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SUSTAINABLE MINED LANDS REHABILITATION USING LANDSCAPE BIOMIMICRY

Article reviews main theoretical and practical issues in the field of biomimicry at landscape level for mined lands rehabilitation. It also includes a successful practical case study of biodiversity development centers creation on open-cut mining lands.
***Keywords*: landscape biomimicry, mined lands, sustainable rehabilitation**

Problem Statement

The world consumption of natural resources increases with exponential growth of population [1]. The scarcest resources are minerals and fossil fuels [2]. Although the problem of mineral resources scarcity is not in the depletion (the amount of the chemical elements is constant in the environment) but rather in the crisis of the technological qualities to supply sufficient amount of the resources for the human needs [3, 4]. Today mining explores deposits with the lowest ever concentration of the mined elements and the technologies itself become more expensive [4, 5]. Thus, intense mining causes the destruction of large land areas. The rehabilitation techniques, on the other hand, have not been as actively and intensively developed.

The development of very expensive and resource intense rehabilitation technologies has been a very popular trend in mined lands rehabilitation. It is caused by the idea that the destructed lands should be returned to the environment and society in the natural condition (to the condition equal to that for premining state). This concept misled scientist and engineers towards the development of intensive and expensive technologies [6]. They often underestimate the value of self rehabilitation, succession plant community potential, and exceptional conditions created. Moreover, often newly self established ecosystems are destroyed to create "a natural system analogy" [7]. More than that there is nothing sustainable in such resource consuming technologies especially if they are not successful.

It is possible to copy techniques used by the nature for the mined lands rehabilitation. We claim that it is should be done at the landscape level evolving all the lower nature organization levels. Only complex rehabilitation approach with multiple levels of nature imitation, future use, and functions could result in sustainable mining lands rehabilitation technologies.

Literature Review

World population exponential growth, dominating urbanization [8], increased need in natural resources and doubled the world mining production for the last 20-30 years [9, 10]. Mining production is based on lands transformation and, therefore, caused exponential rates of mined lands destruction (figure 1-3). The data available from various resources (Alcoa Company, World Gold Council) confirms that current rate of mined lands rehabilitation is stable the level of 0,1 – 1% of the destructed area annually. Such data allows making an assumption, that with current rates of land rehabilitation we will need more than 100 years to restore all the mined lands (at this moment). And many more destructions are foreseen in the future.

The reasons of slow rehabilitation rates are in the lack of appropriate technologies development, low efficiency and high price of old technologies [11], and natural causes [12]. However, the technologies which include the use of native

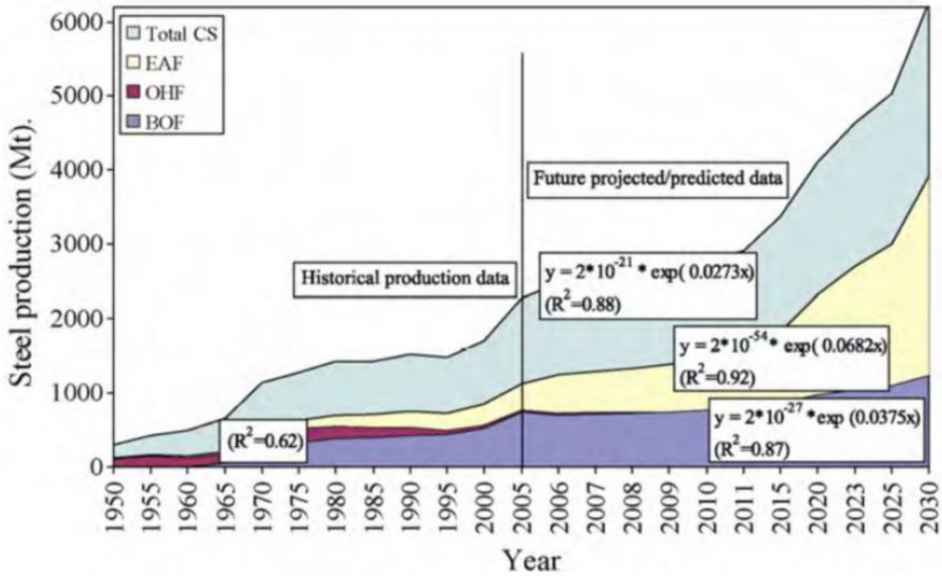

Figure 1 – World steel production trends and projections [9]

plants in the mining lands rehabilitation [12], natural succession changes [6, 13-15], self restoration in general [7] are well described in the literature and in some cases used in the field. Mining destructed landscape rehabilitation process consists of 10 sequential steps [16-17]:

1) Site characterization;
2) Planning and engineering;
3) Material management;
4) Topographic reconstruction;
5) Replacement of topsoil or soil substitute;
6) Surface manipulation;
7) Addition of soil amendments;
8) Revegetation;
9) Irrigation, if needed;
10) Site monitoring and maintenance.

Such standard approach require a lot of financial, time and labor resources and have a large environmental impact [18].The cases of rehabilitation failure supply additional doubts about the sustainability of the technologies [19].

The problem in mentioned concept is connected with the means of nature imitation. Rehabilitation techniques involve intense earth mass movements, layering, irrigation, topographic reconstruction etc. Natural processes work with fewer inputs and with much higher effects [20]. Such conclusions come from discipline known since 1960 and called bionics, but it became more intensively used and researched since the publication of the book by Janine Benyus in 1997. She is the one of those who tried to summary all the approaches of the nature imitation techniques in fairly simple but effective principles.

Biomimicry is the examination of nature, its models, systems, processes, and elements to emulate or take inspiration from in order to solve human problems [21]. It is the most successful in the fields of engineering, design and architecture. There are quite a few examples where biomimicry is used at the landscape level. There could be multiple reasons for that and we are not going to discuss them in this paper. And it is interesting that mined lands rehabilitation should be a bright example of nature imitation at multiple levels, but it is not. Bradshaw mentioned that it happened due to the technical issues dominance in the restoration projects [7]. Others claimed that anthropocentric attitude caused the development of agricultural restoration. Modern trend today is ecosystem restoration [11, 22] – we attempt create ecosystems on mined areas and use their ecosystems services for future generations. On our mind the most sustainable and most nature oriented way of sustainable restoration is mined lands conversion into conserved areas (reservations, parks, open areas). It has been done in many areas via cooperation of scientists and industrial engineers [23, 24].

In this paper we present a system approach towards nature imitation in mining destructed territories restoration. It includes the collocation of well known and original mined lands restoration methods in the complex nature imitation systems of landscape restoration.

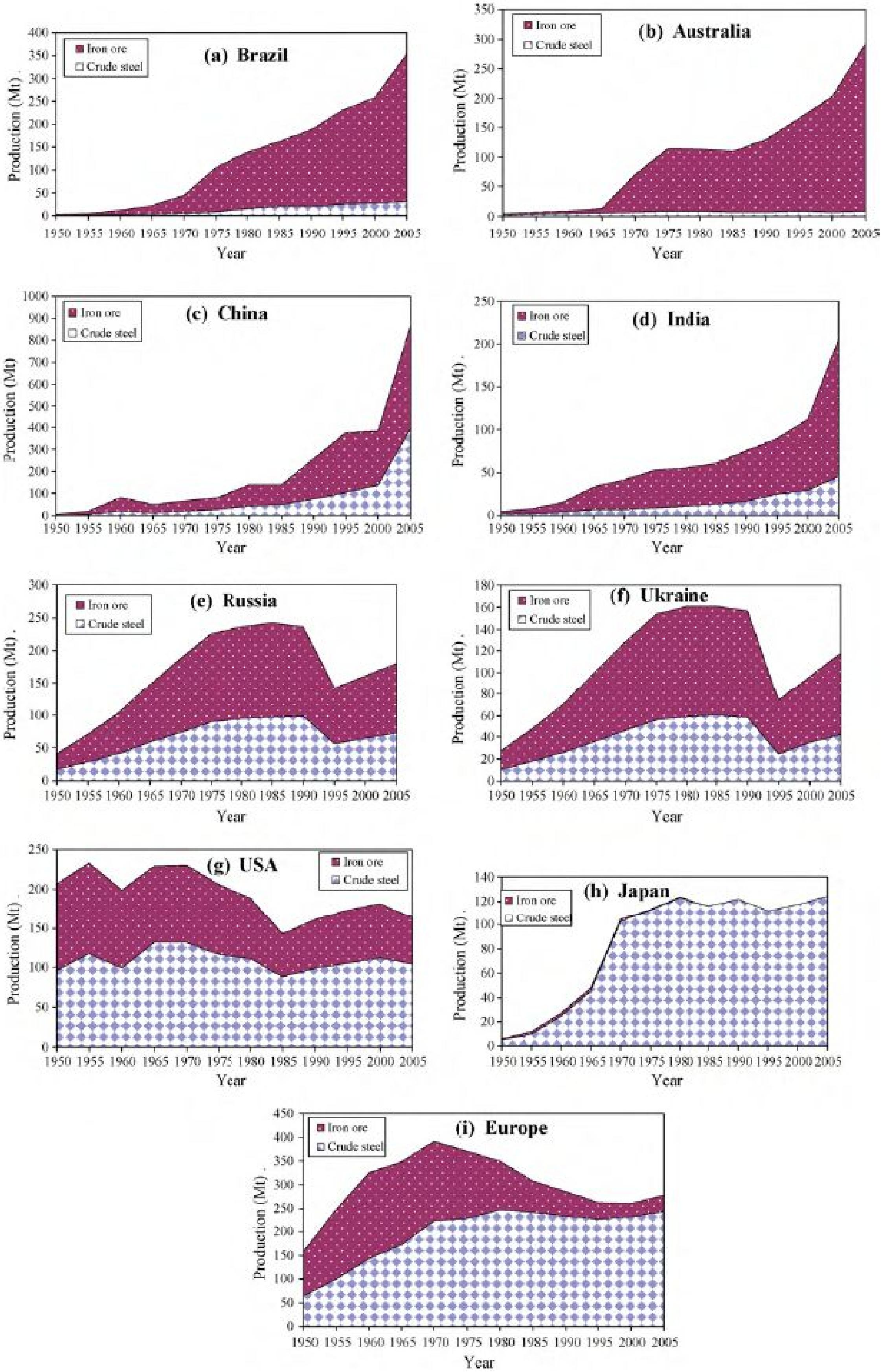

Figure 2 – Historical trends in production of iron ore and crude steel in the major producing countries of the world [9]

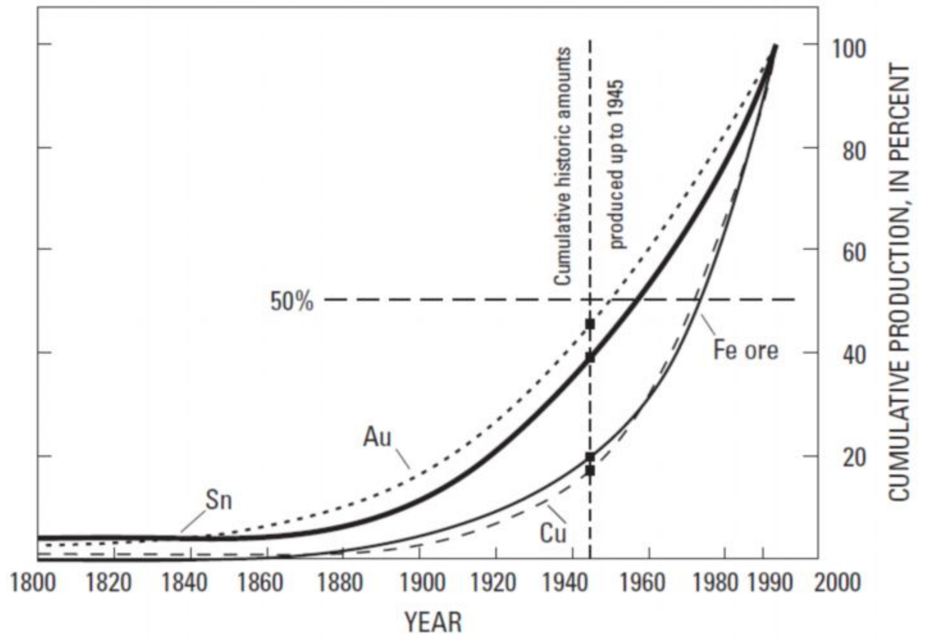

Figure 3 – Cumulative world production of iron (Fe) ore, gold (Au), copper (Cu), and tin (Sn) [10]

Sustainability in land reclamation

Relief construction. Mining lands rehabilitation is considered to be a pathway to sustainability of the area, as if its aim is to meet main goal of sustainability – provide land resources for future generations. But at the same time the needs of ecosystems and natural environment are often ignored. Mining industry excavate or pump mineral resources and fossil fuel, destruct a lot of lands, then use extra resources for restoration, which will be useful for human needs – such anthropogenic approach is often called sustainable in the industry and in the science literature [25-26].

On the other hand the sustainable mining and rehabilitation techniques should be connected with analysis of resources use, human health and ecosystem state. Recently there have been improvements in the development of mining sustainable sound methods and practices. Yu et al., Si et al., Vatalis and Kaliampakos have developed mining specific environmental impact assessment methodologies and techniques [27-30].

Members of the American Society of Mining and Reclamation developed an ecosystem reclamation approach (ERA), which is oriented mainly on geomorphic landscape design, which mimics stable mountain slopes as they present in nature. Such approach is claimed to be cost-effective, attractive and resistant to surface erosion and mass movements [31]. Their geomorphic design mimics natural landscapes the way they were in pre mining state. The main idea of such approach is to achieve functional and aesthetic nature-like characteristics by mimicking nature landscape drainage patterns and relief forms [32]. At the same time such approach does not include the change of mining field regulations and "blind" use of the geomorphic approach will result in construction of new native-like landforms and reclamation cost increase after the main excavation processes are over [33]. Further analysis of the existing techniques concludes that ERA includes specific techniques as natural channel design (stream reconstruction), region and site specific native soils and plants adaptation [31].

Native plants use. The definition of "native" plants and therefore "alien" or "invasive" plants is quite unclear in modern literature. D. Tallamy and R. Darke in their book represent an opinion that if the plant has been for a long time in the studied area "it could be considered as a native regardless of its evolutionary origin". In order to clarify the definition they used "coevolving" principle, which defines native plants as those which established connections with other elements of the ecosystem [35]. It is obvious then that newly installed invasive plants are not the part of historical ecosystem because they do not have established interactions with living organisms' communities. At the same time newly intruded plant species sometimes evolve into ecosystem interactions very fast. It happens in the cases when an invasive plant is a relative to native plant species and therefore surrounding community is "preadapted" to the interactions with such species [35]. Another example is when invasive plants are honey plants and therefore they attract bees and other insects and interact with them in short period of time [36, 37]. We tend to accept the definition of EPA which defines native plants or indigenous plants as those evolved over thousands of years in a particular region. It is allowed them to be adapted to the geography, hydrology, climate and other species in the region [38].

Despite the popularity the use of native plants in industrial lands rehabilitation is quite limited due to the unusual for regions local environmental conditions. Geographically separated areas, with different than local conditions, become "desert islands" for local ecosystems. One of the limitations for ecosystem developments on post-inductrial areas is the lack of the seed banks of appropriate plant species. Using seeding techniques of appropriate adapted plant species was the most successful introduction techniques, which has advantages of easy handling and ready availability, as well as ensuring a wide genetic base [13]. However, succession changes, which lead to the native ecosystem establishment, could be started with non-native plants. Such pro-native approach was proven to be successful on mining areas of Australia [12].

Mining rehabilitation was successful in Western Australia done by Alcoa on post bauxite mining areas. The company practitioners used a complex of techniques to make the technology successful: reconstruction of the soil root zone, special plant seeding technique and post-installation monitoring. Immediate soil replacement, seeding with mixture of 60 native species with increased germination via smoke together with fauna corridors and habitat construction insure the success of the technology [12].

In certain areas of Australia the rehabilitation was so successful that post-mining areas were included in the network of national parks and nature reserves. They are especially valuable owing to wetlands creation options. There are 91 sites reported, which perform nature preservation functions [12]. It was possible on the mineral sands mining areas with the use of rehabilitation principles set [12, 39-40]:

- pre-mining surveys of soils, vegetation, fauna and heritage;
- seed collection of key species from the local to mine lands to conserve genetic material with attention being paid to the seed quality and storage conditions;
- recovery of topsoil immediately prior to mining, incorporating biomass of shrubs and groundcover or ash from burning of trees;
- reconstruction of landform immediately following mining to re-establish topographic patterns, with particular emphasis on drainage;
- early replacement of topsoil to minimize its storage time;
- surface stabilization to enable establishment of native species, many of which have small seedlings and are slow to establish;
- application of moderate doses of mixed fertilizer to aid early vegetation establishment;
- direct seeding of native species as the most biologically and economically efficient means of regeneration (up to 100 species were included in the mix);
- enhancement planting of nursery seedlings for species that are difficult to propagate with field techniques (breaking of dormancy of recalcitrant species with smoke);
- monitoring of ecosystem development, with techniques ranging from visual inspection to computerized sampling.

Scientists from Commonwealth of Independent States have completed enormous amounts of research in coal mining lands rehabilitation [42-43]. Native plants use following the necessary detoxication of the substrates was proposed among other rehabilitation techniques. Australian practitioners moved towards establishment of self-sustaining native woodlands (Eucalyptus) in areas of sub-humid, subtropical climate. Their approach included alternative landforms design (ponds reshaping for runoff accumulation, moderate external slopes with sediment traps at the toes), slopes topsoil strips replacement and aerial seeding of a mix of grass, shrub and tree species [12].

Landscape level approach. In 1997 David Tongway with the group of scientists from CSIRO Division of Wildlife and Ecology created an Ecosystem Function Analysis for mined area as a response on the request of the Australian Centre for Minesite Rehabilitation Research
(now the Australian Centre for Mining Environmental Research). It was based on 20 years experience of rangelands studies, and data from

bauxite, mineral sands, coal, gold, uranium, nickel and iron ore mines with various climates.

Ecosystem Function Analysis (EFA) is consisted of 3 main modules for the evaluation of mined landscape [12, 44, 45]:

1) Landscape function analysis;
2) Vegetation dynamics;
3) Habitat complexity.

Landscape function analysis involves two steps: landscape stratification along transects oriented in the dominant direction of resource mobility and measuring zones in the landscape which either lose or accumulate mobile resources; soil surface condition characterization by assessment into various classes of 10 features at each of the landscape zone types along a transect. Vegetation dynamics module is assessed by using measures of species composition, species similarity to an analogue "natural" site, presence of "shade and shelter" species and target species development, important to the ecosystem self-sustainability. Habitat complexity index estimated for each rehabilitated and analogue site is based on five features, visual canopy cover, shrub cover, ground vegetation cover, the amount of litter, fallen logs and rocks, and free water availability. The summary of the scores for each feature gives the overall comparable habitat complexity score. The advantages of EFA are in the indices comparability of rehabilitate, mined and natural areas as for their landscape function, and in quick and simple conductivity [12].

Biomimicry and bioengineering. Dr. Eugene Odum wrote that "in nature there are a lot of answers about what we should be doing in society. Nature has been here longer than humans and has survived a lot of catastrophes" [46]. The main idea of biomimicry is the imitation of living organisms design, materials and processes in industrial technologies. Such approach should minimize toxicity, celebrate diversity, curb demand and make connections [20]. The main methods of biomimicry use are: seek simple solutions, value place, move resource impact toward zero, rethink waste, use renewable inputs and use non-hazardous materials [47]. There could be multiple applications of the design principles in mined lands rehabilitation.

Seeking simple solutions means use less technological approach, fewer materials, fewer elements for completion of the same function. It might be done through the "passive design" when passive natural systems are included [48-50]. It results in reduction of costs, wastes and resources use. For example, in mining areas rehabilitation, a more simple design would be placement of nutritious for plants and animals matters on the top places of the slopes for their natural distribution along the slopes and water flows versus applying layers of soil-like materials. It is a few times cheaper, simple to use and will result in matter distribution in the places which perform a bigger landscape and ecosystem function.

Valuing places is especially important for the rehabilitation of mined areas, taking into account their position in the cities and enormous land usage. In the mining field it is common today to search for the possibilities of steep slopes exploration in super deep quarries [51]. In rehabilitation it is also important to preserve surrounding areas from destruction via restoration of steeper slopes [23]. The value of the place might be estimated also in the destructed landscape as well. As it is mentioned above, mined areas could be used for native areas preservations, museums, or reserved for other uses.

Sustainability requires the resource impact of the humanity to be shifted towards zero. It is possible to do through the maximization of the resource efficiency and resource demand minimization [48-50]. It could be done through the use of life cycle analysis of the resources use in technologies [52]. It also implies the use of renewable resources in mining rehabilitation. For example, instead of using the topsoil, which is considered as non-renewable resource in Ukraine, should be used wastewater sediments, plants residues, wooden chips, straw etc. The need to avoid the hazardous materials is still present.

Rethinking waste is the most essential trait in the sustainability, which means that if all the waste could be sources for other processes – than we would create an analogue of natural system. Designers promote the use of "three R principle": reduce, reuse and recycle. Up-cycle is also a necessary option taking into account the amount of nowadays wastes [53]. In rehabilitation techniques the wastes of rock material could serve as a building material or as prolonged fertilizer. High waste banks might be suitable for wind generators and solar panels. Water harvesting from mined areas for industrial, residential and agricultural use could prevent leakages and supply increased demand in water. The need to extract multiple recourses from single mining action is also of a high priority.

Renewable inputs require the substitution of resources, which have a long period of regeneration. This way the needs in resources of modern generation will not be set as a higher priority than needs of future generations [54]. We have already written of the need to substitute the soil layers with more easily regenerated materials. The implementation of the principle focuses on the use of passive methods of rehabilitation versus active technical oil-based recultivation. Among passive methods there are geochemical (barriers, flows), bioengineering (various biological self covering materials), biodistribution and others. For example, soil bioengineering, which uses living vegetation and other materials, is successfully used to stabilize slopes, control erosion and enhance the functioning of ecosystems. Ecological (bio) engineering is often much cheaper and uses less resources than traditional engineering approaches [55-56].

Non-hazardous materials inputs rely on their safety for human, environmental and economic health [47, 57]. This obvious principle bans the use of synthetic covers for the rehabilitated areas, chemical pesticides and fertilizers. It also refers to the need of rock waste environmental control (radioactive, chemical and biological) and risk of various substrates application (waste sludge, plant residues, food production wastes).

Sustainable rehabilitation system construction – a case study. Human influence on natural ecosystems is diverse and dynamic. It involves extensive inputs of energy, labor and technologies, which in combination lead to the dynamic environmental destructions. Their rehabilitation requires additional energy, resources and labor. Natural ecosystems nevertheless are self-restored through some time via succession serial changes. Using this trait we propose mobile biodiversity centers creation to activate succession changes and biodiversity development within destructed environments.

The main idea of biodiversity distribution centers creation has been developed during natural and industrial ecosystems research done in 1996-2012. The biodiversity analysis confirms that biodiversity is linked to the development of the whole community and not just separate organisms' distribution. The statement is supported by D. Hooper, P. Vitousek, M. Loreau and others, who indicated biodiversity significance for ecosystems development and their functioning [58-60]. The creation of whole functioning climax ecosystem community is problematic to accomplish due to its common extensive sizes [61]. And even if it would be possible changing environment should destroy such ecosystem due to human activities within certain time frame. That's why we developed the idea of mobile communities able to move away from the influence within the certain time and place frame. However is possible to transfer the vital part of a terrestrial ecosystem – its core plant community. This way we may create high biodiversity ecosystems with mobile biodiversity development cores (BDC).

The proposed principle of mobile BDC creation was tested on mining destructed lands. Surface strip mining technology involves continuous moving of excavation front together with reclamation areas following it in a distance. There is only a narrow strip of land suitable for biodiversity development within the quarry, which would reach the final open pit. Therefore we set 4 experimental cores for biodiversity centers development within the confines of international competition "Quarry Life Award" in 2012. They are constructed with two interchangeable container types (permeable bags, plastic boxes with holes) and composed with rare 11 plants species in monoliths of soil with associated mezofauna and microbiota. The surrounding area was enriched with seeds of the steppe plants (according to the climate zone). The results showed most plants survival rate of 90-94 %. Even though some species died (Caragana scyhtica (Kom.) Pojark; Chamaecytisus graniticus (Rehman) Rothm.), others started distribution in surrounding areas (Stipa capillata L., Stipa lessingiana Trin. Et Rupr., Vinca herbacea Waldst. ex Kit.).

The implementation of the project allowed us to determine main mobile BDC chracteristics. Organisms' development in the BDC and successful distribution depend on the successful placement within litho-geochemical flows of quarry [62]. Mobile BDC should be assembled with interchangeable permeable containers arranged according to the desired use of hydro and gravitational litho-geochemical flows (figure 4). The successful development of plants in containers also depends on presence of 'plant-soil-microbiota' monoliths as a supporting environment. Mobile BDC should consist of perennial plants and other organisms appropriate for the specific climate (best taken locally) and substrate conditions. This way, mobile BDC could be installed in the substrate at any place within the quarry and start biodiversity development. After 2-3 years the BDC could be moved to another place to start a new biodiversity center (figure 4).

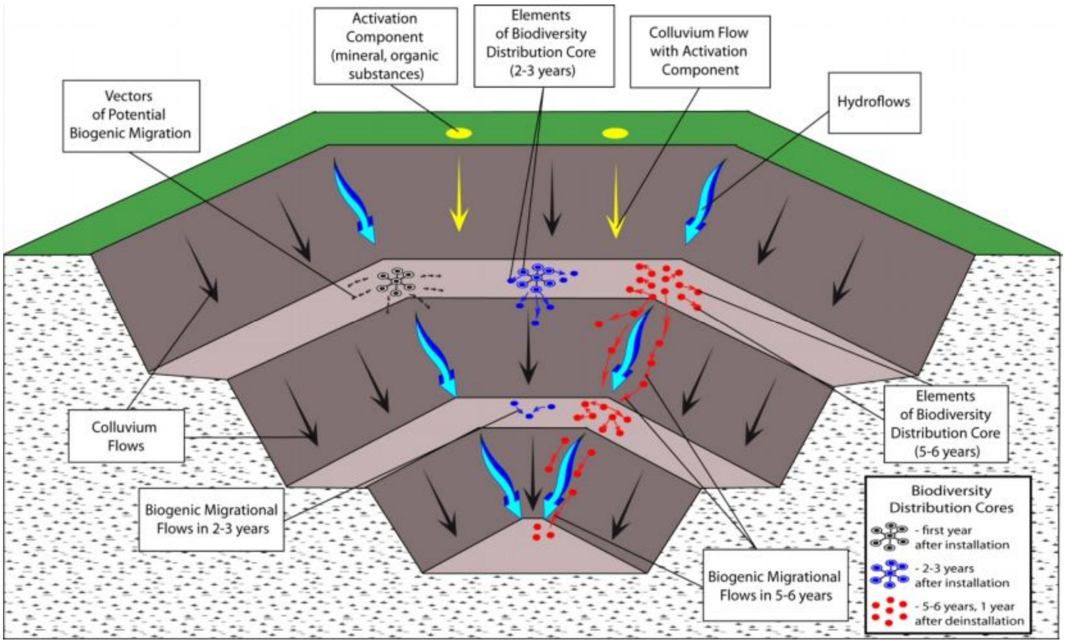

Figure 4 – BDC placement and spatial development dynamics within a quarry

Such BDC have both ecological and technological advantages. They enrich human destructed areas with native biodiversity. Technological benefits are in mobility, possible BDC elements reconstruction and multiple times use. Further development of BDC will result in industrial areas biodiversity development technology creation, which could be used on mining, agricultural and other human destructed lands.

Conclusions

1. Sustainable development of mined landscapes includes their sustainable rehabilitation. Current existing traditional technologies are expensive, environmentally harmful and dangerous for human health taking into consideration high amounts of resources use through the life cycle assessment.

2. Sustainable rehabilitation includes nature imitation approach with its application in soil bioengineering, relief construction and landscape function analysis implementation.

3. The rehabilitation of open cut mined lands could be realized at landscape level with multiple approaches implementation, for example through the biodiversity development centers construction.

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ВІДНОВЛЕННЯ ПОУШЕНИХ ГІРНИЧИМИ РОБОТАМИ ЗЕМЕЛЬ ДЛЯ СТАЛОГО ФУНКЦІОНУВАННЯ З ВИКОРИСТАННЯМ ЛАНДШАФТНОЇ БІОМІМІКРІЇ

У статті наведені основні теоретичні та практичні наробки з напрямку біомімікрії на ландшафтному рівні при відновлені порушених гірничими роботами земель. Наведено успішний практичний приклад створення центрів відновлення біорізноманіття на порушених землях за відкритої розробки корисних копалин.

***Ключові слова*: ландшафтна біомімікрія, землі порушені гірничими роботами, відновлення на засадах сталого розвитку.**

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ВОССТАНОВЛЕНИЕ НАРУШЕННЫХ ГОРНЫМИ РАБОТАМИ ЗЕМЕЛЬ ДЛЯ УСТОЙЧИВОГО ФУНКЦИОНИРОВАНИЯ С ИСПОЛЬЗОВАНИЕМ ЛАНДШАФТНОЙ БИОМИМИКРИИ

В статье приведены основные теоретические и практические наработки в направлении биомимикрии на ландшафтном уровне при восстановлении нарушенных горными работами земель. Приведен успешный практический пример создания центров восстановления биоразнообразия на нарушенных землях при открытой разработке полезных ископаемых.

***Ключевые слова*: ландшафтная биомимикрия, земли нарушенные горными работами, восстановление на принципах устойчивого развития.**