064.X

[120] Shen X.S., Chen S.T., Hu Z.H., Shi Y.S., Zhang Y., 2011. [Investigation of heterotrophic and autotrophic components of soil respiration in a secondary forest in subtropical China]. Huan Jing Ke Xue 32, 3181–3187.

[121] Šimůnek J., Suarez D.L., 1993. Modeling of carbon dioxide transport and production in soil: 1. Model development. Water Resour Res 29, 487–497. https://doi.org/10.1029/92WR02225

[122] Singer M.J. (Michael J., Munns, D.N. (Donald N., 1991. Soils, an introduction 473.

[123] Singh J.S., Gupta S.R., 1977. Plant decomposition and soil respiration in terrestrial ecosystems. The Botanical Review 1977 43:4 43, 449–528. https://doi.org/10.1007/BF02860844

[124] Sinsabaugh R.L., Gallo M.E., Lauber C., Waldrop M.P., Zak D.R., 2005. Extracellular enzyme activities and soil organic matter dynamics for northern hardwood forests receiving simulated nitrogen deposition. Biogeochemistry 75, 201–215. https://doi.org/10.1007/S10533-004-7112-1/METRICS

[125] Sitaula B.K., Bakken L.R., Abrahamsen G., 1995. N-fertilization and soil acidification effects on N2O and CO2 emission from temperate pine forest soil. Soil Biol Biochem 27, 1401–1408. https://doi.org/10.1016/0038-0717(95)00078-S

[126] Six J., Elliott E.T., Paustian K., 2000. Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. Soil Biol Biochem 32, 2099–2103. https://doi.org/10.1016/S0038-0717(00)00179-6

[127] Skopp J., Jawson M.D., Doran J.W., 1990. Steady-State Aerobic Microbial Activity as a Function of Soil Water Content. Soil Science Society of America Journal 54, 1619–1625. https://doi.org/10.2136/SSSAJ1990.03615995005400060018X

[128] Stefanowicz A.M., Kapusta P., Błońska A., Kompała-Baba A., Woźniak G., 2015. Effects of Calamagrostis epigejos, Chamaenerion palustre and Tussilago farfara on nutrient availability and microbial activity in the surface layer of spoil heaps after hard coal mining. Ecol Eng 83, 328–337. https://doi.org/10.1016/J.ECOLENG.2015.06.034

[129] Stöcker G., 1990. Digby P. G. N., Kempton R. A.: Multivariate Analysis of Ecological Communities. Chapman and Hall, London - New York 1987, VIII, 206 S., £25.-. Biometrical Journal 32, 94–94. https://doi.org/10.1002/BIMJ.4710320115

[130] Subke J.A., Inglima I., Cotrufo M.F., 2006. Trends and methodological impacts in soil CO2 efflux partitioning: A metaanalytical review. Glob Chang Biol 12, 921–943. https://doi.org/10.1111/J.1365-2486.2006.01117.X

[131] Tang J., Qi, Y., Xu M., Misson L., Goldstein A.H., 2005. Forest thinning and soil respiration in a ponderosa pine plantation in the Sierra Nevada. Tree Physiol 25, 57–66. https://doi.org/10.1093/TREEPHYS/25.1.57

[132] Ter Braak C.J.F., 1987. The analysis of vegetation-environment relationships by canonical correspondence analysis. Vegetatio 69, 69–77. https://doi.org/10.1007/BF00038688/METRICS

[133] ter Braak C.J.F., Verdonschot P.F.M., 1995. Canonical correspondence analysis and related multivariate methods in aquatic ecology. Aquat Sci 57, 255–289. https://doi.org/10.1007/BF00877430/METRICS

[134] Tisdall J.M., Oades J.M., 1982. Organic matter and water-stable aggregates in soils. Journal of Soil Science 33, 141–163. https://doi.org/10.1111/J.1365-2389.1982.TB01755.X

[135] Tüfekçioğlu A., Küçük M., 2004. Soil Respiration in Young and Old Oriental Spruce Stands and in Adjacent Grasslands in Artvin, Turkey. Turkish Journal of Agriculture and Forestry.

[136] Vose J.M., Ryan M.G., 2002. Seasonal respiration of foliage, fine roots, and woody tissues in relation to growth, tissue N, and photosynthesis. Global Change Biology. 8: 182-193 8, 182–193.

[137] Wang W.J., Dalal R.C., Moody P.W., Smith C.J., 2003. Relationships of soil respiration to microbial biomass, substrate availability and clay content. Soil Biol Biochem 35, 273–284. https://doi.org/10.1016/S0038-0717(02)00274-2

[138] Wang W.W., Jiang X., Zheng B.H., Chen J.Y., Zhao L., Zhang B., Wang S.H., 2018. Composition, mineralization potential and release risk of nitrogen in the sediments of Keluke Lake, a Tibetan Plateau freshwater lake in China. R Soc Open Sci 5. https://doi.org/10.1098/RSOS.180612

[139] Wang Y., Hu Y., Ji B., Liu G., Xue M., 2003. An investigation on the relationship between emission/uptake of greenhouse gases and environmental factors in semiarid grassland. Adv Atmos Sci 20, 119–127. https://doi.org/10.1007/BF03342056/METRICS

[140] Washbourne C.L., Goddard M.A., Le Provost G., Manning D.A.C., Manning P., 2020. Trade-offs and synergies in the ecosystem service demand of urban brownfield stakeholders. Ecosyst Serv 42, 101074. https://doi.org/10.1016/J.ECOSER.2020.101074

[141] Wolińska A., 2019. Metagenomic Achievements in Microbial Diversity Determination in Croplands: A Review. Microbial Diversity

in the Genomic Era 15–35. https://doi.org/10.1016/B978-0-12-814849-5.00002-2

[142] Wolińska A., Stępniewska Z., Bielecka A., Ciepielski J., 2014. Bioelectricity production from soil using microbial fuel cells. Appl Biochem Biotechnol 173, 2287–2296. https://doi.org/10.1007/S12010-014-1034-8

[143] Xiao H.B., Shi Z.H., Li Z.W., Chen J., Huang B., Yue Z.J., Zhan Y.M., 2021. The regulatory effects of biotic and abiotic factors on soil respiration under different land-use types. Ecol Indic 127, 107787. https://doi.org/10.1016/J.ECOLIND.2021.107787

[144] Xu M., Qi Y., 2001. Soil-surface CO_2 efflux and its spatial and temporal variations in a young ponderosa pine plantation in northern California. Glob Chang Biol 7, 667–677. https://doi.org/10.1046/J.1354-1013.2001.00435.X

[145] Kuzyakov Y., 2004. Ecology of Rhizosphere Bioremediation. Phytoremediation 317–353. https://doi.org/10.1002/047127304X.CH10

[146] Yang K., Zhu J., Gu J., Yu L., Wang Z., 2015. Changes in soil phosphorus fractions after 9 years of continuous nitrogen addition in a Larix gmelinii plantation. Ann For Sci 72, 435–442. https://doi.org/10.1007/S13595-014-0444-7

[147] Yu L., Wang Yujie, Wang Yunqi, Sun S., Liu L., 2015. Quantifying components of soil respiration and their response to abiotic factors in two typical subtropical forest stands, southwest China. PLoS One 10. https://doi.org/10.1371/JOURNAL.PONE.0117490

[148] Zaharescu D.G., Palanca-Soler A., Hooda P.S., Tanase, C., Burghelea C.I., Lester R.N., 2017. Riparian vegetation in the alpine connectome: Terrestrial-aquatic and terrestrial-terrestrial interactions. ScTEn 601–602, 247–259. https://doi.org/10.1016/J.SCITOTENV.2017.05.135

[149] Zalasiewicz J., Waters C.N., Ivar do Sul, J.A., Corcoran P.L., Barnosky A.D., Cearreta A., Edgeworth M., Gałuszka A., Jeandel C., Leinfelder R., McNeill J.R., Steffen W., Summerhayes C., Wagreich M., Williams M., Wolfe A.P., Yonan Y., 2016. The geological cycle of plastics and their use as a stratigraphic indicator of the Anthropocene. Anthropocene 13, 4–17. https://doi.org/10.1016/J.ANCENE.2016.01.002

[150] Zarif N., Khan A., Wang Q., 2020. Linking soil acidity to p fractions and exchangeable base cations under increased n and p fertilization of mono and mixed plantations in Northeast China. Forests 11, 1–19. https://doi.org/10.3390/F11121274

[151] Zeng X., Zhang W., Shen H., Cao J., Zhao X., 2014. Soil respiration response in different vegetation types at Mount Taihang, China. Catena (Amst) 116, 78–85. https://doi.org/10.1016/J.CATENA.2013.12.018

[152] Zhang F.G., Zhang Q.G., 2016. Microbial diversity limits soil heterotrophic respiration and mitigates the respiration response to moisture increase. Soil Biol Biochem 98, 180–185. https://doi.org/10.1016/J.SOILBIO.2016.04.017

[153] Zhang H., Shi L., Fu S., 2020. Effects of nitrogen deposition and increased precipitation on soil phosphorus dynamics in a temperate forest. Geoderma 380, 114650. https://doi.org/10.1016/J.GEODERMA.2020.114650

[154] Zhang T., Li Y., Chang S.X., Jiang P., Zhou G., Zhang J., Liu J., 2013. Responses of seasonal and diurnal soil CO_2 effluxes to land-use change from paddy fields to Lei bamboo (Phyllostachys praecox) stands. Atmos Environ 77, 856–864. https://doi.org/10.1016/J.ATMOSENV.2013.06.011

[155] Zheng Z.M., Yu G.R. Fu Y.L., Wang Y.S., Sun X.M., Wang Y.H., 2009. Temperature sensitivity of soil respiration is affected by prevailing climatic conditions and soil organic carbon content: A trans-China based case study. Soil Biol Biochem 41, 1531–1540. https://doi.org/10.1016/J.SOILBIO.2009.04.013

3. The dynamic processes of temporal and spatial patterns in ecosystem processes

The **third** part of the book addresses the dynamic processes of temporal and spatial patterns in ecosystem processes. We focused on considering the integrated effects of these processes at the landscape and between species scale, above- and below-ground level, and their consequences for ecosystem functioning effectiveness. The ecosystem functioning effectiveness is the basis for reasonable (called sustainable) use by human societies.

The continuous change of the mosaic of varied ecosystem stages of natural and human induced ecosystem development in different successional series provide high possibilities to enhance biodiversity, water retention, and carbon sequestration.

It is described how the knowledge available for the natural and semi-natural habitats is applicable to the novel ecosystem of the urban-industry landscape.

3.1. The temporal and spatial patterns and biodiversity during ecosystem development

Biodiversity is frequently characterized by species richness, which is a commonly used diversity measure that reflects the fundamental aspects for understanding the relationship between species diversity, biomass and ecosystem productivity (Díaz & Cabido, 2001). Species richness provides a measure of diversity that is strictly related to many processes that regulate ecosystem functioning. However, based only on species richness, it is challenging to relate particular ecosystem processes to each species and determine their contributions to ecosystem functioning and productivity. The formula used for species richness calculation assumes that all species are equivalent. The functional differences among species are not accounted for. Functional diversity is the crucial determinant of ecosystem functioning (Tilman, 2001).

Most studies focused on the relationship between biomass and diversity of vegetation plant species composition have been conducted in relatively not complex ecosystems, such as poor in-species grasslands and forest monocultures. Regardless of the uncertainty about the biodiversity-biomass relation in natural and semi-natural ecosystems, human-induced environmental change occurrs globally. The ecosystem properties are altered directly through changing abiotic conditions and indirectly by modifying community composition. Some of the changes are revisable.

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However, when human activity causes the transformations that cross the ecological threshold, the novel ecosystem develops. The novel ecosystems evolve under anthropogenically derived conditions frequently on the habitats established de novo by humans (Hobbs et al., 2006; Prach & Hobbs, 2008; Hobbs et al., 2013; Morse et al., 2014). Hobbs et al. (2006) found that in novel ecosystems, the primary production depends on vegetation assemblages composed of plant species not known from any natural or semi-natural vegetation type. The non-analogous species composition is emerging in habitats and environments not known from natural and semi-natural conditions (Keith et al., 2009; Williams, Jackson et al., 2007). The non-analogous plant species assemblages cause consequently the non-analogous composition of the above- and below-ground organisms related to the primary producer (Figure 3.1.1) (Keith et al., 2009; Williams, Jackson et al., 2007).

Figure 3.1.1 During the spontaneous colonization of the mineral material of the post coal mine heaps novel ecosystem, the tree seedlings and juveniles of deciduous and coniferous species are present as the first colonizers together with the herbaceous plant species that are assembled in the vegetation communities. In the picture, herbaceous plant *Chamaenerion palustre* (left top corner) is growing with juvenile coniferous species *Pinus sylvestris* (right bottom corner)

The coal mining industry has been declined all over Europe, with only some mines still remaining active. Inactive coal mine sites are large areas of post mining mineral material, presenting a range of habitats of different moisture conditions. Most of the earlier closed mines were left to nature to undergo successional processes. Some closed mines according to evidence show that post-industrial sites, left to naturally processes to operate, have provided opportunities for colonization by local biodiversity. The specific conditions of post mining sites are colonized by rare species, and sometimes become designated nature reserves (Figure 3.1.2). Such sites can be examples of how the post mining sites provide opportunities for facilitated restoration and enhanced habitat creation, including creating grasslands using strewn green hay from a local meadow. Some features of the buildings associated with these mines can be left to provide the industrial heritage, which together with rare species and extraordinary biodiversity can form an additional interest for the leisure activities of local communities (Figure 3.1.3).

Figure 3.1.2. The Pogoria water reservoir protected area is based on previous post sand mining. It covers an area of 40 ha. The aim of the protection of this area is to preserve, landscape, habitats of water and marsh birds, plant communities, plants and animals. The following plants and fungi that are under total protection: angelica, yellow water lily, marsh helleborine, red helleborine, raspberry honeysuckle. The fauna in this area is represented by a total of 84 species of vertebrates, of which 52 are under total protection, 8 under hunting protection, 10 under fishing protection and 2 under temporary protection

With careful management and strategic planning of the restoration system based on the newest biological and environmental knowledge, using the local topography and soil conditions, the post mining sites have the potential to have high biodiversity value and thus be effectively returned to nature and reintegrated into the landscape.

Many post-industrial sites create the opportunity to provide open spaces for people and for biodiversity by provisioning different types of habitats depending on the environmental conditions left as a consequence of their previous industrial use. The long history of coal mining in Europe is slowly finishing. It has started with the closure of unproductive mines. In UK e.g., planning legislation was

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introduced in 1948 and consolidated into statutes, until the National Planning Policy Framework (2019).

Figure 3.1.3. The coal mine heaps that undergo spontaneous succession are located among towns and cities. In the front part of the picture the belt shape patch of *Calamagrostis epigejos* is dominating, in the background behind there are some tree juvenile individuals. The inhabitants of the local communities can find special place for having a rest and be surrounded by wild life

Traditional restorations and reclamation are aimed at establishing acceptable vegetation as quickly as possible (Bradshaw & Chadwick 1980). For a long time in the past, agricultural or forestry tree planting purposes have been introduced using frequently invasive species *(Quercus robur*, *Padus serotina*, *Pinus nigra* etc.) which have been considered for strange reasons as being better adapted. Such methods were labour and finances consuming, and the results were very questionable. By the 1990s priorities had changed and the approach "do-nothing" along with the nature conservation amenity use became valid end-points of the management and restoration (Anonymous 1994a; 1994b). More recently, the goal of restoration and management is to allow natural processes to operate and create self-supporting ecosystems that are resilient to disturbances without further human assistance (Society for Ecological Restoration 2004). Many examples have shown that natural processes manage to eliminate toxicities and to return to a functioning ecosystem in sites after different mineral resources excavation (HMSO 2021). The effective restoration planning needs to establish long-term monitoring, that enables the understanding the natural processes going on, in an individual site-specific way, in order to develop realistic goals, that consider the biological and environmental rules together with the human population and their needs (Rocha-Nicoleite et al., 2017).

Succession theory and natural regeneration of mining sites

Based on the knowledge of the classical succession theory it should be expected that once the mines are closed down and post coal mining sites stop their operation, the movement of substrate is ceased, then the mineral material of the post mineral resources sites should be initially colonized by lichens, mosses, and liverworts, later by grasses, sedges and rushes and ultimately by herbaceous species, which can be slow to colonize, particularly in areas of high toxicity or poor, oligotrophic mineral soil substrates. It should also be expected that the early colonists are small ephemeral species, with short life cycles, quickly exploiting available resources and taller ruderal species. Plants will exploit the local very limited resources as these become available, and some species will even tolerate the relatively high toxicities and extremes of high, or low, pH levels associated with post-industrial sites (Figure 3.1.4).

Figure 3.1.4. The pure mineral material of the post-coal mine heaps is different in terms of texture. There are parts where the stone fraction prevails in the texture composition, in other parts the gravel and sand fraction present higher participation on the heap surface. Red rush *Phragmites australis* is spreading outside the water body

The post-mineral mining sites can be very variable in their moisture conditions, and water-holding capacities, with localized water accumulation where soils are heavily compacted, or very well drained in locations where substrate particle sizes are large and water can percolate rapidly (Figure 3.1.5). Interesting assemblages of aquatic plant species can quickly colonize open areas of ponds, with associated colonization over time by amphibians and aquatic invertebrates. Reptiles are known to bask on the open sun-facing slopes of pit mounds but are usually sufficiently uncommon to increase the value of sites. Where plants have naturally colonized and become established, it is important to ensure that the implementation of any restoration scheme is mindful of safeguarding them (Lunn 2000).

Figure 3.1.5. The lower microsites are filled with rain water. Such lower microsites are filled with fine material that is moved slowly with rain water and deposited in the hole. In the picture, it is indicated as a light grey part of the heap surface (upper picture). Frequently there are little ponds occurring spontaneously at the bottom of the heaps (bottom picture)

Natural processes in urban and post-industrial sites

Many urban post-industrial (often known as brownfield) sites are known to be ecologically interesting for their spontaneous assemblages of non-analogous plant species. The slow initial colonization often results in a variety of vegetation assemblages at these sites. This type of open mosaic habitat, on previously developed land (Rodwell 2000), is a priority for conservation in many protection strategies such as the United Kingdom's Biodiversity Action Plan (BAP). In recent years as regards urban areas, the spontaneous colonization of post mining sites has resulted in the classification of such sites as nature reserves for specific species conservation. Preserving this kind of vegetation in existing brownfield sites is important for town and city planners as it helps with international biodiversity commitments (Buglife 2009). Where spontaneous open habitats have developed, these can be further enhanced by expedient habitat creation (e.g. meadows), if the vegetation is less developed in some places, and where appropriate depending on the localized conditions and the size of the site. On-site substrate conditions may facilitate particular opportunities, depending on previous history and future development plans.

Figure 3.1.6. The primary colonizers are sometimes very tiny species, such as *Poa compressa* in the picture. These little grassroots exudates attracted a high diversity of microorganisms in the belowground part of the developing ecosystem

Apart from the grasses, the herbaceous plants and vegetation are very important. Bees and hover flies and other pollinating animals require support across towns and cities as well as on agricultural areas and this is being provisioned under the (e.g., in the UK) National Pollinator Strategy (Defra 2014). Increased plant species, and therefore floral diversity, in the open habitats of post-mining and post-industrial sites, can help to promote habitat for pollinators and key invertebrate species, and these sites can be refuges in urban areas (Buglife 2009; 2019). In the UK around 30 species of butterflies, and many species of moths, are associated with brownfield sites and respond rapidly to any changes in condition of these sites (Butterfly Conservation 2019). Butterflies in particular have a preference for the open, varied habitats of post-mining and post-industrial sites, and can naturally colonize sparsely scattered patches of vegetation (Figure 3.1.3). Post-mining and post-industrial sites should also be managed for pollinators, as these post-industrial sites provide safe havens from pesticides. This can be done after a site evaluation for its value for wildlife (Defra 2014). Land managers need to provide essential resources and habitats for pollinators, which require herbaceous species composition of vegetation which is providing pollen and nectar as food sources between February and October, so plants need to be allowed to flower continuously throughout the season, and places to nest and shelter should be left undisturbed during the hibernation period. To prevent sparse vegetation for butterflies from disappearing from these sites, they need occasional disturbance and scrub clearance (Butterfly Conservation 2019).

How to enhance natural process during the Green Infrastructure development in towns and cities

The presence of biodiversity has been seen as an important success criterion of post-industrial green projects, and it has to be seen as a prime tool for regional economic regeneration, neighborhood renewal, and achieving its international biodiversity commitments like in the UK (Doick *et al.* 2009; Pediaditi *et al.* 2010). However, post-industrial sites that have been neglected, and left undisturbed, are often peaceful sanctuaries for biodiversity. Post-mining and post-industrial sites can be used as a component of green infrastructure and open site development for sustainable cities. The enhancement of nature-based solutions for land use management by developing these kinds of open extended areas of post-mining and post-industrial sites is replacing the loss of greenfield sites from the countryside (agriculture and real estate (housing)) and adding to existing urban sprawl (Figure 3.1.7).

Many brownfield sites form mosaics of different land uses with their diversity of soil or soil substrates leading to the development of different plant communities, which are differentiated in their successional age stages, along with patches of native habitat within urban landscapes containing very different species of plants and animals and the associated diverse microorganisms' communities (Bonthoux *et al.* 2014). Landscape connectivity and recolonization dynamics are key factors in continuing species population persistence at these post-mining and post-industrial sites. In addition, these post-mining and post-industrial green spaces can provide opportunities for local people to widen their access to nature and wild life, in order for them to enjoy being in the natural world (Millward & Mostyn 1989; Icarus 2014) and to increase their outdoor recreation through walking in green gyms, dog walking, children playing in wild play areas, bird watching and heritage appreciation.

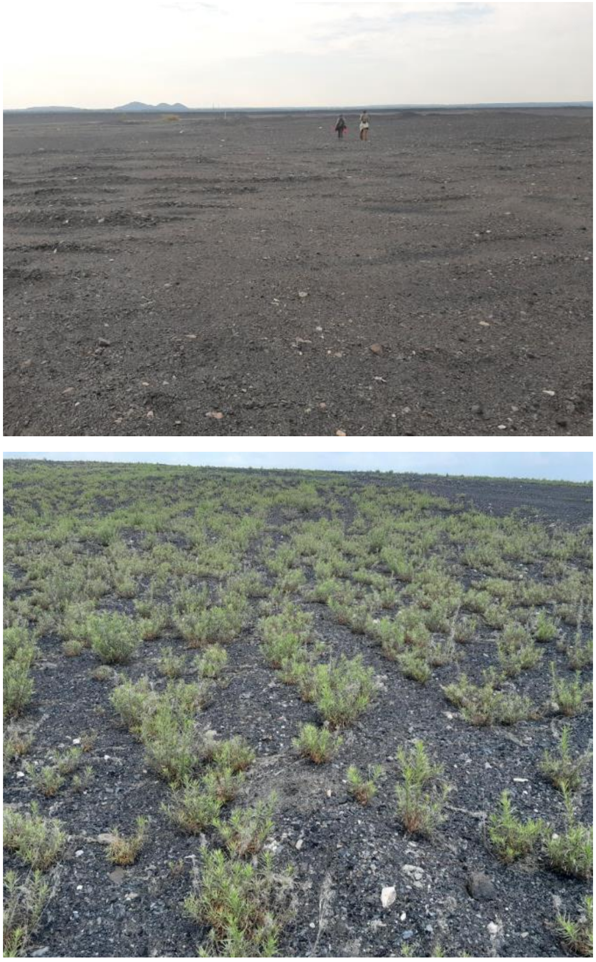

Figure 3.1.7. The just established post coal mine sites (upper picture) are colonized by the first plants in the next growing season (bottom picture)

The nature conservation strategy is different and specific in each country. In Britain, sites with significant biodiversity interest or sites with considerable interest were awarded statutory protection under the Wildlife & Countryside Act (1981) as Sites of Special Scientific Interest (SSSIs) and National Nature

Reserves (NNRs) under rigorously defined criteria (Ratcliffe 1976; Nature Conservancy Council 1989). Also, under EU legislation the sites such as Special Protection Areas (SPAs) under the EC Directive (79/109) for the Conservation of Wild Birds and Special Areas of Conservation (SAC) under the Habitats Directive (1992) were designated. These sites are all natural, or semi-natural. Initially, when the sites were designated among the SSSIs, many of them were post-mining and post-industrial sites due to the Nature Conservation Value.

In the UK, there is another form of preservation is the Local Nature Reserve (LNR). The Local Nature Reserve (LNR) is an area of land pointed by a local authority because of its special local natural interest. The (LNR) can also be assigned due to its educational and local community value (Natural England 2010; Gov.UK 2019). The post-mining and post-industrial area still occurr in urban areas (Natural Environment and Rural Communities Act 2006). These sites should be publicly accessible. The visitors should appreciate and enjoy close contact with wildlife not far from the place, where they live. In Britain, these sites have the lowest level of protection, and the LNR can cover to Natural England's targets, a minimum of 1 ha of LNR per 1000 heads of population (Natural England 2013). The LNR sites are managed by local authorities for their local citizens to provide wildlife and recreation and amenity value.

Country Parks were designated mostly in the 1970s in order to provide areas in towns for local people to visit nature and enjoy recreation, under the Countryside Act 1968 (Gov.UK 2014). The Country Parks are mainly managed by local authorities. They are mainly areas of public open space close to the edge of urban conurbations and have some formal facilities such as cafés, toilets, and car parks. They were often post-industrial sites, hence their proximity to urban areas.

In particular, it is important to underline this fact in respect of the growing body of results reviling the biodiversity developing on post mining and post-industrial sites, that in some countries e.g., in Britain there is a level of designation below the category of Local Nature Reserve and Country Park. These sites of lower level of designation were mostly post mining and post-industrial sites, particularly old coal mines. These non-statutory sites have no legal protection but have been recognized by the local authority responsible for the land, on which they are found, as being of interest for nature conservation. Those sites are called different names in different parts of the country. In the West Midlands they are known as Sites of Interest for Nature Conservation (SINC). There is also a level below this known as Sites of Local Interest for Nature Conservation (SLINC). In Shropshire similar Sites of Interest are designated by Shropshire Wildlife Trust (McKelvey 2014) as sites which are of county significance by a range of diversity, rarity, scientific, research or educational value of their fauna, flora or geology. Criteria for an assessment of nature conservation value are kept under regular review through the Local Sites Partnership (Defra 2020). There are similar designations for geological sites, showing the need for the wider protection of geological features for educational purposes (Box & Cutler 1988). Such sites also provide a link with the past industrial activity.

Figure 3.1.8. The factors influencing the effective industry heritage conservation in order to protect its value for future generations

In the (1970s and 1980s) a number of post-industrial sites in the West Midlands were designated for nature conservation after the revision of the selection criteria for Sites of Importance for Nature Conservation (SINCs) which recognized the value of post-industrial sites across the Black Country and wider West Midlands (Box et al., 1994). Box & Cossons (1988) had earlier argued that the post-mining and post-industrial sites had an intrinsic value for rare species, such as clubmosses (*Lycopodiaceae*), which they found growing in moss and lichen-dominated communities on the acidic clay spoil of an abandoned opencast coal mine in Telford. A large number *Lycopodium calavatum* individuals have been recorded in some abandoned opencast sandstone quarries (unpubl. 2023). Lunn (2000) evaluated colonizing plant species, on sites from coal mines in Yorkshire, with respect to the nationally rare, scarce species lists and local scarcity from published county floras.

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The Nature Based Solutions (NBS), putting nature back into cities and towns, causes vegetation communities and vegetation community involvement as the prerequisite of ecosystem development which is directly or indirectly involved in the economic redevelopment of urban and industrialized areas. Often local communities take ownership of these areas and form groups that manage the site and are responsible for it. Such nearby sites can also promote aspects of healthy living possibilities for the local people who live in the neighbourhood, providing amenity areas for them (Figure 3.1.8).

From local sites up to conserving nature at the landscape scale

The UK has a long tradition of protecting natural values in many aspects. Sir John Lawton has prepared a review of England's wildlife sites (Lawton et al., 2010). In this paper, he appealed for making space for nature. The report suggested a particular approach to conservation efforts to improve existing natural sites in connection with the surrounding sites in adjacent areas to strengthen and expand areas available to wildlife. Sir John Lawton wanted to include the landscape scale approach to targeted nature conservation across the country. Consequently, the current National Planning Policy Framework (NPPF Section 15) (HMSO 2021; Besenyei 2023) requires in each decision the consideration of previously developed land. The use of any site under decision should be analyzed to be for nature and amenity purposes and would be available for nature conservation by allowing land that has been naturally re-colonized to persist as a nature reserve. In particular, the land from old coal mines offers opportunities to provide additional land for nature. Facilitating the re-colonization by nature and providing a strategic habitat creation, extending the amount of land available for wildlife and enhancing ecological networks, especially if this is near existing sites of interest, seem to be crucial.

In England, the history of mining and industry is one of the longest ones. The region of Ironbridge witnessed the Industrial Revolution. In 1913, the number of 2600 deep mines employed more than a million miners. After 1947, only a few were still operating (Falconer & Gould 2011). The conservation of the industrial heritage is particularly strong in this area. The importance of industrial heritage was recognized in the early 1960s and a programme of designation of the most important sites was implemented. It has been decided that the industrial sites would be left to the voluntary sector to look after (Cussons 2011). The preservation of the legacy of England's industrial heritage over the last 50 years was not random. Industrial museums have been created, and six World Heritage Sites have been inscribed, including the site of the birthplace of industry in Ironbridge, near Telford, Shropshire (Falconer & Gould 2011). However, it is inadequately resourced and lacks vision and strategic thinking (Falconer & Gould 2011).

One of the significant UK industrial heritages is Chatterley Whitfield, near Stoke-on-Trent, Staffordshire. This place was the Britain’s first one-million-ton coal mine. It was closed in 1977 and was designated a scheduled monument by Historic England as the most complete example of a large coal mine in England. It has temporarily become a museum but had to close (Chatterley Whitfield 2019). Another example is the Baggeridge Colliery which was owned by the Earl of Dudley. Full production started in 1912 and 550,000 tons were produced annually by 1933. When it was taken into public ownership 1,500 people were employed there (Morris 2019). It was once the largest coal mine in the world, now remaining only by a few short lengths of rails with a cart (AditNow 2019a). The site was later designated a Country Park in 1970 (Mailding 1980a; Mailding 1980b; Besenyei 2023). The site now has 15 different habitat types (Trueman 1991) of which eight are included in the county Biodiversity Action Plan (Staffordshire Biodiversity Action Plan 2019; Potter 1991). The vegetation diversity includes neutral woodland with *Quercus robur* and wet woodland (mainly *Alnus* glutinosa) calcareous woodland with *Fraxinus excelsior* and *Allium ursinum*, lowland heathland, grassland (mostly amenity and some species-rich, 10 ha), reed bed, lakes, streams and ponds. The ongoing management aims to enhance the biodiversity where possible (Gallis et al. 2015). Plant diversity is enhanced by the wide range of soil types in terms of their pH and nutrient content, which support both calcifuges (*Calluna vulgaris* and *Ulex europaeus*) and calcicoles (*Ophrys apifera* and *Blackstonia perfoliata*).

The biodiversity at the site is considered to be good with a good diversity of species mainly as a consequence of the range of varied mosaic of habitats on the particular site (Figure 3.1.9). Biodiversity should be defined as the number of species typical for the particular habitat types that reflect the essence of ecology, the relationship between living organisms and their habitat.

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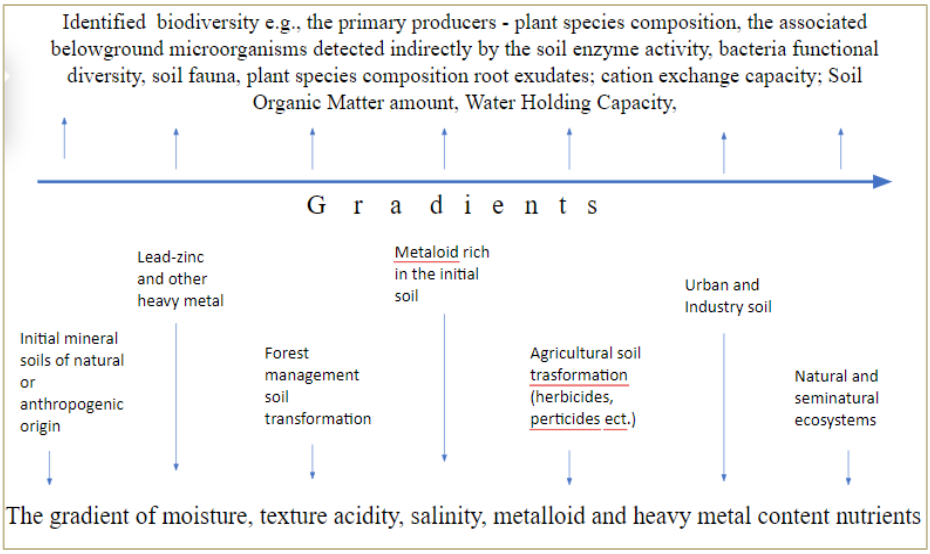

Figure 3.1.9. Biodiversity at the site is in the first place a consequence of the range of varied mosaic of habitats from dry habitats to water on the particular site

The sites of biodiversity can be designated as Sites of Biological Importance (SBI) (Staffordshire Biodiversity Action Plan 2019). In the West Midlands of England there are sites on which over 350 species of plants have been recorded, 29 species of butterflies, 378 species of moths, 15 species of dragonflies and 127 species of birds. Species of note for the region, and nationally, are currant clearwing (Synanthedon tipuliformis) (Lepidoptera, nationally scarce), hornet moth (Sesia apiformis) (Lepidoptera, nationally scarce), white letter hairstreak (Satyrium w-album), white clawed crayfish (Austropotamobius pallipes) (Decapoda, nationally scarce), great crested newt (Triturus cristatus) (Amphibia, Caudata, European protected species), six-belted clearwing (Bembecia ichneumoniformis) (Lepidoptera, nationally scarce), (Lepidoptera, species of principal importance in England and Wales) and dingy skipper (*Erynnis tages*) (Lepidoptera, species of principal importance in England, Wales and Northern Ireland). The increase in orchids has been recorded (Gallis et al., 2015, Besenyei 2022). The outstanding nature conservation value of the wetlands particularly those in the neighbouring area are enhanced by the presence of open water, and pools (Gallis et al., 2015). (South Staffordshire Council, 2019; Green Flag Award 2019). In this respect the sustainable urban drainage pond (SUDS), can be incorporated into the management planning framework (Town & Country Planning Act Section 106; Besenyei 2022) (Figure 3.1.9).

Fair Lady Coppice Colliery opened in 1893 and closed in April 1964. Whilst in operation the spoil was dumped on the heathland and grassland in the area surrounding the pit head (Cannock Chase Council 2016; Cannock Chase Mining Historical Society, no date; Barnes 2019). The natural regeneration was allowed to take place on these sites (Cannock Chase Council 2017). Two ponds were created on top of the plateaus. The poor soil conditions resulted in an open mosaic habitat consisting of early successional stage species along with wild carrot (*Daucus carota*), bird's-foot trefoil (*Lotus corniculatus*), ox-eye daisy (*Leucanthemum vulgare*), and in some patches also with purple moor-grass (*Molinia caerulea*) and wavy hair grass (*Deschampsia flexuosa*). In some areas, grassland is widespread and dominated by ladies' bedstraw (*Galium verum*) and common century (*Centaurium erythraea*). In the shalow water bodies the reed mace (*Typha angustifolia*) along with *Phragmites australis* can be common in the ponds like it is in the Staffordshire sites (Cannock Chase Council 2015; Besenyei 2023).

The site is of value to butterflies. Dingy skipper (*Erynnis tages*) and common blue (*Polyommatus icarus*) are doing well at the site. Small heath (*Coenonympha pamphilus*), large skipper (*Ochlodes sylvanus*), small skipper (*Thymelius sylvestris*), Essex skipper (*Thymelicus lineola*), meadow brown (*Maniola jurtina*) and ringlet (*Aphantopus hyperantus*) are all common. Skylark (Alauda arvensis) and meadow pipit (Anthus pratensis) are known to breed at the site. The wetland areas on the southern plateau supported breeding populations of little ringed plover (*Charadrius dubius*) and lapwing (*Vanellus vanellus*) until 1993 and 2013, respectively. Due to successional vegetation changes, wading birds no longer breed here. The site has recently supported winter populations of snipe (*Gallinago gallinago*) and migrant jack snipe (*Lymnocryptes minimus*) in large numbers. Six species of birds of prey have been regularly recorded at the site. Common lizards (*Zootoca vivipara*) have been recorded on the southern slope and common toad (*Bufo bufo*), common frog (*Rana temporaria*) and smooth new breed in the ponds. Red (*Cervus elaphus*) and muntjac (*Muntiacus reevesi*) deer regularly use the site, and badgers (*Meles meles*) and rabbits (*Oryctolagus cuniculus*) breed on the site.

The site is currently (from 2011) in a ten-year-Higher-Level Stewardship agreement with Natural England for its management (Natural England 2012). The two main objectives for the site are heathland creation and the provision of habitat for wading birds. The tree plantations are to be managed for one hundred years by the company that planted them in accordance with good silvicultural practice (Cannock Chase Council 2015). The bare areas are becoming reduced in number and in extent. However, additional management of scalloping woodland edges, grazing with Dexter cattle, repairing fences, and keeping paths open are undertaken annually. Periodically, when tall vegetation becomes established, the plateaus are scraped with a small digger to retain short plant species and shallow water in the winter for birds and amphibians.

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The site lies between Cannock Chase and Brownhills Common, both large areas of remaining semi-natural heathland, and close to the Chasewater and Southern Staffordshire Coalfield Heaths Site of Special Scientific Interest, thus, within a landscape context increasing the size of local patches of heathland within this corridor is important. The site is used by local dog walkers and children who use the site for wild/informal play. Two football pitches have been on-site since the coal mine closed down.

Granville Colliery was owned by Earl Gower and opened in 1860. It survived Nationalisation in 1947 but closed in June 1979 (AditNow 2019b) when it employed 560 men and was the last working coal mine in Shropshire (Friends of Granville, no date). At its peak in the 1960s it produced 600,000 tons of coal per annum (Shropshire History 2016). It was located in a semi-rural area, with agriculture to the north and east and the industrial villages that now make up the new town of Telford to the south and west.

Extensive natural regeneration has taken place on the land that was once Granville Colliery over the intervening years since its closure (Latham 2019). Telford Nature Conservation Project (1985) provided an ecological report for Telford Development Council from surveys undertaken in 1984 and when there were still remains of mining buildings and associated coal yards where the coal mine had stood. The immediate surroundings of the site suggested they had been modified by mining activities with the result that a patchwork of heavily grazed small meadows, hedgerows, scrub (dominated by hawthorn *Crataegus monogyna*) and areas of impeded drainage had resulted. At that time four main habitats were present that had probably developed since closure, these were heathland, grassland, scrub, and wetland with small pools (with *Juncus* spp. and *Typha latifolia*). There are no records of tree planting taking place at the site in the report, but the large area of coal shale deposits in the centre of the site was rapidly being colonized by birch (*Betula pendula* and *B. pubescens*) (suggesting acidic soil) with occasional Scots pine (*Pinus sylvestris*) and sallow (*Salix cinerea*). The flora here at that time included white melilot (*Melilotus alba*) and ribbed melilot (*M. officinalis*) which are rare in Shropshire, and blue fleabane (*Erigeron acer*) (suggesting alkaline soils) which is uncommon in Shropshire. The pit mound was being colonized by *B. pendula* and some ruderal species, dyer's weed (*Reseda luteola)* and docks (*Rumex* spp.). Over the intervening years the coal mine site has naturally regenerated further and has become incorporated into the re-vegetated post-industrial areas in the vicinity (Landscape Architects 2002; Latham 2019; Telford & Wrekin Council 2019). This wider area has been incorporated into Telford's development plan for the northeast of the town.

The different vegetation types establishment and non-analogous species composition on post-mining and post-industrial sites

Post-industrial sites can give possibilities for meadow creation on varied types of land, including post-coal mine sites (Trueman & Millett 2003; Walker et al., 2004). (). Grassland habitat creation increases plant diversity, along with insects and other animals at new habitats. It has been possible to create the replicas of the phytosociological meadow type *Cynosurus cristatus – Centaurea nigra* hay meadow community (Rodwell 1992) (European Cynosurion) very fresh green hay (Trueman & Millett 2003; Grime et al., 1988; Gamble 2015) on various types of post-industrial sites. A study by Jones et al., (1995) found that good ground preparation and spreading green hay, as well as the use of appropriate management techniques, led to species diversity as much as 90% similar to the source meadow. However, a number of species have proven too difficult to transfer for various reasons, including those which set seed outside the normal harvesting time. Vegetation rich in flowering dicotyledonous species can be obtained within two years of hay being spread on an area equivalent to a third of the size of the source site using hay from a suitable flower-rich MG5 Crested dog's-tail – Black knapweed *Cynosurus cristatus–Centaurea nigra* hay meadow (Besenyei 2000). Some treatment is possible (McCrea et al., 2001a; McCrea et al., 2001b). The soils had pH ranging from 4.5 to 6.5 and thus classified as mesotrophic grasslands (Rodwell 1992).

Figure 3.1.10. The meadow species such as *Daucus carota* (in the middle of the picture) occur spontaneously. The sharp borders of the spontaneous vegetation patches reflect the differences in habitat conditions and explain the difficulties in implementing the necessary management

One of the main problems of habitat creation is the necessity to manage them once created, and many schemes fail as a consequence of not implementing the necessary management regime (Parker 1995) (Figure 3.1.10). The very minimum requirement is the need to cut and remove the hay, ideally removed in late summer. If this cannot be undertaken, the diversity of the vegetation can deteriorate within two seasons (Besenyei 2000). Germination and growth of species in the first season can be disappointing, perhaps because of disturbance, which can result in the germination of weed species which grow more vigorously than the desired species and because many species do not flower for a couple of seasons after establishment. However, common spotted orchid (*Dactylorrhiza fuchsii*) and green winged orchid (*Anacamptis morio*) have been found flowering on post-industrial sites in the second season after seeding (Besenyei 2022).

One of the examples i.e. Case Study of Meadow Creation is located on an Old Colliery – Ettingshall Park Meadow, in Wolverhampton vicinity. In this creation a seed mixture was used. It was devised by Professor Ian C. Trueman to establish a meadow that would only require summer management (Trueman 1993) (pre-dating the publication of the British grassland community descriptions (Rodwell 1992). In preparation for seeding, the subsoil was harrowed several times. Growth of the vegetation has been very open and short over most of the meadow with the plant species such as cornflowers (*Centaurea cyanus*), and yellow rattle (*Rhinanthus minor*) scattered evenly onto the meadow (Besenyei 2022).

It is possible to plan landscape links to facilitate greater connectivity of sites for biodiversity. Careful planning by facilitating nature through the establishment of green corridors and strategic green planting should help to facilitate this action. Footpaths will allow people's access to the wider countryside from these post-industrial sites. Sites of old coal mines should be saved for their amenity and heritage value, as features in the landscape and most of all for their nature conservation potential (Besenyei 2022).

References

[1] AditNow 2019a: Mine Exploration and Mining History – Baggeridge Colliery.https:/www. aditnow.co.uk/Photo/Baggeridge Colliery_83481/, access: 13.09.2019.

[2] AditNow 2019b: Mine Exploration and Mining History – Granville Colliery.https://www aditnow.co.uk/Mines/Granville-Coal-Mine_4428/, access: 29.09.2019.

[3] Anonymous 1994a: Minerals Planning Guidance: Coal Mining and Colliery Spoil Disposal. MPG3, Department of the Environment. HMSO, London.

[4] Anonymous 1994b: Amenity Reclamation of Mineral Sites. Department of the Environment. HMSO, London.

[5] Barnes S. 2019: Cannock Chase Council – on Site Conversation with Author. 13.09.2019.

[6] Besenyei L. 2000: The management of artificially created species-rich meadows in urban landscaping schemes. Unpublished PhD thesis, University of Wolverhampton.

[7] Besenyei L. 2022: Returning Collieries Back to Nature in England, UK In: Green Green scenarios: mining industry responses to environmental challenges of the anthropocene epoch: International Mining Forum 2021. Dyczko, Jagodziński & Woźniak (eds.) 2022 Taylor & Francis Group, London, UK

[8] Bonthoux S., Brun M., Di Pietro F., Greulich S. & Bouché-Pillon S. 2014: How can wastelands promote biodiversity in cities? A review. Landscape and Urban Planning, 132, 79–88.

[9] Box J. & Cutler A. 1988: Earth Science Conservation. Nature Conservancy Council Regional Focus, 25, 29–35.

[10] Box J., Douse A. & Kohler T. 1994: Non-statutory sites of importance for nature conservation in the West Midlands. Journal of Environmental Planning and Management, 37 (3), 361–367.

[11] Box J.D. & Cossons V. 1988: Three species of clubmoss (Lycopodiaceae) at a lowland station in Shropshire. Watsonia, 17, 69–71.

[12] Bradshaw A.D. & Chadwick M.J. 1980: The Restoration of Land. Blackwell, Oxford.

[13] Buglife 2009: Planning for brownfield biodiversity: A best practice guide. Buglife – The Invertebrate Conservation Trust, Peterborough.

[14] Buglife 2019: Brownfield sites under threat. https://www.buglife.org.uk/resources/habitat-hub/brownfield-hub/brownfields-sites-under-threat/, access: 11.10.2019.

[15] Butterfly Conservation 2019: Brownfields for Butterflies. https://butterfly-con-servation.org/sites/default/files/habitat-brownfield-leaflet.pdf, access: 11.10.2019.

[16] Cannock Chase Council 2015: Fair Lady Coppice Nature Reserve Management Plan. Unpublished.

https://doi.org/10.32056/KOMAG/Monograph2023.5

[17] Cannock Chase Council 2016: Parks and Open Spaces – Fair Lady Coppice. https://www.cannockchasedc.gov.uk/residents/leisure/parks-open-spaces/nature-reserves/fair-lady-coppice, access: 25.09.2019.

[18] Cannock Chase Council 2017: Fair Lady Coppice Local Nature Reserve On-site Information Board.

[19] Cannock Chase Mining Historical Society (no date): Coppice (Fair Lady) Colliery – On-site Information Board, access: 13.09.2019.

[20] Chatterley Whitfield 2019: Chatterley Whitfield Friends. https://chatterleywhitfieldfriends.org.uk/, access: 30.09.2019.

[21] Cossons N. 2011: Saving the Age of Industry. Conservation Bulletin, 67, Autumn, 3–6.

[22] Defra 2014: The National Pollinator Strategy: for bees and other pollinators in England. November 2014. Department for Environment, Food and Rural Affairs. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/794706/national-pollinator-strategy.pdf, access: 27.11.2021.

[23] Defra 2020: Nature conservation: Local Sites in positive conservation management in England, 2008/09 to 2018/19. Department for Environment, Food and Rural Affairs. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/857437/Local_Sites_in_positive_conservation_management_England_2008-09-2018-19_FINAL.pdf, access: 27.11.2021.

[24] Doick K.J., Sellers G., Castan-Broto V. & Silverthorne T. 2009: Understanding success in the context of brownfield greening projects: The requirement for outcome evaluation of success assessment. Urban Forestry & Urban Greening, 8 (3), 163–178.

[25] Falconer K. & Gould S. 2011: Stewards of a Global Legacy. Conservation Bulletin, 67, Autumn, 2.

[26] Friends of Granville Country Park (no date): https://friendsofgranvillecountrypark.com/about/, access: 29.09.2019.

[27] Gallis S., Stanford S. & Westwood D. 2015: Baggeridge Country Park Management Plan (2015–2020). South Staffordshire Council.

[28] Gamble D. 2015: Hay Time meadow restoration. Field Studies. https://fsj.field-studies-council.org/media/2123727/fs2015_gamblelr.pdf, access: 27.11.2021.

[29] Gov.UK 2014: Get accreditation for a country park you manage in England. https://www.gov.uk/guidance/get-accreditation-for-your-country-park, access: 27.11.2021.

[30] Gov.UK 2019: Local Nature Reserves, England. https://data.gov.uk/dataset/acdf4a9e-a115-41fb-bbe9-603c819aa7f7/local-nature-reserves-england, access: 27.11.2021.

[31] Green Flag Award 2019: Judging Criteria. http://www.greenflagaward.org.uk/how-it-works/judging-criteria/, access: 27.11.2021.

[32] Grime J.P., Hodgson J.G. & Hunt R. 1988: Comparative Plant Ecology: a functional approach to common British species. Unwin Hyman, London.

[33] HMSO 2021: National Planning Policy Framework. Ministry for Housing, Communities & Local Government, London. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/ file /1005759/NPPF_July_2021.pdf, access: 27.11.2021.

[34] Icarus 2014: Access to Nature: inspiring people to engage with their natural environment. Final Evaluation Report, Part 2, Natural England.

[35] Jones G.H., Trueman I.C. & Millett P. 1995: The use of hay strewing to create species-rich grasslands. (I) General principles and hay strewing versus seed mixes. Land Contamination and Reclamation, 3, 104–107.

[36] Land Use Consultants (no date): Baggeridge Development Plan. Report to Seisdon Rural District Council.

[37] Landscape Architects 2002: Green Network Guidance. Unpublished report to Wrekin Council.

[38] Latham M. 2019: Ecology & Green Infrastructure Specialist Telford & Wrekin Council, email to author 26.09.2019.

[39] Lawton J.H., Brotherton P.N.M., Brown V.K., Elphick C., Fitter A.H., Forshaw J., Haddow R.W., Hilborne S., Leafe R.N., Mace G.M., Southgate M.P., Sutherland W.J., Tew T.E., Varley J. & Wynne G.R. 2010: Ma-king Space for Nature: a review of England's wildlife sites and ecological network. Report to Department for Environment, Food and Rural Affairs (DEFRA).

[40] Lunn J. 2000: Ecological and nature conservation aspects of land affected by mining in the Yorkshire Coalfield. Unpublished Master's thesis, Sheffield Hallam University.

https://doi.org/10.32056/KOMAG/Monograph2023.5

[41] Mailding 1980a: Tree Planting. Sheet number 179/01/86, South Staffordshire District Council.

[42] Mailding 1980b: Soil Reconstruction. Sheet number 179/01/127, South Staffordshire District Council.

[43] McCrea A.R., Trueman I.C. & Fullen M.A. 2001b: A comparison of the effects of four arable crops on the fertility depletion of a sandy silt loam destined for grassland habitat creation. Biological Conservation, 97, 181–187.

[44] McCrea A.R., Trueman I.C. & Fullen M.A. 2004: Factors relating to soil fertility and species diversity in both semi-natural and created meadows in the West Midlands of England. European Journal of Soil Science, 55, 335–348.

[45] McCrea A.R., Trueman I.C., Fullen M.A., Atkinson M.D. & Besenyei L. 2001a: Relationships between soil characteristics and species richness in two botanically heterogeneous created meadows in the Urban English West Midlands. Biological Conservation, 97, 171–180.

[46] McKelvey J. 2014: Land Acquisition & Disposal Policy. Unpublished document Shropshire Wildlife Trust, Shrewsbury.

[47] Millward A. & Mostyn B. 1989: People and nature in cities: the social aspects of planning and managing natural parks in urban areas. Urban Wildlife Now, 2, 1–161. Nature Conservancy Council, Peterborough.

[48] Morris C.D. 2019: Lower Gornal. http://www.lowergornal.co.uk/i_mining_baggeridge.htm, access: 23.09.2019.

[49] Natural England 2010: Local Nature Reserves in England: A guide to their selection and declaration. www.naturalengland.org.uk/publications, access: 27.11.2021.

[50] Natural England 2012: Higher Level Stewardship: Environmental Stewardship Handbook. 4th ed. http://publications.naturalengland.org.uk/publication/2827091, access: 27.11.2021.

[51] Natural England 2013: Monitor of Engagement with the Natural Environment: The national survey on people and the natural environment. Wellbeing and the natural environment. http://publications.naturalengland.org.uk/publication/6710511932538880, access: 27.11.2021.

[52] Nature Conservancy Council 1989: Guidelines for Selection of Biological SSSIs. NCC, Peterborough.

[53] Parker D.M. 1995: Habitat creation – a critical guide. English Nature, Peterborough.

[54] Pediaditi K., Doick K.J. & Moffat A.J. 2010: Monitoring and evaluation practice for brownfield, regeneration to greenspace initiatives. A meta-evaluation of assessment and monitoring tools. Landscape and Urban Planning, 97 (1), 22–36.

[55] Potter S. 1991: A Silvicultural Management Plan for Whites Wood. Baggeridge Country Park, Staffordshire County Council.

[56] Ratcliffe D.A. 1976: Thoughts towards a policy of nature conservation. Biological Conservation, 9 (1), 45–53.

[57] Rocha-Nicoleite E., Overbeck G.E. & Müller S.C. 2017: Degradation by coal mining should be priority in restoration planning. Perspectives in Ecology and Conservation, 15, 202–205.

[58] Rodwell J.S. (ed.) 1992: British Plant Communities. Volume 3. Grassland and montane communities. Cambridge University Press, Cambridge.

[59] Rodwell J.S. (ed.) 2000: British Plant Communities. Volume 5. Maritime communities and vegetation of open habitats. Cambridge University Press, Cambridge.

[60] Shropshire History 2016: Granville Colliery. http://shropshirehistory.com/mining/mines/granville.htm, access: 24.09.2019.

[61] Shropshire Wildlife Trust 2008: Management Brief Granville Nature Reserve 2008–2013. Unpublished.

[62] Society for Ecological Restoration 2004: The SER International Primer on Ecological Restoration. Society for Ecological Restoration International, Tucson, Arizona. www.ser.org, access: 11.10.2019.

[63] South Staffordshire Council 2019: Baggeridge Country Park. https://www.sstaffs.gov.uk/leisure/baggeridge-country-park.cfm, access: 23.09.2019.

[64] Staffordshire Biodiversity Action Plan 2019: Staffordshire Site Designations. http://www.sbap.org.uk/staffordshire/index.php?page=sitedesignations, access: 23.09.2019.

[65] Telford & Wrekin Council 2019: Granville Country Park. https://www.telford.gov.uk/info/20629/local_nature_reserves/3866/granville_country_park, access: 26.09.2019.

https://doi.org/10.32056/KOMAG/Monograph2023.5

[66] Telford Nature Conservation Project 1985: North-east Telford an Ecological Report for Telford Development Council. Unpublished report.

[67] Trueman I.C. & Millett P. 2003: Creating wild-flower meadows by strewing green hay. British Wildlife, 15 (1), 37–44.

[68] Trueman I.C. 1991: Baggeridge Country Park Management Plan. Wolverhampton Polytechnic Environmental Consultancy.

[69] Trueman I.C. 1993: Ettingshall Park Management Plan. University of Wolverhampton Environmental Consultancy.

[70] Walker K.J., Stevens P.A., Stevens D.P., Mountford J.O., Manchester S.J. & Pywell R.F. 2004: The restoration and recreation of species-rich lowland grassland on land formerly managed for intensive agriculture in the UK. Biological Conservation, 119, 1–18.

3.2. Mechanisms of Novel Ecosystems development on post-mineral excavation sites – What do we need to know?

Ecosystem fragmentation, landscape modification, wetland loss, invasive species expansion, mass species extinction, ecosystem function destabilization, e.g., of worldwide nitrogen and carbon cycles, are among the leading frequently listed causes of global climate change. Some of the human influence on environmental change work as drivers of Novel Ecosystem establishment. The new ecological relations described as Novel Ecosystems require many studies, as they have no natural or semi-natural analogues and cover an expanding land area. Both Novel Ecosystem theory and the ecosystem services concept lack investigations appropriate for the applied policy implications (Bridgewater et al., 2011; Graham et al., 2014; Perring et al., 2014).

Post-mining and post-industrial sites can provide very harsh environments due to a number of reasons: high daytime temperatures (in sheltered locations in direct sunlight), poor or non-existent soils, complex texture, poor or excessive drainage as a consequence of compaction from heavy machinery, low water holding capacity, and uneven substrates with large pore sizes in the sediments. These post mining soils substrates are sometimes composed of various types of substrates which have been generated from the component materials being used previously on this site. Such sites can lack a seed bank and are dependent on plant species coming from elsewhere, or being brought there by animals.

The environment is sometimes wrongly considered as a technical mechanism that must be repaired and work only for human economic benefit and usefulness (Robbins & Moore 2013; Morse et al., 2014; Murcia et al., 2014). There is a lack of perception that the environment is biological, hydrological, and hydrogeological entity and all its element are related being the basis of environmental functioning. Identifying the challenges connected with dynamic environmental alternations must be recognized and understood by the management systems and planning practitioners (Collier & Devitt 2016). Each decision and action in the environmental ecosystem mosaic must strengthen natural systems, natural capital, and resilience to mitigate further changes. There is no doubt that the ecological ecosystem mosaic will adapt to any changes, including global changes. The question remains if mankind will manage to adapt, too (Woźniak & Jagodziński 2022).

Figure 3.2.1. Novel ecosystems develop on the basis of the primary production of the vegetation patches built of the non-analogous species composition that colonize the post-mineral excavation sites. The tree seedlings germinate and develop together with herbaceous vegetation

Novel Ecosystems can provide expanding and even augmented ecosystem and environmental functioning, which is the basis for ecosystem services. Novel Ecosystems offer opportunities to fulfil objectives focused on maintaining, e.g., biodiversity, enhancing water retention, and carbon sequestration. Biodiversity is the essential condition that integrates all ecosystem functions (ecosystem services), influencing and enhancing positive human-ecological interactions. For that to happen, socio-economic and administrative instruments that can recognize the potential environmental value of novel ecological assemblages have to be introduced (Tassin & Kull 2015). The fundamental prerequisite includes a fluent communication between scientists and policymakers, followed by extending cooperation between public society and policymakers and dialogue between stakeholders and practitioners. These are the main opportunities for environmentally-focused transformation, especially in changing socio-economic-environmental systems (Morse et al., 2014).

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Many sites fulfil all the conditions listed by Morse et al., (2014). Many such places are established as a side product of mineral excavation, including post-hard coal mining and quarrying of various mineral resources. The side effect of mineral excavation develops in places with many watercourses, wetlands, and terrestrial mineral oligotrophic habitats. Many of them provide unusual (sometimes extreme) abiotic conditions (Woźniak & Jagodziński 2022). As a result, the set of organisms colonizing such sites presents unique compositions associated with outstanding features and biotic opportunities (Hobbs et al., 2013; Kueffer 2013; Robbins & Moore 2013; Woźniak et al., 2015). Adoption of the Novel Ecosystem concept for such sites and landscapes should not be prevented and should be introduced without delay. Novel Ecosystems, for which there is no doubt about ecological novelty, should be separated from those which need more work to assign clear criteria for assessing their environmental status. Such division would provide an adequate response to the uncertainties and challenges for a more open, dynamic approach to conservation effectiveness for the ecosystem, environmental system and enhancement of biodiversity and other ecosystem elements (Zedler et al., 2012; Bridgewater & Yung 2013). The lack of clear criteria for ecological novelty hinders managers and environmental legal frameworks from improving the adaptive capacity of the human-induced transformation. Applying some aspects of the ecological wonder of the Novel Ecosystems mosaic would allow for the enhancement of ecological functioning and human living conditions closer to wildlife. The solutions proposed above will significantly improve environmental conditions (Bridgewater & Yung 2013).

Figure 3.2.2. The plant individual's adaptations are observed in many aspects. In the picture, the grass dominated vegetation patches and *Betula pendula* individual in front of the picture. The shapes of vegetation patches dominated by *Phragmites australis* and *Calamagrostis epigejos* are reflecting precisely the area of the habitats optimal for those vegetation types

It is possible that these post-industrial sites can be colonized over time and ultimately become nature reserves. Much depends on the chosen end point of the restoration and the amount of time and money that is invested. The case studies have shown what can be achieved with very little investment other than being left alone to colonize naturally. Where nature has been given a helping hand by introducing species, this has enabled coverage of spoil by vegetation in a fairly short time frame. Here, management will ultimately become necessary, especially in order to retain a mosaic of early successional and mature vegetation stages. Where it is desirable to retain rare species and early successional species this management will, however, be more costly, especially if shallow water bodies are to remain open.

Human impacts on the environment include modifications, alterations, or changes to biochemical and biophysical conditions of habitats, which cause changes in ecosystem processes, biodiversity, distribution of natural resources and species occurrence (Hawksworth & Bull 2008; Sahney et al., 2010; Wuebbles et al., 2017). Direct or indirect effects of human activities result in, e.g., global warming, biodiversity loss and biodiversity mass extinction. One of the readily observed impacts of human activity is the transformation of landscapes by removing vegetation cover and the resulting vast areas left as open abandoned land. In those situations, a critical question remains: what to do with the large surface area that is significantly altered, changed, or established *de novo* by human activity?

In many countries, restoration ecologists try to undo and reverse the effects of changes caused by human activity and bring ecosystems back to their previous state. Restoration is never smooth and rarely successful (Tropek et al., 2012), similar to the Sisyphean task (Schoukens 2019). The widespread lack of success in restoration efforts has led some restoration ecologists, like Richard Hobbs, to conclude that some ecosystems have changed so much that it is impossible to restore them to their previous state. According to Hobbs, sites that are changed very profoundly, or those that emerged *de novo*, provide a set of unusual conditions for developing a Novel Ecosystem (Hobbs et al., 2013).

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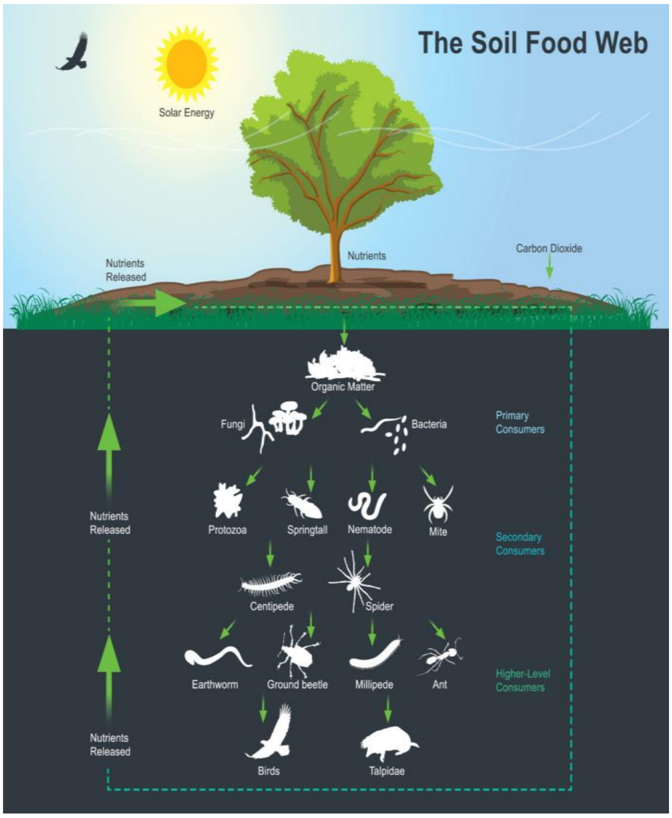

Figure 3.2.3. Simplified scheme of relationships among habitat conditions, vegetation structure, above- and below-ground species composition, and ecosystem functioning in natural and semi-natural habitats; modification of these relationships by intense human agency can lead to crossing a habitat threshold, resulting in a Novel Ecosystem

Some researchers, and many of field work observations and records, provide proof for existence of Novel Ecosystems representing new ecological entities, and they should be identified and enhanced according to their own independent biological, ecological, and environmental rules. Following the Novel Ecosystems concept and pathway of development will bring more benefits to environmental functioning (ecosystem services and human quality of life), than taking the risk of losing time and financial resources to restore them to the previous stage (Morse et al., 2014; Evers et al., 2018). According to one of the available descriptions, a site assigned as a Novel Ecosystem habitat has to fulfil five prerequisite conditions: I) The establishment of the habitat has to take place due to human agents; II) The plant and animal species composition is unknown in the existing ecosystems; III) The Novel Ecosystem has to grow in a new non-analogous manner; IV) It has to develop further as an autonomous, independent system after the human agent stops action; V) Finally, the Novel Ecosystem has to establish a self-maintaining ecosystem. Regardless of this description, there are still many misunderstandings.

Figure 3.2.4. A few year-olds coal mine heap is spontaneously covered by herbaceous vegetation and single deciduous and coniferous trees in between (upper picture). After a few more years the trees are denser, limiting the light access to lower herbaceous vegetation, changing the habitat conditions (lower picture). The changes in light habitat conditions are causing further changes in plant species composition

Morse et al., (2014) presented some concepts of the description. Novel Ecosystems are a unique assemblage of environmental conditions and biota set up due to human (human agency) alteration. The alteration must be sufficient to cross an ecological threshold that moves and maintains a new ecosystem trajectory and prevents its return to a historical, previous course even without additional human disturbance. Furthermore, the resulting Novel Ecosystem must be self-sustaining in ecosystem functioning, including best-adapted species composition, biogeochemistry, feedback relationships, structure, processes, ecosystem functioning and, consequently, ecosystem services.

Regardless of the continuous and very fruitful discussions on the meaning and definition of the novelty idea, some sites should undoubtedly be identified as Novel Ecosystems (Fig. 3.2.5.). Among them are the mineral post-excavation sites like, e.g., opencast sandpits, post-coal-mine heaps, lead-zinc heaps, and limestone quarries.

Figure 3.2.5. The mosaic of habitats enables the immediate biodiversity increase. In the homogenous landscape as presented in the picture, the serious disturbance is generating the circumstances for Novel Ecosystems to develop

The natural world and social interactions are interrelated and shaped by a range of values that come together to rule the processes of decision-making and influence the alterations of the wild, spontaneous ecosystem development trajectories (Woźniak 2010; Hallett et al., 2013). The social, cultural, and institutional contexts of the interrelated processes complicate the estimation and proper assessment of ecological thresholds and the best way to enhance Novel Ecosystems. The managers are overwhelmed by the idea of utility and financial benefits. They are not familiar with the developed ecosystems, while the processes acting in nature save enormous amounts of money only because they are possible and present in particular habitats. The floodplain forests along river embankments and mangrove forests along oceans are good examples of priceless, cost-free, and very efficient protection against floods and tsunamis provided by natural processes.

Another underestimated power of the natural process are the increasingly apparent plant trait adaptations caused by human-induced rapid environmental change (HIREC), which expands the spectra of unknown ecological processes and parameters that plants and other organisms respond to (Kueffer & Daehler 2009; Jackson 2013; Perring et al., 2013). On the one hand, the direct and indirect human influences can cause such profound changes in species composition and ecosystem structure that the limits of ecological resistance will not be enough to prevent crossing the thresholds of ecosystem self-regulation ability (Williams & Jackson 2007; Chen et al., 2011; Yamano et al., 2011; Grimm et al., 2013). On the other hand, the quick adaptation performed by many plants to the new, even very harsh environmental conditions is astonishing. The dynamic transformations of the living organisms to the HIREC factors provide additional proof that the establishment of Novel Ecosystems processes and their autonomous functioning can be a type of natural support for mankind facing global environmental changes.

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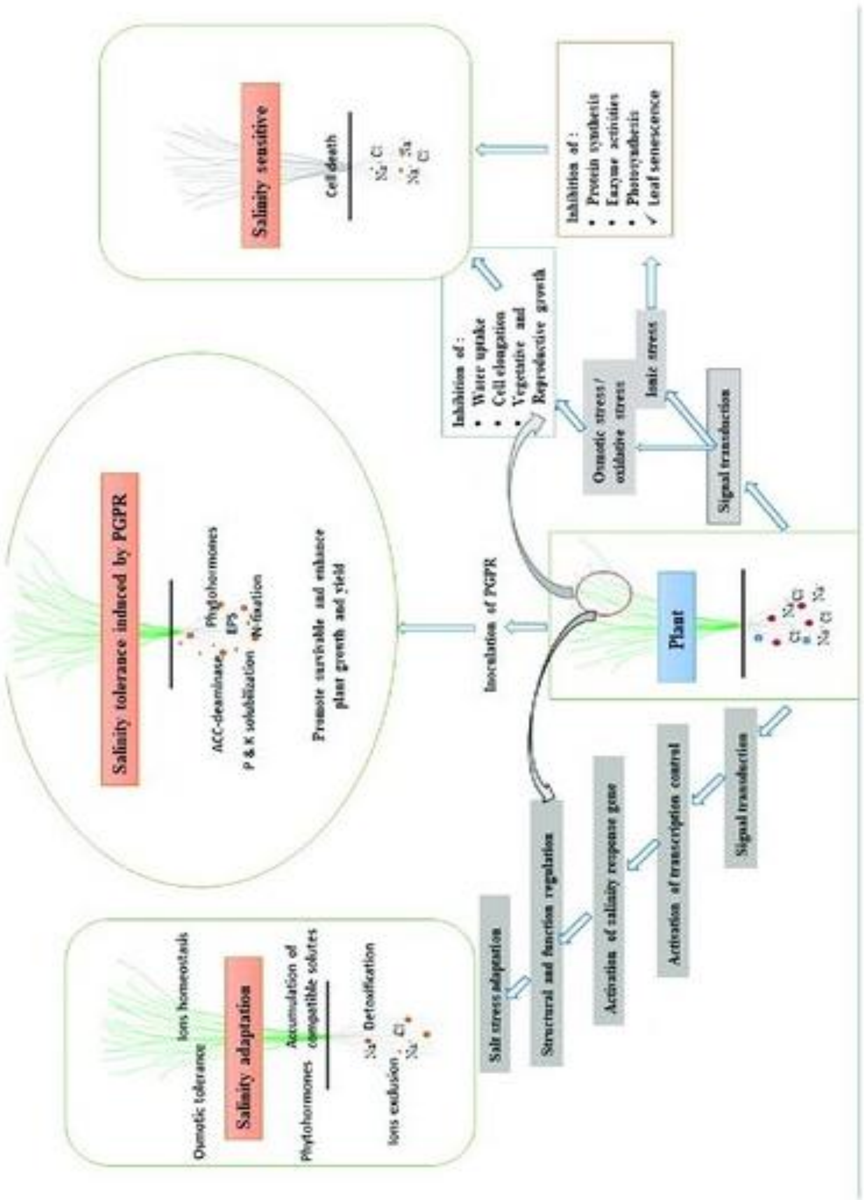

Figure 3.2.6. The plant adaptation, e.g., molecular mechanisms, to salinity stress. The plant adaptation is a continuous process

The direct factors altering ecosystems cover increasing areas of Earth, e.g. wetlands and water bodies. Among the indirect factors, the decreasing abundances of wildlife areas, biodiversity loss, disturbed carbon and nitrogen cycles, and climate change resulting in changing temperatures and precipitation levels have to be listed (Morse et al., 2014; Evers et al., 2018). The rising influence of direct and indirect factors increases the probability that some ecosystems become pushed outside the borders of ecological resistance limits (thresholds) and become Novel Ecosystems (Morse et al., 2014).

The ecosystems function as potential reservoirs for ecosystem services

Novel Ecosystems are unintentional results of deliberate human actions (Perring et al., 2013). However, the emerged Novel Ecosystems can continue with self-sufficient development and are independent of further human activity (Hallett et al., 2013; Hobbs et al., 2013; Morse et al., 2014). A growing body of proof reveals that the old restoration, rehabilitation, and restoration methods used for Novel Ecosystem habitats are not working. In addition, some reclamation work that ignores biological and environmental knowledge brings harm instead of improving ecosystem and environmental functioning (Hobbs et al., 2009; Belnap et al., 2012).

The lack of any existing equivalent ecosystem makes restoration of Novel Ecosystems to their previous state impossible (Hallett et al., 2013). The biological study of some of the Novel Ecosystems has revealed that these ecosystems can provide many services in the urban and industrialized landscape (Woźniak et al., 2018). Some environmentalists regard particular types of Novel Ecosystems as potential reservoirs for ecosystem services (Chapin et al., 2006; Perring et al., 2013). The drivers of novelty regard human activity, which causes the inevitable disturbances and close association of Novel Ecosystem components and adaptations with socio-ecological systems (Collier & Devitt 2016). Some environmentalists suggest that Novel Ecosystems represent examples of socio-ecological resilience (Collier & Devitt 2016) and can be as valuable for humans as the historical ecosystems that they replaced (Hallett et al., 2013). Novel Ecosystems can play an essential role in climate change mitigation (Zedler et al., 2012). Once their presence in the ecosystem mosaic is documented and proven, the main point of management action for Novel Ecosystems and habitats should enhance their critical ecosystem function (Zedler et al., 2012; Moyle 2014; Trueman et al., 2014). How can a system that we do not know and understand be managed?

Among the potential Novel Ecosystems, there are sites on which planned or unplanned human activities have led to establishment of ecosystems with natural

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values. The accidental or deliberate occurrence of new species composition is a sign of novelty (Hobbs et al., 2009; 2013). Furthermore, the new species assemblages are associated with unique above- and below-ground traits, interactions and processes (Kompała-Bąba et al., 2019; Milewska-Hendel et al., 2021).

Mechanisms in the Novel Ecosystem concept approach

The Novel Ecosystem concept approach is present in a growing number of research results. Doley & Audet (2013) have been studying post-mining disturbance sites in altered landscapes. There were no natural reference points. They showed that the spontaneously emerged new ecosystems on these post-industrial landscapes present dynamic balances and functional development of ecosystems that can provide critical environmental goods for the local community. Such unique circumstances should be feasible for managers and satisfy the stakeholders' expectations. The Novel Ecosystems are always composed of new sets of species (Woźniak 2010). The new species composition of plants, as the primary producers, causes a change in vegetation communities, ecosystem structure, and function (Martínez et al., 2010). Novel Ecosystems develop as independent ecological self-sustaining entities. Such a system can take over the ecosystem and environmental functions of the lost ecosystem and support native species establishment. The new environmental systems have not been previously quantified, and the potentially available new services are not identified and understood. Therefore, they are not deliberately enhanced (Lin & Petersen 2013).

Novel Ecosystem theory requires a redefinition of the traditional interactions of humans with nature. Novel Ecosystem theory offers a new opportunity for transformational concepts. However, it still needs a cultural shift and social understanding of natural processes in any ecosystem. Rethinking how we deal with the management of transformed land, restoration actions, and conservation is necessary (Marris 2011; Yung et al., 2013). A comprehensive scientific approach and public dialogues about the heavily transformed, and in particular, the post-mineral excavation sites, should be performed. The interdisciplinary research conducted on an understanding of the adaptation processes, evolutionary, and ecological implications of how Novel Ecosystems function in the long term, would enable a better experience and more appropriate management considerations (Belnap et al., 2012).

Interdisciplinary environmental knowledge is fundamental for understanding the phenomenon of Novel Ecosystems because of the growing demand for the provision of particular ecosystem services in densely populated urban-industrial areas, which is often in contrast with social awareness and economic expectations (Seastedt et al., 2008; Stafford Smith et al., 2009; Belnap et al., 2012; Woźniak et al., 2018). Such an approach demands more appropriate and flexible management strategies if necessary (Harris et al., 2006; Hobbs et al., 2006; Seastedt et al., 2008; Bridgewater & Yung 2013; Hallett et al., 2013; Perring et al., 2013). Novel Ecosystem theory forces management plans and scenarios to introduce an interdisciplinary approach, focused on studies concerning the use of a range of possible practical and strategic opportunities for the enhancement of ecosystem and environmental functioning, for the environmental profit of social transformation (Bridgewater & Yung 2013; Hulvey et al., 2013).

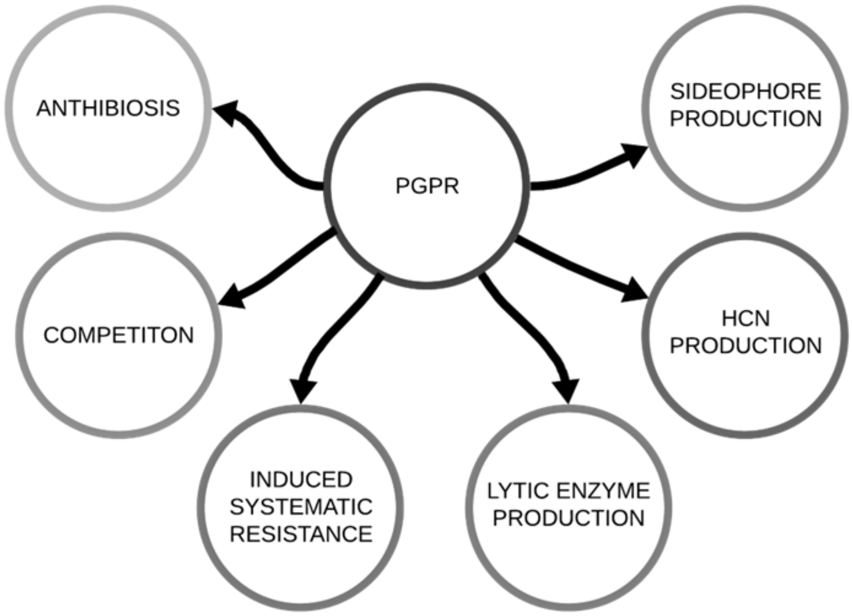

Figure 3.2.7. Different mechanisms by which plant growth-promoting rhizobacteria (PGPR). The microorganisms in increasing biomass establishment support human in phytopathogens impact

The current research provides evidence that the possibilities of taking a Novel Ecosystem approach instead of the non-feasible restoration to a historical reference is often the only rational solution for some sites in the urban-industrial landscape. There are places where entirely new environmental ecology quality has emerged, and it is pointless and not possible to drag the site back to its previous state (Tropek et al., 2012; Doley & Audet 2013). Novel Ecosystem elements in urban-industrial landscapes present new possibilities and potentially

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have high values for reorganization to create a unique mosaic of habitats and ecosystems with new environmental qualities that the designers and planners have to understand and learn to combine (Dooling 2015). The expanding available options provide more comprehensive possibilities for environmentally-friendly change in urban and industrial landscapes (Hobbs et al., 2013).

The recent arrival of Novel Ecosystem theory in scientific papers has spawned a debate on the environmental meaning of connecting the new biotic and abiotic interactions to benefit ecological functioning. This attitude consists of a challenge for the responsible authorities and managers (Bridge-water & Yung 2013; Collier & Devitt 2016). Due to the lack of practical examination of the long-term functioning of Novel Ecosystems, there are some challenges to the usefulness of Novel Ecosystem theory. It is becoming recognized that the existing environmental management frameworks are insufficient and sometimes harmful under the new circumstances where human activity leads to the creation of Novel Ecosystems more frequently (Morse et al., 2014; Evers et al., 2018).

Due to the spontaneous occurrence of nutrient-poor oligotrophic water, wetland, and terrestrial vegetation assemblages, the natural processes show insufficient conservation efforts through ecological reserves. The Novel Ecosystem approach can help ensure long-term protection of the oligotrophic habitats and ecosystems generated in the Anthropocene (Waltert et al., 2011). Furthermore, the current examples of the intensity and dynamics of ecosystem and environmental phenomena expand the current knowledge about the mechanisms involved (Evers et al., 2018). The poor oligotrophic mineral habitats with their moisture gradients (opencast sandpits, quarry excavations, e.g., base-rich limestone, Cambrian sandstone and post-coal mine heaps) provide refuge habitats for many organisms that had been diminished or extirpated along with the intense application of nutrients on agricultural land and subsequent eutrophication.

Studies to improve the understanding of Novel Ecosystems functioning and the enhancement of their recognized natural values, should be intensified to compensate for environmentally harmful human activities and related environmental transformations (Chapin et al., 2006; Hobbs et al., 2013; Perring et al., 2013; Graham et al., 2014; Murcia et al., 2014; Rotherham 2017).

The requirement of greater collaboration between scientists and policy decision-makers, managers, and practitioners should focus on understanding how the processes and functional parameters of Novel Ecosystems work. This knowledge will provide the basis for how Novel Ecosystems should be supported. In principle, further research has to be conducted to find out how to protect specific vegetation species composition and the associated ecosystem relationships, such as the unique biodiversity of Novel Ecosystems, which should be maintained (Hulvey et al., 2013; Morse et al., 2014). The dialogue has to be conducted from the local to the macro-regional level to understand and acknowledge the occurrence, extent, and importance of ecological novelty for the limitation and mitigation of global change.

References

[1] Belnap J., Ludwig J.A., Wilcox B.P., Betancourt J.L., Dean W.R.J., Hoffmann B.D. & Milton S.J. 2012: Introduced and invasive species in novel rangeland ecosystems: friends or foes? Rangeland Ecology & Management, 65 (6), 569–578.

[2] Bridgewater P. & Yung L. 2013: The policy context: Building laws and rules that embrace novelty. [In:] Hobbs R.J., Higgs E.S. & Hall C.M. (eds.): Novel Ecosystems: Intervening in the New Ecological World Order. John Wiley & Sons, Chichester, 272–283.

[3] Bridgewater P., Higgs E.S., Hobbs R.J. & Jackson S.T. 2011: Engaging with novel ecosystems. Frontiers in Ecology and the Environment, 9 (8), 423.

[4] Chapin III F.S., Lovecraft A.L., Zavaleta E.S., Nelson J., Robards M.D., Kofinas G.P., Trainor S.F., Peterson G.D., Huntington H.P. & Naylor R.L. 2006: Policy strategies to address sustainability of Alaskan boreal forests in response to a directionally changing climate. Proceedings of the National Academy of Sciences of the United States of America, 103 (45), 16637–16643.

[5] Chen I.-C., Hill J.K., Ohlemüller R., Roy D.B. & Thomas C.D. 2011: Rapid range shifts of species associated with high levels of climate warming. Science, 333 (6045), 1024–1026.

[6] Collier M.J. & Devitt C. 2016: Novel ecosystems: Challenges and opportunities for the Anthropocene. The Anthropocene Review, 3 (3), 231–242.

[7] Doley D. & Audet P. 2013: Adopting novel ecosystems as suitable rehabilitation alternatives for former mine sites. Ecological Processes, 2, 22.

[8] Dooling S.E. 2015: Novel landscapes: Challenges and opportunities for educating future ecological designers and restoration practitioners. Ecological Restoration, 33 (1), 96–110.

[9] Evers C.R., Wardropper C.B., Branoff B., Granek E.F., Hirsch S.L., Link T.E., Olivero-Lora S. & Wilson C. 2018: The ecosystem services and biodiversity of novel ecosystems: A literature review. Global Ecology and Conservation, 13, e00362.

[10] Graham N.A.J., Cinner J.E., Norström A.V. & Nyström M. 2014: Coral reefs as novel ecosystems: embracing new futures. Current Opinion in Environmental Sustainability, 7, 9–14.

[11] Grime J.P, Hodgson J.G. & Hunt R. 2007: Comparative plant ecology. A functional approach to common British species. 2nd ed. Castlepoint Press.

[12] Grime J.P. 1998: Benefits of plant diversity to ecosystems: immediate, filter and founder effects. Journal of Ecology, 86, 902–910.

[13] Grimm N.B., Chapin III F.S., Bierwagen B., Gonzalez P., Groffman P.M., Luo Y., Melton F., Nadelhoffer K., Pairis A., Raymond P.A., Schimel J. & Williamson C.E. 2013: The impacts of climate change on ecosystem structure and function. Frontiers in Ecology and the Environment, 11 (9), 474–482.

[14] Hallett L.M., Standish R.J., Hulvey K.B., Gardener M.R., Suding K.N., Starzomski B.M., Murphy S.D. & Harris J.A. 2013: Towards a conceptual framework for novel ecosystems. [In:] Hobbs R.J., Higgs E.S. & Hall C.M. (eds.): Novel Ecosystems: Intervening in the New Ecological World Order. John Wiley & Sons, Chichester, 16–28.

[15] Harris J.A., Hobbs R.J., Higgs E. & Aronson J. 2006: Ecological restoration and global climate change. Restoration Ecology, 14 (2), 170–176.

[16] Hawksworth D.L. & Bull A.T. (eds.) 2008: Biodiversity and Conservation in Europe. Springer, Dordrecht.

[17] 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. 2006: Novel ecosystems: theoretical and management aspects of the new ecological world order. Global Ecology and Biogeography, 15 (1), 1–7.

[18] Hobbs R.J., Higgs E. & Harris J.A. 2009: Novel ecosystems: implications for conservation and restoration. Trends in Ecology & Evolution, 24 (11), 599–605.

[19] Hobbs R.J., Higgs E.S. & Hall C.M. (eds.) 2013: Novel Ecosystems: Intervening in the New Ecological World Order. John Wiley & Sons, Chichester.

[20] Hulvey K.B., Standish R.J., Hallett L.M., Starzomski B.M., Murphy S.D., Nelson C.R., Gardener M.R., Kennedy P.L., Seastedt T.R. & Suding K.N. 2013: Incorporating novel ecosystems into management frameworks. [In:] Hobbs R.J., Higgs E.S. & Hall C.M. (eds.): Novel Ecosystems: Intervening in the New Ecological World Order. John Wiley & Sons, Chichester, 157–171.

[21] Jackson S.T. 2013: Perspective: Ecological novelty is not new. [In:] Hobbs R.J., Higgs E.S. & Hall C.M. (eds.): Novel Ecosystems: Intervening in the New Ecological World Order. John Wiley & Sons, Chichester, 61–65.

[22] Kompała-Bąba A., Bierza W., Błońska A., Sierka E., Magurno F., Chmura D., Besenyei L., Radosz Ł. & Woźniak G. 2019: Vegetation diversity on coal mine spoil heaps – how important is the texture of the soil substrate? Biologia, 74, 419–436.

[23] Kueffer C. & Daehler C.C. 2009: A habitat-classification framework and typology for understanding, valuing and managing invasive species impacts. [In:] Inderjit (ed.): Management of Invasive Weeds. Invading Nature: Springer Series in Invasion Ecology. Volume 5. Dordrecht, Springer, 77–101.

[24] Kueffer C. 2013: Integrating natural and social sciences for understanding and managing plant invasions. [In:] Larrue S. (ed.): Biodiversity and Society in the Pacific Islands. Presses Universitaires de Provence, Marseille, France & ANU ePress, Canberra, Australia, 71–95.

[25] Lin B.B. & Petersen B. 2013: Resilience, regime shifts and guided transition under climate change: Examining the practical difficulties of managing continually changing systems. Ecology and Society, 18 (1), 28.

[26] Marris E. 2011: Rambunctious Garden: Saving Nature in a Post-Wild World. Bloomsbury, New York.

[27] Martínez O.J.A., Rodríguez M.A., Rosario I., Soto N., López A. & Lugo A.E. 2010: Structure and species composition of novel forests dominated by an introduced species in northcentral Puerto Rico. New Forests, 39 (1), 1–18.

[28] Milewska-Hendel A., Chmura D., Wyrwał K., Kurczyńska E.U., Kompała-Bąba A., Jagodziński A.M. & Woźniak G. 2021: Cell wall

epitopes in grasses of different novel ecosystem habitats on post-industrial sites. Land Degradation & Development, 32 (4), 1680–1694.

[29] Morse N.B., Pellissier P.A., Cianciola E.N., Brereton R.L., Sullivan M.M., Shonka N.K., Wheeler T.B. & Mc-Dowell W.H. 2014: Novel ecosystems in the Anthropocene: a revision of the novel ecosystem concept for pragmatic applications. Ecology and Society, 19 (2), 12.

[30] Moyle P.B. 2014: Novel aquatic ecosystems: The new reality for streams in California and other Mediterranean climate regions. River Research and Applications, 30 (10), 1335–1344.

[31] Murcia C., Aronson J., Kattan G.H., Moreno-Mateos D., Dixon K. & Simberloff D. 2014: A critique of the 'novel ecosystem' concept. Trends in Ecology & Evolution, 29 (10), 548–553.

[32] Perring M.P., Audet P. & Lamb D. 2014: Novel ecosystems in ecological restoration and rehabilitation: Innovative planning or lowering the bar? Ecological Processes, 3, 8.

[33] Perring M.P., Standish R.J. & Hobbs R.J. 2013: Incorporating novelty and novel ecosystems into restoration planning and practice in the 21st century. Ecological Processes, 2, 18.

[34] Robbins P. & Moore S.A. 2013: Ecological anxiety disorder: diagnosing the politics of the Anthropocene. Cultural Geographies, 20 (1), 3–19.

[35] Rotherham I.D. 2017: Recombinant Ecology – A Hybrid Future? Springer International Publishing.

[36] Sahney S., Benton M.J. & Ferry P.A. 2010: Links between global taxonomic diversity, ecological diversity and the expansion of vertebrates on land. Biology Letters, 6 (4), 544–547.

[37] Schoukens H. 2019: Legal considerations in operationalizing eco-restoration in the European Union: a Sisyphean task or unlocking existing potential? [In:] Akthar-Khavari A. & Richardson B.J. (eds.): Ecological Restoration Law: concepts and case studies. Routledge, Abington-New York, 167–192.

[38] Seastedt T.R., Hobbs R.J. & Suding K.N. 2008: Management of novel ecosystems: are novel approaches required? Frontiers in Ecology and the Environment, 6 (10), 547–553.

[39] Stafford Smith D.M., Abel N., Walker B. & Chapin III F.S. 2009: Drylands: Coping with uncertainty, thresholds and changes in state. [In:] Chapin III F.S., Kofinas G.P. & Folke C. (eds.): Principles of

Ecosystem Stewardship. Resilience-Based Natural Resource Management in a Changing World. Springer, New York, 171–195.

[40] Tassin J. & Kull C.A. 2015: Facing the broader dimensions of biological invasions. Land Use Policy, 42, 165–169.

[41] Tropek R., Kadlec T., Hejda M., Kocarek P., Skuhrovec J., Malenovsky I., Vodka S., Spitzer L., Banar P. & Konvicka M. 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.

[42] Trueman M., Standish R.J. & Hobbs R.J. 2014: Identifying management options for modified vegetation: Application of the novel ecosystems framework to a case study in the Galapagos Islands. Biological Conservation, 172, 37–48.

[43] Waltert M., Bobo K.S., Kaupa S., Montoya M.L., Nsanyi M.S. & Fermon H. 2011: Assessing conservation values: Biodiversity and endemicity in tropical land use systems. PLoS ONE, 6 (1), e16238.

[44] Williams J.W. & Jackson S.T. 2007: Novel climates, no-analog communities, and ecological surprises. Frontiers in Ecology and the Environment, 5 (9), 475–482.

[45] Woźniak G. 2010: Zróżnicowanie roślinności na zwałach pogórniczych Górnego Śląska [Diversity of vegetation on coal-mine heaps of the Upper Silesia (Poland)]. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

[46] Woźniak G., Jagodziński A.M., 2022: Post-mineral Excavation Sites as Novel Ecosystems and Examples of Socio-environmental Resilience In: Green scenarios: mining industry responses to environmental challenges of the anthropocene epoch: International Mining Forum 2021. Dyczko, Jagodziński & Woźniak (eds.) 2022 Taylor & Francis Group, London, UK

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

[48] 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. IntechOpen, 169–194.

[49] Wuebbles D.J., Fahey D.W., Hibbard K.A., DeAngelo B., Doherty S., Hayhoe K., Horton R., Kossin J.P., Taylor P.C., Waple A.M. &

https://doi.org/10.32056/KOMAG/Monograph2023.5

Weaver C.P. 2017: Executive summary. [In:] Wuebbles D.J., Fahey D.W., Hibbard K.A., Dokken D.J., Stewart B.C. & Maycock T.K. (eds.): Climate Science Special Report: Fourth National Climate Assessment. Volume I. U.S. Global Change Research Program, Washington DC, USA, 12–34.

[50] Yamano H., Sugihara K. & Nomura K. 2011: Rapid poleward range expansion of tropical reef corals in response to rising sea surface temperatures. Geophysical Research Letters, 38 (4), L04601.

[51] Yung L., Schwarze S., Carr W., Chapin III F.S. & Marris E. 2013: Engaging the public in novel ecosystems. [In:] Hobbs R.J., Higgs E.S. & Hall C.M. (eds.): Novel Ecosystems: Intervening in the New Ecological World Order. John Wiley & Sons, Chichester, 247–256.

[52] Zedler J.B., Doherty J.M. & Miller N.A. 2012: Shifting restoration policy to address landscape change, novel ecosystems and monitoring. Ecology and Society, 17 (4), 36.

3.3. Relations between soil respiration and biotic parameters in coal mine heaps novel ecosystem

The matter and energy flow is a fundamental process for each ecosystem to function, regardless of the particular ecosystem developmental stage. Each ecosystem starts from the habitat colonization of autotrophic organisms and later with heterotrophic organisms' food chain along with the appropriate microorganisms, saprophyte decomposition activity, leading to e.g., the carbon dioxide release as the side effect of the energy acquisition (Bardgett, van der Putten. 2014; Błaszkowski et al., 2019; Bennett et al., 2019; Bergmann et al., 2020). Depending on the environmental conditions, the best adapted plant species colonize and grow in particular microhabitat places. As a result of the processes of the above-ground biomass development, the foundation of the biochemical characteristics of the soil biomass, soil organic matter (SOM), is established. The biochemical composition of the biomass and the condition of respiration processes influence the amount of carbon dioxide (CO_2) released to the atmosphere. Apart from the biochemical composition of the biomass, the microbial ability to decompose the complex chemical carbon compounds determine the respiration process (Bardgett et al. 2008; Allison et al. 2010; Bahn et al., 2010; Bjørnlund et al., 2012; Woźniak et al., 2023).

Biomass quality and quantity depend on plant species' taxonomic and functional composition and diversity. High diversity enables complementary habitat resource use among competing species in species-rich ecosystems

(Hooper et al., 2005; Zhang et al., 2012). The higher biomass amount in species-rich ecosystems enhances Rs primarily by increasing root, microbial communities and rhizomicrobial respiration (Kuzyakov & Gavrichkova, 2010; Chen & Chen, 2018). Plant species composition diversity increases the quantity and multiplicity of plant exudates-derived food resources in the soil, providing and expanding a variety of niches for saprophytic microbes. Plant species composition diversity influences microenvironment variety and habitat complexity including the soil enzyme activity (Hector et al., 2000; Hooper et al., 2005; Chapman & Newman, 2010; Eisenhauer et al., 2010). Diverse plant species composition provides a litter mixture, which accelerates the decomposition of organic matter via complementary resource use among microbes, resulting in more effective Rs (Handa et al., 2014). The carbon compound decomposition of the soil organic matter (SOM) is related to, e.g., the plant species composition, mesofauna composition, and soil enzyme activity (Sinsabaugh et al., 1991). Biomass carbon compounds are broken down quickly during decomposition, providing an energy source for microbes (Melillo et al., 2002; Bradford et al., 2008; Bradford et al., 2010). Plant species composition plays a crucial role in vegetation and ecosystem development and the regulation of soil respiration (Rs) because the autotrophs are the prevalent organisms synthesizing and through which carbon enters the soil (Chen & Chen, 2018).

The magnitude of soil respiratory metabolism consists of three factors: CO_2 release by plant roots, soil fauna and soil microorganisms, and chemical oxidation of carbon compounds. The rate of soil metabolic processes depends on a number of factors, which include microclimatic conditions (temperature and humidity), the structure of the soil and the content of organic matter - living and SOM. Soil nematodes, whether they are hosts of bacteria, fungi, plants, omnivores or predators, affect the populations of organisms they feed on. Although the contribution of nematodes to soil respiration is probably less than 1%, they can play an important role in soil nutrient cycling by influencing bacterial growth and nutrient availability to plants (Smulczak et al., 2008). All species of *Enchytraeidae* through intensive respiration processes, have a significant contribution to the mineralization of organic matter. Enchytraeidae stimulate the course of mineralization and humification processes, including by loosening the soil, breaking up soil particles and their movement in the soil profile, and catalyzing the activity of microorganisms. The contribution of Enchytraeidae to these processes and to shaping the proper structure and increasing the fertility of soils is often much greater than that of other representatives of soil macro- and mesofauna (Kasprzak 1981).

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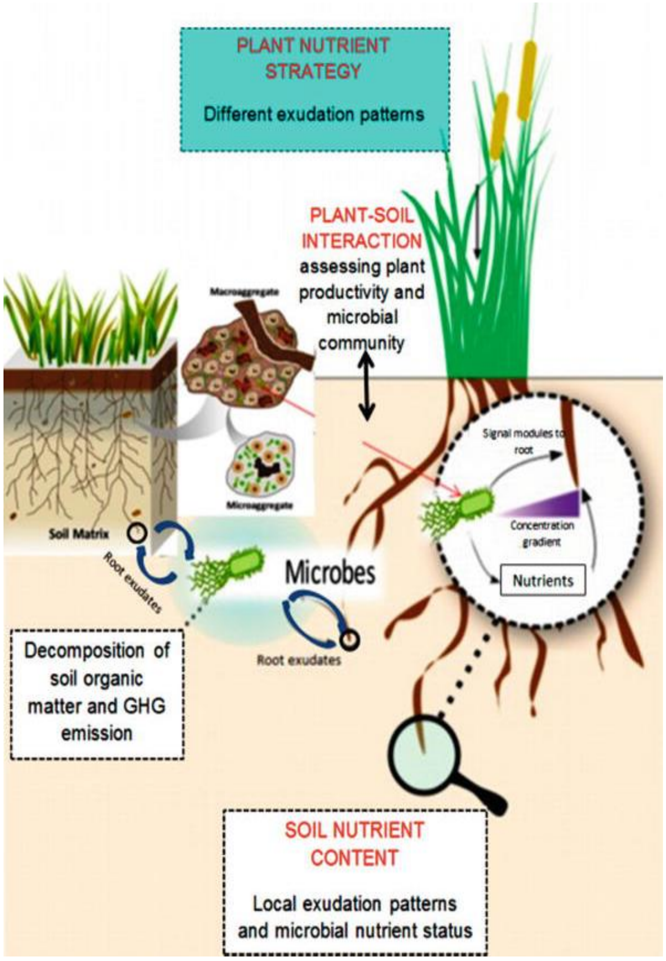

Figure 3.3.1. The scheme presents the baseline of the concepts proposed for the role of root exudates in plant microbe interactions and consequences for ecosystems

For natural and semi natural ecosystems, limited data about the mechanisms of the aspects of the biotic parameters and respiration as a crucial part of the ecosystem functioning are available (Bowden et al., 2011; Buchmann, 2000; Thuille et al., 2000). The knowledge of the biotic factors influences and the nature of the functional respiration processes in the coal mine heaps novel ecosystem is very limited.

The sites that are significantly transformed, or those that are established *de novo*, due to human activities such as the mineral resource mining, provide unusual habitat conditions for organisms that are successfully colonizing such sites. The previous field study and conceptual works revealed that the extreme habitats are colonized by the non-analogous species composition which is assembling spontaneously leading to a development of novel ecosystem (Keith et al., 2009; Woźniak et al., 2011; Błońska et al., 2019; Hobbs et al., 2006; 2009; 2013) such as the mineral post-coal mining habitats. The non-analogous species composition is assembled by the species best adapted to the unusual, extreme habitat condition. The extreme habitat conditions are a trigger to push the living organisms (primary producers, heterotrophs, and saprophytes) to evolve and adapt. The harsh, complex system of habitat conditions is caused by the lack of initial soils in the sites where the novel ecosystems develop. The term soil is strictly defined in soil sciences. In many post mining sites, the mineral material substrate without organic matter of varied texture structure (referred to as the soil substrate further in the text) is colonized by vascular plant species.

The study conducted in order to understand the relations between the soil substrate respiration, the CO_2 release and some biotic parameters in coal mine heaps novel ecosystems will enhance the effectiveness of practical decisions about the coal mine heaps management. Among the biotic habitat parameters, the following aspects could be considered: a.) the plant species composition and diversity of the studied vegetation types, b.) the biomass amount recorded for the studied vegetation types; c.) the soil organic matter amount; d.) the soil enzyme activity; e.) the presence of nematodes and vases.

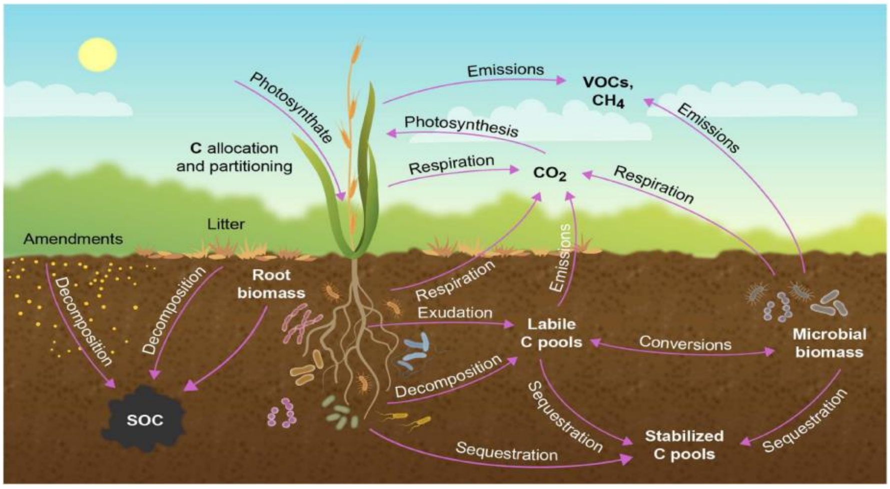

Figure 3.3.2. Transfer of atmospheric CO_2 into biotic and pedologic carbon (C) pools in the plant ecosystem. Carbon enters the soil as root exudates or via decomposition of root or aboveground biomass. In the soil, C exists in root or microbial biomass, as bioavailable labile organic C, or as more recalcitrant C. Carbon exits in the soil as direct emissions, or via root or microbial respiration, with microbial-mediated soil respiration being the major source of CO_2 from terrestrial ecosystems. Carbon is also lost from the ecosystem as volatile organic compounds (VOCs) and methane (CH_4)

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Soil organic matter and the respiration parameters in the studied vegetation types

The majority of the study focused on the relation between the soil organic matter and the soil respiration process, considering the temperature and moisture conditions influencing the process. The factor related to the biochemistry of the soil organic matter is not analyzed. Similarly, there are studies focusing on abiotic factors impacting soil respiration process and much less, if any, on the biotic parameters that are shaping the soil respiration process. Three studies present the impact of the habitat condition on the biochemistry of the individuals of the same species growing in contrasting habitat conditions. The example of *Calamagrostis epigejos* protein quality and quantity composition has shown significant differences between individuals of the same species in response to severe habitat factors [85] (Milewska-Henel et al., 2021). The differences in the above ground biochemistry influence the biochemistry of the resulting SOM soil organic matter and the below ground root exudates.

Soil organic matter (SOM) derives mainly from above and below-ground organic matter synthesized by plants. The formation of SOM establishment is well studied, but it is still unknown how litter biochemical structure and composition influence the formation of new SOM and the decomposition of already existing SOM (Chapman et al., 2016; 2010). There are few studies on the separation of the effect of plant litter composition on carbon transfer from different plant tissues into specific SOM fractions and the determination of the magnitude of the effect on already existing SOC caused by litter amendments, which could be very informative. The effect of the different litter types, such as bark, leaves, twigs, and roots in the soil rhizosphere zone, has been studied (Almeida et al., 2020). (Almeida et al.) 2020 measured the total C and the δ 13C of each soil organic matter fraction, the litter-C input for each SOM fraction, and the molecular composition of the incubated plant material and SOM fractions. The laboratory experiment results revealed no significant differences in total SOM contents among the plant parts such as bark, leaves, twigs, and roots. Contrarily, no litter amendment (control treatment) resulted in a lower total SOM amount, suggesting mineralization of existing SOM. The leaf litter was preferentially transferred to mineral-associated organic matter, while roots contributed more to organic matter (POM). Cumulative C-CO_2 transition from the treatments increased in the subsequent order: twigs > leaves > bark > roots > controls (Almeida et al., 2020).

The addition of twigs, bark, and roots significantly increased (before the experiment) the SOM respiration, while the treatment with leaves addition did not differ from the control. The source of the existing SOM-derived CO_2 came in a similar amount from C decomposed from mineral-associated organic matter, regardless of the treatment. Adding twigs, bark, and roots increased SOM-derived carbon respiration from the roots organic matter. The biochemical composition of plant litter determines the processes of a new supply of organic matter (mineral-associated organic matter MAOM or roots organic matter POM). It controls the decomposition of existing SOM. The plant residues providing more decomposable compounds (leaves) are easily transferred to mineral-associated organic matter MAOM and cause less resistant SOC. In comparison, the plant residues enriched in structural compounds (twigs, bark, and roots) are respired or allocated into the roots organic matter POM, resulting in higher priming effect intensity (Almeida et al., 2020). Zhang et al., (2022) found that the direction of vegetation restoration influences the varied carbon sources. The origin and amount of organic carbon influence the presence, metabolic activity, and functional diversity of the microbial assembly in mineral habitats, such as organic carbon availability in poor mineral habitats such as sandy soils (Zhang et al., 2022).

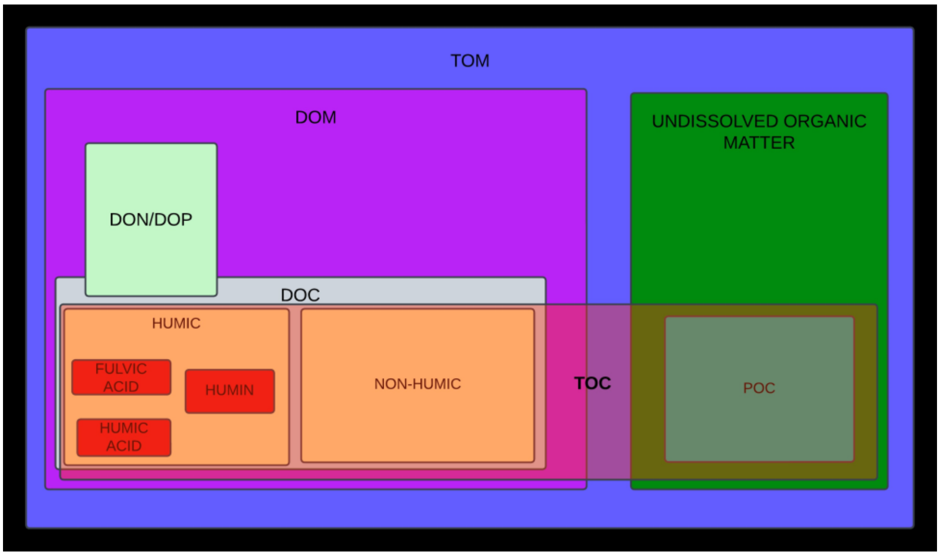

Figure 3.3.3. Simplified Venn representation of the various forms of organic matter found in natural waters. Total Organic Matter (TOM), Total Organic Carbon (TOC), Dissolved Organic Matter (DOM), Dissolved Organic Carbon (DOC), Particulate Organic Carbon (POC), Dissolved Organic Nitrogen (DON), and Dissolved Organic Phosphorus (DOP) are represented. DOC can be further broken down to its humic (humic acid, fulvic acid, and humin) and non-humic material, while new analytical methods continue to reveal more molecular-level detail

Apart from the influence of different plants parts, bark, leaves, twigs, and roots on the soil organic matter on the decomposition process, the participation of the autotrophic and heterotrophic organisms into the total respiration amount is not clear, not to mention the differences caused by the varied species composition or vegetation types. Since autotrophic and heterotrophic respiration will react differently to the soil organic matter quality, biochemistry and origin along changes in environmental conditions, it is crucial to get more insight into both components of soil respiration (Kirschbaum, 1995; Boone et al., 1998). However, the separation of root (including rhizosphere microorganisms) and microbial respiration under field conditions are still difficult. So far, many different approaches have been used in situ, ranging from severe disturbances of a site to very specific requirements, e.g., changes in the carbon isotopic signature of the two respiratory components (either due to a change of the photosynthetic pathway of the vegetation or manipulations with isotope tracers). Autotrophic respiration of intact roots has been measured with root cuvettes in the field (Gansert, 1994) or with excised roots in the laboratory (Burton et al., 1998). Trenching (Fisher and Gosz, 1986; Bowden et al., 2011; Hart and Sollins, 1998; Boone et al., 1998), labelling with 14C, 13C or O (Horwath et al., 1994; Swinnen et al., 1994; Högberg and Ekblad, 1996), inhibiting one respiratory component with species inhibitors or herbicides (Helal and Sauerbeck, 1991; Nakane et al., 1996), and enhancing one component over the other (Bowden et al., 2011) have been used to separate root from microbial respiration. However, the ratio between the two respiration components is generally quite site-specific and varies between 1:9 and 9:1(Hanson et al., 2000).

Biomass amount and the respiration parameters in the studied vegetation types

The plant species composition in the vegetation patch can be assessed by estimating the percentage cover of the whole vegetation and each of the plant species separately. Apart from the percentage cover of the vegetation, the biomass dry and wet weights are measured. The biomass can be divided into the dominant plant species weight and the weight of the rest of the non-dominant plant species. All the biomass and thus the amount of carbon that accumulates in vegetation types in each ecosystem is established due to the balance of photosynthesis (the whole primary production, (P) and the plants (autotrophs) respiration, the energy needed for the plant growth and living processes. The difference between these fluxes is the net primary production (Pn) (Chapin et al., 2006). The photosynthesis carbon is divided into parts that accumulate in biomass (Pn), and the fraction that is used by plants themselves enables their metabolism

(R) and returns relatively quickly to the atmosphere (Friedlingstein et al., 2014). Regardless of the fact that many ecophysiological studies were undertaken to understand the relation between Pn and R dynamics during plants and vegetation development, a general understanding is still missing (Collalti et al., 2020).

Figure 3.3.4. Biomass amount establishment by individuals of the same species depends on the habitat conditions. Both the biomass and habitat conditions influence the rate of soil respiration. Individuals of the same species, *Phragmites australis* can grow and give high biomass amount (upper picture), but in difficult habitat conditions the *Phragmites australis* individuals give low biomass (bottom picture)

Based on metabolic scaling theory, the hypothesis suggests that respiration should scale with biomass (West, Brown, & Enquist, 1999). According to some studies (e.g., Reich, et al., 2006; 2008), respiration scales with whole-plant carbon (C) or nitrogen (N) contents. In this approach, the scaling is similar within and among different species, irrespective of environmental and climatic conditions, which might influence the normalization constant, but not the exponent. The traditional view of forest dynamics assumed the isometric scaling of respiration with biomass set out, for example, by Kira and Shidei (1967) and Odum (1969).

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In the absence of significant disturbances, if respiration increases in parallel with biomass, primary productivity (Pn) necessarily declines because primary productivity (Pn) cannot increase indefinitely but relatively stabilizes at canopy closure in forest ecosystems (O'Connor et al., 2007).

For forest ecosystems, many vegetation models simulate plant respiration considering respiration R to be a fixed fraction of (phosphorus) P. Others more explicitly relate respiration R to biomass amount and thus only indirectly to P (Collalti et al., 2020). The calculation based on the theoretical approach of the two above hypotheses gives quite different results. The differences in obtained results caused both hypotheses (and their supposed underlying mechanisms) have been subject to criticism (e.g., Collalti & Prentice, 2019; Collalti et al., 2018, 2019; O'Connor et al., 2007).

The study performed on the comparison of the identified vegetation groups types cover the relation to the respiration parameters. The results revealed that vegetation percentage cover was the highest in vegetation group cluster 5, and is significantly higher and different from the 3-vegetation group cluster. No significant differences have been stated between the recorded vegetation cover in the vegetation group cluster 2 and 4.

The vegetation percentage cover, the biomass quantity and quality determine the soil or soil substrate respiration. There is a considerable CO_2 flux within terrestrial ecosystems and between the biosphere and the atmosphere (Schlesinger, 1977; Raich & Schlesinger, 1992). Soil CO_2 fluxes include autotrophic root respiration and heterotrophic microbial respiration in the soil. Information on soil CO_2 fluxes and on factors that govern these fluxes is needed to constrain the ecosystem carbon cycling and to decide whether terrestrial ecosystems are carbon sinks or sources (Fan et al., 1995; Goulden et al., 1996; Lavigne et al., 1997; Lindroth et al., 1998). Other factors, such as land-use change, can also enhance or reduce soil CO_2 fluxes. Changes in precipitation (moisture) and temperature, as well as changes in habitat conditions or management practices, will impact soil respiration fluxes and the carbon budget of terrestrial ecosystems (Raich & Potter, 1995; Buchmann 2000).

Soil fauna parameters and the soil respiration in the studied vegetation types

The soil fauna improves litter decomposition at the global biome and ecosystem scales (average enhancement of 27%) (García-Palacios et al., 2013; Soong et al., 2016). The soil fauna is a vital element of ecosystems because of their functional positions in biogeochemical processes, accelerating the efficiency of biomass and litter decomposition and nutrient conversion (Wall et al., 2008).

The data collected on species composition, mesofauna abundance, and biomass enabled to look for evidence of interrelationships between the biotic elements of the study sites. Relatively strong interactions were detected between the biomass and abundance of the studied soil organisms. The abundance of *Vasomonads* and *Nematodes* on vegetated sites is relatively low compared to natural ecosystems. The formation of the first links of succession on a substrate almost completely devoid of life, or on one where it has been forming for a short time, is one of the most interesting issues of environmental biology. Succession processes can be observed, among other things, on various types of post-industrial heaps. Research on succession has been carried out for many years. However, most of the study mainly concerns plants. Studies on the groupings of soil animals at different stages of succession are rare (Tropek et al., 2012; Skubala 2002).

As indicated by Nielsen et al., 2014 local nematode abundance was related to soil characteristics, and no relationships were noted between colony richness and environmental or climatic variables. Family composition was related to average annual precipitation and temperature, suggesting that weather conditions (climate) is a good indicator of local assemblage structure. As a result, climate change could have a significant impact on nematode assemblages, with potential impacts on ecosystem functioning.

Soils or soil substrate below-ground ecosystems are composed of diverse organisms including invertebrate fauna that are responsible for the global turnover of biomass dead organic matter (Bardgett et al., 2014; Fierer 2017; Frouz 2018; Hicks et al., 2017). The small soil animals provide key ecosystem processes influencing significantly the decomposition of organic matter and the matter and energy flow enabling the recycling of nutrients (Frouz 2018; Lavelle et al., 1997; Frouz et al., 2014; Lavelle et al., 2016). Soil animals are varied in their body size. The smallest ones are classified to microfauna (< 0.2 mm), the medium ones into mesofauna (> 0.2 mm), and the largest ones to macrofauna (> 2 mm) (Lavelle et al., 1997; Lavelle 1996). The organisms representing the microfauna such as (e.g. protists and some nematodes), are predators of soil bacteria and fungi. Some groups of soil macrofauna are representing the saprophage organisms and contribute to litter decomposition like the nematodes that are litter-feeding ones (Fierer et al., 2017; Nielsen et al., 2014; Heděnec et al., 2020). Macro- and mesofauna are mostly saprophagous whereas some mesofauna and some larvae are fungal and bacterial feeders (Lavelle et al., 1997; Frouz et al., 2014; Lavelle

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et al., 2016). The diversity in soil fauna composition changes the feeding activity and alters environmental conditions in topsoil and thus influences the composition and diversity of soil microorganisms (Lavelle 1996; Lavelle et al., 1997; Hicks et al., 2017). The activity of soil fauna can be, among others, the explanation for the typically observed, soil CO_2 flux rates significant spatial and temporal variations within and among sites. In our study, the relations between the soil fauna diversity and the soil respiration revealed diversity between the studied vegetation types.

Some of them might be partly related to methodological differences (Raich & Nadelhoffer, 1989; Hanson et al., 1993; Norman et al., 1997). Soil temperature and soil moisture are among the most critical factors controlling the CO_2 flux (Raich & Schlesinger, 1992; Raich & Potter, 1995; Davidson et al., 1998; Buchmann 2000). Soil substrate quantity, and quality, soil texture have also been shown to have an effect (Grant & Rochette, 1994; Randerson et al., 1996; Boone et al., 1998; Pregitzer et al., 1998). There are many studies conducted on how to model the influence of these factors on soil respiration (e.g., Lloyd and Taylor, 1994; Thierron & Laudelout, 1996; Kicklighter et al., 1994; Buchmann 2000). The variability of soil CO_2 fluxes and some of the underlying processes are well known, but they still bear uncertainties that need to be resolved.

What the respiration process is dependent on in coal mine heaps Novel Ecosystems

Two simplifying hypotheses have been proposed for whole-plant respiration. One links respiration to photosynthesis, and the other one to biomass. Using the first-principles carbon balance model with a prescribed live woody biomass turnover, applied at a forest research site where multidecadal measurements are available for comparison, we show that if turnover is fast the accumulation of respiring biomass is low and respiration depends primarily on photosynthesis; while if turnover is slow the accumulation of respiring biomass is high, and respiration depends primarily on biomass. But the first scenario is inconsistent with evidence for substantial carry-over of fixed carbon between years, while the second one implies far too great increase in respiration during stand development, leading to depleted carbohydrate reserves and an unrealistically high mortality risk. These two mutually incompatible hypotheses are thus both incorrect. Respiration is not linearly related either to photosynthesis or to biomass, but it is more strongly controlled by recent photosynthates (and reserve availability) than by total biomass.

The environmental novelty of the coal mine heaps Novel Ecosystems - why the understanding of the Novel Ecosystems processes is important

Many discussions have focused on the definition of novelty of the Novel Ecosystems. As a result, Morse et al., (2014) presented some concepts of the description. Novel Ecosystems are a unique assemblage of environmental conditions and biotic conditions, set up due to human (human agency) alteration. By definition, the alteration must be sufficient to cross an ecological threshold that moves and maintains a new ecosystem trajectory. Regardless of the continuous and very fruitful discussions on the meaning and definition of the novelty idea, some sites should undoubtedly be identified as Novel Ecosystems. Among them the mineral post-excavation sites like, e.g., opencast sandpits, post-hard coal-mine heaps, lead zinc heaps, and limestone quarries are.

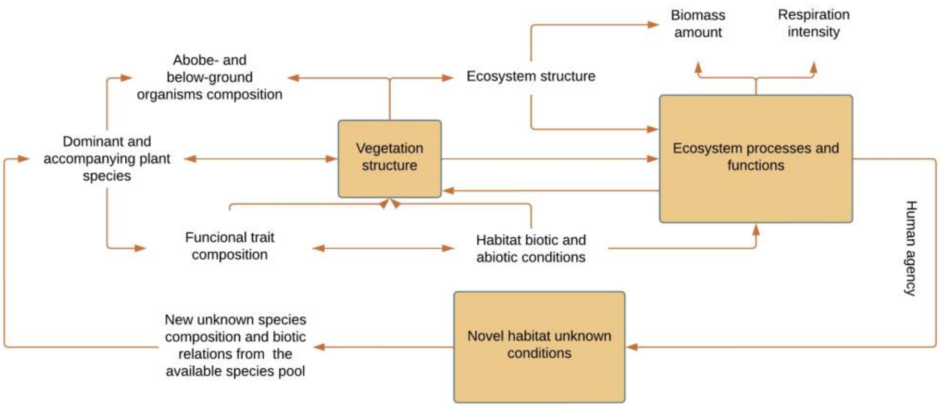

Figure 3.3.5. Simplified scheme of relationships among habitat conditions, vegetation structure, above and below-ground species composition, and ecosystem functioning in natural and semi-natural habitats; modification of these relationships by intense human agency can lead to crossing a habitat threshold, resulting in a Novel Ecosystem

According to some researchers, Novel Ecosystems represent new ecological entities, and they should be identified and enhanced according to their own independently developed biological, ecological, and environmental rules (Rotherham 2017). Following the Novel Ecosystems concept and pathway, the establishment of best adjusted and adapted organisms and their relations with the habitat will bring more benefits to environmental functioning (ecosystem services), than taking the risk of losing time and financial resources to restore, e.g., post mineral excavation sites to the previous stage (Morse et al., 2014; Evers et al., 2018). According to the available descriptions, a site assigned as a Novel Ecosystem habitat has to fulfil five prerequisite conditions: I) The establishment of the habitat has to take place due to human agents; II) The plant and animal species composition is unknown in the existing ecosystems; III) The Novel

Ecosystem has to grow in a new non-analogous manner; IV) It has to develop further as an autonomous, independent system after the human agent stops action; V) Finally, the Novel Ecosystem has to establish a self-maintaining ecosystem. Regardless of this description, there are still many misunderstandings (Morse et al., 2014; Evers et al., 2018).

Understanding of the nature of novel ecosystems requires a study of their functional character. Apart from the identification of the non-analogous species composition of vascular plants, the biological analyses of the biotic parameters' substrate (i.e., the activity of soil enzymes, functional diversity of microorganisms) as well as studies of species functional traits (morphological, biochemical or physiological) revealed that the adaptations that enable them to colonize harsh habitats are necessary (Milewska-Henel et al., 2021).

In our study, we analyzed some biotic habitat parameters concerning the soil respiration quantity. Among the biotic site characteristics, the vegetation species composition diversity indexes of the studied vegetation types, the SOM amount, the enzyme activity, the mesofauna occurrence, and the cover percentage along with the biomass amount in the record vegetation types groups were analyzed in the post coal mine Novel Ecosystems. It is known that natural or anthropogenic disturbances (e.g., logging, agriculture, urbanization, land-use changes, mineral resources excavation) often alter the soil profile, and the habitat conditions are changing carbon stocks and carbon fluxes (Schimel et al., 1997). The magnitude of change in soil or soil substrate CO_2 flux depends on the amount and quality of litter and organic layers, disturbed roots, or the admixture of mineral soil horizons exposed to oxygen. When organic matter, which is almost pure organic carbon, is exposed to oxygen, the organic carbon is oxidized to CO_2 and the adequate flux of energy is released.

The novel ecosystems unusual conditions

The extraction of mineral resources causes strong transformation of the landscape. The harsh habitat conditions are the reason for undertaking a complex study focused on understanding the Novel Ecosystem functioning apart from the complexity of microbial, plant relations and abiotic conditions feedback, and the limited understanding of these relations in natural and semi-natural ecosystems. At the same time, the human industrial and the mineral excavation exploitation activity brings completely new challenges (Błaszkowski et al., 2019; Kałucka & Jagodziński, 2016). The open cast mining and deposition of mineral material from deep mining change the land relief, remove the existing vegetation, and modify the soil structure and composition as well as hydrological conditions

Kompała-Bąba, Bąba 2013; Woźniak et al., 2018; Prach and Walker 2020; Tropek 2012; Frouz et al., 2008]. Specific chemical and physical properties of the mineral substrates create harsh conditions such as low nutrient including organic carbon content, low water-holding capacity, extreme pH and high temperatures (Novák & Prach, 2003; Řehounková et al., 2016; Błońska et al., 2019). In some sites, the changes of conditions and availability of resources are so fundamental that the given bio-geo-chemical habitat threshold is crossed, and as a consequence returning to the initial species composition is impossible. The habitats with *non-analogous* vegetation species composition appearing *de novo* are examples of novel ecosystems (Rotherham, 2017; Hobbs et al., 2013). The spontaneous non-analogous plant species composition has been studied in few habitat types representing the novel ecosystems (Keith et al., 2009; Chen & Chen, 2018; Zhang et al., 2022). Studies have proven the existence of a wide variety of habitat conditions of coal mine heaps regarding moisture, granulometry and salinity, not to mention slope inclination, height, and slope aspect differences. Moreover, the habitat diversity within one coal mine heap is frequently much higher than that between two or more heaps. The great mosaic of microhabitats (e.g., moisture, granulometry, salinity) is reflected by the diverse vegetation patchiness (Vargas and Allen, 2008). The wide microhabitat variety is crucial in the single coal mine heap scale (Błońska et al., 2019; Woźniak et al., 2021; Woźniak et al., 2022). The available studies of non-analogous species composition developed on coal mine heaps revealed that the novel ecosystems were significantly different from the surrounding non-industrial areas. The differences include flora, fauna, bryophytes, lichens and associated heterotrophic such as invertebrates e.g., insects, vertebrates e.g., birds and saprophytic including organisms, bacteria, fungi, mites (*Mesostigmata* group), saprophytic protists, etc., established as a result of the natural processes of colonization and recruitment in the novel habitats [39] (Jiang et al., 2008). The non-analogous species composition of the novel ecosystems presents a self-sustaining system that develops without human intervention (Frouz et al., 2014; Hobbs et al., 2013). It also creates unusual opportunities to study the processes of primary succession in specific combinations of habitat conditions with special attention to substrates with low initial biological activity (Błońska et al., 2022; Chmura et al., 2022; Keith et al., 2009; Morse et al., 2014; Rotherham, 2017; Woźniak et al., 2021, 2023). The CO_2 release, particularly the soil respiration, is a proxy for the ecosystem functioning.

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Plant species composition diversity and the soil respiration parameters

In natural and semi-natural undisturbed ecosystems, the plant species composition of the studied communities plays crucial roles in controlling soil respiration. Vegetation plant species composition is the only way carbon enters the soil and determines the composition of microbial communities. The variety of different plant species assemblage enriches soil autotrophic respiration by intensifying metabolic rates and fine root biomass [Chen & Chen 2018].

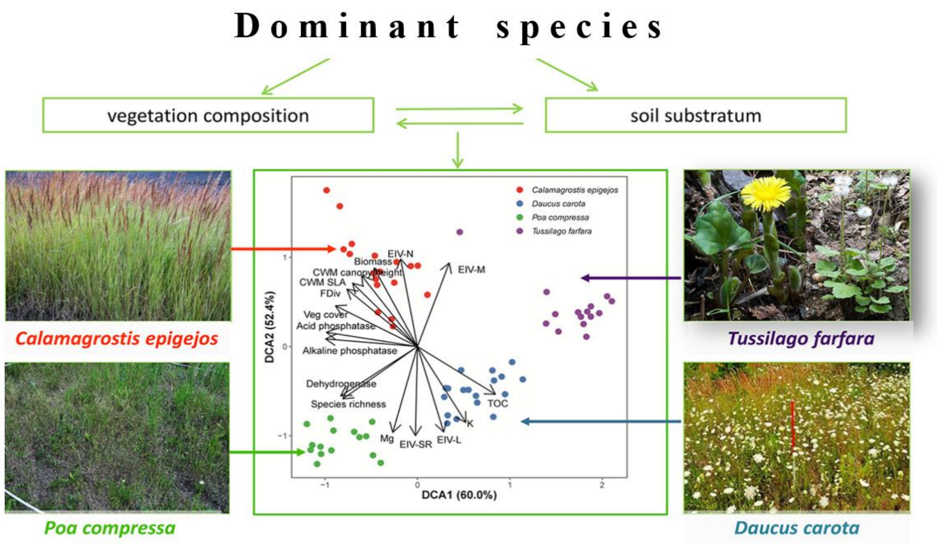

Figure 3.3.6. The dominant species are differently influencing the post-coal mine heaps. The dominant species of higher biomass are not the main factor shaping species diversity and parameters of the post-coal mine heaps soil substratum (after Kompała-Bąba et al., 2020)

The autotrophic diversity promotes soil heterotrophic respiration due to a greater variety of nutrient and carbon resources available for soil microorganisms (Khlifa et al., 2017). The structural complexity of the vegetation can indirectly influence soil respiration by changing (e.g., light) environments (high cover and shading of the lower layers) plant diversity (Mestre et al., 2017), and soil temperature variability (Stell et al., 2021). However, the impact of plant species assemblage diversity on soil respiration is likely to alter significantly in time, as plant litter inputs and root growth are inseparably linked to plant growth and thus often lead to seasonal patterns (Vargas, Allen 2008). Except for the differences in root respiration, plant species communities diversity mainly influences soil respiration *via* the quality and quantity of plant inputs of the remaining biomass biochemistry and, as a result, the attraction of the available microbes (Murphy et al., 2008). It is possible that soil microbial diversity and variety, derived from plant species diversity, plays a crucial impact in the cycling of carbon and nutrients in the soil in terrestrial ecosystems. However, observed proof shows that the role of microbial community composition in driving C fluxes and soil respiration is limited (Zhang et al., 2022). Some empirical studies have revealed that loss of microbial diversity caused higher velocities of soil microbial respiration (Zhang et al., 2022; Allen et al., 2010; Jian et al., 2008). Soil microbial diversity community composition is closely related to plant species composition diversity. However, it independently displays seasonal ways to track changes in soil water content and temperature (Waldrop, Firestone 2006). How above- and below ground diversity collectively shapes seasonal differences in soil respiration at local scales it is unknown (Zhang et al., 2022). The vegetation percentage cover, the biomass amount and soil organic carbon (SOM) are a kind of indexes.

The seasonal changes in soil respiration are also related to the vegetation plant species composition seasonality in temperate zone. Many studies have recorded the changes in soil respiration in the fall, which are particularly important in the overall attenuation of CO2 fluxes. Previously, it has been presented that soil respiration in a temperate forest in the fall was 87% of the total records of ecosystem respiration (Giasson et al., 2013). Giasson et al., (2013) interpreted the higher value of soil respiration during the fall to higher seasonal temperatures and other organic matter. The previous studies point to fall as a crucial season for understanding changes in soil respiration in response to warming (Estiarte & Penuelas, 2015; Kittredge et al., 2018).

Soil enzyme activity and the respiration parameters in the studied vegetation types

The temperature increases could increase extracellular enzyme reaction rates and, consequently, the decomposition process (Sinsabaugh et al., 1991; Fierer et al., 2005; Wallenstein et al., 2011; German et al., 2012; Burns et al., 2013). If warming increases decomposition, soil microbial communities could drain soil C pools (Oechel et al., 2000; Luo et al., 2001; Knorr et al., 2005; Davidson & Janssens, 2006; Hartley et al., 2007; Dorrepaal et al., 2009; Frey et al., 2013; Melillo et al., 2017).

Soil enzyme activity is suggested to be the indicator of soil quality, which can reflect the changes in the ecosystem health, which can be characterized by soil enzymes closely related to crucial soil quality parameters such as biomass, soil organic matter, the resulting microbial activity, and soil physical properties (Dick, Kandeler, 2005).

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Theoretical models predict that increases in soil respiration cause the rapid decomposition of labile C pools, but that soil respiration could return to prewarming levels after labile C has been depleted (Eliasson et al., 2005; Knorr et al., 2005; Kirschbaum, 2006; Bradford et al., 2008; Allison et al., 2010). Two leading hypotheses that aim to explain plateaus in respiration after warming are substrate depletion and thermal acclimation of soil microbial communities (Oechel et al., 2000; Luo et al., 2001; Davidson & Janssens, 2006; Hartley et al., 2007; et al., 2008). The substrate depletion hypothesis postulates that the energy expensive process of enzyme production should only be prompted if substrates limit microbial growth and are available for decomposition (Allison & Vitousek, 2005; Allison et al., 2014). Soil respiration could plateau if labile C is rapidly consumed in response to warming and recalcitrant C is not decomposed at the same rate (Davidson and Janssens, 2006; Hartley et al., 2007; Bradford et al., 2008; Bradford et al., 2010; Karhu et al., 2014; Bölscher et al., 2017; Wu et al., 2017). If substrate depletion is causing plateaus in soil respiration, we would expect the decreased activity of labile C-acquiring enzymes and a potential increase in the activity of recalcitrant C-acquiring enzymes. With these enzyme changes, respiration should increase until labile C-substrates are consumed but decrease or return to pre-warming levels as microbes shift from labile to recalcitrant substrates.

The thermal acclimation hypothesis postulates that microbial communities will adapt to warming and shift their community structure in order to utilize recalcitrant substrates after the consumption of labile substrates (Oechel et al., 2000; Luo et al., 2001; Davidson & Janssens, 2006; Bradford et al., 2008; DeAngelis et al., 2015). If thermal acclimation is causing plateaus in soil respiration, lower rates of soil respiration without changes in extracellular enzyme activity take place. Warm-adapted microbial communities could maintain their investment in enzyme production, even if soil respiration decreased, by allocating more C towards growth (Sinsabaugh et al., 1991; Olander & Vitousek, 2000). The enzyme activity might be tied to the overall demand for C, N, and P and is not driven by the availability of one enzymatic target (Schimel & Weintraub, 2003; Allison & Vitousek, 2005; Waldrop & Zak, 2006; Sinsabaugh et al., 2008; Allison et al., 2014).

The SOM quality and biochemistry is affecting the energy supply for microbial growth and therefore the enzyme release. Some studies show positive correlations between enzyme activities and SOC and Tot N in human-disrupted areas (Chodak, Niklińska, 2010; Ciarkowska et al., 2014). Baldrian et al., (2008) found out that during spontaneous succession on heaps established after brown coal extraction, the presence of SOC and Tot N in the topsoil layer significantly influenced the enzyme activities. The few studies performed on mineral material of post deep hard coal mine heaps results show no significant correlations between SOC amount in the mineral soil substrate and dehydrogenase activity or between SOC and the activity level of acid or alkaline phosphatases (Kompała-Bąba et al., 2021). However, some studies showed a negative correlation between urease activity and SOC (Rodriguez-Loinaz et al., 2008; Šantrůčková et al., 2004; Kompała-Bąba et al., 2021). The SOM in mineral soil substrate of the habitat conditions of the post-coal mine heaps might be rich in carbon related to organic matter of recent or geogenic origin (Abakumov et al., 2013; Markowicz et al., 2015; Stefanowicz et al., 2015; Woźniak et al., 2015; Woźniak et al., 2021). The black hard, geogenic coal is not available to microorganisms, regardless of its high amount of organic carbon (loss of ignition analysis) (10–18%) (Kompała-Bąba et al., 2021). The mineral post-coal mine substrate had low carbon sources for microorganisms (Markowicz et al., 2015; Woźniak et al., 2015). Typical for mineral habitats, the limited amount of carbon available for microorganisms in the total habitat pool of SOC may influence the lack of correlation between SOC and the activity of the studied soil enzymes, mainly derived from soil microorganisms reported by (Kompała-Bąba et al., 2021). The results of some studies have revealed that soil pH influences enzyme activity and soil microbial community structure (Rodriguez-Loinaz et al., 2008). Some studies have detected positive correlations between dehydrogenase and alkaline phosphatase activity, soil functional diversity, and substrate pH.

The tests of soil respiration rates and extracellular enzyme activity together as responses to warming are predicted to change in intensity during different seasons (e.g. decrease in summer, (Wallenstein et al., 2009) or increase in winter, (Baldrian et al., 2013). Passive warming experiments have been deployed in semi-urban areas with long histories of N deposition (Ehrenfeld 2003; Ashton et al., 2005), following historically high N deposition rates (National Atmospheric Deposition Program National Trends Network, Chapman et al., 2016). Herbaceous forest understory plants are often the largest reservoir of diversity in deciduous forests and they can contribute significantly to total forest net primary productivity (NPP) and thus soil organic matter (SOM) (Gilliam et al., 2006), making the forest understory an important focus for understanding the effect of warming on soil C storage.

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References

[1] Abakumov E.V.; Cajthaml T.; Brus J.; Frouz J. Humus Accumulation, Humification, and Humic Acid Composition in Soils of Two Post-Mining Chronosequences after Coal Mining. J Soils Sediments 2013, 13, 491–500, doi:10.1007/S11368-012-0579-9/METRICS.

[2] Alef K. and Nannipieri P. (1995) Methods in Applied Soil Microbiology and Biochemistry. Academic Press.

[3] Allen B.; Willner D.; Oechel W.C.; Lipson D. Top-down Control of Microbial Activity and Biomass in an Arctic Soil Ecosystem. Environ Microbiol 2010, 12, 642–648, doi:10.1111/J.1462-2920.2009.02104.X.

[4] Allison S.D.; Chacon S.S.; German D.P. Substrate Concentration Constraints on Microbial Decomposition. Soil Biol Biochem 2014, 79, 43–49, doi:10.1016/J.SOILBIO.2014.08.021.

[5] Allison S.D.; Vitousek P.M. Responses of Extracellular Enzymes to Simple and Complex Nutrient Inputs. Soil Biol Biochem 2005, 37, 937–944, doi:10.1016/J.SOILBIO.2004.09.014.

[6] Allison S.D.; Wallenstein M.D.; Bradford M.A. Soil-Carbon Response to Warming Dependent on Microbial Physiology. Nature Geoscience 2010 3:5 2010, 3, 336–340, doi:10.1038/ngeo846.

[7] Almeida T. S., Arantes M. R., Lopes Neto J. J., Souza T. M., Pessoa I. P., Medeiros J. L., ... & Carvalho, A. F. (2020). Evaluation of seeds ethanolic extracts of Triplaris gardneriana Wedd. using in vitro and in vivo toxicological methods. Journal of Toxicology and Environmental Health, Part A, 83(4), 135-152.

[8] Ashton I.W., Hyatt L.A., Howe K.M., Gurevitch J., Lerdau M.T. Invasive species accelerate decomposition and litter nitrogen loss in a mixed deciduous forest. Ecological Applications 2005, 15, 1263–1272, doi:10.1890/04-0741.

[9] Bahn M.; Reichstein M.; Davidson E.A.; Grünzweig J.; Jung M.; Carbone M.S.; Epron D.; Misson L.; Nouvellon Y.; Roupsard O.; et al., Soil Respiration at Mean Annual Temperature Predicts Annual Total across Vegetation Types and Biomes. Biogeosciences 2010, 7, 2147–2157, doi:10.5194/BG-7-2147-2010.

[10] Baldrian P.; Šnajdr J.; Merhautová V.; Dobiášová P.; Cajthaml T.; Valášková V. Responses of the Extracellular Enzyme Activities in Hardwood Forest to Soil Temperature and Seasonality and the Potential Effects of Climate Change. Soil Biol Biochem 2013, 56, 60–68, doi:10.1016/J.SOILBIO.2012.01.020.

[11] Baldrian P., Valášková V.: Degradation of Cellulose by Basidiomycetous Fungi. FEMS Microbiol Rev 2008, 32, 501–521, doi:10.1111/j.1574-6976.2008.00106.x.

[12] Bardgett R.D., Freeman C., Ostle N.J.: Microbial Contributions to Climate Change through Carbon Cycle Feedbacks. The ISME Journal 2008 2:8 2008, 2, 805–814, doi:10.1038/ismej.2008.58.

[13] Bardgett R.D., van der Putten W.H.: Belowground Biodiversity and Ecosystem Functioning. Nature 2014 515:7528 2014, 515, 505–511, doi:10.1038/nature13855.

[14] Bennett J.A., Klironomos J.: Mechanisms of Plant–Soil Feedback: Interactions among Biotic and Abiotic Drivers. New Phytologist 2019, 222, 91–96, doi:10.1111/NPH.15603.

[15] Bergmann J., Weigelt A., van der Plas F., Laughlin D.C., Kuyper T.W., Guerrero-Ramirez N., Valverde-Barrantes O.J., Bruelheide H., Fresche G.T., Iversen C.M.: et al. The Fungal Collaboration Gradient Dominates the Root Economics Space in Plants. Sci Adv 2020, 6, doi:10.1126/SCIADV.ABA3756.

[16] Bjørnlund L., Liu M.; Rønn R., Christensen S.: Ekelund F. Nematodes and Protozoa Affect Plants Differently, Depending on Soil Nutrient Status. Eur J Soil Biol 2012, 50, 28–31, doi:10.1016/J.EJSOBI.2011.11.012.

[17] Błaszkowski J., Niezgoda P., Piątek M., Magurno F., Malicka M., Zubek S., Mleczko P., Yorou N.S., Jobim K., Vista X.M., et al., Rhizoglomus Dalpeae, Maiae R. and Silesianum R.: New Species. Mycologia 2019, 111, 965–980, doi:10.1080/00275514.2019.1654637.

[18] Błońska A., Chmura D., Hutniczak A., Wilczek Z., Jarosz J., Besenyei L., Woźniak G.: The Plant Species Composition of an Abandoned Meadow as an Element of an Ecosystem Mosaic within an Urban-Industrial Landscape. Sustainability 2022, Vol. 14, Page 11851 2022, 14, 11851, doi:10.3390/SU141911851.

[19] Błońska E., Lasota J., Tullus A., Lutter R., & Ostonen I. (2019). Impact of deadwood decomposition on soil organic carbon sequestration in Estonian and Polish forests. Annals of Forest Science, 76(4), 1-14.

[20] Bölscher T.; Paterson E.; Freitag T.; Thornton B.; Herrmann A.M. Temperature Sensitivity of Substrate-Use Efficiency Can Result from Altered Microbial Physiology without Change to Community Composition. Soil Biol Biochem 2017, 109, 59–69, doi:10.1016/J.SOILBIO.2017.02.005.

[21] Boone R.D.; Nadelhoffer K.J.; Canary J.D.; Kaye J.P. Roots Exert a Strong Influence on the Temperature Sensitivityof Soil Respiration. Nature 1998 396:6711 1998, 396, 570–572, doi:10.1038/25119.

[22] Bowden R.D., Nadelhoffer K.J., Boone R.D., Melillo J.M., Garrison J.B.: Contributions of Aboveground Litter, Belowground Litter, and Root Respiration to Total Soil Respiration in a Temperate Mixed Hardwood Forest. https://doi.org/10.1139/x93-177 2011, 23, 1402–1407, doi:10.1139/X93-177.

[23] Bradford M.A., Davies C.A., Frey S.D., Maddox T.R., Melillo J.M., Mohan J.E., Reynolds J.F., Treseder K.K., Wallenstein M.D.: Thermal Adaptation of Soil Microbial Respiration to Elevated Temperature. Ecol Lett 2008, 11, 1316–1327, doi:10.1111/J.1461-0248.2008.01251.X.

[24] Bradford M.A.; Watts B.W.; Davies C.A. Thermal Adaptation of Heterotrophic Soil Respiration in Laboratory Microcosms. Glob Chang Biol 2010, 16, 1576–1588, doi:10.1111/J.1365-2486.2009.02040.X.

[25] Buchmann N.: Biotic and Abiotic Factors Controlling Soil Respiration Rates in Picea Abies Stands. Soil Biol Biochem 2000, 32, 1625–1635, doi:10.1016/S0038-0717(00)00077-8.

[26] Burns R.G.: Enzyme Activity in Soil: Location and a Possible Role in Microbial Ecology. Soil Biol Biochem 1982, 14, 423–427, doi:10.1016/0038-0717(82)90099-2.

[27] Burns R.G.; DeForest J.L.; Marxsen J.; Sinsabaugh R.L.; Stromberger M.E.; Wallenstein M.D.; Weintraub M.N.; Zoppini A.: Soil Enzymes in a Changing Environment: Current Knowledge and Future Directions. Soil Biol Biochem 2013, 58, 216–234, doi:10.1016/J.SOILBIO.2012.11.009.

[28] Burton A.J.; Pregitzer K.S.; Zogg G.P.; Zak D.R.: Drought Reduces Root Respiration in Sugar Maple Forests. Ecological Applications 1998, 8, 771, doi:10.1890/1051-0761(1998)008[0771:DRRRIS]2.0.CO;2.

[29] Chapin F. S., Woodwell G. M., Randerson J. T., Rastetter E.B., Lovett G. M., Baldocchi D. D., Clark D.A., Harmon M.E., Schimel D.S., Valentini R., Wirth C., Aber J.D., Cole J.J., Goulden M.L., Harden J.W., Heimann M., Howarth R.W., Matson P.A., McGurie A.D., Melillo J.M., Mooney H.A., Neff J.C., Houghton R.A., Pace M/L., Ryan M.G., Running S.W., Sala O.E., Schlesinger W.H. & Schulze, E. D. (2006). Reconciling carbon-cycle concepts, terminology, and methods. Ecosystems, 9, 1041-1050.

[30] Chapman S.K.; Devine K.A.; Curran C.; Jones R.O.; Gilliam, F.S. Impacts of Soil Nitrogen and Carbon Additions on Forest Understory

Communities with a Long Nitrogen Deposition History. Ecosystems 2016, 19, 142–154, doi:10.1007/S10021-015-9922-5/METRICS.

[31] Chapman S.K.; Newman G.S.: Biodiversity at the Plant-Soil Interface: Microbial Abundance and Community Structure Respond to Litter Mixing. Oecologia 2010, 162, 763–769, doi:10.1007/S00442-009-1498-3.

[32] Chen X., & Chen H. Y. (2018). Global effects of plant litter alterations on soil CO 2 to the atmosphere

[33] Chmura D.; Jagodziński A.M.; Hutniczak A.; Dyczko A.; Woźniak G. Novel Ecosystems in the Urban-Industrial Landscape–Interesting Aspects of Environmental Knowledge Requiring Broadening: A Review. Sustainability 2022, 14, doi:10.3390/SU141710829.

[34] Chodak M.; Niklińska M.: The Effect of Different Tree Species on the Chemical and Microbial Properties of Reclaimed Mine Soils. Biol Fertil Soils 2010, 46, 555–566, doi:10.1007/S00374-010-0462-Z/METRICS.

[35] Ciarkowska K., Sołek-Podwika K., Wieczorek J.: Enzyme Activity as an Indicator of Soil-Rehabilitation Processes at a Zinc and Lead Ore Mining and Processing Area. J Environ Manage 2014, 132, 250–256, doi:10.1016/J.JENVMAN.2013.10.022.

[36] Collalti A., & Prentice I. C. (2019). Is NPP proportional to GPP? Waring's hypothesis twenty years on. Tree Physiology, 39, 1473–1483. https ://doi.org/10.1093/treep hys/tpz034

[37] Collalti A., Thornton P. E., Cescatti A., Rita A., Borghetti M., Nolè A., Trotta C. Ciais P., and Matteucci G. (2019). The sensitivity of the forest carbon budget shifts across processes along with stand development and climate change. Ecological Applications, 29(2), 1–18. https ://doi.org/10.1002/eap.1837

[38] Collalti A., Trotta C., Keenan T.F., Ibrom A., Bond-Lamberty B., Grote R., Vicca S., Reyer C.P.O., Migliavacca M., Veroustraete F., Anav A., Campioli M., Scoccimarro E., Šigut L., Grieco E., Cescatti A., Matteucci G. Thinning Can Reduce Losses in Carbon Use Efficiency and Carbon Stocks in Managed Forests Under Warmer Climate. J Adv Model Earth Syst. 2018 Oct;10(10):2427-2452. doi: 10.1029/2018MS001275. Epub 2018 Oct 15. PMID: 31007835; PMCID: PMC6472666.

[39] Collalti A.; Tjoelker M.G.; Hoch G.; Mäkelä A.; Guidolotti G.; Heskel M.; Petit G.; Ryan M.G.; Battipaglia G.; Matteucci G.; et al. Plant

Respiration: Controlled by Photosynthesis or Biomass? Glob Chang Biol 2020, 26, 1739–1753, doi:10.1111/GCB.14857.

[40] Davidson E.A.; Belk E.; Boone R.D.: Soil Water Content and Temperature as Independent or Confounded Factors Controlling Soil Respiration in a Temperate Mixed Hardwood Forest. Glob Chang Biol 1998, 4, 217–227, doi:10.1046/J.1365-2486.1998.00128.X.

[41] Davidson E.A., Janssens I.A.: Temperature Sensitivity of Soil Carbon Decomposition and Feedbacks to Climate Change. Nature 2006 440:7081 2006, 440, 165–173, doi:10.1038/nature04514.

[42] DeAngelis K.M., Pold G., Topçuoglu B.D., van Diepen, L.T.A., Varney R.M., Blanchard J.L., Melillo J., Frey S.D. Long-Term Forest Soil Warming Alters Microbial Communities in Temperate Forest Soils. Front Microbiol 2015, 6, doi:10.3389/FMICB.2015.00104.

[43] Dick R. P., Kandeler E., & Hillel D. (2005). Encyclopedia of soils in the environment. Earth Environ Sci, 448-456.

[44] Dorrepaal E., Toet S., van Logtestijn R.S.P., Swart E., van de Weg M.J., Callaghan T. v., Aerts R.: Carbon Respiration from Subsurface Peat Accelerated by Climate Warming in the Subarctic. Nature 2009 460:7255 2009, 460, 616–619, doi:10.1038/nature08216.

[45] Dufrêne M., & Legendre P. (1997). Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecological monographs, 67(3), 345-366.

[46] Edwards N.T.; Sollins P. Continuous Measurement of Carbon Dioxide Evolution From Partitioned Forest Floor Components. Ecology 1973, 54, 406–412, doi:10.2307/1934349.

[47] Ehrenfeld J.G.: Effects of Exotic Plant Invasions on Soil Nutrient Cycling Processes. Ecosystems 2003, 6, 503–523, doi:10.1007/S10021-002-0151-3/METRICS.

[48] Eisenhauer N., Beßler H., Engels C., Gleixner G., Habekost M., Milcu A., Partsch S., Sabais A.C.W., Scherber C., Steinbeiss S., et al. Plant Diversity Effects on Soil Microorganisms Support the Singular Hypothesis. Ecology 2010, 91, 485–496, doi:10.1890/08-2338.1.

[49] Eliasson P. E., McMurtrie R. E., Pepper D. A., Strömgren M., Linder S., & Ågren G. I. (2005). The response of heterotrophic CO2 flux to soil warming. Global Change Biology, 11(1), 167-181.

[50] Estiarte M.; Peñuelas J.: Alteration of the Phenology of Leaf Senescence and Fall in Winter Deciduous Species by Climate Change:

Effects on Nutrient Proficiency. Glob Chang Biol 2015, 21, 1005–1017, doi:10.1111/GCB.12804.

[51] Evers C.R., Wardropper C.B., Branoff B., Granek E.F., Hirsch S.L., Link T.E., Olivero-Lora S., Wilson C.: The Ecosystem Services and Biodiversity of Novel Ecosystems: A Literature Review. Glob Ecol Conserv 2018, 13, e00362, doi:10.1016/J.GECCO.2017.E00362.

[52] Fan S.M., Goulden M.L., Munger J.W., Daube B.C., Bakwin P.S., Wofsy S.C., Amthor J.S., Fitzjarrald D.R., Moore K.E., Moore T.R.: Environmental controls on the photosynthesis and respiration of a boreal lichen woodland - a growing-season of whole-ecosystem exchange measurements by eddy-correlation. Oecologia 1995, 102.

[53] Fierer N.: Embracing the Unknown: Disentangling the Complexities of the Soil Microbiome. Nature Reviews Microbiology 2017 15:10 2017, 15, 579–590, doi:10.1038/nrmicro.2017.87.

[54] Fierer N., Craine J.M., Mclauchlan K., Schimel J.P.: Litter quality and the temperature sensitivity of decomposition. Ecology 2005, 86, 320–326, doi:10.1890/04-1254.

[55] Frey S.D., Lee J., Melillo J.M., Six J.: The Temperature Response of Soil Microbial Efficiency and Its Feedback to Climate. Nature Climate Change 2013 3:4 2013, 3, 395–398, doi:10.1038/nclimate1796.

[56] Frouz J.: Effects of Soil Macro- and Mesofauna on Litter Decomposition and Soil Organic Matter Stabilization. Geoderma 2018, 332, 161–172, doi:10.1016/J.GEODERMA.2017.08.039.

[57] Frouz J., & Jilková V. (2008). The effect of ants on soil properties and processes (Hymenoptera: Formicidae). Myrmecological News, 11(11), 191-199.

[58] Frouz J., Špaldoňová A., Fričová K., & Bartuška M. (2014). The effect of earthworms (Lumbricus rubellus) and simulated tillage on soil organic carbon in a long-term microcosm experiment. Soil Biology and Biochemistry, 78, 58-64.

[59] Gansert D.: (1994). Root respiration and its importance for the carbon balance of beech saplings (Fagus sylvatica L.) in a montane beech forest. Plant and Soil, 167, 109-119.

[60] García-Palacios P., Maestre F.T., Kattge J., Wall D.H.: Climate and Litter Quality Differently Modulate the Effects of Soil Fauna on Litter Decomposition across Biomes. Ecol Lett 2013, 16, 1045–1053, doi:10.1111/ELE.12137.

[61] German D.P., Marcelo K.R.B., Stone M.M., Allison S.D.: The Michaelis–Menten Kinetics of Soil Extracellular Enzymes in Response to Temperature: A Cross-Latitudinal Study. Glob Chang Biol 2012, 18, 1468–1479, doi:10.1111/J.1365-2486.2011.02615.X.

[62] Giasson M.A., Ellison A.M., Bowden R.D., Crill P.M., Davidson E.A., Drake J.E., Frey S.D., Hadley J.L., Lavine M., Melillo, J.M., et al. Soil Respiration in a Northeastern US Temperate Forest: A 22-Year Synthesis. Ecosphere 2013, 4, 1–28, doi:10.1890/ES13.00183.1.

[63] Gilliam F.S., Hockenberry A.W., Adams M.B., Gilliam F.S., Hockenberry A.W.: Effects of Atmospheric Nitrogen Deposition on the Herbaceous Layer of a Central Appalachian Hardwood Forest. Journal of the Torrey Botanical Society 2006, 133, 240–254.

[64] Goulden M.L., Munger J.W., Fan S.M., Daube B.C., Wofsy S.C. Exchange of Carbon Dioxide by a Deciduous Forest: Response to Interannual Climate Variability. Science (1979) 1996, 271, 1576–1578, doi:10.1126/SCIENCE.271.5255.1576.

[65] Grant, R.F.; Rochette, P. Soil Microbial Respiration at Different Water Potentials and Temperatures: Theory and Mathematical Modeling. Soil Science Society of America Journal 1994, 58, 1681, doi:10.2136/SSSAJ1994.03615995005800060015X.

[66] Handa, I.T.; Aerts, R.; Berendse, F.; Berg, M.P.; Bruder, A.; Butenschoen, O.; Chauvet, E.; Gessner, M.O.; Jabiol, J.; Makkonen, M.; et al. Consequences of Biodiversity Loss for Litter Decomposition across Biomes. Nature 2014 509:7499 2014, 509, 218–221, doi:10.1038/nature13247.

[67] Hanson, P.J.; Edwards, N.T.; Garten, C.T.; Andrews, J.A. Separating Root and Soil Microbial Contributions to Soil Respiration: A Review of Methods and Observations. Biogeochemistry 2000, 48, 115–146, doi:10.1023/A:1006244819642.

[68] Hanson, P.J.; Wullschleger, S.D.; Bohlman, S.A.; Todd, D.E. Seasonal and Topographic Patterns of Forest Floor CO(2) Efflux from an Upland Oak Forest. Tree Physiol 1993, 13, 1–15, doi:10.1093/TREEPHYS/13.1.1.

[69] Hart, S. C., & Sollins, P. (1998). Soil carbon and nitrogen pools and processes in an old-growth conifer forest 13 years after trenching. Canadian Journal of Forest Research, 28(8), 1261-1265.

[70] Hartley, I.P.; Heinemeyer, A.; Ineson, P. Effects of Three Years of Soil Warming and Shading on the Rate of Soil Respiration: Substrate Availability and Not Thermal Acclimation Mediates Observed

Response. Glob Chang Biol 2007, 13, 1761–1770, doi:10.1111/J.1365-2486.2007.01373.X.

[71] Hector, A.; Beale, A.J.; Minns, A.; Otway, S.J.; Lawton, J.H. Consequences of the Reduction of Plant Diversity for Litter Decomposition: Effects through Litter Quality and Microenvironment. Oikos 2000, 90, 357–371, doi:10.1034/J.1600-0706.2000.900217.X.

[72] Heděnec et al., 2020 Scientific report

[73] HELAL, H.M.; SAUERBECK, D. Short Term Determination of the Actual Respiration Rate of Intact Plant Roots. 1991, 24, 88–92, doi:10.1016/B978-0-444-89104-4.50016-5.

[74] Hicks Pries C.E.; Castanha, C.; Porras, R.C.; Torn, M.S. The Whole-Soil Carbon Flux in Response to Warming. Science (1979) 2017, 355, doi:10.1126/SCIENCE.AAL1319/SUPPL_FILE/HICKSPRIES.SM.PDF.

[75] Hobbs, R. J., Higgs, E. S., & Hall, C. (2013). Novel ecosystems: intervening in the new ecological world order. John Wiley & Sons.

[76] 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.; et al. Novel Ecosystems: Theoretical and Management Aspects of the New Ecological World Order. Global Ecology and Biogeography 2006, 15, 1–7, doi:10.1111/J.1466-822X.2006.00212.X.

[77] Hobbs, R.J.; Higgs, E.; Harris, J.A. Novel Ecosystems: Implications for Conservation and Restoration. Trends Ecol Evol 2009, 24, 599–605, doi:10.1016/J.TREE.2009.05.012.

[78] Högberg, P.; Ekblad, A. Substrate-Induced Respiration Measured in Situ in a C3-Plant Ecosystem Using Additions of C4-Sucrose. Soil Biol Biochem 1996, 28, 1131–1138, doi:10.1016/0038-0717(96)00124-1.

[79] Hooper, D.U.; Chapin, F.S.; Ewel, J.J.; Hector, A.; Inchausti, P.; Lavorel, S.; Lawton, J.H.; Lodge, D.M.; Loreau, M.; Naeem, S.; et al. Effects of Biodiversity on Ecosystem Functioning: A Consensus of Current Knowledge. Ecol Monogr 2005, 75, 3–35, doi:10.1890/04-0922.

[80] Horwath, W.R.; Pregitzer, K.S.; Paul, E.A. 14C Allocation in Tree–Soil Systems. Tree Physiol 1994, 14, 1163–1176, doi:10.1093/TREEPHYS/14.10.1163.

[81] Jiang, L.; Pu, Z.; Nemergut, D.R. On the Importance of the Negative Selection Effect for the Relationship between Biodiversity and Ecosystem Functioning. Oikos 2008, 117, 488–493, doi:10.1111/J.0030-1299.2008.16401.X.

[82] Jobbagy, E.G.; Jackson, R.B. The Vertical Distribution of Soil Organic Carbon and Its Relation to Climate and Vegetation. Ecological Applications 2000, 10, 423, doi:10.2307/2641104.

[83] Kałucka, I.L.; Jagodziński, A.M. Successional Traits of Ectomycorrhizal Fungi in Forest Reclamation after Surface Mining and Agricultural Disturbances: A Review Environmental and Genetic Factors Affecting Productivity of Forest Ecosystems on Forest and Post-Industrial Habitats View Proje., doi:10.12657/denbio.076.009.

[84] Karhu, K.; Auffret, M.D.; Dungait, J.A.J.; Hopkins, D.W.; Prosser, J.I.; Singh, B.K.; Subke, J.A.; Wookey, P.A.; Agren, G.I.; Sebastià, M.T.; et al. Temperature Sensitivity of Soil Respiration Rates Enhanced by Microbial Community Response. Nature 2014 513:7516 2014, 513, 81–84, doi:10.1038/nature13604.

[85] Kasprzak, K. (1947–); (1951–1992), P.W.N.; Zoologii., P.A.Nauk.I. Fragmenta Faunistica, t. 26, Nr 6. MiIZ PAN, sygn. patrz sygn. czas. P.256, T. 26, nr 6 1981, 26, 65–76, doi:10.3161/00159301FF1981.26.6.065.

[86] Keith, S.A.; Newton, A.C.; Herbert, R.J.H.; Morecroft, M.D.; Bealey, C.E. Non-Analogous Community Formation in Response to Climate Change. J Nat Conserv 2009, 17, 228–235, doi:10.1016/J.JNC.2009.04.003.

[87] Khlifa, R.; Paquette, A.; Messier, C.; Reich, P.B.; Munson, A.D. Do Temperate Tree Species Diversity and Identity Influence Soil Microbial Community Function and Composition? Ecol Evol 2017, 7, 7965–7974, doi:10.1002/ECE3.3313.

[88] Kicklighter, D.W.; Melillo, J.M.; Peterjohn, W.T.; Rastetter, E.B.; McGuire, A.D.; Steudler, P.A.; Aber, J.D.; Kicklighter, D.W.; Melillo, J.M.; Peterjohn, W.T.; et al. Aspects of Spatial and Temporal Aggregation in Estimating Regional Carbon Dioxide Fluxes from Temperate Forest Soils. JGR 1994, 99, 1303–1315, doi:10.1029/93JD02964.

[89] Kira, T., & Shidei, T. (1967). Primary production and turnover of organic matter in different forest ecosystems of the Western Pacific. Japanese Journal of Ecology, 17, 70–87. https ://doi.org/10.18960/seitai.17.2_70

[90] Kirschbaum, M.U.F. Temporary Carbon Sequestration Cannot Prevent Climate Change. Mitig Adapt Strateg Glob Chang 2006, 11, 1151–1164, doi:10.1007/S11027-006-9027-8/METRICS.

[91] Kirschbaum, M.U.F. The Temperature Dependence of Soil Organic Matter Decomposition, and the Effect of Global Warming on Soil Organic C Storage. Soil Biol Biochem 1995, 27, 753–760, doi:10.1016/0038-0717(94)00242-S.

[92] Kittredge, H.A.; Cannone, T.; Funk, J.; Chapman, S.K. Soil Respiration and Extracellular Enzyme Production Respond Differently across Seasons to Elevated Temperatures. Plant Soil 2018, 425, 351–361, doi:10.1007/S11104-018-3591-Z/METRICS.

[93] Knorr, W.; Prentice, I.C.; House, J.I.; Holland, E.A. Long-Term Sensitivity of Soil Carbon Turnover to Warming. Nature 2004 433:7023 2005, 433, 298–301, doi:10.1038/nature03226.

[94] Kompała-Bąba, A., & Bąba, W. (2013). The spontaneous succession in a sand-pit–the role of life history traits and species habitat preferences. Polish Journal of Ecology, 61(1), 13-22.

[95] Kompała-Bąba, A.; Bierza, W.; Sierka, E.; Błońska, A.; Besenyei, L.; Woźniak, G. The Role of Plants and Soil Properties in the Enzyme Activities of Substrates on Hard Coal Mine Spoil Heaps. Scientific Reports 2021 11:1 2021, 11, 1–13, doi:10.1038/s41598-021-84673-0.

[96] Kuzyakov, Y.; Gavrichkova, O. REVIEW: Time Lag between Photosynthesis and Carbon Dioxide Efflux from Soil: A Review of Mechanisms and Controls. Glob Chang Biol 2010, 16, 3386–3406, doi:10.1111/J.1365-2486.2010.02179.X.

[97] Lavelle, P. Diversity of Soil Fauna and Ecosystem Function. B Siobgy Intemational No 1996, 33.

[98] Lavelle, P., Spain, A., Blouin, M., Brown, G., Decaëns, T., Grimaldi, M., ... & Zangerlé, A. (2016). Ecosystem engineers in a self-organized soil: a review of concepts and future research questions. Soil Science, 181(3/4), 91-109

[99] Lavelle, P.; Bignell, D.; Lepage, M.; Wolters, V.; Roger, P.; Ineson, P.; Heal, O.W.; Dhillion, S. Soil Function in a Changing World: The Role of Invertebrate Ecosystem Engineers. Eur J Soil Biol 1997.

[100] Lavigne, M.B.; Ryan, M.G.; Anderson, D.E.; Baldocchi, D.D.; Crill, P.M.; Fitzjarrald, D.R.; Goulden, M.L.; Gower, S.T.; Massheder, J.M.; McCaughey, J.H.; et al. Comparing Nocturnal Eddy Covariance Measurements to Estimates of Ecosystem Respiration Made by Scaling Chamber Measurements at Six Coniferous Boreal Sites.

Journal of Geophysical Research: Atmospheres 1997, 102, 28977–28985, doi:10.1029/97JD01173.

[101] Lindroth, A.; Grelle, A.; Morén, A.S. Long-term Measurements of Boreal Forest Carbon Balance Reveal Large Temperature Sensitivity. Glob Chang Biol 1998, 4, 443–450, doi:10.1046/J.1365-2486.1998.00165.X.

[102] Lloyd, J.; Taylor, J.A. On the Temperature Dependence of Soil Respiration. Funct Ecol 1994, 8, 315, doi:10.2307/2389824.

[103] Luo, Y.; Wan, S.; Hui, D.; Wallace, L.L. Acclimatization of Soil Respiration to Warming in a Tall Grass Prairie. Nature 2001 413:6856 2001, 413, 622–625, doi:10.1038/35098065.

[104] Mallik, A.U.; Hu, D. Soil Respiration Following Site Preparation Treatments in Boreal Mixedwood Forest. For Ecol Manage 1997, 97, 265–275, doi:10.1016/S0378-1127(97)00067-4.

[105] Markowicz, A.; Woźniak, G.; Borymski, S.; Piotrowska-Seget, Z.; Chmura, D. Links in the Functional Diversity between Soil Microorganisms and Plant Communities during Natural Succession in Coal Mine Spoil Heaps. Ecol Res 2015, 30, 1005–1014, doi:10.1007/S11284-015-1301-3.

[106] Melillo, J.M.; Frey, S.D.; DeAngelis, K.M.; Werner, W.J.; Bernard, M.J.; Bowles, F.P.; Pold, G.; Knorr, M.A.; Grandy, A.S. Long-Term Pattern and Magnitude of Soil Carbon Feedback to the Climate System in a Warming World. Science (1979) 2017, 358, 101–105, doi:10.1126/SCIENCE.AAN2874/SUPPL_FILE/AAN2874_MELILLO_SM.PDF.

[107] Melillo, J.M.; Steudler, P.A.; Aber, J.D.; Newkirk, K.; Lux, H.; Bowles, F.P.; Catricala, C.; Magill, A.; Ahrens, T.; Morrisseau, S. Soil Warming and Carbon-Cycle Feedbacks to the Climate System. Science (1979) 2002, 298, 2173–2176, doi:10.1126/SCIENCE.1074153.

[108] Mestre, L.; Toro-Manríquez, M.; Soler, R.; Huertas-Herrera, A.; Martínez-Pastur, G.; Lencinas, M.V. The Influence of Canopy-Layer Composition on Understory Plant Diversity in Southern Temperate Forests. For Ecosyst 2017, 4, 1–13, doi:10.1186/S40663-017-0093-Z/TABLES/6.

[109] Milewska-Handel A., Chmura D., Wyrwał K., Kurczyńska E.U., Kompała-Bąba A., Jagodziński A.M., Woźniak G. 2021. Cell wall epitopes in grasses of different novel ecosystem habitats on post-

industrial sites. Land Degradation and Development 32: 1680-1694. DOI:10.1002/Idr.3786.

[110] Moore, J. C. et al. Detritus, trophic dynamics and biodiversity. Ecology Letters 7, 584–600 (2010).

[111] Moore, J.C.; Berlow, E.L.; Coleman, D.C.; de Suiter, P.C.; Dong, Q.; Hastings, A.; Johnson, N.C.; McCann, K.S.; Melville, K.; Morin, P.J.; et al. Detritus, Trophic Dynamics and Biodiversity. Ecol Lett 2004, 7, 584–600, doi:10.1111/J.1461-0248.2004.00606.X.

[112] Morse, N.; Mcdowell, W.H.; Morse, N.B.; Pellissier, P.A.; Cianciola, E.N.; Brereton, R.L.; Sullivan, M.M.; Shonka, N.K.; Wheeler, T.B.; Mcdowell, W.H.; et al. Novel Ecosystems in the Anthropocene: A Revision of the Novel Ecosystem Concept for Pragmatic Applications. Article in ECOLOGY AND SOCIETY 2014, doi:10.5751/ES-06192-190212.

[113] Murphy, M.; Balser, T.; Buchmann, N.; Hahn, V.; Potvin, C. Linking Tree Biodiversity to Belowground Process in a Young Tropical Plantation: Impacts on Soil CO2 Flux. For Ecol Manage 2008, 255, 2577–2588, doi:10.1016/J.FORECO.2008.01.034.

[114] Nakane, K.; Kohno, T.; Horikoshi, T. Root Respiration Rate before and Just after Clear-Felling in a Mature, Deciduous, Broad-Leaved Forest. Ecol Res 1996, 11, 111–119, doi:10.1007/BF02347678.

[115] Nakane, K.; Kohno, T.; Horikoshi, T.; Nakatsubo, T. Soil Carbon Cycling at a Black Spruce (Picea Mariana) Forest Stand in Saskatchewan, Canada. Journal of Geophysical Research: Atmospheres 1997, 102, 28785–28793, doi:10.1029/97JD02313.

[116] Nielsen, U. N. et al. Global-scale patterns of assemblage structure of soil nematodes in relation to climate and ecosystem properties. Glob. Ecol. Biogeogr. 23, 968–978 (2014).

[117] Nielsen, U. N., Ayres, E., Wall, D. H., Li, G., Bardgett, R. D., Wu, T., & Garey, J. R. (2014). Global-scale patterns of assemblage structure of soil nematodes in relation to climate and ecosystem properties. Global Ecology and Biogeography, 23(9), 968-978.

[118] Norman, J.M.; Kucharik, C.J.; Gower, S.T.; Baldocchi, D.D.; Crill, P.M.; Rayment, M.; Savage, K.; Striegl, R.G. A Comparison of Six Methods for Measuring Soil-Surface Carbon Dioxide Fluxes. Journal of Geophysical Research: Atmospheres 1997, 102, 28771–28777, doi:10.1029/97JD01440.

[119] Novák, J.; Prach, K. Vegetation Succession in Basalt Quarries: Pattern on a Landscape Scale. Appl Veg Sci 2003, 6, 111–116, doi:10.1111/J.1654-109X.2003.TB00570.X.

[120] O'Connor, M. P., Kemp, S. J., Agosta, S. J., Hansen, F., Sieg, A. E., Wallace, B. P., … Dunham, A. E. (2007). Reconsidering the mechanistic basis of the metabolic theory of ecology. Oikos, 116, 1058–1072. https ://doi.org/10.1111/j.2006.0030-1299.15534.x

[121] Odum, E. P. (1969). The strategy of ecosystem development. Science, 164(3877), 262–270. https ://doi.org/10.1126/scien ce.164.3877.262.

[122] Oechel, W.C.; Vourlitis, G.L.; Hastings, S.J.; Zuluete, R.C.; Maxman, L.; Kane, D. Acclimation of Ecosystem CO2 Exchange in the Alaskan Arctic in Response to Decadal Climate Warming. Nature 2000 406:6799 2000, 406, 978–981, doi:10.1038/35023137.

[123] Olander, L.P.; Vitousek, P.M. Regulation of Soil Phosphatase and Chitinase Activity by N and P Availability. Biogeochemistry 2000, 49, 175–190, doi:10.1023/A:1006316117817/METRICS.

[124] Prach, K., & Walker, L. R. (2020). Comparative plant succession among terrestrial biomes of the World. Cambridge University Press.

[125] Pregitzer, K.S.; Laskowski, M.J.; Burton, A.J.; Lessard, V.C.; Zak, D.R. Variation in Sugar Maple Root Respiration with Root Diameter and Soil Depth. Tree Physiol 1998, 18, 665–670, doi:10.1093/TREEPHYS/18.10.665.

[126] Raich, J.W.; Nadelhoffer, K.J. Belowground Carbon Allocation in Forest Ecosystems: Global Trends. Ecology 1989, 70, 1346–1354, doi:10.2307/1938194.

[127] Raich, J.W.; Potter, C.S. Global Patterns of Carbon Dioxide Emissions from Soils. Global Biogeochem Cycles 1995, 9, 23–36, doi:10.1029/94GB02723.

[128] RAICH, J.W.; SCHLESINGER, W.H. The Global Carbon Dioxide Flux in Soil Respiration and Its Relationship to Vegetation and Climate. Tellus B 1992, 44, 81–99, doi:10.1034/J.1600-0889.1992.T01-1-00001.X.

[129] Randerson, J.T.; Thompson, M. v.; Malmstrom, C.M.; Field, C.B.; Fung, I.Y. Substrate Limitations for Heterotrophs: Implications for Models That Estimate the Seasonal Cycle of Atmospheric CO 2. Global Biogeochem Cycles 1996, 10, 585–602, doi:10.1029/96GB01981.

[130] Řehounková, K.; Čížek, L.; Řehounek, J.; Šebelíková, L.; Tropek, R.; Lencová, K.; Bogusch, P.; Marhoul, P.; Máca, J. Additional Disturbances as a Beneficial Tool for Restoration of Post-Mining Sites: A Multi-Taxa Approach. Environmental Science and Pollution Research 2016, 23, 13745–13753, doi:10.1007/S11356-016-6585-5.

[131] Reich, P. B., Tjoelker, M. G., Machado, J.-L., & Oleksyn, J. (2006). Universal scaling of respiratory metabolism, size and nitrogen in plants. Nature, 439, 457–461. https ://doi.org/10.1038/natur e04282

[132] Reich, P. B., Tjoelker, M. G., Pregitzer, K. S., Wright, I. J., Oleksyn, J., & Machado, J.-L. (2008). Scaling of respiration to nitrogen in leaves, stems and roots of higher land plants. Ecology Letters, https ://doi.org/10.1111/j.1461-0248.2008.01185.x

[133] Rodríguez-Loinaz, G.; Onaindia, M.; Amezaga, I.; Mijangos, I.; Garbisu, C. Relationship between Vegetation Diversity and Soil Functional Diversity in Native Mixed-Oak Forests. Soil Biol Biochem 2008, 40, 49–60, doi:10.1016/J.SOILBIO.2007.04.015.

[134] Rotherham, I.D. Recombinant Ecology - A Hybrid Future? 2017, doi:10.1007/978-3-319-49797-6.

[135] Šantrůčková, H.; Vrba, J.; Picek, T.; Kopáček, J. Soil Biochemical Activity and Phosphorus Transformations and Losses from Acidified Forest Soils. Soil Biol Biochem 2004, 36, 1569–1576, doi:10.1016/J.SOILBIO.2004.07.015.

[136] SCHIMEL, D.S. Terrestrial Ecosystems and the Carbon Cycle. Glob Chang Biol 1995, 1, 77–91, doi:10.1111/J.1365-2486.1995.TB00008.X.

[137] Schimel, D.S.; Emanuel, W.; Rizzo, B.; Smith, T.; Woodward, F.I.; Fisher, H.; Kittel, T.G.F.; Mckeown, R.; Painter, T.; Rosenbloom, N.; et al. Continental Scale Variability in Ecosystem Processes: Models, Data, and the Role of Disturbance. Ecol Monogr 1997, 67, 251–271.

[138] Schimel, J. P., & Weintraub, M. N. (2003). The implications of exoenzyme activity on microbial carbon and nitrogen limitation in soil: a theoretical model. Soil Biology and Biochemistry, 35(4), 549-563.

[139] Schlesinger, W.H. Carbon Balance in Terrestrial Detritus. Annu Rev Ecol Evol Syst 1977, 8, 51–81, doi:10.1146/ANNUREV.ES.08.110177.000411.

[140] Simpson, E. H. (1949). Measurement of diversity. nature, 163(4148), 688-688.

[141] Sinsabaugh, R.; Antibus, R.K. An Enzymic Approach to the Analysis of Microbial Activity during Plant Litter Decomposition Drought-Induced Piñon Mortality View Project Climate Change Effects on Soil Invertebrate Communities View Project. 1991, doi:10.1016/0167-8809(91)90092-C.

[142] Sinsabaugh, R.L.; Antibus, R.K.; Linkins, A.E. An Enzymic Approach to the Analysis of Microbial Activity during Plant Litter Decomposition. Agric Ecosyst Environ 1991, 34, 43–54, doi:10.1016/0167-8809(91)90092-C.

[143] Sinsabaugh, R.L.; Lauber, C.L.; Weintraub, M.N.; Ahmed, B.; Allison, S.D.; Crenshaw, C.; Contosta, A.R.; Cusack, D.; Frey, S.; Gallo, M.E.; et al. Stoichiometry of Soil Enzyme Activity at Global Scale. Ecol Lett 2008, 11, 1252–1264, doi:10.1111/J.1461-0248.2008.01245.X.

[144] Skubała, P. (2002). Rozwój fauny roztoczy na hałdach, czyli jak przyroda walczy z przemysłem.

[145] Smulczak, L.; Tracz, H. Metabolizm Oddechowy Gleb w Roznych Wariantach Sposobu Przygotowania Gleby Oraz Udzialu Domieszek Na Zalesionych Gruntach Porolnych. Sylwan 2008, 152, 63–71.

[146] Soong, J.L.; Vandegehuchte, M.L.; Horton, A.J.; Nielsen, U.N.; Denef, K.; Shaw, E.A.; de Tomasel, C.M.; Parton, W.; Wall, D.H.; Cotrufo, M.F. Soil Microarthropods Support Ecosystem Productivity and Soil C Accrual: Evidence from a Litter Decomposition Study in the Tallgrass Prairie. Soil Biol Biochem 2016, 92, 230–238, doi:10.1016/J.SOILBIO.2015.10.014.

[147] Stefanowicz, A. M., Kapusta, P., Błońska, A., Kompała-Bąba, A., & Woźniak, G. (2015). Effects of Calamagrostis epigejos, Chamaenerion palustre and Tussilago farfara on nutrient availability and microbial activity in the surface layer of spoil heaps after hard coal mining. Ecological Engineering, 83, 328-337.

[148] Stell, E.; Warner, D.; Jian, J.; Bond-Lamberty, B.; Vargas, R. Spatial Biases of Information Influence Global Estimates of Soil Respiration: How Can We Improve Global Predictions? Glob Chang Biol 2021, 27, 3923–3938, doi:10.1111/GCB.15666.

[149] Swinnen, J.; van Veen, J.A.; Merckx, R. Rhizosphere Carbon Fluxes in Field-Grown Spring Wheat: Model Calculations Based on 14C Partitioning after Pulse-Labelling. Soil Biol Biochem 1994, 26, 171–182, doi:10.1016/0038-0717(94)90160-0.

[150] Thierron, V.; Laudelout, H. Contribution of Root Respiration to Total CO2 Efflux from the Soil of a Deciduous Forest. Canadian Journal of Forest Research 1996, 26, 1142–1148, doi:10.1139/X26-127.

[151] Thuille, A.; Buchmann, N.; Schulze, E.D. Carbon Stocks and Soil Respiration Rates during Deforestation, Grassland Use and Subsequent Norway Spruce Afforestation in the Southern Alps, Italy. Tree Physiol 2000, 20, 849–857, doi:10.1093/TREEPHYS/20.13.849.

[152] Tropek, R., Kadlec, T., Hejda, M., Kocarek, P., Skuhrovec, J., Malenovsky, I., ... & Konvicka, M. (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.

[153] Vargas, R.; Allen, M.F. Environmental Controls and the Influence of Vegetation Type, Fine Roots and Rhizomorphs on Diel and Seasonal Variation in Soil Respiration. New Phytologist 2008, 179, 460–471, doi:10.1111/J.1469-8137.2008.02481.X.

[154] Waldrop, M.P.; Firestone, M.K. Seasonal Dynamics of Microbial Community Composition and Function in Oak Canopy and Open Grassland Soils. Microb Ecol 2006, 52, 470–479, doi:10.1007/S00248-006-9100-6.

[155] Waldrop, M.P.; Zak, D.R. Response of Oxidative Enzyme Activities to Nitrogen Deposition Affects Soil Concentrations of Dissolved Organic Carbon. Ecosystems 2006, 9, 921–933, doi:10.1007/S10021-004-0149-0/METRICS.

[156] Wall, D.H.; Bradford, M.A.; st. John, M.G.; Trofymow, J.A.; Behan-Pelletier, V.; Bignell, D.E.; Dangerfield, J.M.; Parton, W.J.; Rusek, J.; Voigt, W.; et al. Global Decomposition Experiment Shows Soil Animal Impacts on Decomposition Are Climate-Dependent. Glob Chang Biol 2008, 14, 2661–2677, doi:10.1111/J.1365-2486.2008.01672.X.

[157] Wallenstein, M. D., McMahon, S. K., & Schimel, J. P. (2009). Seasonal variation in enzyme activities and temperature sensitivities in Arctic tundra soils. Global Change Biology, 15(7), 1631-1639. Global Change Biology, 24(8), 3462-3471.

[158] Wallenstein, M., Allison, S. D., Ernakovich, J., Steinweg, J. M., & Sinsabaugh, R. (2011). Controls on the temperature sensitivity of soil enzymes: a key driver of in situ enzyme activity rates. Soil enzymology, 245-258.

[159] West, G. B., Brown, J. H., & Enquist, B. J. (1999). A general model for the structure and allometry of plant vascular systems. Nature, 400(6745), 664-667.

[160] Wozniak, 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 Ecology 2015, 16, 23–32, doi:10.1556/168.2015.16.1.3/METRICS.

[161] Woźniak, G. 2010. Zróżnicowanie roślinności na zwałach pogórniczych Górnego Śląska. Diversity of vegetation on coal-mine heaps of the Upper Silesia (Poland). Szafer Institute of Botany, Polish Academy of Sciences, Kraków. p. 320.

[162] Woźniak, G., Chmura, D., Błońska, A., Tokarska-Guzik, B., & Sierka, E. (2011). Applicability of functional groups concept in analysis of spatiotemporal vegetation changes on manmade habitats. synthesis, 11(13), 23-27.

[163] Woźniak, G., Sierka, E., & Wheeler, A. (2018). Urban and industrial habitats: how important they are for ecosystem services (pp. 169-194). London, UK: IntechOpen.

[164] Woźniak, G.; Chmura, D.; Małkowski, E.; Zieleźnik-Rusinowska, P.; Sitko, K.; Ziemer, B.; Błońska, A. Is the Age of Novel Ecosystem the Factor Driving Arbuscular Mycorrhizal Colonization in Poa Compressa and Calamagrostis Epigejos? 2021, 10, 949, doi:10.3390/plants10050949.

[165] Woźniak, G.; Malicka, M.; Kasztowski, J.; Radosz, Ł.; Czarnecka, J.; Vangronsveld, J.; Prostański, D. How Important Are the Relations between Vegetation Diversity and Bacterial Functional Diversity for the Functioning of Novel Ecosystems? Sustainability (Switzerland) 2023, 15, doi:10.3390/SU15010678.

[166] Woźniak, G.; Malicka, M.; Kasztowski, J.; Radosz, Ł.; Czarnecka, J.; Vangronsveld, J.; Prostański, D. How Important Are the Relations between Vegetation Diversity and Bacterial Functional Diversity for the Functioning of Novel Ecosystems? Sustainability 2022, 15, doi:10.3390/SU15010678.

[167] Wu, L.; Yang, Y.; Wang, S.; Yue, H.; Lin, Q.; Hu, Y.; He, Z.; van Nostrand, J.D.; Hale, L.; Li, X.; et al. Alpine Soil Carbon Is Vulnerable to Rapid Microbial Decomposition under Climate Cooling. The ISME Journal 2017 11:9 2017, 11, 2102–2111, doi:10.1038/ismej.2017.75.

[168] Yeates, G.W. Soil Nematodes in Terrestrial Ecosystems. J Nematol 1979, 11, 213–229.

[169] Zhang, F.G.; Zhang, Q.G. Microbial Diversity Limits Soil Heterotrophic Respiration and Mitigates the Respiration Response to Moisture Increase. Soil Biol Biochem 2016, 98, 180–185, doi:10.1016/J.SOILBIO.2016.04.017.

[170] Zhang, M.; Sayer, E.J.; Zhang, W.; Ye, J.; Yuan, Z.; Lin, F.; Hao, Z.; Fang, S.; Mao, Z.; Ren, J.; et al. Seasonal Influence of Biodiversity on Soil Respiration in a Temperate Forest. Plants 2022, 11, 3391, doi:10.3390/PLANTS11233391/S1.

[171] Zhang, Y.; Chen, H.Y.H.; Reich, P.B. Forest Productivity Increases with Evenness, Species Richness and Trait Variation: A Global Meta-Analysis. Journal of Ecology 2012, 100, 742–749, doi:10.1111/J.1365-2745.2011.01944.X.

4. The mechanisms of terrestrial ecosystems function

The **fourth** part of the book, considers the mechanisms by which terrestrial ecosystems function and focus on the flow of water and energy and the cycling of carbon and nutrients, presenting the importance of the impact of organisms on ecosystem processes through trophic interactions (feeding relationships). Particular attention is paid to the role of biodiversity. In the natural and semi-natural ecosystems, some concepts and theories concerning biodiversity in relation to other ecosystem functions are described. In respect to the main focus of this book the numerous environmental effects caused by disturbance including the intermediate disturbance hypothesis are discussed.

The most vital point for understanding the ecosystem function (ecosystem services) of industrial areas includes the biodiversity-ecosystem and function-ecosystem service relationship. In the environment of urban and industrial areas, it might be expected that various aspects of the urban biodiversity-ecosystem service relationship are unique.

4.1. The terrestrial ecosystems function in post-industrial areas

Resource management in a sustainable way is based on a thorough understanding of the complexity of Earth's natural ecosystems and how they can be managed without compromising future generations. Sustainable management of natural resources becomes much more complicated when there is a severe and persistent anthropogenic impact. The interdisciplinary approach should improve the understanding, assessment, and maintenance of natural capital and related ecosystem services in urban-industrial areas. In ecological restoration, the biggest challenge is to find a consensus of suitable biodiversity indicators and economically possible measures, which will produce multiple socially and ecologically guided environmental benefits. There is difficulty reaching such a consensus because of the complexity and different ways of understanding the biodiversity concept. Restoration projects should involve ecologically based methods and approaches, fulfilling many stakeholders' expectations for sustainable development and human well-being. Integrated natural and human models for sustainable management can help to understand the dynamics of ecosystems, including biodiversity and trophic levels, to simulate and evaluate different management scenarios concerning biodiversity and ecosystem services. There is still a need to increase understanding of the role of biodiversity and ecosystem service identification as essential factors influencing the dynamics of the ecosystem and sustainable management scenarios.

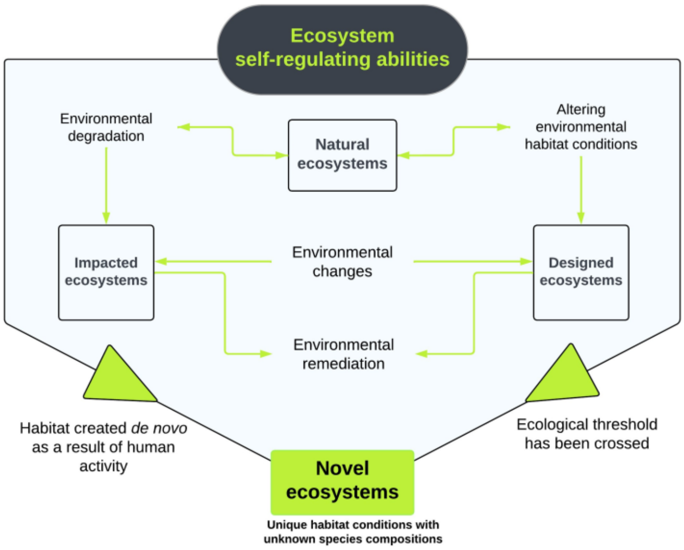

Figure 4.1.1. Scheme of the possible ecological changes and thresholds leading to Novel Ecosystems. The relations between ecosystems of different level of ecosystem disturbance undergoing different trajectories

Humanity is increasingly urban depending on industrial and agricultural products, but continues to depend on nature, i.e. natural capital, for its survival. People are dependent on the natural and anthropogenic functioning of ecosystems, and sustainable management of natural resources based on understanding the functioning of the Earth's natural ecosystems can enable their survival (Natural Resources Wales 2013) in the future (Haughton & Hunter 1994).

These mechanisms change when there is a solid and constant anthropogenic impact. Therefore, a multi-level approach should be taken to improve understanding, assessment, and maintenance of ecosystem services. An ecosystem is "a set of interacting species and their local, non-biological environment functioning together to sustain life" (Moll & Petit 1994). Ecosystem services are "the benefits human populations derive, directly or indirectly, from ecosystem functions" according to Costanza et al., (1997). Many of these ecological services are not consumed by humans directly but are needed to sustain the ecosystems themselves (Bolund & Hunhammar 1999). It is essential information for considering that, in the twentieth century the Earth has entered the Anthropocene epoch (Crutzen 2002). The main characteristic of the Anthropocene epoch is that human influences are shifting natural conditions beyond their limits, beyond the biological requirements which humans need for their existence (Steffen et al., 2007).

Large areas of the Earth's land surface are transformed through intensive agriculture, expanding urbanization, and industrialization. Often such human activities change the world ecosystems and landscapes in drastic ways. Intensive research has revealed that the pressure of land use throughout the globe has influenced the environment, ranging from modification in the composition of atmospheric gases to the extensive transformation of the Earth's ecosystems (Wackernagel et al., 2002). The Millennium Ecosystem Assessment (MEA) revealed that 60% of ecosystem services are at risk because natural resources have been affected by exploitation and unsustainable use (MEA 2005).

According to the Millennium Ecosystem Assessment (MEA 2005), "Ecosystem services are indispensable to the living conditions of all people in all places". Ecosystem services can only be provided by ecosystems, which are functioning effectively. However, there is a good evidence base that outlines the importance of biodiversity to ecosystem functioning. Still, less research is focused on the direct relationship between biodiversity and ecosystem services (Binner et al., 2017), e.g., concerning urban areas, particularly the understanding of biodiversity in urban woodlands. Many world ecosystems have been damaged or disturbed by human activity. Those changed ecosystems need to be restored and managed accordingly, including the concept of Novel Ecosystems when necessary (Hoekstra et al., 2005; Hobbs 2007).

The fact that human quality of life quality can increase while environmental quality deteriorates is considered as the Environmentalists' Paradox (Raudsepp-Hearne et al., 2010). Because humans as well as the ecosystem services that they need depend on nature (Pascual et al., 2017), the approach that natural capital could be decoupled from human needs seems paradoxical.

Natural capital is the key provider of natural assets, among which ecosystem services are fundamental. Frequently the terminology regarding natural capital and ecosystem services is used interchangeably, complicating the understanding of this complex subject (Binner et al., 2017). Natural capital can be considered the stock, or natural assets, within an ecosystem or an area. It is a part of total capital, which is natural, human, social, and manufactured capital combined. These forms of capital can be partly substitutable for one another (Sen 1999). Furthermore, substitution may be a rational choice for humans, but there may be no substitutes for some ecosystem services. States have to co-create a symbiotic future of natural forces (soil, water, air, and living organisms) with human forces (innovations, development, and human well-being).

An essential element in the delivery of ecosystem services is biodiversity, understood as all living organisms. Still, in many cases, it is not the diversity of the microorganisms that is important, but the presence of a viable population of at least one species representing a particular functional group. Biological diversity, and numbers of species, are also a service in itself. Moreover, there are fundamental interconnected relationships between biodiversity and ecosystem functions, including diversity.

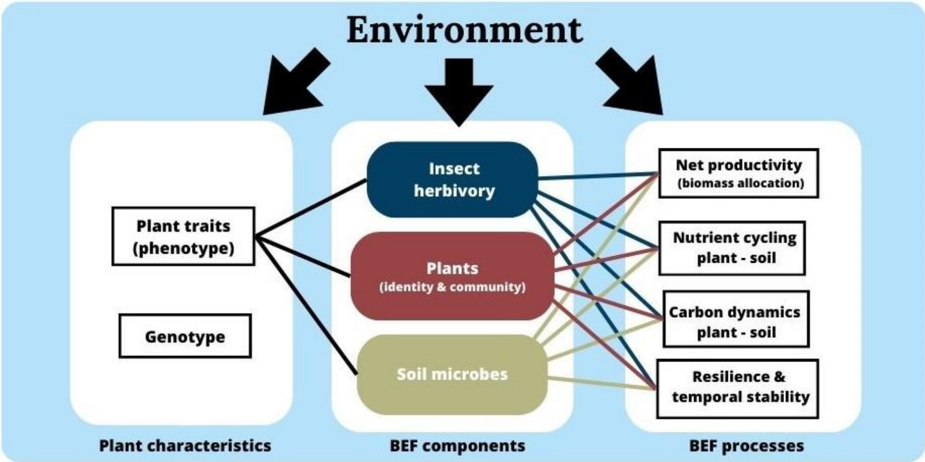

Figure 4.1.2. The basic inter-connected relationships between biodiversity, ecosystem functioning and ecosystem services. Conceptual overview of important relationships between plants traits and the biodiversity–ecosystem function (BEF) components and processes to be targeted when developing predictive BEF theory using willow short-rotation coppice (SRC) as a model. The BEF components relate to plant growth and productivity (green), insect herbivory as an important above ground trophic interaction (red), and soil microbes representing an important part of below ground trophic interactions (yellow). The BEF processes listed are considered important for the functioning of plant communities, modified from (Woźniak et al., (2018) – changed)

The relationships among the ecosystem elements are complex and not fully recognized and understood. The created models have to be simplified and translated into more informative formats for stakeholders and decision-makers. In this way, the decision-makers should be able to incorporate the ecosystem principles into management practices. Management practices may facilitate the enhancement of ecosystem services for human quality of life in urban-industrial sites.

The community composition in the city or industrial areas, i.e., organism composition and relationships developing on soil/soil substratum, is different from non-industrial habitats.

Many of the urban, industrial, and post-industrial areas represent complex land-cover mosaics. Some habitats of the mosaic represent sites where the “novel ecosystems" assemblage *sensu* Hobbs et al., (2013) develop in terms of their composition of ecological components and interactions (Wu 2014). In such new environmental situations, in habitats under continuous human pressure in urban areas or created by human activity, some organisms perform various functions. In industrial or post-industrial areas, understanding which features of particular organisms, communities, vegetation types, or habitat characteristics are most important turns out to be crucial (Piekarska-Stachowiak et al., 2014). The most vital point for understanding the ecosystem function (ecosystem services) of industrial areas is the biodiversity-ecosystem, and function-ecosystem service relationship. In the environment of urban and industrial areas, it might be expected that various aspects of the urban biodiversity-ecosystem service relationship are unique.

Many industrial areas are deficient in nutrients (oligotrophic) and are at the initial developmental stage. These sites are valuable in terms of their potential for biodiversity enhancement (Fig. 4.1.3.). This uniqueness implies an urgent need for the study of the biodiversity-ecosystem, function-ecosystem service relationship on the one hand, and the need for the decision makers and stakeholders to take this uniqueness into account in policy and management recommendations on the other hand. This uniqueness also implies that there is a high potential for the enhancement of those habitats. However, ecosystem dynamics in industrial landscapes is poorly understood (Pataki et al., 2011; Gómez-Baggethun & Barton 2013), especially when it comes to designing, creating, and restoring ecological processes, functions, and services in those areas (Benayas et al., 2009; Pataki et al., 2011).

There are severe contemporary constraints in understanding the biodiversity-ecosystem service relationship, which is a concept of the Blue-Green City. This concept supports and enhances the natural potential, primarily due to composition of primary producers using them, e.g., to reduce flood risk or to help improve the air, soil, and water quality. When people use nature (green plants or blue water) to help manage and enhance urban-industrial environments, e.g., in managing stormwater, it is often referred to as blue-green infrastructure. Green infrastructure as an ecological-environmental entity is a larger concept associated with the services provided through ecological functioning for the social, economic, and environmental health of the surrounding urban-industrial environment. The aim of the concept of the Blue-Green City approach is to recreate a water-based, and hydro-biological system based on biogeochemical processes by joining water management with the green infrastructure in urban areas. The Blue-Green project includes, for example, the idea of managing flood risk by combining the hydrological and ecological, e.g., specific vegetation type potential of the urban-industrial landscape.

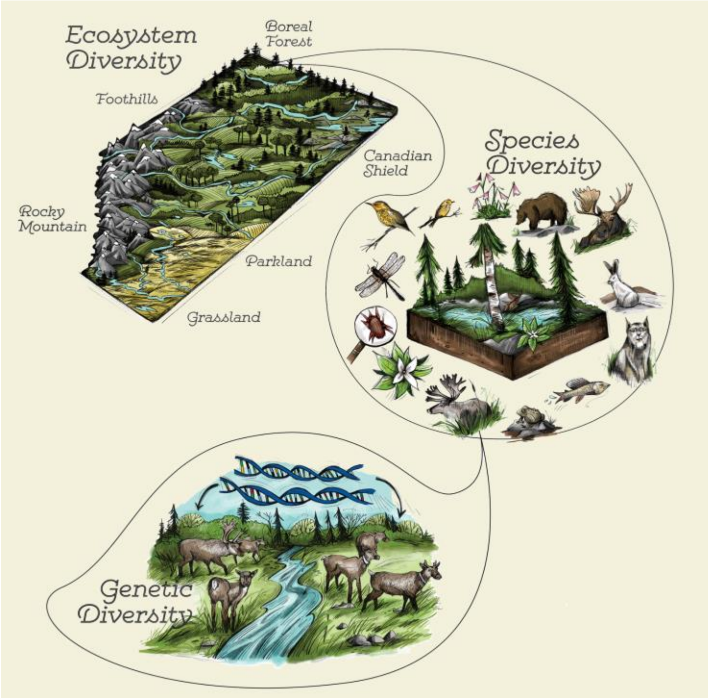

Figure 4.1.3. The most individual and specific measure of biodiversity is genetic diversity or genetic variation within a species. This diversity looks at differences among individuals within a population. The broader measure includes species diversity, biodiversity: the number of different species in a particular ecosystem. This type of diversity reports what can be found at an area. At the ecosystem diversity level, biologists look at many types of functional units of living communities interacting with their environments

The interaction between blue and green plants and water systems can enrich the urban-industrial environment. An example of such solutions is the Blue-Green City project in Newcastle, UK (Newcastle 2016). In terms of ecology and hydrology, the aims of the Newcastle project are the following: the creation of an urban flood model to simulate the movement of water and sediment through blue-green features; improve water quality, habitat, and biodiversity using a system of blue-green natural components using the power and potential of biological processes (*Blue-Green Cities Research Project: http://www.bluegreencities.ac.uk*).

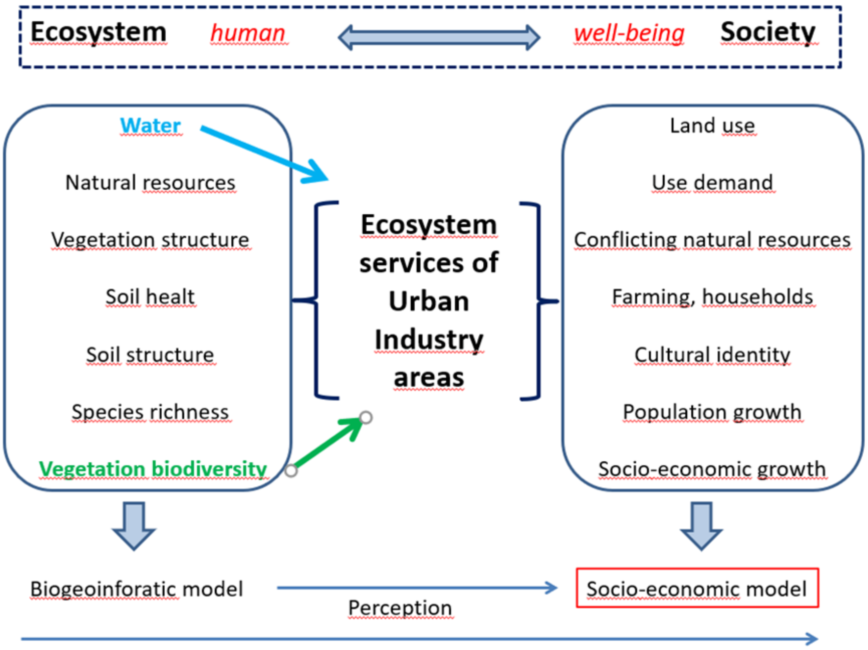

Figure 4.1.4. The complexity of the Blue-Green City concept in relation to the special mosaic of urban--industrial sites, land management, land requirements, and demand (Woźniak et al. 2018 – changed)

The Newcastle project is an example of an enterprise that considers both the ecological and hydrological elements, which are equally crucial for urban-industrial ecosystem functioning. The Anthropocene epoch forces humans to change their way of thinking about urban-industry environmental management and introduce a different way of acting. Humans need to focus on nature-based approaches. All the possibilities for enhancing biodiversity have to be used in management practices. The development and enhancement of varied microhabitats support increasing biodiversity. The monitoring of a biodiversity index might be an approach to a nature-based solution.

Restoration and regeneration of areas transformed and changed by industry can be a long and complicated process. Post-industrial sites generally represent heavily altered and affected ecosystems, which have lost their primary biodiversity and most of their ecosystem functions and services (Bradshaw 2000). The wide range of biodiversity restoration and ecosystem services in post-industrial (particularly post-mining) sites has received wide attention among restoration scientists (Prach & Pyšek 2001; Rahmonov 2009; Walker et al., 2014; Tarvainen & Tolvanen 2015). Although scientific attention to ecosystem services has been growing, there has been a solid tendency to conduct short-term experimental studies in which biodiversity was experimentally manipulated (in the laboratory or much less frequently in the field; Cardinale et al., 2012). However, some studies on vegetation development and spontaneous succession on urban and post-coal-mine sites were performed over ten years. Long-term research conducted in the field provided exciting results about the mechanisms concerning spontaneous vegetation, ecosystem development, and biodiversity enrichment in a broad spatiotemporal context (Woźniak 2010; Kompała-Bąba 2013).

Increasing the biodiversity (as the prerequisite) of all ecosystem services, which are dependent on ecosystem functions, is the main aim of ecological restoration (Whisenant 1999; Farber et al., 2006). In post-mining and post-industrial sites, the restoration and enhancement of biodiversity and ecosystem function should be related to the wider landscape and various local micro-habitats in a broad spatiotemporal context. Limiting the repair and management planning exclusively to the post-industrial and post-mining sites is the most common mistake of decision-makers. The essential prerequisites of soil/soil substratum physical features like erosion control, water infiltration, recognition, assessment, and the biotic spoil (spoil substratum) parameters, including bacteria and arbuscular mycorrhiza fungi (AMF), require wise, scientifically based decisions.

The decision process must include the actions supporting the spontaneous vegetation development and introducing specific plant species possessing the most necessary traits for the particular circumstances, all of which are prerequisites for the establishment of the best-adapted vegetation (Chmura et al., 2013; Markowicz et al., 2015; Stefanowicz et al., 2015; Woźniak et al., 2015; Bąba et al., 2016). Plants and vegetation as the primary producers are the fundamental elements of each developing ecosystem. Their restoration or enhancement is the basis for the re-establishment of primary productivity of urban post-industrial sites of diverse organisms, carbon sequestration, and increasing the regulation and aesthetic values of sites and the landscape. Ecologists (SER 2004; Tarvainen & Tolvanen 2015) prefer to emphasize the reestablishment or the increase of biodiversity as a goal of restoration.

Post-industrial sites need to be managed in an area-specific way precisely adjusted to each object and microhabitat variety. The site-specific approach is necessary for choosing the most appropriate restoration method, which is the optimal effect in terms of environmental/ecosystem function recovery. The ecosystem reestablishment approach presents a type of gradient, or a continuum, of ecological restoration depending on the intensity and level of spontaneous processes. The intervention levels may have a broad range, and technical reclamation may be necessary in cases of, e.g., chemical industry toxic

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contamination. Sometimes it involves heavy interventions, such as the restructuring of landforms, importing soil and/or removal of deposited material on the one hand, and the spontaneous colonization by organisms and succession so that the ecosystem is expected to recover principally through natural processes, on the other hand (Woźniak 2010; Holl & Aide 2011; Walker et al., 2014).

Figure 4.1.5. The abiotic site conditions of post-industrial sites are so different from the natural and semi-natural ones that it is inappropriate to use the experience from natural habitats for the reclamation practice; the agricultural and forest bridging engineering practices are unacceptable

For post-industrial ecosystem development and re-establishment of functioning, and the ecosystem services that may be accrued, primary or secondary succession through natural, spontaneous processes is the most appropriate for several reasons: a.) many of the post-industrial, particularly the post-mineral excavation sites, can be classified as Novel Ecosystems *sensu* Hobbs et al., (2013). According to Novel Ecosystems theory, the habitats of Novel Ecosystems cannot recover to the previous state. The only way for the Novel Ecosystems habitats to establish ecosystem functioning is to develop in adjustment to the new environmental conditions, with previously unknown nonanalogous plant species vegetation and ecosystem composition; b.) the high microsite heterogeneity and variety on post-industrial sites requires low-scale actions which are not economically beneficial; the natural, spontaneous processes can achieve it; c.) the recognition and increasing understanding of natural, spontaneous succession enables the facilitation and enhancement of biological processes by assisted restoration of ecosystem function reestablishment, to speed up when necessary natural regeneration and reestablishment of the ecosystem under adverse environmental conditions (Woźniak et al., 2015); d.) it should be understood and accepted that the target ecosystem mosaic may not always be an accurate replacement of the original ecosystem that was lost by open cast or underground mining or industrial activities, but a system of synusia of living organisms that are best adjusted to the new post-industrial conditions; e.) the factors influencing spontaneous succession of post-industrial sites have to be assessed, through studies of various measures and approaches, and this should be the basis for planning of effective ecological restoration (Prach & Pyšek 2001; Alday et al., 2016; Horáčková et al., 2016; Nikolic et al., 2016); f.) at the beginning of spontaneous succession, the early successional stages create a mosaic of species group composition traits that is of high conservation value, e.g., annual and early successional species (Chmura et al., 2011; Řehounková et al., 2016; Tropek et al., 2016);

Figure 4.1.6. The coal mine heaps are sometimes close to human settlements. The maintenance of early successional stages should be a goal of restoration projects. The open habitats of early succession are appropriate for wildlife, e.g., habitats for butterflies in the urban-industrial landscape are scarce. In the picture there is one of the research plots carried out by the Geobotny and Ecosystem Functioning University of Silesia

g.) the maintenance of early successional stages should be a goal of restoration projects; the open habitats of early succession are appropriate for wildlife, e.g., habitats for butterflies in the urban-industrial landscape are scarce; h.) technical

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reclamation, in comparison to spontaneous succession, can negatively influence the local biodiversity since it decreases the number of habitats that support specialized threatened species (Prach & Pyšek 2001; Řehounková et al., 2016). It may even enhance and maintain the pool of seeded alien species that may spread to the surrounding landscape and additionally threaten the urban-industrial environment (Rydgren et al., 2016); i.) spontaneous primary succession in post-industrial and urban areas frequently leads to establishing a self-sustaining, well-functioning ecosystem. However, they may be Novel Ecosystems *sensu* Hobbs et al., (2013) which are different ecosystems compared to those that occur in natural and semi-natural habitats; j.) the habitat and microhabitat differences caused by adverse oligotrophic mineral environmental conditions, and the omission of and ignoring the rules and mechanisms of biological processes, are very often the reasons why reclamation fails; k.) some post-industrial sites present the requirements for a development of extreme endemism. Such sites are environmental islands, and processes of microevolution could be expected to occur. This issue still needs to be investigated.

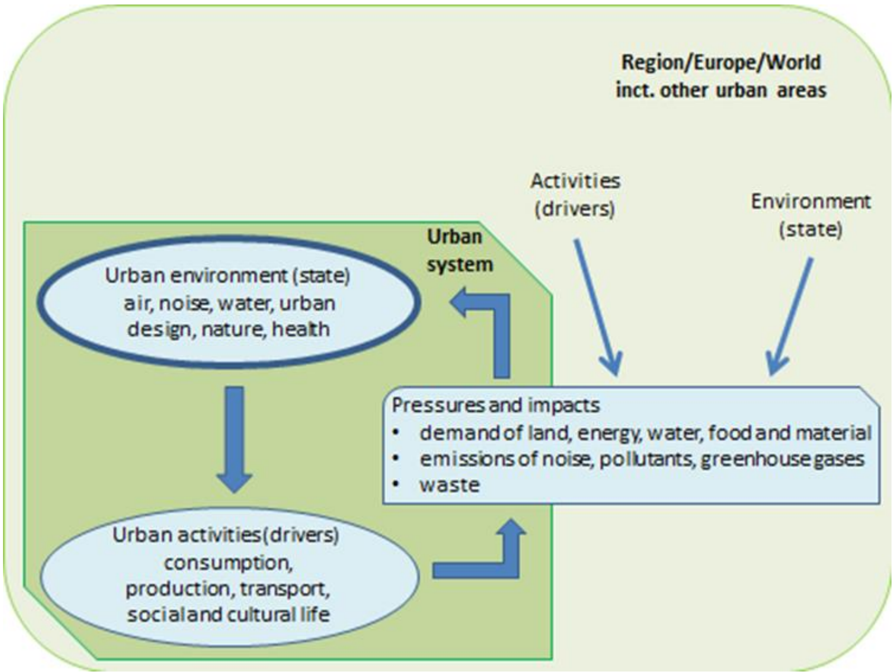

Figure 4.1.7. Some aspects of plant functional diversity of vegetation development on post-coal-mining heaps. The urban environment in relation to areas and activities beyond cities and towns

The ecosystem is always reflecting the environmental habitat conditions

At present, we are facing a significant challenge concerning the proper ecosystem and environmental management of urban and industrial habitats: How important are some of the novel ecosystems for ecosystem services? The answer to this question requires understanding that in the ecological restoration – ecosystem functioning reestablishment, the biggest challenge is to find a consensus of suitable biodiversity enhancement, which will produce multiple socially and ecologically guided environmental benefits. The biodiversity changes can be monitored by using multiscale biodiversity indicators followed by economically possible measurements. Our contemporary "pyramids" (as Żelaziński J. said), like their Egyptian counterparts, also contain treasures (in particular, environmental treasures). In time, we will find that the landscape we have known so well since childhood has changed, and we miss the "hills of anthropogenic origin" that are so memorable.

Figure 4.1.8. At each organizational level the ecosystem is always reflecting the environmental habitat conditions, this is the basis of ecology, the relations between living organisms and the habitat condition they occupy

Many years of development of city and industrial activity and frequent failure to undertake adequate environmental protection projects have led to upsetting of the natural ability of the environment to self-regulate and balance. However, there are also entirely degraded ecosystems whose conditions require de novo restoration to preserve Nature-Based Solutions to fulfil the broadest range of ecosystem services, following the principles of sustainable development. Sustainable development is understood as re-establishing ecosystem functioning for the efficient provision of ecosystem services for human society, which can be based only on supporting and enhancing natural processes. The self-reestablished ecosystem will be best adapted to the variety of post-mineral mining habitat conditions. The succession on the vast areas of post-coal mining sites starts from single tiny plant individual - primary producers.

Attention should be paid above all to the need of maintaining the comprehensive nature of the transformation process, including social, technical, and environmental issues, based on the newest scientific knowledge.

Figure 4.1.9. The succession on the vast areas of post-coal mining sites starts from single tiny plant individual - primary producers. The self-reestablished ecosystem will be best adapted to the variety of post-mineral mining habitat conditions.
The single seedlings of the herbaceous plant *Polygonum aviculare* (upper picture - spring). After half a year a denser clump from the few seedlings developed (lower picture - autumn of the same year)

The relationships between ecosystem services and multidimensional human needs are complex. The oversimplification of these relationships through an omission of locally relevant ecosystem functional elements in environmental management can lead to the loss of valuable novel ecosystems, which in turn can significantly affect biodiversity. Therefore, it is important to make appropriate decisions in the field of environmental management, taking into account social, technical and environmental issues, based on the latest scientific knowledge (Lapointe et al., 2021).

References

[1] Alday J.G., Zaldívar P., Torroba-Balmori P., Fernández-Santos B. & Martínez-Ruiz C. 2016: Natural Forest expansion on reclaimed coal mines in Northern Spain: the role of native shrubs as suitable microsites. Environmental Science and Pollution Research, 23 (14), 13606–13616.

[2] Bąba W., Błońska A., Kompala-Bąba A., Małkowski Ł., Ziemer B., Sierka E., Nowak T., Woźniak G. & Be-senyei L. 2016: Arbuscular mycorrhizal fungi (AMF) root colonization dynamics of *Molinia caerulea* (L.) Moench. in grasslands and post-industrial sites. Ecological Engineering, 95, 817–827.

[3] Benayas J.M.R., Newton A.C., Diaz A. & Bullock J.M. 2009: Enhancement of biodiversity and ecosystem services by ecological restoration: A meta-analysis. Science, 325 (5944), 1121–1124.

[4] Binner A.R., Smith G., Bateman I.J., Day B.H., Agarwala M. & Harwood A. 2017: Valuing the social and environmental contribution of woodlands and trees in England, Scotland and Wales. Forestry Commission Research Report, Forestry Commission, Edinburgh.

[5] Bolund P. & Hunhammar S. 1999: Ecosystem services in urban areas. Ecological Economics, 29 (2), 293–301.

[6] Bradshaw A. 2000: The use of natural processes in reclamation – advantages and difficulties. Landscape and Urban Planning, 51 (2–4), 89–100.

[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. 2012: Biodiversity loss and its impact on humanity. Nature, 486 (7401), 59–67.

[8] Chmura D., Molenda T., Błońska A. & Woźniak G. 2011: Sites of leachate inflows on coalmine heaps as refuges of rare mountainous species. Polish Journal of Environmental Studies, 20 (3), 551–557.

[9] Chmura D., Nejfeld P., Borowska M., Woźniak G., Nowak T. & Tokarska-Guzik B. 2013: The importance of land use type in *Fallopia*

https://doi.org/10.32056/KOMAG/Monograph2023.5

(*Reynoutria*) *japonica* invasion in the suburban environment. Polish Journal of Ecology, 61 (2), 379–384.

[10] Costanza R., d'Arge R., de Groot R., Farber S., Grasso M., Hannon B., Limburg K., Naeem S., O'Neill R.V, Paruelo J., Raskin R.G., Sutton P. & van den Belt M. 1997: The value of the world's ecosystem services and natural capital. Nature, 387 (15), 253–260.

[11] Crutzen P.J. 2002: Geology of mankind. Nature, 415, 23.

[12] Farber S., Costanza R., Childers D.L., Erickson J., Gross K., Grove M., Hopkinson C.S., Kahn J., Pincetl S., Troy A., Warren P. & Wilson M. 2006: Linking ecology and economics for ecosystem management. BioScience, 56 (2), 121–133.

[13] Gómez-Baggethun E. & Barton D.N. 2013: Classifying and valuing ecosystem services for urban planning. Ecological Economics, 86, 235–245.

[14] Haughton G. & Hunter C. 1994: Sustainable Cities. Regional Policy and Development. Jessica Kingsley Publishers Ltd, Regional Studies Association, London.

[15] Hobbs R.J. 2007: Setting effective and realistic restoration goals: key directions for research. Restoration Eco-logy, 15 (2), 354–357.

[16] Hobbs R.J., Higgs E.S. & Hall C.M. 2013: Defining novel ecosystems. [In:] Hobbs R.J., Higgs E.S. & Hall C.M. (eds.): Novel Ecosystems: Intervening in the New Ecological World Order. John Wiley & Sons Ltd., Chichester, 58–60.

[17] Hoekstra J.M., Boucher T.M., Ricketts T.H. & Roberts C. 2005: Confronting a biome crisis: global disparities of habitat loss and protection. Ecology Letters, 8 (1), 23–29.

[18] Holl K.D. & Aide T.M. 2011: When and where to actively restore ecosystems? Forest Ecology and Management, 261 (10), 1558–1563.

[19] Horáčková M., Řehounková K. & Prach K. 2016: Are seed and dispersal characteristics of plants capable of predicting colonization of post-mining sites? Environmental Science and Pollution Research, 23 (14), 13617–13625.

[20] Kompała-Bąba A. 2013: Abiotic and biotic factors affecting the diversity of ruderal vegetation (Silesian Uplands Poland). Sorus, Poznań.

[21] Lapointe M., Gurney G.G., Coulthard S. & Cumming G.S. 2021: Ecosystem services, well-being benefits and urbanization associations in a Small Island Developing State. People and Nature, 3 (2), 391–404.

[22] Markowicz A., Woźniak G., Borymski S., Piotrowska-Seget Z. & Chmura D. 2015: Links in the functional diversity between soil microorganisms and plant communities during natural succession in coal mine spoil heaps. Ecological Research, 30, 1005–1014.

[23] MEA – Millennium Ecosystem Assessment. 2005: Ecosystems and Human Well-being: Biodiversity Synthesis. World Resources Institute, Washington DC.

[24] Moll G. & Petit J. 1994: The urban ecosystem: putting nature back in the picture. Urban Forests, 14 (5), 8–15.

[25] Natural Resources Wales 2013: Introducing Sustainable Management of Natural Resources. Cyfoeth Naturiol Cymru, Natural Resources Wales. https://naturalresources.wales, access: 02.06.2021.

[26] Newcastle 2016: http://www.bluegreencities.ac.uk/about/blue-greencitiesdefinition.aspx, access: 02.06.2021.

[27] Nikolic N., Böcker R. & Nikolic M. 2016: Long-term passive restoration following fluvial deposition of sulphidic copper tailings: nature filters out the solutions. Environmental Science and Pollution Research, 23 (14), 13672–13680.

[28] Pascual U., Balvanera P., Díaz S., Pataki G., Roth E., Stenseke M., Watson R.T., Dessane E.B., Islar M., Kelemen E., Maris V., Quaas M., Subramanian S.M., Wittmer H., Adlan A., Ahn S., Al-Hafedh Y.S., Amankwah E., Asah S.T., Berry P., Bilgin A., Breslow S.J., Bullock C., Cáceres D., Daly-Hassen H., Figueroa E., Golden C.D., Gómez-Baggethun E., González-Jiménez D., Houdet J., Keune H., Kumar R., Ma K., May P.H., Mead A., O'Farrell P., Pandit R., Pengue W., Pichis-Madruga R., Popa F., Preston S., Pacheco-Balanza D., Saarikoski H., Strassburg B.B., van den Belt M., Verma M., Wickson F. & Yagi N. 2017: Valuing nature's contributions to people: the IPBES approach. Current Opinion in Environmental Sustainability, 26, 7–16.

[29] Pataki D.E., Carreiro M.M., Cherrier J., Grulke N.E., Jennings V., Pincetl S., Pouyat R.V., Whitlow T.H. & Zipperer W.C. 2011: Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions, and misconceptions. Frontiers in Ecology and the Environment, 9 (1), 27–36.

[30] Piekarska-Stachowiak A., Szary M., Ziemer B., Besenyei L. & Woźniak G. 2014: An application of the plant functional group

concept to restoration practice on coal mine spoil heaps. Ecological Research, 29, 843–853.

[31] Prach K. & Pyšek P. 2001: Using spontaneous succession for restoration of human-disturbed habitats: Experience from Central Europe. Ecological Engineering, 17 (1), 55–62.

[32] Rahmonov O. 2009: The chemical composition of plant litter of black locust (*Robinia pseudoacacia* L.) and its ecological role in sandy ecosystems. Acta Ecologica Sinica, 29 (4), 237–243.

[33] Raudsepp-Hearne C., Peterson G.D., Tengö M., Bennett E.M., Holland T., Benessaiah K., MacDonald G.K. & Pfeifer L. 2010: Untangling the environmentalist's paradox: Why is human well-being increasing as ecosystem services degrade? BioScience, 60 (8), 576–589.

[34] Řehounková K., Čížek L., Řehounek J., Šebelíková L., Tropek R., Lencová K., Bogusch P., Marhoul P. & Máca J. 2016: Additional disturbances as a beneficial tool for restoration of post-mining sites: a multi-taxa approach. Environmental Science and Pollution Research, 23 (14), 13745–13753.

[35] Rydgren K., Auestad I., Hamre L.N., Hagen D., Rosef L. & Skjerdal G. 2016: Long-term persistence of seeded grass species: an unwanted side effect of ecological restoration. Environmental Science and Pollution Research, 23 (14), 13591–13597.

[36] Sen A. 1999: Development as Freedom. Oxford University Press, Oxford.

[37] SER – Society for Ecological Restoration International Science & Policy Working Group. 2004: The SER International Primer on Ecological Restoration. Society for Ecological Restoration International Science & Policy Working Group. www.ser.org & Tucson, Society for Ecological Restoration International.

[38] Stefanowicz A.M., Kapusta P., Błońska A., Kompała-Bąba A. & Woźniak G. 2015: Effects of *Calamagrostis epigejos*, *Chamaenerion palustre* and *Tussilago farfara* on nutrient availability and microbial activity in the surface layer of spoil heaps after hard coal mining. Ecological Engineering, 83, 328–337.

[39] Steffen W., Crutzen P.J. & McNeill J.R. 2007: The Anthropocene: are humans now overwhelming the great forces of nature. AMBIO: A Journal of the Human Environment, 36 (8), 614–621.

[40] Tarvainen O. & Tolvanen A. 2015: Healing the wounds in the landscape – reclaiming gravel roads in conservation areas.

Environmental Science and Pollution Research, 23 (14), 13732–13744.

[41] Tropek R., Cerna I., Straka J., Kocarek P., Malenovsky I., Tichanek F. & Sebek P. 2016: In search for a compromise between biodiversity conservation and human health protection in restoration of fly ash deposits: effect of anti-dust treatments on five groups of arthropods. Environmental Science and Pollution Research, 23 (14), 13653–13660.

[42] Wackernagel M., Schulz N.B., Deumling D., Linares A.C., Jenkins M., Kapos V., Monfreda C., Loh J., Myers N., Norgaard R. & Randers J. 2002: Tracking the ecological overshoot of the human economy. Proceedings of the National Academy of Sciences of the United States of America, 99 (14), 9266–9271.

[43] Walker L.R., Hölzel N., Marrs R., del Moral R. & Prach K. 2014: Optimization of intervention levels in ecological restoration. Applied Vegetation Science, 17 (2), 187–192.

[44] Whisenant S.G. 1999: Repairing Damaged Wildlands: A Process-Orientated, Landscape-Scale Approach. Cambridge University Press, Cambridge.

[45] Woźniak G. 2010: Zróżnicowanie roślinności na zwałach pogórniczych Górnego Śląska [Diversity of vegetation on coal-mine heaps of the Upper Silesia (Poland)]. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

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

[47] 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. IntechOpen, 169–194.

[48] Wu J. 2014: Urban ecology and sustainability: The state-of-the-science and future directions. Landscape and Urban Planning, 125, 209–221.

https://doi.org/10.32056/KOMAG/Monograph2023.5

4.2 The post-industrial sites maintaining species diversity in the urban-industrial landscape

Long-term industrial development has changed the natural environment significantly. The exploitation of coal, sand, gravel, limestone, and dolomites caused changes in the surface and landscape. Some of the side products of excavation of mineral resources provide specific mineral oligotrophic habitats in the urban-industrial ecological mosaic. The systematic and ecological diversity of protected and endangered species, spontaneously colonizing and growing in post-industrial habitats, can be presented.

The spontaneous flora and vegetation of habitats like quarries, sand and gravel pits, heaps, and subsidence reservoirs are outstanding due to their floristic richness and the participation of rare protected and endangered species. The occurrence of protected and endangered species enriches the ecosystem function in densely populated urban-industrial landscape (habitat and ecosystem) mosaics by maintaining biodiversity in ecosystem services for humans.

Figure 4.2.1. The particular sites micro habitat conditions are unambiguously and precisely identified by plant seeds and diaspora of the best adapted species individuals that are able to germinate. In the picture, the halophyte *Salsola kali* seedling is presented

The previous study revealed that group of endangered and protected vascular plant species recorded in post-industrial areas of the Silesian Upland covers 7.4% of species in the whole flora of the Silesian Province. The analyzed species belong to 59 botanical families, consisting of 45% of the recorded flora of the Silesian Province. The 23 species represent the *Orchidaceae* family (50% of all species occurring in Poland, all members of the *Orchidaceae* family are protected). The presence of 66 endangered species in the Silesian Voivodeship and 21 in Poland proves that the ecological habitat conditions of post-industrial areas are suitable as secondary habitats for these species. Hence, post-industrial sites help to essentially support the survival of the endangered species. As a result of spontaneous colonization and succession, post-industrial areas have become refugees for species disappearing in natural habitats (Bacler-Żbikowska, Nowak 2022).

Human activity in many European industrial centres, has been growing over the last centuries. As a result of the long industrial development, the natural environment has changed significantly. The exploitation of gravel, limestone, coal, sand, and dolomites caused changes in the surface and landscape. Mineral resources exploitation (open cast and deep mining) changes the hydrology and influences surface waters. Besides the intense environmental transformation, some of the side products of mineral resources excavation provide additional, specific, mineral oligotrophic habitats in the urban-industrial habitat mosaic, such as water and wetland habitats. An example of an extending area of water body habitats is where the continuous collapse of the mine sidewalks caused land subsidence, up to 10 m deep, with the subsidence areas becoming filled with groundwater over time.

Figure 4.2.2. The lack of disturbance and time enable the plants individuals to colonize and develop the coal mine heaps of mineral habitats successfully. In the picture, the left middle part shows the tree juveniles and some herbaceous vegetation patches scattered on the constrained habitat

The industrial activity in the Upper Silesian Industrial District has been growing over many centuries. However, during the last 200 years, it has been connected with intense industrialization. The main branches of industry

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developed in this area, which exerted the most significant impact on the landscape and the natural landscape environment, are the mining and metallurgical industries in the broad sense. The zinc and lead are extracted, and iron ore was also a vital natural resource all over Europe. The development of mining entailed the need to extract back-filling sand (Malon 2010; Dulias 2018). An enormous amount of back-filling sand occurs in the vicinity area of Jaworzno. Sandy deposits of glacial and partly aeolian accumulation occur here. Other valuable mineral resources such as sedimentary rocks of various ages were also exploited in the Europe industry centre, including Silesia (Malon 2010; Dulias 2018).

The exploitation of mineral resources by mining operations disturbs hydrology and influences surface waters. Due to their floristic richness, including the participation of rare and endangered species, the flora of quarries, sand and gravel pits and heaps, sinking reservoirs, and post-coal mining heaps have been the subject of interest for many botanists, geobotanist biologists, ecologists, and environmentalists. As a result of spontaneous colonization and succession, post-mineral excavation areas have become refugia for species disappearing in natural habitats (Tokarska-Guzik & Rostański 2001; Woźniak et al., 2018; Bacler-Żbikowska, Nowak 2022).

This study aimed to present the taxonomic and ecological diversity of a selected group of protected and endangered species that are spontaneously colonizing and growing on post-mineral excavation habitats. The second aim is to show the importance of maintaining functional biodiversity by presenting the spectrum of ecological indexes represented by the analyzed group of protected and endangered species affecting the ecosystem services provided by post-mineral excavation habitats in densely populated urban-industrial landscapes (Kondracki 2011).

Characteristics of the studied post-mineral excavation sites

Quarries of carbonate rocks are essential natural resources mined in the Silesian Upland. Most of the resources have been identified mostly in the northern part – of the Katowice Upland (Dulias & Hibszer 2004). In the vicinity of Strzelce Opolskie, limestone mined for the cement industry (Dulias 2018) is also important for this industry. Many smaller quarries supplied limestone and marl for the limestone industry. They were mined in the south of the country.

The walls and bottoms of the excavations are an ideal habitat for colonization by limestone rock and xerothermic species. Due to the varied exposure of the excavation walls, they are inhabited by both shade-loving and photophilous species. Sometimes water accumulates on the bottom of the excavation, creating reservoirs or periodically existing ponds. At that time, in the absence of treatments, such flooding was colonized by hammer plant species and peat bog vegetation. The development of excavations for recreational and educational purposes is also noted.

Figure 4.2.3. The limestone base rich habitats are colonized by specific species such as *Tofieldia calyculata* (in the middle of the picture)

Opencast *sandpits* as the result of sand excavations cover about 50 km^2 in the SilesianVoivodeship (Czylok 2004). The pits are 15–20 m deep (Dulias 2018). Some mines are closed at present, and some have been closed for several dozen years (Czylok 2004). They have been reclaimed and managed to establish forests or are subject to secondary vegetation succession, and others are filled with water. In the case of open excavations, the level of groundwater at the bottom always changes. An alkaline reaction and high mineralization is characteristic. The soil formed in these excavations has the form of initial peat with changeable pH depending on groundwater level (Czylok & Szymczyk 2009). Opencast sandpits often provide substitute habitats for numerous scarce plant species.

Figure 4.2.4. The opencast sandpits are colonized by lards population of *Liparis loesli,* a plant species protected by the EU regulations

Heaps in the Silesian Upland, especially in its central and southwestern parts, post hard coal mine heaps are very common. There are also heaps, much less frequent, associated with zinc and lead ores (Dulias 2018). Heaps and post-mining sites are diverse in petrographic, mineral, chemical, granulometric, and pH composition. They also have very different shapes (Żmuda 1973). These areas are mineral soil substrates. Due to spontaneous processes in many places, formation of plant communities both common and rare species and even species under protection takes place (Rostański 2006; Woźniak 2010; Holeksa et al., 2015; Nowak et al., 2015).

Figure 4.2.5. The coal mine heaps are colonized by plants from the first year of establishment

Figure 4.2.6. The existing spontaneous diverse vegetation are sometimes covered by a new layer of mineral material of coal mine heap

Subsidence reservoirs-the presence of several thousand water reservoirs in the Silesian Upland, which arose as a result of direct or indirect human influence, is sometimes called the "anthropogenic lake district" (Rzętała 2008; Rzętała & Jaguś 2012). Some of them are associated with subsidence (Rzętała 2008). These reservoirs are created due to underground mining of coal, zinc, and lead ores (Machowski 2003; 2010). Two hundred fifty-one subsidence reservoirs are present (Jankowski & Wach 1980; Machowski 2003). Subsidence reservoirs perform an essential natural function, contributing to creating wetland habitats for plant and animal species previously not found in the area. They are critical as breeding habitats for birds (Machowski 2003).

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Figure 4.2.7. The subsidence reservoirs, becoming quickly a diverse water and wetland ecosystem

The analyses of species and subspecies growing spontaneously on post-mineral excavation sites included those recorded in the Red List of vascular plants of the Śląskie Voivodeship (Parusel & Urbisz 2012) and protected by law (Journal of Laws 2014, item 1409).

Data on the occurrence of the examined flora elements of the Silesian Upland were obtained from scientific and popular science publications containing detailed data (Celiński et al., 1974-1975; 1976; Duda 1992; Orczewska et al., 1993; Stebel 1993; Michalska 1994; Domański et al., 1995; Hereźniak 1995; Holak & Pawełko 1995; Czylok & Rahmonow 1996; Babczyńska-Sendek & Andrzejczuk 1997; Babczyńska-Sendek et al., 1997; Bernacki et al., 1997; Tokarska-Guzik 1997; Kołodziejek 1999; Madowicz 2000; Szeląg 2000; Woźniak & Kompała 2000; Woźniak & Rostański 2000; Hereźniak et al., 2001; Pasierbiński & Rostański 2001; Czylok & Baryła 2003; Spałek 2003; Szymczyk et al., 2003; 2011; Bzdęga et al., 2004; Absalon et al., 2005; Rostański 2006; Bula 2007; Chmura & Molenda 2007; Szczepańczyk 2007; Zalewska-Gałosz 2008; Cabała et al., 2009; Czylok & Szymczyk 2009; Czylok et al., 2009; Kompała-Bąba & Bąba 2009; Krajewski 2009; 2011; 2012; 2016a; 2016b; Błońska 2010; Błońska et al., 2011; Parusel & Parusel 2011; Tokarska-Guzik et al., 2011; Gębicki et al., 2013; Bula et al., 2014; Osiadacz & Kręciała 2014; Śliwińska-Wyrzychowska et al., 2014; Krajewski & Płachno 2015; Krajewski et al., 2015; Sieka et al., 2015).

The types of post-industrial habitats were also listed, where the species occurrence was recorded: quarries, sand/gravel pits, heaps, and subsidence reservoirs. The ecological characteristics of species include the following habitat parameters: light indicator (L), thermal index (T), soil moisture index (W), trophic index (T), soil acidity index (R), soil resistance index NaCl or/and in water (S) and an indicator of resistance to increased content of heavy metals (M). The values of the listed indicators are based on available sources (Zarzycki et al., 2002; Pladias 2014-2020). Moreover, the syntaxonomic affiliation of individual species was determined (Zarzycki et al., 2002; Matuszkiewicz 2012). Thanks to syntaxonomic characteristics, information on the importance of post-mineral excavation habitats as refugee habitats was presented.

The group of endangered and protected vascular plant species recorded in post-industrial areas of the Silesian Upland consists of 7.4% of the total number of species in the flora of the Silesian Province. The occurrence of 23 species from the *Orchidaceae* family, about 50% of all species occurring in Poland, and the botanical family, whose representatives are all legally protected in our country are precious. As many as 66 endangered species in the Silesian Voivodeship and 21 in Poland confirm that the ecological conditions in post-industrial areas are suitable for creating substitute habitats for these species.

The characteristics of ecological features of the analysed species present a broad spectrum, reflected by the diversity of habitat conditions characterizing post-industrial areas. The colonization by the species in question is not supported. It occurs spontaneously, which means that the post-industrial sites help the endangered species to survive. Such areas can contribute to the enrichment of biodiversity. In the future, such results may also be the basis for further comparative analysis with other post-industrial, post-excavation regions in Poland and abroad.

The protected and endangered species flora colonizing and growing spontaneously on post coal mining and post-industrial sites

In the post-mineral excavation sites of the Silesian Upland, 154 protected and endangered species, belonging to 59 botanical families, make up 45% of the recorded flora of the Silesian Province. The most represented ones belong to the following families: *Orchidaceae* (23 species), *Cyperaceae* (15), *Rosaceae* (8), *Fabaceae* and *Asteraceae* (7 species), *Poaceae* and *Potamogetonaceae* (6 species). Five species are spore plants – ferns, horsetails, and club mosses, and the rest are seed plants.

Thirty species under strict and 33 under partial protection were recorded. Many of the recorded species are also endangered in Poland.

The most significant number of protected and endangered species was recorded in quarries (80), in a similar number on sand and gravel pits (58) and on heaps (55), while the least in sinkhole reservoirs (35). As many as 14 species

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were present on three different types of objects: *Centaurium erythraea* subsp. *erythraea*, *Epipactis atrorubens*, *E. palustris*, *Eriophorum latifolium*, *Malaxis monophyllos*, *Melampyrum sylvaticum*, *Myricaria germanica*, *Najas marina*, *Neottia nidus-avis*, *Polypodium vulgare*, *Potentilla collina*, *Pyrola chlorantha*, *P. minor*, and *Viola rupestris*. Two species – *Schoenoplectus tabernaemontani* and *Utricularia australis* – occurred on four types of post-industrial facilities.

The analysis of the group of protection and endangered species regarding the participation of particular light index values shows that the most of the analyzed species growing on the post-mineral excavation sites represent the habitats of moderate light and full light. Most of the analyzed species represent the habitats of moderately cool and moderately warm conditions. The number of protected and endangered species growing on the post-mineral excavation sites, regarding particular soil moisture indexes, shows that species of fresh soil habitats clearly dominate. Nearly half of the species represent aquatic habitats, and the number of dry soil species is smaller (Fig. 4.2.8C.). Among the analysed spectrum of the trophy index, the mesotrophic species are the largest group. The presence of species occurring on alkaline soils is justified by the presence of the largest number of protected and threatened species in quarries. The second-largest group is made up of soil species from alkaline to neutral (Fig. 4.2.8D.).

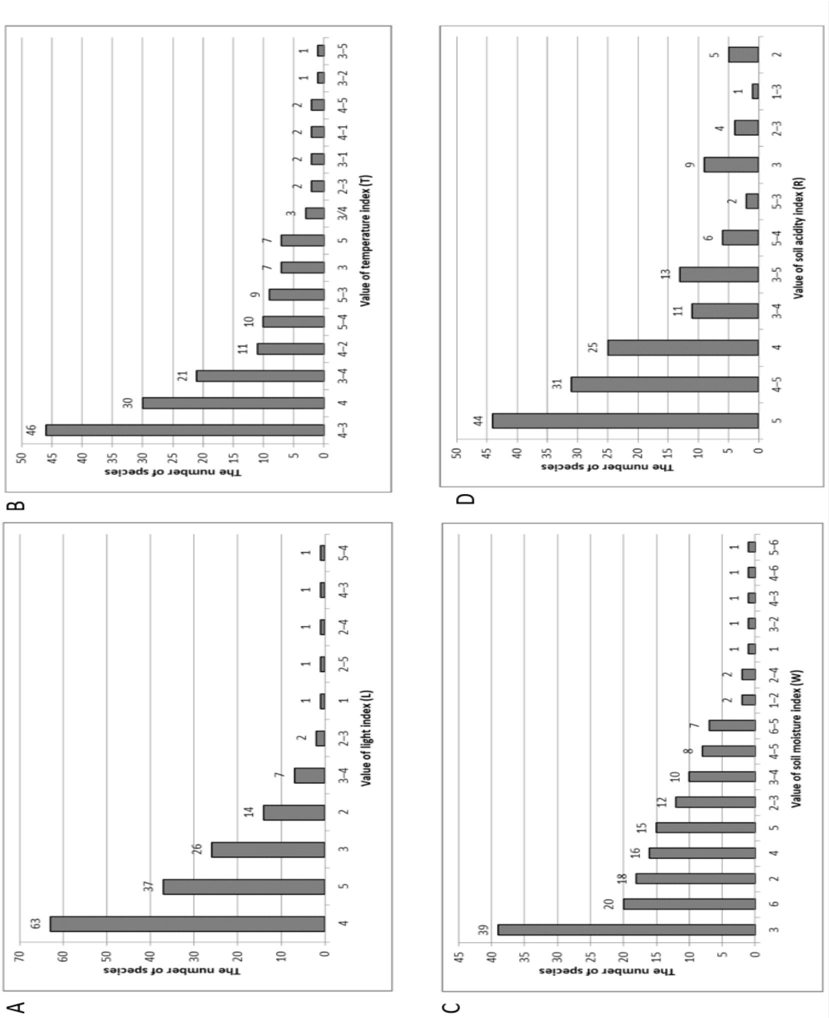

Figure 4.2.8. A.) The number of species of protected and endangered species group growing on the post-mineral excavation sites, representing particular light indexes:
1 – deep shade, 2 – moderate shade, 3 – half shade, 4 – moderate light, 5 – full light;
B.) Comparison of number of protected and endangered species growing on post-mineral excavation sites representing particular temperature indexes: 1 – the coldest areas of the country, mainly 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, 5 – the warmest regions and micro-habitats, thermally advantaged areas C.) Comparison of number of protected and endangered species growing on the post-mineral excavation sites representing particular soil moisture indexes: 1 – very dry habitats, 2 – dry habitats, 3 – moderately moist habitats, 4 – very moist habitats, 5 – wet habitats, 6 – aquatic habitats; D.) Comparison of number of protected and endangered species growing on the post-mineral excavation sites representing particular soil acidity indexes: 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)

Among the analyzed species, twelve – *Centaurium pulchellum*, *Dactylorhiza incarnata*, *Ophio-glossum vulgatum*, *Batrachium aquatile*, *B. circinatum*, *B. trichophyllum*, *Callitriche autumnalis*, *Cladium mariscus*, *Nuphar lutea*, *Nymphaea alba*, *Najas marina*, *Zannichellia palustris* were observed as optional halophytes. In turn, *Bulboschoenus maritimus* occurred mainly on soils with increased NaCl content (obligatory halophyte).

According to the criteria used in this study, three species (*Botrychium lunaria*, *Carlina acaulis*, *Alchemilla glacescens*) were classified as tolerant of increased contents of heavy metals.

Endangered and protected species of post-industrial habitats of the Silesian Upland represented 23 phytosociological classes. Some species are classified in two or three classes. However, the most probable one, based on local conditions, was selected for analysis. The most represented are deciduous forest species from the *Querco-Fagetea* class (33 species) and xerothermic grassland species from the *Festuco-Brometea* class (28). Water species of the *Potametea* class (20) and low-marsh meadows of the *Scheuchzerio-Caricetea nigrae* class (18) are also of great importance.

The recorded species represent the following phytosociological affiliation: ***Alnetea glutinosae*** - Forests with dominant black alder *Alnus glutinosa* or thickets of broad-leaved willows with alder, in depressions with complex drainage during periodically high water levels, on wet peat or peat-mineral soils; ***Asplenietea rupestria*** - Vegetation of this unit represents natural communities of rock crevices in rocky parts of the mountains; in the lowlands more often as anthropogenic communities in secondary habitats (walls, ruins); ***Bidentetea tripartiti*** - Natural and semi-natural therophyte communities on silty shores of water and periodically flooded depressions; ***Chenopodietea*** - The previously distinguished vegetation unit which was gathering vegetation patches occurring among root crops, e.g., potato, beetroot, carrots; ***Epilobietea angustifolii*** - Unit of nitrophilic communities occurring on strata frequently trampled, and habitats of ruderal origin; ***Festuco-Brometea*** - The communities of thermophilic grasslands of a steppe character, on a substrate with an alkaline reaction, rich in calcium; ***Isoëto-Nanojuncetea*** - Vegetation patches of small summer and autumn therophytes, appearing ephemerally on moist and mineral wet habitats; ***Koelerio glaucae-Corynephoretea canescentis*** - This unit gathers vegetation patches of psammophilus grasslands occurring in dry and relatively poor sandy or gravelly habitats; ***Littorelletea uniflorae*** - The vegetation communities which are composed of small aquatic or semi-aquatic perennials occurring in inland soft, oligo- or mesotrophic water bodies built up mostly by perennial plants; ***Molinio-***

Arrhenatheretea - Semi-natural and anthropogenic meadow and pasture communities on meso- and eutrophic undisturbed mineral and organic-mineral soils, possibly mineralized and dried muck made of low peat; ***Nardo-Callunetea*** - Communities of moors and poor *Nardus* grasslands. Semi-natural and anthropogenic communities, which in the original landscape occupied a small area under specific environmental conditions, spread spontaneously and developed in their present form as a result of human activity; ***Oxycocco-Sphagnetea*** - Shrub-sphagnum, sometimes with woody plants, communities of wet heaths, and raised bogs in acidic oligo- and dystrophic habitats fed exclusively or mainly by rainwater; ***Phragmitetea*** - Communities of rushes and salt meadows. The societies of grassland rushes, large sludge rushes, and other rushes with the participation of magnificent dicotyledonous perennials occurring on the coast and in coastal zones of inland stagnant and flowing water reservoirs; ***Potametea*** - The unit gathers (Eurosiberian) communities of freshwater macrophytes in mesotrophic and eutrophic inland water reservoirs; ***Querco-Fagetea*** - This unit gathers meso- and eutrophic deciduous forests that shed their leaves for winter, growing on mineral soils with varying degrees of moisture and representing in the humid parts of temperate continents a zonal type of plants formation; ***Ruppietea maritimae*** - Vegetation patches of mainly rooted aquatic plant communities; extremely specialized communities of open so-called submarine meadowsin the sublittoral zone, covering the seabed to a depth of 4 m; ***Scheuchzerio-Caricetea nigrae*** - The vegetation of low sage communities of marsh, and transitional fens, rich in bryophytes, create habitats of Nature 2000 identified under the number 7140; ***Stellarietea mediae*** - Communities of arable fields that arise spontaneously in the conditions of human agricultural extensive activity. For a long time, these vegetation patches have been considered as undesirable vegetation and plants competing with crops; ***Thlaspietea rotundifolii*** - Pioneering vegetation communities of movable or poorly fixed screes in rocky parts of mountains and stonework in mountain sections of river valleys; ***Trifolio-Geranietea sanguinei*** - Thermophilic fringe vegetation communities in the contact zone of some forest or shrub communities with grass and grassland communities; ***Utricularietea intermedio-minoris*** - A specialized ecological group of vegetation communities occurring in shallow dystrophic water reservoirs on a peat substrate, in valleys and depressions in the peat bog complex, and in oligo- and dystrophic reservoirs; ***Vaccinio-Piceetea*** - Holarctic-boreal acidophilic, oligo- and mesotrophic forest vegetation communities with a predominance of coniferous woody species, shrubs, and mesophilic bryophytes;

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Regardless of the above-presented results, the post-industrial, post-mineral excavation of large areas in the Silesian Upland is still analysed primarily due to its economic importance (Henzel et al., 2009; Zagórska 2013). According to the current law prescription, the analyzed sites undergo reclamation and development management plans (Ostręga & Uberman 2010; Pałasz 2012 and literature cited therein). Unfortunately, the law does not follow the knowledge concerning the dynamic biological, ecological, and ecosystem functioning processes. In some cases, the lack of application of the newest environmental experiences and scientific expertise in environmental management decisions and restoration actions, causes more harm to the ecosystem's functioning than the mineral resources excavations themselves. Hopefully, global change challenges will force the law to follow the enhancement of ecosystem functioning of the *de novo* established human-created habitats. The issues of effective reclamation and its directions are the subject of numerous studies (e.g., Różkowski et al., 2010; Poros & Sobczyk 2013; 2014; Pietrzyk-Sokulska & Kulczycka 2014; Sobala & Pukowiec 2014; Bednarczyk et al., 2015).

Most of them are agricultural and engineering-focused, ignoring theecosystem functioning parameters, neglecting that all human life aspects depends on ecosystem functioning – ecosystem services. Unfortunately, it is common practice that the site is more likely to be restored in an old fashioned, wrong way, harmful for ecosystem function. The restored area is reused for economic purposes while preserving cultural heritage, and biodiversity enhancement centres are scarce. From the nature perspective, attempts of reclamation treatments seldom bring the expected results and sometimes harm the natural environment more than the industry activity alone (Woźniak 2010; Rostański et al., 2015; Woźniak et al., 2018). The same was observed and recorded in other countries a long time ago (Box 1999; Tropek et al., 2012). The high environmental value of many of the post-mineral excavation sites is neglected and ignored because of a lack of knowledge, partially because law and regulations do not follow the current scientific achievements.

Plants associated with soils rich in heavy metals – metallophytes' natural habitats – are the calamine grasslands. The calamine grasslands are an excellent example of a specific group of species established on post-mineral excavation habitats. The reclamation activities destroy the valuable metallophytes communities (Rostański et al., 2015).

Other critical examples are peat bogs, wetlands, and water ecosystems. Generally, the natural potential of these ecosystems can be lost during the wrong so-called reclamation actions.

Figure 4.2.9. Among the analyzed species, *Epipactis palustris* individuals are very numerous on different types of post-excavation sites

The described biodiversity of post-industrial areas contributed to paying attention to the natural approach to the reclamation process (Rostański 2000; 2001; 2006; Tokarska-Guzik 2000; Woźniak & Kompała 2000; Rostański & Tokarska-Guzik 2001). Research on organism strategies, intense adaptation processes, and mechanisms of spontaneous natural development occurring during the colonization process of post-industrial areas, provides vast possibilities for practitioners (Woźniak 2006; 2010; Woźniak & Cohn 2007; Błońska et al., 2019a; 2019b; 2020; Kompała-Bąba et al., 2020). The natural processes and adaptations of organisms are of great economic importance and contribute to a full implementation of the well-understood sustainable development principles in the undertaken reclamation activities. In the Anthropocene, each action that affects environmental ecosystem functioning should proceed, applying the Natural Capital and Novel Ecosystems concepts.

Biodiversity and natural values of post-mineral exploitation sites

Post-industrial, particularly post-mineral exploitation sites subjected to spontaneous succession, are characterized by specific habitat conditions, and thus unique biocoenoses often arise (Tokarska-Guzik & Rostański 2001; Woźniak

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2010; Woźniak et al., 2018). These habitats often provide conditions for high levels of biodiversity to establish and develop.

Figure 4.2.10. Among the analyzed species, *Lycopodiella inundata* are rare on dump open sandpit

The number of 581 plant species were found in the dumps after hard coal mining (Rostański 2006), while in the Olkusz Ore District, there were more than 800 species of vascular plants (Nowak et al., 2011), which is about 20% of Poland's flora. The described areas can be enclaves of rare and disappearing plant species in a given area (Tokarska-Guzik 1996; Rostański 1997; 2000; Tokarska-Guzik & Rostański 2001; Woźniak 2010; Woźniak et al., 2018). Metalliferous areas are habitats where calcareous grasslands develop (Kapusta et al., 2010) – a natural habitat protected under the European Union law (Council Directive 1992). Specific forms of nature protection like SSSI are available to preserve precious wildlife in post-industrial areas in the UK (Rostański et al., 2015). Many ecosystem functions of the post-industrial, post-mineral excavation sites could provide ecosystem services for people in the urban and industrialized lands. The best-developed galman grasslands in the Olkusz Ore District are preserved in ecological reserves in the Natura 2000 area with calamine grasslands (Kowolik et al., 2010; Rostański et al., 2015; Regional Directorate for Environment Protection in Katowice 2019). Some sites have also been included in the UNESCO World Heritage List. The surface form of protection as a natural and landscape complex called "Żabie Doły" covered former flotation settlers. The primary biological value of this area is its richness in bird species. The following example is the open cast sandpit, which exhibits high natural values (Kompała-

Bąba & Bąba 2009; Krajewski 2009). The habitat conditions enable the colonization of one representative of the orchid family – *Liparis loeselii*. This plant species is present in Annex II of the Habitats Directive (Council Directive 1992). Due to the presence of the protected species *Liparis loeselii*, the Natura 2000 area has been established in the previous excavations area (Regional Directorate for Environment Protection in Katowice 2019). Natural habitats are protected under the Habitats Directive (1992) on post-mineral excavation sites shores and drained bottoms of water reservoirs with communities from *Littorelletea*, hard-water oligos, and mesotrophic reservoirs with underwater meadows of *Charetea* shores. Therefore, to protect these animals, the Natura 2000 "Underground Tarnogórsko-Bytomskie Underground" area was established. These examples confirm the importance of secondary habitats for preserving biodiversity in an area of increasing human impact.

Figure 4.2.11. Among the analyzed species, *Pinguicula vulgaris* individuals are present on dump open sandpit

In industrial, post-mineral excavation space, spontaneous development and the continuous adaptation and evolution of new ecological units and systems in post-industrial areas indirectly contribute to improving the functioning and quality of human life. For all types of such regions, unexpectedly large species diversity has been recorded. The organisms' diversity results from specific, varied micro-habitats present in a relatively small area. Such a variety of microhabitats contributes to increasing the potential for colonization by a broad group of species. In addition to plants, the biocenosis function for various animal groups is emphasized (Tropek & Konvicka 2008; Tropek et al., 2010; 2013; Rostański et al., 2015). Thus, a specific "network of life" is created, increasing the surface of green wildlife areas and supporting the flow of genes in regions with significant fragmentation of habitats.

Biodiversity as the basis of ecosystem functions

The close relationship among biodiversity (including rare and protected species), ecosystem functioning and ecosystem services has been proven. However, it is still poorly understood (Balvanera et al., 2016). Many authors accept that biodiversity is an ecosystem service itself, and many field studies provide supporting data (Balvanera et al., 2016; de Groot et al., 2016). It is very often difficult to estimate the role of individual species in providing specific ecosystem services (de Groot et al., 2016). Scientists undertake many projects regarding this problem. Species diversity plays an essential role in increasing resistance to invasive species and other disturbances (Wilsey & Polley 2002), which is extremely important in the areas transformed by the human economy. Although seemingly most species seem superfluous, long-term studies show that high species diversity gives more excellent stability to the ecosystem, which leads to more significant and more stable provision of ecosystem services (Yachi & Loreau 1999).

Figure 4.2.12. Spontaneous wetland establishment on an opencast sandpit filled with water or dumped is rich in rare and protected vascular plant species. In the wetlands of anthropogenic origin, the *Sphagnum* mosses are very important

Large species diversity is, above all, a precious source of difficult-to-estimate non-material benefits. It is underestimated and even ignored. However, it predominantly affects human life, including economic, physical, mental, spiritual, and aesthetic health, not to mention nutrition and shelter. The richness of vascular plant species and the related above and below-ground diversity of organisms also shows a relationship among, services such as atmosphere regulation or pollinators, prevention of erosion, and stimulation of soil-forming processes (Balvanera et al., 2016). Identified donors of ecosystem services in the studied area are rare and endangered species on the scale of the Silesian Voivodeship, Poland, Europe, and the world. In the case of plants, there is a clear beneficial relationship between the richness of plant species and ecosystem services related to the supply of usable raw materials (e.g., medicinal, cosmetic, nutritional), genetic resources, erosion control, or soil-forming processes (Balvanera et al., 2016; de Groot et al., 2016).

Biodiversity enhancement and the concept of ecosystem services in terms of post-mineral excavation sites

Natural resources are of interest to various disciplines, social, economic, and above all-natural sciences. The concept of ecosystem services allows combining research results from multiple fields and determining the functions of selected ecosystems beneficial for humans (Solon 2008).

Currently, the Millennium Ecosystem Assessment (MEA 2005) divides ecosystem services into four main groups: supply services related to: food production (breeding of plants and animals) and obtaining food from the wildlife (collecting, hunting, and fishing); obtaining raw materials of biological origin, including wood or fibrous raw materials; genetic, medical, or decorative resources related to biological diversity; water supply.

Regulatory services related to: regulation of air composition; climate regulation (temperature, rainfall) and atmospheric composition; regulation of extreme phenomena, i.e., floods, storms, hurricanes, fires, and prevention of erosion; biological regulation, i.e., regulation of pest numbers, pollination, and their spread; regulation of soil processes (soil-forming processes and improving the usable quality of soils); regulation of the absorption of dust, gas, and water pollution.

Supporting services, among others elemental circulation, primary production, or habitat functions. Cultural functions such as aesthetic, tourist, spiritual, scientific or educational functions. All services mutually support each other and affect the integrity of the entire ecosystem. For example, procurement services are directly related to acquiring specific ecosystem goods, which may impoverish other benefits.

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It is necessary to identify the ecosystem component directly responsible for providing the service to identify and evaluate a particular ecosystem service. Pollinators or flowering plants considered rare and endangered might be an example of an ecosystem component available to identify and assess a functional ecosystem service unit (Kremen 2005).

There are various connections, both positive and negative, between individual functions. Changing the quality of one ecosystem function causes changes in the related ecosystem services (Solon 2008). At the same time, the growth and protection of biodiversity causes an increase in all ecosystem services (Hockings 2003; Perrings et al., 2011).

Figure 4.2.13. Spontaneous wetland establishment on an opencast sandpit can be created by *Rhynchospora alba*

In turn, obtaining natural resources is associated with a temporary decrease in some ecosystem services. Therefore, it is necessary to reconstruct the nature of the transformed exploitation areas to restore and enhance the natural regeneration of the biological ecosystem services and, consequently, economic value (DEFRA 2011). We live in an age called the Anthropocene. The number of natural habitats decreases year after year in favour of areas subject to substantial human influence. In recent years, there have been increasing numbers of publications regarding the valuation of ecosystem services in natural areas and areas used by man (e.g., Rosin et al., 2011; Szkaradkiewicz et al., 2014; Wieliczko 2016), as well as the protected areas (Boćkowski & Rogowski 2018).

Traditionally, human changed areas were considered to be more impoverished ones. However, scientific research is often different. Thinking about the natural environment with the concept of natural capital, Novel Ecosystems, and ecosystem services, gives a new perspective for practitioners. Spatial planning and management of urbanized areas and an implementation of sustainable development in such areas require detailed analyses of the factors influencing the ecosystem functioning to enhance the rebuilding and re-establishment of the type of ecosystem which is best adapted to new habitat conditions. All natural resources and natural conditions considered from the perspective of their suitability for humans, meeting their broadly understood needs, represent the environment's potential (Sudra 2015). It depends on the structure (biodiversity) and functioning of a given ecosystem and processes occurring in neighbouring ecosystems (Solon 2008).

Human activities sometimes contribute to the reduction of the potential of ecosystems. It is essential to identify when to restore environmental benefits and when natural processes are the most beneficial for the ecosystem and biological as well as ecological approaches to re-establish.

Investments in the scientific understanding of the mechanisms of reconstruction and sustainable use of ecosystems generate beneficial natural, economic, and social results (de Groot et al., 2010). The recreation of ecosystem function of the terrain's ability to provide ecosystem services, even of the sites most distorted in an irreversible manner, e.g., by opencast mines, is possible through natural processes (Zipper et al., 2011; Larondelle & Haase 2012).

The assessment of the costs necessary to preserve ecosystem services is met by Landscape Equivalency Analysis making it possible to balance economic activities with ecosystem protection goals. The group of endangered and protected vascular plant species recorded in post-industrial, post-mineral excavation areas of the Silesian Upland consists of 7.4% of the total number of species in the flora of the Silesian Province. It is very diverse both systematically and in a variety of habitats. There are 23 species from the *Orchidaceae* family, about 50% of all species occurring in Poland, and the botanical family, whose representatives are all legally protected in our country. As many as 66 endangered species in the Silesian Voivodeship and 21 in Poland confirm that the ecological conditions in post-industrial areas are suitable for creating substitute habitats for these species.

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The ecological features of the analyzed group of endangered and protected vascular plant species present a broad spectrum, representing the diversity of habitat conditions characterizing the post-mineral excavation areas. Humans, e.g., through reclamation treatments, do not support settlement by plants. It occurs spontaneously during the colonization and establishment process. The post-industrial sites enhance the survival of endangered species. Such habitats contribute to the enrichment of biodiversity. At the same time, biodiversity is the prerequisite condition for ecosystem functioning and consequently for ecosystem services. In the future, the post-mineral excavation sites may be the basis for further comparative analysis with other post-industrial areas in Poland and abroad.

References

[1] Absalon D., Leśniok M., Nita J., Parusel J.B. & Wower A. 2005: Będzin – przyroda i krajobrazy. Urząd Miejski w Będzinie, Będzin.

[2] Babczyńska-Sendek B. & Andrzejczuk I. 1997: Goryczka krzyżowa *Gentiana cruciata* L. w okolicach Tarnowskich Gór. Natura Silesiae Superioris, 1, 33–42.

[3] Babczyńska-Sendek B., Kompała A. & Maćkowiak G. 1997: Nowe stanowisko *Euphorbia epithymoides* (*Euphorbiaceae*) na Wyżynie Śląskiej. Fragmenta Floristica et Geobotanica, Series Polonica, 4, 371–374.

[4] Balvanera P., Quijas S., Martín-López B., Barrios E., Dee L., Isbell F., Durance I., White P., Blanchard R. & de Groot R. 2016: The links between biodiversity and ecosystem services. [In:] Potschin M., Haines-Young R., Fish R. & Turner R.K. (eds.): Routledge Handbook od Ecosystem Services. 1st ed. Routledge, Taylor & Francis Group, London–New York, 45–59.

[5] Bednarczyk S., Galiniak G., Różkowski K. & Kaznowska-Opala K. 2015: Charakterystyka rekultywacji terenów poeksploatacyjnych w Kopalni Piasku „Szczakowa" w Jaworznie. Przegląd Górniczy, 71 (9), 85–91.

[6] Bernacki L., Butwiłowska B. & Bernacka M. 1997: Występowanie *Iris sibirica* L. i *Gladiolus imbricatus* L. w zachodniej części Płaskowyżu Rybnickiego (Wyżyna Śląska). Acta Biologica Silesiana, 30 (47), 153–160.

[7] 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.

[8] Błońska A., Babczyńska-Sendek B. & Kołtuniak A. 2011: Nowe stanowisko *Orchis militaris* (*Orchidaceae*) na Garbie Tarnogórskim (Wyżyna Śląska). Fragmenta Floristica et Geobotanica Polonica, 1 (18), 177–180.

[9] Błońska A., Kidawa J., Molenda T. & Chmura D. 2020: Hydrogeochemical conditions of the development of anthropogenic carbonate swamps: A case study of an abandoned Polish sandpit. Polish Journal of Environmental Studies, 29 (1), 561–569.

[10] Błońska A., Kompała-Bąba A., Sierka E., Besenyei L., Magurno F., Frydecka K., Bierza W. & Woźniak G. 2019a: Impact of selected plant species on enzymatic activity of soil substratum on post-mining heaps. Journal of Ecological Engineering, 20 (1), 138–144.

[11] Błońska A., Kompała-Bąba A., Sierka E., Bierza W., Magurno F., Besenyei L., Ryś K. & Woźniak G. 2019b: 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.

[12] Boćkowski M. & Rogowski W. 2018: Wycena usług ekosystemowych oraz ich zastosowanie w rachunku ekonomicznym – praktyczne przykłady w zarządzaniu zasobami przyrodniczymi. Studia i Prace Kolegium Zarządzania i Finansów, 167, 37–64.

[13] Box J. 1999: Nature conservation and post-industrial landscapes. Industrial Archaeology Review, 21 (2), 137–146.

[14] Bula R. 2007: Materiały do atlasu rozmieszczenia oraz stanu zasobów roślin chronionych i zagrożonych rejonu górnośląskiego – PRESS. Część 11. *Iris sibirica* L. (*Iridaceae*). Natura Silesiae Superioris, 10, 5–18.

[15] Bula R., Kloczkowska A., Parusel J.B., Romańczyk M. & Sokół K. 2014: Monitoring przyrodniczy Programu aktywizacji gospodarczej oraz zachowania dziedzictwa kulturowego Beskidów i Jury Krakowsko-Częstochowskiej Owca Plus na lata 2010–2014. Raport 2014. Centrum Dziedzictwa Przyrody Górnego Śląska.

[16] Bzdęga K., Pasierbiński A. & Chmura D. 2004: Rola hałd pogórniczych w utrzymaniu regionalnej różnorodności florystycznej Górnego Śląska. Chrońmy Przyrodę Ojczystą, 60 (2), 17–33.

[17] Cabała S., Gębicki C., Pierzgalski K. & Zygmunt J. 2009: Przyroda Częstochowy – strefy ochronne i stanowiska cenne przyrodniczo. Częstochowa.

[18] Celiński F., Ludera F., Rostański K., Sendek A. & Wika S. 1974-1975: Nowe stanowiska rzadkich roślin naczyniowych na Górnym Śląsku i terenach przyległych. Cz. I i II. Zeszyty Przyrodnicze OTPN, 14–15, 11–31.

[19] Celiński F., Rostański K., Sendek A., Wika S. & Cabała S. 1976: Nowe stanowiska rzadkich roślin naczyniowych na Górnym Śląsku i terenach przyległych. Cz. III. Zeszyty Przyrodnicze OTPN, 16, 15–31.

[20] Chmura D. & Molenda T. 2007: Nowe stanowisko omiegu górskiego *Doronicum austriacum* Jacg. na Górnym Śląsku. Chrońmy Przyrodę Ojczystą, 63 (1), 20–24.

[21] Council Directive 1992: Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora.

[22] Czylok A. & Baryła J. 2003: Notatki florystyczne i ekologiczne z okolic Dąbrowy Górniczej i Sławkowa (Wyżyna Śląska). Natura Silesiae Superioris, 7, 11–17.

[23] Czylok A. & Rahmonow O. 1996: Unikatowe układy fitocenotyczne w wyrobiskach wschodniej części województwa katowickiego. Kształtowanie środowiska geograficznego i ochrona przyrody na obszarach uprzemysłowionych i zurbanizowanych, 23, 27–31.

[24] Czylok A. & Szymczyk A. 2009: Sand quarries as biotopes of rare and critically endangered plant species. [In:] Mirek Z. & Nikel A. (eds.): Rare, relict and endangered plants and fungi in Poland. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków, 187–192.

[25] Czylok A. 2004: Wyrobiska po eksploatacji piasku na Wyżynie Śląskiej i ich roślinność. [In:] Partyka J. (ed.): Zróżnicowanie i przemiany środowiska przyrodniczo-kulturowego Wyżyny Krakowsko-Częstochowskiej. Tom 1. Przyroda. Wyd. Ojcowski Park Narodowy, Ojców, 205–212.

[26] Czylok A., Tyc A. & Kubajak A. 2009: Przewodnik przyrodniczy po Dąbrowie Górniczej. Wydawnictwo Kubajak, Krzeszowice.

[27] 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.

[28] de Groot R.S., 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.

[29] DEFRA 2011: Biodiversity 2020: A strategy for England's wildlife and ecosystem services. Department for Environment, Food and Rural Affairs, London.

[30] Domański R., Stebel A.M. & Stebel A. 1995: Godne ochrony obiekty przyrodnicze w południowej części województwa katowickiego. Część II. Kształtowanie środowiska geograficznego i ochrona przyrody na obszarach uprzemysłowionych i zurbanizowanych, 18, 11–17.

[31] Duda W. 1992: Flora naczyniowa gminy Poraj. Ziemia Częstochowska, 18, 23–50.

[32] Dulias R. & Hibszer A. 2004: Województwo śląskie: przyroda, gospodarka, dziedzictwo kulturowe. Wydawnictwo Kubajak, Kraków.

[33] Dulias R. 2018: Geografia fizyczna Wyżyny Śląskiej. Wydawnictwo Uniwersytetu Śląskiego, Katowice.

[34] Gębicki C., Śliwińska-Wyrzychowska A. & Karlikowska J. 2013: Skalne Jeziorko (stanowisko 2). [In:] Śliwińska-Wyrzychowska A. (ed.): Kopalnia przywrócona naturze – Przewodnik po przyrodniczej ścieżce dydaktyczno-edukacyjnej na obszarze nieczynnej kopalni odkrywkowej "Lipówka" w Rudnikach koło Częstochowy. Agencja Wydawnicza "ARGI", Częstochowa, 29–34.

[35] Henzel H., Śmietana K., Zagórska E. & Bolek T. 2009: Klasyfikacja terenów poprzemysłowych w województwie śląskim. Świat Nieruchomości, 1 (67), 16–21.

[36] Hereźniak J. 1995: Regionalna lista zagrożonych gatunków roślin naczyniowych w północnej części Wyżyny Śląsko-Krakowskiej. [In:] Materiały z Konferencji i Sympozjów 50 Zjazdu PTB. 26 June–01 July 1995, Poland, Kraków, 1–139.

[37] Hereźniak J., Grzyl A., Kołodziejek J. & Lawrynowicz M. 2001: Materiały do flory północnej części Wyżyny Śląsko-Krakowskiej – rzadkie i interesujące gatunki roślin naczyniowych. Cz. 2. Fragmenta Floristica et Geobotanica Polonica, 8, 35–41.

[38] Hockings M. 2003: Systems for assessing the effectiveness of management in protected areas. BioScience, 53 (9), 823–832.

https://doi.org/10.32056/KOMAG/Monograph2023.5

[39] Holak E. & Pawełko K. 1995: Nowe stanowisko łączenia baldaszkowatego (*Butomus umbellatus* L.) na terenie Górnośląskiego Okręgu Przemysłowego. Kształtowanie środowiska geograficznego i ochrona przyrody na obszarach uprzemysłowionych i zurbanizowanych, 19, 12–15.

[40] Holeksa J., Błońska A., Kompała-Bąba A., Woźniak G., Kurek P., Szarek-Łukaszewska G., Grodzińska K. & Żywiec M. 2015: The vegetation of 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, 105–127.

[41] Jankowski A.T. & Wach J. 1980: Uwagi o zbiornikach antropogenicznych na terenie GOP i jego obrzeżach. [In:] Materiały VII Sympozjum Polsko-Czechosłowackiego „Przeobrażenia środowiska geograficznego w obszarach uprzemysłowionych i zurbanizowanych". UŚ, Oddział Katowicki PTG, Sosnowiec–Kozubnik, 65–76.

[42] Journal of Laws (2014) item 1409 – Regulation of the Minister of the Environment on the Protection of the Species of Plants, 9 October 2014.

[43] Kapusta P., Szarek-Łukaszewska G., Grodzińska K. & Godzik B. 2010: Murawy galmanowe okolic Olkusza (południowa Polska) i problemy ich ochrony. Chrońmy Przyrodę Ojczystą, 66 (1), 27–34.

[44] Kaźmierczakowa R., Bloch-Orłowska J., Celka Z., Cwener A., Dajdok Z., Michalska-Hejduk D., Pawlikowski P., Szczęśniak E. & Ziarnek K. 2016: Polish red list of pteridophytes and flowering plants. Institute of Nature Conservation, Polish Academy of Sciences, Kraków.

[45] Kołodziejek J. 1999: Rzadkie i interesujące gatunki roślin naczyniowych na górniczo zniekształconych obszarach środkowej części Częstochowskiego Okręgu Rudonośnego. Fragmenta Floristica et Geobotanica Polonica, 6, 39–43.

[46] Kompała-Bąba A. & Bąba W. 2009: Threatened and protected species in the Kuźnica Warężyńska sandpit (Wyżyna Śląska Upland, S Poland). [In:] Mirek Z. & Nikel A. (eds.): Rare, relict and endangered plants and fungi in Poland. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków, 259–268.

[47] Kompała-Bąba A., Sierka E., Dyderski M.K., Bierza W., Magurno F., Besenyei L., Błońska A., Ryś K., Jagodziński A.M. & Woźniak G. 2020: Do the dominant plant species impact the substrate and

vegetation composition of post-coal mining spoil heaps? Ecological Engineering, 143, 105685.

[48] Kondracki J. 2011: Geografia regionalna Polski. Wydawnictwo Naukowe PWN, Warszawa.

[49] Kowolik M., Szarek-Łukaszewska G. & Jędrzejczyk-Korycińska M. 2010: Użytek ekologiczny „Pleszczotka górska" w cynkowo-ołowiowym terenie pogórniczym – potrzeba aktywnej ochrony. Chrońmy Przyrodę Ojczystą, 66 (1), 35–38.

[50] Krajewski Ł. & Płachno B.J. 2015: *Utricularia bremii* (*Lentibulariaceae*) in Poland. Polish Botanical Journal, 60 (1), 105–109.

[51] Krajewski Ł. 2009: Przyroda zbiornika Kuźnica Warężyńska. Cz. 3. Flora. Przyroda Górnego Śląska, 57, 8–9.

[52] Krajewski Ł. 2011: Zespół *Cladietum marisci* w piaskowni w Dąbrowie Górniczej na tle rozmieszczenia kłoci wiechowatej *Cladium mariscus* w Polsce. Chrońmy Przyrodę Ojczystą, 67 (3), 276–283.

[53] Krajewski Ł. 2012: Ramienice (*Characeae*) Zagłębia Dąbrowskiego (S Poland). Natura Silesiae Superioris, 13, 13–56.

[54] Krajewski Ł. 2016a: Cibora żółta w Dąbrowie Górniczej. Przyroda Górnego Śląska, 83, 3–15.

[55] Krajewski Ł. 2016b: Ramienice na hałdzie KWK „Porąbka-Klimontów" w Sosnowcu. Przyroda Górnego Śląska, 84 (3), 6–7.

[56] Krajewski Ł., Pawlikowski P., Gutowska E., Jarzombkowski F., Kauzal P., Kotowska K., Kowalska M., Brzezińska K. & Dzierża P. 2015: Nowe dane o rozmieszczeniu i warunkach siedliskowych ramienic (C*haraceae*) Polski (2010–2012) z uwzględnieniem terenów chronionych i objętych programem rolnośrodowiskowym. Woda-Środowisko-Obszary Wiejskie, 15 (2), 65–85.

[57] Kremen C. 2005: Managing ecosystem services: what do we need to know about their ecology? Ecology Letters, 8 (5), 468–479.

[58] Larondelle N. & Haase D. 2012: Valuing post-mining landscapes using an ecosystem services approach – An example from Germany. Ecological Indicators, 18, 567–574.

[59] Machowski R. 2003: Zbiorniki w nieckach osiadania i zapadliskach w krajobrazie Wyżyny Śląskiej. Woda w przestrzeni przyrodniczej i kulturowej. Prace Komisji Krajobrazu Kulturowego, 2, 115–123.

https://doi.org/10.32056/KOMAG/Monograph2023.5

[60] Machowski R. 2010: Przemiany geosystemów zbiorników wodnych powstałych w nieckach osiadania na Wyżynie Katowickiej. Wydawnictwo Uniwersytetu Śląskiego, Katowice.

[61] Madowicz A. 2000: Problem zagospodarowania terenów poprzemysłowych na przykładzie kamieniołomu G. Kijowa w Będzinie. Kształtowanie środowiska geograficznego i ochrona przyrody na obszarach uprzemysłowionych i zurbanizowanych, 30, 19–28.

[62] Malon A. 2010: Piaski podsadzkowe. Państwowy Instytut Geologiczny – Państwowy Instytut Badawczy. http://geoportal.pgi.gov.pl/css/surowce/images/2009/pdf/09_42_piaski_podsadzkowe.pdf, access: 02.07.2021.

[63] Matuszkiewicz W. 2012: Przewodnik do oznaczania zbiorowisk roślinnych Polski. Wydawnictwo Naukowe PWN, Warszawa.

[64] MEA – Millennium Ecosystem Assessment. 2005: Ecosystems and Human Well-being: Biodiversity Synthesis. World Resources Institute, Washington DC.

[65] Michalska D. 1994: Zmiany we florze i roślinności w rezerwacie „Góra Zborów" w ostatnich dwudziestu latach. Fragmenta Floristica et Geobotanica Series Polonica, 1, 181–207.

[66] Nowak T., Jędrzejczyk-Korycińska M., Kapusta P. & Szarek-Łukaszewska G. 2015: Characteristics of 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, 147–166.

[67] Nowak T., Kapusta P., Jędrzejczyk-Korycińska M., Szarek-Łukaszewska G. & Godzik B. 2011: The vascular plants of the Olkusz Ore-bearing Region [Rośliny naczyniowe Olkuskiego Okręgu Rudnego]. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

[68] Orczewska A., Czylok A. & Kimsa S. 1993: Charakterystyka florystyczno-faunistyczna projektowanego rezerwatu przyrody na wyrobisku kopalni dolomitu „Blachówka" w Bytomiu. Kształtowanie środowiska geograficznego i ochrona przyrody na obszarach uprzemysłowionych i zurbanizowanych, 9, 13–22.

[69] Osiadacz B. & Kręciała M. 2014: *Ophrys apifera* Huds. (Orchidaceae), a new orchid species to the flora of Poland. Biodiversity: Research and Conservation, 36 (1), 11–16.

[70] Ostręga A. & Uberman R. 2010: Kierunki rekultywacji i zagospodarowania – sposób wyboru, klasyfikacja i przykłady. Górnictwo i Geoinżynieria, 34 (4), 445–461.

[71] Pałasz J. 2012: Uwarunkowania organizacyjno-prawne procesów rekultywacji i rewitalizacji terenów poprzemysłowych w Polsce. Zeszyty Naukowe Politechniki Śląskiej. Seria Organizacja i Zarządzanie, 62 (1875), 5–23.

[72] Parusel J.B. & Urbisz A. 2012: Czerwona lista roślin naczyniowych województwa śląskiego. [In:] Parusel J.B. (ed.): Czerwone listy wybranych grup grzybów i roślin województwa śląskiego. Centrum Dziedzictwa Przyrody Górnego Śląska, Katowice, Raporty Opinie, 6 (2), 105–177.

[73] Parusel T. & Parusel J. 2011: Ekologiczna analiza flory naczyniowej kamieniołomu Penczków w Mysłowicach-Dziećkowicach. Kształtowanie środowiska geograficznego i ochrona przyrody na obszarach uprzemysłowionych i zurbanizowanych, 43, 58–69.

[74] Pasierbiński A. & Rostański A. 2001: Zróżnicowanie flory naczyniowej zwałowisk pogórniczych zlokalizowanych na terenach leśnych aglomeracji katowickiej. Natura Silesiae Superioris, Suplement, 5, 19–31.

[75] Perrings C., Duraiappah A., Larigauderie A. & Mooney H. 2011: The Biodiversity and Ecosystem Services Science–Policy Interface. Science, 331 (6021), 1139–1140.

[76] Pietrzyk-Sokulska E. & Kulczycka J. 2014: Rekultywacja i zagospodarowanie wyrobisk poeksploatacyjnych — problemy środowiskowe, ekonomiczne i społeczne. Technika Poszukiwań Geologicznych, Geotermia, Zrównoważony Rozwój, 2, 29–40.

[77] Pladias (2014–2020): Database of the Czech Flora and Vegetation. www.pladias.cz, access: 18.11.2019.

[78] 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.

[79] Poros M. & Sobczyk W. 2014: Kierunki rekultywacji terenów pogórniczych obszaru chęcińsko-kieleckiego w kontekście ich wykorzystania w aktywnej edukacji geologicznej. Rocznik Ochrona Środowiska, 16 (1), 386–403.

[80] Regional Directorate for Environment Protection in Katowice 2019: Obszary Natura 2000. Regionalna Dyrekcja Ochrony Środowiska w

Katowicach. http://natura2000.gdos.gov.pl/wyszukiwarka-n2k, access: 18.11.2019.

[81] Rosin Z.M., Takacs V., Báldi A., Banaszak-Cibicka W., Dajdok Z., Dolata P.T., Kwieciński Z., Łangowska A., Moroń D., Skórka P., Tobółka M., Tryjanowski P. & Wuczyński A. 2011: Koncepcja świadczeń ekosystemowych i jej znaczenie w ochronie przyrody krajobrazu rolniczego. Chrońmy Przyrodę Ojczystą, 67 (1), 3–20.

[82] Rostański A. & Tokarska-Guzik B. 2001: Możliwości i ograniczenia przyrodniczego zagospodarowania terenów poprzemysłowych. Natura Silesiae Superioris, Suplement, 5, 5–17.

[83] Rostański A. 1997: Flora spontaniczna hałd Górnego Śląska. Archiwum Ochrony Środowiska, 23 (3–4), 159–165.

[84] Rostański A. 2000: Rekultywacja i zagospodarowanie nieużytków poprzemysłowych – rozwiązania alternatywne. Inżynieria Ekologiczna, 1, 81–86.

[85] Rostański A. 2001: Rola lokalnych zasobów genowych w zagospodarowaniu nieużytków poprzemysłowych. [In:] Materiały Sympozjum – Warsztaty 2001 nt. Przywracanie wartości użytkowych terenom górniczym, 163–172.

[86] Rostański A. 2006: Spontaniczne kształtowanie się pokrywy roślinnej na zwałowiskach po górnictwie węgla kamiennego na Górnym Śląsku [Spontaneous plant cover on colliery spoil heaps in Upper Silesia (Southern Poland)]. University of Silesia, Katowice.

[87] Rostański A., Jędrzejczyk-Korycińska M. & Nowak T. 2015: Ochrona przyrody obszarów metalonośnych. [In:] Wierzbicka M. (ed.): Ekotoksykologia: rośliny, gleby, metale. Wydawnictwo Uniwersytetu Warszawskiego, Warszawa, 507–521.

[88] Różkowski K., Polak K. & Cała M. 2010: Wybrane problemy związane z rekultywacją wyrobisk w kierunku wodnym. Górnictwo i Geoinżynieria, 34 (4), 517–525.

[89] Rzętała M. & Jaguś A. 2012: New lake district in Europe: origin and hydrochemical characteristic. Water and Environment Journal, 26 (1), 108–117.

[90] Rzętała M. 2008: Funkcjonowanie zbiorników wodnych oraz przebieg procesów limnicznych w warunkach zróżnicowanej antropopresji na przykładzie regionu górnośląskiego. Wydawnictwo Uniwersytetu Śląskiego, Katowice.

[91] Sieka P., Urbisz A. & Babczyńska-Sendek B. 2015: Godne ochrony stanowisko flory oraz roślinności kserotermicznej na wzgórzu Golcówka w Imielinie (Wyżyna Śląska). Chrońmy Przyrodę Ojczystą, 71 (5), 380–387.

[92] Sobala M. & Pukowiec K. 2014: Stan zagospodarowania nieczynnych kamieniołomów na terenie Beskidu Śląskiego i Żywieckiego a polityka przestrzenna gmin. Prace Komisji Krajobrazu Kulturowego, 26, 127–138.

[93] Solon J. 2008: Koncepcja "Ecosystem Services" i jej zastosowania w badaniach ekologiczno-krajobrazowych. [In:] Chmielewski T.J. (ed.): Struktura i funkcjonowanie systemów krajobrazowych: meta-analizy, modele, teorie i ich zastosowania. Problemy Ekologii Krajobrazu, 21, 25–44.

[94] Spałek K. 2003: Materiały do rozmieszczenia rzadkich i interesujących gatunków paprotników (*Pteridophyta*) na Równinie Opolskiej. Fragmenta Floristica et Geobotanica Polonica, 10, 209–220.

[95] Stebel A. 1993: Nowe stanowiska widłaka goździstego *Lycopodium clavatum* L. na Płaskowyżu Rybnickim i w południowo-wschodniej części Kotliny Raciborskiej. Kształtowanie środowiska geograficznego i ochrona przyrody na obszarach uprzemysłowionych i zurbanizowanych, 10, 43–45.

[96] Sudra P. 2015: Usługi ekosystemowe na tle wybranych koncepcji ekologii miasta. Człowiek i Środowisko, 39 (1), 61–73.

[97] Szczepańczyk A. 2007: Powyrobiskowe tereny w zachodniej części miasta Piekary Śląskie jako potencjalny użytek ekologiczny. Kształtowanie środowiska geograficznego i ochrona przyrody na obszarach uprzemysłowionych i zurbanizowanych, 38, 46–54.

[98] Szeląg Z. 2000: Materiały do flory Wyżyny Krakowsko-Częstochowskiej. Fragmenta Floristica et Geobotanica Polonica, 7, 93–103.

[99] Szkaradkiewicz M., Kazak J., Sabura K. & Oleszek J. 2014: Usługi ekosystemów jeziornych – klasyfikacja, waloryzacja, zastosowania. Acta Scientiarum Polonorum, Formatio Circumiectus, 13 (3), 91–99.

[100] Szymczyk A., Rahmonov O. & Parusel T. 2011: Zróżnicowanie ekologiczne flory i roślinności wyrobiska po eksploatacji piasków „Siemonia". Acta Geographica Silesiana, 9, 63–74.

https://doi.org/10.32056/KOMAG/Monograph2023.5

[101] Szymczyk A., Stebel A. & Czylok A. 2003: Wroniec widlasty *Huperzia selago* na Wyżynie Śląskiej. Chrońmy Przyrodę Ojczystą, 59 (3), 75–78.

[102] Śliwińska-Wyrzychowska A., Bogdanowicz M., Musielińska R., Bąbelewska A. & Witkowska E. 2014: Krajobrazowe i botaniczne walory nieczynnego kamieniołomu Lipówka w Rudnikach koło Częstochowy. Prace Komisji Krajobrazu Kulturowego, 26, 45–55.

[103] Tokarska-Guzik B. & Rostański A. 2001: Możliwości i ograniczenia przyrodniczego zagospodarowania terenów poprzemysłowych. [In:] Rostański K. (ed.): Hałdy poprzemysłowe – obiekty badań botanicznych. Natura Silesiae Superioris, Suplement, 5–17.

[104] Tokarska-Guzik B. 1996: Rola hałd zasadowych w utrzymaniu lokalnej bioróżnorodności. Przegląd Przyrodniczy, 7 (3–4), 261–266.

[105] Tokarska-Guzik B. 1997: Rozmieszczenie i zasoby roślin chronionych na terenie miasta Jaworzno. Acta Biologica Silesiana, 30, 106–124.

[106] Tokarska-Guzik B. 2000: Przyrodnicze zagospodarowanie nieużytków miejsko-przemysłowych na przykładzie centrów górniczych Europy. Inżynieria Ekologiczna, 1, 72–80.

[107] Tokarska-Guzik B., Rostański A., Gorczyca J., Herczek A. & Dulias R. 2011: Waloryzacja przyrodnicza miasta Jaworzna. Zakład Badawczo-Usługowy "Ekos". https://www.um.jaworzno.pl/pl/natura/przyroda_i_ekologia/39/waloryzacja_przyrodnicza_miasta.html, access: 20.06.2021.

[108] 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 & Development, 19 (1), 104–114.

[109] 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.

[110] Tropek R., Kadlec T., Hejda M., Kocarek P., Skuhrovec J., Malenovsky I., Vodka S., Spitzer L., Banar P. & Konvicka M. 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.

[111] Tropek R., Kadlec T., Karesova P., Spitzer L., Kocarek P., Malenovsky I., Banar P., Tuf I.H., Hejda M. & Konvicka M. 2010: Spontaneous succession in limestone quarries as an effective

restoration tool for endangered arthropods and plants. Journal of Applied Ecology, 47 (1), 139–147.

[112] Wieliczko B. 2016: Wykorzystanie usług ekosystemów w zarządzaniu zasobami naturalnymi w rolnictwie. Studia i Prace WNEiZ US, 46 (2), 135–144.

[113] Wilsey B.J. & Polley H.W. 2002: Reductions in grassland species evenness increase dicot seedling invasion and spittle bug infestation. Ecology Letters, 5 (5), 676–684.

[114] Woźniak G. & Cohn E. 2007: Monitoring of spontaneous vegetation dynamics on post coal mining waste sites in Upper Silesia, Poland. [In:] Sarsby R.W. & Felton A.J. (eds.): Geotechnical and Environmental Aspects of Waste Disposal Sites – Proceedings of the 4th International Symposium on Geotechnics Related to the Environment. Taylor and Francis Group, London, 289–294.

[115] Woźniak G. & Kompała A. 2000: Rola procesów naturalnych w rekultywacji nieużytków poprzemysłowych. Inżynieria Ekologiczna, 1, 87–93.

[116] Woźniak G. & Rostański A. 2000: Rola traw w spontanicznej sukcesji roślinnej na osadnikach ziemnych wód kopalnianych na Górnym Śląsku. Łąkarstwo w Polsce, 3, 159–167.

[117] Woźniak G. 2006: Colonization process on coal mine sedimentation pools (Upper Silesia, Poland). Polish Botanical Studies, 22, 561–568.

[118] Woźniak G. 2010: Zróżnicowanie roślinności na zwałach pogórniczych Górnego Śląska [Diversity of vegetation on coal-mine heaps of the Upper Silesia (Poland)]. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

[119] 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. IntechOpen, 169–194.

[120] 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.

[121] Zagórska E. 2013: Wojewódzkie bazy danych o terenach poprzemysłowych i zdegradowanych jako przykład podejmowanych działań w dziedzinie rewitalizacji terenów poprzemysłowych i zdegradowanych. Studia Ekonomiczne, 155, 108–121.

https://doi.org/10.32056/KOMAG/Monograph2023.5

[122] Zalewska-Gałosz J. 2008: Rodzaj *Potamogeton* L. w Polsce – taksonomia i rozmieszczenie. Instytut Botaniki Uniwersytetu Jagiellońskiego, Kraków.

[123] Zarzycki K., Trzcińska-Tacik H., Różański W., Szelag Z., Wołek J. & Korzeniak U. 2002: Ecological indicator values of vascular plants of Poland. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

[124] Zipper C.E., Burger J.A., Skousen J.G., Angel P.N., Barton C.D., Davis V. & Franklin J.A. 2011: Restoring forests and associated ecosystem services on Appalachian coal surface mines. Environmental Management, 47, 751–765.

[125] Żmuda S. 1973: Antropogeniczne przeobrażenia środowiska przyrodniczego konurbacji górnośląskiej. Śląski Instytut Naukowy, PWN, Warszawa–Kraków.

5. The environmental prerequisite of Natural Capital

The **fifth** part presents the potential and recorded possibilities of the post-industrial, post-excavation sites to provide ecosystem services. The first chapter of this "New Approach" part presents the idea and concept of the natural capital framework with respect to the environmental circumstances that have emerged along with the gradient of post-industrial and post-excavation habitats. The following chapters present the results of studies dealing with species composition and diversity of communities in relationship to different groups of organisms on various mineral soil substratum habitats.

5.1. Natural Capital as the basis of new approach to Environmental Management

We are currently observing significant transformations that affect the quality of human life. Careless use of the environment significantly limits its resources and leads to its destruction. Therefore, responsible management of the natural environment and natural capital is crucial for us to benefit from it in the future. The natural environment, natural processes related to all environmental components, largely determine wild welfare. Ecological economics gives tremendous importance to biological processes (capital) that create everything on which people are dependent. Natural capital is closely related to the state of ecosystems.

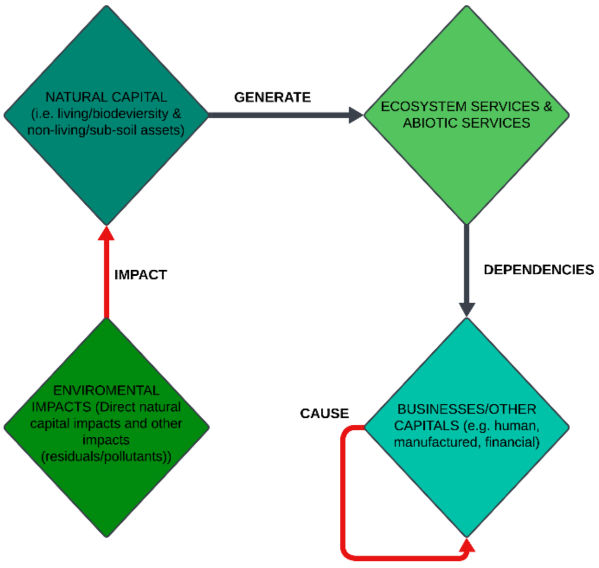

Figure 5.1.1. The natural processes, ecosystem functioning (capital) that create everything on which people are dependent. Inter-relationships between natural capital, ecosystem and abiotic services, businesses and other capitals, and environmental impacts, part of the total economic value of the planet

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Natural capital is the entity of the living and non-living components of ecosystems. It “includes all forms of ecosystems and natural resources that create human welfare”. The relationship between ecosystems and processes generates goods and services for people. Natural capital consists mainly of ecosystems, primary producers, species composition, the related above and below-ground organisms, the processes, and resulting ecosystem functioning, which are the fundamentals for providing ecological services. Ecosystem services maintain people’s lives and the balance of ecosystems. Undoubtedly, natural capital stocks and services of biological systems are of crucial importance for the functioning of life on the Earth. Moreover, they contribute to the welfare of people, forming “part of the total economic value of the planet”.

The issue dealt with in the paper is, among others, the concept of natural capital in post-industrial landscapes. Currently, this issue assumes significant importance due to the environmental crisis and depletion of natural resources. Furthermore, changes in the economy and technology mean that natural capital is currently undergoing further significant transformations. In these circumstances, a new approach to environmental management, including the concept of natural capital, is becoming an urgent need.

Natural processes, colonization and spontaneous succession

The rapid development of civilization, including urbanization, the constant demand for natural resources, especially energy resources, the development of chemical industry, fertilizers and herbicides in agriculture, etc., lead to a transformation of the environment.

The uncontrolled exploitation of natural capital is causing loss of biodiversity, water retention, and climate change (Jeżowski 2012). According to the Millennium Ecosystem Assessment (MEA 2005), significant threats to many ecosystems and the natural environment are visible in Europe and on a global scale.

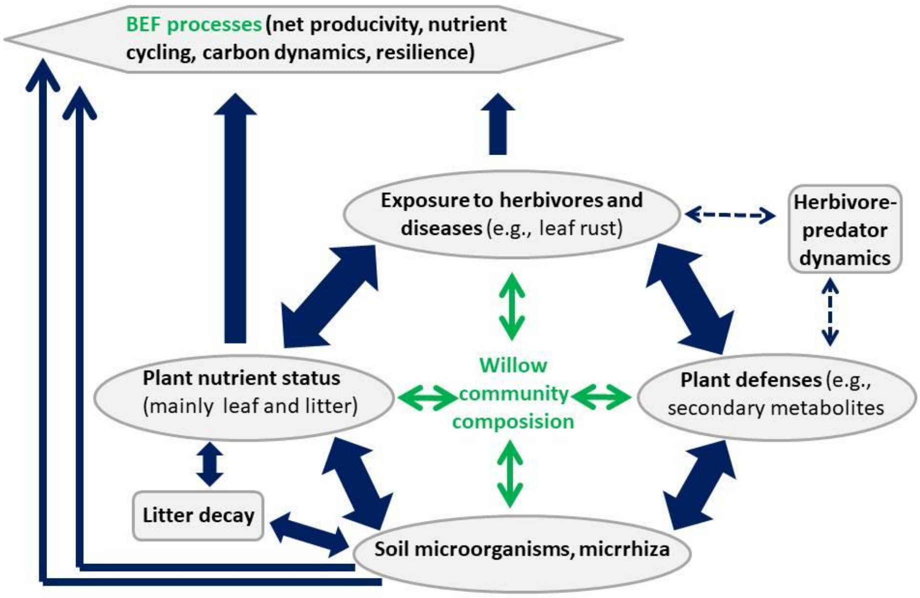

Figure 5.1.2. Functional relationships are linking individual elements of the natural environment, including oxygen released by plants in photosynthesis processes; breathing the oxygen; emission of gases; the penetration of gases (air) into the soil or substrate; rainfall; evaporation; providing mineral salts; soil irrigation; the formation of soil from dead fragments of living organisms; soil hydration; evaporation; weathering and rock formation; penetration of elements and minerals; water mineralization; rock dissolution; the shape of soil from rocks; soil formation process; leaching of components from the soil to the rocks; water mineralization; rock solubility

Ecological economics gives tremendous importance to elements of natural processes (capital) that create everything on which people are dependent. Natural capital consists mainly of ecosystems, primary producers, species composition, the related above- and below-ground organisms, the processes, and resulting ecosystem functioning, which are the fundamentals for providing ecological services. The ecosystem services maintain people’s lives and the balance of ecosystems on the Earth.

Surprisingly, research shows that some areas associated with exploitation of mineral resources are unique and valuable habitats. Urban post-industrial landscapes create a unique, specific structure, becoming an excellent site for a colonization of plants and animals, including rare species. Such places require special care, and their protection seems obvious (Box 1999). Apart from their natural value, they are a testimony to the post-industrial activity of man.

Therefore, they are worth protecting and preserving for future generations (Tokarska-Guzik 2000). Undoubtedly, these areas, like the whole landscape, create an exceptional natural capital. Concerning natural capital, domestic and foreign literature raises some questions related to it, among others: ecosystem services (e.g. de Groot et al., 2002; 2010; Turner & Daily 2008; Fisher et al., 2009; Costanza et al., 2014), critical natural capital resources (e.g. Ekins 2003; Ekins et al., 2003; de Groot et al., 2003; Brand 2009; Pelenc & Ballet 2015), a capability approach (e.g. Ballet et al., 2013; Pelenc & Ballet 2015), as well as sustainable development (among others: Ekins et al., 2003; Pelenc & Ballet 2015).

Natural capital and other capitals

The very word “capital” “comes from (neo-classical) economics and is defined as the stock of real goods, with power of producing further goods (or utilities) in the future” (de Groot et al., 2003). According to de Groot et al., (2003), the following factors refer to the capital: land, labour, and artificial infrastructure. Costanza and Daly (1992) used the terms natural capital, human and manufactured capital. For the first time, the term “natural capital” was used by E.F. Schumacher in 1973 (Solon et al., 2017). This concept gained popularity and slowly became adequately understood and appreciated in the 1990s (Telega 2014). The concept of natural capital is widely discussed by Barbier (2019).

The term “natural capital” is an interdisciplinary term relatively new in natural sciences. It is also related to the term and concept of “ecosystem services” (Telega 2014; 2015; Barbier 2019). Modern economies use a combination of many forms of capital. One of them is natural capital (Binner et al., 2017). Natural processes (capital) create everything on which the people are dependent.

The Earth, ecosystems, ecosystem processes, and functioning geology with mineral diversity, water, air resources, etc., form the natural capital. On the other hand, knowledge, work and technologies create human capital. Artificial capital includes buildings, infrastructure, etc. (Costanza & Daly 1992; de Groot et al., 2003; Jeżowski 2012). None of this could emerge without the geological, hydrological, atmospheric, pedospheric and biospheric resources and interlinked relationships between those elements.

Figure 5.1.3. The value of the spontaneous succession as a way of introducing the best adapted persistent individuals of plants on the mineral material of coal mine heaps can be calculated by means of the costs of the old fashioned generally unsuccessful reclamation

The essential component of natural capital, which completes the generated capital, human and social capital, is the Earth (Goździewicz-Biechońska 2017). Natural capital has become transformed into such systems as agriculture or aquaculture (de Groot et al., 2003). As Telega (2015) writes, preserving natural capital intact is unrealistic and unjustified, given the constant pursuit of prosperity. As defined by Solon et al., 2017 "Capital of nature (natural) means real and potential resources, forces, processes and structural elements of nature as well as composition and mutual relationship between various components of the environment, due to which life processes on Earth are maintained. Natural capital is a component of the capital of nature. (…). Natural capital includes all forms of ecosystems and natural resources that participate in the creation of human welfare but are not a product of its work".

Binner et al., (2017) defined natural capital in the following way: "Natural capital is the stock of physical assets that generate flows of environmental goods and services that benefit people".

According to Ekins et al., (2003): "Natural capital is a metaphor to indicate the importance of elements of nature (e.g., minerals, ecosystems and ecosystem processes) to human society". Many environmental factors define natural

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ecosystems by characteristics that "determine the ecosystems' capacity to provide goods and services" (Ekins et al., 2003).

According to Hodgson and Winram (2017): "Natural capital refers to the stock of natural assets upon which our economy and society is built". Natural processes provide the natural capital that provides value and goods for people, such as timber or minerals. Even more significant components include biodiversity increase, water retention, carbon sequestration, climate regulation, and air purification. Sometimes production is simply the result of natural capital combining with natural processes, sometimes people need to come up with some innovations to realize the benefits (Fig. 5.1.4.). In the publication "Natural Capital Account 2016–2017", Hodgson and Winram (2017) from Forest Enterprise England (FEE) highlight the Natural Capital Account (NCA), which they use to make forest-related decisions binding. From the publication "Forest Enterprise England – Natural Capital Accounts 2015/16", we learn that Forest Enterprise England (FEE), together with environmental economics consultants, have "developed the first organisation-wide Natural Capital Account (NCA)". The natural capital account allows to quantify the total value of services provided by natural assets under the care of FEE in a relatively orderly and transparent way.

The paper from 1997 emphasizes the fact that natural capital stocks and services of ecological systems are of crucial importance for the Earth's functioning. They contribute to the welfare of people, forming a "part of the total economic value of the planet" (Costanza et al., 1997). Based on published research and original calculations, the authors estimated the economic value of 17 ecosystem services for 16 biomes. According to their accounting the entire biosphere is worth US $ 16–54 trillion per year (Costanza et al., 1997). Dominati et al., (2010) pay special attention to ecosystem services and soil natural capital, distinguishing five related elements: a.) "Soil natural capital, characterised by standard soil properties well known to soil scientists. b.) The processes behind soil natural capital formation, maintenance and degradation. c.) Drivers (anthropogenic and natural) of soil processes. e.) Provisioning, regulating, and cultural ecosystem services. f.) Human needs fulfilled by soil ecosystem services".

In turn, Olewiler (2006) defines natural capital as follows: natural capital is becoming the conceptual framework for identification, measurement and assessment of "the role that the natural environment plays in sustaining communities". For example, different organizations in Canada (the National Round Table on the Economy and Environment, or the Nature Conservancy) use the term "natural capital" to analyze and measure environmental sustainability (Olewiler 2006).

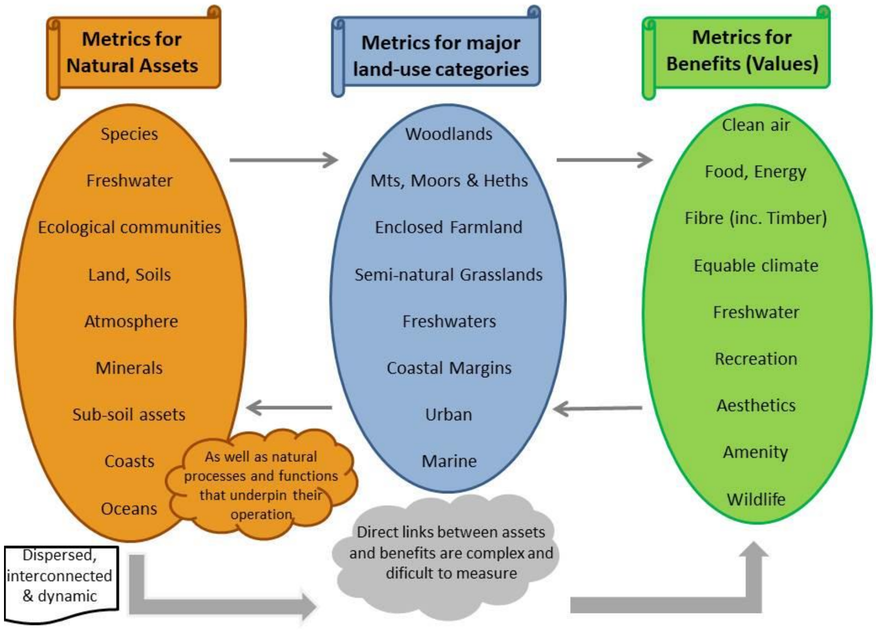

Figure 5.1.4. The flow of benefits coming from natural capital. Metrics for natural capital assets, major types of land use and benefits from natural capital

According to Ekins et al., (2003), natural capital depends on four environmental factors: air, water, land, and habitats. The biological, ecological, and environmental functions of natural capital are the following ones: regulatory, production, habitat, and information. Regulatory functions are the crucial ones that regulate ecological processes. For example, biomass production functions such as crops, e.g., food, are partially possible due to natural ecosystem enhancement (pollinators). The habitat functions such as providing natural places of refuge for wild plants and animals by ecosystems or information functions mean providing opportunities for recreation or education.

Natural capital is a term used for the entity of the living and non-living components of ecosystems. The relationship between organisms, populations, ecosystems, and related processes provides goods and services for people. Riparian vegetation buffers and holds the soil in place during flooding, preventing erosion and improving water quality. The varied types of vegetation: woodlands, forests, and particular water bodies, lakes, oceans, wetlands and peatlands store the carbon in organic matter as biomass and, even more critical, as soil organic

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matter (SOM), thereby significantly influencing the regulation of climate. Lakes and mountains provide recreational opportunities. These benefits come from the interactions between biotic and abiotic ecosystem elements (Fisher et al., 2009; Guerry et al., 2015). Plants as primary producers, animals, and microbes – the decomposers, are the main parts of each ecosystem providing essential services. Some ecosystems are human-engineered and a part or component of the social and ecological mosaic system, which includes, e.g., agroecosystems, urbanized, and industrialized areas.

For a very long time, natural capital has not been included in economic calculations. Substantially wrong assumptions caused any natural element which does not bring any financial benefits, to be considered as having no value, which led to an increasing asymmetry in economic systems. Necessarily this asymmetry needs to be balanced. Moreover, the asymmetry can be removed due to a better understanding of the essence of natural capital, which is undoubtedly crucial to maintaining all people's needs and society's existence. Humans are ruthlessly losing what they need (natural capital) for something they sometimes do not need. The significance of natural capital and ecosystem services has been strongly emphasized in the Millennium Ecosystem Assessment, stating that human activities are the reasons for the decline in ecosystem services (MEA 2005; Kinzig et al., 2011; Guerry et al., 2015).

Currently, understanding ecosystems and natural capital resilience on different scales is vitally important. First, it is related to the concerns connected with the responses of ecosystems to climate change (Folke et al., 2002; Guerry et al., 2015). Second, natural capital resilience gives the ability to adapt and provide ecosystem services for the safety of the social and ecological systems. Therefore, it is essential to understand complex social and environmental systems (Figure 5.1.5.); Regan et al., 2005; Biggs et al., 2012; Reyers et al., 2012; Guerry et al., 2015; Liu et al., 2015; Scheffer et al., 2015.

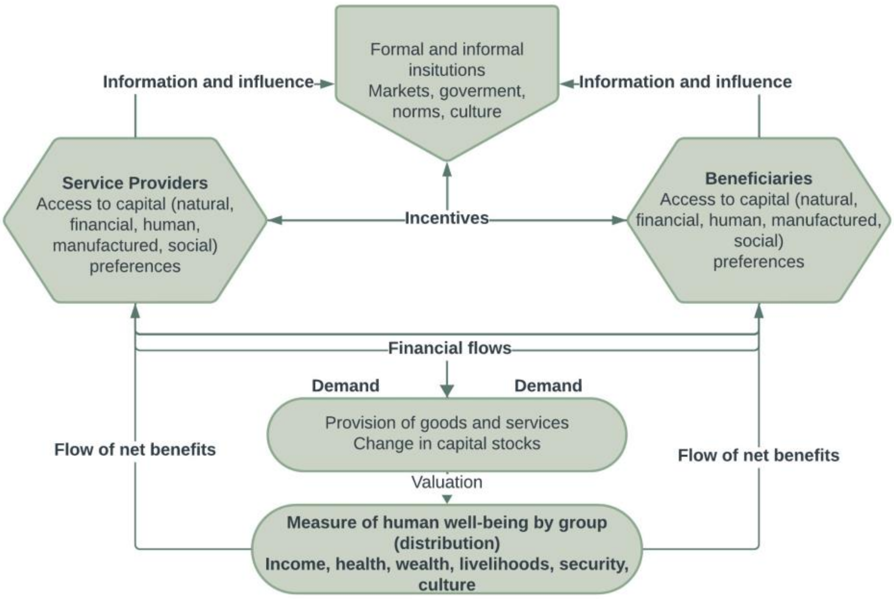

Figure 5.1.5. The scheme for natural capital in the context of formal and informal decision-making institutions along with other forms of capital: financial, human, manufactured, and social. Formal and informal institutions influence decisions by both service providers and beneficiaries. Access to various forms of capital ("capabilities") affect the decisions of service suppliers and beneficiaries. The joint actions of service providers and beneficiaries determine the flow of goods and services (including ecosystem services). Natural capital is the only type of capital which is self-recreating which makes it the basis and source for all other known types of capital

In literature, you can also find definitions referring to the so-called "critical" natural capital (de Groot et al., 2003), e.g.: a.) "critical natural capital may then be defined as natural capital which is responsible for important environmental functions and which cannot be substituted in the provision of these functions by manufactured capital" (Ekins et al., 2003); b.) "critical natural capital (life-supporting capital) – capital necessary for life reproduction (the ozone layer, biodiversity, river ecosystems, wetlands swamps, forests as species habitats)", (Telega 2014).

De Groot et al., (2003) distinguish two types of criticalities. The first type is based on the ecocentric perspective – focused mainly on maintaining regulatory and habitat functions. The second type is based on an anthropocentric view and shows the ecosystem services that are most important for our survival. This type of criticality focuses mainly on the production and information functions of natural ecosystems. According to the authors, the criticality depends on ecology and economics, political and social background.

As reported by de Groot et al., (2003) after MacDonald et al., (1999), comprehensive definitions of critical natural capital are rare or focus on the functional aspect of fundamental values of ecosystems for overall functioning of the biosphere.

The value of natural capital

Sometimes the term "natural capital" has a similar meaning to "ecosystem services", although there are some significant differences. For example, natural capital is a resource that can survive. At the same time, environmental goods and services are variable (liquid) and appear due to biogeochemical and ecological processes over time (Binner et al., 2017). The concept of "ecosystem services" is inseparably connected with natural capital, from which we benefit. Ecosystem services are "the supply of matter, energy, and information needed for human life provided by biosphere" (Telega 2015). Ecology is understood as relationships between living organisms and their non-living abiotic habitat. The application of the term ecology in other meanings is wrong and misleading and has no scientific justification.

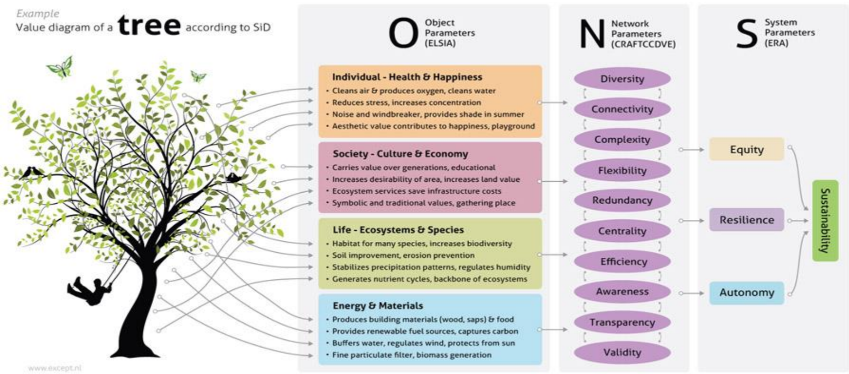

Figure 5.1.6. What value does a tree have? A tree is worth more than just the price of its wood, as it provides a home to many animals, it acts as shade in summer, it buffers and filters rainwater, it cleans the air, and it also supplies a number of other ecosystem services. It may also be valuable in other terms, for example culturally, and for its role in the ecosystem as a whole. Therefore, the value of a tree in its entirety is not the same as the price for its wood in the store, and can be expressed in a different manner, for example in liters of water buffered and filtered, its contribution to biodiversity and well being, and so on

According to Solon et al., (2017), different authors distinguish different definitions of ecosystem services. And so: "(1) Costanza et al., (1997); Solon (2008) – a set of products (e.g., wood, forest fruit, wild game) and ecosystem services (e.g., water and air purification, oxygen production, recreation areas) used by society; (2) Boyd & Banzhaf (2007) – nature components consumed directly or experienced to build human needs; (3) TEEB (2010) – elements of ecosystems used (actively or passively) to produce human welfare; (4) direct and indirect contributions of ecosystems to human needs. The concept of goods and benefits is synonymous with ecosystem services" (Solon et al., 2017).

There is no unambiguous definition regarding natural capital and ecosystem services, and there is terminological chaos regarding this issue (Telega 2015; Solon et al., 2017). Moreover, sometimes expression of ecosystem services is used interchangeably with environmental services. Unfortunately, the word "ecosystem" and the word "environment" have different connotations. People understand the word "ecosystem" as an integrated system of related connected biotic and abiotic elements related frequently in feedback loops in a dynamic balance. Unfortunately for many people, "environment" means environmental services connected with waste and recycling services provided by local institutions or government (Nahlik et al., 2012; Guerry et al., 2015). The lack of discipline in using precisely defined terms in environmental sciences and practical applications worsens the situation on a global scale.

The environmental sciences - the application aspects

In recent decades, there has been progress in defining, developing and separating the concept of natural capital and ecosystem services (Goldman-Benner et al., 2012). Climate change, biodiversity loss, increasing water deficiency, the underestimated importance of people's dependence on nature, and links between the functioning of ecosystems and society's survival, have attracted human awareness. The close human relationship with nature is recognized. Attention in this subject is still growing, however, not quickly enough (UK National Ecosystem Assessment 2011; Duraiappah et al., 2014; Risky Business Project 2014). Andrejczuk (2013) presents concepts of cooperation between people and nature in the landscape. He mentions five visions: a.) "The conception of deification of nature and respect for it. b.) The consumer conception. c.) The conception of nature conservation. d.) The conception of the greening of the economy and life. e.) The sustainable development conception".

Humans are closely related to the development of cities. Life in cities is more straightforward. Nowadays, people focus on education, life comfort, and rendered services (the city is perceived as a driving force for development). Citizens often move away from nature. Their relationship with nature is less recognizable (Guerry et al., 2015).

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Figure 5.1.7. Environmental engineering - What is wrong? Why did the engineers always concur and frequently fail with nature?

Issues related to the environment are sometimes considered and discussed at various meetings, including the World Economic Forum, during which environmental problems are considered among the critical issues in business (World Economic Forum 2015). Therefore, introducing new environmentally friendly solutions and the right decisions regarding arable land concerning natural capital is very important. The Ministry of the Environment, Industry, Agriculture, and Finance should adopt and practice the concept of ecosystem services and natural capital. Ecosystem services and ideas for natural capital should cover a wide range of decision-making and alteration in parts of the world where transformations are going on. These solutions should be used and go beyond classic protection. It is essential to help and support issues related to the environment that are sometimes considered and discussed at various meetings, including the World Economic Forum (Goldstein et al., 2012; Arkema et al., 2015; Guerry et al., 2015; Li et al., 2015). Environmental problems are regarded among the critical issues in business (World Economic Forum 2015).

Figure 5.1.8. Living organisms will colonize each available habitat. The fundamental nature capital is the unreplaceable adaptation potential of living organisms. This picture is presenting that opposite to the predictions of the succession theory the tree seedlings are able to colonized the rocks as the first. The adaptation processes enabled the selected tree seedlings to be independent from the soil formation process and the lichens, mosses and annuals first colonizers

Appling available knowledge in advanced science, a wide range of biological and biotechnological methods for analysis, management, and decision can support identifying the critical natural capital elements. Developing and creating accessible tools might be possible to prepare maps of natural capital and ecosystem services distribution. It is possible to explore a quantification system attached values to a particular element of the environment that highlights spatial and temporal aspects. For example, it concerns the differences in social and natural capital perceptions of ecosystem services causes and effects, the specific needs in delivering services to various groups of people, and the associated trade-offs between the education intensity and required social appreciation (Guerry et al., 2015). The scientific challenges and progress can be described by five groups: 1) understanding the resilience and provision of ecosystem services in industrial and urban contexts; 2) obtaining and developing knowledge about the emergence, persistence, and value of natural capital in highly populated areas; 3) studying the ecosystem services resources in terms of ecosystem and environment functioning; 4) working out the rules of natural capital, ecosystem services management and monitoring the effects of the discussions and actions; 5) understanding the mechanisms of impact of policy and management on ecosystem services provisioning systems and natural capital persistence and regeneration (Guerry et al., 2015).

For all of the above to be feasible, constant knowledge development using the newest advanced biology, biochemistry, hydrobiology, biophysics, and even biotechnology is necessary. New metrics, data, and tools will make it easier to monitor, assess, and account for the nature benefits to human society survival. In addition, developing knowledge about the synergic feedbacks within the natural capital of Novel Ecosystems can provide tangible ways to identify and weigh trade-offs derived from different management and policy decisions (Guerry et al., 2015).

The study of mapping and looking for relationships among multiple ecosystem service quantifications and biodiversity has resulted in progress (Raudsepp-Hearne et al., 2010; Cardinale et al., 2012). Those results can support the information needed to predict changes in the critical drivers of the ecosystem and climate, and differences in land use (Lawler et al., 2014). In this area, geoinformatics, spectral data, and numerical maps have allowed the development of spatial modelling. Furthermore, the use of the geoinformatic methods can be beneficial in assessing how changes in ecosystems and their essential ecosystem functional processes are likely to cause changes in the provision and persistence of ecosystem services (Guerry et al., 2015).

Natural capital providing ecosystem services

In Novel Ecosystems, the organism's complex adaptive system dynamics is fundamental and still very little understood. The natural power of adaptability and evolutionary processes are an irreplaceable biological power affecting and enhancing the natural capital providing ecosystem services. The organism's adaptations to novel ecosystems include feedback and synergisms with a high potential to compensate for significant disruptions and challenges such as climate change and other functional constraints (Mooney et al., 2009; Seppelt et al., 2011). A similar mechanism develops in complex natural systems shaping ecosystem resilience and the related ecosystem services (Biggs et al., 2012; Reyers et al., 2013). Recent progress in understanding the strength of spontaneous and natural ecosystems, including ecosystem services, incorporates social science and natural science has helped to learn how the environmental and social systems respond to maintaining or undermining a dynamic balance and sustainable development. As a result, wild, natural, semi-natural, and anthropogenic Novel Ecosystems, as well as closely related ecosystem services, are more secure in an uncertain future.

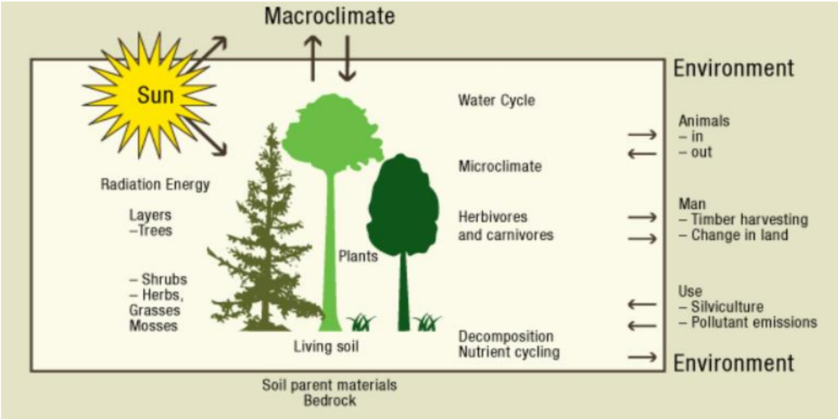

Figure 5.1.9. None of human products will be ever as efficient and optimised as natural solutions and processes

This new environmental management should emerge by combining approaches including ecosystem services, geoinformatics modelling assisted by continuous evaluation, and design of new, better solutions to obtain more secure natural capital and ecosystem services in the future (Reyers et al., 2015). For decision-makers, managers, and politicians, the process and criteria of ecosystem services validation are not always clear. Monetary valuation, market and nonmarket valuation methods known from economics are sometimes used and help to estimate ecosystem service values (Bateman et al., 2015). When considering human health or livelihoods, the monetary valuation is insufficient for robust extrapolation and is highly contested or lacks robustness for some ecosystem services (Plummer 2009; Seppelt et al., 2011). For many environmental solutions, the monetary value metrics are not relevant to make the decision. To report the outcomes in biogeochemical terms or directly in terms of impacts on human health or livelihood, we need to consider the newest scientific achievements in biogeochemical, environmental, scientific, and applied knowledge (Myers et al., 2013; Guerry et al., 2015; Ruckelshaus et al., 2015).

Sen (1985) and Guerry et al., (2015) underline that the costs, rules, and limits in access to various forms of capital ("capabilities") affect the decisions of service suppliers and beneficiaries of the provided goods, and the life conditions of different groups in society. Components of the system change on relatively long timescales, including essential regulating services and matching them with the conditions of life and human health metrics. It is a significant research gap to be filled. Natural capital accounting helps to avoid the wrong, insufficient approach, focusing only on trends in providing services. Natural capital needs time to be rebuilt and maintained. Its regeneration is costless. Natural capital accounts will point to areas with a "natural capital deficit", and intervention is required. The report called "inclusive wealth" attempts to value social, human, manufactured, and natural assets (Arrow et al., 2004). The performance of wealth can provide a helpful gauge of sustainability. The maintenance of natural capital involves a significant time scale and has to include a future time scale. The appropriateness of limiting natural capital is controversial and highly questionable ethically. Regarding climate change, society should divide the natural capital over time (Stern 2008; Guerry et al., 2015). Cooperation between scientists (biologists, chemists, hydrologists, geographers, environmentalists) and the economy, markets, and different institutions should provide possibilities to work out a balance between absorbing, conserving, and valuing natural capital asserts (Kinzig et al., 2011).

Social and ecological systems are complex and differ from ecosystem services and biogeochemical scales. The governance of social and biogeochemical systems should reflect and account for the complex temporal and spatial intersection (Ostrom 1998; 2010; Shogren & Taylor 2008; Camerer et al., 2011; Polasky et al., 2014; Bateman et al., 2015; Guerry et al., 2015). Knowledge of cultural norms of the surrounding nature is a prerequisite for implementing changes in human-nature interactions. Based on the literature, we can learn that the study on evaluating the impacts of protected areas (for example Andam et al., 2010; Ferraro et al., 2011; Sala et al., 2013) and PES (provision of ecosystem services) programme on social and biogeochemical outcomes can be an example (Arriagada et al., 2012; Li et al., 2015). The development of a system for education can explain the impacts of natural capital and ecosystem services for health impacts and conservation action enhancement (Ferraro & Pattanayak 2006). The best education and health care systems will not be helpful if will not be available fresh air, water, and food free from GMOs, herbicides, pesticides, etc. In this respect, the evaluation of ecosystem function reestablishment, habitat restoration, recreation, and conservation actions remains a primary challenge not for the future but for now. The evaluation of impacts has to start with the relevant ecosystem functioning and socio-economic and biogeochemical monitoring measures.

Many of the current monitoring systems and collected data are inadequate because they are not comprehensive. Tracking data collection has to be more relevant to ecosystem function, particularly the functioning of Novel Ecosystems. Proper monitoring systems and management impact assessment can be the basis for an efficiently working post-implementation programme (Ferraro & Pattanayak 2006; Ferraro et al., 2015; Guerry et al., 2015). Understanding complex multidimensional relationships and links between the above and below-ground biotic and abiotic components is incomplete and dynamically changing with the emerging novel climate and ecosystem conditions, not to mention the social and ecological dynamic processes. Some management scenarios need a long time to observe the results and introduce the impact assessment procedure. When the aim is to restore the transformed site, it can eventually result in biodiversity loss (or increase), but it can take decades or even more (Tilman et al., 1994; Schultz et al., 2015). In many actions (like vehicle use reduction), the result can be assessed after a much shorter time (Ferraro et al., 2015; Guerry et al., 2015; Li et al., 2015).

Natural capital is significant for the flow of ecosystems and sustainable development

According to Guerry et al., 2015, some governments and international organizations are trying to include natural capital and ecosystem services in management plans, but this is still not a standard practice. Nevertheless, these activities can be observed, among others, in China, South Africa, Costa Rica, Belize, or Great Britain.

China plans to become the "ecological civilization of the 21st Century" (Guerry et al., 2015). Interest in this topic led to the compilation of a comprehensive book (Pan 2015), which shows the difficulties associated with economic growth and ecological sustainability in China. According to Arriagada et al., 2012, Costa Rican authorities pay attention to payments for environmental services (PES). As a result, the share of forests on farms increased over eight years from 11% to 17%. In South Africa, you may come across the Grassland Programme Initiative. It aims to protect both biodiversity and ecosystem services (Egoh et al., 2011).

The development of post-mining areas in Great Britain is related to protecting and preserving these areas natural values and historical heritage (Besenyei – personal communications). Places of high biodiversity in brownfield areas can be included, according to strictly defined, detailed rules. In the UK, the Sites of Special Scientific Interest (SSSI) are a common form of protection. The government and territorial administration units are obliged to protect these areas, and enhance and follow the Wildlife and Countryside Act (1981). This form of protection may cover areas of particular interest due to flora, fauna, and biological processes in the place, taking into account geological, physiographic, or scientific features. Clayhanger in Walsall is an example of a Site of Special Scientific Interest (SSSI), where gangue protection arises from the exploitation of hard coal, water-filled settling troughs, and the remains of unfertilized pastures. Based on

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strict and transparent criteria, valuable non-status areas (SSSI) are protected as National Nature Reserves (NNR), (O'Halloran 1988). A Local Nature Reserve (LNR) establishment is another form of protection in post-industrial areas, including mining areas.

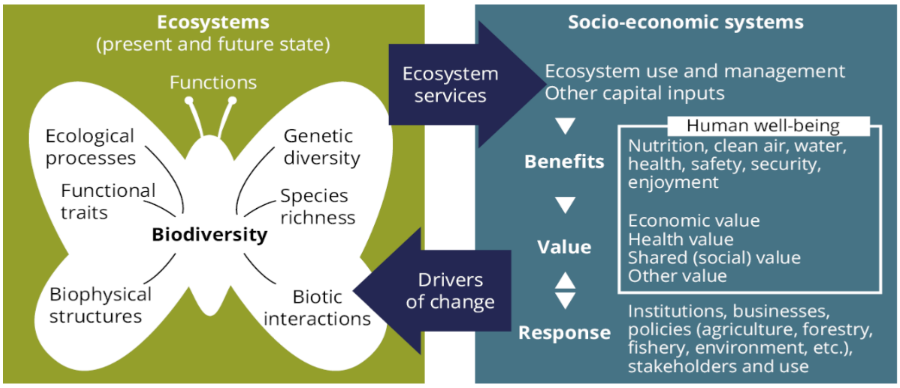

Figure 5.1.10. Natural capital is significant for the flow of ecosystems and sustainable development

They are designated by local authorities, taking into account their specific regional, natural, educational, and social values (Natural England 2010). Country Parks covering post-industrial areas with exciting elements of animate or inanimate nature are another form of protection. In turn, other valuable areas in West Midlands in the mid-west part of Great Britain, where Black Country is located, are places identified as Sites of Interest for Nature Conservation (SINC) and Sites of Local Interest for Nature Conservation (SLINC). In Staffordshire, Cheshire, and Greater Manchester, one can see Sites of Biological Interest (SBI) and places important due to local biological values, Biological Action Sites (BAS). Post-mining areas resulting from the closure of mines allow the spontaneous spread of organisms that adapt to the conditions which prevail in these areas, thus creating refuges for wildlife. Since the beginning of the 1960s, the Department of the Environment in the United Kingdom has emphasized the importance of protecting the industrial heritage. The natural and historical aspects are considered, implementing a programme whose goal was to designate valuable natural areas and cover them with appropriate forms of protection (Besenyei – personal communications).

Natural capital, including ecosystem services, is an essential element of the economy. It is worth noting that preserving natural capital does not mean giving up the consumption of biological, geological, chemical, and environmental goods, but requires a respect for the environment and several changes that will significantly help preserve its value (Telega 2015). Some factors can influence natural capital negatively and be a real threat (Ekins et al., 2003). The overuse of natural capital may destabilize a natural balance – upsetting its stability (Islam et al., 2019).

Natural capital is significant for the flow of ecosystems and sustainable development (Islam et al., 2019). Therefore, its maintenance is one of the most critical problems facing the 21st Century (Clark 2007; Brand 2009; Islam et al., 2019). However, despite the consensus on the main idea of sustainable development it is controversial is controversial, which type of capital should be preserved for the present and future generations. For a long time, the natural capital has been neglected. Finally, cultivated natural capital, artificial, social, and human capital, have been acknowledged as capital that should be preserved (Brand 2009). To achieve the success of sustainable development (Guerry et al., 2015) suggests taking the following actions on this issue: a.) preparation and development of evidence combined with decisions that would affect natural capital and ecosystem services as well as human well-being; b.) establishing cooperation with representatives from various sectors of the economy and society; c.) policy changes. Cooperation with various representatives may turn into action. Joint commitment, knowledge, and mutual understanding will allow the co-creation of tools to solve broadly set challenges (Guerry et al., 2015).

References

[1] Andam K.S., Ferraro P.J., Sims K.R.E., Healy A. & Holland M.B. 2010: Protected areas reduced poverty in Costa Rica and Thailand. Proceedings of the National Academy of Sciences of the United States of America, 107 (22), 9996–10001.

[2] Andrejczuk W. 2013: Koncepcje współdziałania człowieka i natury w krajobrazie. Krajobraz a człowiek w czasie i przestrzeni. Prace Komisji Krajobrazu Kulturowego, 20, 9–16.

[3] Arkema K.K., Verutes G.M., Wood S.A., Clarke-Samuels C., Rosado S., Canto M., Rosenthal A., Ruckelshaus M., Guannel G., Toft J., Faries J., Silver J.M., Griffin R. & Guerry A.D. 2015: Embedding ecosystem services in coastal planning leads to better outcomes for people and nature. Proceedings of the National Academy of Sciences of the United States of America, 112 (24), 7390–7395.

[4] Arriagada R.A., Ferraro P.J., Sills E.O., Pattanayak S.K. & Cordero-Sancho S. 2012: Do payments for environmental services affect forest

cover? A farm-level evaluation from Costa Rica. Land Economics, 88 (2), 382–399.

[5] Arrow K., Dasgupta P., Goulder L., Daily G., Ehrlich P., Heal G., Levin S., Mäler K.-G., Schneider S., Starrett D. & Walker B. 2004: Are we consuming too much? Journal of Economic Perspectives, 18 (3), 147–172.

[6] Ballet J., Koffi J.-M. & Pelenc J. 2013: Environment, justice and the capability approach. Ecological Economics, 85, 28–34.

[7] Barbier E.B. 2019: The concept of natural capital. Oxford Review of Economic Policy, 35 (1), 14–36.

[8] Bateman I.J., Coombes E., Fitzherbert E., Binner A., Bad'ura T., Carbone C., Fisher B., Naidoo R. & Watkinson A.R. 2015: Conserving tropical biodiversity via market forces and spatial targeting. Proceedings of the National Academy of Sciences of the United States of America, 112 (24), 7408–7413.

[9] Biggs R., Schlüter M., Biggs D., Bohensky E.L., BurnSilver S., Cundill G., Dakos V., Daw T.M., Evans L.S., Kotschy K., Leitch A.M., Meek C., Quinlan A., Raudsepp-Hearne C., Robards M.D., Schoon M.L., Schultz L. & West P.C. 2012: Toward principles for enhancing the resilience of ecosystem services. Annual Review of Environment and Resources, 37, 421–448.

[10] Binner A., Smith G., Bateman I., Day B., Agarwala M. & Harwood A. 2017: Valuing the social and environmental contribution of woodlands and trees in England, Scotland and Wales. Forestry Commission Research Report, Forestry Commission, Edinburgh.

[11] Box J. 1999: Nature conservation and post-industrial landscapes. Industrial Archaeology Review, 21 (2), 137–146.

[12] Boyd J. & Banzhaf S. 2007: What are ecosystem services? The need for standardized environmental accounting units. Ecological Economics, 63 (2–3), 616–626.

[13] Brand F. 2009: Critical natural capital revisited: Ecological resilience and sustainable development. Ecological Economics, 68 (3), 605–612.

[14] Camerer C.F., Loewenstein G. & Rabin M. (eds.) 2011: Advances in Behavioural Economics. Princeton University Press, Princeton

[15] 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. 2012: Biodiversity loss and its impact on humanity. Nature, 486 (7401), 59–67.

[16] Clark W.C. 2007: Sustainability science: A room of its own. Proceedings of the National Academy of Sciences of the United States of America, 104 (6), 1737–1738.

[17] Costanza R. & Daly H.E. 1992: Natural capital and sustainable development. Conservation Biology, 6 (1), 37–46.

[18] Costanza R., d'Arge R., de Groot R., Farber S., Grasso M., Hannon B., Limburg K., Naeem S., O'Neill R.V, Paruelo J., Raskin R.G., Sutton P. & van den Belt M. 1997: The value of the world's ecosystem services and natural capital. Nature, 387 (15), 253–260.

[19] Costanza R., de Groot R., Sutton P., van der Ploeg S., Anderson S.J., Kubiszewski I., Farber S. & Turner R.K. 2014: Changes in the global value of ecosystem services. Global Environmental Change, 26 (1), 152–158.

[20] de Groot R., Van der Perk J., Chiesura A. & van Vliet A. 2003: Importance and threat as determining factors for criticality of natural capital. Ecological Economics, 44 (2–3), 187–204.

[21] de Groot R.S., 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.

[22] de Groot R.S., Wilson M.A. & Boumans R.M.J. 2002: A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics, 41 (3), 393–408.

[23] Dominati E., Patterson M. & Mackay A. 2010: A framework for classifying and quantifying the natural capital and ecosystem services of soils. Ecological Economics, 69 (9), 1858–1868.

[24] Duraiappah A.K., Asah S.T., Brondizio E.S., Kosoy N., O'Farrell P.J., Prieur-Richard A.-H., Subramanian S.M. & Takeuchi K. 2014: Managing the mismatches to provide ecosystem services for human well-being: a conceptual framework for understanding the New Commons. Current Opinion in Environmental Sustainability, 7, 94–100.

[25] Egoh B.N., Reyers B., Rouget M. & Richardson D.M. 2011: Identifying priority areas for ecosystem service management in South African grasslands. Journal of Environmental Management, 92 (6), 1642–1650.

https://doi.org/10.32056/KOMAG/Monograph2023.5

[26] Ekins P. 2003: Identifying critical natural capital: Conclusions about critical natural capital. Ecological Economics, 44 (2–3), 277–292.

[27] Ekins P., Simon S., Deutsch L., Folke C. & de Groot R. 2003: A framework for the practical application of the concepts of critical natural capital and strong sustainability. Ecological Economics, 44 (2–3), 165–185.

[28] Ferraro P.J. & Pattanayak S.K. 2006: Money for nothing? A call for empirical evaluation of biodiversity conservation investments. PLoS Biology, 4 (4), e105.

[29] Ferraro P.J., Hanauer M.M. & Sims K.R.E. 2011: Conditions associated with protected area success in conservation and poverty reduction. Proceedings of the National Academy of Sciences of the United States of America, 108 (34), 13913–13918.

[30] Ferraro P.J., Hanauer M.M., Miteva D.A., Nelson J.L., Pattanayak S.K., Nolte C. & Sims K.R.E. 2015: Estimating the impacts of conservation on ecosystem services and poverty by integrating modeling and evaluation. Proceedings of the National Academy of Sciences of the United States of America, 112 (24), 7420–7425.

[31] Fisher B., Turner R.K. & Morling P. 2009: Defining and classifying ecosystem services for decision making. Ecological Economics, 68 (3), 643–653.

[32] Folke C., Carpenter S., Elmqvist T., Gunderson L., Holling C.S. & Walker B. 2002: Resilience and sustain-able development: Building adaptive capacity in a world of transformations. AMBIO: A Journal of the Human Environment, 31 (5), 437–440.

[33] Forest Enterprise England – Natural Capital Accounts 2015/16. 2016 Forestry Commission, England. Report.

[34] Goldman-Benner R.L., Benitez S., Boucher T., Calvache A., Daily G., Kareiva P., Kroeger T. & Ramos A. 2012: Water funds and payments for ecosystem services: Practice learns from theory and theory can learn from practice. Oryx, 46 (1), 55–63.

[35] Goldstein J.H., Caldarone G., Duarte T.K., Ennaanay D., Hannahs N., Mendoza G., Polasky S., Wolny S. & Daily G.C. 2012: Integrating ecosystem-service tradeoffs into land-use decisions. Proceedings of the National Academy of Sciences of the United States of America, 109 (19), 7565–7570.

[36] Goździewicz-Biechońska J. 2017: Nowe paradygmaty ochrony ziemi jako zasobu środowiska w prawie rolnym. Przegląd Prawa Rolnego, 2 (21), 77–92.

[37] Guerry A.D., Polasky S., Lubchenco J., Chaplin-Kramer R., Daily G.C., Griffin R., Ruckelshaus M., Bateman I.J., Duraiappah A., Elmqvist T., Feldman M.W., Folke C., Hoekstra J., Kareiva P.M., Keeler B.L., Li S., McKenzie E., Ouyang Z., Reyers B., Ricketts T.H., Rockström J., Tallis H. & Vira B. 2015: Natural capital and ecosystem services informing decisions: From promise to practice. Proceedings of the National Aca-demy of Sciences of the United States of America, 112 (24), 7348–7355.

[38] Hodgson S. & Winram M. 2017: Natural Capital Account 2016–2017. Forestry Commission, England.

[39] Islam M., Yamaguchi R., Sugiawan Y. & Managi S. 2019: Valuing natural capital and ecosystem services: a literature review. Sustainability Science, 14, 159–174.

[40] Jeżowski P. 2012: Rozwój zrównoważony i jego nowe wyzwania. Kwartalnik Kolegium Ekonomiczno-Społecznego, Studia i Prace, 2, 99–124.

[41] Kinzig A.P., Perrings C., Chapin III F.S., Polasky S., Smith V.K., Tilman D. & Turner II B.L. 2011: Paying for ecosystem services – Promise and peril. Science, 334 (6056), 603–604.

[42] Lawler J.J., Lewis D.J., Nelson E., Plantinga A.J., Polasky S., Withey J.C., Helmers D.P., Martinuzzi S., Pennington D. & Radeloff V.C. 2014: Projected land-use change impacts on ecosystem services in the United States. Proceedings of the National Academy of Sciences of the United States of America, 111 (20), 7492–7497.

[43] Li C., Zheng H., Li S., Chen X., Li J., Zeng W., Liang Y., Polasky S., Feldman M.W., Ruckelshaus M., Ouyang Z. & Daily G.C. 2015: Impacts of conservation and human development policy across stakeholders and scales. Proceedings of the National Academy of Sciences of the United States of America, 112 (24), 7396–7401.

[44] Liu J., Mooney H., Hull V., Davis S.J., Gaskell J., Hertel T., Lubchenco J., Seto K.C., Gleick P., Kremen C. & Li S. 2015: Systems integration for global sustainability. Science, 347 (6225), 1258832.

[45] MacDonald D.V., Hanley N. & Moffatt I. 1999: Applying the concept of natural capital criticality to regional resource management. Ecological Economics, 29 (1), 73–87.

https://doi.org/10.32056/KOMAG/Monograph2023.5

[46] MEA – Millennium Ecosystem Assessment. 2005: Ecosystems and Human Well-being: Biodiversity Synthesis. World Resources Institute, Washington DC.

[47] Mooney H., Larigauderie A., Cesario M., Elmquist T., Hoegh-Guldberg O., Lavorel S., Mace G.M., Palmer M., Scholes R. & Yahara T. 2009: Biodiversity, climate change and ecosystem services. Current Opinion in Environmental Sustainability, 1 (1), 46–54.

[48] Myers S.S., Gaffikin L., Golden C.D., Ostfeld R.S., Redford K.H., Ricketts T.H., Turner W.R. & Osofsky S.A. 2013: Human health impacts of ecosystem alteration. Proceedings of the National Academy of Sciences of the United States of America, 110 (47), 18753–18760.

[49] Nahlik A.M., Kentula M.E., Fennessy M.S. & Landers D.H. 2012: Where is the consensus? A proposed foundation for moving ecosystem service concepts into practice. Ecological Economics, 77, 27–35.

[50] Natural England 2010: Local Nature Reserves in England: A guide to their selection and declaration. www.naturalengland.org.uk/publications, access: 27.11.2021.

[51] O'Halloran D. 1988: Earth Science Conservation. Nature Conservancy Council, 24, 1–59.

[52] Olewiler N. 2006: Environmental sustainability for urban areas: The role of natural capital indicators. Cities, 23 (3), 184–195.

[53] Ostrom E. 1998: A behavioural approach to the rational choice theory of collective action: Presidential Address, American Political Science Association, 1997. The American Political Science Review, 92 (1), 1–22.

[54] Ostrom E. 2010: Beyond markets and states: Polycentric governance of complex economic systems. American Economic Review, 100 (3), 641–672.

[55] Pan J. 2015: China's Environmental Governing and Ecological Civilization. Springer, Berlin–Heidelberg.

[56] Pelenc J. & Ballet J. 2015: Strong sustainability, critical natural capital and the capability approach. Ecological Economics, 112, 36–44.

[57] Plummer M.L. 2009: Assessing benefit transfer for the valuation of ecosystem services. Frontiers in Ecology and the Environment, 7 (1), 38–45.

[58] Polasky S., Lewis D.J., Plantinga A.J. & Nelson E. 2014: Implementing the optimal provision of ecosystem services.

Proceedings of the National Academy of Sciences of the United States of America, 111 (17), 6248–6253.

[59] Raudsepp-Hearne C., Peterson G.D. & Bennett E.M. 2010: Ecosystem service bundles for analysing trade-offs in diverse landscapes. Proceedings of the National Academy of Sciences of the United States of America, 107 (11), 5242–5247.

[60] Regan H.M., Ben-Haim Y., Langford B., Wilson W.G., Lundberg P., Andelman S.J. & Burgman M.A. 2005: Robust decision-making under severe uncertainty for conservation management. Ecological Applications, 15 (4), 1471–1477.

[61] Reyers B., Biggs R., Cumming G.S., Elmqvist T., Hejnowicz A.P. & Polasky S. 2013: Getting the measure of ecosystem services: a social-ecological approach. Frontiers in Ecology and the Environment, 11 (5), 268–273.

[62] Reyers B., Nel J.L., O'Farrell P.J., Sitas N. & Nel D.C. 2015: Navigating complexity through knowledge coproduction: Mainstreaming ecosystem services into disaster risk reduction. Proceedings of the National Academy of Sciences of the United States of America, 112 (24), 7362–7368.

[63] Reyers B., Polasky S., Tallis H., Mooney H.A. & Larigauderie A. 2012: Finding common ground for biodiversity and ecosystem services. BioScience, 62 (5), 503–507.

[64] Risky Business Project 2014: Risky Business: The Economic Risks of Climate Change in the United States. https://riskybusiness.org/reports, access: 20.02.2020.

[65] Ruckelshaus M., McKenzie E., Tallis H., Guerry A., Daily G., Kareiva P., Polasky S., Ricketts T., Bhagabati N., Wood S.A. & Bernhardt J. 2015: Notes from the field: Lessons learned from using ecosystem service approaches to inform real-world decisions. Ecological Economics, 115, 11–21.

[66] Sala E., Costello C., Dougherty D., Heal G., Kelleher K., Murray J.H., Rosenberg A.A. & Sumaila R. 2013: A general business model for marine reserves. PLoS ONE, 8 (4), e58799.

[67] Scheffer M., Barrett S., Carpenter S.R., Folke C., Green A.J., Holmgren M., Hughes T.P., Kosten S., van de Leemput I.A., Nepstad D.C., van Nes E.H., Peeters E.T.H.M. & Walker B. 2015: Creating a safe operating space for iconic ecosystems. Science, 347 (6228), 1317–1319.

https://doi.org/10.32056/KOMAG/Monograph2023.5

[68] Schultz L., Folke C., Österblom H. & Olsson P. 2015: Adaptive governance, ecosystem management, and natural capital. Proceedings of the National Academy of Sciences of the United States of America, 112 (24), 7369–7374.

[69] Sen A. 1985: Commodities and Capabilities. Elsevier, Amsterdam, North-Holland.

[70] Seppelt R., Dormann C.F., Eppink F.V., Lautenbach S. & Schmidt S. 2011: A quantitative review of ecosystem service studies: approaches, shortcomings and the road ahead. Journal of Applied Ecology, 48 (3), 630–636.

[71] Shogren J.F. & Taylor L.O. 2008: On behavioural-environmental economics. Review of Environmental Economics and Policy, 2 (1), 26–44.

[72] Solon J. 2008: Koncepcja "Ecosystem Services" i jej zastosowania w badaniach ekologiczno-krajobrazowych. [In:] Chmielewski T.J. (ed.): Struktura i funkcjonowanie systemów krajobrazowych: meta-analizy, modele, teorie i ich zastosowania. Problemy Ekologii Krajobrazu, 21, 25–44.

[73] Solon J., Roo-Zielińska E., Affek A., Kowalska A., Kruczkowska B., Wolski J., Degórski M., Grabińska B., Kołaczkowska E., Regulska E. & Zawiska I. 2017: Świadczenia ekosystemowe w krajobrazie młodoglacjalnym. Ocena potencjału i wykorzystania. Wydawnictwo Akademickie SEDNO, Polska Akademia Nauk, Instytut Geografii i Przestrzennego Zagospodarowania im. Stanisława Leszczyckiego, Warszawa.

[74] Stern N. 2008: The economics of climate change. American Economic Review: Papers & Proceedings, 98 (2), 1–37.

[75] TEEB 2010: The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB. Report.

[76] Telega I. 2014: Kapitał naturalny w koncepcji rozwoju trwałego. Rozprawa doktorska. Uniwersytet Ekonomiczny w Krakowie, Wydział Finansów, Katedra Polityki Przemysłowej i Ekologicznej.

[77] Telega I. 2015: Kapitał naturalny a proces ekologizacji gospodarki. [In:] Kożuch M. (ed.): Ekologizacja gospodarki. Wydawnictwo Fundacja Uniwersytetu Ekonomicznego w Krakowie, Kraków, 31–47.

[78] Tilman D., May R.M., Lehman C.L. & Nowak M.A. 1994: Habitat destruction and the extinction debt. Nature, 371 (6492), 65–66.

[79] Tokarska-Guzik B. 2000: Przyrodnicze zagospodarowanie nieużytków miejsko-przemysłowych na przykładzie centrów górniczych Europy. Inżynieria Ekologiczna, 1, 72–80.

[80] Turner R.K. & Daily G.C. 2008: The ecosystem services framework and natural capital conservation. Environmental and Resource Economics, 39, 25–35.

[81] UK National Ecosystem Assessment – Synthesis of the Key Findings. 2011: UNEP-WCMC, Cambridge.

[82] Wildlife and Countryside Act 1981: http://www.legislation.gov.uk/ukpga/1981/69, access: 22.02.2020.

[83] World Economic Forum 2015: Global Risks 2015. 10th ed. https://www3.weforum.org/docs/WEF_Global_Risks_2015_Report15.pdf, access: 20.02.2020.

5.2 The scientific approach applied in practices and its successfulness

Mining of natural mineral resources causes transformation of the landscape, vegetation cover, hydrological system, soils, and other environmental elements. Practitioners reclaim the post-excavation sites over a long time to repair the environment. It was believed that the areas that could not be used for agricultural or forestry purposes need to be reclaimed. The fertilization of the mineral soil substrate and planting of herbaceous plants, shrubs, and trees were conducted. Unfortunately, alien plants were frequently planted. Global environmental change shows that these practices were not successful. Environmentalists studied the reasons for the failure of reclamation practices.

The study of spontaneous succession, which took place on the same post-mineral excavation sites, has shown that the natural processes are more effective in recovering ecosystem functioning on post-mineral excavation sites. The spontaneous vegetation development and ecosystem functioning on post-mineral excavation sites are non-analogous to any known natural and seminatural habitats. The non-analogous Novel Ecosystems on post-mineral excavation sites are very poorly understood. Adaptation processes are very intense on post-mineral excavation sites. Studies provide evidence that Novel Ecosystems support Ecosystem Services for citizens in the densely populated urban-industrial areas. Understanding the Novel Ecosystems' functioning is crucial for the right actions on the sites that need to be managed to enhance ecosystem functioning (Natural Capital) and Ecosystem Services. Understanding the functioning of

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the Novel Ecosystems and urban-industrial ecosystems and their proper management is crucial for preventing global change.

Figure 5.2.1. Large-scale excavation of mineral resources, including coal mining industry development, leads to significant changes in urban-industrial landscapes. The areas rich in natural resources are mainly influenced by human activity

The period of the most significant expansion in industrial activity in Silesia was recorded during the second half of the nineteenth and twentieth centuries (Jaros 1965; Dulias 2010; Krzysztofik et al., 2012; Fagiewicz 2014; Forman 2014; Kicki & Sobczyk 2016). Underground and opencast mining results in severe landscape transformations in hydrology, vegetation cover, and other biotic and abiotic aspects of the natural environment (Prach et al., 2014). In some cases, the loss of ecosystem functions (Szumacher & Pabjanek 2017) is caused by habitat transformation. Defragmentation occurs temporarily until the robust adaptation processes start to act. The previous mining activity left mine buildings, coal heaps, sedimentation pools, mine shafts, open-pits, coal mine drainage, and other surface relief changes, which can be seen even in the centres of the cities in many regions (Rayfield et al., 2005; Domański 2009; DeLong et al., 2012; Anawar et al., 2013; Tarolli & Sofia 2016; Limpitlaw et al., 2017).

Coal mine companies conduct the mining of coal as an energy source. Some coal mines obtain coking coal. Apart from iron ore, this coal is an important raw material for producing steel, which remains one of the critical materials used in construction, producing various types of machinery, ships, cars, or just everyday objects. Its demand all over the world is growing systematically. The production of one ton of steel requires the use of approx. 800 kg of coal. Technologies that could replace coke in its output are highly unprofitable, and there is no indication that this could change in the coming years.

Figure 5.2.2. Environmentalists studied the reasons for the failure of reclamation practices. The spontaneous vegetation development and ecosystem functioning on post-mineral excavation sites are non-analogous when compared any known natural and seminatural habitats. During the next few years, the heap area is covered by scarce vegetation (middle picture). After a few decades trees grow and create patches of tree stands (bottom picture)

The exploitation of coal resources causes environmental transformation, including changes to the atmosphere, hydrosphere, and lithosphere. The salinity of surface waters results from drainage of the rock mass. In the landscape, significant amounts of side material are heaped and continuous and discontinuous deformations (direct impacts) and the related changes, e.g., changes in water conditions or lowering of the area and changes in its morphology occur. The listed examples do not close the catalogue of changes caused by the broadly understood mining activity.

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The necessary changes in the approach according to the newest environmental knowledge and experience

On average about 16 million Mg of coal is mined annually. Along with the coal exploitation, many side-effects mineral materials are excavated (on average about 11 million Mg annually). During excavation, the side-effect mineral materials constitute the mineral material on the heaps. The composition of mineral material on the heaps is determined by the geological and mining conditions occurring in the mines and the high-quality requirements for coal production. Sedimentary rocks with variable proportions are present on the heaps, depending on the geology of the deposit, its exploitation levels, and the group of geological layers (Fig. 5.2.3.). Thus, in terms of petrography, post-mining heaps gather mineral materials which are: sandstones of various grain sizes and clay (carbonate) binder; clay shales, which are clay fraction rock with an admixture of mudstone.

Most of the post-mining heaps are disposed on the Earth's surface. Only a tiny part of them is used in underground workings. According to legal requirements reclamation should include the combination of activities which minimize adverse environmental effects of surface mining and mined lands in order to return them to practical usefulness. End uses may be agriculture, woodland, or residential and commercial development. Some reclamation components include practices that control erosion and sedimentation, stabilize slopes, and avoid and repair impacts on wildlife habitat. The final step is usually topsoil replacement and revegetation with suitable plant species. Reclamation is often phased to be concurrent throughout the life of the mining project.

Figure 5.2.3. The differences in particle size of the mineral material collected on heaps do not prevent plants from colonizing the sites in the first year after storage

Due to individual technical, economic, and social conditions, each mine has a different concept of heap management on the surface. Still, it is always carried out following local spatial development plans. After the work related to incorporating heaps is completed, the stage of technical reclamation (including profiling of slopes) is followed. The biological reclamation takes place, after the technical reclamation whose final effect is called greening, e.g., by planting trees. On some heaps over the years, reclamation has been carried out using various methods. First, after shaping and compacting, a layer of fertile soil is applied, and then a mixture of grasses is fed with artificial fertilizer.

Why are the current reclamation actions unsuccessful?

Environmental scientists have collected a growing base of ecological knowledge about self-rebuilding natural capital, Novel Ecosystems, and ecosystem services, which can be synthesized to the scope of mining-related issues (Tropek & Konvička 2008; 2011; Tropek et al., 2012). There is a still-growing body of knowledge of mineral mining influence on transforming and establishing terrestrial, wetland, and aquatic ecosystems. In such heavily changed habitats, spontaneous vegetation succession and related soil substratum biogeochemical processes are dynamic and challenging to predict. Vegetation and ecosystem establishment occur in former mining areas that remain untouched for many years without management (Woźniak 2010; Krzysztofik et al., 2020). Environmental scientists have analyzed this spontaneous vegetation succession in former mineral mining areas worldwide (Krzaklewski 1995; Bradshaw 2000; Grodzińska et al., 2000; Wiegleb & Felinks 2001; Rostański 2006; Woźniak 2010; Nicia et al., 2014; Urbancová et al., 2014; Kodir et al., 2017). Many scientists have also studied and discussed varied reclamation strategies on mineral mining heaps (Fox et al., 1998; Evans & Willgoose 2000; Hameed et al., 2000; Jochimsen 2001; Hancock et al., 2003; Krzaklewski & Pietrzykowski 2007; Martínez-Ruiz & Marrs 2007).

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Figure 5.2.4. Differently from the succession theory expectations, no mosses and lichens are observed during the colonization of the mineral material of the post-coal mine heaps. The individuals of herbaceous plants which are the first colonizers on the soil substrate of coal mine heaps is frequently observed

In non-reclaimed heaps, spontaneous vegetation succession and novel ecosystem establishment have taken place. The harsh habitat conditions, e.g., lack of nutrients, no seed bank, varied soil substratum particle size compositions (Martínez-Ruiz & Fernández-Santos 2005; Zhang & Zhao 2009), and in some mineral excavation sites, the content of heavy metals (e.g., Cabala et al., 2006; Błońska et al., 2019) do not prevent the establishment of plant communities of widely varying species composition. In the areas set up *de novo* during and after the excavation, mineral resources are effectively colonized by plants with other environmental demands. In one patch, wetland and grassland species grow together, creating an unexpected and unusual species composition, unknown from the natural and seminatural ecosystem (Woźniak 2010). Depending on the bedrock prerequisites and partially on the surrounding vegetation, forest and non-forest ecosystems occur spontaneously (Rahmonov & Oleś 2010; Rahmonov et al., 2014; Kompała-Bąba et al., 2019).

The post-mining areas (heaps) differ in many habitat and microhabitat parameters. As a result, the organisms (plants) colonizing the sites during the initial stages of succession are characterized by the ecological plasticity of individual species of a specific set of features (height, seed production, biomass, and root features). In the next stage, they develop into phytocenosis and zoocenosis in extreme habitats (Woźniak 2010) and compete for an effectively functioning ecosystem (Rahmonov & Oleś 2010; Rahmonov et al., 2013).

Figure 5.2.5. The soil respiration measurement has been performed in spontaneous herbaceous vegetation type (upper picture) and covered by trees vegetation type (bottom picture) recorded on post-coal mine heaps in Silesia. Soil respiration is a measure of carbon dioxide (CO_2) released from the soil from the decomposition of soil organic matter (SOM) by soil microbes and respiration from plant roots and soil fauna. It is an important indicator of soil health because it indicates the level of microbial activity, SOM content, and its decomposition. Soil Respiration Chamber Soil CO_2 Efflux Compatible to TARGAS-1 Portable Photosynthesis System PPS

The organisms of the first stages of succession produce biomass, mostly plants (the primary producers), which are the starting material for forming soil organic matter (SOM) and soil organic carbon (SOC; Fox et al., 1998; Evans & Willgoose 2000). In this way, the relationship between vegetation species composition and soil is significant (Frieswyk et al., 2007; Tian et al., 2008; Tang

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et al., 2010; Alday et al., 2011; Rahmonov et al., 2020). The early-successional organisms possess traits that adapt them and give them both morphological and physiological features to colonize and establish in the conditions and habitats of post-mineral excavation sites (Díaz et al., 2007; Frieswyk et al., 2007).

There are some field studies concerning the influence of post-mineral mining areas on the development and functioning of an ecosystem mosaic and the resulting environments of urban-industrial landscapes. Some of the studies present the results of cognitive models (e.g., former mining "path-centered mosaics") and development mechanisms. Environmental planning (or lack of it) is nevertheless equally crucial in managing this type of area. The paper analyzes two critical elements whose development depends on each other in this particular case. In the first case, the fall of mining led to the abandonment of the land, and only parts of it found new management methods (Díaz et al., 2007; Mokany et al., 2008; Domański 2009; Krzysztofik et al., 2012; Fagiewicz 2014; Drozdek et al., 2017).

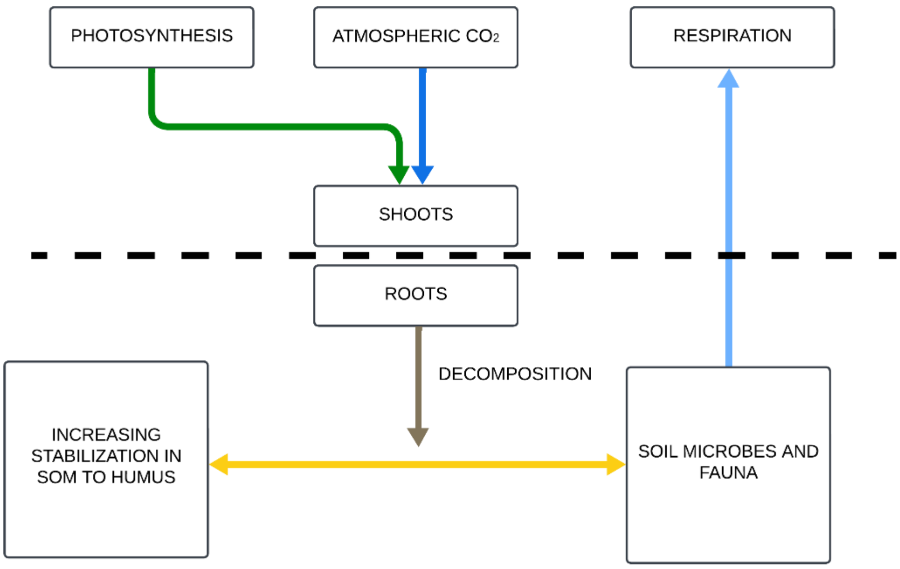

Figure 5.2.6. Soil respiration is a measure of carbon dioxide (CO_2) released from the soil as a result of decomposition of soil organic matter (SOM) by soil microbes and respiration from plant roots and soil fauna. It is an important indicator of soil health because it indicates the level of microbial activity, SOM content and its decomposition

In the second case, the abandoned post-mineral mining area remained unmanaged. On the non-reclaimed areas, research was undertaken into the development, diversity of vegetation, soil formation, novel ecosystem development, and chemical features of the mineral soil substratum (Rahmonov & Oleś 2010; Woźniak 2010; Rahmonov et al., 2013; Kompała-Bąba et al., 2019).

Biocenotic systems belong to dynamically changing elements of the geosystem, hence each of them sooner or later will be replaced by another one. Changes in the ecosystems are caused by various factors, both natural and anthropogenic. The ability to change is one of the most important ecosystem features, resulting from the open system of energy and matter in circulation (Rahmonov et al., 2010). Such systems include, among others, undeveloped post-mineral excavation sites and their process of regeneration which depends primarily on the type of bedrock/gangue material and its properties (Burghardt 1994; Oleś et al., 2004; Tang et al., 2010).

In non-reclaimed sites of mining areas, the vegetation succession is sometimes initiated by, e.g., *Poa compressa, Tussilago farfara, Calamagrostis epigejos*. The individuals of *Calamagrostis epigejos* show high ecological plasticity and a broad spectrum of habitat colonization. Its extensive root system is supported by nutrients from the heap soil substratum and water from atmospheric precipitation. The rapid colonization process on coal mine heaps leads to vegetation community assemblages dominated, e.g., by *Calamagrostis epigejos* on the soil substrate surface.

Figure 5.2.7. Vegetation patches dominated by the successful colonizer *Calamagrostis epigejos* on coal mine heap mineral material. The picture presents one of the study plots established during the project conducted by the Geobotany and ecosystem functioning research group at the University of Silesia

The root system of *C. epigejos* inhibits erosive processes. *C. epigejos* spreads vegetatively, contributing to its rapid and extensive spread across large areas (Rebele & Lehmann 2001; Rahmonov 2009; Piekarska-Stachowiak et al., 2014). In most heaps and post-industrial regions of Poland and Europe, this species initiates habitat-forming processes by creating thick turf (Zhang & Zhao 2009). Annual biomass production and decomposition of this species lead to an increase in the amount of organic matter on an inferior substrate surface. In subsequent years, it can independently create an organic layer consisting of this species residues, which enriches the soil and provides nutrients to other species.

On post-mineral excavation sites including post-coal mine heaps regardless of the amount of nutrient elements the small or medium particle sizes promote the colonization of vegetation (Christensen 2001; Wang et al., 2011; Hemkemeyer et al., 2018), which is associated with high water holding capacity and aeration. The analyzed area of the substrate is characterized by the mentioned features, hence the formation of the tree-dominated (forest) community takes place relatively quickly in different types of post-mineral excavation sites.

Ecosystems development on post-mineral excavation sites represents a dynamically changing part of the environment. Each of them will be replaced by another one, appropriate to the successional stage. Various factors cause changes in ecosystems. The ability to adapt and change is one of the most critical ecosystem features. The adaptation processes of living organisms in extreme habitat conditions of the post-mineral excavation sites are underestimated. It is the organism's response resulting from the open system of energy and matter in circulation (Rahmonov & Oleś 2010).

Figure 5.2.8. The early establishment of the best adapted single tree individuals juveniles during the successional process on coal mine heap mineral material

In the former mining areas, mostly a multiway reclamation takes place. The multiway direction in vegetation development applies to both opencast mines and coal mine heaps (Burghardt 1994; Tang et al., 2010; Alday et al., 2011).

Figure 5.2.9. The establishment of wetland *Phargmites australis* clone via the vigorous rhizome spread, on the habitat that is expected to be very dry, during the successional process on coal mine heap mineral material

Natural succession occurs on non-reclaimed fragments, and the features of rock material storage significantly impact its process (Martínez-Ruiz & Fernández-Santos 2005; Rostański 2006; Kompała-Bąba et al., 2019; Rahmonov et al., 2020). Therefore, a succession can evolve in different directions in each area following the features of the geochemical traits of the soil substratum of the heap. Their common feature is the sequence of meadow, grassland, wetland, and ruderal species at the initial succession stages in most post-coal mining areas in Europe (Prach 2003; Prach et al., 2013; Błońska et al., 2019).

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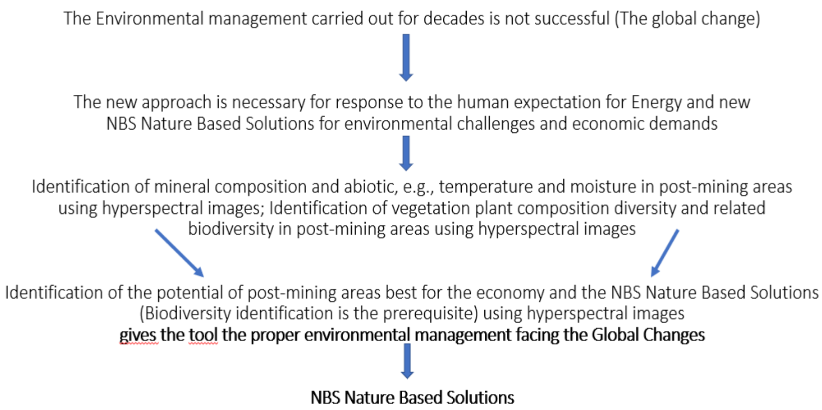

Figure 5.2.10. The new approach is necessary for response to the human expectation for Energy and new NBS Nature Based Solutions for environmental challenges and economic demands

The legislation prescription concerning the reclamation practices is not updated according to the newest knowledge achieved by environmental sciences. Humans need to observe, understand, follow, and enhance the power and magnitude of natural adaptive, multilevel processes when facing the global environmental change forces.

References

[1] Alday J.G., Marrs R.H. & Martínez-Ruiz C. 2011: Vegetation succession on reclaimed coal wastes in Spain: the influence of soil and environmental factors. Applied Vegetation Science, 14, 84–94.

[2] Anawar H.M., Canha N., Santa-Regina I. & Freitas M.C. 2013: Adaptation, tolerance, and evolution of plant species in a pyrite mine in response to contamination level and properties of mine tailings: sustainable rehabilitation. Journal of Soils and Sediments, 13, 730–741.

[3] Błońska A., Kompała-Bąba A., Sierka E., Bierza W., Magurno F., Besenyei L., Ryś K. & Woźniak G. 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.

[4] Bradshaw A. 2000: The use of natural processes in reclamation – advantages and difficulties. Landscape and Urban Planning, 51 (2–4), 89–100.

[5] Burghardt W. 1994: Soils in urban and industrial environments. Zeitschrift für Pflanzenernährung und Bodenkund, 157 (3), 214–250.

[6] Cabala J., Idziak A.F. & Szymala A. 2006: Physicochemical and geophysical investigation of soils from former coal mining terrains in southern Poland. [In:] Cardu M., Ciccu R., Lovera E. & Michelotti E. (eds.): Proceedings of the 15th Mining Planing and Equipment Section, Torino, Italy, 543–548.

[7] Christensen B.T. 2001: Physical fractionation of soil and structural and functional complexity in organic matter turnover. European Journal of Soil Science, 52 (3), 345–353.

[8] DeLong C., Skousen J. & Pena-Yewtukhiw E. 2012: Bulk density of rocky soils in forestry reclamation. Soil Science Society of America Journal, 76 (5), 1810–1815.

[9] Díaz S., Lavorel S., de Bello F., Quétier F., Grigulis K. & Robson T.M. 2007: Incorporating plant functional diversity effects in ecosystem service assessments. Proceedings of the National Academy of Sciences of the United States of America, 104, 20684–20689.

[10] Domański B. 2009: Post-industrial area regeneration – Specificity of challenges and instruments. [In:] Jarczewski W. (ed.): Spatial Aspects of Revitalization of Downtowns, Housing Estates, Post-Industrial, Post-Military and Old-Railway Areas. Revitalization of Polish Cities. Institute of Urban and Regional Deve-lopment, Kraków, 125–138.

[11] Drozdek M.E., Greinert A., Kostecki J., Tokarska-Osyczka A. & Wasylewicz R. 2017: Thematic parks in urban post-industrial areas. Acta Scientiarum Polonorum, Architectura, 16 (1), 65–77.

[12] Dulias R. 2010: Landscape planning in areas of sand extraction in the Silesian Upland, Poland. Landscape and Urban Planning, 95 (3), 91–104.

[13] Evans K.G. & Willgoose G.R. 2000: Post-mining landform evolution modelling: 2. Effects of vegetation and surface ripping. Earth Surface Processes and Landforms, 25 (8), 803–823.

[14] Fagiewicz K. 2014: Spatial processes of landscape transformation in mining areas (case study of opencast lignite mines in Morzysław, Niesłusz, Gosławice). Polish Journal of Environmental Studies, 23 (4), 1123–1136.

[15] Forman R.T.T. 2014: Urban Ecology: Science of Cities. Cambridge University Press, Cambridge.

https://doi.org/10.32056/KOMAG/Monograph2023.5

[16] Fox H.R., Moore H.M. & McIntosh A.D. (eds.) 1998: Land Reclamation: Achieving Sustainable Benefits. In 4th International Conference, Proceedings of the International Association of Land Reclamationists, Nottingham, The Netherlands, Balkema: Dordrecht.

[17] Frieswyk C.B., Johnston C.A. & Zedler J.B. 2007: Identifying and characterizing dominant plants as an indicator of community condition. Journal of Great Lakes Research, 33, 125–135.

[18] Grodzińska K., Korzeniak U., Szarek-Łukaszewska G. & Godzik B. 2000: Colonization of zinc mine spoils in southern Poland – preliminary studies on vegetation, seed rain and seed bank. Fragmenta Floristica et Geobotanica, 45 (1–2), 123–145.

[19] Hameed A., Jaabir M. & Sankaran S. 2000: Geoenvironmental reclamation – Paddy cultivation in mercury polluted lands. [In:] Paithankar A.G., Jha P.K. & Agarwal R.K. (eds.): Geoenvironmental Reclamation. International Symposium. Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi, 79–85.

[20] Hancock G.R., Loch R.J. & Willgoose G.R. 2003: The design of post-mining landscapes using geomorphic principles. Earth Surface Processes and Landforms, 28 (10), 1097–1110.

[21] Hemkemeyer M., Dohrmann A.B., Christensen B.T. & Tebbe C.C. 2018: Bacterial preferences for specific soil particle size fractions revealed by community analyses. Frontiers in Microbiology, 9, 149.

[22] Jaros J. 1965: History of Coal Mining in Upper Silesian Coal Basin. Ossolineum, Wrocław.

[23] Jochimsen M.E. 2001: Vegetation development and species assemblages in a long-term reclamation project on mine spoil. Ecological Engineering, 17 (2–3), 187–198.

[24] Kicki J. & Sobczyk E.J. (eds.) 2016: Prawne, techniczne, ekonomiczne i środowiskowe aspekty gospodarki skałą płonną w kopalniach węgla kamiennego. Wydawnictwo IGSMiE PAN, Kraków.

[25] Kodir A., Hartono D.M., Haeruman H. & Mansur I. 2017: Integrated post mining landscape for sustainable land use: A case study in South Sumatera, Indonesia. Sustainable Environment Research, 27, 203–213.

[26] Kompała-Bąba A., Bierza W., Błońska A., Sierka E., Magurno F., Chmura D., Besenyei L., Radosz Ł. & Woźniak G. 2019: Vegetation

diversity on coal mine spoil heaps – how important is the texture of the soil substrate? Biologia, 74 (4), 419–436.

[27] Krzaklewski W. & Pietrzykowski M. 2007: Diagnoza siedlisk na terenach pogórniczych rekultywowanych dla leśnictwa, ze szczególnym uwzględnieniem metody fitosocjologiczno-glebowej. Sylwan, 1, 51–57.

[28] Krzaklewski W. 1995: The method of directed succession in reclamation work. Postępy Techniki w Leśnictwie, 56, 1–9.

[29] Krzysztofik R., Dulias R., Kantor-Pietraga I., Spórna T. & Dragan W. 2020: Paths of urban planning in a post-mining area. A case study of a former sandpit in southern Poland. Land Use Policy, 99, 104801.

[30] Krzysztofik R., Runge J. & Kantor-Pietraga I. 2012: Paths of environmental and economic reclamation: the case of post-mining brownfields. Polish Journal of Environmental Studies, 21 (1), 219–223.

[31] Limpitlaw D., Alsum A., & Neale D. 2017: Calculating ecological footprints for mining companies – an introduction to the methodology and an assessment of the benefits. The Journal of the Southern African Institute of Mining and Metallurgy, 117 (1), 13–18.

[32] Martínez-Ruiz C. & Fernández-Santos B. 2005: Natural revegetation on topsoiled mining-spoils according to the exposure. Acta Oecologica, 28 (3), 231–238.

[33] Martínez-Ruiz C. & Marrs R.H. 2007: Some factors affecting successional change on uranium mine wastes: Insights for ecological restoration. Applied Vegetation Science, 10 (3), 333–342.

[34] Mokany K., Ash J. & Roxburgh S. 2008: Functional identity is more important than diversity in influencing ecosystem processes in a temperate native grassland. Journal of Ecology, 96, 884–893.

[35] Nicia P., Bejger R., Błońska A., Zadrożny P. & Gawlik A. 2014: Characteristics of the habitat conditions of ash-alder carr (*Fraxinio-Alnetum*) in the Błedowskie Swamp. Journal of Food, Agriculture & Environment, 12 (2), 1227–1232.

[36] Oleś W., Rahmonov O., Rzętała M., Pytel S. & Malik I. 2004: The ways of industrial wastelands management in the Upper Silesian Region. Ekologia (Bratislava), 23 (Suppl. 1), 244–251.

[37] Piekarska-Stachowiak A., Szary M., Ziemer B., Besenyei L. & Woźniak G. 2014: An application of the plant functional group

https://doi.org/10.32056/KOMAG/Monograph2023.5

concept to restoration practice on coal mine spoil heaps. Ecological Research, 29, 843–853.

[38] Prach K. 2003: Spontaneous succession in Central-European man-made habitats: What information can be used in restoration practice? Applied Vegetation Science, 6 (2), 125–129.

[39] Prach K., Lencová K., Řehounková K., Dvořáková H., Jírová A., Konvalinková P., Mudrák O., Novák J. & Trnková R. 2013: Spontaneous vegetation succession at different central European mining sites: a comparison across seres. Environmental Science and Pollution Research, 20 (11), 7680–7685.

[40] Prach K., Řehounková K., Lencová K., Jírová A., Konvalinková P., Mudrák O., Študent V., Vaněček Z., Tichý L., Petřík P., Šmilauer P. & Pyšek P. 2014: Vegetation succession in restoration of disturbed sites in Central Europe: the direction of succession and species richness across 19 seres. Applied Vegetation Science, 17 (2), 193–200.

[41] Rahmonov O. & Oleś W. 2010: Vegetation succession over an area of a medieval ecological disaster. The case of the Błędów desert, Poland. Erdkunde, 64 (3), 241–255.

[42] Rahmonov O. 2009: The chemical composition of plant litter of black locust (*Robinia pseudoacacia* L.) and its ecological role in sandy ecosystems. Acta Ecologica Sinica, 29 (4), 237–243.

[43] Rahmonov O., Czylok A., Orczewska A., Majgier L. & Parusel T. 2014: Chemical composition of the leaves of *Reynoutria japonica* Houtt. and soil features in polluted areas. Central European Journal of Biology, 9 (3), 320–330.

[44] Rahmonov O., Krzysztofik R., Środek D. & Smolarek-Lach J. 2020: Vegetation- and environmental changes on non-reclaimed spoil heaps in Southern Poland. Biology, 9 (7), 164.

[45] Rahmonov O., Parusel T., Szymczak A. 2010. The development of ecological systems in the area transformed by human impact (settling ponds of “Jan Kanty” black coal mine). [In:] Rahmonov O. (ed.): Anthropogenic Aspects of Landscape Transformations, 6, 88–95.

[46] Rahmonov O., Snytko V.A., Szczypek T. & Parusel T. 2013: Vegetation development on post-industrial territories of the Silesian Upland (Southern Poland). Geography and Natural Resources, 34 (1), 96–103.

[47] Rayfield B., Anand M. & Laurence S. 2005: Assessing simple versus complex restoration strategies for indu-strially disturbed forests. Restoration Ecology, 13 (4), 639–650.

[48] Rebele F. & Lehmann C. 2001: Biological Flora of Central Europe: *Calamagrostis epigejos* (L.) Roth. Flora, 196, 325–344.

[49] Rostański A. 2006: Spontaniczne kształtowanie się pokrywy roślinnej na zwałowiskach po górnictwie węgla kamiennego na Górnym Śląsku [Spontaneous plant cover on colliery spoil heaps in Upper Silesia (Southern Poland)]. University of Silesia, Katowice.

[50] Szumacher I. & Pabjanek P. 2017: Temporal changes in ecosystem services in European cities in the continental biogeographical region in the period from 1990–2012. Sustainability, 9 (4), 665.

[51] Tang B., Liu S.R., Cai D.X., Lu L.H., He R.M., Gao Y.X. & Di W.Z. 2010: Soil physical and chemical cha-racteristics under different vegetation restoration patterns in China south subtropical area. Chinese Journal of Applied Ecology, 21 (10), 2479–2486.

[52] Tarolli P. & Sofia G. 2016: Human topographic signatures and derived geomorphic processes across landscapes. Geomorphology, 255, 140–161.

[53] Tian J.-Q., Zhou Z.-Y., Bao B. & Sun J.-X. 2008: Variations of soil particle size distribution with land-use types and influences on soil organic carbon and nitrogen. Chinese Journal of Plant Ecology, 32 (3), 601–610.

[54] 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 & Development, 19 (1), 104–114.

[55] Tropek R. & Konvička M. 2011: Should restoration damage rare biotopes? Biological Conservation, 144 (5), 1299.

[56] Tropek R., Kadlec T., Hejda M., Kocarek P., Skuhrovec J., Malenovsky I., Vodka S., Spitzer L., Banar P. & Konvicka M. 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.

[57] Urbancová L., Lacková E., Kvíčala M., Čecháková L., Čechák J. & Stalmachová B. 2014: Plant communities on brownfield sites in Upper Silesia (Czech Republic). Carpathian Journal of Earth and Environmental Sciences, 9 (2), 171–177.

https://doi.org/10.32056/KOMAG/Monograph2023.5

[58] Wang L.Y., Han Y.Z., Zhang C.L. & Pei Z.Y. 2011: Reclaimed soil properties and weathered gangue change characteristics under various vegetation types on gangue pile. Acta Ecologica Sinicia, 31 (21), 6429–6441.

[59] Wiegleb G. & Felinks B. 2001: Primary succession in post-mining landscapes of Lower Lusatia – chance or necessity. Ecological Engineering, 17 (2–3), 199–217.

[60] Woźniak G. 2010: Zróżnicowanie roślinności na zwałach pogórniczych Górnego Śląska [Diversity of vegetation on coal-mine heaps of the Upper Silesia (Poland)]. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

[61] Zhang J.Y. & Zhao H.L. 2009: Changes in soil particles fraction and their effects on stability of soil-vegetation system in restoration processes of degraded sandy grassland. Ecology Environment Science, 18 (4), 1395–1401.

6. Environmental knowledge as the prerequisite for effective and management

The **sixth** part consists of chapters that are focused on various aspects of current and future possible and recommended understanding, education, and applicability of the ideas of natural capital, novel ecosystems and environmental health, and the ecosystem services inevitably linked to human conditions of life. The education activity should help to spread information about the potential environmental value of post-excavation sites. Novel ecosystems are particularly important because of their regulation of ecosystem services. The possible educational initiatives that can be undertaken, for example by coal mine enterprises, are presented.

6.1. Environmental knowledge - from science to managers

The environment is transformed due to agriculture, different types of industry, and the exploitation of natural mineral resources. Human activities have impacted the environment for a long time The abiotic and biotic elements and their relationships with the environment have been altered in many places. Knowledge and understanding of the inseparable links between human health and environmental health increase. However, environmental protection activities, conducted up to now, are insufficient on a global scale (global change). There is a need to analyze the reasons for inefficiency and list possible erroneous actions in various human activities in mining areas. As a result, a change of the current paradigm is necessary. The modern approach must include the current state of knowledge regarding mechanisms of ecosystem functioning, particularly the Novel Ecosystems and the natural environment, and their roles in providing ecosystem services for the urban-industrial landscape and societies.

The innate potential of poor oligotrophic habitats determines their functioning and environmental value for the urban-industrial landscape mosaic particularly in post-mining areas. The species composition of spontaneously established vegetation and developing ecosystems are optimally adapted to the specific abiotic conditions of post-mining mineral habitats. A new type of internal relationship develops with regard to the flows of matter and energy in novel ecosystems. The essential functions of ecosystems, including ecosystems created in mining areas, include the demand for regulation potential of natural processes (e.g., regulation of the water balance, retention and increases of biodiversity, carbon sequestration). Strengthening of the opportunities to adapt to newly established ecosystem, functioning in a comprehensive environmental approach, should be one of the aims of corporate social responsibility in the face

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of global changes. The potential of the natural environment is defined as natural capital, on which ecosystem functioning (ecosystem services) and all aspects of the economy are dependent. We aim at presenting the current interdisciplinary environmental knowledge which should be included in companies' actions with respect to all the aspects of economic activity, to limit and counteract global change.

The environment has been transformed due to the excessive exploitation of natural resources (firstly agriculture and different types of industry (chemical, textile), and secondly the exploitation of natural mineral resources). Human activities have an increasing impact on the existing vegetation and ecosystems. The abiotic and biotic elements of the soil or soil substrate have been changed or ultimately destroyed in many places. Knowledge and understanding of the inseparable links between human health and environmental health are increasing (Hartig et al., 2014).

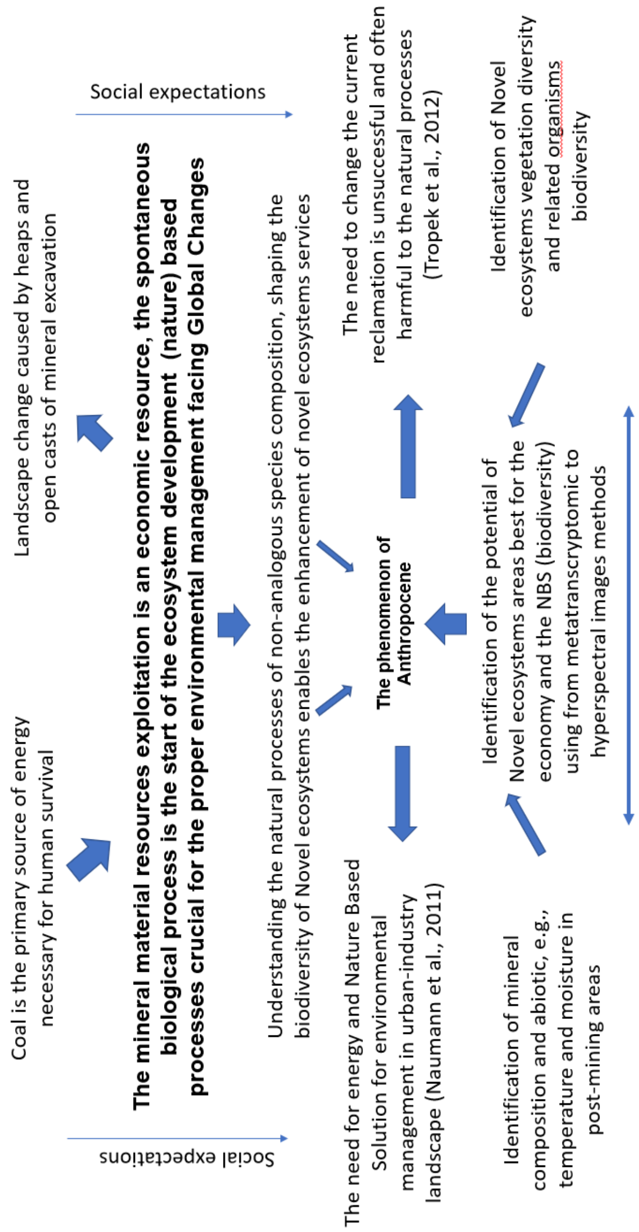

Figure 6.1.1. The modern approach must include the current state of knowledge regarding mechanisms of ecosystem functioning, particularly the Novel Ecosystems and the natural environment, and their roles in providing ecosystem services for the urban-industrial landscape and societies. There is also growing awareness of the fundamental importance of primary producers – plant species composition and vegetation (photosynthetic organisms) for the functioning of ecosystems and the environment. Naumann et al., 2011; Tropek et al., 2012)

Environmental protection activities conducted for many years are insufficient or inappropriate and ineffective considering the deteriorating condition of the environment on a global scale (global change). Therefore, there is a need to analyze the reason for inefficiency and list possible erroneous actions in various mining areas. Transformation of the paradigm is necessary. The modern approach must include the current state of knowledge regarding the functioning mechanisms of ecosystems and the natural environment with respect to their roles in providing ecosystem services for the urban-industrial landscape and societies.

Figure 6.1.2. The old fashion approach to reclamation would not predict that the mineral material could be colonized by tree seedlings so successfully. This colonisation is a natural ability that should be included in mangers' plans

Environmental managers should consider the post-mining areas as ecosystems in which anthropogenic elements dominate, and they should also consider their natural potential to determine ecosystem functioning. The various functions of the biological system in post-industrial regions depend on the relationships among its components: the type of substrate, groundwater, and surface water, the availability of living organisms that can colonize the post-mining areas to create vegetation, and ultimately ecosystems. Spontaneously established ecosystems are optimally adapted to the specific abiotic conditions of post-mining mineral habitats and create a new type, the so-called novel ecosystems of mining areas. The essential functions of ecosystems, including ecosystems created in mining areas, include the regulation potential of natural processes (e.g., regulation of the water balance, retention and increases of biodiversity, carbon sequestration).

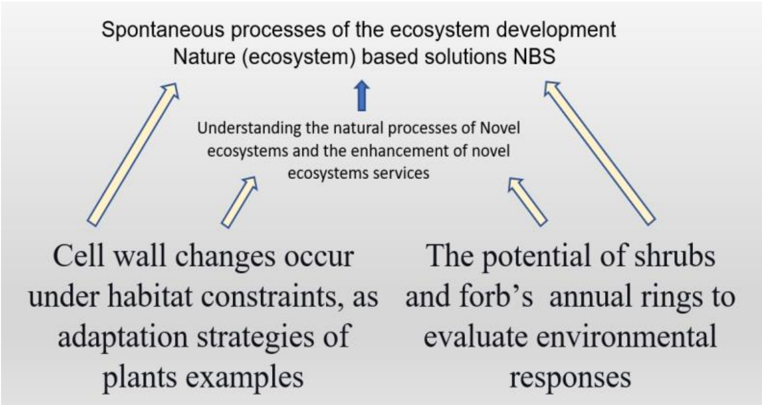

Figure 6.1.3. The nature-based processes should be incorporated and enhanced as human activity. They would never be so precise in matching the plants or other living organisms' traits with the habitat conditions regardless of the habitat origin natural or anthropogenic

The current corporate social responsibility task is to strengthen the opportunities of newly established ecosystem functioning in a comprehensive environmental approach. The potential of the natural environment is defined as natural capital, on which ecosystem functioning (ecosystem services) are dependent (Costanza et al., 1997; Daily 1997; MEA 2005).

The functioning of ecosystems is fundamental for humans

Corporate responsibility is about companies contributing responsibly to society, as part of their fundamental workings, in their ethical, sustainable development, social, and economic behaviours. The modern concept of development in post-mineral mining areas must consider the identification and enhancement of providing ecosystem services of the post-excavation areas in terms of the natural capital and novel ecosystems concepts.

Regardless of the severe disturbances, e.g., in post-industrial areas, new living conditions are created which support a previously unknown composition of various species – a unique ecosystem (*sensu* Hobbs et al., 2013) – significantly different from the formerly known plant communities in the surrounding ecosystems (e.g., Rawlik et al., 2018a; 2018b; 2021). At the end of the 20th century, the concept of ecosystem services provided by ecosystem functions was introduced. Ecosystem services enable mankind to survive and develop.

Figure 6.1.4. Spontaneous colonization and succession are some of the most influential functions of ecosystems and they are fundamental for human economy

Ecosystem services are built, self-reconstructing, and only available due to properly functioning ecosystems which are possible due to the natural capital that has become the subject of scientific research and analysis in ecology, nature protection, economics, and social sciences. Let us suppose that one considers what is necessary for a human life, from the air he/she breathes, the water consumed, food and shelter, to recreation and natural beauty. In that case, it turns out that human health depends on environmental health, ecosystem functioning, and the high-quality services it provides.

The existing relationships among environmental health, social aspects, human health, and economy, although complex, often indirect, displaced in space and time, and dependent on some modifying forces, are evident and inevitable (Fig. 6.1.7.). The Millennium Ecosystem Assessment (MEA 2005) indicated that the primary ecosystem services on which human health depends directly are the following ones: freshwater, food, raw materials, medicines, nutrient cycling, water purification, control of infectious diseases, climate regulation, and recreation. It has been shown that direct contact with elements of wildlife and ecosystem services helps to improve the functioning of the immune system, mood, and concentration while reducing stress and increasing the benefits of physical exercise. As a consequence, this leads to the expected reduction in the occurrence of diseases in large urban-industrial centre of Europe. For millennia, ecosystem services seemed to be inexhaustible and available for free. However, with the growing global population and consumerist lifestyle, human pressure on ecosystems has increased (and is still growing).

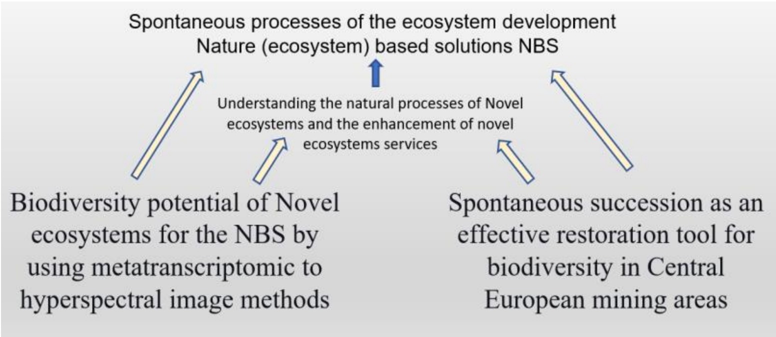

Figure 6.1.5. The interdisciplinary study, using a wide range of different methods, is the best approach to biodiversity potential and functioning of Novel Ecosystems understanding for the NBS and ecosystem service identification and enhancement (from metatranscriptomic to hyperspectral image)

Deforestation, agricultural expansion, urbanization, extraction and combustion of fossil fuels, car and air travel, or the spread of invasive species, disrupt the stability of natural ecosystems, threatening environmental health, and as a consequence, the availability and quality of ecosystem services on which the condition of human life depends. If disturbed ecosystems cannot meet the needs of society's ecosystem services, this will, directly and indirectly, affect livelihoods, income, local migration, and even social or political conflicts.

Figure 6.1.6. Even the best-preserved undisturbed forest patches like this of the endemic *Abietetum polonicum* community do not provide high biodiversity. The variety of habitats spontaneously colonized by best-adapted species ensures the highest biodiversity

Disturbances of intermediate intensity and the spontaneously establishing ecosystems, at different stages of development scattered in the landscape, enhance diversity significantly. In this respect, there seems to be a stereotype in the human consciousness that disturbed and non-optimally functioning ecosystems impact the physical and mental health of humans. Since the natural processes that drive ecosystems and provide ecosystem services are available for free, they have no economic value, so they can be considered worthless. This pernicious way of thinking is currently being changed by pointing out the importance, from a financial point of view, of facing the possibility of losing, e.g., the natural capital of pollination services. Natural capital is the only type of self-reproducible capital. Human well-being is a condition that arises as a result of adequate access to primary materials necessary for a good life, ensuring freedom of choice and action as well as health, good social relationships, and security. Well-being depends on the aggregate value of ecosystem goods and benefits provided (Solon et al., 2017).

Figure 6.1.7. Along with the flowering plants, the pollinators number are growing, providing irreplaceable services for the economy. As grasses are not attractive for pollinators, they should not cover large areas

We are not paid directly for services provided by the ecosystem. We bear much higher costs for their loss, paying for the reconstruction and construction of complex ecosystem functions and biogeo-chemical feedback relationships on which the society is dependent. The loss of soil fertility and erosion reduces yields due to the eradication of soil organisms, e.g., herbicides and insecticides. Biodiversity is considered the basis for natural ecosystems that provide countless services (ecosystem services). In this respect, properly functioning and diverse ecosystems (based on biogeochemical processes), adaptable and resistant to disturbances, should be maintained. Due to constant natural selection, living organisms, including plants, adapt to fulfill various functions in ecosystems and thus the natural environment.

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Figure 6.1.8. The post-mineral excavation sites are environmental islands providing significant habitat and consequently biodiversity enhancement to the local landscape concerning the transition of the natural environment

The organisms (primarily plants), through adaptation processes, have adjusted to environmental conditions, including abiotic factors (e.g., precipitation, nutrient gradients) and biotic interactions (e.g., competition or herbivory relationships between different groups of organisms). Assessment of patterns of plant functioning is necessary to understand nature (biosphere, atmosphere, and the dynamics of ecosystems, such as the formation of plant communities or the course and dynamics of nutrient cycles such as carbon and nitrogen). It is equally important to create conditions for developing and maintaining a mosaic of ecosystems, each shaped by natural processes in response to available habitat and natural environmental conditions. It is also necessary to use spontaneous biological processes.

Wherever there is a possibility, natural processes should be introduced into greenery arranged in urban and industrial areas. Today, most ecosystems have been transformed, directly or indirectly, by humans, by the unintentional or intentional introduction of new species that cause changes in the functioning of ecosystems, and degradation of abiotic elements, e.g., by excessive soil fertilization or industrial activity. As a result of these activities, novel ecosystems have been created, carrying – on the one hand – a new potential of ecosystem services and, on the other hand – requiring new paradigms indicating how to manage urban and industrial landscapes to optimize ecosystem functioning. It is essential to be aware that an even, regularly trimmed, single-species lawn provides negligible ecosystem services, compared to the same-sized varied meadow mimicking semi-natural flower meadows, mowed two (maximum three) times a season.

Figure 6.1.9. The meadows rich in flowering species are crucial for many ecosystem services, for pollinators in particular

Such a meadow creates the living conditions for countless insects, including pollinating insects. Understanding of the functional mechanisms of developing ecosystems and establishing habitats resulting from mining activities (broadly understood as exploitation of mineral resources) and the use of comprehensive, interdisciplinary knowledge about the possibilities of giving new functions to the emerging ecosystems, should be the priority subject of all the institutions involved. For effective management, taking into account ecosystem services, researchers suggest the use of proven solutions "based on nature" and its unsurpassed adaptability, allowing the adaptation of individual organisms, as well as entire biological systems, to adjust to changes in the environment.

Figure 6.1.10. Frequently single individual species colonize the open site by growing there and increasing the covered area

The approach to the adaptation of organisms within the meaning of "recombinant ecosystem – hybrid future" (*sensu* Rotherham 2017) can be applied

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"based on the ecosystem". In addition to the reconstruction, the recombinant ecosystem considers the social, economic, and cultural benefits. The benefits of ecosystem services and the risk of their loss are not always clearly visible and fully realized. Therefore, constant care for the proper functioning of ecosystems, to which the health and resilience of human survival are inseparably linked, is critical. The heaps occurring in Silesia, water reservoirs in depressions, sedimentation pools, or urban ecosystems, meet the criteria set by the conceptual and theoretical assumptions. They can undoubtedly be considered elements of novel ecosystems. Such elements significantly enrich the landscape of the urban-industrial agglomeration, as is the case in other urban - industrial centre of Europe (Rotherham 2017). Nature, and its natural processes, can play a fundamental and essential role in restoring the biological and environmental value of post-mining landscapes. In Europe, many positive examples enable the processes of natural succession, which can be called spontaneous regeneration of mining areas. Adopting a new approach that will consider the significant contribution and importance of biological processes is necessary for the emergence of independently functioning, new types of novel ecosystems.

The environmental management - the prerequisite of future ecosystem optimal diversity

Novel ecosystems can emerge in the unusual conditions of mineral soil substrates which can prevail in post-mining sites. The new approach requires a change in the current paradigm concerning post-industrial areas. Post-industrial sites, particularly the post-mineral extraction areas, should be considered in association with the natural environment and ecosystem functioning, not only with respect to the economic benefits for human use. This recommended approach will require essential updates in national legislation regarding the legal regulations regarding environmental protection. Novel ecosystems are established in special mineral site conditions of post-mining habitats. They create an unknown natural resource that can significantly improve ecosystem services, mainly the services, on a landscape scale, providing social, recreational, and health opportunities for local communities.

Figure 6.1.11. The post-exploitation areas often consist of a mosaic of various microhabitats, including a gradient of moisture conditions which can be inhabited by an adequate range of species of plants and animal organisms that have become established in the course of ecological succession

The change in emphasis from a solely economic approach to a socio-environmental approach can provide an additional platform for informing stakeholders and establishing relationships with communities in the area. Effective interaction and communication between groups and individual stakeholders is also an essential aspect of developing a positive partnership when deciding on the most appropriate development scenarios for a site. Let us suppose that there is a decision to leave the site undeveloped enabling natural processes and natural succession (i.e., re-wilding of the area) to occur. In that case, it should not be considered solely as a cheap or low-cost option that is convenient and easy to carry out for mining companies. Entrepreneurs need to understand the possibilities and environmental potential of the area to later manage it effectively for optimal emerging ecosystem functioning opportunities, and the most effective provision of ecosystem services particular biodiversity and its integral part the adpativty phenomemon (Figure 6.1.12. and Figure 6.1.13.).

The natural environment is a complicated network of dynamic connections and often synergistic feedbacks between numerous biotic and abiotic elements operating at various spatial and temporal scales. The environment will not improve until it is accepted that the mosaic of ecosystems, with their inter-related functions, provide natural capital and ecosystem services in addition to economic benefits (Woźniak et al., 2018). Humanity has understood a small part of the dependencies driving ecosystem and environmental functioning, and there is still much more to do. Having access only to limited knowledge about the mechanisms of the functional and dynamic processes of novel ecosystems, ignoring or having an incomplete understanding of natural biogeochemical processes, one cannot feel self-confident in making decisions about the environment. Because of a lack of knowledge, some environmental management actions can cause serious, often irreversible, damage to the complex processes of ecosystems and their ecological functioning. How post-mining sites are managed in the future should be very different, depending on the post-mineral excavation functions envisaged for them or the ecosystem services the area can provide.

Figure 6.1.12. The salt present in the mineral soil substratum enhances the halophyte occurrence such *Puccinellia distance* an *Atriplex hastata* subsp. *prostrata*. Such microhabitats must be inhabited by an adequate range of species of plants and animal organisms that are adapted to physiological drought

In some cases, the combination of natural processes and spontaneous succession can play a crucial role in self-multiplication of the natural capital and resulting ecosystem services at a site, and consequently benefit human health and well-being. Society should appreciate the power of nature itself in restoring best-adjusted ecosystems (landscape elements) depending on the prevailing habitat conditions or landscape (the mosaic of ecosystems) without additional human intervention (habitat and wildlife development). Schopf & Foster (2014) recorded the growth of a "natural wilderness" with a rich ecology on an area of post-industrial urban spoil in Toronto (Canada). In some circumstances, management decisions can support natural processes through appropriate environmental management interventions. It will not be possible to restore all areas to their former use (see Hobbs et al., 2006; 2013). However, utterly new habitat conditions can arise in some instances, i.e., completely new ecosystems are being established, the so-called "novel ecosystems" (Box 1999; Doley et al., 2012; Schopf & Foster 2014). Box (1999) cited an example of the range of vegetation types following natural regeneration on post-coal mining spoil heaps in Telford, UK, with one mound now classified as a Site of Special Scientific Interest. The research results exemplify why post-industrial site management must not be guided solely by engineering, agricultural, and practical approaches. When deciding on the functions to be performed by a given site, the increase of economic returns for investors should not be the only aim. Natural areas that can be identified as a value must, where possible, be left to regenerate and restore the environmental ecosystem functions lost by industrially transformed (including by mineral exploitation) areas. Therefore, in the proper management of post-industrial and post-exploitation regions, it will be essential to understand the natural processes in these areas (De Sousa 2014).

Figure 6.1.13. The potential of adaptivity of plants, colonizing the post coal mine heaps, is presented e.g., by wetland plant *Phragmites australis* individuals that are able to grow on the top of the heaps, where the water supply can be expected to be limited

The post-exploitation areas often consist of a mosaic of various microhabitats, which can be inhabited by an adequate range of species of plants and animal organisms that have become established in the course of ecological succession. The colonizing species represent different habitat preferences concerning light, water, nutrients, litter quality or pH (e.g., Skorupski et al., 2013; Urbanowski et al., 2018; 2021a, 2021b). Knowledge about the system of spontaneous successional processes is still not well understood. Therefore, research should include a better understanding of successional processes occurring on the surface of a given area and below the surface, within the soil (soil substrate), particularly on such unusual habitats as the post-industrial and post-mining sites that may develop novel ecosystems. Feedback relationships and processes related to the role of soil microorganisms in the formation of soil substrate, CO_2 sequestration in soil/soil substrates, and the relationships among soil organisms (bacteria, fungi, Enchytraeidae, Nematoda) and plants still require further research (e.g., Horodecki & Jagodziński 2017; 2019; Horodecki et al., 2019). It also seems essential to understand the role of mycorrhiza in the processes of plant colonization in post-industrial areas (often contaminated

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land; e.g., Kałucka et al., 2016; Kałucka & Jagodziński 2016; 2017). Understanding the diversity (both the taxonomic and functional diversity) of organisms has been proven to be extremely important (Hatfield et al., 2018), and future post-industrial activities must be based upon a complete understanding of the above processes (De Sousa 2014).

Environmental management activities can create positive opportunities for greater industrial and academic cooperation to aid effective post-industrial reclamation and restoration. One of the critical issues for the establishment of novel ecosystems on post-industrial landscapes seems to be the role of various organisms (plants, microorganisms) and the flexibility of living organisms to adapt and participate in the process of cleaning contaminated areas, e.g., those contaminated with heavy metals, petroleum substances, aromatic hydrocarbons, etc., as a part of their life processes. Living organisms can have the biological potential to prevent the pollutants from further contaminating the water, soil, or air systems. In turn, natural processes, and biological potential can help to manage the sites, plants, and microorganisms, providing the abilities for remediation. This biological potential of organisms to adapt to the changing environmental habitat conditions is used in the remediation processes. The contaminants which may be bound in the soil, may be broken down into smaller constituent parts that other living organisms can metabolize (Ptaszek et al., 2020). However, it is crucial to understand the mechanisms of plant response to various stress conditions (drought, temperature, salinity, heavy metals, etc.) that the plants encounter in post-mining areas, to support or carefully mimic the spontaneous natural processes.

Figure 6.1.14. The mineral soil substratum is frequently characterized by a varied mixture of sizes of mineral particles. The texture combination size might also be challenging for some organisms including plants, particularly for the root system of plants

Some post-industrial sites are of little economic value and can become places of natural, environmental, social, and cultural significance. The earlier history of the area, industrial processes, and their current use appear to be crucial for proposing appropriate scenarios for the land use in the case of a particular place. Where buildings of the former industrial infrastructure have survived, they may be left in the landscape as part of the area industrial heritage (i.e., incorporated into the landscape and used to strengthen the historical function). The buildings can be adapted, for example, as museum buildings where visitors can learn about mining activities, the mining process, applied technologies, and post-industrial environmental restoration, or they can be used as potential ecological research and development centres. Such places can also be used for tourism, recreation, education, the organization of significant sports events, or as a meeting place for people during organized festivities, thereby contributing to the social and community enhancement of the area. It is worth mentioning that technological tools, particularly those in existing research geoinformatics, may facilitate the restoration and recovery of post-industrial sites. These jointly shared experiences may, in the future, promote cooperation and enable the identification of the best scenarios for the repair and redevelopment of various places which were covered by industrial activity in the past. Some of these post-industrial landscapes could be wrongly called wastelands. Still, it has been shown that they could become fully functioning places that will provide sites for (novel) ecosystem establishment with a range of ecosystem services (regulatory, cultural, social, and economic) that serve the society.

Management of the post-mining sites should be based on the newest scientific knowledge. Novel ecosystems enable the improvement of the environment, the restoration of habitats and ecosystem functions, enabling the provision of services for life and human well-being in urban and industrial areas. Therefore, Corporate Social Responsibility is necessary to change a company's commitment to include the newest knowledge about the functioning of ecosystems and the environment concerning the concept of Natural Capital, Ecosystem Services, and landscape restoration. The opportunity given by the mosaic of Novel Ecosystems is used by restoring ecosystems in post-industrial areas (created after coal mining) to improve environmental health. The potential of natural processes occurring in the habitats of post-mining regions enables the creation of biological systems adapted to the type of substrate – Novel Ecosystems.

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References

[1] Box J. 1999: Nature conservation and post-industrial landscapes. Industrial Archaeology Review, 21 (2), 137–146.

[2] Costanza R., d'Arge R., de Groot R., Farber S., Grasso M., Hannon B., Limburg K., Naeem S., O'Neill R.V, Paruelo J., Raskin R.G., Sutton P. & van den Belt M. 1997: The value of the world's ecosystem services and natural capital. Nature, 387 (15), 253–260.

[3] Daily G.C. (ed.) 1997: Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington, DC.

[4] De Sousa C. 2014: The greening of urban post-industrial landscapes: past practices and emerging trends. Local Environment, 19 (10), 1049–1067.

[5] Doley D., Audet P. & Mulligan D.R. 2012: Examining the Australian context for post-mined land rehabilitation: Reconciling a paradigm for the development of *natural* and *novel* ecosystems among post-disturbance landscapes. Agriculture, Ecosystems & Environment, 163, 85–93.

[6] Hartig T., Mitchell R., de Vries S. & Frumkin H. 2014: Nature and Health. Annual Review of Public Health, 35, 207–228.

[7] Hatfield J.H., Harrison M.L.K. & Banks-Leite C. 2018: Functional diversity metrics: how they are affected by landscape change and how they represent ecosystem functioning in the tropics. Current Landscape Ecology Reports, 3, 35–42.

[8] 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. 2006: Novel ecosystems: theoretical and management aspects of the new ecological world order. Global Ecology and Biogeography, 15 (1), 1–7.

[9] Hobbs R.J., Higgs E.S. & Hall C.M. (eds.) 2013: Novel Ecosystems: Intervening in the New Ecological World Order. John Wiley & Sons Ltd., Chichester.

[10] Horodecki P. & Jagodziński A.M. 2017: Tree species effects on litter decomposition in pure stands on afforested post-mining sites. Forest Ecology and Management, 406, 1–11.

[11] Horodecki P. & Jagodziński A.M. 2019: Site type effect on litter decomposition rates: A three-year comparison of decomposition process between spoil heap and forest sites. Forests, 10 (4), 353.

[12] Horodecki P., Nowiński M. & Jagodziński A.M. 2019: Advantages of mixed tree stands in restoration of upper soil layers on postmining sites: A five-year leaf litter decomposition experiment. Land Degradation & Development, 30, 3–13.

[13] Kałucka I.L. & Jagodziński A.M. 2016: Successional traits of ectomycorrhizal fungi in forest reclamation after surface mining and agricultural disturbances: A review. Dendrobiology, 76, 91–104.

[14] Kałucka I.L. & Jagodziński A.M. 2017: Ectomycorrhizal fungi: a major player in early succession. [In:] Varma A., Prasad R. & Tuteja N. (eds.): Mycorrhiza – Function, Diversity, State of the Art. 4th ed. Springer International Publishing, 187–229.

[15] Kałucka I.L., Jagodziński A.M. & Nowiński M. 2016: Biodiversity of ectomycorrhizal fungi in surface mine spoil restoration stands in Poland – first time recorded, rare and red-listed species. Acta Mycologica, 51 (2), 1080.

[16] MEA – Millennium Ecosystem Assessment. 2005: Ecosystems and Human Well-being: Biodiversity Synthesis. World Resources Institute, Washington DC.

[17] Naumann, S. et al., 2011. Assessment of the potential of ecosystem-based approaches to climate change adaptation and mitigation in Europe. Final report to the European Commission, DG Environment. Berlin, Oxford, UK: Ecologic Institute, Environmental Change Institute, Oxford University Centre for the Environment.

[18] Ptaszek N., Pacwa-Płociniczak M., Noszczyńska M. & Płociniczak T. 2020: Comparative study on multiway enhanced bio- and phytoremediation of aged petroleum-contaminated soil. Agronomy, 10 (7), 947.

[19] Rawlik M., Kasprowicz M. & Jagodziński A.M. 2018a: Differentiation of herb layer vascular flora in reclaimed areas depends on the species composition of forest stands. Forest Ecology and Management, 409, 541–551.

[20] Rawlik M., Kasprowicz M., Jagodziński A.M., Kaźmierowski C., Łukowiak R. & Grzebisz W. 2021: Tree species have a greater influence on species composition of the herb layer than soil texture on a forested post-mining area. Land Degradation & Development, 32 (5), 2013–2024.

[21] Rawlik M., Kasprowicz M., Jagodziński A.M., Kaźmierowski C., Łukowiak R. & Grzebisz W. 2018b: Canopy tree species determine

herb layer biomass and species composition on a reclaimed mine spoil heap. Science of the Total Environment, 635, 1205–1214.

[22] Rotherham I.D. 2017: Recombinant Ecology – A Hybrid Future? Springer International Publishing.

[23] Schopf H. & Foster J. 2014: Buried localities: archaeological exploration of a Toronto dump and wilderness refuge. Local Environment, 19 (10), 1086–1109.

[24] Skorupski M., Horodecki P. & Jagodziński A.M. 2013: Roztocze z rzędu Mesostigmata (Arachnida, Acari) na terenach przemysłowych i poprzemysłowych w Polsce [Mite species of Mesostigmata order (Arachnida, Acari) in industrial and postindustrial areas of Poland]. Nauka Przyroda Technologie, 7 (1), 11.

[25] Solon J., Roo-Zielińska E., Affek A., Kowalska A., Kruczkowska B., Wolski J., Degórski M., Grabińska B., Kołaczkowska E., Regulska E. & Zawiska I. 2017: Świadczenia ekosystemowe w krajobrazie młodoglacjalnym. Ocena potencjału i wykorzystania. Wydawnictwo Akademickie SEDNO, Polska Akademia Nauk, Instytut Geografii i Przestrzennego Zagospodarowania im. Stanisława Leszczyckiego, Warszawa.

[26] Tropek, R., Kadlec, T., Hejda, M., Kocarek, P., Skuhrovec, J., Malenovsky, I., Konvicka, M. (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.

[27] Urbanowski C.K., Horodecki P., Kamczyc J., Skorupski M. & Jagodziński A.M. 2018: Succession of mite assemblages (Acari, Mesostigmata) during decomposition of tree leaves in forest stands growing on reclaimed post-mining spoil heap and adjacent forest habitats. Forests, 9 (11), 718.

[28] Urbanowski C.K., Horodecki P., Kamczyc J., Skorupski M. & Jagodziński A.M. 2021a: Does litter decomposition affect mite communities (Acari, Mesostigmata)? A five-year litterbag experiment with 14 tree species in mixed forest stands growing on post-industrial area. Geoderma, 391, 114963.

[29] Urbanowski C.K., Horodecki P., Kamczyc J., Skorupski M. & Jagodziński A.M. 2021b: Predatory mite instars (Acari, Mesostigmata) and decomposing tree leaves in mixed and monoculture stands growing on a spoil heap and surrounding forests. Experimental and Applied Acarology, 84, 703–731.

[30] 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. IntechOpen, 169–194.

6.2. The possibility and identification of using the nature-based solutions

The mining activity causes changes in the landscape. One of the environment friendly approaches includes the possibility and identification of the use of nature-based solutions. The direct impacts, such as post-coal mine heaps, and indirect impacts, such as land deformation due to subsidence, are observed. The results showed that the applied reclamation measures allow for their implementation following the provisions of the Spatial Development Plans and legal acts, which require restoring the reclamation areas to their proper condition. Entrepreneurs declare that they approach all the issues related to changes and transformations of the environment caused by economic activity very carefully and rationally, which is included in the carried out rehabilitation programmes. The used methods make little use of natural capital ecosystems created as a result of coal mining. The concept of increasing the scope of ecosystem services to improve environmental quality is also not taken into account.

The mining industry impact on the natural environment is generally perceived as an unfavourable activity. It manifests itself in a negative impact on humans (Blanco et al., 2019), referred to as ecosystem disservices. In industrial regions, adverse impacts are co-created both by humans (changes in the environment related to, e.g., the exploitation of raw materials) and ecosystems (impoverished biodiversity of ecosystems) (Cox et al., 2018).

However, the impacts of hard coal mining and processing can, directly and indirectly, impact air, water, soil ecosystems, and animal and human health during every phase of the coal "life cycle", from resource extraction to final by-product disposal. Further treatment of the areas created by mining or processing is limited by the different legal regulations in each country, e.g., the Polish Geological and Mining Law (2011).

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Figure 6.2.1. The differences in the texture of the mineral material gathered on the post-coal mine heap with respect to the ability of plants to colonize and successfully grow on the mineral material

In addition, the managers apply good practices, taking into account the provisions of reclamation programmes for post-mining areas and their intended purpose. Land reclamation has played a significant role in the urban development process of post-mining areas. The reclamation should be carried out as quickly as possible after the end of waste disposal. It should be carried out as quickly as possible after the end of waste storage.

The reclamation practices, conducted on post-coal mine sites by the administrators of these areas, on the example activity of the Restructuring of Mines Company, identify the possibilities for practitioners to introduce the newest scientific achievements into their applications.

Mining activity and environmental habitat diversity

The environmental impacts of natural mining resources can occur on a local, regional, and global scale through direct and indirect effects of mining practices. The effects of mining activity can lead to erosion of the Earth's surface, the formation of sinkholes (sedimentation pools), loss of biodiversity, or contamination of soil, groundwater (Marschalko et al., 2012), and surface water with substances from mining processes (Huang et al., 2018). Industrial activity leads directly to the exclusion of agricultural and forest areas from their current use.

The mining areas become investment areas for the construction of mining infrastructure, i.e., shafts, processing plants, railway sidings, transport routes, storage yards, and other facilities necessary for the mining operation. In close connection with the operation of mining sites, the areas are occupied by underground water sedimentation pools and post-mining by-product heaps. These so-called heaps are formed from the excavated material or arise due to processing and treatment of minerals.

The effects of mining activity also influence the functioning of local communities and the natural environment (Sierka et al., 2012). The indirect effects of mining activities on the environment are manifested by changes in geomorphology, water relations, deformation of the land surface, or impacts on buildings, roads, and forest areas (Giam et al., 2018).

Post coal mine heaps sedimentation pools and subsidences - the wetland and water habitat resources enrichment

The mineral material deposited on post-coal mine heaps is represented by the mineral forms in the Carboniferous geological period. It consists of, among others, sandstones of various grain sizes and clay (carbonate) binder, amorphous mudstones, or clay shales, which are clay fraction rock with an admixture of mudstone and coal shale (Ribeiro et al., 2011). If it meets the required criteria, the material collected on post-coal mine heaps can be used to fill transformed areas (Finkelman et al., 2021), including road construction by builders.

The areas transformed by deep hard coal processing activities include sedimentation pools and subsidences (Fig. 6.2.3), designed to purify the water, used in the technological process, by allowing gravity to remove from the coal dust suspension of water, prior to introducing it into surface waters.

The composition of the dust in sedimentation pools depends mainly on the size of the particles. The research showed that the coal dust masses collected in the sedimentation pools depend mainly on the size and the content of carbon particles. Coal dust has been documented in the regional waters and on the surface of the ocean and the seabed, causing a severe impact on aquatic fauna and flora (Johnson & Bustin 2006), including ocean acidification (Brown & Spiegel 2019).

Figure 6.2.2. The water body, regardless of its origin will be quickly colonized by water and wetland organisms

Reservoirs in subsidence basins have been and are still of interest in terms of the impacts of underground hard coal mining on geomorphological changes (Marschalko et al., 2009), their dynamics and forecasting future surface transformations, and the effects of land depression in Europe (Doležalová et al., 2009).

Figure 6.2.3. The water body, similar to the post coal mine subsidences, are frequently colonized by *Iris pseudoacorus*

As an indirect result of underground coal mining, the appearance of subsidence basins is observed. With the emergence of a reservoir, large land areas are often occupied, and the existing vegetation is destroyed, which leads to a decrease in biodiversity. In the subsequent stages, the processes of spontaneous succession most often lead to the formation of a water ecosystem similar in nature to those formed in natural reservoirs (Pierzchała & Sierka 2020). The size, extent, and course of land subsidence depend on the depth of exploitation and the sequence of layers with different mechanical properties, the nature of tectonic dislocations, and the extraction system.

Generally land subsidence, induced by underground coal mining, is one of the adverse impacts of mining, which not only destroys soil structure and changes its properties, but also causes other eco-environmental problems (Marschalko et al., 2012), such as a limitation of vegetation growth, a reduction of crop production, a plant death, an acceleration of soil water erosion, a degradation of the landscape, a surface soil fracture, dropping of groundwater table, changes in topographic and hydrologic conditions, loss of agricultural land and topsoil, and so on (Kuter et al., 2014).

Figure 6.2.4. The initial vegetation creates a mosaic of patches that reflects the habitat conditions and the plant species individual's morphological, anatomical and physiological traits that enable the plants to colonize the post coal mining heap habitats

Various impacts of subsidence are indicated, which, apart from soil erosion, land surface changes, drainage, watering, and reduction of yields, also include removal of nitrogen availability for plants (Kuter et al., 2014). Due to the functioning of the reservoirs, an important issue is their role as reservoirs that receive or store water transferred from outside the catchment area, e.g., drainage water from a mine. These waters may be saline and contain coal dust, which is why ecosystems with particular habitat conditions are formed (Kašovská et al., 2014).

The methods of ecosystem re-establishment on mineral material of coal mine heaps

The exploitation of energy resources has been carried out for over 100 years. It has led to the transformation of land, which should be supported by remedial measures in the form of reclamation and development. According to provisions of the law, the other decisions about the so-called disused waste rock dumps depend on the purpose of the land, based on the Local Spatial Development Plans for individual municipalities.

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Figure 6.2.5. The spontaneous vegetation patches are most frequently dominated by one species while the other accompanying plant species are scarce. The coal dust of the sedimentation pool spontaneously covered by *Phragmites australis*

The mine restoration has become an important part of the sustainable development strategy in many countries. Good planning and environmental management minimize the impacts of mining on the environment and helps preserve eco-diversity (Rosa et al., 2020). The steps are taken to reduce the nuisance of areas transformed by mining activities and restore their ecological functions. A reconstruction planning framework for such regions should include an integrated analysis of the ecosystem services and socio-ecological system, provided to facilitate community involvement and deliver social benefits (Woźniak et al., 2018). Ecological restoration and mine reclamation have become important parts of the sustainable development strategy in many countries.

Figure 6.2.6. The spontaneous herbaceous vegetation patches are less frequently represented in the vegetation mosaic. In the picture the biennial *Daucus carota* individuals have dominated the patch, and the other accompanying plant species are not abundant. The *Tanacetum vulgare* individuals are present at the bottom of the picture

After shaping and compacting, a layer of fertile soil is frequently applied, and then a mixture of grasses is fed with artificial fertilizer. Then the so-called hydro-seeding is made.

Observations comparing the long-term effects of primary succession and the introduction of plants by planting or sowing are few.

Figure 6.2.7. The crucial element of slope management is a prevention against erosion. The spontaneous herbaceous patches of *Tussilago farfara* provide slope protection due to the dense net of rhizomes. Moreover, this plant prefers the coal mine heaps and other coarse mineral particle habitats to fine mineral material

The regularly updated knowledge and the newest achievements of biological sciences about the natural processes in the changing environment are not shared among the practitioners. The legislation system does not force practitioners and decision-makers to follow the dynamic adaptation processes in nature. Human activities should support and enhance the natural adaptation process. Humans cannot act as effectively as the adaptation processes to the changing environment at various organizational levels, from the molecular one to the landscape.

Discontinuous deformations are one of the effects of mining exploitation on the surface. They can take the form of cracks, crevices, faults, sinkholes, landslides, funnels, and uplift. In nature, such changes in the surface bring many different habitat conditions and intermediate disturbances which significantly enhance biodiversity. Most of them are related to the so-called shallow exploitation, very often occurring due to shallow goaf "activation" by exploitation carried out at greater depths.

In the managed forest areas, discontinuous deformations in the form of valleys of varying depths and diameters are formed. Reclamation of these areas consist of filling the funnels with material, fertilizing the appropriate type of soil, and planting trees following the guidelines of the Forest Inspectorate. It is worth noting that the reclamation works have to be preceded by an engineering reconnaissance. An additional but significant difficulty in designing and carrying out reclamation works in forest areas includes minimizing forest stand losses, i.e., limiting tree clearance to enable the task to be carried out.

Figure 6.2.8. The quarry walls are colonized by tree species mainly by *Betula pendula*, and *Populus tremula*

As a result of the normalization of water relations, these reservoirs usually fill up spontaneously with water, and the natural succession of vegetation restores the dynamic ecological balance. For environmental reasons, the emerging water bodies are part of the so-called small retention. They are part of the concept of actions to mitigate climate change and support the development of biodiversity. It often turns out that reservoirs of such genesis are areas of the incredible richness of the organic world, refuges for flora and fauna, and abundant in rare and protected species. Such a situation may influence plants and invertebrates (Sierka et al., 2012).

However, from a legal point of view, it damages the environment, and measures must be taken to remedy it. These reservoirs are often covered with post-coal mine mineral rock material. Still, after a change in law, they are left without interference or strengthening the banks with mineral material as part of reclamation activities. These reservoirs are also places to collect water from the drainage of exploited deposits. They often show signs of salinity. In the areas taken over by the SRK there are water reservoirs used by mines as sedimentation pools for underground water (and only they bear the hallmark of salinity) to pre-purify water of suspended solids before discharging it into the reservoir. The accumulated sediments are examined before taking the decision on the further treatment of the site. If the test results show that the collected sediments are of material value due to their carbon content, the deposits are selected and sold. Then the water is pumped out of the pools. The pools are filled with appropriate material due to changes in the legislation on the use of post-coal mine mineral rock material to fill unfavourably transformed areas. Material masses are required. The last stage is biological reclamation consisting of fertilizing the earth masses and then planting, bushing, or planting trees.

Figure 6.2.9. The spontaneous vegetation has to be monitored in order to understand the mechanisms of the novel ecosystem functioning

A separate issue is related to the water reservoirs formed in septic basins resulting from subsidence caused by mining exploitation. It is very often the case that an ecosystem is created in the resulting pool and in its surroundings. Its violation is a violation of nature. These pools remain intact, or cleaning works are carried out in their surroundings. Most often, these types of reservoirs are managed by the Angling Associations. Some pools were built in the areas designated according to the Local Spatial Development Plan in the case of a development other than water.

During the spontaneous colonization of the mineral material of the post-coal mine heaps, the novel ecosystem of the tree seedlings and juveniles of deciduous and coniferous species is present as the first colonizers together with the herbaceous plant species that are assembled in the vegetation communities.

Prospective activities assume that corporate social responsibility should be carried out, e.g., due to the increasing pressure of society and local authorities in solving environmental problems for the areas where the exploitation and development of post-mining activities are carried out. These should be the ways to continue a good, open dialogue with local communities.

Entrepreneurs declare that they approach all issues related to changes and transformations of the environment caused by economic activity very carefully and rationally, which is included in the carried out rehabilitation programmes. Unfortunately, the rehabilitation programmes do not take into consideration the natural processes. For the tasks to be financed from the National Fund for Environmental Protection and Water Management in Warsaw, the "Programme for the implementation of projects in the field of environmental protection" was developed and approved by a resolution of the Management Board of the SRK, which is being implemented successively. The nature-based solutions are much cheaper and more persistent, they do not need maintenance because they are self-sustaining. Moreover, such solutions recover the ecosystem functioning what ensures the best provision of ecosystem services.

Figure 6.2.10. The coarse mineral material of the quarry is colonized by coniferous and deciduous tree seedlings

Restoring functions to transformed regions is one of the most important and, simultaneously, more complex issues, mainly due to environmental, social, legal, technical, and economic aspects. Due to the necessity to carry out, among others, the extraction of mineral resources and manage their inevitable effects, it is also essential to carry out extensive activities and educational initiatives to familiarize stakeholders, local communities, and contractors with this issue and the tasks performed by entrepreneurs. The presented practices for reclamation areas, affected by direct or indirect industrial transformations include applications that effectively lead to diversified land development in accordance with the law in force.

It seems, that both the needs and the natural values of the existing objects are not considered in deciding processes on their future use. The analysis of the effects of hard coal mining and processing, and their impacts on the natural environment on a local and global scale, indicates that the latest scientific research results are used to a small extent in reclamation-restoration activities. As a result, a need appeared to use the idea of natural capital and ecosystem services for the functioning of novel ecosystems both in legal acts and in practice. A deep understanding of the phenomena and processes is crucial for an efficient limitation of global change and unfortunately it is not included in the Polish and European legislation system.

Figure 6.2.11. There are many proofs concerning the need to include the dynamic adaptation processes performed by nature and the nature-based solutions for enhancing the ecosystem function and ecosystem services. The picture above is an example of a natural solution that would not be expected by reclamation practitioners

The legislation system does not enforce the practitioners and decision-makers to follow the dynamic adaptation processes in nature. Human activity should make use of nature-based solutions for better reconditioning of the environment.

References

[1] Blanco J., Dendoncker N., Barnaud C. & Sirami C. 2019: Ecosystem disservices matter: Towards their systematic integration within ecosystem service research and policy. Ecosystem Services, 36, 100913.

[2] Brown B. & Spiegel S.J. 2019: Coal, climate justice, and the cultural politics of energy transition. Global Environmental Politics, 19 (2), 149–168.

[3] Cox D.T.C., Hudson H.L., Plummer K.E., Siriwardena G.M., Anderson K., Hancock S., Devine-Wright P. & Gaston K.J. 2018:

Covariation in urban birds providing cultural services or disservices and people. Journal of Applied Ecology, 55 (5), 2308–2319.

[4] Doležalová H., Kajzar V., Souček K. & Staš L. 2009: Evaluation of mining subsidence using GPS data. Acta Geodynamica et Geomaterialia, 6 (155), 359–367.

[5] Finkelman R.B., Wolfe A. & Hendryx M.S. 2021: The future environmental and health impacts of coal. Energy Geoscience, 2 (2), 99–112.

[6] Giam X., Olden J.D. & Simberloff D. 2018: Impact of coal mining on stream biodiversity in the US and its regulatory implications. Nature Sustainability, 1 (4), 176–183.

[7] Huang L., Krigsvoll G., Johansen F., Liu Y. & Zhang X. 2018: Carbon emission of global construction sector. Renewable and Sustainable Energy Reviews, 81 (2), 1906–1916.

[8] Johnson R. & Bustin R.M. 2006: Coal dust dispersal around a marine coal terminal (1977–1999), British Columbia: The fate of coal dust in the marine environment. International Journal of Coal Geology, 68 (1–2), 57–69.

[9] Kašovská K., Pierzchała Ł., Sierka E. & Stalmachová B. 2014: Impact of the salinity gradient on the mollusc fauna in flooded mine subsidences (Karvina, Czech Republic). Archives of Environmental Protection, 40 (1), 87–99.

[10] Kuter N., Dilaver Z. & Gül E. 2014: Determination of suitable plant species for reclamation at an abandoned coal mine area. International Journal of Mining, Reclamation and Environment, 28 (5), 268–276.

[11] Marschalko M., Třeslín L. & Fuka M. 2009: Possible impact of current and former mining activities on a research locality in the Ostrava-Karviná District. Górnictwo i Geoinżynieria, 33 (1), 429–442.

[12] Marschalko M., Yilmaz I., Bednárik M. & Kubečka K. 2012: Deformation of slopes as a cause of underground mining activities: three case studies from Ostrava–Karviná coal field (Czech Republic). Environmental Monitoring and Assessment, 184, 6709–6733.

[13] Orwell G. 1937: The Road to Wigan Pier. Part One, Chapter 2. Project Gutenberg of Australia, 18–31. https://libcom.org/files/wiganpier.pdf,

[14] Pierzchała Ł. & Sierka E. 2020: Do submerged plants improve the water quality in mining subsidence reservoirs? Applied Ecology and Environmental Research, 18 (4), 5661–5672.

[15] Ribeiro J., da Silva E.F., de Jesus A.P. & Flores D. 2011: Petrographic and geochemical characterization of coal waste piles from Douro Coalfield (NW Portugal). International Journal of Coal Geology, 87 (3–4), 226–236.

[16] Rosa J.C.S., Morrison-Saunders A., Hughes M. & Sánchez L.E. 2020: Planning mine restoration through ecosystem services to enhance community engagement and deliver social benefits. Restoration Ecology, 28 (4), 937–946.

[17] Sierka E., Stalmachová B., Molenda T., Chmura D. & Pierzchała Ł. 2012: Environmental and socio-economic importance of mining subsidence reservoirs. Ben – Technická Literatura, Praha.

[18] Wang Y.-J., Zhang D.-C., Lian D.-J., Li Y.-F. & Wang X.-F. 2009: Environment cumulative effects of coal exploitation and its assessment. Procedia Earth and Planetary Science, 1 (1), 1072–1080.

[19] 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. IntechOpen, 169–194.

[20] Woźniak G. 2010: Zróżnicowanie roślinności na zwałach pogórniczych Górnego Śląska [Diversity of vegetation on coal-mine heaps of the Upper Silesia (Poland)]. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

6.3. Values of post-industrial Novel Ecosystems for enhancement of ecosystem services in the Anthropocene Epoch

For the last two centuries, the natural environment has been severely altered or damaged. For a very long time, environmental protection has been part of the industrial strategy for restoration. Regardless of the frequent mention of ecological protection in official documents, environmental parameters are getting worse and worse – the global change crisis reflects the seriousness of the situation. The reason for that might be the focus exclusively on agriculture and forestry – to the exclusion of the enhancement of wildlife development and functioning of ecosystems best adapted to new human-created habitats. This enhancement has to be based on a scientific understanding of the dynamic changes in the functioning of adapted novel ecosystems. This approach is fundamental for urban areas and sites transformed by industry, particularly post-mineral excavations covering increasing areas of land at the global scale. At the same time, there are also very densely populated areas. Many studies show that biological, biogeochemical processes, serve as surprising solutions for re-establishing well-functioning ecosystems in new severe habitats.

Environmental management policies in the Anthropocene Epoch must include the importance of estimating the value of the post-excavation novel ecosystem habitats to enhance ecosystem services.

Anthropocene is the name of a new geological epoch initiated by human activity. The term was proposed by Paul Crutzen (the Nobel Prize winner in Chemistry). At one point, human activity started to cause dangerous changes in the environment by introducing, e.g., hazardous chemicals, causing, among others, an ozone hole and climate change. Modifications in land management, deforestation, and fossil fuel extraction contribute to irreversible changes in geology and landscape on the Earth (Crutzen 2006). Most scientists consider the 18^{th} century industrial revolution to be the beginning of this epoch. An apparent acceleration occurred in the middle of the 20^{th} century when atomic energy was invented and first used. The artificial radioactive signal from the nuclear bomb explosion of 16 July 1945 was traceable in the environment (Zalasiewicz et al., 2015).

A steady increase in human economic activity has been recorded, which has an increasing impact on the environment and natural resources (Vitousek et al., 1997; Foley et al., 2005). Destroyed, simplified, fragmented ecosystems, in turn, are becoming more and more common around the world, covering a growing part of the Earth (Ellis et al., 2010). As a result, the functioning of natural ecosystems has been affected and is being transformed. Part of the altered ecosystems or established newly created habitats has turned out to become new ecosystems (novel ecosystems; Morse et al., 2014). Human activities, agriculture, urbanization, and industry have a significant impact on many ecosystems. The era of the "new man" entails negative and often irreversible changes in nature. One of the most extreme manifestations of these changes is the loss of biodiversity associated with the massive extinction of species called the sixth catastrophe or sixth great extinction (Barnosky et al., 2011). In addition, human changes on the Earth's surface through rapid urbanization, transform the environment for agriculture and industry (Cardinale et al., 2012). The challenge is to support as much microhabitat diversity as possible to provide habitat conditions to establish biodiversity. Many poor post-mineral excavation oligotrophic sites offer refuge habitats for endangered species. Many of the species become endangered because of agricultural fertilizers, herbicides, and pesticides use.

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Figure 6.3.1. The quarry mineral material is colonized by tree juveniles both coniferous and deciduous tree species

In the 18th century, an industrialization, which began in Great Britain, spread around the world. Today, people live on a rapidly urbanizing and industrialized planet (McPhearson et al., 2016). At the current rate of development, the global population of cities will increase from about four billion, the level in the second decade of the 21st century, to more than six billion by 2045. Urban and industrial landscapes are primarily associated with the everyday presence of humans in the environment. Unfortunately, there has been an increasing lack of space for wildlife (Haase 2014).

Diversity of living organisms during spontaneous succession

There is a wide range and immense diversity of living organisms and spontaneous biological phenomena in natural and semi-natural ecosystems, determining ecosystem processes and functioning (Irvine et al., 2013). The dynamics of human economic activity caused the transformation or diminishing of natural and semi-natural ecosystems and the emergence of new habitats. These sites are the direct result of deliberate or unintentional human action, which has led to the crossing of an ecological threshold. The unknown previous conditions facilitate the new trajectory of vegetation and ecosystem development and inhibit the return to the old system regardless of the presence or lack of additional human intervention. The new ecosystem is a unique set of *de novo* human-created habitat conditions, attracting colonization and establishment of the best-adapted flora, fauna, and many related above and below-ground organisms. The resulting novel ecosystem is self-sufficient regarding its species composition, structure, and biogeochemistry, and frequently can provide efficient ecosystem services (Woźniak et al., 2018). A characteristic feature of the new ecosystem is the change in species composition and relationships among species (e.g., plants and bacteria or fungi) compared with ecosystems recorded before the ecological threshold has been crossed (Morse et al., 2014).

The spontaneous processes in novel ecosystem habitats, such as post-mineral excavation pits and heaps connected with the natural mineral exploitation side-effect sites, have been studied for some time. Unexpectedly, such sites provide a high microhabitat variety supporting the spontaneous colonization of different organisms, resulting in increased diversity of primary producers, the photosynthesizing organisms, mainly plant species. Biodiversity is an essential criterion for the success of projects in restoring habitats in post-industrial, including post-mining areas (Cardinale et al., 2012; Morse et al., 2014; McPhearson et al., 2016; Woźniak et al., 2018).

Figure 6.3.2. Many rare and protected species are colonizing post-mining sites such as *Cephalanthera longifolia* which occurs in anthropogenic habitats such as quarries

The UK Government, e.g., has identified ecosystem services in urban-industrial landscape enhancement as a critical tool for regional economic regeneration, habitat restoration, and the implementation of international commitments on biodiversity (Doick et al., 2009; Pediaditi et al., 2010). Urban and post-industrial areas, including post-mining sites that have been left behind and have become overgrown by spontaneous succession, are often valuable biodiversity and wildlife centres. They can compose a part of developing blue-green infrastructure for sustainable cities. Many of them form mosaics of various substrates on which different plant communities grow, creating an ecosystem together with the related animals (micro-, meso- and macrofauna) and microorganisms (Bonthoux et al., 2014; Woźniak et al., 2015). Post-industrial, particularly the post-mineral excavation areas, can be challenging environments

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for many reasons: toxicity, high daytime temperatures (in sheltered areas in direct sunlight), weak or non-existent soils, insufficient or excessive drainage due to compaction caused by heavy equipment or, in contrast, a complex, large pore substrate unable to hold water (Frouz et al., 2008; Woźniak 2010; Frouz 2014; Woźniak et al., 2015; Wiesmeier et al., 2019).

These substrates often consist of different mineral material types excavated from deep down. The soil-forming process in such habitats can take up to decades. This process involves living organisms, mainly plants, as a source of organic material, leading to a slow accumulation of organic matter. Such places do not have a seed bank and depend on plant species from other areas or brought in by animals (Frouz et al., 2008; Woźniak 2010; Woźniak et al., 2015). Apart from the environmental transformation conducted for 200 years, some surprisingly efficient self-naturalized processes have occurred. The industrial development of mining in Wigan, UK, is an example of how dynamic economic growth took place at the natural environment's expense. Due to spontaneous biological processes, the watercourse in the Wigan previous mining site changed into a system of ponds. In the small wetland areas, coastal vegetation has developed. According to natural hydrological processes, the current network of ditches and wetlands in the Wigan mining area will probably transform into streams with meanders and riverbeds. In some parts, the prolonged water flow has contributed to the colonization of these water bodies by rare animal species associated with humid habitats. In the UK, a particular programme supports the Natural Process, which will bring several benefits in natural capital protection and contribute to better ecosystem services provision (Anderson & France 1994; Davies 2010; Rands et al., 2010).

Natural Process in Natural Capital

Ecosystem services are typically classified into four categories (MEA 2005; Cowling et al., 2008; TEEB 2011). There are many classifications, but in natural and seminatural ecosystems, there are generally four main ecosystem services listed: a.) supply services – including starting material from ecosystems, for example, food, water, medicinal plants, and other resources; b.) regulatory services – maintain functions such as air and soil quality, flood prevention, and control of rainwater and disease; c.) habitat or ancillary services – provide a basis for other services, supporting living space for organisms and maintaining the diversity of plants and animals; d.) cultural services – including intangible, socioeconomic benefits (such as psychological and cognitive benefits) that people gain from contact with the environment, such as recreation, aesthetic, spiritual, psychological services, and tourism. e.) Wigan Flashes in the UK, a previous mining area, mainly supports natural, spontaneous processes to improve ecosystem functioning, including increasing biodiversity, carbon sequestration, and water retention. Apart from those essential services, the old mining area provides services related to cultural ecosystems.

A significant increase in biodiversity and improved retention in a previous coal mining area is highly valued and could not be provided due to anything other than the natural complex process. Nowadays, more and more people use this place to watch birds and walk. Thus, the site provides vital regulatory ecosystem services (flood mitigation) and recreational and cultural services.

Nature, including wildlife, has spontaneously developed in the vast majority of areas previously considered to be degraded due to industrial activity (Cohn et al., 2001). Thus, supporting processes that spontaneously operate at restoring and providing ecosystem services after almost a century have dominated the post-industrial landscape, now providing the essential regulation of ecosystem services on the urban-industrial landscape. However, the cultural ecosystem services are much more easily recognized by people.

Many organisms, including bees and other insects, are associated with spontaneously developing vegetation in open poor oligotrophic habitats. In the UK, the protection of such developing new systems exists in the British National Pollination Strategy (Defra 2018). The richness of plant species, and thus the diversity of flora, in the open, primarily oligotrophic post-industrial habitats, can help promote habitats for pollinators and key invertebrate species. Besides, if the post-mining, post-mineral excavation habitats are within urban boundaries, they may provide refuge habitats in urban areas (Buglife 2009; 2019). About 30 butterfly species are associated with post-industrial areas and protected in these habitats in the UK (Butterfly Conservation 2019). In particular, butterflies prefer open, diverse post-industrial habitats and can naturally colonize the highly dispersed fragments of the mosaic of vegetation remaining in the initial stages. Post-mineral excavation areas should also be managed for pollinators, as these post-industrial areas provide safe shelter from pesticides (Defra 2018).

To prevent the disappearance of rare vegetation and accompanying butterflies, it is sometimes necessary to introduce occasional disturbances and remove bushes (Butterfly Conservation 2019). In addition, ecosystems developing in post-mining areas, and located near urban settlements, often become places of recreation, walks, green gyms, wild playgrounds (bird watching), and some of them are also attractive viewpoints (Millward & Mostyn 1989; Icarus 2014). In the UK, city parks were established mainly in the 1970s, and they are not statutorily protected. These are primarily open public space areas

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on the edge of urban agglomerations with amenities such as toilets, a café, and parking. In the majority of cases, these were post-industrial areas, hence their proximity to urban areas. The largest park in Europe has a similar history – the Silesian Park, established in the 1970s and 1980s in the Upper Silesian Industrial District (Bacler-Żbikowska et al., 2015).

In the 1960s, many post-industrial, mostly post-coal-mine sites in the West Midlands, were identified as Sites of Conservation Interest (SINCs). In the Black Country and West Midlands, some post-industrial, particularly post-coal-mine sites, were recognized as high ecological and environmental value sites, due to the different species composition that has colonized those sites and the resulting ecological processes which have developed (Box et al., 1994). Box & Cossons (1988) found that post-industrial sites are almost exclusively home to rare species such as the *Lycopodiaceae*. They grow on the acidic clay substrate of an abandoned Telford opencast coal mine (Box & Cossons 1988). Such an example from Poland is the inactive quarry in Poland's most industrially transformed region – the Silesian Upland, which became the first Polish habitat for the bee orchid *Ophrys apifera* (Osiadacz & Kręciała 2014).

In his book under the title "Review of England's Wildlife Sites in England", Sir John Lawton appealed to the public and the authorities to create a space for nature inside the urban-industrial landscape. The report suggests a targeted approach to conservation efforts to improve the condition and development of existing open areas, by connecting neighbouring sites to strengthen and expand spaces available to wildlife, for human well-being (Lawton et al., 2010).

Figure 6.3.3. In the herb layer of the forest community that developed spontaneously on the post-mineral quarry habitat *Pyrola secunda* abundant presence has been recorded

Long-term studies conducted in the Silesia industrial region (Poland) found that the first colonizers were algae. Apart from annual plant species, long-lived herbaceous plants become the first colonizers during spontaneous succession on the hard coal mine heaps. Some plant species will tolerate extraordinarily high or low pH levels or high salinity (Woźniak 2010). The natural processes often take a long time, creating a sustained system that does not need any additional investment or work load. Unfortunately, economically focused people looking for defined benefits do not want to dedicate time and wait for the solutions that nature can develop. The dynamic economic, so-called development strategy would instead cause additional harm to the environment and developing ecosystem functioning, rather than take enough time to understand the natural adaptation processes and support them when necessary.

These post-industrial places, both in the UK and Poland, can vary significantly in retaining water. Local water accumulations often take place in microhabitats, where the soil was heavily compacted. Interesting groups of aquatic plant species can quickly colonize the open water-filled hollows. In local depressions of various sizes and depths formed in post-mining areas, amphibians and aquatic invertebrates appear together with wetland vegetation. Observations conducted during the study in Poland and the Czech Republic were similar (Sierka et al., 2009; Woźniak 2010). The animals related to the particular wetland vegetation types significantly increase the values of biodiversity indicators. In the UK, where plants have naturally colonized and created communities, post-mining areas are being examined to create the conditions for their further development (Lunn 2000).

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Figure 6.3.4. In the herb layer of the forest community that developed spontaneously on the post-mineral quarry habitat the individuals of *Lycopodium clavatum* have been observed

The valuable wetland vegetation and ecosystems are crucial elements of the natural values that spontaneously emerged, e.g., in the post-coal mine heaps in the UK's Wigan region and the Silesia Region in Poland. Apart from the wetland vegetation and ecosystems, *Danthonia decumbens* grasslands are a particular type of heathland vegetation in Great Britain. *D. decumbens* is not the grass that would be expected in the Wigan old mining area. However, a unique heritage of industrial activity can lead to new, unexpected habitats and associated plant communities of Novel ecosystems (Champion 2018; James 2018).

The slow initial colonization of post-mining areas in the UK often leads to many diverse assembled vegetation communities. This type of open mosaic habitat on previously managed land is a conservation priority. The habitat mosaic of open vegetation patches is protected by the UK Biodiversity Action Plan (BAP) and it is a legally protected habitat (Rodwell 2000).

Wetland vegetation and ecosystems

Reversing the management policy based on dehumidification, to facilitate construction and move towards restoring the functionality of aquatic and wetland ecosystems and creating a larger wetland area, slowing down the flow and retaining water to mitigate flooding, indicates how thinking has changed. In addition, the re-use of post-industrial and post-mining regions has changed in order to strengthen the significant role of environmental management in achieving sustainable water resources development. Canals and concrete embankments are strictly avoided. Unfortunately, in Poland hydrotechnical canalization and regulation of water courses, is wrongly considered as the best solution for flooding. It is known worldwide that such an approach is the worst when water retention is the target.

Figure 6.3.5. In the open area of the post-mineral quarry, the individuals of *actylorhiza majalis* have been recorded

The unexpected diversity (within and between sites) of the spontaneously developed vegetation on the heaps of deposited rock in Wigan and other European mining regions, provides proof of the rightness of the distinction of Novel Ecosystems as a new system of biotic and abiotic elements adapted to habitats under significant human pressure in the Anthropocene. Preserving the diversity of vegetation and ecosystems in post-mining areas is essential for urban planners, as it helps international commitments maintain and enhance biodiversity (Buglife 2009; 2019). There is a level of protection category lower than the Local Nature Reserve (LRP) and Country Park (CP) in the UK. Many places covered by this form of protection are post-industrial areas (particularly post-coal-mining).

The landscape approach protects the ecosystem and environmental processes throughout the country. Therefore, the current national planning policy framework requires the authorities of different parts of the country to ensure efficient land use and create the necessary conditions to ensure sustainable use of previously converted land. The solutions, explained above, are an appropriate approach, particularly true for supporting wetlands and aquatic habitats (Andersson et al., 2015). The proper recognition of the environmental potential of available land is a prerequisite to identifying the most supportive management system for ecosystem functioning. The applied management depends on the characteristics of the site. Such an approach may include natural and recreational purposes and provide an opportunity for nature conservation. Enabling the preservation of the identified environmental value of land previously transformed by humans (industry or agriculture) should be considered. Thus, closed mine sites can constitute additional open spaces valuable to ecosystem recovery in the urban and industrial landscape (Bonthoux et al., 2014). Facilitating the restoration and deployment of open ecosystem services makes them available for spontaneous processes that help create strategic habitats in the face of challenges posed by global change. Increasing the area available for wildlife and strengthening ecological networks, primarily if they are close to existing natural sites, is the main point for environmental management to mitigate global change. The economy and short-term financial benefits cannot be the only prerequisite for decisions on the management of an area (Buglife 2019).

Understanding and perceiving the functioning of novel ecosystems must be the key to the successful transformation required for urban-industrial areas, to make them climate-resilient (Royal Society 2014). In urban-industrial areas, such ways of developing green infrastructure are increasingly leading to the development of blue-green infrastructure to meet the challenges of climate change. Benefits resulting from the existence and development of blue-green infrastructure include biodiversity increase, air temperature cooling, rainwater absorption, protection of drinking water supply (retention), and human health improvement (Elmqvist et al., 2013).

It is, therefore, necessary to use all available urban, industrial, and post-industrial areas to develop blue-green infrastructure. These benefits are the urban-industrial ecosystem services that residents and visitors derive from local and regional ecosystems (Gómez-Baggethun et al., 2013; Larondelle et al., 2014). These benefits are not just products of the functioning of ecosystems, but rather the development of people and ecosystems combined in the complex social and environmental systems of industrial cities, in which the choices made to meet these challenges have an impact on the social, economic, and above all ecological situation (Andersson et al., 2015; McPhearson et al., 2016). The system of designing and managing urban ecosystems to ensure a resilient and equitable supply of ecosystem services requires local expertise (Faehnle et al., 2015). For some projects, contributions from engineers, architects, and designers might be required (Ahern et al., 2014) because the supply of urban ecosystem services must be compatible with those who will use them locally and regionally (Haase et al., 2014; McPhearson et al., 2015). There is a positive feedback loop in this system, usually a negative feedback loop: urbanization and industrialization cause change, being a reason for the decline in species diversity and, consequently, the ecosystem functioning efficiency and the availability of ecosystem services. However, “they are inextricably linked” (MEA 2005).

References

[1] Ahern J., Cilliers S. & Niemelä J. 2014: The concept of ecosystem services in adaptive urban planning and design: A framework for supporting innovation. Landscape and Urban Planning, 125, 254–259.

[2] Anderson D. & France A.A. 1994: Wigan Coal and Iron. Smiths of Wigan, Smiths Books, Wigan.

[3] Andersson M., McPhearson T., Kremer P., Gomez-Baggethun E., Haase D., Tuvendal M. & Wurster D. 2015: Scale and context dependence of ecosystem service providing units. Ecosystem Services, 12, 157–164.

[4] Bacler-Żbikowska B., Grzędzicka E., Kowalik K., Poraj A., Drozd Ł., Frądczak M., Golasz K., Stodółka A. & Żbikowski J. 2015: Przyroda Parku Śląskiego. Fundacja Park Śląski, Chorzów.

[5] Barnosky A.D., Matzke N., Tomiya S., Wogan G.O.U., Swartz B., Quental T.B., Marshall C., McGuire J.L., Lindsey E.L., Maguire K.C., Mersey B. & Ferrer E.A. 2011: Has the Earth’s sixth mass extinction already arrived? Nature, 471 (7336), 51–57.

[6] Bonthoux S., Brun M., Di Pietro F., Greulich S. & Bouché-Pillon S. 2014: How can wastelands promote biodiversity in cities? A review. Landscape and Urban Planning, 132, 79–88.

[7] Box J., Douse A. & Kohler T. 1994: Non-statutory sites of importance for nature conservation in the West Midlands. Journal of Environmental Planning and Management, 37 (3), 361–367.

[8] Box J.D. & Cossons V. 1988: Three species of clubmoss (Lycopodiaceae) at a lowland station in Shropshire. Watsonia, 17, 69–71.

[9] Buglife 2009: Planning for Brownfield Biodiversity: A best practice guide. Buglife – The Invertebrate Conservation Trust, Peterborough.

[10] Buglife 2019: Brownfield sites under threat. https://www.buglife.org.uk/resources/habitat-hub/brownfield-hub/brownfields-sites-under-threat, access: 27.05.2021.

[11] Butterfly Conservation 2019: Brownfields for Butterflies. Available from: https://butterfly-con-servation.org/sites/default/files/habitat-brownfield-leaflet.pdf, access: 27.05.2021.

[12] 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 S.D. & Naeem S. 2012: Biodiversity loss and its impact on humanity. Nature, 486 (7401), 59–67.

[13] Champion M. 2018: Biodiversity impacts at various scales following conservation management of synanthropic sites in North West England. PhD thesis, Edge Hill University.

[14] Cohn E.V.J., Rostański A., Tokarska-Guzik B., Trueman I.C. & Woźniak G. 2001: The flora and vegetation of an old solvay process tip in Jaworzno (Upper Silesia, Poland). Acta Societatis Botanicorum Poloniae, 70 (1), 47–60.

[15] Cowling R.M., Egoh B., Knight A.T., O'Farrell P.J., Reyers B., Rouget M., Roux D.J., Welz A. & Wilhelm-Rechman A. 2008: An operational model for mainstreaming ecosystem services for implementation. Proceedings of the National Academy of Sciences of the United States of America, 105 (28), 9483–9488.

[16] Crutzen P.J. 2006: The "Anthropocene". [In:] Ehlers E. & Krafft T. (eds.): Earth System Science in the Anthropocene. Springer, Berlin, Heidelberg, 13–18.

[17] Davies A. 2010: Coal Mining in Lancashire & Cheshire. Amberly Publishing, Stroud.

[18] Defra 2018: National Pollinator Strategy: Implementation Plan, 2018–2021. Department for Environment, Food and Rural Affairs. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/912826/nps-implementation-plan-2018-2021.pdf, access: 28.05.2021.

[19] Doick K.J., Sellers G., Castan-Broto V. & Silverthorne T. 2009: Understanding success in the context of brownfield greening projects: The requirement for outcome evaluation of success assessment. Urban Forestry & Urban Greening, 8 (3), 163–178.

[20] Ellis E.C., Goldewijk K.K., Siebert S., Lightman D. & Ramankutty N. 2010: Anthropogenic transformation of the biomes, 1700 to 2000. Global Ecology and Biogeography, 19 (5), 589–606.

[21] Elmqvist T., Fragkias M., Goodness J., Güneralp B., Marcotullio P.J., McDonald R.I., Parnell S., Schewenius M., Sendstad M., Seto K.C. & Wilkinson C. 2013: Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities. A Global Assessment. Springer, New York.

[22] Faehnle M., Söderman T., Schulman H. & Lehvävirta S. 2015: Scale-sensitive integration of ecosystem services in urban planning. GeoJournal, 80, 411–425.

[23] Foley J.A., DeFries R., Asner G.P., Barford C., Bonan G., Carpenter S.R., Chapin F.S., Coe M.T., Daily G.C., Gibbs H.K., Helkowski J.H., Holloway T., Howard E.A., Kucharik C.J., Monfreda C., Patz J.A., Prentice I.C., Ramankutty N. & Snyder P.K. 2005: Global consequences of land use. Science, 309 (5734), 570–574.

[24] Frouz J. (ed.) 2014: Soil Biota and Ecosystem Development in Post Mining Sites. CRC Press, Taylor & Francis Group, Boca Raton.

[25] Frouz J., Prach K., Pižl V., Háněl L., Starý J., Tajovský K., Materna J., Balík V., Kalčík J. & Řehounková K. 2008: Interactions between soil development, vegetation and soil fauna during spontaneous succession in post mining sites. European Journal of Soil Biology, 44 (1), 109–121.

[26] Gómez-Baggethun E., Gren Å., Barton D.N., Langemeyer J., McPhearson T., O'Farrell P., Andersson E., Hamstead Z. & Kremer P. 2013: Urban ecosystem services. [In:] Elmqvist T., Fragkias M., Goodness J., Güneralp B., Marcotullio P.J., McDonald R.I., Parnell S., Schewenius M., Sendstad M., Seto K.C. & Wilkinson C. (eds.): Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities. A Global Assessment. Springer, New York, 175–251.

[27] Haase D. 2014: The nature of urban land use and why it is a special case. [In:] Seto K.C. & Reenberg A. (eds.): Rethinking Global Land Use in an Urban Era. Strüngmann Forum Reports. Volume 14. MIT Press, Cambridge.

https://doi.org/10.32056/KOMAG/Monograph2023.5

[28] Haase D., Larondelle N., Andersson E., Artmann M., Borgström S., Breuste J., Gomez-Baggethun E., Gren Å., Hamstead Z., Hansen R., Kabisch N., Kremer P., Langemeyer J., Rall E.L., McPhearson T., Pauleit S., Qureshi S., Schwarz N., Voigt A., Wurster D. & Elmqvist T. 2014: A quantitative review of urban eco-system service assessments: concepts, models, and implementation. Ambio, 43, 413–433.

[29] Icarus 2014: Access to Nature: inspiring people to engage with their natural environment. Final Evaluation Report. Part 2. Natural England.

[30] Irvine K.N., Warber S.L., Devine-Wright P. & Gaston K.J. 2013: Understanding urban green space as a health resource: a qualitative comparison of visit motivation and derived effects among park users in Sheffield, UK. International Journal of Environmental Research and Public Health, 10 (1), 417–442.

[31] James P. 2018: The Biology of Urban Environments. Oxford University Press, Oxford.

[32] Larondelle N., Hamstead Z.A., Kremer P., Haase D. & McPhearson T. 201*4:* Applying a novel urban structure classification to compare the relationships of urban structure and surface temperature in Berlin and New York City. *Applied Geography*, 53, 427–437.

[33] Lawton J.H., Brotherton P.N.M., Brown V.K., Elphick C., Fitter A.H., Forshaw J., Haddow R.W., Hilborne S., Leafe R.N., Mace G.M., Southgate M.P., Sutherland W.J., Tew T.E., Varley J. & Wynne G.R. 2010: Ma-king Space for Nature: a review of England's wildlife sites and ecological network. Report to Department for Environment, Food and Rural Affairs (Defra).

[34] Lunn J. 2000: Ecological and nature conservation aspects of land affected by mining in the Yorkshire Coalfield. Unpublished Master's thesis, Sheffield Hallam University.

[35] McPhearson T., Andersson E., Elmqvist T. & Frantzeskaki N. 2015: Resilience of and through urban ecosystem services. Ecosystem Services, 12, 152–156.

[36] McPhearson T., Pickett S.T.A., Grimm N.B., Niemelä J., Alberti M., Elmqvist T., Weber C., Hasse D., Breuste J. & Qureshi S. 2016: Advancing urban ecology toward a science of cities. BioScience, 66 (3), 198—212.

[37] MEA – Millennium Ecosystem Assessment. 2005: Ecosystems and Human Well-being: Biodiversity Synthesis. World Resources Institute, Washington DC.

[38] Millward A. & Mostyn B. 1989: People and nature in cities: the social aspects of planning and managing natural parks in urban areas. Urban Wildlife Now 2. Nature Conservancy Council, Peterborough.

[39] Morse N.B., Pellissier P.A., Cianciola E.N., Brereton R.L., Sullivan M.M., Shonka N.K., Wheeler T.B. & Mc Dowell W.H. 2014: Novel ecosystems in the Anthropocene: a revision of the novel ecosystem concept for pragmatic applications. Ecology and Society, 19 (2), 12.

[40] Osiadacz B. & Kręciała M. 2014: *Ophrys apifera* Huds. (Orchidaceae), a new orchid species to the flora of Poland. Biodiversity: Research and Conservation, 36 (1), 11–16.

[41] Pediaditi K., Doick K.J. & Moffat A.J. 2010: Monitoring and evaluation practice for brownfield, regeneration to greenspace initiatives. A meta-evaluation of assessment and monitoring tools. Landscape and Urban Planning, 97 (1), 22–36.

[42] Rands M.R.W., Adams W.M., Bennun L., Butchart S.H.M., Clements A., Coomes D., Entwistle A., Hodge I., Kapos V., Scharlemann J.P.W., Sutherland W.J. & Vira B. 2010: Biodiversity conservation: challenges beyond 2010. Science, 329 (5997), 1298–1302.

[43] Rodwell J.S. (ed.) 2000: British Plant Communities. Volume 5: Maritime Communities and Vegetation of Open Habitats. Cambridge University Press, Cambridge.

[44] Royal Society 2014: Resilience to Extreme Weather. Royal Society Science Policy Centre, Report DES3400. Report 02/14, Royal Society, London.

[45] Sierka E., Molenda T. & Chmura D. 2009: Environmental repercussion of subsidence reservoirs reclamation. Journal of Water and Land Development, 13a (10), 41–52.

[46] TEEB 2011: Manual for Cities: Ecosystem Services in Urban Management. http://www.teebweb.org/publication/teeb-manual-for-cities-ecosystem-services-in-urban-management, access: 28.05.2021.

[47] Vitousek P.M., Mooney H.A., Lubchenco J. & Melillo J.M. 1997: Human domination of Earth’s ecosystems. Science, 277 (5325), 494–499.

[48] Wiesmeier M., Urbanski L., Hobley E., Lang B., von Lützow M., Marin-Spiotta E., van Wesemael B., Rabot E., Ließ M., Garcia-Franco

N., Wollschläger U., Vogel H.-J. & Kögel-Knabner I. 2019: Soil organic carbon storage as a key function of soils – A review of drivers and indicators at various scales. Geoderma, 333 (1), 149–162.

[49] Woźniak G. 2010: Zróżnicowanie roślinności na zwałach pogórniczych Górnego Śląska [Diversity of vegetation on coal-mine heaps of the Upper Silesia (Poland)]. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

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

[51] 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. IntechOpen, 169–194.

[52] Zalasiewicz J., Waters C.N., Williams M., Barnosky A.D., Cearreta A., Crutzen P., Ellis E., Ellis M.A., Fair-child I.J., Grinevald J., Haff P.K., Hajdas I., Leinfelder R., McNeill J., Odada E.O., Poirier C., Richter D., Steffen W., Summerhayes C., Syvitski J.P.M., Vidas D., Wagreich M., Wing S.L., Wolfe A.P., Zhisheng A. & Oreskes N. 2015: When did the Anthropocene begin? A mid-twentieth-century boundary level is stratigraphically optimal. Quaternary International, 383, 196–203.

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Novel Ecosystem Development in Urban-Industry Areas as The Prerequisite of Modern Economy

Abstract

The Monograph is oriented onto a scientific analysis and description of the Novel Ecosystem development in urban and industrial habitats from the point of view of modern economy requirements. It highlights interdisciplinary issues related to functioning of ecosystems, presenting an innovative approach to post-mining areas. It should be borne in mind that it is possible to develop goal-oriented actions and activities, using an individual site-specific approach enabling to counteract global changes. Due to the research results it can be stated that in post mining areas there many valuable habitats and ecosystems, having a significant natural potential.

The Monograph gives practical guidelines in the scope of developing innovative solutions for managing the natural environment in post-mining areas. The knowledge content includes the principles of ecosystem functioning, characteristics of abiotic and biotic parameters, dynamic processes such as temporal and spatial patterns in ecosystem changes, operational mechanisms of ecosystems enabling to compare terrestrial and aquatic ecosystems as well as documented possibilities of using the natural capital based on the research results on the species composition and diversity of communities.

The Monograph emphasizes the importance of knowledge dissemination in the scope of natural capital ideas, novel ecosystems, environmental health and ecosystem services as well as the need to develop a new approach to the post–mining land management practices.

Unfortunately, so far both national and international processes, that concern the functioning of the natural environment, have been elaborated mainly from the perspective of their usefullness to humans and not from the perspective of protecting the environment.

There are many examples, confirming the fact, that human activities are carried out against basic natural laws of the environment functioning.

The authors believe that a development of proposals for pro-environmental activities should be elaborated in accordanece with the latest knowledge on the natural environment functioning. It is crucial that meeting the challenges, resulting from the global climate changes, should be based on interdisciplinary knowledge of the environment biological and natural functioning.

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