

EFFECT OF PRISTINE SOIL ADDITION ON THE COMMUNITY STRUCTURE POST BIOREMEDIATION.

Abstract

The pollution of crude oil on agricultural soil has become a menace in the world today. The ecologically friendly approach of restoring this polluted soil back to its original state is pertinent. In this study, 1000 g of crude oil polluted soil was amended with 12.5g of cow dung and 500 g of unpolluted soil, 1000 g of polluted soil with crude oil without cow dung amendment, and 1000 g of unpolluted soil without crude oil and cow dung amendment was the control. The setup was monitored for their physicochemical parameters such as total petroleum hydrocarbon (TPH), polyaromatic hydrocarbon (PAH), temperature, pH, electrical conductivity (Ec), and total organic nitrogen (TON). The microbiological characterization for viable and culturable was done for total heterotrophic bacteria (THB) and hydrocarbon utilizing bacteria (HUB) while non-culturable but viable characterization was done using metagenomics-shotgun analysis to compare the changes in community structure before, during, and after remediation. The THB observed in the samples were 1.9×10^7 , 1.3×10^3 , 4.0×10^6 , 3.58×10^8 , 2.15×10^9 while HUB was 1.6×10^3 , 1.0×10^1 , 1.67×10^3 , 2.5×10^4 , and 3.55×10^4 respectively for A, B, J1, J2, and J3. Over 90 % removal of the TPH was achieved by the treatment. The molecular characterization showed that Proteobacteria was the dominant phylum identified in the pristine soil, but Actinobacteria were the most dominant in the soil with treatment. Nitrogen-fixing

Bradirhizobium elkanii was found to be 0.66%, 5.11%, 10.43% before pollution, during natural attenuation, and with unpolluted soil addition with cow dung amendment. Denitrifying *Nocardiodes daejeonensis* and *Nocardiodes terra* were identified at 0.1 and 2.0% respectively only three (3) months after the end of the bioremediation treatment.

Keywords: Bioremediation, Pristine soil. Biostimulation, Alpha diversity, cow dung, crude-oil pollution.

Introduction

In recent decades, contaminated land management has become a major concern in Nigeria and the world at large. Bioremediation is an internationally approved technology for cost-effective clean-up of oil-contaminated sites. These technologies involve enhancing the natural biological transformation of chemical petroleum-derived contaminants into less toxic and/or less mobile forms. These technologies are gaining increased attention due to their low cost and effectiveness (Kanissery and Sims, 2011). Bio-stimulation involves the modification of the environment to stimulate existing bacteria capable of bioremediation. This can be done by the addition of various forms of rate-limiting nutrients and electron acceptors, such as phosphorus, nitrogen, oxygen, or carbon (Kanissery and Sims, 2011).

Microorganisms play a major role in bioremediation and their absolute number can determine the overall degradative ability (Adeyinka and Urum, 2001). Bio-stimulation emphasis is placed on identifying and adjusting certain physical and chemical factors (such as soil temperature, pH, moisture content, nutrient content, etc.) that may reduce biodegradation of the contaminants by the indigenous microorganism in the affected site (Adeyinka and Urum, 2001)

The primary advantage of bio-stimulation is that bioremediation will be undertaken by already present native microorganisms that are well-suited to the subsurface environment and are well distributed spatially within the subsurface while the primary disadvantage is that the delivery of additives in a manner that allows the additives to be readily available to subsurface microorganisms is based on the local geology of the subsurface (Kanissery and Sims, 2011).

The soil is a dynamic natural body having properties derived from the combined effects of climate and abiotic activities (Nõges et al., 2016). The deliberate addition of microorganisms increases biodiversity at the site of the spill and helps in the study of the relationship between diversity and ecosystem service functions. It is imperative to understand the dynamics of the population of bacterial communities, what bacteria are present, in what numbers, and how these numbers change as a function of time in the soil (Hirano and Upper, 1991). Crude oil pollution affects not just the fertility of the soil, but it affects food production and leads to diseases and death of human beings and animals alike (Muzaffar et al., 2012).

According to Dhaliwal et al., (2020), different techniques have been proffered for remediating soils such as physical, chemical, and biological methods. These methods mentioned above are very expensive, not safe, labor-intensive, and require keen monitoring (Salleh et al., 2003). However, bioremediation is an easier, cheaper, and more eco-friendly approach and has shown to be efficient in degrading, immobilizing, or mineralizing hydrocarbon pollutants (Abatenh et al., 2017; Azubuike et al., 2016).

A more recent technique for monitoring pollutant degradation is metagenomics, which helps to analyze and decode the community DNAs (Bharagava et al., 2019; Aydin et al., 2016) and the

possible functional outcomes in that community (Pinu et al., 2019). An understanding of the community dynamics during bioremediation using metagenomics will give a clearer indication of what is responsible for the pollutant reduction during bioremediation and the restoration of biodiversity (Mani and Kumar, 2014).

Attention is mostly given to TPH reduction without much reference to functions. This informed the need to achieve both hydrocarbon reduction and ecosystem function restoration via metagenomics in this study. Metagenomics is used to analyze microbial functions, structure, and detect functional genes (Mu et al., 2015; Alkorta et al., 2017).

This study investigated the extant hydrocarbonoclastic microbes in petroleum-contaminated soil during a bioremediation protocol and the biodiversity of the soil three (3) months post bioremediation using metagenomics to determine the effect of total petroleum hydrocarbon (TPH) dissipation on the community structure and restoration of ecosystem function in the soil.

Materials and Methods

Sample Collection

The soil samples were collected from an agricultural farm using an auger from three different points at depths of 0 – 30 cm, mixed to form a composite sample, and kept in a sterile bag. The soil was artificially polluted with crude oil. 1000 g of crude oil polluted soil was weighed and placed in earthen pots containing 500g of unpolluted soil to which 12.5g of cow dung (CD) was added. In another pot was 1000 g of polluted soil without amendment or unpolluted soil and in another 1000 g of unpolluted soil. The content was mixed thoroughly for homogeneity and monitored for physicochemical parameters and microbiological characteristics.

Physicochemical characteristics

Determination of total petroleum hydrocarbon (TPH) content and polyaromatic hydrocarbon (PAH) content of soils

Ten (10) grams of a composite soil sample from each treatment pot was weighed into a solvent rinsed beaker. Thereafter, 20–50 ml of dichloromethane (DCM) was added to the samples. Samples were spiked with ortho-terphenyl and shaken in a vortex mixer for 1–5 minutes. The mixture was placed in an orbital shaker for 10–30 minutes and the extract were filtered through a glass funnel with glass wool and anhydrous sodium sulfate. The extract was transferred to a Teflon-lined screw-cap vial ready for TPH and PAH analysis. TPH and PAH contents determination were done according to the method stipulated by USEPA 8015C and USEPA 8270D respectively. Other physicochemical parameters monitored were pH (EPA 9045D), electrical conductivity (ASTM D1125), total organic nitrogen (ASTME258), and temperature (APHA 2005).

Culture dependent microbial identification

The culture-dependent hydrocarbon utilizing bacteria (HUB) was carried out by enriching the samples in a 250ml Erlenmeyer flask containing 1g of the soil sample. One hundred (100ml) of sterilized Bussnell Hass Broth (BHB) having 1% weight by volume of crude oil and naphthalene as the sole carbon source. The Erlenmeyer flask containing the mixture was kept at room temperature for seven (7) days on a rotary shaker. After seven (7) days, 0.1ml of the sample was inoculated on BHB mineral salt agar using the vapor transfer method and incubated for 7 days. Bacterial enumeration, isolation, and identification were done. The total heterotrophic bacteria

(THB) were carried out using the spread plate method. One gram (1g) of soil sample was weighed into 9.0ml of sterile normal saline to give a 10-fold dilution 10^1 from which 0.1ml was taken and put in a sterile test tube containing 9.0ml of normal saline to give 10^2 diluent until 10^4 and 10^5 was achieved. 0.1ml of the dilution was then aseptically spread into sterile Petri dishes containing nutrient agar, the petri dish was inverted, incubated at 28°C for 24 hours, and observed for the total viable count (Chikere et al, 2019)

Non-culture-dependent identification.

The viable but nonculturable bacteria were determined using metagenomic sequencing by Zymo Research Corp, Irvine, California, U.S.A. The DNA extraction was done using the ZymoBIOMICS-96 MagBead DNA kit. The library preparation was done using Nextera DNA Flex Library Prep Kit. The final library was sequenced on NovaSeq. The community dynamic profiling was done using shotgun analysis. Raw sequence reads were trimmed to remove low-quality fractions and adapters with Trimmomatic-0.33 (Bolger et al, 2015). Microbial composition was profiled using Centrifuge (Kim et al., 2016). Alpha and beta diversity

Results and Discussion

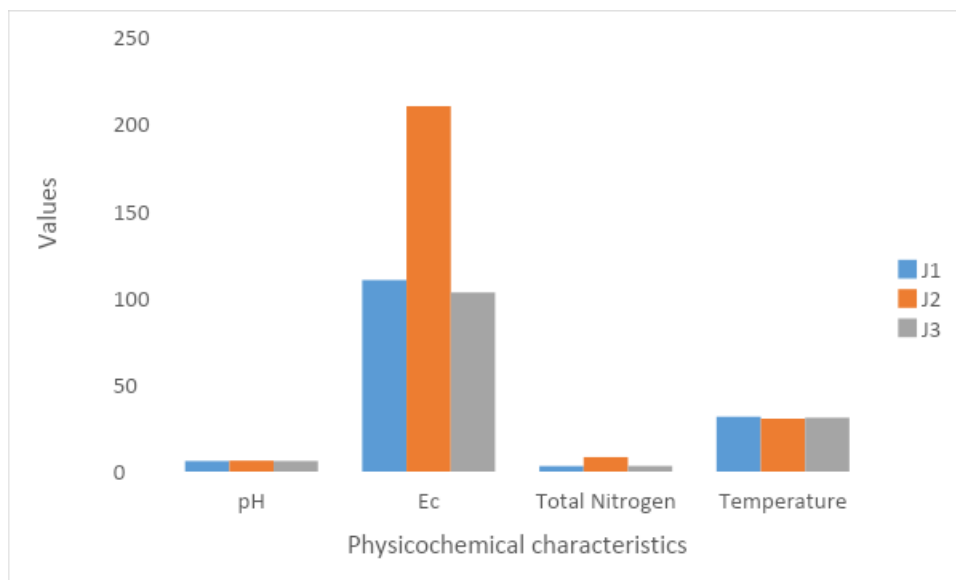


Fig 1: Physicochemical characteristics of replicates

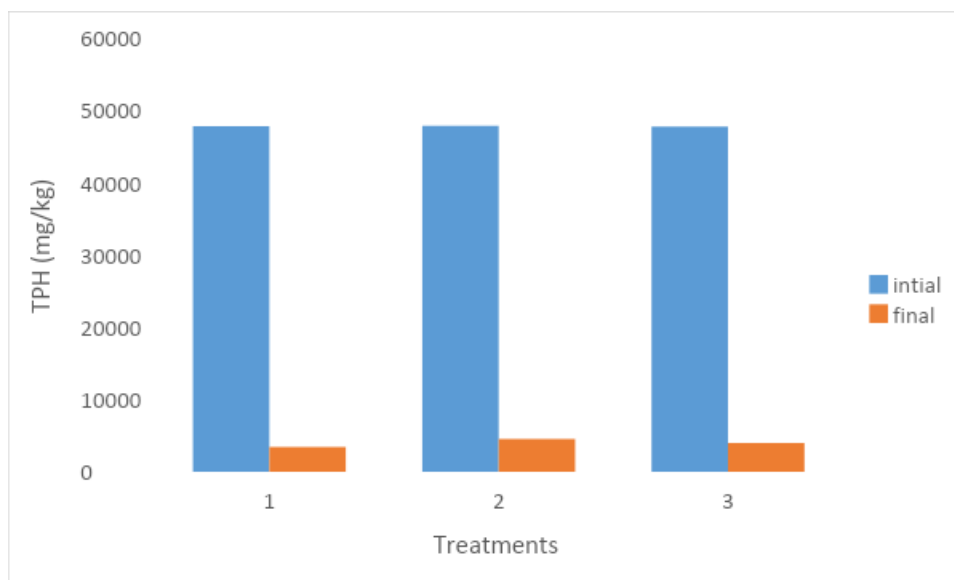


Fig 2: Total petroleum hydrocarbon reduction in samples.

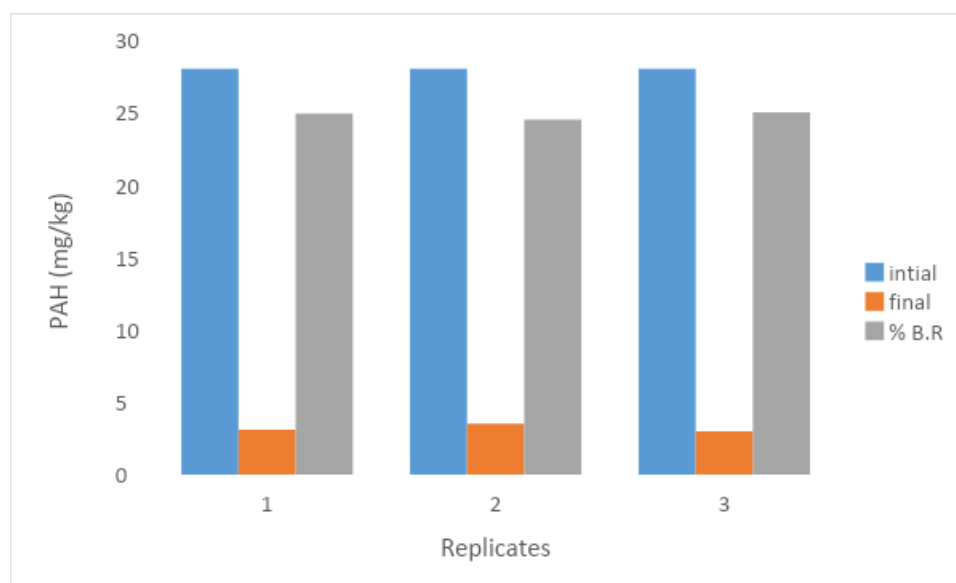


Fig 3: Polyaromatic hydrocarbon reduction and % bioremediation during the study.

Enumeration of bacterial isolates in samples

Table 1: THB and HUB of samples

Samples	THB	HUB
A	1.9×10^7	1.6×10^3
B	1.3×10^3	1.0×10^1
J1	4.0×10^6	1.67×10^3

J2	3.58×10^8	2.5×10^4
J3	2.15×10^9	3.55×10^4

The THB observed in the samples were 1.9×10^7 , 1.3×10^3 , 4.0×10^6 , 3.58×10^8 , 2.15×10^9 while HUB was 1.6×10^3 , 1.0×10^1 , 1.67×10^3 , 2.5×10^4 , and 3.55×10^4 respectively for A, B, J1, J2, and J3. The treatments increased the microbial structure of the soil, this may be due to the rich nutrient in the cow dung amendment.

Physicochemical characterization of treatments.

The pH range of the setup was 6.0-6.3 with the highest range being in J3. The conductivity ranged between 110-210 with J2 having the highest value. The temperature was fairly constant amongst replicates during the course of the bioremediation. The study investigated the effectiveness of unpolluted soil addition in the restoration of community structure and ecosystem functions during bioremediation of petroleum-contaminated soil. Treatments employed were able to efficiently degrade hydrocarbon and reduce the total petroleum hydrocarbons ranging between C6 – C30. as seen in Fig.1. This agrees with Baranu et al, 2021. Physicochemical characteristics of the treatments indicate the presence of high organic matter in the treated soil and, soil acidity. Organic matter helps the soil's ability to degrade pollutants while the acidity of soil indicates the microbial flora that will be found there. The electrical conductivity indicates the fertility of the soil. The TPH of the replicates was fairly constant during the course of bioremediation ranging

between 47708 to 47771 initial concentration and 3425 to 4516 final concentrations. The % Bioremediation as proposed by Bento et al, 2005 was between 90-93. The polyaromatic hydrocarbon percentage reduction was between 87 % to 88.9 % (Fig 3).

Molecular Characterization of Samples

The dominant phylum observed across the various treatments was Proteobacteria with 69.7% in 5B (Fig 4), 89.1% in 7.J3 at the end of the three (3) month remediation protocol and 86.5% three (3) months post bioremediation. However, the dominant phylum observed in the pristine soil was Actinobacteria at 76.3%, followed by Proteobacteria at 16.5% and the least was Firmicutes at 0.9%.

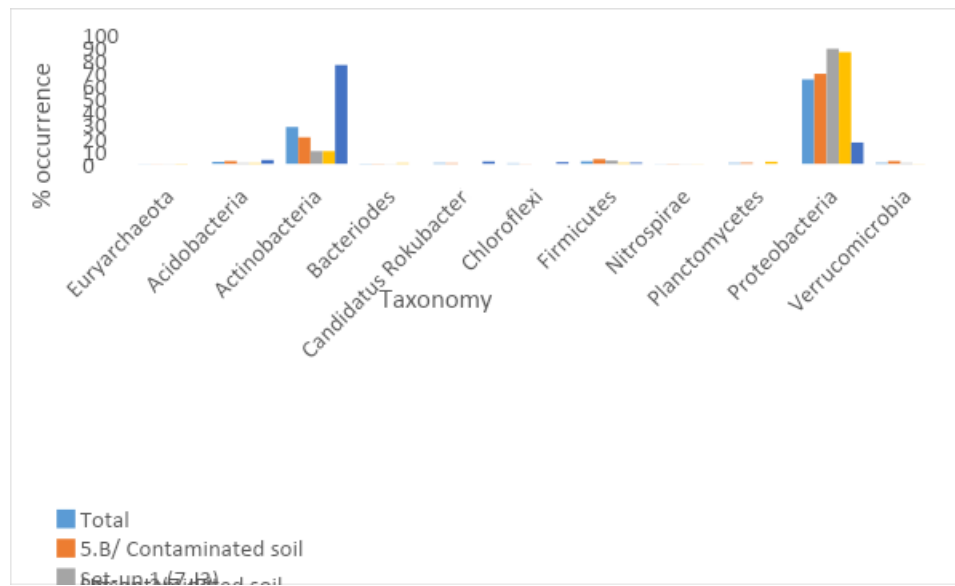


Fig 4: Dominant phylum identified and their percentage occurrence.

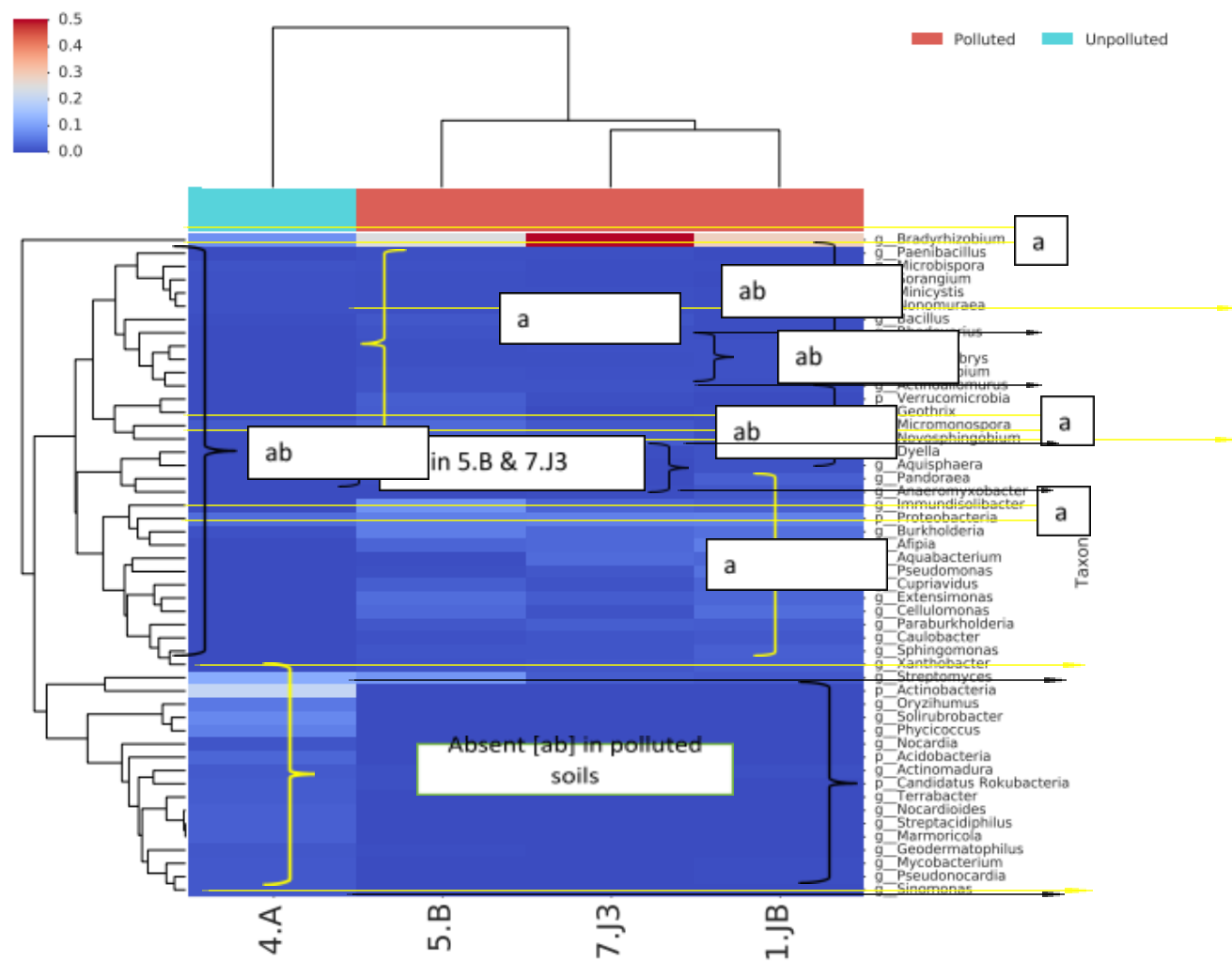


Fig 5: Gene pool between the unpolluted, polluted without amendments, and polluted with amendments.

The observed genus in this group [pristine soil (4. A), polluted soil without amendment (5. B), polluted soil with 12.5 g of cow dung, and 500 g of pristine soil at the end of 3-month bioremediation (7. J3) and 3 months post bioremediation (1. JB)] are shown in Fig 4. The yellow arrow with [a] indicates the genus present while the black arrow with [ab] indicates the absent genus in the samples. The organisms observed in this group are *Bradyrhizobium*, *Paenibacillus*, *Microbispora*, *Sorangium*, *Minicystis*, *Nonomuraea*, *Bacillus*, *Rhodovarius*, *Azospira*, *Pseudolabrys*, *Azorhizobium*, *Actinoallomarus*, *Verrucomicrobia*, *Geothrix*, *Micromonospora*,

Novosphingobium, Dyella, Aquisphaera, Pandoraea, Anaeromyxobacter, Immunodisolibacter, Proteobacteria (Unknown), Burkholderia, Afipia, Aquabacterium, Pseudomonas, Cupriavidus, Extensimonas, Cellulomonas, Paraburkholderia, Caulobacter, Sphingomonas, Xanthobacter, Streptomyces, Actinobacteria, Oryzihumus, Solirubrobacter, Phycococcus, Nocardia, Acidobacteria, Actinomadura, Candidatus Rokubacteria, Terrabacter, Nocardiodes, Streptacidiphilus, Marmoricola, Geodermatophilus, Mycobacterium, Pseudonocardia, and Sinomonas. Out of all these organisms, those present in the pristine soil are *Streptomyces, Actinobacteria, Oryzihumus, Solirubrobacter, Phycococcus, Nocardia, Acidobacteria, Actinomadura, Candidatus Rokubacteria, Terrabacter, Nocardiodes, Streptacidiphilus, Marmoricola, Geodermatophilus, Mycobacterium, Pseudonocardia* and *Sinomonas, Bradyrhizobium, Micromonospora* and an unknown genus of Proteobacteria. All these organisms that were present in the pristine soil (4. A) are absent in the polluted soil without amendment (5. B) except *Streptomyces*, which is present, however, none of these are present in the polluted soils with amendment (7. J3 & 1. JB). The genera *Dyella, Aquisphaera, Pandoraea, Anaeromyxobacter* are absent in 4. A, 5. B & 7. J3 but *Pandoraea, Anaeromyxobacter* moderately present in 1. JB. *Anaeromyxobacter* is a deltaproteobacterium usually found in large numbers in rice paddy soils, a large number in river/sediments but found in small amounts in upland soils (Masuda et al, 2017), this explains why it is in such a small amount here (less than 0.05) a diazotrophic bacteria capable of increasing nitrogen-fixing capabilities in paddy soil environments (Masuda et al, 2020), and its resurgence 3 months post bioremediation suggests that the soil will soon become fertile for plant growth. Although this agrees with Masuda et al, 2020, *Anaeromyxobacter dehalogens* have been described as an organism with the ability to

reduce Fe (III) to Fe (II) and reduce NO_3^- to NH_4^+ with NO_2^- as the intermediate through the pathway of respiratory ammonification. Although *Anaeromyxobacter* has not been classified as a denitrifier due to its ability to reduce NO_3^- to NH_4^+ and its absence of *nirK* and *nirS*, it has been shown to influence chemodenitrification through Fe (III) and NO_3^- reduction and ultimately denitrifies to N_2 via coupled biotic-abiotic reactions (Onley et al, 2018).

Two species of *Pandoraea* were identified in this study, *pnomenusa* and an unknown species. According to Liz et al, 2009, *Pandoraea pnomenusa* has been implicated in a consortium of polychlorinated biphenyl (PCB) from transformer oil-polluted soils.

The clustering in Fig 5 is within polluted samples indicating that the microbial communities of polluted soils are similar while those observed in the pristine soil are not genetically similar. This difference is important in using pristine soil to stimulate the degradation of hydrocarbons during bioremediation because it introduces gene families that would not have been there ordinarily due to the adverse effects of crude oil on the soil community. Interestingly of all the genera observed in these four samples, *Bradyrhizobium* and *Proteobacteria spp* (unknown) is present in all four (although they are not present in the same numbers). *Bradyrhizobium* is highest in 7. J3 and least in 1. JB. A trend where the genus *Paenibacillus*, *Microbispora*, *Sorangium*, *Minicystis*, *Nonomuraea*, *Bacillus*, *Rhodovarius*, *Azospira*, *Pseudolabrys*, *Azorhizobium*, *Actinoallomarus*, *Verrucomicrobia*, *Geothrix*, *Micromonospora*, *Novosphingobium*, *Dyella*, and *Aquisphaera* were absent in 1. JB just like 4. A was observed. This indicates the soil genus in 1. JB was returning closer to those observed in pristine soil (4. A) than the other polluted soils (5. B, and 7. J3). This

suggests that the addition of pristine soil is effective in restoring the microbial community after bioremediation.

The alpha diversity shows the measurement of the microbial diversity in samples. The unpolluted soil had the lowest diversity while the polluted soil without amendment had the highest microbial diversity. Sample 7.J3 (500g of pristine soil and 12.5g of cow dung at the end of the bioremediation protocol) showed an increase in microbial diversity three months post bioremediation (1J.B) (Fig 6). This further suggests that the pristine soil addition during bioremediation is more effective in restoring microbial diversity and possible ecosystem functions than natural attenuation.

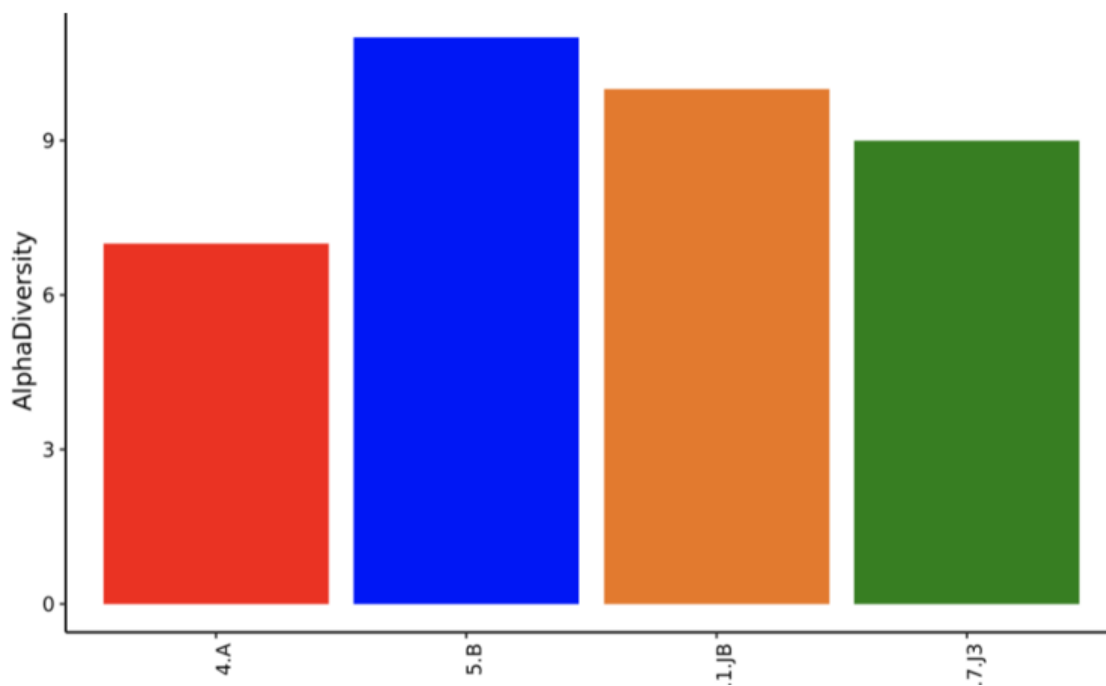


Fig 6: Alpha diversity showing the measurement of microbial diversity within samples.

Conclusion

The study showed that the addition of unpolluted soil with cow dung amendment was effective in remediating crude oil polluted agricultural soils using TPH as an index for successful bioremediation, however, the indigenous microorganisms in the unpolluted soil were able to enhance the biodegradation of the pollutants and improve the soil's biodiversity. Interestingly, the treatment with 500 g of unpolluted soil with 12.5g of cow dung proved to be very effective in encouraging the growth of hydrocarbon utilizing bacteria and resurgence of nitrogen fixers like *B. elkanii* and overall biodiversity barely three (3) months post bioremediation. The use of as low as 12.5g of organic nutrient (cow dung) enriched the bacterial structure of the soil which in turn will improve the ecosystem function of the soil barely three months after remediation.

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