# Review: Synthetic Microbial Consortia in Bioremediation and Biodegradation

**K.S. Adamu[1], Y.H. Bichi[1], A.Y. Nasiru[2], A.M. Babangida[3], M.M. Umar[1], G. Usman[4], R. Muhammad[5]**

[1]*Department of Microbiology, Faculty of Life Science, Bayero University Kano, Kano State Nigeria.*

[2]*Department of Microbiology, Abubakar Tafawa Balewa University, Bauchi state, Nigeria.*

[3]*Department of Biochemistry, Bayero University Kano, Kano State, Nigeria.*

[4]*Department of Environmental Studies, Ahmadu Bello University Zaria, Kaduna State, Nigeria.*

[5]*Department of Chemistry, Abubakar Tafawa Balewa University, Bauchi state, Nigeria.*

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**Abstract:** Since ancient times, we have worked with microbial consortia in a variety of contexts, including wastewater treatment, the production of biogas, additionally to biodegradation and bio cleansing. The great ability of microbial consortiums is, however, a very long way from being completely realized. Last few years have seen a surge in interest in biosynthesis and bioprocessing related to the understanding and use of microbial consortia. It can be difficult to implement complex tasks in a single population. Synthetic consortiums of microorganisms have long utilized in biotechnology procedures like waste management, agricultural farming, and fermentation. Today, microbial consortiums are being engineered for a range of uses by synthetic biologists. The division of collaborative work in consortia is crucial for the breakdown of environmental contaminants that are persistent, cultures need to be resilient to the complicated environment, which often needs several phases. As a result, bioremediation may greatly benefit from the use of synthetic microbial consortiums [1]. The created and improved synthetic microbial community can operate as a culture (seed culture) for ex situ remediation methods including biodegradation in smaller reactors and bio augmentation of in situ bioremediation practices. In order to prevent genetic contamination from environmental microorganisms, the use of designed microbial consortia is currently, to a large degree, restricted in carefully monitored bioprocesses. In this review, an overview of undefined naturally occurring microbial consortia and their application was discussed. We introduced the notion of synthetic microbial consortia, system biology, we discussed Importance of synthetic microbial consortia with relevant examples of how they add value to bio refineries. We did an overview of microbial consortia in biotechnological process, application of microbial consortia in bioremediation and biodegradation was further discussed.

**Keywords:** Synthetic Microbial Consortia, Bioremediation, Biodegradation.

## I. Introduction

The materials and energy cycle, as well as the ecological balance of the environment, are all maintained by microorganisms [2]. Bioremediation, which is one of the most affordable and secure ways to restore the environment, is being further researched as a result of increasingly sophisticated synthetic environmental toxins [3]. The field of synthetic biology which is an applied discipline that was created in the previous century and uses engineering ideas in the design of system [4]. Synthetic biology goals is to construct and tamper with biologically based components, systems, and technologies to produce novel functionality. Redesigning can also be done with it current biological original systems. The realms of energy, medicine, and environmental research all benefit greatly from synthetic biology. The creation of synthetic microbial consortia, or artificial consortia systems made by co-cultivating or co-growing two or more microorganisms in a particular habitat is a significant emerging field of research in synthetic [5]. Wide-ranging applications of synthetic microbial consortiums show how synthetic biology and microbiology interact. The design, assembly and improvement through optimization of artificial microbial consortium to perform certain roles are made possible by the quick development of synthetic biology.

In a variety of disciplines, including wastewater treatment, the production of biogas, as well as biodegradation and bioremediation, humans have dealt with undefined microbial consortia for millennia [6]. However, microbial consortia's huge potential is still far from being realized [7]. Biosynthesis and bioprocessing have recently shown a great deal of interest in the study and use of microbial consortia [8].

For programming innovative complicated behaviors and ideal properties for useful biotechnology applications, synthetic microbial consortia created using synthetic biology techniques would be an option [7]. A significant new area for synthetic biology, synthetic microbial consortia could carry out wild range of difficult tasks and also being able to withstand more variable settings than single

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culture [9]. By utilizing synthetic microbial consortia for bioprocessing, synthetic biologists hope to take advantage of these benefits [10].

When it comes to the detailed examination, blueprint, and assembly of mix cultures, scientists have made significant progress. The "973" project in China, "Design and Development of Microbial Consortia," was financed by the National Basic Research Program of China in January 2014. Attempting to suit industrial needs, this research set out to address basic issues in the engineering of both synthetic and natural microbial consortia. According to [11], significant advancements have been made in China in the study, design, and construction of microbial consortia for microbial fuel cells (MFCs), vitamin C fermentation, polyhydroxyalkanoate (PHA) generation, methane production, wastewater treatment, biodegradation, and other applications. As a potential alternative strategy for lignocellulosic biorefineries, synthetic microbial consortia are thus showing promise [12]. Superior skills in biosynthesis and biodegradation have previously been demonstrated by several synthetic microbial consortia.

In this review, an overview of undefined naturally occurring microbial consortia and their application was discussed. We introduced the notion of synthetic Microbial Consortia, system biology and discussed Importance of synthetic microbial consortia with relevant examples of how they add value to bio refineries. We did an overview of microbial consortia in biotechnological process, application of microbial consortia in bioremediation and biodegradation was further discussed.

## II. Naturally Occuring Microbial Consortia

The term "naturally occurring microbial consortia" refers to groups of microbes that live together in a certain setting. These consortia can be found in a variety of habitats which include soil, Polar Regions, water, deep sea vents, hot springs, etc. Early in the 20th century, Russian microbiologist Sergei Winogradsky made the discovery that microbes play a part in biogeochemical cycles, which led to the beginning of the study of microbial consortia. The idea of microbial ecology, which seeks to comprehend interactions between microbes and their environment, was developed as a result of Winogradsky's study [13].

The rumen of cows and other ruminants contains one of the best-known instances of microbial consortia. These animals can digest plant material that would otherwise be indigestible to humans and other non-ruminant animals thanks to the intricate microbial environment of the rumen. These microbial consortia have undergone significant research, which has sparked the creation of brand-new technologies for the manufacture of biofuels and other commodities [14].

As a result of their potential to be utilized in biotechnology, environmental cleanup, and human health, microbial consortia have attracted increasing attention in recent years. Microbial consortia, for instance, have been employed in the development of probiotics, the bioremediation of contaminated locations, and the treatment of wastewater. In general, research on naturally occurring microbial consortia is an active and fascinating field that has the potential to transform a wide range of scientific and technological sectors [15].

### 2.1 Types of Microbial Relationships and Their Application in Bioremediation and Biodegradation

There are several types of microbial relationships that are important in bioremediation and biodegradation.

Protocooperation: is a type of mutualism where two or more organisms interact in a way that benefits all parties involved. In waste treatment, protocooperation is commonly used in bioremediation and biodegradation processes to break down harmful pollutants into less harmful compounds. The use of bacteria consortia to break down hydrocarbons in oil-contaminated soil, is one example of protocooperation in bioremediation. In this process, different bacterial species work together to break down complex hydrocarbons into simpler compounds which are absorbed effortlessly by plants or further degraded by other bacteria. A research carried out by Zhang [16]. Showed that the use of bacterial consortia was more effective in degrading hydrocarbons unlike the use of a single bacterial species [16].

The use of bacteria and fungi in the breakdown of plastics, is another example. A research carried out by [17], revealed that a bacterial-fungal consortium was used to degrade polyethylene terephthalate (PET) plastic. The fungi were able to break down the PET into smaller compounds, which were then consumed by the bacteria. This protocooperation between the fungi and bacteria resulted in a more efficient degradation of the plastic compared to the use of either organism alone [17].

Mutualism: is a type of symbiotic relationship in which both organisms involved benefit from the interaction. In waste treatment, mutualism is commonly used in bioremediation and biodegradation processes to break down harmful pollutants into less harmful compounds. The application of microbial consortia to breakdown organic pollutants is one example of mutualism in bioremediation. In this process, different microbial species work together to break down complex organic compounds into simpler compounds that can be effortlessly consumed by plants or further degraded by other microbes. A research carried out by [18] showed that the use of microbial consortia was more effective in degrading organic pollutants compared to using a single microbe species [18].

Another example is the application of microbes and plants in phytoremediation. In this process, plants are used to absorb pollutants from the soil, and microbes are used to break down the pollutants into less harmful compounds. The plants and microbes benefit each other by providing nutrients and a suitable environment for growth. A research carried out by [19] showed that the use of plants and microbes in phytoremediation was effective in reducing the amount of hydrocarbons in polluted soil [19].

Commensalism: is a type of symbiotic association whereby one organism gains from the interaction while the other organism neither gains nor harmed. In waste treatment, commensalism can be used in bioremediation and biodegradation processes to extract contaminants from the environment. One example of commensalism in bioremediation is application of bacteria to extract heavy metals from wastewater. In this method, the bacteria attach to the surface of the heavy metal ions, and the ions are subsequently removed from the wastewater. The bacteria benefit from the availability of nutrients in the wastewater, while the heavy metal ions are removed from the environment. A research carried out by [20] showed that the use of bacteria was effective in removing heavy metals from wastewater [20].

Another example is the use of fungi in biodegradation processes. Fungi can break down complex organic compounds into simpler compounds that can be easily absorbed by other organisms. In this process, the fungi benefit from the availability of nutrients in the organic compound, while other organisms benefit from the breakdown of the compound. A research carried out by [21] showed that the use of fungi was effective in breaking down lignin, a complex organic compound found in plant material [21].

Syntrophism: is a type of mutualistic symbiotic relationship between two organisms in which both benefit from the interaction. In waste treatment, syntrophism can be used in biodegradation processes in eliminating organic wastes from the environment. One example of syntrophism in biodegradation is the use of anaerobic bacteria in breaking down organic compounds. Anaerobic bacteria use organic compounds as energy source and produce methane gas as a byproduct. However, some organic compounds are too complex to be degraded by one type of bacteria alone. In this case, syntrophic bacteria work in conjunction with the primary bacteria to break down the complex organic compounds into simpler compounds that can be used by the primary bacteria. A research carried out by [22] showed that the use of syntrophic bacteria was effective in breaking down complex organic compounds in wastewater [22].

Another example is the use of methanogenic archaea in the breakdown of organic compounds. Methanogenic archaea use the byproducts of syntrophic bacteria, such as hydrogen gas and volatile fatty acids, to produce methane gas. Methanogenic archaea benefit from the availability of these byproducts, while the syntrophic bacteria benefit from the removal of the byproducts from their environment. A research carried out by [23] showed that the use of methanogenic archaea was effective in the breakdown of organic compounds in wastewater [23].

## III. Synthetic Microbial Consortia

Microbial consortia are groups of microorganisms from different species that work together to produce lignocellulose biomass. They are often used in environmental engineering for wastewater treatment or bioremediation. They work in tandem, and joining non-compatible strains can result in competitive or even antagonistic behavior with negative effects on process efficiency. The presence of more than one organism can lead to the observation of population dynamics, which is necessary in order to measure and control population development and interactions within their configurations. As a result, a variety of approaches were developed to find solutions to population dynamics in co-cultures [24].

Biotechnology is a branch of biotechnology that uses the structure of microbial consortia to increase the efficiency of existing biological control schemes, and it is already being applied commercially in the context of sustainable agriculture. The proposed microbial consortia made up of carefully selected, well-characterized beneficial bacteria and fungi exhibiting different bio control strategies were analyzed in the present study, using the microbial library of the bio control company koppert biological systems.

### 3.1 Synthetic Biology

Biology synthetic genetic engineering was developed as a result of rapid evolution of biology for decades. It relies on recent advances in microbiology, molecular biology, and genetic engineering, as well as the extension of these fields by means of "sciences and methods" from chemistry, engineering, biology, and materials sciences." Synthetic biology uses all of the available genetic engineering techniques, but it aims at a faster and simpler way. It is best understood as a "unique term" that refers to a group of activities that ranges from the basic sciences to cutting-edge technology," rather than as a new scientific theory [25].

In application of engineering principles, synthetic biology is used to break down genetic information into DNA "parts," so that those parts can be understood in terms of how they can be joined to form desired work in living cells. Synthetic biology has the following characteristics: a shift from a discipline based on biology to one based on diverse scientific disciplines, a focus on standardization, modularity, and the rational design of organisms, among other things. Microorganisms are used in many synthetic biology to produce drugs and high-value chemicals. However, "advances in plant science are demonstrating that plants are much

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more effective and effective producers of chemicals, drugs, and vaccines than microorganisms or traditional chemical synthesis." The commercialization of plant-based synbio platforms is also on the horizon.

Synthetic biology addresses a variety of ethical, economic, and regulatory challenges. Synthetic biology has positive effects on society and wildlife, such as "cures for many illnesses," consistent supply of therapeutic compounds, and enabling the development of new organisms and products that are impossible to imagine. According to a proponent of synthetic biology, the method could benefit businesses and consumers by reducing price fluctuations, product availability, and quality that result from a dependency on natural resources. Synthetic biology can also contribute to the preservation and sustainable use of biodiversity by reducing pressure on some overharvested, unsustainably managed, or illegally sourced wild flora while still providing the market with the final product [26]. As synthetic biology becomes widespread, it is possible that methods can shift from large-scale cultivation of crops that have just one fragrance or flavoring to the cultivation of crops such as sugarcane, or any other crop that can be processed efficiently into a feedstock for microbial fermentations [27].

## IV. Synthetic Microbial Consortia in Biotechnological Processes

The term "synthetic microbial consortia" describes created basic microbial communities with a predetermined composition of two or more (usually two to three) species/strains. They show significant potentials in a range of technological applications, such as biological synthesis, bioremediation, and bio-enhancement.

### 4.1 Synthetic microbial consortia in environmental engineering

According to [28] artificial microbial consortia employed in environmental engineering produce biogas via anaerobic breakdown of surplus activated sludge from wastewater treatment combined with food residues. Syntrophic associations between methanogens and fermentative bacteria play essential roles in the synthesis of methane in anaerobic digestion, which is thought to be an environmentally beneficial and energy-efficient method for producing bioenergy.

### 4.2 Cyanobacteria/microalgae: pollutant removal

The ability of cyanobacteria and microalgae to convert or degrade contaminants is profitably used in bioremediation techniques of several contaminated environments. Microalgae, which may make up to 27% of microbial biomass present in all soils., and cyanobacteria, which are capable of fixing di-nitrogen, are both common in soil and aquatic environments [29]. These organisms help in both pollution detection and environmental pollution transformation [30].They have been connected to the metabolism of several organophosphate pesticides, including monocrotophos, quinalphos, and methyl parathion [31].DDT (1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane) poisoning of soil over time can affect the species composition of algae and cyanobacteria, which can act as helpful bio-indicators of pollution [32].Green algae (*Chlorococcum* spp.) turned DDT into DDE (1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene while cyanobacteria, particularly di-nitrogen-fixing species of Anabaena and Nostoc, preferred to transform DDT into DDD (1,1-dichloro-2,2 bis(p-chlorophenyl) ethane). Species differences can determine the toxic effects of pollutants and how they are transformed by cyanobacteria or microalgae. Given their capacity to break down hydrocarbons, Cyanobacterial mats in the Arabian Gulf Coasts following oil pollution had already drawn adequate attention [33]. Most of the oil's hydrocarbons were broken down, albeit slowly, by bacteria that were isolated from the blue-green Cyanobacterial mats that were forming on Kuwait's oily beaches. Black oil was digested by alcano-trophic bacteria, certain microalgae, and cyanobacteria even though the oil is poisonous to the algae [34].

### 4.3 Consortium of cyanobacteria/microalgae for pollutant removal: proof-of-principle

Diverse communities (consortia) are capable of carrying out multi-step processes that are challenging or even impractical for specific species or strains [7]. Living in close quarters can help individuals be more resilient to environmental changes, maintain personal stability, share metabolites during nutrient shortages, and fend off invasion by other species. The application of consortia of cyanobacteria/microalgae-bacteria for pollutant breakdown has been the subject of numerous proof-of-principle investigations.

### 4.4 Organic pollutants

Algal/cyanobacterial species can vary in their ability to produce O2, their susceptibility to contaminants, and their capacity to maintain bacterial symbionts in various ways. As an illustration, consider the algal-bacterial microcosms made up of the green alga *Chlorella*, the salicylate-degrading *Ralstonia basilensis*, the phenol-degrading Acinetobacter haemolyticus, the phenanthrene-degrading *Pseudomonas migulae*, and the phenanthrene-degrading *Sphingomonas yanoikuyae*.

### 4.5 Metal pollutants

Polysaccharides and carbohydrates with negatively-charged groups make up the cyano-bacterial and micro algal cell walls. The main mechanism for removing metal from wastewaters is the binding of the majority of metals to negatively charged ligand groups. Besides this method of metallic adsorption on surfaces of cells and extracellular polysaccharides, other methods include cellular absorption, integration into vacuoles or aragonite ($CaCO_3$) structures, and internal or external precipitation. Algal bloom in wastewaters offers a quick, sustainable method in removing metal contaminants. To this goal, a three-step procedure for the purification of uranium from wastewaters was described by [35]. Prior to the removal of U-algal particles from the water column to the sediments, the ligands in algal cell walls effectively remove U (VI) from wastewaters. The heterotrophic bacteria then use the carbon, nitrogen, and phosphorus from the dead algal cells to complete the final reduction of U (VI) to U (IV). Salicylate was discovered to be metabolized by the algal-bacterial consortium made up of *C. sorokiniana and R. basilensis*, which then removed heavy metals from the solutions (Muoz et al., 2006). At pH 5.0, the consortium is more effective in removing copper than the individual organism, but nickel, cadmium, and zinc were less effective. Heavy metals are removed from wastewaters using dried biomass made of cyanobacteria and bacteria, and metals are then recovered using desorption. In bacterial communities, metal tolerance is influenced by changes in genetic code, physiological adaptability, or the replacement of vulnerable species by resistant bacteria. The species makeup of the algal community and the genetic and physiological structure of bacterial populations are correlated with the reaction of bacteria to metals, but not with the quantity of metal pollution. Between bacterial and algal species, there is a significant and species-specific relationship [36].

### 4.6 Nutrient removal from wastewaters

Active sludge technique was perhaps the first significant application of biotechnology in bioremediation, and it is still a useful method for containing pollutants [37]. A microalga, Chlorella vulgaris Hamburg and bacteria from activated sludge combined to enhance the efficiency of waste stabilization ponds by removing organic matter, nutrients, and pathogens, increasing oxygen levels without the need for aeration, and effectively separating algal biomass through sedimentation [38]. Algal-bacterial consortiums are now used in facultative ponds and high rate algal ponds (HRAPs) as a result of numerous advancements. In HRAPs, the floccular biomass known as "ALBAZOD," which consists of bound-together zooplankton, bacteria, algae, and detritus, is most common. The total algal component and cellular dimensions of various organisms were altered in these floccular substances as a result of both environmental and/or pond operational changes [39]. In addition to serving the fundamental purpose of containment, many types of biological reactors now provide the ideal parameters of temperature, pH, oxygen transport, mixing, and substrate concentration for effective cellular metabolism. Both organic matter and ammonium were successfully oxidized by the *C. sorokiniana* -mixed bacterial culture from the activated sludge method in the tubular biofilm photo-bioreactor [40]. The biofilm photo-bioreactors are cost-effective and can remove up to 99% of NH4+, 86% of PO4+, and 75% of total COD from the environment. In order to eliminate highly loaded nutrients, [41] presented a hybrid bioreactor with efficiency of 81% for total phosphorus, 74% for total dissolved phosphorus, 82% for total nitrogen, 79% for NO3 -N, and 86% for NH4 +-N. Utilizing an algal-bacterial consortia for wastewater reclamation is an environmentally beneficial method that also involves the removal of nutrients from biomass.

## V. Application of Synthetic Microbial Consortia for Bioremediation

Microorganisms are present everywhere in the environment [42]. To survive and flourish in intricate microbial communities, the majority of them stick with one another. The structure and functions of the community are shaped by ecological interactions between species [43]. Microbial communities are better able to cycle nutrients and carry out complex tasks than single populations because of their diversity of roles and division of labor. Growing up in a mixed-culture setting also shows higher resiliency and resistance to environmental changes for individual members [44].The consortium-based concept, which relies on synthetic microbial consortia made up of two or more species performing favorable functions co-operatively based on the principles of microbial interaction in nature, has become promising for resilient and cost-effective biotechnologies. It was inspired by these distinctive characteristics of environmental microbial communities. Since ancient times, we have worked with microbial consortia in a variety of contexts, including wastewater treatment, the production of biogas, as well as bioremediation. The great potential of microbial consortia is, however, very far from being completely realized. Biosynthesis and bioprocessing have recently shown a large amount of interest in the study and use of microbial consortia [45-47]. For instance, a biorefinery that uses biomass as a feedstock can produce fuels and chemicals sustainably while reducing the climate impact that regular petroleum refineries create [48]. Considering how common lignocellulose is in nature, it is a cheap source of raw materials for biorefineries. To achieve stable and efficient biosynthetic use from cellulose-based feedstock, it is currently difficult to genetically engineer complicated pathways, such as cellulolytic pathways, like in model strains [46]. Thus, a promising alternative strategy for lignocellulosic biorefineries is the bioconversion of cellulosic biomass utilizing artificial microbial consortia [49]. In terms of biosynthesis and biodegradation, certain artificial microbial consortia have already demonstrated exceptional [50-53]. However, using the enormous potential of microbial consortia is hampered by the absence of rational design in these groups [54]. Yeast and Escherichia coli strains, which are frequently not found growing together in nature, are examples of model microorganisms that can be genetically engineered. [54 - 55] These organisms may lack cooperative and communicative genetic bases. To create a reasonable design of synthetic microbial consortia, it is still extremely difficult to understand the underlying molecular pathways among co-existing microorganisms despite substantial studies on microbial interactions. Understanding and using synthetic microbial consortia now presents potential problems due to the recent rapid development of omics technology as well as genome-editing techniques. Omics equipments provide researchers with comprehensive views of metabolic fluxes, growth dynamics, regulations in defined consortia and so on [56 -58], but further

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work is still required to identify specific genes/pathways and connect them between consortia members to achieve specific consortia phenotypes. The CRISPR/Cas-based toolkits also allow for quick and effective genome editing, transcriptional control, as well as high-throughput and trackable mutagenesis [59-63]. However, the machinery needs to be optimized, especially for non-model microorganisms. Engineering applications including the synthesis of biofuels and bioproducts and target biodegradation will be made possible by the integration and use in technical gears in synthetic microbial consortia (Fig. 1).

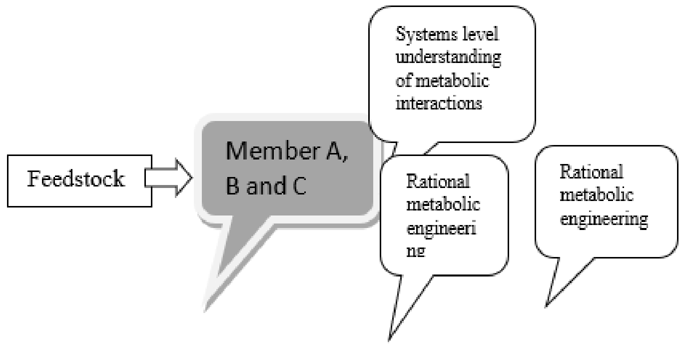


Fig 1: Microbial Synthetic Consortia for Bioremediation

### 5.1 Synthetic Microbial Consortia for Bioremediation or Biodegradation

Synthetic microbial consortia may play important roles in bioremediation as the division of labor in consortia is essential for the breakdown of persistent pollutants, which often requires multiple steps, and cultures must be resistant to the complex environment. The newly developed synthetic consortia can serve as a seed culture for in-situ remediation techniques such as biodegradation in smaller reactors and bioaugmentation of in-situ bioremediation procedures. Toto prevent genetic contamination from environmental microorganisms, the use of designed microbial consortia is currently, to a large degree, restricted in carefully monitored bioprocesses. In batch research, the dechlorinating bacteria *Dehalococcoides sp.* was inhibited by acetylene, a byproduct of tetra- and trichloroethene biodegradation, which was removed by cultivating an acetylene-fermenting *bacterium*, *Pelobacter*. The byproducts of acetylene fermentation served as a carbon and energy source for the dechlorinating bacteria's development [64] A consortium made up of the bacteria *Bacillus clausii T* and *Bacillus clausii* O/C, isolated from human probiotics, also reduced the toxicity of antibiotics and demonstrated a greater elimination efficiency of specific antibiotics than pure cultures. The consortium mineralized three PAHs with varying concentrations in 70 days on average. Additionally, compared to any of the isolates, the consortium demonstrated more efficient anthracene breakdown [62]. A defined microalgal-bacterial consortium that included the bacteria *Sphingomonas sp.* GY2B, *Burkholderia cepacia* GS3C, *Pseudomonas sp.* GP3A, and Pandoraea pnomenusa GP3B as well as the oil-tolerant *microalga Scenedesmus obliquus* GH2 effectively degraded the aliphatic and aromatic hydrocarbons of crude oil. This consortium eliminated almost all alkanes, alkyl cycloalkanes, alkylbenzenes, naphthalene, and phenanthrene among others [65].

## VI. Application of Synthetic Microbial Consortia for Biodegradation

Synthetic microbial consortia, like synthetic biology in general, are based on the design-build-test-learn (DBTL) closed-loop research paradigm and exhibit engineering characteristics. A genetically engineered group of microbial species known as a synthetic microbial consortium is designed to work together to perform specific activities, such as biodegradation [65]

Artificial microbial consortia may be utilized for biodegradation. We can create microbial consortiums via genetic engineering that can destroy a range of substances, including pollutants, plastics, and other difficult-to-degrade materials [66].

Utilizing artificial microbial consortia for biodegradation has less detrimental environmental consequences, uses resources more efficiently, and may be less expensive than conventional waste treatment techniques [67].

Synthetic microbial consortia can be used to biodegrade and convert a variety of pollutants and complicated mixed substances. These consortia, which are made up of fewer but very active species, can be used to either degrade or transform a variety of pollutants, such as vaporized organic compounds (VOCs), polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), polychlorinated naphthalenes (PCNs), polychlorinated biphenyls (PCBs) [68].

Synthetic microbial consortia can be used to hasten the biodegradation of resistant contaminants because of the faster growth rates, synergistic interactions, and metabolic diversity of microorganisms. Because bacteria have such a diverse spectrum of metabolic capacities, these consortiums can also be used for biotransformation. Biotransformation comprises the elimination of hindered groups from the contaminants by utilizing synthetically designed microbial consortia. Synthetic microbial consortia can easily be modified to fit a system's needs. They are therefore appropriate for a variety of industrial, agricultural, and environmental applications [18]

The synthetic consortium needs stability for long-term functioning maintenance, much like a natural community does. As a result, the community must be able to maintain itself or return to its pre-disturbance state [69]. Stability as a concept has many facets on its own. Popular stability metrics include resistance stability and resilience stability [70].

### 6.1 Ecological Restoration

The two main goals of restoration ecology using synthetic microbial consortia are the degradation of contaminants and the restoration of biodiversity. While pure bacterial systems may function well in the lab, they often encounter difficulties when used on real contaminated settings [71].

Synthetic microbial consortia may exhibit better adaptability and potentially greater breakdown efficiency than pure bacterial systems. Examples include the use of *Pseudomonas* sp. and *Acinetobacter* sp. XM-02 to treat alkane (diesel and crude oil) pollution [72]. *Acinetobacter sp.* XM-02 may degrade alkane on its own.

Alkanes cannot be broken down by *Pseudomonas* sp., but it can make surfactants that lower the medium's surface tension and increase microbial contact with the oil's surface. Alkane was broken down by the co-culture system at a rate that was 8.06% faster than by a single strain. Restoration of ecological variation can be accomplished, for example, by immunizing groups or species. Most often, it is employed to restore saline-alkaline or low-fertility soils. According to [73] mixing chitinolytic and halotolerant bacteria improved the efficiency of phytoremediation of saline-alkaline soil. Plant diseases are negatively impacted by halotolerant bacteria, and chitinolytic bacteria may be able to relieve salt stress in plants [74].

## VII. Conclusions and Future Prospects

The construction of synthetic microbial consortia is faced with several challenges; some areas that need improvement involve understanding naturally intricate communities, reducing mutation in genetically engineered consortia, and as well as controlling population composition. Future studies should focus on developing an understanding of microbial relationships and metabolic pathways in synthetic consortia for practical metabolic engineering design, developing cutting-edge, highly effective tools for genome editing non-model microorganisms, and creating low-cost gene-chip assays for controlled evolution in numerous communities. The development of systems biology, synthetic biology, analytical, and modeling techniques is crucial for the success of synthetic microbial consortiums. Synthetic microbial consortia won't fully demonstrate their power in biosynthesis and biodegradation, and other engineering applications, until we understand the codes nature gives microbes which allow them to build strong and stable associations.

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