BIOREMEDIATION OF CONTAMINATED SITES

Solution of the Future

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1. Preface

1.1 Motivation

Since pollution in any form is a huge problem in today's society, we decided to dedicate our paper to different biotechnological methods that help clean up the environment. We depend on the health of our planet and are responsible for keeping it a liveable habitat as all living beings on earth bear the consequences of pollution. The human species developed great technological knowledge, which we find all the more exciting as soon as it is used in meaningful and problem-solving purposes.

1.2 Relevance

With progress in biotechnology, bioremediation (BR) emerged to one of the most rapidly developing research-areas of environmental restoration (Dua et al. 2002). We believe that BR will gain in importance because the humongous pollution and contamination of today will lead to long term ecotoxicological effects on terrestrial, groundwater, and aquatic ecosystem which sooner or later have to be cured (Fent 2004). A significant amount of industrial organic chemicals are released into the environment deliberately, for example, pesticides or products to insulate electric transformers. Others are released accidentally, like the oil-spill of the Deepwater Horizon-catastrophe that contaminated immense areas around the Mexican Gulf (Dua et al. 2002).

Another example would be the DDT-pesticide pollution shortly after the Second World War which still has an impact on today's life such as residues in foodstuff or breast milk (Rappl et Waiblinger 2009), but also, DDT causes for example damages in eggshells of birds (Upmeier 2001). But there are a lot more toxic substances, for example, microplastic, heavy metal (HM) pollution, or oil spills that harm nature strongly. Even though there is already lots of research going on, we believe in increasing research among this research area because it is of major significance to find effective solutions for decomposing such toxic substances to heal nature where necessary and keep the biodiversity alive.

1.3 Acknowledgments

We thank Madame Wermeille, from who we received competent Knowledge and professional advice through an interview. Also, she provided very detailed and helpful sources, on which our paper is based. **Who is Mme. Wermeille?**

2. Introduction

2.1 Context

To achieve the greatest possible understanding for the reader of this paper, basic knowledge has to be provided and some keywords have to be defined: Biotechnology is the study of the use of biological organisms, processes or systems, to manufacture products that improve the quality of human life. It includes the five colours of biotechnology that deal with different branches of it. In this paper, we specified in BR, a sub-area of grey biotechnology which deals with the balancing of the environment by the removal and disposal of various chemical contaminants by using microorganisms and also plants. Those contaminants are for example toxic substances like petroleum hydrocarbons, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, phthalate esters, nitroaromatic compounds, industrial solvents, pesticides, and metals (Dua et al. 2002). Generally, BR is mainly about the protection of the Fauna and Flora (Niglia 2019).

A wide range of BR methods has been developed, including a great number of new microorganisms that can degrade toxic substances (Dua et al. 2002). In terms of BR -methods, one distinguishes between In-situ and Off-situ methods. (Some techniques contain both types). In-situ methods always take place directly at the contaminated site whereas off-situ methods are typical for transporting the contaminated substance into a decontamination station where the biotechnological process of decontamination is implemented (Eiswirth n.d.).

Whether in- or off-situ methods are applied to the contaminated site depends on the ground of the site and the local conditions. Moisture, soil composition PH-value and the concentration of other chemicals like nitrogen or minerals are important factors, but in order to apply the most suitable method, three basic principles have to be considered: The amenability of the pollutants to biological transformation to less toxic substances, the bioavailability of the contaminant to microorganisms and the opportunity for bioprocess optimization (Dua et al. 2002).

2.2 Objective

The main goal of this paper is the analysis of two of the most important and common methods of BR. The microbial remediation (MR) of oil spills that deals with the degradation of harmful oil with the help of bacteria and phytoremediation (PR) which is about decontaminating the soil with the use of specific plants. In this paper, we want to answer the following question: when where, and why the technique used, what are the financial costs it brings? We want to examine the two techniques in those aspects and compare them to each other to evaluate. To achieve this, we conducted an interview with Madam Christiane Wermeille, head of contaminated sites section of the Federal Department of the Environment, Transport, Energy and Communications (DETEC), to gain expertise.

But before we get started with the different methods, the scientific history of BR has to be outlined:

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2.3 Scientific History

The first known appearance of BR goes back to the Romans, around 600 BC. They created sophisticated sewage systems where Water was drained and cleaned by natural Biodegradation. Of course, their BR techniques were not as advanced and well developed as they are today, so they were quite inefficient (Angelova 2018).

Much later in 1960, George Robinson, the assistant county petroleum engineer for Santa Maria, California, had the idea of making custom mixtures of dried bacteria cultures for commercial use. He experimented with microbes inside of polluted glass jars and gained public attention with his “bug-brew” recipes. In 1972, scientists tried successfully to clean the fuel tanks of the RMS Queen Mary, a passenger ship of the United Kingdom, by using those microbes. Ever since then, scientists put lots of research into the improvement of Microbes that serve a BR purpose. Today, a great amount and variety of well-adapted, useful microbes exist (Anonymous n.d. and Reding 2019).

2.4 Recent Events

To complete the scientific history, two of the most important key events of BR are added. Since great progress was made in the last 3 decades concerning BR, and science is still making discoveries almost on a daily bases, we had to choose between several discoveries that were significant in the developing process of BR techniques.

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In 1999, opportunities for improving degradation performance have been discovered. Progress in genetic engineering techniques brought science closer to the goal of genetically engineered microorganisms (GEMs) that functioned as “designer biocatalysts” (Dua et al. 2002). This discovery was applied 10 years ago in the following event: On the 20th of April 2010, the oil platform “Deepwater Horizon” exploded, leading to high oil pollution in the Mexican golf, harming nature with longterm ecotoxicological effects. The oil-contamination of this event was the first wide-scale environmental application of emerging systems biology tools based on microbial gene analysis. These tools provided unprecedented insights into the overall response of microbial communities to oil, gas, and dispersant released to marine ecosystems (Kujawinski 2020).

To finish, not a recent, but an important scientific event in close future: In June 2020 in Tokyo, Japan, there will be the International Conference on Microbial Bioremediation and Biodegradation Systems (ICMBBS) where leading academic scientists will be brought together to exchange their research results in terms of MBR and Biodegradation (ICMBBS 2020).

3. Techniques

3.1 Microbial Remediation

As already mentioned before, a very known BR is that of Oil spills, using microbial technology. The environmental pollution resulting from petroleum hydrocarbons (PHCs) has increased due to the seismic increase in population and modernization of society, causing an urgent need for remediation. The bacteria degrading PHCs are omnipresent in nature and use these degraded compounds as sources of carbon and energy. In the last 30 years, major gains were achieved because of rapidly developing MR technology. Nevertheless, the technology is not omnipotent as Its practical application is affected by environmental factors, reducing technology's large-scale application (Xu 2018).

In most cases, sites that are contaminated by PHCs are degraded by indigenous bacteria. The revealing of a large number of hydrocarbon-degrading bacteria in oil-rich sites were made by many studies. Their abundance and quantity are closely related to the types of PHCs and environmental factors. However, in all cases, carbon and energy allow their growth and reproduction. The developing microbial biotechnology allows the identification and screening of functional microorganisms from petroleum hydrocarbon contaminated sites. Until 2017 bacteria from more than 79 genera, with the capability of degrading PHCs, have been identified (Tremblay et al. 2017). Acinetobacter, Kocuria, Streptoc, Staphylococcus, Rhodococcus, and many more, turned out to play essential roles in the degradation of crude oil.

There are different methods in which microorganisms such as bacteria are used. One example of remediation of oil spills is called bioaugmentation. It is an in-situ BR technology, introducing indigenous microbial cultures to the contaminated site. Usually, this method is used when the oil persists for decades, or the native bacteria population cannot break down the hydrocarbons. The Introduction allows an augmentation of microbial degradation at the site. The bacteria used for such remediation can oxidize the hydrocarbons while converting them into harmless products, following the general equation $C_nH_n + O_2 \rightarrow H_2O + CO_2$. An aggregation of different microbial cultures provides a metabolic diversity, enhancing the degradation of a wider range of hydrocarbon compounds (Macaulay and Rees 2014, p.17). The oil spill cleaning up technique can be applied on land as well as in water. Before applying this method, some factors have to be considered for example the chemical composition of the oil as well as its concentration and a physical state or also some dangers like that the bacteria may become a dominant species while the presence of hydrocarbons (Williams 2016).

A possible reaction process on an oil-spilled site includes the addition of one oxygen molecule which is the key step for the degradation of hydrocarbons. An epoxide can be the first intermediate to form, allowing a better solubility in water and introduces a reactive site for the next reactions. Different enzyme systems are known for the degradation of alkanes. In the case of a bacterium called Pseudomonas, it isolates the omega-hydroxylase system consisting of three proteins. The fatty acids which are intermediates of the degradation of alkanes, are further decomposed and can be excreted by the bacteria, serving as an enhancement for hydrocarbon degradation. The resulting products are Biomass, CO_2, Organic acids, and Dihydroxy compounds. (Hassanshahian et Cappello 2013, p.109)

The catastrophe of Exxon Valdez is e great example of a case study, related to BR. In 1989 in Exxon Valdez, a ship carrying 163'000 tons of crude oil grounded on Blight Reef in Alaska, an area with important fisheries and scenic wildlife such as bald eagles and sea otters. Approximately 40 million liters of crude oil were spilled into the sea (Stillich 2009), spreading widely and contaminating shores over an estimated length of 1800 km along the south coast of Alaska (ITOPF unknown year).

”*The best estimates are: 250,000 seabirds, 2,800 sea otters, 300 harbor seals, 250 bald eagles, up to 22 killer whales, and billions of salmon and herring eggs.”* (Lyon and Weiss 2010)

Up to that date, it was the largest and most expensive spill in American waters, causing a clean-up operation with 10000 workers along the shoreline and costs exceeding 7 billion $ (Lyon and Weiss 2010). One clean-up technique besides high pressure- and hot water washing was BR. Five months after the incident EPA (Environment Protection Agency) recommended ways of supplying the use of BR. The recommended technique is nowadays known as biostimulation (Bretthauer 1989). Contrary to the bioaugmentation where a consortium of different bacteria is introduced into the affected area, fertilizers are added to the contaminated site to enhance the growth of bacteria naturally present in the environment. The costs for biostimulation vary from $30 to $100 per cubic meter of soil.

Certain of the hydrocarbons can be degraded naturally by these indigenous bacteria. Especially the addition of oleophilic fertilizers enhances the removal of oil from cobblestone and gravel surfaces. In order to provide the maximum clean-up through BR, the EPA suggested that only areas with heavy oil-spill should be cleaned physically before applying the nutrients on the contaminated area. Also, the rates of application were important to ensure the effective filling of fertilizers, while producing a minimum environmental impact.

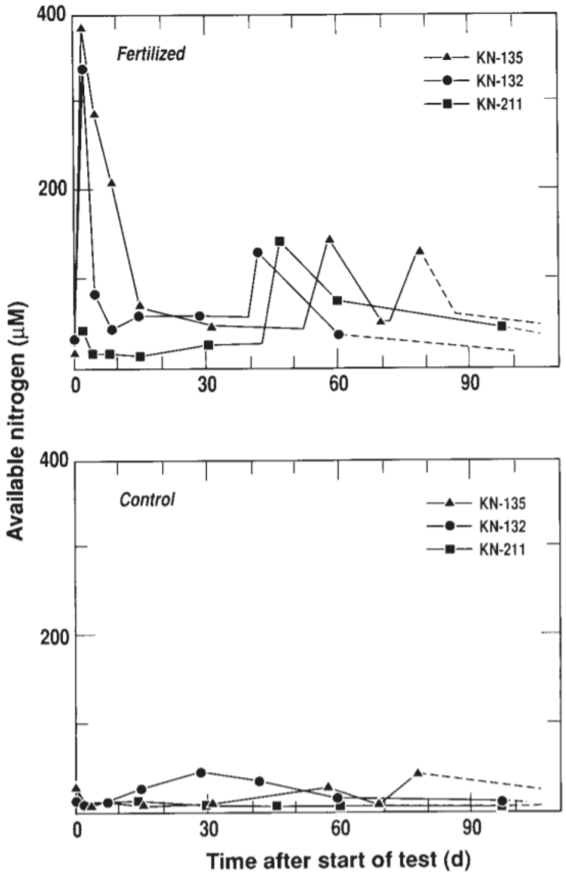

Figure 1 Graph showing amount of Nitrogen (Bragg et al. 1994, p.414)

The application of 0.2kg / m^2 allows a thin coat of the nutrient covering the oiled area. Nitrogen and Phosphate should be released in rates of 1-10 and 0.1-0.5 mg per day for a duration of 40 days (Bretthauer 1989). According to an article by Bragg et Prince, the recommendations above were implemented. The shores were treated with Inipol EAP 22, a stable microemulsion with a core of urea surrounded by oleic acid carrier consisting of 7.4% of Nitrogen and 0.7% Phosphor. The other applied fertilizer was called Customblen consisting of 28% of Nitrogen and 3.5% of Phosphor. Within 3 years Approximately 50 tons of Nitrogen and 5 tons of Phosphor were poured into the water on the shorelines. The monitoring of hydrocarbon losses proved that BR could be accelerated up to five times when adding fertilizers. The graphs represent the measurements of nitrogen that were made at beaches during remediation processes. KN-135 fertilizer being applied on day 0,53 and 72. KN-211 on day 0 and 44. KN-132 on days 0 and 40 (Bragg et al. 1994, p.414). As the measured amount of Nitrogen decreased after the days it had got applied, it confirms that BR via biostimulation was a working technique in the case of the Exxon Valdez incident. By 2014 scientists estimated a remaining volume of up to 79 m^3 of oil and an ongoing recovering. However, the NOAA (National Oceanic and Atmospheric Administration) reported the recovering of many species like Seals, Otters, Eagles, and several fishes (Shigenaka 2014).

3.2 Phytoremediation

“*Phytoremediation is an environmentally friendly and cost-effective alternative to current remediation technologies*” (Lee 2013)

PR unlike other BR technologies entirely relies on microbial bacteria but uses suitable plants to decontaminate the soil or groundwater. Plants (*phyto* = plant and Latin *remedium* = restoring of balance (Wikipedia 2020)) are planted into the decontaminated soil where they then either absorb the toxins, enhance the bacterial populations that detoxify the soil with the help of plant interactions (physical, biochemical, biological, chemical and microbiological). The contaminants in the ground can be controlled or stabilized in various ways depending on the mechanism used (Azubuike et al. 2016). There are several types of PR mechanisms (accumulation or extraction, degradation, filtration, stabilization, and volatilization) in each of which the plant plays a different role as shown in Figure 2. Extraction is mainly used to dispose of toxic HMs while the other mechanisms are mostly used to remove organic compounds (Azubuike et al. 2016).

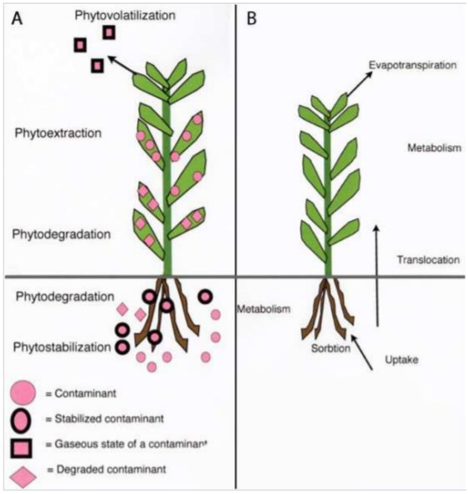

Figure 2 Different mechanism of phytoremediation (Greipsson 2011, p. 3)

The plants can take up HMs as well as organic compounds, more specific: toxic HMs, radio nuclides, and organic contaminants including chlorinated solvents, BTEX compounds, non-aromatic petroleum hydrocarbons, nitro toluene ammunition wastes, and excess nutrients (Dadrasnia et al. 2013, no pages). It is an In-Situ BR technology as the soil is treated locally and the plants brought to the decontaminated site. This method is practical for dense soil but obviously can only affect the area of the roots of the plants (Riser-Roberts 1998, p. 113).

When choosing which plant(s) to use as a phytoremediator one should consider the following: the time to reach goal of decontamination, the above-ground biomass (animals should not be able to eat the plant, especially because of the toxins), structure of roots (volume as well as if it is fibrous or tap which is important for the depth of the contaminant), plant survival and strength to endure environmental conditions, plant growth rate and availability of site monitoring (Azubuike et al. 2016). Possible phytoremediators are in *Table 1* in the appendix.

PR is reported to cost around US$37.7/m^3. This cost can be reduced by enhancing the mechanisms, more precise predictions, or avoiding not unforeseen events (Wan et al. 2016).

3.2.1 Phytoextraction

Before the explanation of phytoextraction, "Hyperaccumulation" must be defined: "*The ability of a plant to accumulate HMs in its above-ground parts without phytotoxic symptoms at concentrations up to 100–1,000-fold higher than in non-hyperaccumulating species*" (Suman et al. 2018). The higher the hyperaccumulation of a plant, the more successful the phytoextraction in which plants absorb metal contaminants from soil or groundwater through their roots. The metal accumulates in the above-ground biomass (Chyn 2011) which can then be harvested (Hasan et al. 2019, p. 3-4). The uptake through roots can be increased by giving Ethylenediamine tetraacetic acid (EDTA) to the plant. EDTA is often used in agriculture and also mobilizes HMs. The faster uptake of metals through EDTA or other amendments is shown in Figure 3 where the curve of uptake over time gets steeper when the chemicals are also taken up by the

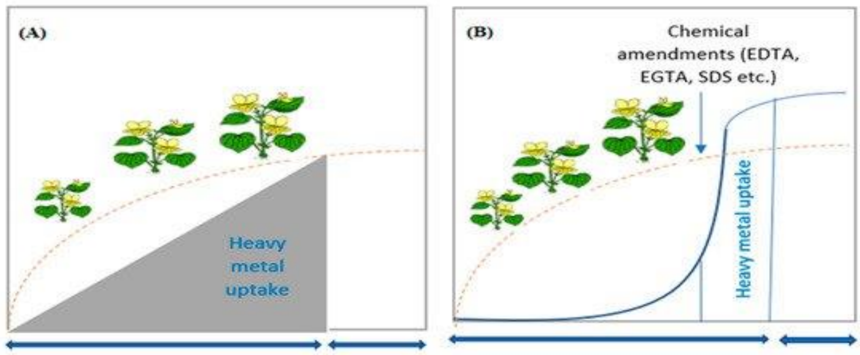

Figure 3 Chemical amendments can increase the uptake of HMs in plants. In Figure A shows the uptake of HMs of hyperaccumulators and Figure B depicts the uptake of HMs of non-hyperaccumulators where after a certain time chemical amendments are absorbed with the HMs by the plant (Hasan et al., p. 3).

plant. Figure 3 also shows that non-hyperaccumulators with amendments can absorb the same amount of HMs as hyperaccumulators.

Some plants can even take up HMs through the leaves where metals penetrate the stomata of the leaf tissue and are transferred toward the vascular bundle (Hasan et al. 2019, p. 2-4).

4. Interview

of which institution?

Because of the corona crisis, our first planned interview with Eva Zellmann, an academic employee of the department for *Altlasten/Bodenschutz* could not take place. Because of the situation, she also denied an interview via email, so we quickly had to find another partner. We managed to get in contact with Madame Wermeille, head of the Contaminated Sites section, and send her our questions. Her responses mostly contained links and documents where we could find the answers. Even though we were disappointed at first, the documents turned out to be very informative and rich in detail. Therefore we will not present the answers here, the interview is attached in the appendix.

5. Discussion

5.1 Comparison of Microbial Remediation and Phytoremediation

As said above, BR might provide cheaper and more effective ways than other non-BR techniques to clean the earth from contaminants but the aim was to compare different BR techniques where we take the duration of achieving desired state, cost, and effort and other aspects into consideration. The following paragraphs reflect the ad- and disadvantages of each method which we then consider for evaluation. Also, the fact that no ethnic incorrectness in today’s perspective is caused is of great importance.

5.1.1 Microbial Remediation

Advantages: MR is less costly as it is simple and does not require labour or intensive equipment and can be used on-site which also makes it more simple than off-site remediation (Kiat et al. 2014). As mentioned above, biostimulation (a form of MR) costs $30/m^3 to $100/m^3. MR helps to remove the toxic components of petroleum. At the same time, thanks to minimal physical disruption of the site and low energy consumption it is also more environmentally friendly than other processes/strategies like burning (Kiat et al. 2014). Microorganisms have a large range of degradative capabilities and show a vast diversity (Dua et. al. 2002, p. 144).

Disadvantages: On the downside, MR is unable to produce fast response and results. Results can be seen after weeks, months, or years depending on the situation, the climate, location, etc.. It requires planning and knowledge on using BR and the microbial bacteria have to be specifically tailored to each polluted site since not all microorganisms or bacteria can be introduced to the polluted site (Kiat et al. 2014).

5.1.2 Phytoremediation

Advantages: PR costs around $37/m^3 or $7,5/m^2 (Xiao-Ming et al. 2016). Phytostabilization is safer than other BR technologies and least affects the natural environment in a negative way (Radziemska et al. 2017, no pages). PR, in general, is environmentally friendly, it does not require a lot of machinery, monitoring, no livings are killed or destroyed and in all mechanisms except volatilization there are no bad emissions for the environment during the process. Also, the decontamination can be done with such ease so that no big government project with big machines or long planning is required. Especially because it is so simple, the technique could be taught at any school, farmers could then use it themselves and the required seeds soled at any ordinary gardening center (Kaller 2014). Simple processes with effective results are essential in for the utilization of PR in developing countries. Phytoextraction for example can be enhanced through chemical amendments such as EDTA.

Disadvantages: Just as MR, PR has a very long process duration. Trees and plants can take months or years to grow and achieve the desired decontamination. Also, in phytovolatilization, some contaminant particles might be released into the air which could cause unforeseen damage. However, this amount is quite small and the extent has not been fully verified yet (The Interstate Technology & Regulatory CouncilPhytotechnologies Team 2009, p. 4). Another disadvantage is that if metals accumulate in the plant, the roots, or particularly the above-ground biomass the toxins might continue down the food chain (Radziemska et al. 2017, no pages). Many factors must be considered when choosing the plant.

5.1.3 Evaluation

We can see that both MR and PR have a very long duration of decontamination but are environmentally friendly and cost-effective. Probably MR is slightly more expensive and according to (Anonymous n.d.) it is cheaper to grow plants than the equivalent biomass of bacterial biomass and additionally, plants are easier to monitor, grow. Also, microbial bacteria have to be tailored where the right type might not even be found. The trade-off of PR is the risk of spreading toxins to animals. However, MB exceeds PR in diversity, and therefore the applicable area. Kapagunta and Majumber (2018) clearly state that PR is advantageous over MR considering their economic feasibility, widespread pollution degradation capacity, and also a high rate of contaminant reduction or degradation. Overall it seems that PR is the slightly better solution on land or for underground water but for anything in the open water the MR is advantages. ous However, it is important to protect other animals from eating the contaminants and that the chemical amendments are not used to much as that could cause unknown problems.

"*Its application is very environmentally friendly and result in sustainable management of our natural resources.*" (Mutambu et Masaka 2019, p. 6, about bioremediation)

5.2 Future Research

PR will be further explored with the objective of partially resolving environmental pollution. The future research lies in removing the following three limitations of BR: incomplete understanding of microbial processes, unsatisfied stimulation of microbes with the material, difficulties with making sure the microbes are in contact with the contaminants. The improvement of these three would increase the BR 's efficiency (National Research Council 1993, p. 92). Additionally, better knowledge of the biotic and abiotic factors influencing the natural selection of remediation organisms will prove very important. Also, the analysis of genomic and proteomic sequences of microbes may be useful. Then one could engineer more effective microorganisms to clean the site. (Kapagunta et Majumber 2018)

To increase the efficiency of phytoextraction, today, research on how to increase the hyperaccumulation is made with genetic engineering. The developed plants should endure more HMs and have a larger capacity than before (Chyn 2011).

6. Summary

BR uses microorganisms to detoxify sites In-Situ or Off-Situ. It has been researched for about 30 years and already many cases of contamination were solved with its application. Research regarding BR is expanding due to it's beneficing of finding more effective methods. We were able to successfully interview Mrs. Wermeille via email, however, she gave us links where we could find the answers which made the interview a bit different than expected. In the analysis between MB and PR, we found that both had similar dis- and advantages and were environmentally friendly and most importantly sustainable. Both have a long process duration, require little energy and machinery, and are cost-saving.

The reader may read only the summary of the whole paper. Therefore, do not use abbreviations only in a summary, spell out the terms at least once.

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Table 1 Plants with potentials as phytoremediatorTable 1: URL:https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5026719/table/Tab2/?report=objectonly (23/04/2020)

8. Appendix

Table 1 Plants with potentials as phytoremediator **Reference is missing**

Plant	Nature of pollutant	Initial concentration	Mechanism of removal	% Removal	Reference
Ludwigia octovalvis	Gasoline	2,07,800 mg/kg TPH	Biosurfactant enhanced rhizodegradation	93.5	Almansoory et al. (2015)
Aegiceras corniculatum	Brominated diphenyl ethers (BDE-47)	5 μg/gdw	Biostimulated degradation	58.2	Chen et al. (2015)
Spartina maritima	As, Cu, Pb, Zn	5–2153 mg/kg	Bioaugmented rhizoaccumulation	19–65	Mesa et al. (2015)
Arundo donax	Cd and Zn	78.9 and 66.6 kBq/dm^3 respectively	Rhizofiltration	100	Dürešová et al. (2014)
Eichhorina crassipes (water hyacinth)	Heavy metals (Fe, Zn, Cd, Cu, B, and Cr)	0.02–20 mg/L	Rhizofiltration	99.3	Elias et al. (2014)
Phragmites australis	PAHs	229.67 ± 15.56 μg/g	Rhizodegradation	58.47	Gregorio et al. (2014)
Plectranthus amboinicus	Pb	5–200 mg/kg	Rhizofiltration	50–100	Ignatius et al. (2014)
Luffa acutangula	Anthracene and fluoranthene	50 mg/kg	Phytostimulation[a]	85.9–99.5	Somtrakoon et al. (2014)
Dracaena reflexa	Diesel	1–5 wt%	Rhizodegradation	90–98	Dadrasnia and Agamuthu (2013)
Sparganium sp.	Polychlorinated biphenyls	6.260 ± 9.3 10^{-3} μg/g	Biostimulated rhizodegradation	91.5	Gregorio et al. (2013)
Amaranthus paniculatus	Ni	25–150 μM	Phytoaccumulation	25–60	Iori et al. (2013)
Rizophora mangle	TPH	33,215.16 mg/kg	Phytoextraction and phytostimulation	87	Moreira et al. (2013)
Populusdeltoides x nigra and Arabidopsis thaliana	Silver nanoparticles and Ag^+	0.01–100 mg/L	Phytoaccumulation	20–70	Wang et al. (2013)
Carex pendula	Pb	1.0–10 mg/L	Rhizofiltration		Yadav et al. (2011)

Interview

Fragen an Frau Christiane Wermeille **Who is Mme. Wermeille?**

1. Was für Methoden kennen Sie, und in welchen Fällen wenden sie welche an?

   Die wichtigsten Verfahren sind in diesem Dokument aufgeführt (Seite 35): Evaluation von Sanierungsvarianten (PDF, 786 kB, 19.02.2014). Sie finden auch die wichtigen Kriterien für die Wahl eines Verfahrens (vorhandene Schadstoffe, Ort der Schadstoffe, ...).

   Hier sind noch zusätzliche Informationen über die in-situ-Verfahren: In-situ-Sanierung (PDF, 1 MB, 28.03.2017)

2. Wie lange dauert eine Sanierung?

   Dies ist sehr unterschiedlich: Die Sanierung kann von einigen Wochen für eine Schießanlage bis zu mehreren Jahren für eine grosse Altlast dauern (z.B. 16 Jahre für die Industriemülldeponie Bonfol).

3. Wie kann man in Zukunft eine Sanierung vorbeugen?

   Ich verstehe die Frage nicht. Heute wird versucht, zukünftige Sanierungen durch geeignete Abfallbehandlungsmaßnahmen zu vermeiden. Aber die Standorte, die schon heute sanierungsbedürftig sind, müssen alle saniert werden.

4. Wie wichtig sind Bio-Altlastensanierungen in der Zukunft?

   Sie werden vermutlich die gleiche Rolle als heute spielen. Das bedeutet, sie werden nur in wenigen Fällen gebraucht werden.

5. Wie funktioniert die Methode mit den Mikroorganismen?

   Eine detaillierte Beschreibung der verschiedenen biologischen Verfahren finden Sie hier: Anhang A1: Faktenblätter zu den technischen In-situ-Verfahren (PDF, 589 kB, 28.03.2017)

6. Weshalb waren die VASA-Ausgaben ausgerechnet 2013 höher als die Einnahmen? (https://www.bafu.admin.ch/bafu/de/home/themen/altlasten/dossiers/magazin-umwelt-altlasten/finanzierung--so-bezahlen-wir-die-altlastenzeche/_jcr_content/par/image/image.imagespooler.jpg/1479329651488/564.1000/vasa_finanzen.png)

   Die VASA-Auszahlungen hatten im Jahr 2008 einen damaligen Höhepunkt erreicht und danach bis 2011 stetig abgenommen. Die tieferen Werte in den Jahren 2010 bis 2012 sind vor allem darauf zurückzuführen, dass die geplanten Teilzahlungen an die Sanierung der Sondermülldeponie Kölliken (SMDK) aufgrund verschiedener Abklärungen nicht erfolgen konnten. 2013 konnten diese Teilzahlungen getätigt werden, was den starken Anstieg in diesem Jahr erklärt.

   Mehr Informationen und aktuellere Daten finden Sie hier: https://www.bafu.admin.ch/bafu/de/home/themen/altlasten/fachinformationen/altlastenfinanzierung/aktueller-stand-des-vasa-fonds.html

7. Was sind Pros und Contras der von Ihnen vorhin genannten Methoden?

   Viele Elemente über die Vor- und Nachteile von den verschiedenen Verfahren sind in den folgenden Dokumenten erwähnt:

   Evaluation von Sanierungsvarianten (PDF, 786 kB, 19.02.2014)

   In-situ-Sanierung (PDF, 1 MB, 28.03.2017)

   Ein Dokument (auf Englisch) über Pro und Contra noch hier: https://www.itqb.unl.pt/~imartins/Dua_etal_2002.pdf

8. Gibt es Orte oder Stellen an denen falsche Methoden oder Methoden verwendet werden, obwohl sie nötig werden?

Vor dem Beginn einer Sanierung muss immer eine detaillierte Analyse der Variante gemacht werden.

9. Welche Methoden sparen am meisten Ressourcen bzgl. Energie, Rohstoffe, Zeit Geld?

   Eine eindeutige Antwort ist hier nicht möglich. Das ist abhängig von den Schadstoffen, den Mengen, der Lokalisation (im Boden, im Grundwasser, …).

   Die wichtigen Informationen finden Sie hier: Evaluation von Sanierungsvarianten (PDF, 786 kB, 19.02.2014).

   Wie Sie sehen werden, gibt es keine Verfahrensbewertung oder Punktevergabe. Es gibt nur eine Liste von Kriterien, die zu berücksichtigen sind. Eine genaue Bewertung all dieser Kriterien ist für jede Altlast erforderlich.

10. Welche Methoden sind schlecht für die Umwelt, welche vielleicht sehr gut?

    Gleiche Antwort wie Frage 9.

11. Ist es nicht ein Risiko Mikroorganismen zu produzieren, die vielleicht sehr schädlich sein könnten und drastische unerwartete Effekte auf die Umwelt haben könnten?

    Nur Mikroorganismen, die schon am Standort vorhanden sind, können gebraucht werden. Für die Anwendung von fremden Mikroorganismen ist eine detaillierte Studie nötig und es sind strenge Bedingungen. Ich schicke Ihnen im Anhang der Mail alle Informationen darüber.

12. Falls die Mikroorganismen "gründlich" getestet werden: Wie und wie lange?

    Siehe Fiche im Anhang.

13. Worin liegt der Hauptunterschied zwischen dem in-situ und dem off-situ verfahren?
14. Was sind Aspekte der biologischen Altlasten Sanierung, welche Sie in einer wissenschaftlichen Arbeit auf jeden Fall einbeziehen würden?

    Siehe Fiche im Anhang.

15. Wie relevant ist die biologische Altlasten Sanierung in der Zukunft?

    Siehe Frage 4.

16. Gibt es verschiedene biotechnologischen Sanierungsverfahren?

    Ja, siehe Frage 5.

17. In welchem Sanierungsverfahren spielt die Biotechnologie eine entscheidende Rolle, bzw. welche Sanierungsverfahren basieren auf Biotechnologie?

    Ich kenne keine.

18. Kennen Sie berühmte Case-studies? Kennen Sie Umweltkatastrophen, welche durch biotechnologischen Sanierungsverfahren bearbeitet wurden?

    Es sind ein Paar Altlasten, die durch Mikrobiologischen Verfahren saniert wurden. Aber ich kenne keine Publikation darüber.