



Microbial Diversity: Values and Roles in Ecosystems

**Onen, O. I.^{1*}, Aboh, A. A.², Mfam, A. N.¹, Akor, M. O.³, Nweke, C. N.¹
and Osuagwu, A. N.⁴**

¹*Department of Botany, University of Agriculture, Makurdi, P.M.B. 2373, Benue State, Nigeria.*

²*Department of Agronomy, Cross River University of Science and Technology,
P.M.B. 1123, Calabar, Cross River State, Nigeria.*

³*National Environmental Standards and Regulations Enforcement Agency (NESREA), Nigeria.*

⁴*Department of Plant Science and Biotechnology, Michael Okpara University of Agriculture, Umudike,
P.M.B. 7267, Umuahia, Abia State, Nigeria.*

Authors' contributions

This work was carried out in collaboration among all authors. Author OOI designed the study, managed the literature searches and wrote the first draft of the manuscript. Author MAN wrote the protocol. Author AMO also managed the literature searches. Author NCN edited the first draft of the manuscript. Author OAN also managed the literature searches. Author AAA also manage the literature search and assisted in editing the first manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJOB/2020/v9i130075

Editor(s):

(1) Dr. P. Dhasarathan, Anna University, India.

Reviewers:

(1) Ozoude, Theresa Obiageli, Veritas University, Nigeria.

(2) Paola Taydé Vázquez Villegas, Instituto Tecnológico Superior de Cintalapa, Chiapas, México.

Complete Peer review History: <http://www.sdiarticle4.com/review-history/52591>

Review Article

Received 08 January 2020

Accepted 13 March 2020

Published 23 April 2020

ABSTRACT

Microorganisms are described as multicultural microscopic organisms, which are cosmopolitan in nature, (i.e. they are widely distributed in air, water, soil, sea, mountains, hot springs and also in bodies of living plants and animals including the human), possessing a diverse array of metabolism. Microbial diversity includes a large collection of organisms. It includes a range of variability in all kinds of microorganisms like fungi, bacteria and viruses in the natural world. Microorganisms serves as the mainstay of life on Earth. Microorganisms represent the richest treasury or part in chemistry and molecular diversity in nature, establishing the basis for ecological processes such as biogeochemical cycles and food chains, also maintaining essential relationships among themselves and with higher organisms. Microbial diversity exploration has been encouraged by the fact that

*Corresponding author: E-mail: onenonenibiang@yahoo.com;

microbes are vital for life since they perform numerous functions essential for the biosphere. Maintaining multiple ecosystems functions and services, inclusively: nutrient cycling, litter decomposition primary production and climate regulation are among the key roles performed by microbial communities. Microbes not only reshaped the oceans and atmosphere but also gave rise to conditions conducive to multicellular organisms. The diversity of microorganisms is important in the maintenance and conservation of global genetic resources.

Keywords: Microbial diversity; ecosystem; environment; microorganisms.

1. INTRODUCTION

The world of microbes is exceedingly unexamined stock (reservoir) of biodiversity on the earth. It is a valuable extreme in biology under increased research and investigation [1,2]. Microbes stands in the place of most of the Earth's biodiversity and play an important part in the processes of the ecosystem, providing functions that serves as blessings sustain maintaining all of life [1]. Microorganisms serves as the mainstay of life on Earth. Over billions of years, they have evolved into every conceivable niche on the planet [3]. Microorganisms represent the richest treasury or part in chemistry and molecular diversity in nature, establishing the basis for ecological processes such as biogeochemical cycles and food chains, also maintaining essential relationships among themselves and with higher organisms [4]. The microbial world became an area of intense interest in the past decade, and the discoveries were amazing [3]. It has been reported that a large body of research conducted during the past two decades indicates that ecosystem functioning is positively related to plant diversity. Unlike in plants, there is a limited knowledge of the relationship between microbial diversity and ecosystem functioning in existence, especially in terrestrial environments [5]. Several authors [6,2] stated that microbial diversity exploration has been spurred by the fact that microbes are vital for life since they perform numerous functions essential for the biosphere that include nutrient recycling and environmental detoxification. Maintaining multiple ecosystems functions and services, inclusively: nutrient cycling, litter decomposition primary production and climate regulation are among the key roles performed by microbial communities [5]. Lodge et al. [7] reported that microorganisms in some cases, may influence ecosystem processes indirectly by altering the diversity of other organisms. Microorganisms play a perfect and often excellent role ecosystems functioning in maintaining a sustainable biosphere and productivity [6,2]. Microorganisms diversity is key

to the functioning of the ecosystem, because there is necessity to maintain ecological processes such as organic matter decomposition, nutrient cycling, soil aggregation and controlling pathogens within the ecosystem [4]. Sean and Jack [3] reported that microorganisms not only reshaped the water bodies and atmosphere but also gave rise to conditions conducive to multicellular organisms. Delgado et al. [5] reported that under controlled experimental conditions, diversity of soil organisms can promote multifunctionality. However, none of these studies have clearly marked the relationship between soil microbial diversity and multifunctionality on the global scale [5].

Among the diverse ecosystem processes on Earth, plant productivity and nutrient cycling are among those most essential for sustaining human well-being. Due to the persistent population increase globally, substantial increases in plant production and demand for land use will extremely be required to sustain future demand for food and fiber [5], thus ensuring food security. There is behavioral similarities in in many ways between microbial ecosystems and large-scale ecosystems, but notwithstanding, there are important exceptions [3]. Knowledge of the elements or constituents accounting for the great number of functions linked to plant production and nutrient cycling under a changing environment is, thus, critical to maintain and control natural and human-dominated or controlled ecosystems. Soil microbial diversity plays major functions in sustaining ecosystem multifunctionality by encouraging processes such as litter decomposition and organic matter mineralization, which permit the transfer of matter and energy among above-ground and below-ground communities [5]. Evidence are been provided by a growing body of experimental and observational studies, that the relationship existing among biodiversity and ecosystem functioning is more in a straight direction (linear) than saturating. To this extent, whatsoever loss

in microbial diversity as an effect of global environmental changes such as land use, nitrogen enrichment and climate change would likely change the capacity of microbes to maintain multiple above-ground and belowground ecosystem functions [5]. Having an idea of the connection between ecosystem functioning and microbial diversity distribution, biodiversity patterns and the key drivers of these patterns in natural habitats may be valuable for prediction of ecosystem responses to a changing environment [8,1,9].

The diversity of microorganisms is the basis to sustenance and conservation of global genetic resources. As the widest limits of environments are searched into, the richness of microbial diversity is increasingly clear or obvious. Steps must be taken to estimate, record, and protect (conserve) microbial diversity, to sustain human health and to enrich the human state of being worldwide through wise use and conservation of genetic resources of the microbial world [10]. Pajares et al. [1] pointed out that with the advancing growth of molecular-based techniques, there is an emergence of a new interest in knowing the distribution patterns and functional traits of microbial communities. However, most of this research has been focused in temperate regions, and the principal mechanisms controlling microbial community variation within the tropics are insufficiently understood. Tropical ecosystems are distinct and complex and are not the same in valuable ways from those of temperate regions. Thus, in the part of global change, it is of importance to understand how environmental factors, biogeographical patterns and land use changes act upon each other to control the structure and function of microbial communities in tropical ecosystems [1]. Most studies of microbial communities and processes have been carried out in temperate regions, while tropical environments have rarely been examined. It is possible that various rules apply to microbial life in these ecosystems. For instance, elevated nitrogen deposition by human activities may increase or aggravate (exacerbate) phosphorus deficiency in tropical regions, in unusual ways in temperate ecosystems [1]. However, it is insufficiently known how phosphorus availability influences soil microbes, or how microbial series of actions interact with nitrogen deposition in tropical ecosystems. Moreover, microorganisms distribution is determined by environmental factors (temperature, PH, Oxygen concentration, humidity etc), but also can vary in relation to

temporal and spatial scale. These factors controls biodiversity patterns of larger organisms, but their functions in microbial diversity are distinctly unowned, particularly in tropical systems [1]. Therefore, in this paper we try to look at the diversity in microorganisms, their distribution in ecosystems, conservation and applications.

Microbial ecologists in the main time have faced many fundamental challenges such as the lack of ecologically coherent species identification, lack of adequate methods for evaluating population sizes and community composition in nature, and enormous taxonomic and functional diversity [11]. To this extent, it is general acceptance that the extent of microbial diversity is yet to be adequately characterized and that there is an enormous mismatch between the knowledge of that diversity and its values in both ecosystem process and economic development [6,2].

2. WHAT IS MICROBIAL DIVERSITY?

Microbial diversity refers specifically to large collection of microorganisms. It indicates a variety of studies that are important for several national purposes. It includes a range of variability in all kinds of microorganisms like fungi, bacteria, and viruses in the natural world. It is anatural resources that is unseen [12]. Microorganisms form one of the abundant life forms in the universe, but their true profile is unknown to many. Their microscopic nature possibly might be the reason. For this reason only, they remained unexplored till about 300 years ago [13]. The diversity of life on earth is credited to microorganisms. They exist in numbers than plants, vertebrates, and insects put together. Microorganisms have been in existence many decades ago. They are found in almost everywhere on earth and can act on anything, including metals, acids, petroleum, and natural gas—all of which are toxic to us [14].

Microbes exhibit essential characteristics as a unit or multicultural living organisms that are microscopic in nature and are found almost everywhere in the universe, (i.e. air, water, soil, sea, mountains, hot springs also in other living organisms like plants and animals humans inclusive. Microorganisms are highly adaptability thus forming their own excellent world from all biological indications [13]. The branch of biology that is concern with the form, reproduction, physiology, structure, metabolism and classification of microscopic living organisms (fungi,

bacteria, protozoa, algae and viruses) is termed microbiology [13]. Their distribution in nature, how they relate with one other and other living organisms in the environment, their effects on plants and animals are incisive. Part of it also is their ability to alter the environment chemically and physical, and how they connects to chemical and physical agents [13].

Microbes are better and suitable when studying the basis and essentials of life processes. They can be cultured and manipulated easily even with little space and care compared to plants and animals. They possesses rapid growth rate and can reproduce quickly than many other living organisms. Their pattern of metabolism processes is similar to that of higher life forms [13]. [13] pointed out that the enzymes involve in glucose utilization in cells of mammalian tissues are similar to that of unicellular yeast. The energy liberated in the breakdown of glucose is trapped and later used for the essential activities of the cells, whether they are bacteria, yeast, protozoa or muscle cells.

Plants are known for sun energy utilization during photosynthesis which is one of their major characteristics, while chemical substances are needed by animals for their life processes. This is why some microorganisms possesses similar

characteristics with plants, some with animals and some both [13].

3. MICROBIAL DIVERSITY

3.1 In Preserved Ecosystems

Only few species (about 0.1 to 10%) microorganisms are so far know based on the habitat investigated. This is due to the enormous nature of their diversity [4]. The seasonal variability existing in diversity of microbes is not yet comprehended in an agro ecosystem, since a microbial community in each season seem to prevail in occurrence, followed by other less sufficient that often are below the level of detection using the current methods of evaluation [5,15]. Microbial diversity is specially important to ecosystem functions, because ecological processes such as organic matter decomposition, nutrient cycling, soil aggregation and controlling pathogens need to be maintain within the ecosystem [4]. The diversity in functionality is vital in ecological of microorganisms assessment within the ecosystem, principally because little is known about the relationship between the structural and functional diversity of these microorganisms. There is, however, a consensus that microbial diversity is directly related to ecosystem stability [16].



Fig. 1. Microbes live everywhere—even in places we used to think were incompatible with life
(<http://www.learn.genetics.utah.edu/content/gsl/microbes/>)

3.2 In Agro Ecosystems

Microbial diversity as an agroecosystems quality indicator has been very much argued, particularly in the last decade, with the emergence of molecular biology techniques that have favored the evaluation of microbes in environmental samples. The actuality that the diversity of microorganisms naturally stayed unchanged throughout the year is the main debate in favor of such environmental feature. From biological stand the soil may be rich in spite of the prolong or constant use of land for agricultural practices, since majority of microbes present in this environment are considered very vital in the control of diseases and pests of agricultural pest biologically [4]. Therefore, the processes of microorganisms play vital role in the functioning of production systems, carrying out tasks directly related to their productivity and sustainability [17].

4. THE DISTRIBUTION OF MICROBIAL DIVERSITY, WHAT ARE THE DECISIVE FACTORS?

Microbial ecologists in the last few decades have employed enormous settings of molecular techniques to characterize microbial communities, encouraging the recognition of particular assemblages of organism or community characteristics. However, examining or making a relative estimate between studies is frequently hard to do, as each technique has its peculiar set of biases, reducing the potential for meta-analysis. Dominant physicochemical drivers of microbial community manner of organization using consistent methodologies have been made known by few studies on global survey on microbial diversity [3]. According to current theory, a variety of contemporary and historical processes contribute to observed patterns in the spatial and temporal distributions of microbial populations. These processes include mutation, selection, dispersal and drift [11]. However, it has been reported of recent that multi-study group have begun to standardize their data collection and analysis workflows to establish large intra-comparable databases. Also, as sampling efforts intensified, the number of recent phylotypes discovered ceased not to increase surpassing previous estimates, and to a great extent past estimates for multicellular organismal diversity [18,3]. The intricate interactions within and shared by both biological and physicochemical parameters that decide how communities of microorganisms come together

or assemble in natural ecosystems negotiation has just been started [3]. According to [3], an initial step in this journey has been to characterize the environmental axes that are vital for filtering diversity. For example, we know that salinity is a strong driver of community structure in aquatic environments, pH is a dominant force in soil systems, and host-associated and environmental communities are very distinct from one another.

Microbes perform different methods of metabolisms, utilizing all from sunlight, to organic carbon and inorganic minerals as energy sources, and they can switch among these metabolic modes. Microorganisms are capable of surviving under a staggering array of physicochemical conditions, from hot springs to acid mine drainage [3]. The cross-feeding of one another and carving out highly specific niches and distinct life history strategies by microorganisms were achieved because microorganisms are capable of producing and consuming a great number of metabolites with complex carbohydrates, peptides, lipids and antibiotics inclusively [3]. Moreso, speedy evolution and speciation in microorganisms can of significant assistance to diversity on ecological timescales [3]. Beyond fine-scale niche partitioning, microbial diversity is also controlled by stochastic forces, like extremely high rates of dispersal, coupled with the ability of many microorganisms to become dormant when conditions are not conducive to growth [3]. These processes appear to give rise to a persistent seed bank of scarce but viable microbes [3], often referred to as the 'rare biosphere', with almost endless phylogenetic and functional potential for populating emerging or transient niches [3]. The balance between niches (e.g. pH or temperature driving changes in microbial dominance) and neutral (e.g. stochastic dispersal and dormancy) processes will influence the diversity of microbial ecosystems. According to Singh et al. [3] recent work has suggested that increasing environmental heterogeneity or noise disrupts the deterministic coupling between ecosystem properties and ecological diversity, which results in neutrally assembled communities. The extent of alpha diversity in neutrally assembled communities is not totally determined by the composition of the metapopulation from which the local species pool is drawn [3]. If the local species pool is drawn from various source populations of varying composition at a high sufficient rate of dispersal, then the diversity of the local population will be

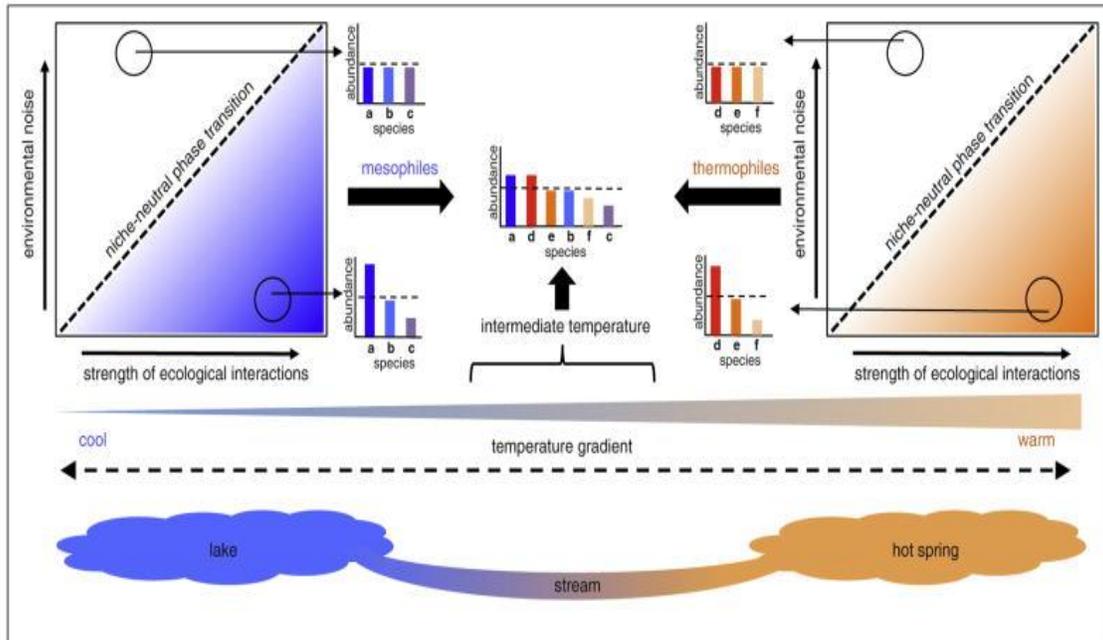


Fig. 2. Schematic diagram of ecological interactions with environmental noise

higher than any of the individual source populations (i.e. the apparent meta-community will be a mixture of the source communities; see Fig. 2). The level of alpha diversity in niche-structured systems will depend upon the volume of niche space and how finely this space can be partitioned. Over evolutionary time, as novel ecotypes arise, there will be a rapid saturation of niche-volume, with a small number of taxa dominating most of the available resources [3].

Both deterministic and stochastic processes are important for shaping microbial diversity. Each environment selects for a particular set of taxa (e.g. 3 ‘mesophiles’ in the lake and 3 ‘thermophiles’ in the hot spring). These different sets of taxa inhabit incompatible ecological niches that are widely separated along an environmental gradient (i.e. temperature). Singh et al. [3] stated that the structure of each community (i.e. the relative abundances of species) is determined by competition for niche space, unless environmental noise is too high or ecological interactions are too weak, in which case no species will have an advantage. As such, niche-structured communities will tend to have a highly uneven rank-abundance pattern (i.e. there will be winners and losers in the competition for niche-space), while neutral communities should, on average, have a more even rank-abundance distribution (i.e. no species

has an advantage). When the two communities are forced to mix along an environmental gradient (see ‘the stream’ below Fig. 2), ecological diversity is increased — both in terms of community richness and evenness — independent of niche/neutral dynamics. This maximum in diversity has been described before in many systems (e.g. the Intermediate Disturbance Hypothesis). The diversity maximum in the stream is a non-equilibrium state that would dissipate if the environmental mixing were to stop. The below diagram (Fig. 2) can be further complicated by further dispersal from outside the system (i.e. meta-communities and island biogeography models), speciation and extinction [3].

5. MICROBIAL DIVERSITY AND THEIR ENVIRONMENT

From oceanic weather patterns, to the oxidation of Earth’s atmosphere, and multi-cellular hosts health, microbes construct or manage their environments. Truly civilization by man would soon fail suddenly without microbes, followed by the remaining life on Earth. The following section details a few examples of how microbial communities modifies their environment [15]. Climate scientists are now noticing a sleeping giant under the Arctic tundra. Permafrost locks away around half of global soil carbon, but these

regions are beginning to melt due to human climate change, which is having a unsuitable or inadequate influence on the poles. Soil warming has been shown to alter the diversity and function of microorganism's communities [3]. Melting of permafrost soils will likely result in large-scale losses in soil carbon in the form of methane and carbon dioxide as a result of microbial activity [3]. Depending on the rate of the increasing temperature, permafrost soils would account for an 8–18% increase in anthropogenic carbon emissions over the next 100 years. This positive biological feedback on climate change could reshape the structure of the entire biosphere [3].

Another captivating way that microbes manage their physical environments comes from early in Earth's history, when bacterial communities gave rise to naturally occurring nuclear fission reactors [3]. Certain bacteria are able to respire uranium (i.e. use oxidized uranium as an electron acceptor). However, the early earth had an anoxic, reducing atmosphere, and uranium, which is insoluble in its reduced form, remained locked away in rock and sediment. The increase of cyanobacteria brought about the constant production of O₂, which began to weather the Earth's crust and pile up in the atmosphere over hundreds of millions of years [3]. Uranium deposits were gradually oxidized, which allowed uranium to dissolve in water and be carried into lakes. This process led to the enrichment for uranium-respiring microbes in these bodies of water. These microbes reduced the uranium, which made it fall out of solution and settle to the bottom of the lakes. Over time, uranium was enriched and deposited on lakebeds until critical mass was achieved and the lakes became natural fission reactors. This process was only possible early in Earth's history, when the radioactive isotope of uranium was still at high enough abundance [3].

Gut-associated microbial communities can also affect their mammalian hosts. Host diet and activity can have great influence on the gut microbiome composition and function, even on daily timescales [3]. Bacteria, fungi, viruses, and other microorganisms that compose your body's microflora play a key function in your mental and physical health [19]. It has also been noticed that, gut microbiota are essential to maintaining their hosts health. Gut microbes are also connected in driving obesity and a number of metabolic disorders. In fact, microbial dysbioses

have been implicated in a number of behavioral disorders [3].

6. DORMANCY CONTRIBUTES TO THE MAINTENANCE OF MICROBIAL DIVERSITY

Dormancy is a protective strategy used by many organisms to overcome adverse environmental conditions. By entering a reversible state of low metabolic activity, dormant individuals become members of a seed bank, which can determine community dynamics in future generations. However, microbial communities are also arranged by species responses to environmental variables that fluctuate through time [20]. Dormancy is one trait that allows species to contend with temporal variability of environmental conditions. This bet-hedging strategy allows dormant individuals to become members of a seed bank, which can contribute to the diversity and dynamics of communities in future generations [20]. A common life history strategy among microbes is dormancy. Majority of microbes are capable of resisting stressors such as temperature, desiccation, and antibiotics by entering resting states or by forming spores. Microbial dormancy is also believed to be important in natural systems. Despite evidence that dormancy is wide spread, we have little theoretical expectation as to how it affect the structure of natural, complex microbial communities [20].

7. MICROBIAL ECOLOGY AND THE FUTURE

As true estimation of the measure or degree and intricacy of microbial ecosystems grows, we can begin to extrapolate how our new knowledge could shape our future. It is clear that microbes can influence their environments, and it is possible that they could be harnessed to engineer our planet and our health. Although our current knowledge of the metabolic mechanisms and evolutionary processes that underpin most microbial ecosystem changes is extremely limited, speedy progress in technologies advances that help illustrate these processes are set to drastically increase the present rate of knowledge acquisition. Microbial ecology is changing the way we practice medicine, so that instead of trying to deal with the one-disease-one-pathogen paradigm, clinical practice is adopting ecological approaches to diagnose and treat complex conditions [3]. Similarly, industrial

processes that once relied on biotechnology derived from a single organism are starting to embrace complexity and explore ways to standardize metabolic interactions within complex communities to elicit reproducible biochemical transformations [3]. Indeed, even agriculture and ecosystem restoration, which have long had a deep appreciation of the role of bacteria in shaping the relevant environments, are starting to use systems biology, molecular analysis, and modeling to elucidate the mechanism of action for improving crop productivity, disease suppression, and stress tolerance [3].

Many areas of research have come to appreciate how microbial communities can serve as tractable models. The exceeding population sizes and rapid growth rates of microorganisms is an indicator that microbial ecology may change the fields of ecology and evolution by providing a biological system that is easily manipulated to test specific hypotheses [3]. Likewise, the complex process of assembly of community, or community response to environmental disturbance (perturbations), can now be followed under controlled, replicated conditions in microbial mesocosms and microcosms. Together, these microbiome-enabled experimental approaches will help transform biology into a more quantitative discipline. With the ability to replicate and test eco-evolutionary processes, we can start to ask about the forces underlying these levels of biological organization [3].

8. CONSERVATION OF MICROBIAL DIVERSITY

According to Bhardwaj and Garg [6], the problem of biodiversity is importantly one of conflict resolution surrounding the human kind on one side and living organisms inhabiting different environment on other side. Having a knowledge on the effects of land use change on soil microorganisms is also a major conservation frontier [1]. Microbial diversity conservation requires certain specialized techniques for applications in reclaiming a degraded habitat. The following techniques (ex situ and in situ) can be used in biodiversity preservation.

8.1 Ex-situ Preservation

Preventing habitats destruction or degradation is one of the most important and active method of biodiversity conservation [6]. Bhardwaj and Garg

[6] reported that because of the uncertainties associated with *in-situ* conservation of microorganisms, ex-situ preservation plays a major role in microbiology and include the gene banks, culture collections and microbial resource centers forming the repository for microbial isolates and do away with need for costly and time consuming re-isolation protocols. Adoption of steps or policies for ex-situ conservation of biodiversity, preferably in the country of origin was strengthened by The Convention on Biological Diversity (CBD). The World Federation for Culture Collection (WFCC) and Directory of Collection of Cultures of Microorganisms supported the use of this approach [6]. Moreover four other associations that directed towards this effort are Oceanic and Atmospheric Administration for marine microbial diversity, National Institute of Health for deciphering the emerging microbial pathogen diversity, American Society for Microbiology and American Phytopathological Society [6]. The ex-situ collections of microorganisms form the key repositories of biodiversity and an important resource for the future as these could be linked to the research programs and developmental aspects of the country that owns it by integrating the microbiological aspects, molecular evolution, systematics and microbial chemistry with genome science. Enhanced funding of stock centers and greater emphasis on education and research in microbial systematics will amplify the broad base of research into microbial diversity [6].

8.2 In-situ Preservation

In-situ conservation is the preservation of biological resources in their natural occurring habitat. *In-situ* preservation involves on site conservation of the microbial flora. It involve the conservation of the ecosystems, natural habitats, maintenance as well as recovery of viable populations of species in their natural surroundings and or in surroundings where their distinctive properties have been established by them when it comes to cultivated or domesticated species. Conservation of all subsets of life existing in interplaying networks will lead to preservation of microbes as well [6]. Avoiding deforestation and encouraging trees planting (Aforestation) will protect the soil surface from erosion, which harbor's diverse microflora. Controlling pollution of water bodies such as oceans, river or lakes will preserve phytoplanktons, zooplanktons (rotiferans, microalgae, diatoms, dinoflagellates) and other

floating microbes such as *Vibrio parahaemolyticus*, *Bacillus sp.*, *Spirillum sp.*, *Aquaspirillum sp.* and others [6]. Certain countries such as Italy, Canada, Brazil, Mexico, Chile, Argentina, are facing new kind of natural conservation on account of widespread jungle fires [6].

The key factor to forest ecosystem function is microbial diversity. Bhardwaj and Garg [6] stated that large-scale endemic fires in Andes Mountain ranges increased the carbon content besides considerable increase in phosphorus, calcium, zinc and other trace elements. This contributed towards increase in number and variety of microorganisms in soil after second or third rains [6].

9. VALUES AND UTILITY OF MICROBIAL DIVERSITY

Man has no idea or has not perceived Microorganisms for numerous reasons, their contributions live the earth have not been well valued. The only aspect of their numerous actions that have drawn much concern is their ability to cause misery of disease and injury. Thus, they are closely connected with the health and welfare of human beings. Microorganisms are used in the production of curd, cheese, butter, wine, antibiotics (eg penicillin), manufacture of organic acids, alcohols and processing of domestic and industrial wastes. Man benefits from the activities of microbes almost at all-time [13].

Bhardwaj and Garg [6] stated that the direct value of microbes rests in their utilization in biotechnology, as single cell protein products, as biofertilizers, while indirect value involve their role as decomposers and involvement in recycling of plant and animal matter, as indicators of environmental pollution, as bioremediation agents and in other subtle functions of human life.

9.1 Major Applications of Microbial Diversity in Natural Ecosystems

According to Bhardwaj and Garg [6], microbial diversity existing in natural ecosystems has the following major applications:

9.1.1 Cycling of matter: Biogeochemical role

Soil acts as the source of nutrition for the growth of a spectrum of microorganisms which have

remarkable ability to degrade a wide variety of complex organic compounds due to their metabolic variability. Microorganisms helps in recycling of organic nutrient (phosphorus, oxygen, carbon, nitrogen and sulphur elements) and replenishing the environment with these by degrading substrates obtained from dead and decaying plant and animal remains [6]. Microorganisms act as active decomposers and scavengers to mop up the biosphere. Thus, the replenishment is vital on account of reuse of vital elements [6].

9.1.2 Sustainable land use

Microbes perform essential functions in maintaining soil fertility. They can act as indicators for assessment of sustainable land use in space and time. A combination and improvement of many notions of sustainability may help acquire an incorporated signal of functional ecophysiology of microbiota. Human activities (addition of pesticides) affect the microbial components of an ecological niche and at the same time have effect on biotransformation reaction occurring in soil. Application of pesticide affects or slow's down major processes as sulphur oxidation, nitrification and nitrogen fixation [6]. Bhardwaj and Garg [6] stated in his work that although plant physiologists sometimes view soil as simply a source of nutrients to plants, it is actually a complex ecosystem hosting bacteria, fungi, protists, and animals. Bhardwaj and Garg [6] again reported that, Gadd reviewed the metal tolerance of Vasicular -Arbuscular Mycorrhiza (VAM) fungi at heavy metal contaminated sites [6]. Bhardwaj and Garg [6] reported large effects of mycorrhizae as in increasing accumulation of Cu, Ni, Pb, and Zn in grass. *Ehrhartia calycina* have been found, especially at low soil pH [6].

According to Lladó et al. [21] fungi are considered the main decomposers in forest soils because of their ability to produce a wide range of extracellular enzymes that allow them to efficiently degrade the recalcitrant fraction of dead plant biomass. Moreover, mycorrhizal fungi play a pivotal function in Nitrogen and Phosphorus mobilization and sequestration in the forest soil and are also determinants for significant soil transport of Carbon [21].

9.2 Microbial Products for Agriculture Purposes

Application of fertilizers that are produced by non-renewable and constantly depleting

petroleum based feed stocks are depended upon by modern agriculture. Thus use of biofertilizers that involve a spectrum of microbes including members of family Rhizobiaceae, certain actinomycetes as *Frankia*, cyanobacteria, free-living or loosely associated bacteria as *Azotobacter*, *Azospirillum* and certain, phosphate solubilizing fungi help in bioameliorating the essential nutrients as nitrogen, phosphate to soil that in turn increases growth and yield of crop plants [6]. Bhardwaj and Garg [6] documented that the diversity of soil microbial communities can be key to the capacity of soils to suppress soil-borne plant diseases. Bhardwaj and Garg [6] further stated that the health of soil can be defined in terms of its microbiological capacity to suppress the activity of plant pathogenic microbes which could be general owing to aseptic activities of a myriad of undefined organisms or specific suppressiveness due to antagonism. Bhardwaj and Garg [6] reported that DAPG production by *Pseudomonas fluorescens* was reported to suppress rice bacterial blight in Indian. Hence, rhizosphere bacteria could be used as biocontrol agents for plant diseases. Kennedy isolated specific rhizobacteria and reported the management of weeds by these soil bacteria [6].

9.3 Biodegradation of Xenobiotics

According to [19], biodegradation is the biological catalyzed reduction in complexity of chemical compounds. Infact biodegradation is the process by which organic substances are broken down into smaller compounds by living micro organisms [19]. Chekol and Gebreyhannes [22] reported that human kind is increasingly using pesticides as BHC, DDT, 2,4-D,2,4,5-T for getting rid of unwanted weeds, insect pests or pathogenic microorganisms. Removing chemical from the environment can be achieved by ease and in environment-friendly manner by biological methods that involve use of microorganisms and plants to degrade a xenobiotic compound and thus decontamination of the polluted site (Bioremediation: the use of biological based processes to remove environmental pollutants) or purification of hazardous wastes in water (Biotreatment) [22]. Biodegradation is defined as a natural process whereas bioremediation is developed as a way to encourage or accelerate the degradation of pollutants (liquid and solid wastes, contaminated ground water, and toxic and hazardous products), which renders the site region free from contaminated soil and ground

water [22]. Bhardwaj and Garg [6] stated biological treatments are more effective as these methods change toxic chemicals to less toxic ones and have a significant degree of self-regulation. Microbes possess various capacities to bio-transform and, in some cases, to totally destroy toxic chemicals in our environment. These transformations alter the chemistry of the hazardous chemical, thus, they may also change toxicity, environmental fate, and bioaccumulation potential [6]. Many halogenated chemicals (chlorinated aromatic compounds), which are major contaminants, nitro-aromatics and other conjugated hydrocarbons-polluted contaminated sites could be recovered or restored by the use of the vanguard organisms isolated from contaminated sites by enrichment cultures [6]. Bhardwaj and Garg [6] reported that *Spingomonas paucimobilis* BPSI-3 that was isolated from Polychlorinated Biphenyl (PCB) contaminated soil was observed to degrade halogenated Polycyclic Aromatic Hydrocarbons (PAHs) and biphenyls. Bioremediation of petroleum hydrocarbon contaminates in marine habitats by anaerobic hydrocarbon metabolism via bioaugmentation and stressed to reject the approach of nutrient amendment as it can potentially exert as oxygen demand due to biological ammonia oxidation was also noted by Bhardwaj and Garg [6].

In nature, majority reactions result in mineralization of the contaminant, but sometime recalcitrant formed during the process act as potent toxic compound than the original xenobiotic chemical. According to Bhardwaj and Garg [6], *P. putida* and *Burkholderia cepacia* have even been genetically engineered to cover a wider range of contaminants though pseudomonads possess metabolic plasmids too. The use of recombinant field application vectors for PCB and non-ionic surfactant degradation, as single microbe hardly possesses all the enzymes for mineralization of a xenobiotic as stated by Bhardwaj and Garg [6]. Heavy metals serve as common contaminants and are threats to soil quality and sustainability of natural soil resource, recovering of this contaminated soil through *in-situ* bioremediation using microorganisms is a low cost and effective tool to reduce environmental pollution [6].

9.4 Industrial Application

According to Bhardwaj and Garg [6], biotechnology has a practical definition that "it is

application of power of microbe's biosynthetic capabilities to manufacture high-value products that are too complex for chemical synthesis by economically viable processes, resulting in value addition and financial gains". The standard definition of biotechnology is any technique that uses living organisms or substances from those organisms to make or modify a product, to improve plants or animals, or to develop microorganisms for specific uses [22]. Soil microorganisms have been reported by Bhardwaj and Garg [6] to have the most valuable source of natural products, providing industrially important antibiotics and biocatalysts. Bhardwaj and Garg [6] reported that the development of novel cultivation dependent and molecular cultivation-independent approaches has paved the way for a new era of product recovery from soil microorganisms. According to Bhardwaj and Garg [6] several microorganisms are extracted from soil and used in industrial production of various kinds as food processing and production, development of biocides and biocontrol agents, medicines and other natural products and pharmaceutical companies spend millions of dollars annually screening soil and litter for useful microorganisms.

The microbe itself could be a naturally occurring or even it could be genetically engineered through human ingenuity [6].

Chekol and Gebreyhannes [22] stated that with the recognition of the unity of biochemical life processes in microorganisms and higher forms of life, including human beings, the use of microorganisms as a tool to explore fundamental life processes became attractive due to the following facts: they reproduced very rapidly; they can be cultured in small and vast quantities conveniently and rapidly; their growth can be manipulated easily by physical and chemicals means; and their cells can be broken apart or the contents can be separated into fractions of various particle sizes. Microorganisms play domineering roles in biotechnology. Bhardwaj and Garg [6] reported that in recent years microbial enzyme technology has grown to a multimillion dollar industry and exploration of microbial strain for discovering enzymes with novel properties as well as in discovery and production of other pharmaceutical products.

Bhardwaj and Garg [6] again stated that discovery of several novel genes isolated from new microbes provided phylogenetic similarities

in divergent groups of microorganisms. Thus such information opens new ways to analyze and classify microbes on basis of new advanced methods [6]. The ten most clinically important human pathogenic bacteria include approximately 1,500 to 6,000 genes. Thus deciphering the vital genes (genes that produce proteins required for growth and survival of bacteria) would open the process of production of new antimicrobial compounds inhibiting the growth process [6]. Bhardwaj and Garg [6] reported that a new programme Via Gene has been devised that predicts the essentiality of bacterial genes using a combination of DNA sequence descriptors and cutting edge pattern recognition methods. The oligophilic bacteria could be used as tools to monitor asepsis in pharmaceutical production units. Bhardwaj and Garg [6] again submitted that a new area of interest and rediscovery is phage therapy that involves the use of bacteriophages for therapeutic measures i.e. for control of pathogenic bacteria in several countries of Eastern Europe and former Soviet Union. Biotechnologically phages could be utilized for control of environmentally problematic introduced genetically engineered microbes [6].

10. CONCLUSION

Microorganisms are described as the pillars of life on earth. Their ability to perform numerous functions essential to life stimulated the vigorous pursuit of their exploration and the incite to the study of their diversity. Their multi-functionality in maintaining ecosystem's functions which serve as the basic life supporting system cannot be overlooked. Fundamental life processes studies are made easy and interesting due to the exceptionality of microorganisms. The diversity of soil microorganisms has been known to perform several roles like suppressing soil borne plant diseases, and maintaining soil nutrient. Environmental friendly methods of removing chemical contaminants from the environment involves the use of microbes. There are indications or it has been shown that, exploration of microbial world and it's diversity would further be beneficial to not just humans but also to ecosystems that serves as life supporting units.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Pajares S, Bohannan BJM, Souza V. Editorial: The role of microbial communities in tropical ecosystems. *Front. Microbiol.* 2016;7:1805.
DOI: 10.3389/fmicb.2016.01805
2. Singh V, Joshi BB, Awasthi SK, Bhatt RP. Conservation of microbial diversity to sustain primary and secondary productivity. *International Journal of Agroforestry and Silviculture.* 2014;1:014-015.
3. Sean MG, Jack AG. Microbial diversity – exploration of natural ecosystems and microbiomes. National Center for Biotechnology Information. US National Library of Medicine 8600 Rockville Pike, Bethesda MD, 20894 USA; 2015.
4. Jeremias PP, Harry LP, Nieva K, Renata CR, Denize RZ, Lidia MF. Microbial diversity relevance and relationship between environmental conservation and human health. *Braz.Arch.Biol.Technol.* 2015;58(1).
5. Delgado BM, Fernando TM, Peter BR, Thomas CJ, Juan JG, Daniel E, Miguel B, Colin DC, Brajesh KS. Microbial diversity drives multifunctionality in terrestrial ecosystems. *Nat Commun.* 2016;7: 10541.
DOI: 10.1038/ncomms 10541
6. Bhardwaj V, Garg N. Importance of exploration of microbial biodiversity. *ISCA Journal of Biological Sciences.* 2012;1(3): 78-83.
7. Lodge DJ, Hawksworth DI, Ritchie BJ. Microbial diversity and tropical forest functioning. *Ecological Studies.* 1996; 122.
8. Jing X, Sanders NJ, Shi Y, Chu H, Classen AT, Zhao K, et al. The links between ecosystem multifunctionality and above- and below-ground biodiversity are mediated by climate. *Nat. Commun.* 2015;6:8159.
DOI: 10.1038/ncomms9159
9. Tripathi BM, Song W, Slik JWF, Sukri RS, Jaafar S, Dong K, Adams JM. Distinctive tropical forest variant have unique soil microbial communities, but not always Low microbial diversity. *Front. Microbiol.* 2016; 7:376.
DOI: 10.3389/fmicb.2016.00376
10. Colwell RR. Microbial diversity: The importance of exploration and conservation. University of Maryland Biotechnology Institute. *IndMicrobiol Biotech.* 1997;18:302.
Available:<https://doi.org/10.1038/sj.jim.2900390>
11. Macalady JL, Hamilton TL, Grettenberger CL, Jones DS, Tsao LE, Burgos WD. Energy, ecology and the distribution of microbial life. *Phil Trans R Soc B.* 2013;368:20120383.
Available:<http://dx.doi.org/10.1098/rstb.2012.0383>
12. Available:<http://www.sciencemathhistoryliteraturetechnologyhealthlawbusiness.AllSectionsElectronicEngineering/Sociology/2008EconomicCrisis>
13. Available:<http://www.peservearticles.com/biology/what-is-microbial-diversity/12363#>
14. Available:<http://www.learn.genetics.utah.edu/content/gsl/microbes/>
15. Torsvik V, Ovreas L. Microbial diversity and function in soil: from gene to ecosystems. *Curr Opin microbial.* 2002;5(3):240-245.
16. Yamanaka T, Helgeland L, Farstad IN, Fukushima H, Midtevd T, Brandtzaeg P. Microbial colonization drives lymphocyte accumulation and differentiation in the follicle-associated epithelium of peyers patches. *J Immunol.* 2003;170(2):816-822.
17. Bonkowski M, Roy J. Soil microbial diversity and soil functioning affect competition among grasses in experimental microcosms. *Oecologia.* 2005;143:232-240.
18. Scheffers BR, Joppa LN, Pimm SL, Laurance WF. What we know and don't know about Earth missing biodiversity. *Trends EcolEvol.* 2012;501-510.
19. Mercola J. The importance of microbial diversity in gut health and diseases. *Natural Newsletter;* 2014.
20. Jones SE, Lennon JT. Dormancy contribute to the maintenance of microbial diversity. *PNAS.* 2010;107(13):5881-5886.
21. Lladó S, López-Mondéjar R, Baldrian P. Forest soil bacteria: Diversity,

- involvement in ecosystem processes and respond to global change. *Microbial Moi Bio. Rev.* 2017;81:e00063-16.
22. Chekol C, Gebreyhannes M. Application and Current Trends of Biotechnology: A Brief Review. *Austin J. Biotechnol Bioeng.* 2018;5(1);1088.

© 2020 Onen et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:

The peer review history for this paper can be accessed here:
<http://www.sdiarticle4.com/review-history/52591>