Environmental Biotechnology
Prof. Pinaki Sar
Department of Biotechnology
Indian Institute of Technology, Kharagpur

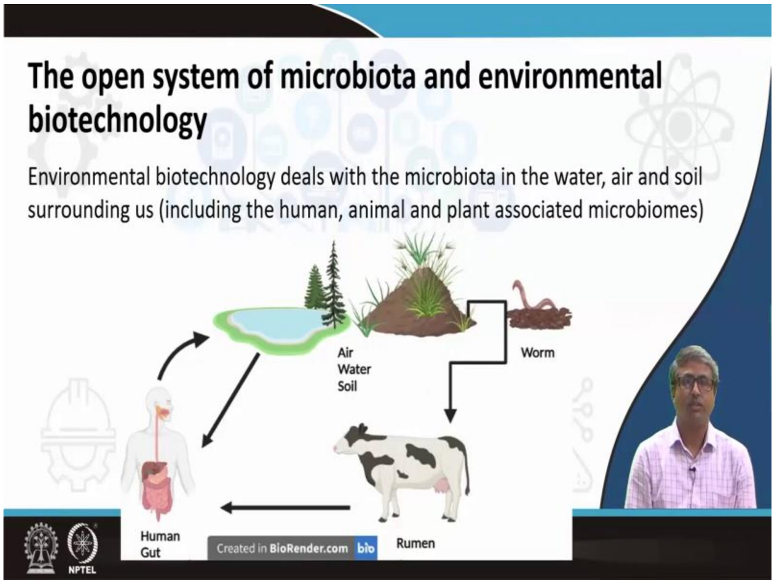
Lecture – 09
Microbial Ecology and Environmental Biotechnology - Part A

Welcome to today's lecture on Microbial Ecology and Environmental Biotechnology Part A, for this NPTEL online course on environmental biotechnology.

(Refer Slide Time: 00:45)

So, in today's lecture we are going to cover the following concepts. Firstly the open system of microbiota and environmental processes in biotechnology will be discussed. This will be followed by interrelation between microbial ecology and environmental biotechnology and then the conceptual paradigm for gaining better insights into the microbial control of the environmental processes will be highlighted.

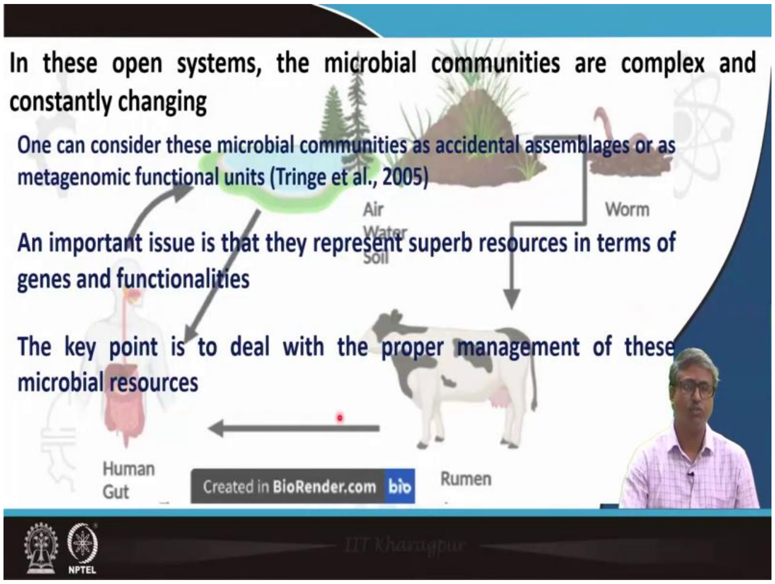
(Refer Slide Time: 01:20)



So, let us begin with the concept of microbial resources and environmental continuum. As we all understand that microorganisms occupy all niches around the biosphere including the air, water, soil systems within animal and plant bodies. And these microbial communities or microbiota represent an open system and in environmental biotechnology these open systems which are present across the domains of the plant, animal and also the surface water terrestrial deep subsurface habitat and even within the worms and other animals are all exploited.

Environmental biotechnology in this in this regard deals with the microorganisms which are present in all these environment I repeat the water, air, soil surrounding us whatever environment we have around us including the animals of course the human and also the plants within which we have numerous microorganisms as endophytes and epiphytes. And during this course of environmental biotechnology application and environmental biotechnology research we have understood that microorganisms living around the different domains of this biosphere can be utilized as potential resource for addressing different issues relevant to environmental biotechnology.

(Refer Slide Time: 03:17)



And together these represent a number of open systems because they are continuously interacting with each other. Now in these open systems the microbial communities are complex and also they are constantly changing. As you can understand the microbial communities within the water bodies within the forest within the soil ecosystem in and around the other environment where lower eukaryotic organisms are surviving and even within the different animal systems animal body like women and also within the human body including human gut and other parts of the human body wherever microorganisms have been reported to occupy as part of human microbiome.

They all represent these open systems which are significantly complex and also they are exhibiting a dynamic property that means they are changing constantly. Now, one can consider these microbial communities wherever they are maybe in water or in soil or in rumen or in human gut as an accidental assemblage or as meta genomic functional units. Regarding this meta genomic functional units and the concept of metagenome we are going to discuss shortly.

But in a very simplistic way while these microbial communities could be developed as aggregation of different microbial members microbial species which we can referred as an accidental assemblage which is then naturally allowed during the course of evolution. And acclimatization and other acceptance and other processes are allow to save the community. Or it can be interpreted as assemblage of numerous genomic units that is the genomes which together represent the meta genome.

Metagenome means the collection of all the genomes present within a particular environment within a particular ecosystem. Now important issue is that they represent these microbial communities within different habitats different niche they represent a superb resource in terms of the genes and the functionalities why it is so? Because no matter whether it is the ecosystem that we are talking about or the microbial ecosystem that we are talking about within the within the water system surface water system or within the ground water system or within the soil agricultural soil or within the forest soil or within the intestinal tract or other body parts of the of the lower eukaryotic organisms or in animals or within the plant bodies.

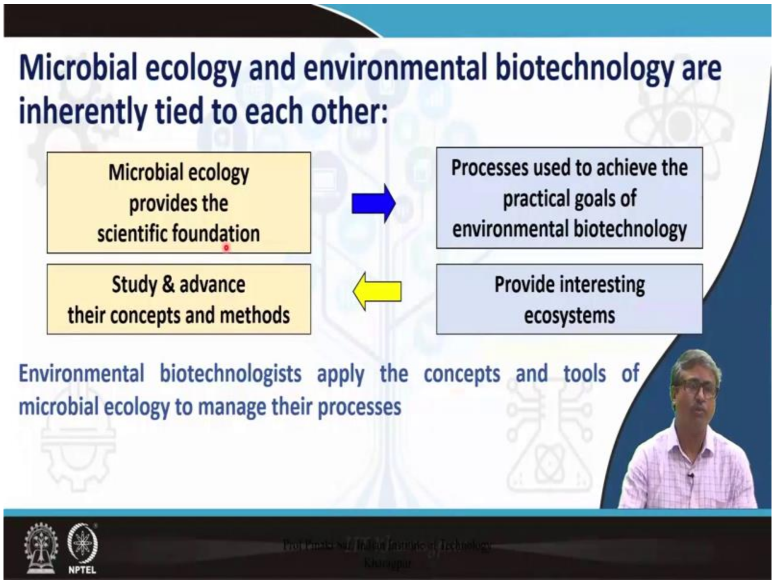
They are composed of at least few thousands of species members and each of these species members they have at least few 1000's or 1000's of genes within them. Now when we try to consider the collective effect of all these species together if we consider that there are 1000 species and each of them are containing few 100s or few 1000 genes together. Then this is going to give us a huge collection of genes and not only genes most of the genes are going to encode for some function. So, eventually is a huge collection of function.

So, eventually during the course of this course we will also learn and will try to discuss that in detail that in environmental biotechnology we are trying to exploit these huge resources which are hidden which is stored within the microbial communities because of this large assemblage of organisms their genes and other functionalities. Now the key point with respect to the exploitation of these resources is to deal with the proper management of these microbial resources.

There may be very useful set of genes or useful set of enzymes harbored by microbial community present within an agricultural soil but that has to be harnessed for agricultural purposes. There may be similar very important group of organisms or collection of genes present within a forest ecosystem but again that has to be used in order to achieve the better ecosystem services from the forest ecosystem community, microbial community of a forest soil.

Or it could be possible for a wastewater treatment plant where the microbial communities could be exploited to gain resources out of this wastewater treatment in terms of energy or in terms of other value added products.

(Refer Slide Time: 08:42)



Now microbial ecology and environmental biotechnology are inherently tied to each other how? Now if we look at this concept that microbial ecology provides the scientific foundation. It is basically dealing with the concept of how microorganisms are acting functioning within a particular ecosystem. So, basically it provides the scientific details about the functionalities of the micro organisms all the microorganisms together within a particular ecosystem.

Whereas environmental biotechnology deals with the processes that have practical goals we can have different practical goals different aims within the territory of environmental biotechnology. So the in different application these microbial ecology concepts are going to be utilized. So, this is one side of the interaction that microbial ecology provides the scientific foundation for its application in environmental biotechnology.

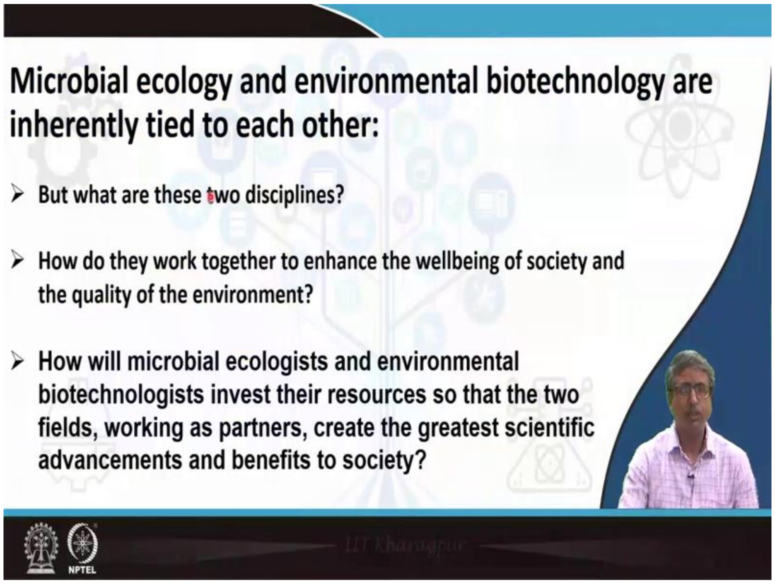
On the other hand environmental biotechnology provides the interesting ecosystem whether it is the case of an agricultural soil where we want to enhance the soil fertility or we want to manage the contaminants present in the soil or it is the wastewater treatment process where we want to increase the efficacy of the waste water treatment in terms of the major contaminants and as well as we want to produce certain valuable compounds from the wastewater treatment process microorganisms.

So, when we have such an ecosystem with us either its waste water treatment system or kind of an other contaminated soil or agricultural soil or a forest environment those environments those applications requirement provides a new requirement that we need to study and understand those ecosystem in a better way. So, that the concepts and the understanding are improved and then we try to evolve a better concept and better methods and then those could be implemented successfully.

So, this is kind of an both way interaction. So, where microbial ecology provides the scientific foundation to the environmental biotechnology which actually addresses or deals with the practical aspects the to achieve the practical goals on the other hand different environmental biotechnology problems like remediation of a landfill or treatment of a particular type of wastewater or sequestration of carbon dioxide from atmosphere.

All these provide new challenges in front of the microbial ecologist because they need to study those ecosystems and they need to develop concepts improved concepts or new concepts and incorporate new methods or improved methods in order to better understand and then implement those concepts into the achieving the practical goals of environmental biotechnology. Now the other aspect is this environmental biotechnology apply these concepts whatever concepts we learn from the microbial ecology and also the tools that we use or develop during our research and other efforts within microbial ecology area in order to manage the environmental processes.

(Refer Slide Time: 12:35)

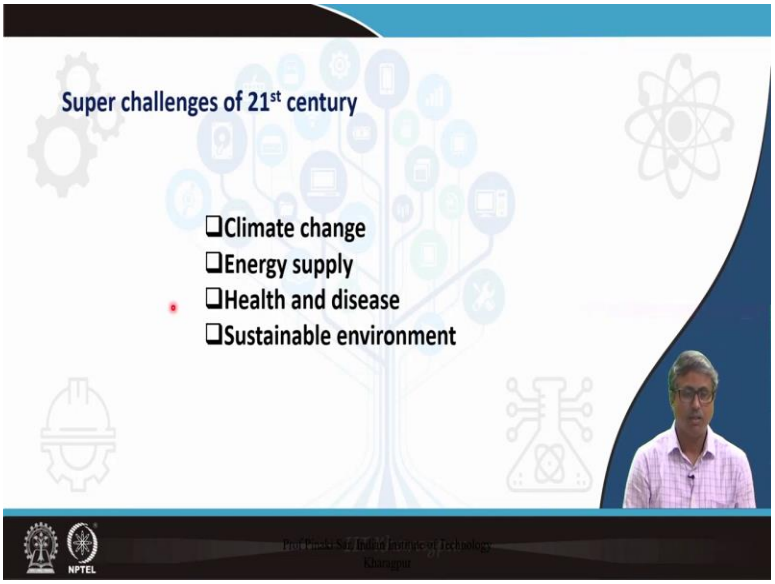


Now if we want to understand that how this microbial ecology and environmental biotechnology are tied together we need to first understand that what are these two disciplines this microbial ecology and environmental biotechnology. The second point would be that how do they work together because one environmental biotechnology deals with more like the application side of the processes and microbial ecology deals with the scientific foundation of the the processes which are performed by microorganisms.

Now we need to understand that how do these two things work together this science and the application to enhance the well-being of the society and the quality of the environment. And finally when we try to understand that how we can enhance the well-being of society and the quality of the environment after gaining the better insight or a better insight or into the microbial functionalities within a particular ecosystem.

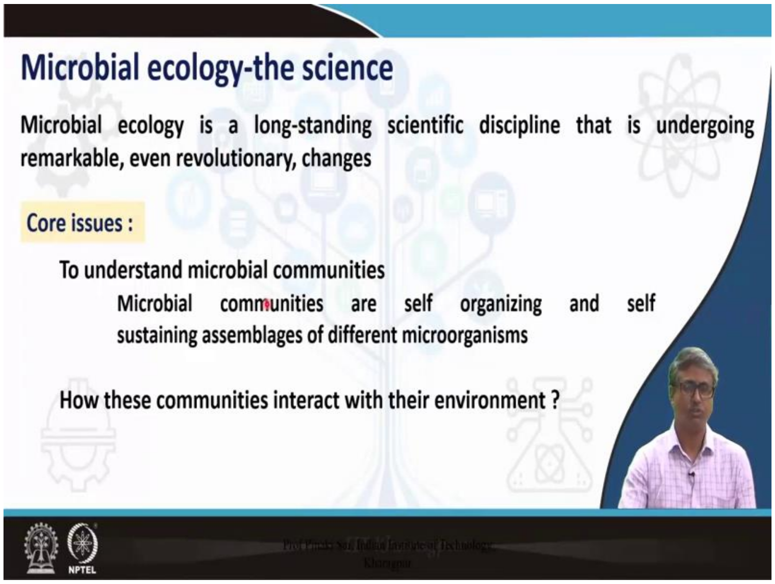
We need to understand that how this microbial ecologist and environmental biotechnologist invest their resources. So, that the; two fields working as partners create the greatest scientific advancements and benefits to the society. So, during this course of the lecture I am going to highlight some of the major aspects of these points.

(Refer Slide Time: 14:09)



So, before we enter into the details of the points we just remind you about the super challenges of this century. These are the climate change energy supply health and diseases and sustainable environment. So, when we talk about application of environmental biotechnology it basically provides the application for all these four major challenges. So, microbial ecology is providing the inner scientific core in our scientific basis which will armed environmental biotechnology to address the issues related to climate change, energy supply health and diseases and having a sustainable environment.

(Refer Slide Time: 14:50)



Now what is microbial ecology? So, microbial ecology is basically the science and it is a long-standing scientific discipline that is undergoing remarkable even revolutionary changes over the past nearly us 80 years or so. We see that it has undergone revolutionary changes. Now the core issues of microbial ecology are very well defined the first issue is to understand the microbial communities. So, whether it is agricultural soil a particular type of soil or it is a particular wastewater or an effluent or a river water.

A clean pristine river water or contaminated river water or it is a landfill or it is a ground water no matter what environment we are talking about we are researching on. In all such environments the microbial ecologists they try to understand the microbial communities. And now what is this microbial communities. So, microbial communities are basically self organizing and self sustaining assemblages of different microorganisms. So, here I would like to emphasize on two aspects.

One is the self organizing that means in any kind of environment the organization of the community that is what are the species members who will be present there and who will be more abundant than whom who controls this. So, it is kind of self regulated however it is highly governed by the local and regional environmental conditions or often geo logical conditions as well. So, you can say it is a geo environmental conditions which control the organization of the microorganisms present in a particular community.

So, firstly the self organizing: So, nobody directly dictates that what are the organisms will be present there. It is kind of a self evolving self controlling the microorganisms they themselves identify that this is going to be my suitable niche and other microorganisms also able to decide that whether the particular niche is suitable for them or not suitable for them. And the second aspect is the self sustaining.

Nobody is going to feed them it is the nature who is going to supply the inorganic or organic resources from which the microorganisms themselves will obtain their nutrients unlike the animals particularly the human that where we need to be provided with food and other facilities for our sustenance. Microorganisms are absolutely self-sustaining they are able to manage their necessary nutrients macronutrients micronutrients everything from the nature itself.

And then so the communities are self organizing and self sustaining assemblages of different microorganisms. So, when you say assemblages of different microorganism it gives us a sense that this must be collection of some species some members. So, do we have any definition any kind of quantitative understanding that how many organisms will be there? Yes, there are certain experimental evidences available which indicate that in a normal soil sample we can have up to 10 to the power 6 that is 1 million organisms present.

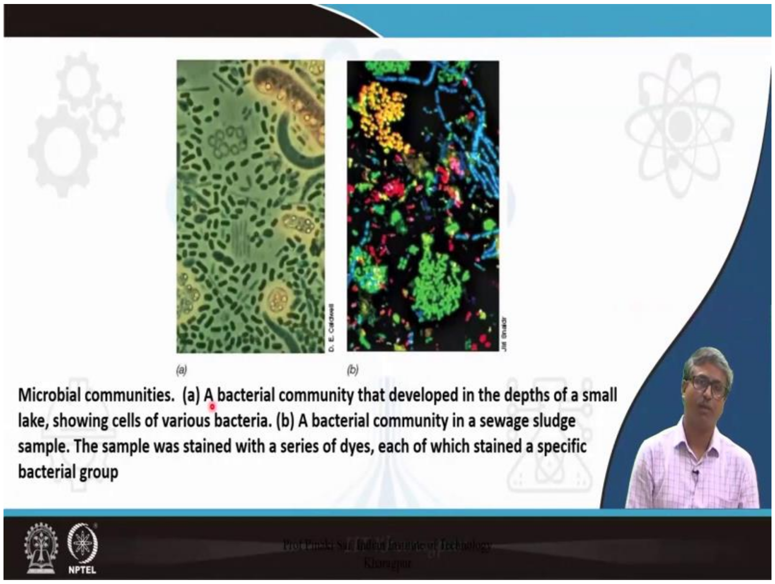
And these could be represented by around few 1000s up to 10000 or so different species members these are we are talking about mainly the bacteria and archaea. Mainly bacteria most of the environments we see the back it is dominated by bacteria except few extremophilic environment where archaea are also dominant. So, when we say assemblage of different microorganisms we are trying to emphasize on prokaryotic microorganisms that is mostly bacteria.

So, this different means it is truly different that means if I say that it is almost like 10000 different species. So, 10000 different species mean each of the species are different they have their genomes are different their genomic compositions the genes they contain the enzymes they the encode everything is different. So, their functionalities are different. So, if we have 10000 different species in any kind of given microbial community that means they ideally represent collection of 10000 different collection of genes or enzymes which is which is huge.

Now understanding that with respect to any particular community is a great task. So, we need to understand that it is not a very simple way of explaining everything. To understand the real complexity we need to really deploy very advanced and sophisticated methods because the number of organisms could be very high. The second aspect is that how these communities interact with their environment?

And when we say environment it is both the biotic and abiotic environment that means the communities are constituted by as I said let us say it is constituted by 5000 different species and each of the species members are at least few 100s of cells are there. So, these species member individual 1000s of species members they interact with themselves as we have learned during our ecological lectures they interact with themselves and also they interact with the physical or physic-chemical components of the ecosystem that is different electron donor electron acceptors, temperature, pH of dissolve oxygen concentration and many other such parameters.

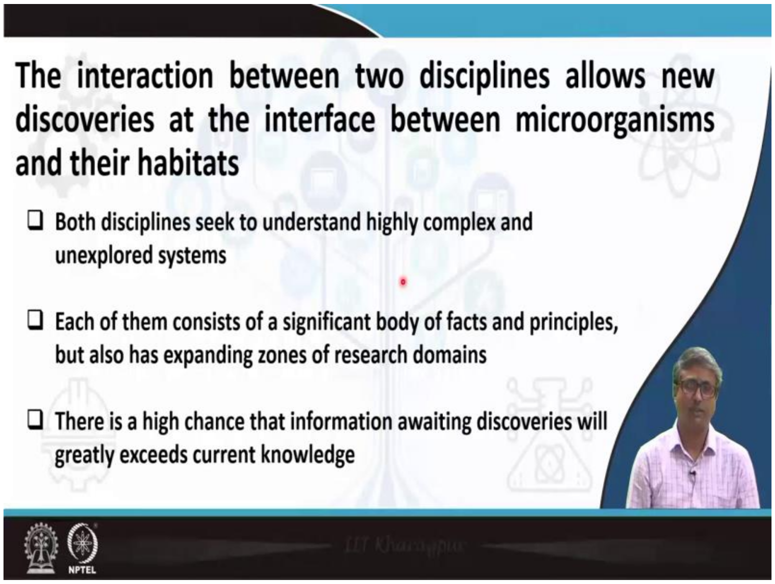
(Refer Slide Time: 21:02)



So, here are the two examples of the microbial communities. On the left a panel we have a bacterial community that developed in the in the depths of a small lake showing the cells of various bacteria as you can see taken by a normal light microscope. Whereas on the right side we have a bacterial community of sewage sludge sample the sample was stained with a series of fullers and dyes each of which stained with a specific bacterial group.

So, they these are stained with bacterial group specific dyes. So, that we can actually demarcate the presence of or we can see the presence and aggregation of different bacterial members within the sample and as you can see the red green yellow blue all these colors indicate the assemblage of different bacterial members bacterial taxa. And each of the taxa is actually demarcated or coated with or are or marked with a different fluorescent dye.

(Refer Slide Time: 22:01)

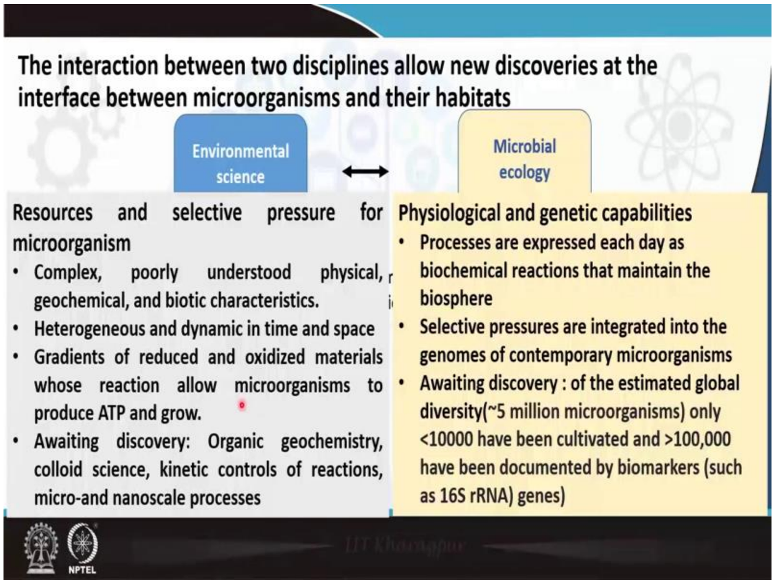


Now the interaction between the two disciplines allows new discoveries at the interface between microorganisms and their habitat. Now both disciplines that the environmental biotechnology environmental science and technology and the microbial ecology both of them seek to understand highly complex and unexplored systems. So, there are numerous systems where we want to expand or deploy the concept of microbial ecology and gain some kind of understanding and then apply those understanding for the benefit of the society or benefit of this planet.

Each of these systems consist of significant body of facts and principles including the environmental systems or ecological systems as well as the microbiological systems but also has expanding zones of research domains. So, we have some kind of knowledge base that we know certain principles certain facts which are applicable for a given microbial community or given environmental system as well as we have some scopes or a lots of scope for expanding our knowledge and understanding on every particular domains including the environmental domains or ecosystem domain as well as the microbial community domain.

Now there is a high chance that information awaiting discoveries will greatly exceeds current knowledge this is also very interesting because what we know currently may not be sufficient and it is it is. So, true that we started realizing that what we know is actually the tip of the iceberg. We know maybe 0.1% or 1% of the entire the microbial populations microbial community. And also the kind of functions they can execute the kind of changes they can brought within a particular environment remains totally unexplored.

(Refer Slide Time: 23:58)



Now let us look into this diagram that the interaction between the two discipline are depicted here. So, we have on the left side the the environmental science which is basically representing the biosphere habitats on the right side we have the microbial ecology or ecological systems which are naturally occurring micro organisms. So, within the environmental fields we have all the kinds of environment including the soil the water the waste water the river the any kind of environment where we want to understand the how the microbial processes are going to influence the environmental processes.

Now if we look at this environmental part these are basically providing the resources and selective pressure for the microorganism both. So, they are they are the house they provide the room for the organisms to live. They provide the essential nutrients but also they put tremendous pressure selective pressure who will thrive who will live in a particular environment and who cannot live in a particular environment who can live along with whom all these are dictated by these environmental conditions.

So, which basically is constituted by the complex, poorly understood physical geochemical and biotic characteristics. So, within any environmental setup wherever we are studying it we need to understand that these could be very complex and often they are poorly understood or they are incompletely understood and there could be many physico physical geochemical and other characteristics.

Heterogeneous and dynamics in time and space could be there. Gradients of reduced and oxidized material this is going to be very important in our subsequent understanding. That gradients of reduced and oxidized materials could be present or would be there and these the whose reaction allow the micro organisms to produce ATP and grow. So, it may be appearing to us that they are just some chemical species like iron or sulfur or nitrogen species.

But if we look very carefully some nitrogen compound like ammonia or some nitrogen compound like nitrate can behave differently or can control differently the microbial communities because nitrate can be utilized as an electron acceptor where as ammonia can be utilized as an electron donor. So, thereby the kind of microbial interactions they engage with will differ will depend on the kind of reduced and oxidized materials present within the environment.

And there are certain things which are avoiding discovery like the organic geochemistry, colloid science, kinetic controls of reactions, micro and nano scale processes. Similarly on the microbial ecology side we have the physiological and genetic capabilities which is including basically the processes which are expressed each day as biochemical reactions that maintain the biosphere.

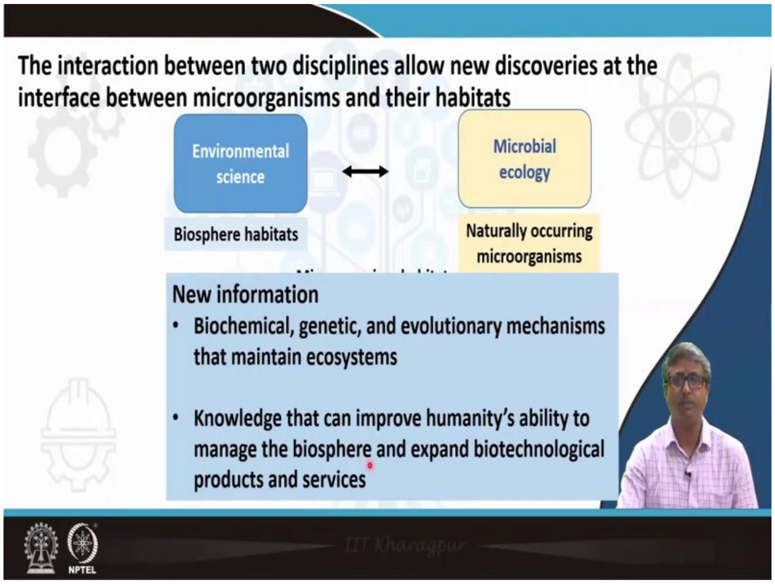
So, within any community within any microbial community we have numerous processes going on each day and that maintain that particular part of the biosphere. Selective pressures are integrated into the genome of contemporary microorganisms which are present there. So, if we have consistently low pH environment in a particular ecosystem we may expect that microbial ecology will try to adjust, will try to acclimatize, will try to control the species distribution in such a way that more organisms which are capable of withstanding low pH will proliferate in general.

So assemblage of low pH maintenance or low pH homeostasis genes or organisms who are capable of controlling the pH around their environment would be dominated. So, these are selective pressures which are eventually integrated the effect are integrated or effect can be seen within a within a genomes and avoiding discovery is a huge of the estimated global diversity of 5 million microorganisms.

We can see that only less than 10000 have been cultivated so, far. These are the number of species that we are talking about. So, out of so, many species which are which are expected that on our planet there could be around 5 million microorganisms only it is less than 10000 which have been cultivated that means these organisms are grown in the laboratory cultivated means grown in the laboratory under controlled organisms and they are ready for further investigation.

And in compared to that we have more than lakhs have been documented by biomarkers such as 16s ribosomal RNA genes we have several lacks of sequences which are representing the 16s ribosomal RNA marker gene sequences which are available in the database. So, this comparison just highlights that the point of discovery which is still awaiting. That we have few lacks of different or sequences biomarker sequences indicating that there could be so, many organisms present on a particular environment but when you look into the number of cultivated species these are so, less.

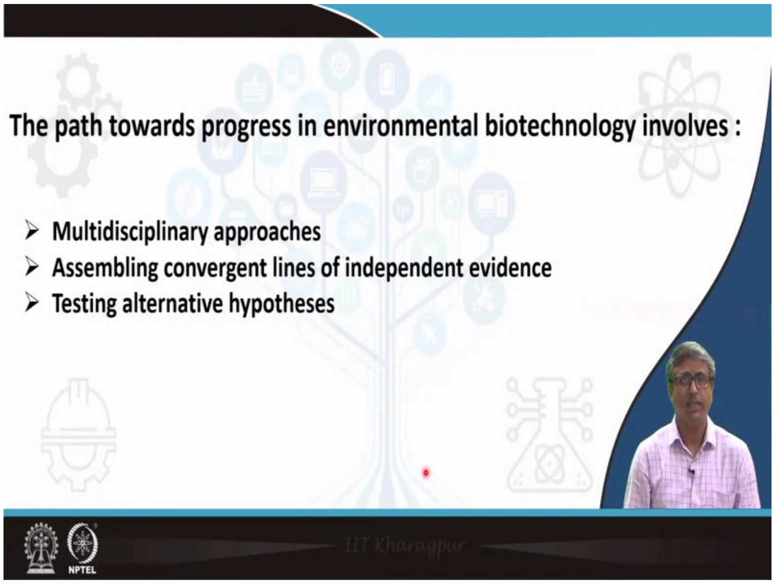
(Refer Slide Time: 29:25)



And this interaction finally is going to lead us to lead us towards new information what are these new information? These include the biochemical genetic and evolutionary mechanisms that maintain the ecosystems. And also the knowledge that can improve humanity's ability to manage the biosphere and expand the biotechnological products and services again that in the top of the mind we have the super challenges of this century.

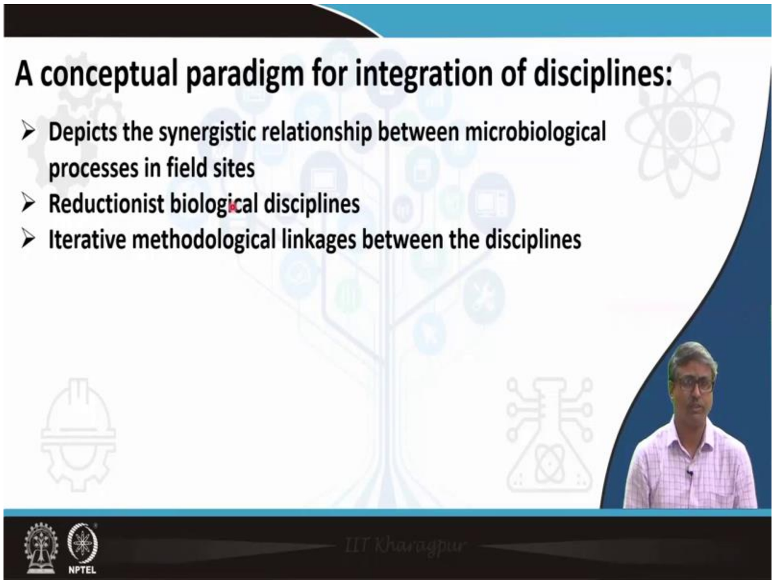
So, whenever we try to expand the biotechnological products and services we should keep in mind that we are targeting something on that line.

(Refer Slide Time: 30:07)



Now the path towards progress in environmental biotechnology involves multi-disciplinary approach, assembling convergent lines of independent evidence and testing alternate hypothesis because multiple processes are expected to be happening there.

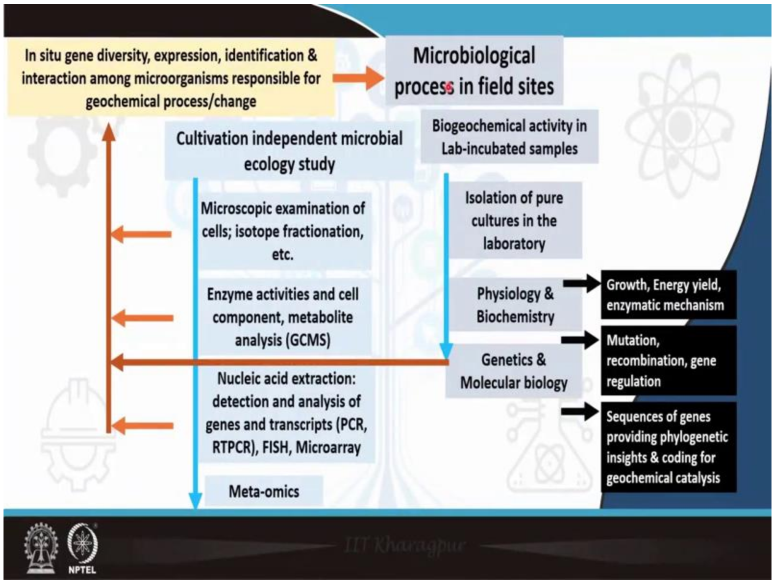
(Refer Slide Time: 30:20)



Now in the next few minutes I am going to present a conceptual paradigm for integration of the disciplines because it is truly very complex. So, it depicts this paradigm is going to depict the synergistic relationship between microbiological processes in a field site. Because as I mentioned there could be few 1000 different organisms different species each of them will having different sets of enzymes.

So their ability to function within a particular environment will be of course different. And so, a synergistic relationship must be maintained within that reductionist biological disciplines and iterative methodological linkage between the discipline. So, let us look at this.

(Refer Slide Time: 31:02)



So, we have a microbiological process that we would like to investigate in a particular field site. So, this is our sampling site or research site where the microbiological processes which are which are to be investigated. So, first and foremost important point is the biogeochemical activity monitoring in lab incubated samples. So, what are the activities biogeochemical activities this environmental sample environmental microbial communities are able to do that has to be studied using lab incubated samples.

Here sample refers to the samples collected from the field sites. These are not any individual singular bacterial species or microbial species. These are the samples the soil sample water samples which are to be incubated within the lab environment to understand the biogeochemical activity. Next we have two co two distinct but interrelated courses of action. The one is the isolation of pure cultures in the laboratory followed by investigating their physiology and biochemistry and then subsequently their genetics and molecular biology.

Now if we do this like isolation of the pure culture followed by their physiological and biochemical investigation this biochemical and physiological investigation will give us idea about the growth, energy yield, enzymatic mechanism etcetera carried to be carried out or potentially be carried out by these microorganisms. On the other hand the genetics and molecular biology experiments would provide us information about the mutation, recombination, gene regulation, sequence of different genes providing phylogenetic insights and coding for geochemical catalysis.

So, what are the reactions that keep that can be performed by these types these organisms which are isolated in the laboratory can be obtained when we do this analysis. On the other hand the cultivation independent microbial ecology study where we will not attempt to isolate any specific microbial species or any space microbial organism. So, it is basically done through a set of experiments where direct isolation of organisms are not involved.

But microscopic examinations of cells directly from the sample followed by isotopic fractionation etcetera are performed. We can use different fluorescent tagged probes to to identify different types of organisms. The next is the assessing the enzyme activities directly from the environmental sample and cell components, metabolites analysis through GCMS and other chromatographic techniques.

And finally the nucleic acid extraction based method where we extract the nucleic acid that is the DNA or RNA directly from the sample. And then detection and analysis of genes and different transcripts that is the RNAs are performed by PCR based or reverse transcriptase PCR based reactions fluorescent in situ hybridization and microarray are also applied. So, these steps totally avoid the use of the isolation of any pure culture bacteria.

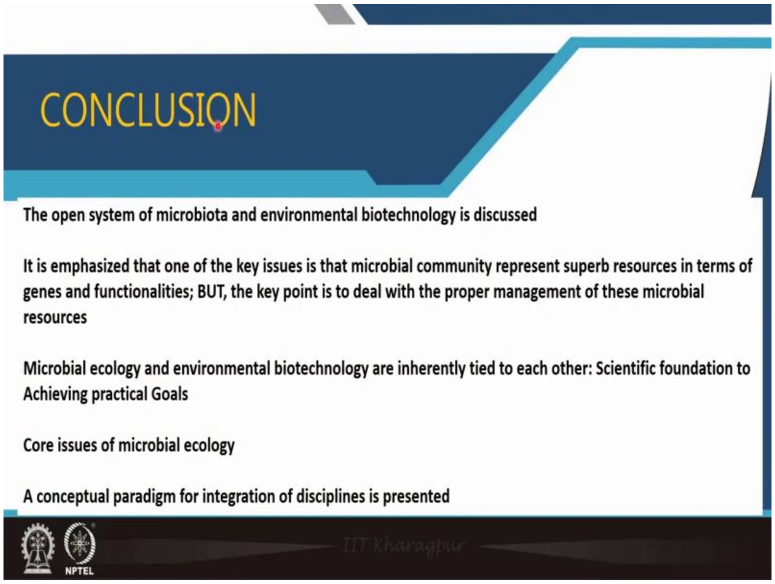
And finally the meta omics based approaches where we use either the meta genomics or meta transcriptomics or metaproteomics based concept using the sample as our resource. Now all these methodological steps eventually help us to understand the in situ gene diversity the what are the genes present there. How these genes are being expressed also it provides us the identification and interaction among the microorganisms present within the particular environment.

And also the organisms responsible for a geochemical process a particular geochemical process or geochemical change or multiple process or multiple changes.

(Refer Slide Time: 35:07)

So, this part of my lecture is for this part of the lecture the following references can be used.

(Refer Slide Time: 35:15)



And in conclusion the open system of microbiota and environmental biotechnology is discussed. It is emphasized that one of the key issues is the microbial community represent the supers resource in terms of genes and functionalities but the key point is to deal with the proper management of these microbial resources for their successful application in environmental biotechnology.

Microbial ecology and environmental biotechnology are inherently tied to each other one provides the scientific foundation and other helps us to achieve the practical goals. And the core issues of environment microbial ecology are highlighted. And finally a conceptual paradigm for integration of disciplines is presented, thank you.