Microbial Biodiversity and Sustainable Development

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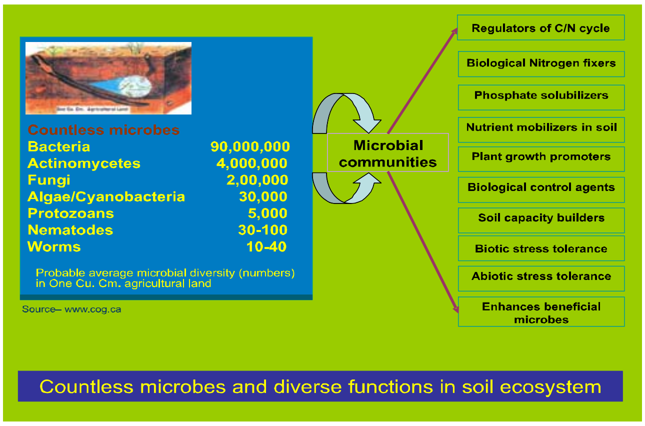
Microorganisms constitute a cosmopolitan, extensive and diverse assemblage of morphologically and physiologically distinct organisms such as bacteria, viruses, protests, fungi, nematodes etc. that provide their habitats functional and ecological characteristics. Many of them are somehow fuzzily described by their tiny, unseen size and their characteristics properties that they impart in nature. The prokaryotes, the oldest life forms and ancestors of all kinds of organisms on this Earth, were probably the first forms of the life. Prokaryotes with cells having hereditary information not bound by the nucleus (karyon) were existed twice longer (3.8 Ga=appx. 10^9 years) than eukaryotic organisms such as fungi, plants and animals (2 Gyr) in which the DNA is bound in a nucleus. Although the microbial type and composition and the various microbial processes that they impart may be different in different habitats, the functional activities and the quality of processes are almost similar. The prokaryotic abundance within the ocean and soil are estimated to be 1.2×10^{29} and 2.6×10^{29} while that on the ocean and terrestrial subsurfaces is 3.5×10^{30} and 0.25–2.5 $\times10^{30}$ respectively. This estimation of unseen majority of prokaryotes on the Earth represents the likely largest living surface covering this biosphere and this enormous interface between the living (biotic) and abiotic world is one of the major reasons in being their real wealth for this planet and for their significance in regulating several biogeochemical cycles and transforming organic matter.

Microorganisms that have evolved on the Earth at least 10^9 years earlier, have been privileged to provide conducive conditions on the planet that have cleared the roadmap for the survival of all the living creatures to come. It has always remained a question to what extent the diversity of prokaryotic life forms can possibly be correlated with that of enormous diversity of plants and animal lives? Now with the advent of modern molecular tools it can be answered that the microbial life forms can not be correlated with that of higher versions of life mainly because of their diverse life style and phenotypic nature, micro-level size, high level of existence in terms of numbers, continuously changing behaviour in the environment, and complex functional properties in terms of metabolic capabilities, adaptations and survival strategies and mechanisms in many harsh conditions. Thus microbial diversity with its own biosphere, interactions and ecology is among the one of the most fascinating areas today for the researchers that has many hidden things to uncover.

Majority of microbes are also associated with plants and animals, not only as pathogens but as associative organisms as well that mutually benefit each other. Such associations are under strict scientific investigation in these days to get answers about significance of the multitrophic interactions with plants and animals and survival and performance under a given ecological niche. The kind of interactions within the microbes and their hosts and non-hosts and within the biotic communities and abiotic components represent a classical ecological relationship constitutes the basis of cooperative and constitutive livelihood in the natures that leads to benefits in many cases but to losses in others. The associations of microbes with the hosts and other habitats are critical determinants for many issues related to the quality of the ecological success, impact of environment, global climate change, production of greenhouse gases, quality of human, plant and animal



Countless microbes and diverse functions in soil ecosystem

health, and finally loss or gain in agricultural productivity and food.

Microorganisms find their home in numerous diverse conditions, they can thrive well in the most natural habitats but, at the same time, they can live happily in the extreme heights of physiological environments like colds, high temperature, frost, hot springs, droughts, acidic and salinity conditions. These organisms have many unexplored and hidden things to tell since they have faced a lot of diverse conditions during their evolutionary track and this make their communities so diverse that even in the era of most modern instrumentation backup, we could only predict their presence up to only 1% and rest 99% are predicted to be unexplored. One gram of the soil may harbor up to 10 billion microorganisms of possible of thousands of different species and with this huge microbial dynamics, soil ecosystems are to a large extent uncharted. This is also true for the aquatic systems especially marine ecosystems, which cover more than 70% of the Earths' surface. Microbial diversity poses great complexity, divergence and variability at different levels of biological parameters, especially in terms of genetic variability within taxonomic groups (genera and species), number (species richness in confined region), relative abundance (evenness) of taxons and functional groups (guilds) in communities. Spatial and temporal patterns of microbial diversity are also obscure and therefore, estimating prokaryote diversity in natural ecosystems is a priority in current ecological research. Other important aspects to be addressed are the range of the processes, complexities of the multitrophic interactions and final benefits (functional aspects) of the whole community level characterization to the plant, soil, and other organisms living together.

The hidden base of the plant system thrives in a diverse, ever changing environment of microbial communities including bacteria, fungi and other microbes living side by side and approaching each other in lieu of their own betterment. Thus the area of soil surrounding the root zone is an unique place of physical, biochemical, molecular and ecological interface through which the roots and microbes in the surroundings are gaining their nutrition and health supplements. This zone, the so-called rhizosphere is supposed to be self-regulatory by secreting/excreting numerous chemicals in the surrounding soils, which, then attracts of many microbial communities to survive there, and in return, keep plants healthy by many known mechanisms. It is estimated that nearly 5-21% of the photosynthetically fixed carbon materials is eventually excreted/secreted in the rhizosphere by the roots in the form of exudates. Because of a rich source of nutrition, rhizosphere constitutes an important region for different microbes to thrive and establish their communities there.

Marine microbial wealth is being studied far last few decades and recent reports of hitherto unknown groups like picoautotrophs such as *Prochlorococcus* have their significant contributions in the marine ecology. However, the information about the number of species in marine systems is still very limited and scattered. Assessing microbial diversity is a daunting task. Exploration, collection and conservation of microbial diversity is a topic of considerable importance and interest, not only from the point of view of defining the number of species but from the view of functional characteristics that they impart in nature.

Microbial communities : the well wishers of the Earth

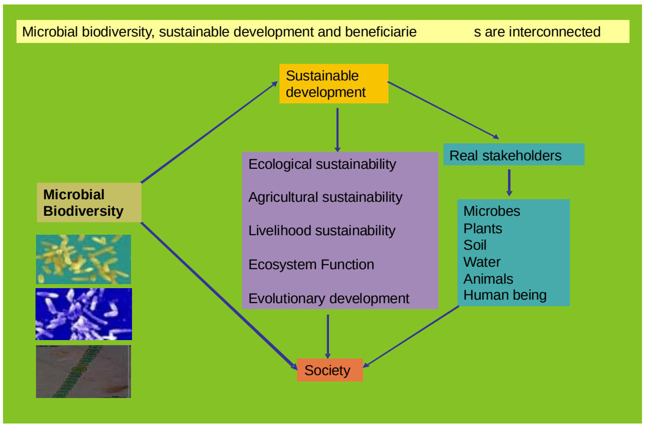
In any defined ecological condition, microbial communities are the important drivers of the ecosystem function and reflect their dominance in terms of the physical, chemical or biological properties they impart. They have a lot of functions to make the ecosystem functional and alive.

Soils cover almost all of the terrestrial area on Earth and have an indispensable ecological function in the global cycles of carbon, nitrogen and sulfur. Due to their physico-chemical complexity with many micro-niches, they teem with bio-diversity, both phylogenetically and functionally. A single gram of soil has been estimated to contain thousands to millions of different bacterial, archaeal and eukaryotic species interwoven in extremely complex food webs. Communities of soil microbes carry out a multitude of small-scale processes that underlie many environmentally important functions. However, the explicit functional and ecological roles of individual taxa remain uncertain because most microbes withstand laboratory cultivation. Therefore the most basic questions in microbial ecology "who is out there?" and "what are they doing?" are still often unanswered for many environments and for many microbial taxa. Ideally, especially the second question requires simultaneously information about the identity of taxa within a community and about functional processes performed. While soils seem to harbor the most complex microbial communities, these considerations apply to many other environments as well, like e.g. oceans and sediments.

The economic valuation of microbial diversity

The issue of resource valuation is a key variable in investment decisions. One aspect of the process of changing both government and local perceptions about the need to conserve biodiversity including microbial diversity is to show that the sustainable use of biodiversity has positive economic value. Greater understanding of the functioning of ecosystems combined with enhanced valuation techniques will have an increasing impact on national conservation strategies.

Benefits estimates can be important in showing that funds committed to conservation of microbial diversity and its use may be regarded as an investment that contributes to maintaining and enhancing the well being of communities and their economies. It can also be important in showing that the costs of proposed



conservation programmes are justifiable. Alternatively, such estimates can indicate the level of "cost of inaction", *i.e.*, the cost in terms of reduced or lost benefits if no action is taken to conserve biodiversity and use it in a sustainable way. The extent to which countries could bear the cost of conservation will depend on how fast and to what extent they will benefit materially from their microbial resources on a sustainable basis.

Biodiversity, including microbial diversity, is taken to satisfy human needs in two ways:

1. individual organisms that collectively make up the biota have specific properties make them of direct value in satisfying the consumption or production needs of society (and hence the demand for particular species); and
2. the combination of organisms and their role in sustaining biophysical cycles within the ecosystem.

However, in considering the problem of valuation, it is important to distinguish between three different concepts of value:

1. the first value corresponds to how the markets place value on the goods and services provided by biodiversity;
2. the second value is that which the individual privately places on biodiversity;
3. the third is a concept of social value which is the aggregate impact on the welfare of all

individuals in society, both now and in future.

The millions of independent decisions that are directly responsible for most of biodiversity loss that is occurring around the world are based upon the market values. Because the market value of biodiversity loss does not completely reflect all the changes in social welfare associated with that loss, the market therefore underestimates the true social value of biodiversity.

Direct economic value of microbial diversity:

Many direct economic values were derived from microbial diversity. Microorganisms are well established and becoming increasingly significant in national economies. They are used for food production and preservation, production of antibiotics, making of oral contraceptives and other medicines, manufacture of vaccines, management of pests and pathogens, bioleaching of metals, increasing soil fertility, generating biofuels, creating perfumes, monitoring pollutants, ridding coal mines from methane, cleaning up of oil spills, waste water treatment, assaying of chemicals and serving as tools for medical research.

From a cursory analysis of the top best-selling drugs, it is apparent that apart from treating important diseases:

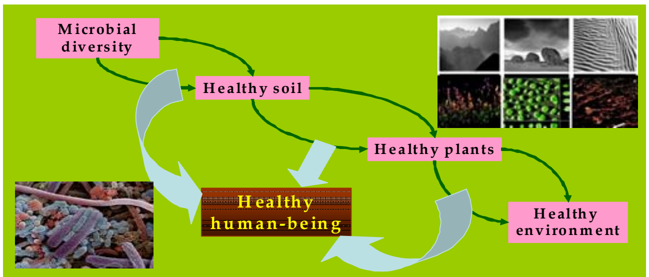
1. most of them are low molecular weight heterocyclic organic molecules;
2. a large number are enzyme inhibitors or receptor active compounds;
3. four of them are derived from microorganisms
4. none of the therapeutic products produced by recombinant DNA techniques are yet in the top 20 best-selling drugs.

Despite the fact that industrial and commercial application of microorganisms is responsible for products worth billions of dollars, there is good reason to think that we have barely scratched the surface of the range of microbial capabilities. The potential for microbial biodiversity to supply new and vitally needed medicines, fine chemicals and novel applications is enormous. Only a fraction of all microorganisms have been isolated, screened, identified and used, and vast numbers have yet to be recognized and have their genetic potential realized. The capacity of the genetic library to supply more of the same is still largely untapped and promises untold future benefits. Recently, scientists have found another medically useful compound, gliotoxin, among fungi which gave humanity penicillin and cyclosporin A. The latter is used routinely by surgeons to guard against rejection of organs by providing a way to make transplanted organs invisible to the body's immune system without compromising their other functions. Gliotoxin could relieve transplant patients of dangers of taking drugs (*e.g.* cyclosporin A) that suppress the immune system and expose the patient to a serious risk of infection. Gliotoxin also has characteristics that may make it a powerful tool in designing anti-cancer drugs.

Soil microbial diversity and the impact of agricultural practices

Microorganisms form a vibrant living community in the soil contributing to a number of nutrient transformations. They are involved in organic matter decomposition, N_2-fixation, solubilization and immobilization of several major and minor nutrients. Microbes also play an important role in soil structure maintenance, soil borne disease control and plant growth promotion through secretion of hormones.

The diversity and richness of soil microorganisms has been a fascinating subject for scientists over the years, but till today relatively little is known on the complex living biota in the soil and their biophysical



Microbial diversity in the rhizosphere directly regulate crop and soil health and thereby, influence environmental and human well-being. Belowground microbial communities has straight forward benefits for plants in a better supply of and access to the nutrients. Implications of such research are now coming in the benefit of farmers through commercialization of microbial products. The success stories with *Trichoderma, Beauveria, Pseudomonas* and other biological pesticides and biofertilizers are enough to justify these facts.

and biochemical functions in the soil ecosystem. But during the last 50 years, many beneficial effects of microbes in soil have been discovered and we have been making use of microorganisms for improving productivity in agriculture, industry and pharmaceuticals. With growing awareness on agro biodiversity conservation and management during the last decade, a parallel interest has been generated on understanding soil microbial biodiversity (SMD) as well. SMD is a vast frontier of potential gold mine for the biotechnology industry as it offers countless new genes and biochemical pathways.

The Challenge....

Study the physiology of microbial communities under a range of abiotic conditions to improve our ability to predict ecosystem function in the face of environmental change.

Emerging goals for microbial ecologists in 2010 onwards

Identify which microbes are active under different *in situ* conditions Understand the physiology and ecological roles of different microbial taxa. Measure and model how microbial physiology affects the dynamic response of ecosystem function to changing environments.

Two parameters become important while evaluating the significance of microorganisms in soil i.e., abundance and diversity. While abundance may increase or decrease over short periods of time in response to management practices and inputs, diversity is a more complex and stable attribute and reflects a state of near equilibrium. The latter is more important to understand the functional significance of microorganisms at a given site. High variation can be found for abundance between different soil types, seasons and land uses. In view of the large fluctuations and the undependability of numbers, microbial biomass is often used as a more reliable parameter to assess the abundance. In terms of biomass, fungi dominate in the soil followed by bacteria and actinomycetes. The total populations and live biomass are only reflections of the status of the soil at a given point of time, but do not give a clear picture of the living diversity as influenced by different land use practices over time. The greatest uncertainty in population counts is our inability in recovering all the organisms in the culture. Generally only about 5-10 percent of the organisms in the soil can be recovered through normal viable counts. Even direct counting methods do not reflect the true composition of the population in the soil.

Despite these limitations, conventional studies on soil microbiology have always relied on total population counts, enrichment and isolation of pure cultures to study their practical significance, estimation of microbial biomass and carbon dioxide evolution. Only recently, studies on soil microbial diversity have been initiated using the standard methods developed for eukaryotes. Although diversity can be studied at the level of genera, species, community and ecosystem, species diversity is the most commonly studied parameter in the soil. Many indices have been described for assessing the species richness and evenness. More recently molecular genetics tools have also been used to study microbial diversity in soil.

Links between diversity and ecosystem functioning

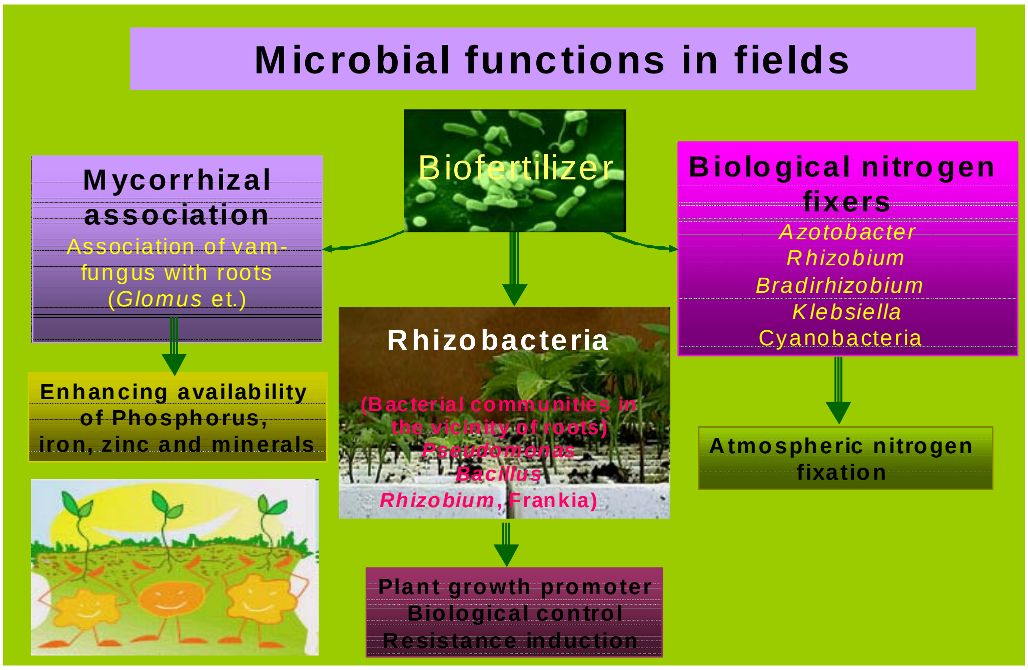
Ecosystem functions provided by microbes are the transformation of inorganic carbon into biomass by primary producers, nutrient regeneration and cycling, conversion of organic matter including humus that would otherwise be lost from the food web into living biomass, regulation of biogeochemical cycles and consequently climate. Functions such as degradation of organic matter (including oil or pesticides) require complex metabolic pathways. Microorganisms account for the main portion of the global metabolism (and biomass). Thus, also for functioning, the microorganisms might be the unseen majority. Moreover, by using molecular tools it has been recently shown that unicellular cyanobacteria in the ocean might fix molecular nitrogen and that aerobic anoxygenic phototrophs are abundant and diverse in the ocean. Together these unexpected and major findings indicate that our knowledge on species and functional diversity in ecosystems is rudimentary.

Diverse life forms for valuable functions

Microorganisms are involved in a number of biochemical processes that contribute to improved plant nutrient availability. These include 1) mineralization 2) nitrogen fixation 3) nitrification/ denitrification 4) phosphate solubilization 5) antibiosis 6) siderophores production 7) plant growth regulation and 8) induced resistance. Several groups of organisms act both competitively and synergistically to mediate the above processes. Soil and crop management research over the years has helped in understanding the impact of various natural factors and agricultural practices on the population and diversity of microorganisms in soil. Soil management practices in general and those that influence the fertility in particular have an immediate impact on microbial population. General typical soil management practices and their impact on biotic activity have already been summarized. In view of the practical importance, most of the studies have been focused on agriculturally useful organisms like nitrogen fixers and phosphate solubilizers. Tillage, soil erosion, crop rotations, manuring, burning and pesticide application were the major agricultural practices whose impact has been studied in detail.

> One of the fundamental challenges in microbial ecology is to examine how microbial communities that differ in composition may also differ in function.

Species diversity at a particular site is not always related with the microbial biomass or carbon dioxide evolution, which indicates the total microbial activity. In general, cultivated soils have greater diversity than fallow lands. The impact of land use is highly variable. Each kind of vegetation (natural or crop) provides a particular substrate, which encourages some microbial species over others in the rhizosphere. Although several studies indicate that cultivation increases the population and diversity in soils, there have been few reports of increased population under minimum tillage with residue incorporation as compared to conventional tillage. However, this superiority was restricted to surface soil (0-75mm) and in deeper layers conventional tillage caused more population build up.



Soil biota influence soil properties through the formation of stable aggregates, bonding through fungal hyphae and polysaccharides, but accelerated erosion and loss of clay and organic carbon fractions can cause significant decline in microbial population and diversity.

The Need for more Accurate Economic Indicators

Our national accounting systems failed to reflect biological resources in national accounts. Economic growth is traditionally measured as a percentage of the Gross National Product (GNP). As the most visible and widely used measure of economic progress, the GNP plays an important role in national policies of international lending agencies. It is therefore a matter of concern if those accounts produce seriously distorted or inaccurate measures of economic performance as this could lead to misguided and ultimately unsustainable policies. That appears to be the case. These measures do not capture the real value of a nation's assets.

This difference in the treatment of biological resources and other tangible assets gives the wrong signals to policymakers. It reinforces a false dichotomy between the economy and the "environment" that leads policymakers to ignore or destroy the latter in the name of economic development. It confuses the depletion of valuable assets with generation of income. Thus, it promotes and seems to validate the idea that rapid rates of economic growth can be achieved and sustained by destroying the resource base. The result can be illusory gains in income and permanent loss in wealth. The gradual decrease in the future productive potential of biological resources should be reflected in national accounts by a depreciation allowance that amortizes the asset's value over its useful lifetime.

In all countries around the world, biological resource assets are legitimately drawn upon to finance economic growth. The revenues derived from resource extraction are used to finance investments in industrial capacity, infrastructure, and education. A reasonable accounting system would recognize that one kind of asset has been exchanged for another. Should a farmer cut and sell the timber in his woods to raise money for a new barn, his private accounts would reflect the acquisition of a new asset, the barn, and the loss of an old asset, the timber. He thinks himself better off because nowhere is the loss of a valuable asset reflected. This can lead to serious miscalculation of the development potential of biological resource-dependent economies by confusing gross and net capital formation. If the same farmer used the proceeds from his timber sale to finance a winter vacation, he would be poorer on his return and no longer able to afford the barn. But the present national income accounts would register only a gain, not a loss, in wealth. Thus, in biological resource-dependent countries, failure to extend the concept of depreciation to the capital stock embodied in biological resources, which are such a significant source of income and consumption, overstates the level and growth of income.

Changes in natural resource accounting that could remedy the problems inherent in the present system are required. Countries will have to modify their national accounts to integrate the costs of the depletion of degradation of biological resources into the decision-making process. Although the need for biological resource accounting is widely recognized, there remain questions regarding the most conceptually sound and the most practical method for representing in national income accounts the value of biological resources consumed or degraded and the economic costs of their degradation. Neo-classical economists say there are no methodologies to cost the total economic value of biological diversity.

The future

Although in some cases the price of a resource is a reasonable approximation of its value, this is not so in the case of microorganisms. A major reason is that markets for the ecological services provided by these organisms, now and in the future, do not exist. Estimates of the value in use of the services provided by ecosystems will depend on the understanding of what these services are. How best can the value of ecosystems (current or future) goods and services be accurately measured, quantified or predicted? This is an issue of global concern. For example, what is the value of saving millions of human lives or maintaining the soil fertility? Certainly the values are higher than those of the antibiotics, vaccines or biofertilizers.

Although the question of how to measure the economic values of biodiversity including microbial diversity is a task primarily for economist, there is a need to provide them with the background they require carrying out evaluation. An accounting of the full range of ecosystem benefits accruing to society is essential for understanding the economic implications of alternative use options for the system. Although estimation of direct use values is a long established area in resource economics, much less attention has been paid to indirect use values. Valuation of ecosystems services and functions is the interface and involves conceptual linkage between ecology and economics.

To help economists, we need to know much more on:-

1. components of species habitats that is crucial to habitat existence;
2. effect at the ecosystems level of the loss of a dominant species;
3. mixing of species which are necessary for ecosystems functions;
4. critical sizes of various ecosystems for sustaining biodiversity and ecological services;
5. significance of interconnectedness of various ecosystems;
6. effects of the reduction of biodiversity in an ecosystem on the functioning of the system;
7. role of species diversity in ecosystems integrity and resilience;
8. ecosystem types or biomes critical to biodiversity conservation;
9. interactions between terrestrial and aquatic ecosystems;
10. ecological services critical to the maintenance of the life-support systems;
11. relations between biodiversity, standing biomes and productivity of ecosystems;
12. species interactions and interactions between organisms;
13. habitat specificity;

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