Microbial Community Tracking in Bioremediation

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Chemical industries are an important science and technological paradox now. They save many lives while they also serve as vital sources of pollutants to many others. Striving to synthesize new chemical substances to compete with other organisms and to improve the lifestyle forms an important quest of human creativity. There are already more than 68 million organic and inorganic substances and about 58 million chemical reactions registered in the Chemical Abstracts Service (CAS) Registry System. Everyday about 15,000 new additions are being made [1]. Unfortunately, the human efforts to know the environmental fate of these chemical substances are relatively lesser. Toxic and persistent nature and environmental effects of many chemical substances remain unpredictable. Warning about their adverse human and environmental health efforts to the public is usually given very late, which is exemplified by the pesticide DDT [1,1,1-trichloro-2,2-di(4-chlorophenyl)ethane]. After its extensive public use in 1970s, the environmental concerns of this pesticide were recognized late in 1980s in the developed countries. In many other countries, there are economic compulsions for its production and use in public health. The organochlorine chemical substances such as DDT can reach the soil or the atmosphere and condense into soil as well as water, aerosols, and snow. 'Grasshoppering' by the evaporation and condensation cycle of these chemical substances allows their global distribution, irrespective of their origin of manufacture or use, and their transfer from the terrestrial environments to aquatic ecosystems.

Traditionally, the organic chemical pollutants are petrochemicals, pesticides and detergents. But the new breed of chemical pollutants includes pharmaceuticals, antibiotics, nano-particles, and many others. Pollution by these chemical substances may result from the accidents during manufacturing, storage and use, or deliberate disposal. Most chemical substances reach soils and hence, the capacity of the soils to retain or release them is an important determinant affecting their persistence and fate in the environment. Persistent organic pollutants have gained the attention of the policy makers of international community. The Stockholm Convention on Persistent Organic Pollutants, signed in 2001 and with 176 parties to the international community. The changes in the microbial communities can be crucial for the functional integrity of soils. Among many ecosystem services provided by microbial communities, their ability to metabolize organic pollutants to obtain either carbon or energy for their growth is of great importance in the present-day human-dominated Earth. The microbial transformation and immobilization processes continue to contribute significantly to the natural attenuation of polluted environments. The pollutant degrading abilities of microbial groups are generally dose-dependent. The biodegradative process involves the transfer of substrates and products within the microbial community, which is referred to as metabolic cooperation [5]. Some of the chemical substances with unusual substituent or structural elements defy the natural capabilities of microorganisms for degrading them, while others require the addition of nutrients at the ecologically relevant stoichiometric levels to support the heterotrophic microbial growth. Many others are toxic or inhibitory to microorganisms. The natural process of degradation (bioattenuation), the intentional stimulation (biostimulation) by addition of water, nutrient, electron donors or acceptors and the addition of microbial members with proven capabilities (bioaugmentation) are fundamental to the in

Soils do harbour many life-forms besides supporting most land-based life. Paradoxically, the degradation of the mineral parent rock and organic matter which releases essential nutrients for life goes on alongside the accumulation of dead organic matter in soils. In soils, archaea and bacteria are abundant, up to 109 g-1d.w. soil and they can weigh approximately 500 kg of C ha-1. The diversity of archaeal and bacterial communities is determined by the ratio of the total number of individuals in the community and the abundance of the most abundant members of that community. A ton of soil may contain more than a million of different microbial taxa [2]. The abundance, diversity and community stability of microorganisms are fundamental to many soil functions. For at least 75% of the 4 billion year history of life on the Earth, microorganisms have dominated the ecosystem processes, but for the 0.00000001%time period (last century) by the human-centric activities [3].

Many archaean and bacterial taxa are present at low abundance but they can increase rapidly and function under the favourable environmental conditions. The functional redundancy in microbial communities is considered to overpower the microbial diversity-function relationships. The recent findings suggested that the survival of a microbial invader and the microbial diversity was negatively correlated in soils. Both the amount of resources used and the rate of their consumption could be related to the decrease in the competitive ability of the microbial invader in species-rich vs. species-poor communities [4]. The changes in the microbial communities can be crucial for the functional integrity of soils. Among many ecosystem services provided by microbial communities, their ability to metabolize organic pollutants to obtain either carbon or energy for their growth is of great importance in the present-day human-dominated Earth. The microbial transformation and immobilization processes continue to contribute significantly to the natural attenuation of polluted environments. The pollutant degrading abilities of microbial groups are generally dose-dependent. The biodegradative process involves the transfer of substrates and products within the microbial community, which is referred to as metabolic cooperation [5]. Some of the chemical substances with unusual substituent or structural elements defy the natural capabilities of microorganisms for degrading them, while others require the addition of nutrients at the ecologically relevant stoichiometric levels to support the heterotrophic microbial growth. Many others are toxic or inhibitory to microorganisms. The natural process of degradation (bioattenuation), the intentional stimulation (biostimulation) by addition of water, nutrient, electron donors or acceptors and the addition of microbial members with proven capabilities (bioaugmentation) are fundamental to the in

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situ bioremediation process. Soil priming or activation by the use of soil with prior exposure to pollutants for remediating the freshly contaminated soils largely depend on the metabolic potential of microbial communities. Thus, the key driving force behind various biological treatments of pollutants during bioremediation continues to be the microbial communities.

Small size, high surface-area-to-volume ratio, and large contact interfaces with their surrounding environment are some of the ideal features of microorganisms as bioindicators of chemical pollutant stressors. The microbiological information, besides the chemistry of polluted soils, is necessary for the assessment of risks in polluted sites, and feasibility and efficacy of the bioremediation efforts. The enumeration of microbial members, the estimation of their functions/ enzymatic activities or survival tests or toxicity assessment has been extensively used to describe the environmental impact of chemical pollutants. The reductionistic approaches have provided stronger evidence of microbial roles in degradation and transformation. Any impact of a chemical pollutant will change the microbial community; reduction or alterations of the community structure, at the levels of species or guilds may occur. Long-term pollution will have evolutionary consequences even at low toxicant levels. The sensitive species may become reduced or get extinct while others may benefit from reduced competition and/or cooperation. Interestingly, there are reports on the development of tolerance at the microbial community levels. The ‘Pollutant induced community tolerance’ can be used as a quantitative measure of the degree of ecological disturbance [6]. Relative to the conventional microbial methods such those based on cultivation, respiration or enzymatic function related to nutrient cycles, the approaches based on the pollution induced (microbial) community tolerance (or sensitivity) will be more advantageous.

The recent developments on high-throughput microbial methods are promising, not only for profiling but also tracking the changes in microbial communities. These methods are required to shift from the descriptive approaches to predictive analyses for the mutual benefits in microbial ecology and ecotoxicology. The DNA of soil microbial communities can be extracted; target genes of taxonomic or functional perspective can be amplified by the Polymerase Chain Reaction (PCR) and detected. PCR-based amplification of nucleic acids allows the microbial community profiling, independent of cultivation in the laboratory. The early community profiling methods such as Terminal Restriction Length Polymorphism (T-RFLP) provide the overall patterns, not directly identifying each individual species or genus in that community. Also, they can only simultaneously monitor or identify up to 200 dominant populations. The development of microarrays (or microchips) based on the property of a single stranded DNA or RNA molecule to hybridize to a complementary molecule attached to a solid support has extended the capabilities of detecting more number of taxa. The phylogenetic microarrays such as the PhyloChip which targets the known diversity within the rRNA genes can simultaneously detect up to 50,000 bacterial, and archaeal taxa. Using probes targeting the key genes involved in microbial processes, another high-throughput method for tracking microbial communities through space and time [7]. The on-site solutions are achievable using the 'Laboratory-On-a-Chip (LOC)', also known as 'Micro Total Analysis Systems (µTAS)' or 'Biological Micro-Electronic Mechanical Systems (BioMEMS)' [8]. The developments as well as the decreasing cost of high-throughput tools and computational tools will make microbial community tracking in bioremediation an important activity. Application of these tools for site specific characterization, risk assessment of polluted sites, and the selection of proper bioremediation methods will make it feasible to find environmentally benign and economical solutions that would be impossible to obtain using the conventional methods.

References