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The Significance Role of Plants: As Ecological Engineers in the Regeneration of Destroyed Sandy Ecosystems by Human Impacts

Abstract

Anthropogenic sandy areas are exceptionally extreme habitats for plant colonization because of unstable substratum and a lack of soil cover. The main aim of this work is to show the role of selected plant species considered as ecosystem engineers in the reconstruction process of destroyed ecological systems after intensive mining production. This problem has been discussed based on cryptogamous plants (algal crust, *Polytrichum piliferum*), herbaceous plants (*Elymus arenarius*, *Hieracium pilosella*) and bush ones (*Salix acutifolia*), distributed on the sand of the eastern part of the Silesian Upland. Ecosystem engineers play a significant role in the process of formation of ecosystems, as well as in the initial stages of their development as their further activity. Use of ecosystem engineers could also provide more rapid reconstruction of destroyed ecological systems.

Introduction

Anthropogenic sandy areas are exceptionally extreme habitats for plant colonization because of unstable substratum and a lack of soil surface. However, some species of plants with specific morphological and physiological characteristics do appear here. Mostly these are representatives of species of cryptogamous plants (algae, mosses) and species of vascular plants with a type R strategy (Rahmonov, Czylok, Simanauskiene, 2006; Rahmonov, Czylok, Wach, 2006). Their modest requirements of trophic elements allow them to initiate the colonization on such poor sandy areas and further successive fixation, and then, because of that,

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new species with higher habitat requirements have possibilities to appear here. First of all, those pioneer species just facilitate the colonization for new species by making accessible general food resources. Such types of species should be considered as engineers of ecosystems.

Thus, ecosystem engineers are any organisms which indirectly or directly change the accessibility of food resources for other species by changing some physical conditions of biotic or abiotic materials. Following in this way they first modify and create micro-habitats which later compose the macro-habitat. C.G. Jones et al. (1994) identified two different types of ecosystem engineers.

Allogenic engineers which modify the environment by mechanically changing materials from one form to another by the transformation of living or dead materials from one physical condition into other, for example, by mechanic way.

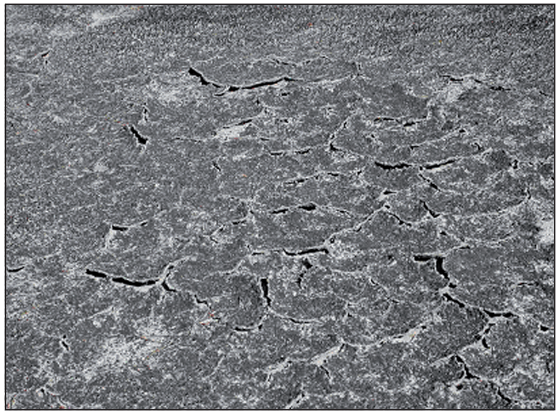
Autogenic engineers which modify the environment by modifying themselves, i.e. changing their own physical structure, for example, their living or dead tissues. Most of the species studied for the present article belong to the autogenic engineers.

The main aim of this article is to show the role of selected plant species considered as ecosystem engineers in the reconstruction process of destroyed ecological systems after intensive mining production. This problem has been discussed based on cryptogamous plants (algal crust, *Polytrichum piliferum*), herbal plants (*Elymus arenarius*, *Hieracium pilosella*) and vascular ones (*Salix acutifolia*), distributed on the sand of the eastern part of the Silesian Upland.

Cryptogamous plants

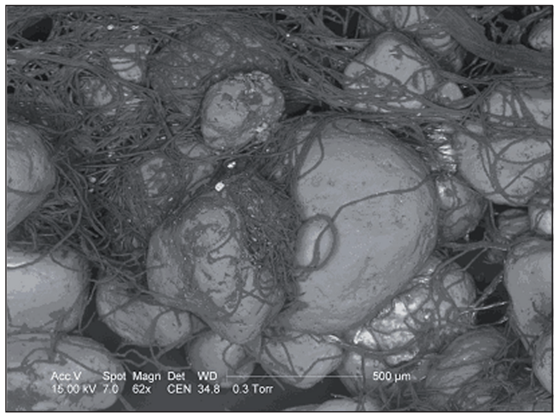
Algal crust

Crust with a predominance of overground soil algae creates on deflationary pavements or on the surfaces with high participation of dust-muddy fraction accompanying sands (Phot. 1). In the case of the latter, it occurs due to high humidity of sand, where algal spores easily find favourable conditions for development. As time passes, they occupy more and larger surfaces and in that way step by step stop aeolian processes (Rahmonov, Piątek, 2007), but the complete stopping initiated by creating of ecological system. The main role of ecosystem engineers consists of the modification of humidity relations within sands, sand stabilization (Phot. 2), which facilitates vascular plant sprouting and preserves remains of dead plants which are the main food item of many living organisms.



Phot. 1. Morphological type of crust — algal crust (phot. by O. Rahmonov)

Fot. 1. Morfologiczny typ skorupy — skorupa glonowa (fot. O. Rahmonov)



Phot. 2. Sand stabilization by filamentous algae (phot. by O. Rahmonov)

Fot. 2. Piaski ustabilizowane przez nitkowate glony (fot. O. Rahmonov)

Polytrichum piliferum

Participation of cryptogamous plants showing a highly interesting ecology in the process of the succession on destroyed anthropogenic areas is significant. From that side, the emphasis should be on a representative of mosses, *Polytrichum piliferum*, which is well adapted to sandy habitats (Phot. 3). This species occupies surfaces which have already been completely colonized by algae and bunkers in sand dunes, where the movement of sand is comparatively slow, but the substratum is characterized by high humidity. Some authors consider this event as one of the most important factors, conditioning the development of this species within such kind of ecosystems. It is concluded from the observation that in the case of covering by sand, *Polytrichum piliferum* pushes through its beds and grows up like inflexible stems without leaves. Just after stems appear under the ground of the area the leaves start developing (Kobendzina, 1969). The species mentioned forms thick beds, which fix the substratum very well. Because the mats of *Polytrichum piliferum* keep humidity well they are usually colonized by pine seedlings, sandy pussy-willow and rare birch. With the laps of arborescent species developing the moss is getting out step by step due to excessive shading of the area and forming the earliest stages of the appearance of a forest (Rahmonov, 2007).

Phot. 3. Stabilization of sand by the patches of *Polytrichum piliferum* (phot. by O. Rahmonov)

Fot. 3. Unieruchamianie piasku przez płaty *Polytrichum piliferum* (fot. O. Rahmonov)

Flowering plants

Elymus arenarius

This species is characterized by xenomorphic morphology and has rough leaves with blue-waxen coating. In Poland this species appears only in the wild on the sands of the Baltic coast (Podbielkowski, Podbielkowska, 1992) from where it was introduced to the Bledowsk desert area (Krutikow, 1961).

Dynamics of sand fields play an essential role in the development of *Elymus arenarius*. Freshly appearing sandy layers make the reconstruction of broad stem sprouts permanent, and as a consequence overground parts of the plant develop (Alekhin, 1951; Kobendza, 1958), in horizontal as well as vertical directions. Successive development of underground organs of plants well fixes the substratum and limits aeolian processes and begins the process of reconstruction of destroyed ecological systems.

Elymus arenarius has richly bifurcating strong sprouts and very long roots spreading to different directions composing a special web which fixes the flying sand well. At the same time of the stabilization process of the surface the general mass of storage of organic material in the soil increases. That situation will cause the appearance of favourable environmental conditions for other species, which earlier could not settle on such grounds because of special environmental requirements. From the other hand such consolidation of flying sands caused the disappearance of *Elymus arenarius*. This seemingly paradoxical situation is directly connected with the ecology of characterized species (Bond, 1952). Expanding patches of *Elymus arenarius* assemblage consolidate the sand, and then the sand is getting to be more packed. As a consequence, the relationships between soil and surface become worse, plants are getting weaker and die out. This species develops well on airy sands.

Hieracium pilosella

Hieracium pilosella is common in the study area and has great possibilities for adaptation to extreme environmental conditions, prefering dry habitats and avoiding even a minimally wet substratum. This species is characterized by a less-developed overground part and a well-expanded underground part. Leaves and stems of this species are covered by bushy nap of bristly hairs for protection against excessive evaporation. Sprouts covered by sand produce newcomer roots. In this way Mouse-ear Hawkweed composes broad root systems, which stabilise moving sand (Rahmonow, 1999). The underground part of this plant looks like thick felt of roots. After 16 test pits under the bunches of *Hieracium pilosella* appeared that it does not have patches, but an extremely compact root system near 10—15 cm depth and sprouts of up to 20 cm in length. Such kind of root system allows acquisition of a lot of water during a short time after strong rain. This species propagates itself by vegetation forming circular shape clones with oldest specimens in its central part, but younger and younger towards its peripheral zones. The absence of other species inside the clone of *Hieracium pilosella* developing on poor and acid soils should be explained by the lack of microorganisms which could detoxicate and delete dead remains (Rabotnov, 1985).

Some species of trees and bushes react on aeolian processes like herbal plants, because in comparison to the latter more sand accumulates around them due to their sizes (height, degree of growth). That is why their role in the process of composing and fixing dunes is significant and easily seen. Inside appearing sandy hillocks, trees and bushes are blowing up to different heights. During gradual powdering by flying sands these plants produce newcomer roots from brunches and trunks.

Salix acutifolia

This is a bush with strong features for fixing flying sands. Sprouts of this pussy-willow, and especially young branches, are covered by white wax coating, which plays a significant role in its water economy, protecting at the same time against excessive heating of sprouts. This species was, and still is, commonly used to fix losses sands (Budaeva, Budaev, 1990; Szczypek, Wika, Wach, 1994; Rahmonow, 1999; Rahmonov, 2007).

It is concluded from field observations that the studied plant very well propagates itself by vegetation. Sometimes the length of the roots between the mother plant and its sprout reaches almost 8 metres. Moreover, it produces newcomer roots on the trunks covered by sand.

Phot. 4. Willow development on surface of looses sand and dry ground (phot. by O. Rahmonov)

Fot. 4. Rozwój wierzby na powierzchni luźnego i suchego piasku (fot. O. Rahmonov)

Salix acutifolia grows comparatively quickly and has strong promoting. Fast growing of sprouds contributes to appearance in short-time barriers for flying sands. It should be stressed that this plant takes part not only in the stabilization process of the sandy surface but also in the process of enriching that sand by organic substances (Rahmonov, Malik, Orczewska, 2004). As a deciduous and fast-growing species produces a lot of organic substances, which is in its way are a very important stimulating element for the appearance of humus. It has also significant meaning in economy, because local people made baskets from thin and light branches of that plant. At the place of cut branches newcomers appear very quickly. Thus, the biomass is comparatively fast and grows together with the percentage of shadow cast on the sandy surface. *Salix acutifolia* should be considered here as the keystone species, which plays a significant role for the determination of the assemblage structure (Rahmonov, Kręciała, 2004).

Content of nutrient elements in plant litter of *Salix acutifolia*

In litter of European Violet Willow (*Salix acutifolia*) the content of selected macro- and microelements, which are necessary to plant development, was investigated (Table 1). Content of organic carbon in all samples has the similar size and it is shaped in the interval from 48% to about 53%. But significant content of nitrogen occurs in leaf litter, and in the remaining organs it reaches smaller size (Table 1). Among organs investigated in willow the high cumulating capacity is observed in leaves. In leaves, within the most important nutrients for the plants, investigated elements are arranged in respect of content as follows K > P > Na > Ca > Zn > Mg > Fe. In respect of microelements this order is below-presented: Al > Ba > Mn > Cd > Co > Sr > Pb > Cu > Li > Ni. In a case of iron, aluminium and lead the author states that the larger content of them occur in bark and young branches. It is undoubtedly cumulating of elements in plants. Trace elements are mostly cumulated in bark and branches (Fig. 1).

Leaf litter has weakly acid reaction (pH 5.41 in water and 5.17 in KCl), whereas bark and young branches reveal very acid reaction. Influence of reaction is of deciding importance for microorganism colonisation at initial stage of succession.

Salix acutifolia litter is characterised by the richness in nutrient elements (Table 1). Quick decomposition of willow leaves is advantageous habitat conditions for the development of microorganisms. Litter of willow and other broad-leaved species is rich in elements of alkaline character and nitrogen (Rodin, Bazelević, 1965; Dziadowiec, 1990). It contains small amount of tannin substances, waxes and tars, on contrary to pine needles. For that reason willow litter is mainly decomposed by bacterial flora. Every year production of leaves and their decomposition is the most important factor stimulating the formation of biocenoses, including the soil. Soil originating under the canopy of different trees has heterogeneous and mosaic character (Jankowski, Bednarek, 2000).

In the majority the areas after sand exploitation in eastern part of Silesian Upland (southern Poland) undergo the processes of land reclamation. They most often consist in introduction of trees not in conformity with their habitat. There are most often alien species for the Polish flora (among others *Padus serotina*, *Pinus nigra*, *Quercus rubra* and others). The consequence of land reclamation is most often the formation of unispecies and even-aged plantation. In such monoculture there is a lack of vascular plants and it is characterised by poor floristic composition. Landscape, which was created in result of land reclamation, is different from its natural equivalent. In such situations the sequence of plant-soil succession is restrained. One should emphasise that just natural succession, not human being, is responsible for the formation of ecosystems. In areas, where land reclamation was

TABLE 1

TABELA 1

Chemical composition and foliar nutrients of plants litter in European Violet Willow (*Salix acutifolia*)

Skład chemiczny oraz składniki pokarmowe opadu wierzby kaspijskiej *Salix acutifolia*

Samples	Corg	Nt	P	Ba	Mn	Na	Co	Al	Zn	Cd	Pb	Ni	Cu	Sr	Li	pH	
	[mg/kg]															H_zO	KCl
Leaf litter	52.66	1.710	2260	42.20	33.22	1700	18.24	43.36	1240	20	10	1.40	9.40	18.34	4.86	5.41	5.17
Bark	48.70	1.350	800	17.16	10.48	390	18.82	309.70	160	4	130	1.30	11.26	4.40	4.60	3.48	2.81
Branches	49.35	0.630	180	24.30	6.60	530	17.34	74.68	100	n.o	120	3.78	4.86	2.88	4.70	3.53	2.89

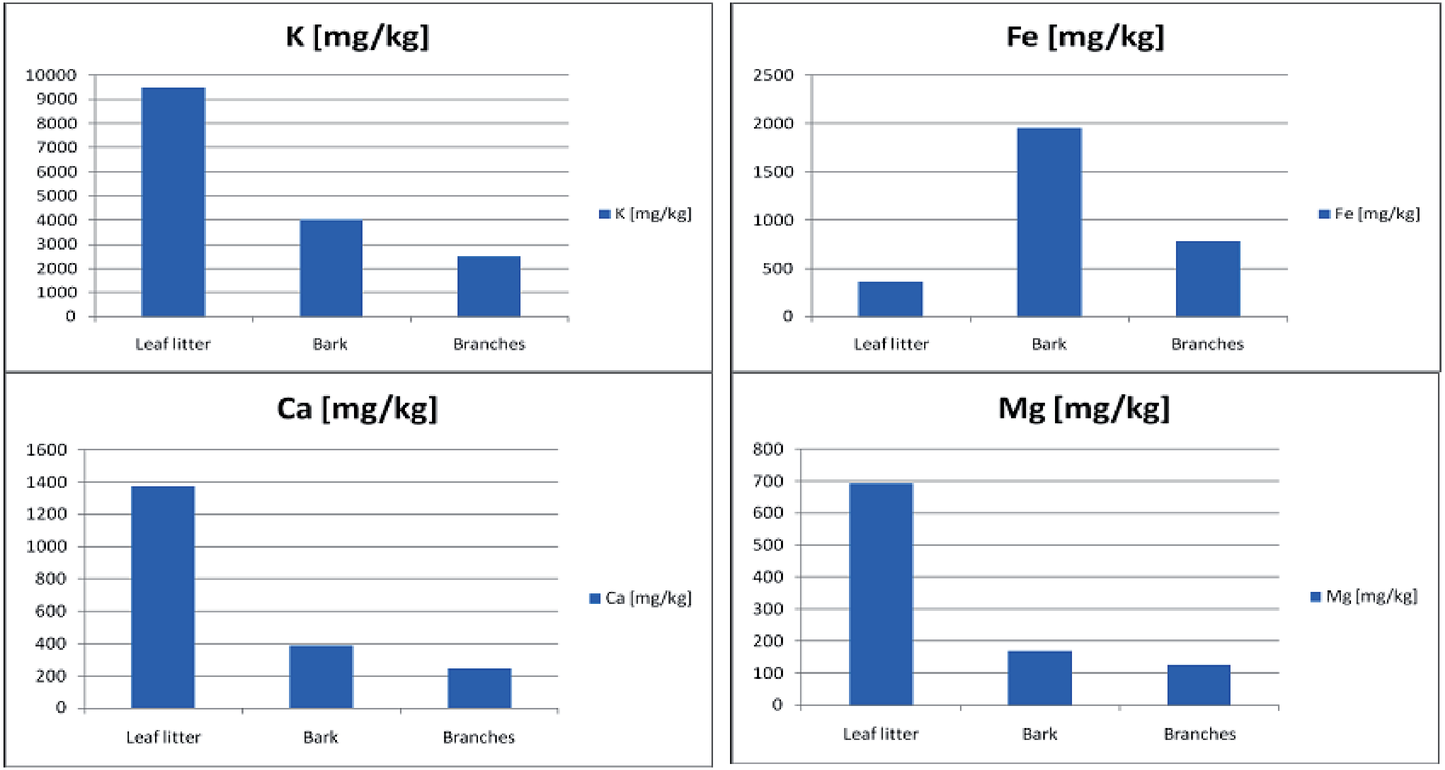


Fig. 1. Chemical composition of plant litter of *Salix acutifolia*

Rys. 1. Skład chemiczny opadu wierzby ostrolistnej *Salix acutifolia* not carried out, *Salix acutifolia* is responsible for the formation of biocenoses and just it in sandy areas creates biocenoses similar to natural ones (Rahmonov, Kręciała, 2004; Rahmonov, 2007; Rahmonov, Malik, Orczewska, 2004).

Ecological role of ecosystem engineers in sandy environments

The flora of sandy areas uses for development only water from atmospheric precipitation. However, precipitation water cannot always be used by plants in sufficient amounts, because of such type of substratum which is advantageous to rapid infiltration.

Decisive in settlement on sandy areas are processes of vegetative and generative reproduction. Following observations it is concluded that the vegetative reproduction dominates over the generative on a sandy area. For example, herbal species such as *Corynephorus canescens*, *Elymus arenarius*, *Hieracium pilosella* as well as tree-bushes *Salix acutifolia*, *S. arenaria*, and *Populus tremula* propogate themselves by vegetation on sandy areas (Rahmonov, 2001).

Dead plant remains — inside the soil or on its surface — enrich the substratum by organic substances. One of the most important forms of habitat composition by plants is the accumulation of dead remains and fallen leaves inside the soil and on its surface, for supporting possibilities for saprophyte elements of a biocenosis getting main trophic elements. Then the activity of saprophytes has an impact on edaphic conditions of plant growth, for example, humidity relationships, content of mineral trophic elements, ventilation of the soil and its reaction. Ecosystem engineers have an influence on the changing of micro-environment of the soil, changing of surface structure, on the drainage and transfer of heat and gases. Their behaviour is like a physical barrier for the seeds and young plants. Ecosystem engineers also have a strong influence upon the taxonomical structure and composition of floral assemblages.

It is also characteristic of ecosystem engineers to change the availability (quality, quantity, decay) of resources used by other taxa, excluding biomass coming directly from the population of allogenic engineers. Engineering is not only the direct delivery of resources sch as fruits, leaves or something else. The simplest example is forest growth. Trees and bushes are direct springs of nourishment and living space for many organisms, but in addition to it their branches, leaves or living tissue participate in the engineering process. However, forest growth produces physical structures, which change the habitat and decay, and also the abundance of other resources (Rahmonov, 2007). Trees change hydrology, circulation of trophic elements and stability of the soil, as well as humidity, temperature, light, speed of wind and level. Certainly, but this moment is rarely mentioned in the literature, numerous inhabitants of such appeared habitats depend of physical conditions changing by autogenic engineers and from food resources which are coming but not specially transported here; thus without ecological engineers most part of other organism could be disappeared. These changes compose the autogenic engineering (Jones, Lawton, Shachak, 1994). Plants are also allogenic engineers. In Puerto Rico, the trees of *Dacryodes excelsa* are able to withstand even hurricanes because their long roots link and stable the substratum of the upper layers of rocks; that is why these species are dominant in mountain tropical forests where hurricanes occur regularly.

Conclusions

Ecosystem engineers play a significant role in the process of formation of ecosystems, as well as in the initial stages of their development as their further activity. Activity of ecosystem engineers usually has a positive influence on the biodiversity and the heterogeneity of environments. However, sometimes that influence could be also negative and destroy the function and biocoenosis structure. Use of ecosystem engineers could also provide more rapid reconstruction of destroyed ecological systems.

Investigations proved the possibility to apply *Salix acutifolia* as ecosystem engineers in revitalising and reclamation activities in areas of extreme edaphic conditions. The role of *Salix acutifolia* in soil-forming process and creating plant communities is connected with large amount of nutrients, originating from litter decomposition (leaf, bark, fine twigs) and enriching sandy substratum. This property of in case of *Salix acutifolia* causes that it can develop in sandy areas. It points at the possibility to apply this species as ecosystem engineers in land reclamation activities in anthropogenically transformed areas as the alternative for presently applied cost-consuming methods, based on introduction of alien species to the landscape. Investigations carried out simultaneously proved that the most advantageous way to restore natural values to transformed areas is giving up land reclamation in favour of succession of natural vegetation (Rahmonov, 2007).

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РОЛЬ РАСТИТЕЛЬНОСТИ КАК ЭКОЛОГИЧЕСКИХ ИНЖЕНЕРОВ В РЕГЕНЕРАЦИИ ПРЕОБРАЗОВАННЫХ ЧЕЛОВЕКОМ ПЕСЧАНЫХ ЭКОСИСТЕМ

Резюме

Антропогенно обусловленные песчаные территории являются исключительным экстремальным биотопом для развития растительности, из-за подвижного субстрата и отсутствия почвенного покрова. Главная цель настоящей статьи — представление роли избранных видов растений как экологических инженеров в регенерации преобразованных экологических систем на территориях деградированных открытой разработкой минерального сырья. Данная проблема обсуждается на основании споровых (водоросли, почвенная корка, *Polytrichum piliferum*), травянистых видов (*Elymus arenarius*, *Hieracium pilosella*), а также кустарника *Salix acutifolia*, имеющихся на песчаных биотопах восточной части Силезской возвышенности. Данные виды как экологические инженеры играют существенную роль в процессе формирования экосистем как на начальной их стадии, так и течение последующего функционирования. Наблюдения показывают, что использование экологических инженеров может привести к быстрому возобновлению экологических систем.

Oimahmad Rahmonov

ROLA ROŚLINNOŚCI JAKO INŻYNIERÓW SYSTEMOWYCH W REGENERACJI ODKSZTAŁCONYCH PRZEZ CZŁOWIEKA EKOSYSTEMÓW PIASZCZYSTYCH

Streszczenie

Z uwagi na ruchome podłoże oraz brak pokrywy glebowej antropogenicznie uwarunkowane obszary piaszczyste stanowią wyjątkowe ekstremalne siedlisko rozwoju roślinności. Głównym celem niniejszego artykułu jest przedstawienie roli wybranych gatunków roślin jako inżynierów ekosystemowych w procesach regeneracyjnych odkształconych systemów ekologicznych na obszarach zniszczonych przez górnictwo odkrywkowe. Problem ten omówiono na podstawie gatunków zarodnikowych (glony, skorupa glebowa, *Polytrichum piliferum*), zielnych (*Elymus arenarius*, *Hieracium pilosella*) oraz krzewu *Salix acutifolia*, występujących na siedliskach piaszczystych wschodniej części Wyżyny Śląskiej. Gatunki te jako inżynierowie ekosystemowi odgrywają istotną rolę w procesie formowania się ekosystemów nie tylko w jego początkowym stadium. Obserwacje dowodzą, że mogą doprowadzić do szybkiego odnowienia układów ekologicznych.