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Plants on duty – phytotechnologies and phytoremediation at a glance

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ABSTRACT

Phytotechnologies are plant based technologies of remediation and containment of pollutions. Many advantages of phytotechnologies such as control of water and biogeochemical cycles, positive impact on soil characteristics and lowering the risk of erosion, contaminant immobilization and destruction, habitat restoration, low costs of implementation, and high public acceptance, decide that in more and more cases it is a preferred and recommended method of rehabilitation. Vegetation selected to the particular site conditions and having required characteristics will shape other biotic communities. It is thus immensely important to gather detailed knowledge about all the elements and processes occurring at the place of interest, before employing adequate phytotechnology application.

KEY WORDS: ecotechnologies, rehabilitation, remediation, watershed management, pollution control

Introduction

As the degradation of ecosystems progress scientists and engineers look for more advanced and sophisticated techniques for protection, remediation, and restoration. These techniques are often very expensive and the results are not as pronounced as one would like them to be. From this disappointment a new approach emerged, the one that turns away from single specialized solutions to multi-disciplinary and integrated methods. Most environmental problems derive from lack of understanding of ecosystem functioning. Solutions based on this insufficient knowledge are short-sighted and often harmful. Holistic approach, broad understanding of all the elements and processes operating in nature, sociological aspects and economical constrains, integrates numerous problems, but shows broad perspective for successful solutions (IETC 2003).

Plants, as primary producers, are the base of terrestrial and many aquatic ecosystems. Their abundance and species composition play vital role in energy flow (mainly through photosynthesis) (Danilov-Danil'yan *et al.* 2009), as well as elements and water cycles. However, with the human development and urban spread, especially visible in the previous

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century, plant cover noticeably declined. The results of this reduction affected humans well-being, as provided ecosystem services also decreased (Assessment 2005). Thus it seems crucial to reestablish vegetation cover in places where it was severely damaged or deliberately removed to satisfy short-sighted needs. In the last century the amount of inorganic and organic contaminants (especially synthetic substances) rose dramatically degrading many ecosystems. In that case creation of artificial buffering zones and constructed wetlands may counterbalance negative effects of pollution *et al.* 2010).

Ecotechnologies rely on immanent ability of ecosystems to flexibly respond to disturbances, even man-made (IETC 2003). In that context vegetation can be used to strengthen carrying capacity, through water filtration, control of biochemical cycles, as well as habitat creation and biodiversity increase. Plants also have an aesthetic value for humans, and thus are welcome by society as a solution to environmental problems.

What are phytotechnologies?

As its name suggests phytotechnologies are plant based technologies. The UNEP states that by engaging ecological engineering principles phytotechnologies are ecotechnologies, using an integrative approach. They are used to solve environmental problems such as degradation and rehabilitation of already degraded ecosystems, as well as control of environmental processes in the watershed (IETC 2003). They are used to protect and remediate soil, sediments, surface water and groundwater. Of course different aims and objectives require appropriate phytotechnology application but the essential mechanisms remain the same. Those mechanisms which facilitate nutrient and pollutant degradation, removal and sequestrations originate from natural physiological processes occurring in plants or in rhizosphere. Because those mechanisms are natural and because plants are commonly available the costs of using phytotechnologies are relatively low when compared to traditional solutions (Technology and Team 2009, Vaněk *et al.* 2010).

Advantages of phytotechnologies

Being at the bottom of a trophic chain vegetation plays vital role in energy flow and organic matter distribution. It controls water cycle and biogeochemical cycles, not only locally but regionally and globall as well (Zalewski 2002). Advantages of phytotechnologies are directly linked to high biomass of vegetation. The benefits of maintaining high plant biomass include:

1. Water retention and infiltration control, as plants are capable of intercepting and evaporating rainwater – limiting the infiltration, up-taking and transpiring water from the different soil levels (as well as groundwater), and minimizing runoff. Water control is also important from the point of view of catastrophic events. Vegetation limits the possibility of serious floods and droughts (van Beukering *et al*. 2003, Whetton *et al.* 1993)
2. Stabilization of temperature and heat budget. By releasing water through evapotranspiration process plants cool themselves and the surroundings. Vast

amount of trees or other plants can visibly alter the water vapor concentration which causes cloud cover and precipitation (Budyko 1986). Even agricultural plants show positive impact reducing range of extreme temperatures (Ryszkowski 1998).

3. Change in soil characteristics. Via roots plants release phytochemicals such as sugars, amino acids, enzymes, proteins, etc. Those substances, called rhizodeposits, are a carbon source for soil microbes, thus making their proliferation up to four times greater than in sites without vegetation (Philippot *et al.* 2013; Technology and Team 2009). Some of the secondary metabolites are involved in establishing symbiotic relationships or in deterring pathogens and pests. Soil pH (in the vicinity of the plants) can change up to two units depending on the ions uptake. Soil oxygen pressure is affected by water uptake as well as root respiration – oxygen release (Philippot *et al.* 2013). With water plants also uptake dissolved inorganic nutrients thus changing their concentration is soil. This process is sometimes enhanced by microbial activity.

4. Minimizing erosion rates. As roots penetrate the soil they stabilize it and make it less vulnerable to water- and wind-induced erosion (Kirkby 1995). Soil migration can be a problem also with regard to pollution spread. If the soil is contaminated leaching will lead to pollution dispersal (nonpoint source) (Technology and Team 2009).

5. Mitigating transfer of nutrients and pollutants from terrestrial to aquatic ecosystems. Aquatic ecosystems like oceans and seas, lakes, ponds and rivers are sinks for carbon, nitrogen and many contaminants. Vegetation has the capacity of reducing the amount of biogenic compounds and harmful substances flowing to those ecosystems though water control and nutrient uptake.

6. By sequestering carbon and nitrogen in vegetation it is possible to balance global climate patterns (Zalewski & Wagner-Lotkowska 2004). The above-mentioned stabilization of temperature is yet another example of plants positive influence on climate.

7. Providing habitat and enhancing biodiversity. In most of phytotechnology projects habitat restoration is a by-product but it is not less important. Creation of wetlands, for example, mainly purifies the water but also provides habitat for fish and other animals (Grayson *et al.* 1999). Furthermore increased diversity of animals can diminish the impact of pests on vegetation, both wild and agricultural (Zalewski & Wagner-Lotkowska 2004).

8. New source of bioenergy. Some plants can be used as a source of energy, because they grow fast and produce a lot of biomass. One of the best known examples are poplars and willows. Kept in a short rotation coppice they produce enough biomass to make their plantations profitable (Marmiroli *et al.* 2006). Mixed coppice systems, consisting of trees and arable crops or grasses, offer not only a stable source of biofuel but also higher biodiversity and habitat stability than monocultures (Costanzo & Bàrberi 2014). From agricultural waste biogas can be produced and also used as a source of energy (Ehret *et al.* 2015).

9. Increased value of land. The more services are provided by certain land patch the higher is its value. All above-mentioned advantages result in larger range of provided ecosystem services thus creating attractive and desirable areas (Assessment 2005). Land degradation results in lower productivity, which in turn lowers land value and market price. Therefore protection and

reestablishment of vegetation cover will increase it (Sinden & King 1996).
10. Possibility of restoration and rehabilitation of degraded site. Using plants as an instrument of remediation is widely applied. Phytotechnologies considered as eco-friendly technology, offer in situ treatment of contaminated media as well as many positive side-effects including, but not limited to, all the benefits of maintaining high plant biomass.
11. A sense of well-being. In light of ecosystem services vegetation is a key element responsible for human well-being. All the provisioning and supporting services are directly linked to the state of plant cover. Most of the regulating services and some of the cultural services also depend on florae abundance, composition, and diversity (Assessment 2005).
Using phytotechnologies is also beneficial in terms of cost-effectiveness. Compared to traditional methods of remediation, which often require energy-consuming equipment and advanced reagents, phytoremediation offers solar driven and relatively simple techniques. The costs of using phytotechnologies is around 10–20% of the mechanical treatment costs (Vaněk *et al.* 2010). There is also high public acceptance for plant based technologies as they provide wide range of environmental benefits and the possibility of adverse effects on ecosystems is minimal (Thangavel & Sridevi 2014).

How to choose adequate phytotechnology?

Before starting any rehabilitation project it is very important to gather information regarding all the elements and processes occurring in the particular ecosystem or watershed. The more detailed and thorough the knowledge is the better solution can be applied. In the planning phase it is also important to set measurable goals as to be able to evaluate the success. Pre-defined objectives, goals, targets and metrics allow to calculate how well selected solution works at any time during the project operation (DuBowy 2013). It is also important for making adjustments to the rehabilitation plan and optimization of the system – adaptive management (Zalewski 2011).

According to Phytotechnology Technical and Regulatory Guidance and Decision Trees (Technology and Team 2009) most commonly applied phytotechnologies include: phytostabilization covers, riparian buffers, ponds, lagoons and basins, tree hydraulic barriers phytoremediation groundcovers, phytoremediation tree stands and constructed treatment wetlands.

- *Phytostabilization covers* are used on impacted soil and sediments to stabilize it, prevent erosion and contaminant dispersal associated with it. Plants extract the contaminant and sequester it in their tissues. Vegetation covers can also be used to prevent infiltration and protect clean surface water. In that case plants limit the infiltration and surface runoff, minimizing the risk of contamination spread.
- *Tree hydraulic barriers* can effectively contain contaminant present in groundwater. To reduce movement of impacted groundwater actively tapping it trees both extract and transpire water, and sequester pollution. Also clean groundwater can be protected against lateral migration of contaminants based on evapotranspiration.
- *Phytoremediation groundcovers* and *phytoremediation tree stands* use degradation processes occurring in plants

and in rhizosphere. Groundcovers break down contaminants present in soils and sediments, while tree stands target contaminants in groundwater.

- *Riparian buffers* are among the most universal applications, since they can limit the pollution spread to protect surface water (also by erosion control), but are phytoremediation application as well. The media which buffers protect are: impacted surface water, clean and impacted groundwater. The remediated media may include surface and groundwater.
- *Ponds, lagoons and basins* are small reservoirs which prevent the spread of contaminated water or remediate impacted surface water. In the first case stagnating water is used by plants (extraction, transpiration, sequestration) and it evaporates and infiltrates. Remediated media can include waste water.
- *Constructed treatment wetlands* are wide-spread techniques of remediating surface water. Macrophytes metabolize contaminants and provide oxygen for aerobic degradation of organic matter and nitrification.

Selecting suitable plants for chosen application is also very important. Plants must not only have satisfying accumulation capacity but they also have to blend into rehabilitated habitat. It is absolutely unacceptable to use non-native and invasive species, regardless of their beneficial role in their natural habitats. A screening process should start with identification of species already existing on site. If those species have remediation potential (appear in the phytotechnology databases) it is recommended to use those plants. If not, it is necessary to look for the suitable species in the databases or scientific journals. In some cases that might not be enough and one would have to look for hybrids or related species. If that option also fails GMO species should be taken into consideration. When the use of plants is impossible, as they would not survive certain contamination levels, phytotechnologies cannot be used and other approaches ought to be considered.

Conclusion

Many possible applications of phytotechnologies result in growing interest in this type of environmental solutions. Other advantages linked to high plant biomass make the use of phytotechnologies even more tempting. But there are also some limitations one have to keep in mind. Not always plants can survive high contamination levels. Climate conditions and seasonal changes can interfere with vegetation growth. A large surface area is often required to achieve certain cleanup goals. And last but not least, phytotechnologies and phytoremediations are fairly new practices and the knowledge concerning themis still limited.

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Streszczenie

W świetle postępującej degradacji środowiska naukowcy i inżynierowie szukają coraz bardziej zaawansowanych metod pozwalających na ochronę, remediację i rekultywację ekosystemów. Obecnie preferowane są rozwiązania holistycznie, biorące pod uwagę nie tylko aspekty środowiskowe, ale również ekonomiczne i społeczne.

Fitotechnologie to metody remediacji i zatrzymywania zanieczyszczeń oparte o wykorzystanie roślin, procesów zachodzących w ich tkankach oraz w ryzosferze. Zwiększanie pokrywy roślinnej powiększa pojemność środowiska poprzez filtrację wody, kontrolę cykli biogeochemicznych, a także tworzenie siedlisk i zwiększanie bioróżnorodności. Rośliny mają też pewną wartość estetyczną, dlatego ich wykorzystanie w celu rozwiązywania problemów środowiskowych jest mile widziane przez społeczeństwo. Wśród zalet fitotechnologii należy również wymienić ich koszt, który szacunkowo jest około 10-20% niższy niż analogicznej skuteczności rozwiązanie tradycyjne (Vaněk i inni 2010).

Dobór odpowiedniego rozwiązania podyktowany jest celem przedsięwzięcia. Najczęściej wykorzystywane rozwiązania zatrzymujące zanieczyszczenia to stabilizujące pokrywy roślinne i drzewne bariery hydrauliczne. Rozwiązania mające na

celu zniszczenie zanieczyszczenia to pokrywy i drzewostany fitoremediacyjne. Część rozwiązań ma potencjał remediacyjny, ale także zatrzymuje zanieczyszczenia, to m.in.: strefy buforowe, adaptowane zbiorniki małej retencji oraz oczyszczalnie hydrofitowe.

Wykorzystanie fitotechnologii ograniczone jest stężeniami zanieczyszczeń, których rośliny mogą nie przetrwać oraz warunkami klimatycznymi i sezonowymi, a także koniecznością poświęcenia dużego obszaru pod uprawę. Ponadto zabiegi wykorzystujące rośliny są stosunkowo nowymi rozwiązaniami i jeszcze nie wszystko wiadomo o ich możliwościach i konsekwencjach użycia.