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REVIEW ARTICLE

# Restoration of Heavy Metal Contaminated Soil from Microbial Consortium Mediated Approach

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**Abstract**

Various factors contribute to environmental degradation, including ecosystem disruption and pollution, damaged freshwater sources and arable land, compromised in some way, and reduced biological diversity and the general health of the environment. Because individuals have only been allotted one Earth to deal with, irreparable damage to the environment could spell the end of human existence. Mindless consumption and economic expansion have begun to have negative consequences on Mother Nature. The environmental degradation of global agricultural soil pollution caused by heavy metals has socioeconomic impacts on the challenging situations to sustainable improvement, with dangerous effects on human and ecosystem health; in view that soil is a non-renewable resource. This pollution destroys the esthetic values of soil quality. Degradation may produce lower yields from poor farming practices, excessive use of fertilizers and pesticides, leakage from landfills, etc. Where this occurs, the challenging task is to lessen the amount of these chemical substances and gain agricultural soils appropriate for growing eco-friendly crops. Microbial-mediated bioremediation delves into the philosophy behind the concept of green/clean development solutions for remediating heavy metal contamination. A widely accepted green method that is mostly overall executed in situ; and suitable for the establishment/re-establishment of crops on treated soils. The microbial metabolism of indigenous microorganisms can be exploited for degradation. Integrating these revolutionary technologies with sustainable and profitable land use, ought to result in green and sustainable remediation strategies by figuring out future directions and research challenges for the bioremediation of agricultural soils.

**Keywords** Soil, Bioremediation, Environmental degradation, Environmental Pollution, Heavy metals, Microbial remediation, Toxicity.

## 1. Introduction

Due to extensive agricultural practices, the majority of our natural surroundings have decreased in quality. Most farmers convert grasslands and forests into farmland, which degrades the quality of existing forests and vegetation cover. The drive to use the land as a resource for making expensive goods, crops, and cattle has resulted in the degradation of natural habitats like forests, wildlife, and fertile plains. Intensive agricultural operations deplete fertile lands and neighboring vegetation cover by accumulating hazardous compounds such as minerals and heavy metals, which disrupt biological and chemical activities in the soil. Agricultural wastes, chemical fertilizers, and pesticide runoff into marine and freshwater areas have also harmed wildlife habitats and natural water supplies. With intensified growth and development of modern agriculture and enhanced manufacturing capacity, our natural resources soil, and water are getting polluted. Hence, resulting in a decrease in the ability of the environment to meet social and ecological goals and requirements. One of the most demanding and difficult problems for sustainable improvement is the heavy metal pollution of agricultural soil worldwide, with dangerous effects on the ecosystem and human health. Expanding industries, sewage

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slime, spillage of petrochemicals, animal manures, coal combustion, land application of fertilizers, and wastewater irrigation are the key sources of heavy metals soil contamination (Manzoor, Goyal, Gupta, A, & Gupta, S, 2020). On these soils, vegetation grows shows a reduction in yield, growth, and performance. Thus, limiting crop production, demanding an urgent remediation urge and global awareness about approaches to preserve and retain the environment with their real applications. Where this occurs, the challenging task is to lessen the amount of these chemical substances and gain agricultural soils appropriate for growing ecofriendly crops. The slowly occurring geochemical cycle of heavy metals in nature that is hampered by man which could make hazardous and noxious effects on all life forms (public fitness and flora and fauna and aquatic biota) is making an emergency call and consequent resulting need for increased awareness that could put off or neutralize its toxic outcomes in soil, sediments, and wastewater.

The use of microbes and plants as natural bioremediation agents is thus a possible solution since it includes cost-effective and sustainable remediation innovations. The potential natural-based method of microbial-mediated bioremediation is an innovative solution for remediating heavy metal contamination. Bioremediation is a widely established environmentally friendly process that is typically carried out in situ; and suitable for the establishment/re-establishment of crops on treated soils. For degradation, the microbial metabolism of indigenous microorganisms can be used. Integrating these revolutionary technologies with sustainable and profitable land use, ought to result in green and long-term remediation strategies by figuring out future directions and research challenges for the bioremediation of agricultural soils. The environmental damage we do is now not accounted for in social and economic terms. Because of this lack of "environmental value," we have been able to over-exploit "free" natural resources, which are, of course, not free. It has also resulted in an overabundance of inexpensive things with very short life spans that are lavishly tossed into the environment after usage, and then more cheap goods are acquired and discarded again, and so on, harming the planet's ability to restore its environmental services in good time. This paradigm of our contact with the environment must be altered. Certainly, we do not have the right to exploit and destroy it without regard for future generations of humans and animals who will be hereafter us. The flow diagram for the mitigation strategies and remediation of soil for the improvement of the quality of soil is shown in Figure 1.

The soil is being polluted by pollutants draining from the surroundings. The ultimate goal of the research is to create a low-impact solution and implement cost-effective remediation. Fungi and bacteria have metabolic processes that can break down contaminants. Consequently, bioremediation strategies must be identified. Assessing soil quality and microbiological diversity is essential to monitoring system performance and potential. The detailed bioremediation approaches which could be implemented are mentioned in Figure 2**.**

### *1.1. Bacterial bioremediation*

Bacteria are ubiquitously present within side the surrounding environment. Biosorption with the aid of using bacteria is a less expensive and green method to put off pollution, along with non-biodegradable factors, like heavy metals, derived from polluted soil. Bacterial biomass may be residing or non-residing cells. Bacterial species have tailored and evolved mechanisms for metal ions remediation and resistance for their survival (Mustapha & Halimoon, 2015; Akhtar, K., Akhtar, M.W., & Khalid, 2019). Bacterial biomass accomplishes the speedy elimination of metals such as Pb, Cu, Cd, Zn, and Cr (Ozer, A., & Ozer, D, 2019). Biosorption performance relies upon heavy metal ions and bacterial species (Hassan, Awad, Kabir, Oh & Joo, 2010). The bacterial cell wall is the primary physical contact linking the bacterial biomass and metal ions. The carboxyl groups can bind Cd on the surface by complexation (Yee & Fein, 2019). The amino groups showed key removal of Cr via electrostatic interactions and chelation. Bacterial species need to be uncovered to the contaminant's pollutants for enzymatic induction earlier than they use them for bioremediation. There is a minimal requirement of contaminant concentration to provoke enzymatic expression important for the process (Adenipekun&Lawal, 2012). Species like *Desulfovibrio, Pseudomonas, Geobacter,* and *Bacillus* have been used for bioremediation.

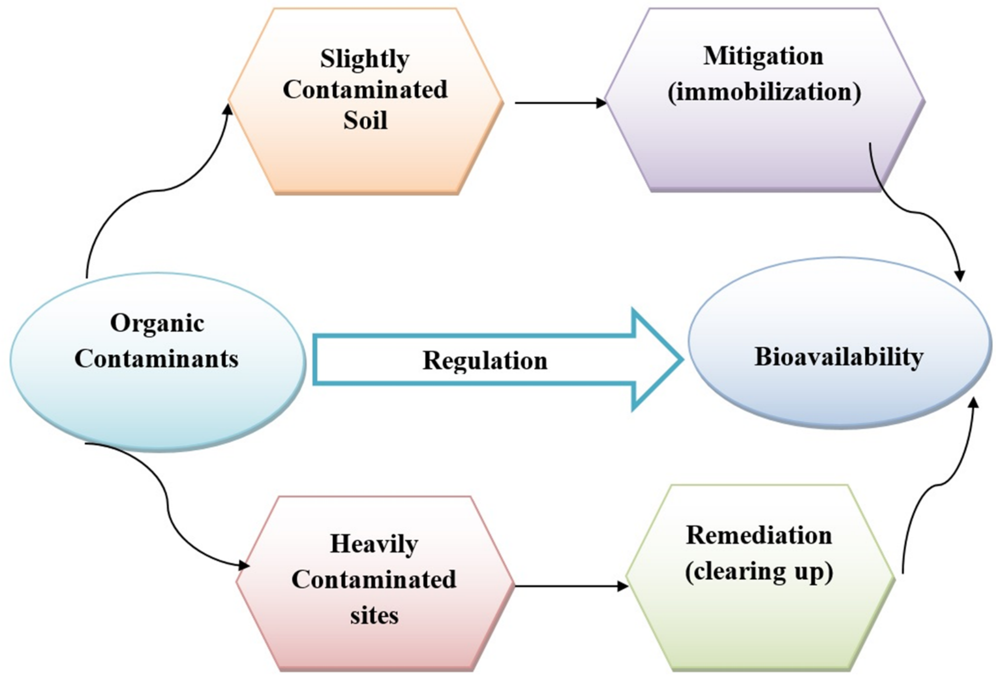


**Figure 1. Strategies of mitigation and remediation for slightly and heavily contaminated soil.**

### *1.2. Algal bioremediation*

Different species of algae are found in massive quantities in marine ecosystems Abbas, Ismail, Mostafa & Sulaymon, 2014). Among the three algal groups; i.e., Phaeophyta*, Chlorophyta,* and *Rhodophyta* (i.e., brown, red, and green, respectively), brown algae had been mentioned to own higher biosorption ability (phytoremediation). Biosorption of metal ions varies with the structure and kind of the algal biomass, chemical constitution, and charge of the heavy metal ion (Brinza, Dring, &Gavrilescu, 2007; Oyedepo, 2019). Different algae, in dead or alive forms, have been employed, in combination or in single, in column or batch, for in-situ remediation. The presence of hydroxyl, amine, carboxyl, phosphate, and sulphate are potential key metal sites in algal proteins, which work by complex formation process during heavy metal remediation (Romera, Gonzalez, Ballester, Blazquez, & Munoz, 2019). Because algae are autotrophic, they require few nutrients and generate a significant number of biomass when compared to other microbial biosorbents. These biosorbents have also been utilized to remove heavy metals due to their high sorption ability (Abbas *et al.,* 2014). Algae biomass is employed in the bioremediation of contaminated sites, and heavy metal-polluted effluent via adsorption or cell integration. Phycoremediation is the utilization of several forms of cyanobacteria and algae for heavy metal remediation through toxicant removal or degradation (Chabukdhara *et al.,* 2017). Algae have chemical moieties on their surface that act as metal binding sites, such as carboxyl, hydroxyl, amide, and, phosphate (Abbas *et al.,* 2014). Napiorkowska-Krzebietke et al. used dead *Chlorella vulgaris* cells that were employed to remove $Cd^{2+}$, $Cu^{2+}$, and $Pb^{2+}$ ions from aqueous solutions under various biosorbent dosage, pH, and contact time conditions. These findings indicate that *C. vulgaris* biomass is an effective biosorbent for removing of $Cd^{2+}$, $Cu^{2+}$, and $Pb^{2+}$ at 95.5%, 97.7%, and 99.4%, respectively, from a mixed solution containing 50 mg/dm$^3$ of each metal. Ions could be thought of as agents in the bioremediation process.

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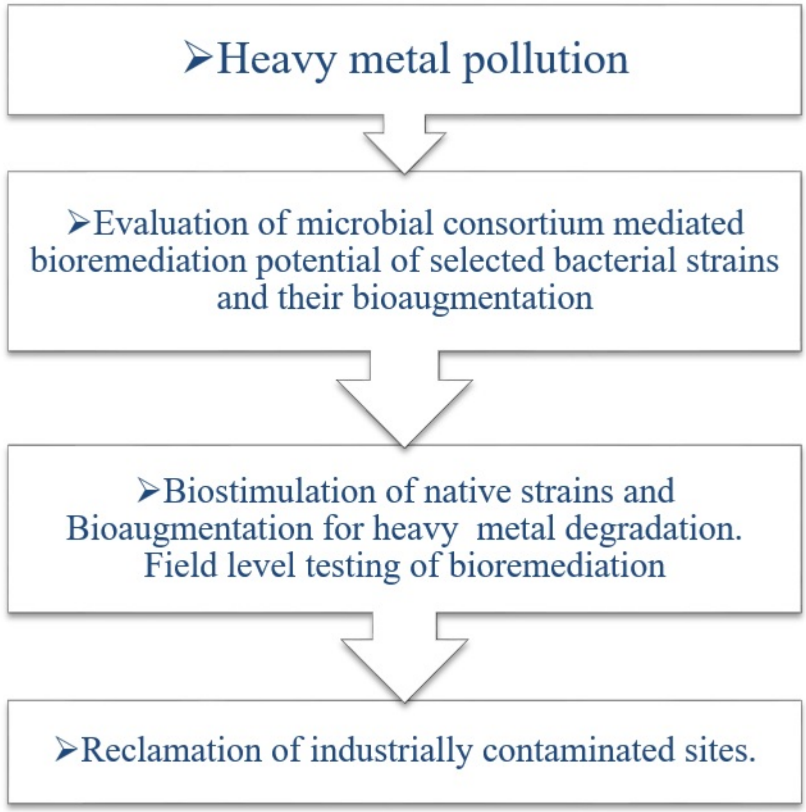


**Figure 2. Bioremediation for heavily contaminated soil.**

### *1.3. Fungal bioremediation*

Fungi are exploited substantially in commercial applications (Abdi & Kazemi, 2015). Fungi are adapted (as in ecology, morphology, and metabolism) in keeping with environmental situations and are accountable for techniques like nutrient cycling and decomposition under natural conditions (Archana & Jaitly, 2015). Mycoremediation entails the use of fungus (dead or alive) in contamination removal from various environmental (Hamba & Tamiru, 2016; Esterhuizen-Londt, Schwartz, & Pflugmacher, 2019). As a result, it offers a comprehensive remedial approach because full mineralization of pollutants in nature is achievable (Thenmozhi, Arumugam, Nagasathya, Thajuddin, & Paneerselvam, 2013). It has been shown that *Saccha-romyces cerevisiae* may sequester up to 65-79% of Pb and Cd from polluted soil (Damodaran, Suresh, & Mohan, 2011). The biosorption system is composed of fungal cell walls (having proteins, chitin, lipids, glucans, polysaccharides, and pigments,) and functional groups like carboxyl, hydroxyl, sulphate, amino, or phosphate and it is mediated via interactions like adsorption, ion exchange, and complexation (Ismail & Moustafa, 2016; Gadd & Mowll, 2019). *Aspergillus sp.* had been mentioned to put off Cr from tannery effluent; it eliminated 65% of the chromium from the wastewater against 85% from the synthetic medium (Srivastava & Thakur, 2019; Raj, Mohan, &Vidya Shetty, 2011). Mushrooms have performed a crucial function in human food plans throughout records because of their dietary and therapeutic qualities. Other than their use as meals, they may be used for myco-remediation because of their ability for heavy metallic uptake. Metal uptake via mushrooms is affected by age of mycelia, contact time, and fructification (Demirbas, 2019; Isildak, Turkekul, Elmastas, &Tuzen, 2019). Different species of white-rot fungi, such as *Termitomyces clypeatus* and *Pleurotusostreatus* reported degrading persistent pollutants (Singh, 2006).

## 2. Microbial world for smart degradation of environmental pollutants

Microorganisms carry out the transportation of HMs utilizing membrane-linked transport mechanisms and transform them into non-hazardous forms (Igiri et al., 2018). Microorganisms use processes like biosorption, bioaccumulation, biotransformation, and bioleaching to stay alive in a metal-polluted environment. These techniques have been used in clean-up processes summarized in Table 1.

**Table 1. Microbe-mediated remediation of heavy metals.**

| Microbial group | HM contamination | Microorganism | References |
|---|---|---|---|
| Bacteria | Lead | *Bacillus subtilis* X3 | Qiao et al., 2019 |
| | Cadmium | *Pseudomonas aeruginosa* | Chellaiah, 2018 |
| | Cadmium | *Cupriavidussp. strain* | Li et al., 2019 |
| | Cadmium and lead | *Pseudomonas aeruginosa* and *Bacillus cereus* | Nath et al., 2018 |
| | Copper, cadmium, and zinc | *Desulfovibriodesulfurica* | Yue et al., 2015 |
| | Nickel | *Bacillus* sp. KL1 | Taran et al., 2019 |
| | Cadmium and zinc | *Synechococcus*sp. | Blindauer et al., 2008 |
| | Copper, palladium, and zinc | *Pseudomonas aeruginosa* | Teitzel and Parsek, 2003 |
| | Mercury | *Bacillus firmus* | Noroozi et al., 2017 |
| | Mercury, cadmium, and zinc | *Escherichia coli* | Lerebours et al., 2016 |
| Algae | Ar(V) | *Lessonianigrescens* | Hansen et al., 2006 |
| | Cadmium, zinc, lead, and nickel | *Asparagopsisarmata* | Romera et al., 2007 |
| | Lead, nickel, cadmium, and zinc | *Codiumvermilara* | Romera et al., 2007 |
| | Lead, nickel, and cadmium | *Cystoseirabarbata* | Yalçın et al., 2012 |
| Fungi | Lead | *Botrytis cinereal* | Akar et al., 2005 |
| | Copper, lead, and Cr(VI) | *Aspergillus niger* | Dursun et al., 2003 |
| | Silver | *Pleurotus platypus* | Das et al., 2010 |
| | Copper | *Rhizopusoryzae* | Fu et al., 2012 |

There have been various reports on the use of biofilms for heavy metal removal. Biofilm is an effective bioremediation technology as well as a biological stabilizer. Biofilms have a very high tolerance for hazardous inorganic elements, even at deadly doses. A study on *Rhodotorula mucilaginosa* indicated that metal removal effectiveness ranged from 4.79% to 10.25% for planktonic cells and from 91.71% to 91.71% for biofilm cells (Goher *et al.,* 2016). Biofilm bioremediation processes could be either via biosorbent or exopolymeric compounds present in biofilms that comprise molecules with surfactant or emulsifier characteristics (El-Masry *et al.,* 2004). The application of synergistic heavy metal resistant bacteria and fungus for bioremediation of heavy metal for *Bacillus megaterium* and *Rhizopus stolonifer,* which had previously been isolated and discovered as tolerating cadmium, lead, and nickel pollution, were studied for heavy metal bioremediation. *B. megaterium* was exposed to 3200 mg/L of $NiSO_4$, $PbCl_2$, and $CdCl_2$, but *R. stolonifer* was exposed to 3200 mg/L of $PbCl_2$, $NiSO_4$ only treated to 800 mg of $CdCl_2$. Furthermore, the two organisms were exposed for 96 hours at 30 °C to 1500 mg/L of all three metals (500 mg/L of each heavy metal). After the investigation, the synergistic growth of *R. stolonifer*and *B. megaterium* exhibited the highest Pb uptake (541.50 mg). The individual growth of *B. megaterium* and *R. stolonifer* also exhibited the highest Ni (501.05 mg) and Cd (479.10 mg) absorption. *B. megaterium* had the highest combined heavy metal uptake. For individual metal contaminations, synergistic microbe growth resulted in the greatest loss of Pb (25.24%) and the least loss of Ni (40.41%). In the instance of mixed metal pollution, the microorganisms' synergistic proliferation suppressed the bioremediation efficacy of *B. megaterium* and improved the efficacy of *R. stolonifer*. The findings demonstrated the efficacy of these organisms for heavy metal bioremediation and, as a result, their potential as bioremediation agents in polluted environments, both individually and in synergistic growth, and that this occurs via bioaccumulation.

### 3. *Microbial consortium mediated bioremediation*

Numerous studies have demonstrated that it is challenging for a single strain to completely degrade contaminants. The bacteria with varied elimination capacities are mixed because different strains have diverse metabolic pathways, and the microbial consortium can combine the benefits of each strain to ensure effective pollutant destruction. Mixed microbial consortia performed well in terms of increased pollutant breakdown and substrate tolerance. The performance of the group of microorganisms is superior to the culture of a single strain. The degradation of contaminants was influenced by the microbial consortium. Some currently extant microbial strains isolated from the natural flora and intestinal flora have been reported to have the intrinsic capacity to digest contaminants. These isolates are appropriate for the bioremediation of pollutants. Because the microbial consortium destroys contaminants more efficiently than a single strain, it has emerged as a key technology. In the natural environment, bioremediation is generally performed by a microbial consortium rather than a single species, and different strains or species have distinct functional roles. Co-cultivating a microbial consortium accelerates the biodegradation of contaminants in the soil and is more efficient than cultivating a single bacterium. The bacterial consortium can bioremediate polluted environments successfully. The following succinct description of the mechanism:

1. First, the bacterial consortium's synergistic metabolic breakdown quickens. Members of the bacterial consortium can break down crucial intermediary compounds created by other consortium members, minimizing the buildup of intermediate products and enhancing the metabolic pathways for organic pollutant biodegradation (Mechanism 1).
2. Second, certain strains of bacterial consortiums create a lot of high-efficiency biosurfactants, which makes pollutants more soluble and concentrated and increases their biodegradability and bioavailability (Mechanism 2).
3. Third, the microbial community may regulate itself and adjust as the substance is degrading.
4. Individual cultures cannot degrade pollutants as effectively as microbial consortiums (Mechanism 3).
5. Fourth, the microbial consortium can use compounds produced by the breakdown of pollutants to encourage the proliferation of strains (Mechanism 4).
6. Fifth, a high degree of degradation can be seen in the crude enzyme generated in the intracellular area of the microbial community activity (Mechanism 5).

**https://doi.org/10.51323/JIAR. 06/01/01.02.2023.1-9**

7. Sixth, Bacterial consortium strains have a biochemical synergistic effect that boosts bacterial activity and pollutants degradation (Mechanism 6).

The microbial consortia consequently exhibit a strong capacity to digest soil contaminants. The consortium of microalgae and strains can also dramatically increase the breakdown as well as the flexibility of microbial cells. A bacterial consortium was shown to be more effective at removing contaminants when surfactants are added than when the bacterial consortium is used alone. Additionally, the biodegradation of the bacterial consortia may be aided by the addition of charcoal or immobilized laccase. The bacterial consortia can therefore be supplemented by these chemicals to increase the capacity of microorganisms to digest contaminants. More high-throughput microbial technology research is needed to develop management plans for bioremediation of contaminated soil. The addition of bacterial consortia to soil will improve environmental sustainability. It will also be crucial for the ecologically friendly rehabilitation of contaminated land and will pave the way for new avenues of sustainable development. Because microbes are nature's original recyclers, they can be employed for bioremediation. They can also convert chemicals into sources of energy and raw materials for their growth, resulting in a low-cost and environmentally benign biological process. Due to their excessive commercial use, heavy metals turn out to be a worldwide real environmental problem. Applications of bacteria as whole-cell catalysts for decontamination and bioremediation suggested that many bacteria can use pollutants as carbon assets, letting them decontaminate risky chemical compounds within side the surrounding environment. By modifying the *Pseudomonas putida* bacterium to metabolize 1, 3-dichloropropene under anaerobic conditions for bioremediation, utilizing a set of standardized techniques, *P. putida*gained both improved natural capabilities and introducing novel functions in it (https://www.ibiology.org/bioengineering/bioremediation). The choice preference organisms or plants must have a tolerance, need to show improved transformational abilities, convert poisonous chemical compounds to harmless forms that allow the organism to reduce the poisonous impact of the metal, and at the same time, keep the metal contained. Thus, by developing an understanding of microbial communities and their response to the natural environment and pollutants, together with what is understood in their genetic and biochemical history. To live on, microorganism goes through many extraordinary mechanisms to stand the uptake of heavy metal ions. These mechanisms include entrapment, biosorption, efflux, precipitation, reduction, and complexation (Ali & Omar, 2021). Microorganisms consequently may be a promising, limitless useful resource for new environmental biotechnologies. The microorganisms can be used natively or isolated from various resources at the polluted location (Abdi &Kazemi, 2015; Archana&Jaitly, 2015). Microorganisms that might be concerned with biodegradation are examples: *Actinobacteria, Acinetobacter, Alcaligenes, Bacillus, Arthrobacter, Flavobacterium, Methylosinus, Beijerinckia, Mycococcus, Nitrosomonas, Mycobacterium,Xanthobacter, Penicillium, Nocardia, Pseudomonas, Phanerochaete, Trametes, Rhizoctonia,* and *Serratia.*

## 4. Conclusion

Microbial bioremediation is an ecofriendly approach. Subsequently, by building up a comprehension of microbial networks as well as their reaction to the natural surroundings as well as contaminants, together with what is perceived in their genetic and biochemical history, it is conceivable to enhance our capabilities to biodegrade and conduct field trials with these identified microbes for bioremediation techniques. Current research should need to intensify on novel effective microorganisms for bioremediation to shorter duration and new technologies for large-scale production to increase the effectiveness of the bioremediation technology that should further reduce environmental stress on the terrestrial and aquatic ecosystems.

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