Effect of prescribed fire on soil quality in the Long Island Central Pine Barrens

Taylor Ellinghaus, College of Agriculture and Life Sciences, Cornell University, Ithaca, NY 14853

Saviana D'Agostino, College of Environmental Science and Forestry, Syracuse, NY 13210

Simon Majowka, College of Agricultural and Life Sciences, University of Wisconsin-Madison, Madison, WI 53706

Kathy Schwager, Environmental Protection Division, Brookhaven National Laboratory, Upton, NY 11973

Abstract

The Long Island Central Pine Barrens is a fire adapted ecosystem that has experienced suppression for several decades. Brookhaven National Laboratory (BNL) has an active prescribed fire program, making it a great area to examine their impact on the environment. Soil is the foundation of an ecosystem. Both the biotic and abiotic characteristics of soils are important in determining what vegetation can thrive, which in turn supports the rest of the food web and influences the fire regime. Fire regime in turn can change the composition of the soil and the resulting ecological effects. Little is known about the effect that fire has on the pine barrens soil in the short and long term. In this study abiotic and biotic indicators are used to assess soil characteristics. Soil samples were taken from various areas around the BNL site. The control samples were areas that have not been burned in the last fifteen years, infrequent plots have been burned once in the last fifteen years and frequent plots have been burned several times in the last thirty years. The samples were sifted, and macroscopic and microscopic organisms were recorded. The pH of the soil was recorded as well as the root biomass. Micro- and macro-fauna were more abundant in frequently burned sites, while diversity and evenness were higher in control sites. Infrequently burned sites had the lowest overall abundance but had greater

diversity and evenness than frequently burned sites. The pH levels were lowest in the frequently burned plots, but only slightly with little difference between all the plots. The potassium levels were consistently high among all the plots, while the phosphorus levels fluctuated greatly between plots with no consistent trend. The nitrogenous results were inconclusive due to faulty tests. The root biomass was lowest in soil sampled from control areas, followed by frequently burned areas, with the infrequently burned areas having the highest root biomass. This study aligns with BNL's mission to protect local flora and fauna and the habitats in which they reside. As a result of this study, we have gained skills in grub and microorganism identification, microscopy, soil sampling, and data collection.

Introduction

Prescribed fires create conspicuous changes to the aboveground environment. It is important to take into account the less visible changes that occur underground as well. Soil quality contributes to the functioning of an ecosystem as a whole, acting as a foundation for the vegetation that grows, which in turn supports the rest of the trophic pyramid (Le Stradic et al. 2021). The Central Long Island Pine Barrens has acidic (ranging from 4.0 to 4.5), sandy, course textured and nutrient poor soil as a result of the slow decomposition of pine needles (Jordan et al. 2003; Shah et al. 2011). Because of the porous nature of the soil, the water from the heavy rainfall in the region drains quickly (Shah et al. 2011). The dominant tree species are pitch pine (*Pinus rigida*), scarlet oak (*Quercus coccinea*) and the white oak (*Quercus alba*) (*Overview | Central Pine Barrens Joint Planning and Policy Commission*, n.d.).

Frequent wildfires are an important part of the pine barrens ecosystem, without which there is a conversion to a closed-canopy forest (Jordan et al. 2003). Mesophication is the succession of an ecosystem where the buildup of organic matter creates moist conditions that are less conducive to fire, and as a result fire adapted and resistant plants are replaced with shade adapted and fire susceptible plants (Nowacki 2008).

Quigley et al. suggest that poor soil quality may be conducive to maintaining the sparse canopy characteristic of the pine barrens (2020). This goes against common perception of "good" soil health being soil that is high in nutrients. In the 2025 Long Island Forest Health and Wildlife Risk Reduction Field Trip held on Long Island, it was apparent that the Long Island Pine Barrens is its own unique biome that thrives off of processes and factors, such as fire, that may seem counterintuitive to ecosystem health in the public perception.

Fires are thought to have been common around Indigenous settlements (Jordan et al. 2003). Pollen and ash from the soil record support large fires having occurred on Long Island and the presence of pine barrens in the pre-Columbian era (Jordan et al. 2003). At the time of European settlement in the mid seventeenth century, Long Island was most likely dominated by oak forests and other hardwood forests but was extensively harvested by European settlers (Jordan et al. 2003). There are many indicators for soil health, three were selected for the time constraints of the study and relative simplicity.

Microorganisms

Soil will also be analyzed for the presence of microfauna and macrofauna as indicators of soil ecosystem health. The primary group of microfauna found within soils are microarthropods, including orders such as Acari, Collembolans, Symphylans, and Diplurians (Dervash et al., 2018). Microarthropods contribute significantly to decomposition processes, food webs, nutrient cycling, and soil microstructure formation (Dervash et al., 2018). Macrofauna include any invertebrates visible to the naked eye, such as ants, isopods, millipedes, beetles, and larvae. Soil macrofauna are a key factor in soil fertility (Sofo et al., 2020) as well as in food webs, similar to microarthropods. Pressler et al., in their study found that microarthropod populations are expected to have a similar abundance between burned and unburned plots, but are expected to have a decrease in richness, evenness and diversity. The same study (Pressler et al.) found that while nematode abundance is expected to decrease by 88% and overall richness, evenness, and diversity of all soil mesofauna after fire can be expected to decrease by up to 99%. Observed macrofauna populations also decreased in total abundance and species richness after fire (Gongalsky et al, 2012).

Chemical Properties

Soil was tested for pH, potassium, phosphorus and nitrogen. pH is considered the “master soil variable” due to the bevy of influence it has on the soil and the organisms within. Such influences include precipitation of organic material, soil enzyme activity, nutrient availability and biodegradation (Le Stradic 2021, Neina 2019). pH in BNL’s pine barrens have been historically recorded at values ranging from 5.9 to 6.3, giving the area an overall acidic soil (Jack 2006). Canopy cover and species present in a plot can also impact the pH of the soil as the pH of rainwater can get altered as it washes over leaves and plant stems and gets absorbed into the soil (Jack 2006).

Nitrogen, phosphorus, and potassium are known to be co-limiting factors on terrestrial plant development (Fang et al. 2024). Due to the sandy nature of pine barren soil, there is an expectation of low nutrient availability, as sandier soils tend to hold less nutrients and water. It has been noted that the presence of frequent burns in pitch pine barrens has decreased the acidity of the soil and increased nitrogen availability (Burns 1952). The presence of fire is expected to increase both nutrient availability and pH, although pH increases following a burn and decreases over time (Le Stradic et al. 2021; Memoli et al. 2020).

Root Biomass

The root biomass is also considered an indicator of ecosystem health, as they are responsible for the uptake and storage of nutrients and water for a plant, providing structural support, and facilitating interactions between the plant and symbiotic fungi (O'Keefe et al. 2021; Qi et al. 2019). As a result of constant fires, plants are adapted to store their biomass belowground (Le Stradic et al. 2021). Eisenhauer et al. states that plant diversity increases root biomass, which is likely to increase resource availability to microbes (2017). Water permeability decreases after a burn, which can increase its availability to plants (Memoli et al. 2020).

The root to shoot ratio (RSR) is also an important dimension of root biomass, as this influences the nutrient uptake of a plant (Lynch et al., 2011; Huang et al. 2021). Le Stradic et al. states that fine roots are very important for acquisition of nutrients after a fire, because materials on the surface are burned away (Le Stradic et al. 2021). According to Huang et al., the root to shoot ratio should be around 0.25 in the Long Island area based off of biome, however the Long Island Pine Barrens differs from temperate forests in the region (2021).

The carbon stores in the soil can also be estimated through root biomass, although estimates may not be accurate (Le Stradic et al. 2021; Qi et al. 2019; Robinson 2007; Waring and Powers 2017). Young plants have higher root biomasses, and as the plant grows, the RSR increases (Qi et al. 2019). Root to shoot ratio also is an important indicator of competitive interactions between different plant species (Qi et al. 2019).

In a study conducted in 2005 by Davis at Brookhaven National Laboratory (BNL), the understory composition differed between oak-dominated communities and pitch pine forests. Oak-dominated communities are characteristic of an area in the pine barrens that has not been frequently burned, and a pitch pine forest is characteristic of an area that has been more frequently burned. Davis noted that the dominant species are *Carex pensylvanica*, *Gaylussacia baccata*, *Quercus ilicifolia*, *Vaccinium pallidum*, *Vaccinium angustifolium*, and *Pteridium aquilinum*. The prevalence of *G. baccata* was 11% lower in the pitch pine forest and the prevalence of *Q. ilicifolia* was 30% higher in pitch pine forests.

According to the optimal partitioning hypothesis, plants distribute more biomass to their roots under stressful, low nutrient, and poor climatic conditions (Qi et al. 2019). Under this assumption, the frequently plots would have the most root biomass, followed by infrequently burned plots and then control plots. Root biomass is greater closer to trees (Adame et al. 2017), so it would be expected that frequently burned plots would have less root biomass because of the lower density of trees. The use of a soil corer limits the roots sampled to less than 20 mm in diameter (Adame et al. 2017).

Materials and Methods

Soil samples were collected in control, frequently, and infrequently burned plots using a soil core sampler. Control plots are areas that have not been burned in the last fifteen years, infrequently burned plots are areas that have been burned once in the last fifteen years, and frequently burned plots are areas that have burned in the last fifteen years and in the last fifteen years before that. Control, infrequent and frequent sites were previously established based off of their fire history by S. C. Gilvarg. Transects were randomly selected using surveyor's judgement. Square transects measuring three meters by three meters were established in each site. Samples were taken in each transect three meters apart, with Kestrel™ Drops placed at each site and an iButton® placed in the middle of the two sites, to monitor weather conditions.

Temperature effects the makeup of microarthropod communities, with fluctuating microclimates and more variation in temperature conditions contributing to more species diversity (Huhta et al, 2001). Weather plays an important role in the chemical properties of soil, especially pH. pH is known to be inversely related to temperature (Cheng et al. 2014). Thus, excessively hot days can cause more acidic soils. Soil cores were then sifted using the first two layers of a soil sieve, the first layer being equivalent to four m^2 (layer A) and the second layer 1 m^2 (layer B), for a total of two layers of soil (Layers A & B). Soil layers were stored in a warm, dry place for further processing.

Microscopy

Soil samples were analyzed for presence of macro- and microscopic animal species including nematodes, acari, collembola and any other organisms that were present. All species were identified to the lowest taxonomic rank possible. Microscopy samples were prepared from Layer B of each of the sifted soil samples. A total of fifty grams of soil was analyzed from each sample in subsamples of 10 grams. For each subsample, 10 grams of soil was taken at random and combined with 5 mL of water. Any macro- and micro- fauna species found were saved and identified in order to calculate difference in evenness, diversity, and absolute abundance between plots with different fire management.

Chemical Properties

The soil, once sifted, was tested for a variety of chemical properties. The four chemical properties tested were pH and concentrations of phosphorus, nitrogen, and potassium. Each soil sample was tested for all four of the properties twice, once from layer A and once from layer B. The Akasha® soil test kit was used to calculate these properties.

To test pH, approximately one gram of soil along with 1 capsule containing a powder mixture of methyl red and bromothymol blue provided by the kit were added to a sterilized vial. Then, approximately 4 mL of water was added. Following the addition of water, the vial was capped, shaken vigorously, then left to sit for 1 minute until the concoction fully settled and changed color. Once done, the color of the mixture was compared to the kit's chart to approximate the pH level to the nearest 0.5. The tests for nitrogen, phosphorus, and potassium each required filling a sterilized vial with 3 grams of soil and 15 mL of water then shaking to form a mixture of 1 part soil and 5 parts water. The mixture was then left to stand undisturbed until the sediment fully settled. Once settled, using a sterilized dropper, approximately 4 mL of the mixture was transferred to a vial, taking care not to disturb the sediment in the process. Then, depending on the chemical being tested, its associated indicator capsule was added to the vial. The vial was then capped and shaken thoroughly then left to sit for 10 minutes. Lastly, the color of the mixture was compared to its respective chart to determine the qualitative amounts of chemical in the soil, ranging from very low to high. All equipment, including tweezers, droppers, and vials were sterilized between each test.

Plant Roots

Once the soil samples were sifted, plant roots remain on the top layer. They were sorted from the rest of the remaining soil particles after being rinsed in a sieve. The roots were then dried in a 60°C oven in a paper bag for at least 48 hours. Excess dirt was removed as best as possible from dry roots and was then weighed.

Results

Microscopy

Samples from frequent fire plots had the most abundance with 35 individuals, followed by control plots with 5 individuals, and infrequent plots with 4 individuals (Figure 2). The most abundant organism present was Rhinotermitidae with 31 individuals present among all the samples. The next most represented organism was individuals from the class Collembola, with 8 individuals within the class, including Tullbergiidae, Allonychirurs and Onychiurinae. Other organisms found included Symphyla, *Agriotes spp.*, Dorylinae, *Tenebrio molitor*, and Coleoptera spp. (Figure 1).

Species diversity within the plots was calculated using the Shannon Diversity Index. Diversity was lowest in the frequent plots, with an index of 0.64, followed by infrequent plots with an index of 1.04, and control plots with an index of 1.61. Evenness of the species was highest in the control plots with a value of 1, followed by infrequent plots with an evenness of 0.75, and frequent plots with an evenness of 0.18. Frequent plots had the highest absolute abundance with 35 organisms (Figure 2), followed by control plots with 5 organisms, and infrequent plots with 4. The Kruskal Wallis test was used to determine the significance of the diversity, evenness, and abundance between the sites. None of the variables were statistically significant, with diversity and evenness resulting in a p-value of 0.368, and abundance having a p-value of 0.438.

Treatment	Absolute Abundance	Diversity	Evenness
Control	5	1.609438	1
Infrequent	4	1.039721	0.75

Frequent	35	0.640036	0.180021

Figure 1: Table showing the calculated absolute abundance, diversity, and evenness of organisms in soil samples.

Treatment	Organisms Found
Frequent	35
Infrequent	4
Control	5

Figure 2: Table showing the number of organisms found in samples.

Chemical Properties

After pH tests were conducted, the data was sorted into control, infrequent fire, and frequent fire values and were averaged. Figure 3 shows the three averages compared, with control and infrequent plots both having an average pH of 6.0 and the frequent plots showing an average pH of 5.65. Most sites gave a pH value of 6, with only two of the three frequent plots resulting in a lower value. A Kruskal Wallis test was used to determine the significance of the data. The resulting p-value was 0.2283, meaning the data was not significant.

After conducting the tests for P, N, and K, the qualitative results were described numerically, with a value of 1 representing very low amounts of the specific chemical and a value of 4 representing high amounts of said chemical. The values for each chemical were sorted by plot treatment type then averaged (Figure 3). The nitrogenous test proved faulty and only showed inconclusive results, thus said chemical characteristic has been excluded from the results. Kruskal Wallis tests were used to determine the significance of both the phosphorus, and the potassium results due to both data sets lacking the normality needed for an ANOVA test. The potassium Krustal Wallis test resulted in a p-value of 0.1173, meaning the data lacks significant differences. The phosphorus Krustal Wallis test resulted in a p-value of 0.01623, meaning that there is some significance in the data, specifically between the control plots and the frequent plots.

Treatment	pH Average	P Average	K Average
Control	6.0	3.25	3.75
Frequent	5.65	2.1	4
Infrequent	6.0	2	3.5

Figure 3: Table showing the average pH, phosphorus, and potassium values from each type of treatment plot. The qualitative data from the phosphorus and potassium tests were represented numerically with values closer to 4 representing high amounts of the nutrient and values closer to 1 representing low amounts of the nutrient.

Root Biomass

The Kruskal Wallis test was used to determine the significance of the results, with the website "Statistics Kingdom." In total, 37 samples were collected, with one sample being one soil core. I compared my results first in three separate categories; control, infrequent and frequent fire. I got a p-value of 0.2269, which is insignificant. There was marginal significance between the control and infrequent values, with a p-value of 0.08533.

Treatment	Average of Weight of dry roots (g)
Infrequent	3.21
Frequent	3.07
Control	2.15
Grand Total	**2.86**

Figure 4: Average root biomass by treatment type

The plots were also separated into two categories, plots that have not experienced fire (control) and plots that have experienced fire (infrequent and frequent). A Mann Whitney U test was performed on these categories and a p-value of 13.85 was obtained, indicating marginal significance.

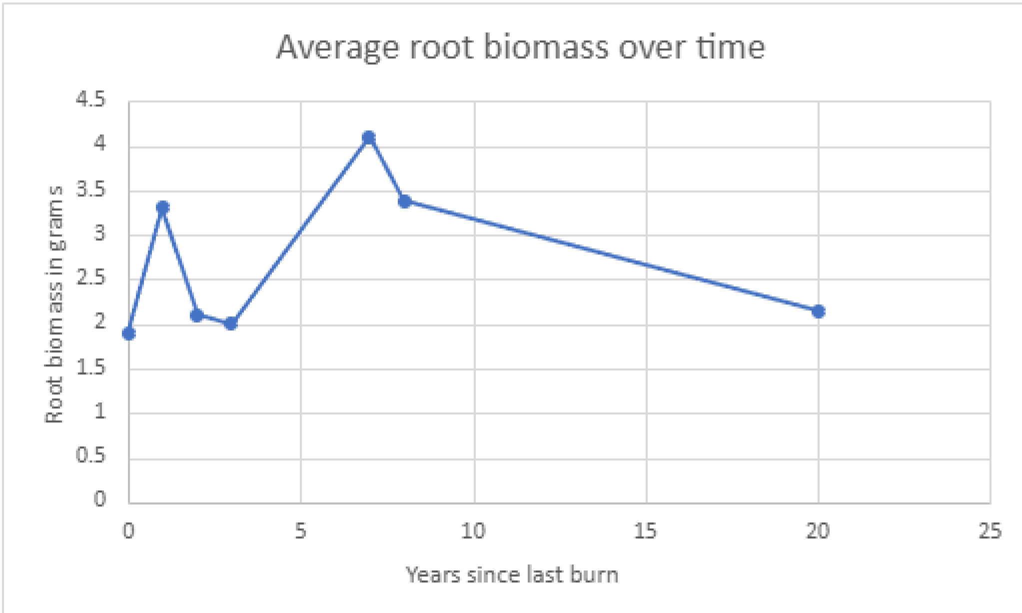

Figure 5: Average root biomass by years since last burned

A Kruskal Wallis test was also preformed on the data sorted by how long it had been since the plot was last burned (0-1 years, 2-3 years, 7-8 years and no recorded fire). I got a p-value of <0.05 (0.00367) and still was less than 0.05 when using the Bonferroni Correction Method, meaning that the differences in the data are significant, although it varied greatly when comparing different treatment groups.

Discussion

Microscopy

Calculations of diversity, absolute abundance, and evenness between plots with different fuel treatments were not statistically significant. However, there were still some noticeable differences in the results between sites. Consistent with previous studies, frequently burned plots had the lowest diversity (Figure 1) compared to infrequently burned and control plots (Pressler et al. 2018). Even though diversity was lower, absolute abundance was higher, which could potentially indicate higher recolonization rates on frequently burned plots. The makeup of organisms found on control plots was noticeably different to both infrequent and control plots. While infrequent and control plots were made up of mostly micro-fauna, or a mixture of micro- and macro- fauna, frequently burned plots were made up mostly of macro-fauna, specifically Rhinotermitidae. This could indicate areas that are frequently burned offer more hospitable conditions for macro-fauna rather than micro-fauna. This is also consistent with literature that suggests micro-fauna communities, and specifically micro-arthropod communities, have slower rebounds than larger species after fire occurs (Gongalsky et al., 2012).

While preliminary results could be taken from this study, sample sizes were small- and the time frame over which samples were taken were relatively short, potentially impacting the gathered results.

Chemical Properties

The pH tests resulted in little significant difference in pH levels among the varied treatment plots. Most plots tested resulted in a pH of 6.0, with the only plots showing more acidity being frequent plots. While this could potentially show a slight inverse relationship between pH and frequency of fire, the majority of frequent plots resulted in a pH of 6.0, weakening the trend. Future studies should collect more samples, especially from infrequent and control plots to better understand the potential relationship between fire frequency and pH. Le Stradic et al. states that pH increases after a fire and decreases over time (2021). The frequently burned plot with the highest average pH was the one that was burned most frequently, giving some credence to the study. Future studies could conduct multiple pH tests of the same burned plot over a long period of time to detect this relationship.

The nutrient tests had a variety of results. The nitrogen test, as mentioned previously, was unable to produce usable results and was removed from the analysis. The potassium tests revealed no significant difference among the sites. Potassium was found to be relatively high in most sites, with only two tests (one from an infrequent and another from a control) resulting in a value of medium. The phosphorus tests did show significance between results, mostly between the frequent and the control plots. This potentially provides evidence for an inverse relationship between frequency of fire and phosphorus levels. More research should be done with a higher number of samples to better define this potential relationship.

Root Biomass

Both the infrequent and frequent plots had a higher root biomass than the control, with the infrequent having a higher root biomass than frequent samples. This observed difference can be attributed to either the change in vegetation that occurs because of fire disturbances or the vegetation expanding its root system. This finding is supported by the optimal partitioning hypothesis mentioned earlier, as a pine barren is a stressful, low nutrient, and poor climatic environment. As a burned plot would be expected to exhibit these characteristics, it follows that it would have a higher root biomass.

The most significant finding from the root survey was the statistical significance of the differences in control and infrequent treatment root biomass. There was greater statistical significance between the results when they were grouped by years since last burn as opposed to the previously stated control, frequent and infrequent categories.

In a study conducted by Siefert in 2005 in the Long Island Central Pine Barrens, increased canopy cover was found to negatively correlate with the total understory cover.

Frequently burned plots often have a lower total canopy cover, which would probably coincide with a higher understory cover. The higher density of understory vegetation in the frequently burned plots could explain the observed greater root biomass.

Extensive underground root systems may serve as an adaptation to fire (Gilvarg, a). O'Keefe et al. found the greatest theoretical root hydraulic conductivity scaled by root biomass at the intermediate frequency of burning at every 4 years compared to every year and every 20 years and explained that this may cause accelerated levels of shrub growth and woody encroachment in drought conditions (2021). This could explain why the highest average root biomass was from the infrequently burned plots.

Sources of Error

Microscopy

The procedures for collecting and preparing microscopy samples changed throughout the study as information on the best possible way to find organisms was better understood. The amount of soil sampled was changed throughout the study to account for time, going from half of the overall sample to 50 grams of each sample. More soil sampled allows for the chance of more organisms to be found. Future studies should standardize the amount of soil being tested to optimize organism identification. This study found that keeping soil at room temperature, combining samples with water, and testing samples within 48 hours yielded the best results for finding organisms. Future studies should ensure that samples are stored consistently to ensure organisms stay alive or do not decompose.

Additionally, sample sizes were small, with 10 samples, broken down into 20 subsamples, in total being used, possibly influencing results and number of organisms being found. More collected samples would be more conducive to gathering organisms for identification and may influence the statistical significance of any results found. Besides increasing the number of samples used, future studies should also increase the time over which samples are collected. Seasons and weather patterns impact what organisms, and how many, may be found. Lengthening the time of collection would decrease the variability of species prevalence based on season.

Chemical Properties

The sources of error mainly come from the central method for collecting chemical results: the Akasha® soil testing kit. The testing kit puts all of the chemical results into question due to its high capacity for error. As discussed, prior, the nitrogen tests did not produce results. Instead of the purple color it was supposed to portray when conducted, the mixture instead turned cloudy white, a color not indicated on the provided testing key. This problem forced the nitrogenous results to be left out of the analysis. Furthermore, the phosphorus test required more time and more consistent shaking than the other tests to produce visible results, putting the accuracy of its results into question.

Additionally, the test was highly subject to human error. The provided capsules used to test the soil were hard to open and often led to spillage and potential contamination. The subjective test of comparing the color of the mixture to the provided test key is highly problematic. The color the mixture appears to take is highly dependent on several factors, including light levels and individual eye quality. Different people may interpret the same test tube as different colors depending on their own specific vision. Furthermore, human bias can shift how one perceives color, such as making a test tube appear darker in color because it fits better with the hypothesis. While measures were taken to standardize the testing regime, such as having one person doing all the testing and putting the test tubes under indirect sunlight, the possibility of flawed and skewed chemical results is high. Future research should use more specific chemical tests for better quality results.

Root Biomass

The procedures used to collect the samples changed throughout the study. A soil corer was used throughout, ensuring that the volume of soil collected was consistent. Some samples were kept in a freezer and then defrosted, while some were kept at room temperature entirely. In future studies, the samples should all be kept in a freezer, then examined close to the time they were collected.

Additionally, the use of the sieves was difficult in ensuring uniformity. Many of the roots found in the sample were extremely fine, and dirt was often captured in the dense roots. The roots were rinsed, however removing all of the dirt was not possible without more sophisticated rinsing technology. Overall, the weight of the dirt and non-root particles may not have had too much of an impact on the observed difference between treatments, as the rinsing and sifting procedures among samples was relatively uniform.

Additionally, Ericaceae plants that are one of the dominant understory species in the pine barrens have stems underground, which may have been included in the root biomass measure (Gilvarg, b). However, in the Le Stradic et al. study, the rhizomes were included in the course root measure (2021).

In future studies, a greater number of samples would be conducive to exploring the differences between treatments. Proximity to plants may influence the root biomass. In samples collected using the square method, there may have been a bias towards selecting bare ground to sample. The method used to collect the last eighteen samples should be the preferred sampling method for future studies, as it provides a more random sample and samples a greater area of the plot.

Additionally, collecting other root measures would provide further insight into how roots funtion in the Long Island Central Pine Barrens ecosystem in response to fire, such as root to shoot ratio and hydrological measures.

Overall

The main issues that occurred during this study were the small sample size. Additionally, soil collected was from around 13 cm deep, which is not standard and presents difficulty when comparing results to other studies that use 10 cm as a standard.

Acknowledgements

This project was supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) under the Science Undergraduate Laboratory Internships Program (SULI). We would also like to thank our mentor Sam Gilvarg for his help with our project, as well as our fellow SULI interns. No export control.

Citations

Adame, M. F., Cherian, S., Reef, R., & Stewart-Koster, B. (2017). Mangrove root biomass and the uncertainty of belowground carbon estimations. Forest Ecology and Management, 403, 52–60. https://doi.org/10.1016/j.foreco.2017.08.016

Addo-Danso, S. D., Prescott, C. E., & Smith, A. R. (2016). Methods for estimating root biomass and production in forest and woodland ecosystem carbon studies: A review. Forest Ecology and Management, 359, 332–351. https://doi.org/10.1016/j.foreco.2015.08.015

Burns, P. Y. (1952). Effect of Fire on Forest Soils in the Pine Barren Region of New Jersey. Yale School of Forestry & Environmental Studies Bulletin Series, 47, 10. https://elischolar.library.yale.edu/cgi/viewcontent.cgi article=1063&context=yale_fes_bulletin

Cheng-Jim J., Yuan-He Y., Wen-Xuan H., Yan-Fang H., Smith, J., Smith, P. (2014) Climatic and Edaphic Controls on Soil pH in Alpine Grasslands on the Tibetan Plateau, China: A Quantitative Analysis, Pedosphere, Volume 24, Issue 1, Pages 39-44, ISSN 1002-0160, https://doi.org/10.1016/S1002-0160(13)60078-8.

Davis, M. (2005). Analysis of the Under-story Vegetation within the Central Pine Barrens of Long Island. https://www.bnl.gov/esd/wildlife/files/research/pdf/davis_paper_2005.pdf

Dervash, M., Bhat, R., Mushtaq, N., & Singh, V. (2018, May 14). Dynamics and Importance of Soil Mesofauna. Research Gate. https://www.researchgate.net/publication/325119590_Dynamics_and_Importance_of_Soil_Mesofauna

Eisenhauer, N., Lanoue, A., Strecker, T., Scheu, S., Steinauer, K., Thakur, M. P., & Mommer, L. (2017). Root biomass and exudates link plant diversity with soil bacterial and fungal biomass. Scientific Reports, 7(1). https://doi.org/10.1038/srep44641

Fang, J., Chen, B., Wang, F., Li, W., Zhang, H., Fang, J., Liu, S., Zheng, Z., Guo, M., & Niu, S. (2024). Nitrogen, phosphorus, and potassium co-limitation in terrestrial ecosystems: A global meta-analysis. Plants, People, Planet, 6(6), 1329–1340. https://doi.org/10.1002/ppp3.10524

Gilvarg, S. C. Plant Adaptations to Fire, a, [PowerPoint slides].

Gilvarg, S. C. The Ericaceae of New England: Diversity, Ecology and Phylogeny, b, [PowerPoint slides].

Gongalsky, K., Malmstrom, A., Zaitsev, A., Shakhab, S., Bengtsson, J., & Persson, T. (2012). Do burned areas recover from inside? An experiment with soil fauna in a heterogeneous landscape. *Applied Soil Ecology*, *59*, 73–86. https://doi.org/10.1016/j.apsoil.2012.03.017

Huang, Y., Ciais, P., Santoro, M., Makowski, D., Chave, J., Schepaschenko, D., Abramoff, R. Z., Goll, D. S., Yang, H., Chen, Y., Wei, W., & Piao, S. (2021). A global map of root biomass across the world's forests. Earth System Science Data, 13(9), 4263–4274. https://doi.org/10.5194/essd-13-4263-2021

Huhta, V., & Hänninen, S.-M. (2001). Effects of temperature and moisture fluctuations on an experimental soil microarthropod community. *Pedobiologia*, *45*(3), 279–286. https://doi.org/10.1078/0031-4056-00085

Jack, N. (2006). Baseline pH and the Variability of pH within Plots and Community Types of the Central Pine Barrens. https://www.bnl.gov/esd/wildlife/files/research/pdf/jack_paper_2006.pdf

Jordan, M. J., Patterson, W. A., & Windisch, A. G. (2003). Conceptual ecological models for the Long Island pitch pine barrens: implications for managing rare plant communities. Forest Ecology and Management, 185(1-2), 151-168. https://doi.org/10.1016/s03781127(03)00252-4

Le Stradic, S., Roumet, C., Durigan, G., Cancian, L., & Fidelis, A. (2021). Variation in biomass allocation and root functional parameters in response to fire history in Brazilian savannas. *Journal of Ecology*, *109*(12), 4143–4157. https://doi.org/10.1111/1365-2745.13786

Lynch, J., Marschner, P., & Rengel, Z. (2011). Chapter 13 - Effect of Internal and External Factors on Root Growth and Development. In Marschner's Mineral Nutrition of Higher Plants (Third Edition) (pp. 331–346). Academic Press. https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/root-shoot-ratio

Memoli, V., Panico, S. C., Santorufo, L., Barile, R., Di Natale, G., Di Nunzio, A., Toscanesi, M., Trifuoggi, M., De Marco, A., & Maisto, G. (2020). Do Wildfires Cause Changes in Soil Quality in the Short Term? International Journal of Environmental Research and Public Health, 17(15), 5343. https://doi.org/10.3390/ijerph17155343

Natural Resources Conservation Service. (2021). Soil Health Technical Note No. 450-06: Cropland In-Field Soil Health Assessment Guide. In ncrs.usda.gov. United States

Department of Agriculture. https://www.nrcs.usda.gov/sites/default/files/2022-10/Cropland_InField_Soil_Health_Assessment_Guide.pdf

Neina, D. (2019). The Role of Soil pH in Plant Nutrition and Soil Remediation, Applied and Environmental Soil Science, 2019, 5794869, 9 pages, https://doi.org/10.1155/2019/5794869

Nowacki, G. J., & Abrams, M. D. (2008). The Demise of Fire and "Mesophication" of Forests in the Eastern United States. BioScience, 58(2), 123–138. Forest Service: Unites States Department of Agriculture. https://doi.org/10.1641/b580207

O'Keefe, K., Bachle, S., Keen, R., Tooley, E. G., & Nippert, J. B. (2021). Root traits reveal safety and efficiency differences in grasses and shrubs exposed to different fire regimes. *Functional Ecology*, *36*(2), 368–379. https://doi.org/10.1111/1365-2435.13972

Overview | Central Pine Barrens Joint Planning and Policy Commission. (n.d.). Pb.state.ny.us. Retrieved July 7, 2025, from https://pb.state.ny.us/central-pine-barrens/overview/

Pressler, Y., Moore, J. C., & Cotrufo, M. F. (2018). Belowground community responses to fire: meta-analysis reveals contrasting responses of soil microorganisms and mesofauna. Oikos, 128(3), 309–327. https://doi.org/10.1111/oik.05738

Qi, Y., Wei, W., Chen, C., & Chen, L. (2019). Plant root-shoot biomass allocation over diverse biomes: A global synthesis. Global Ecology and Conservation, 18. https://doi.org/10.1016/j.gecco.2019.e00606

Quigley, K. M., Kolka, R., Sturtevant, B. R., Dickinson, M. B., Kern, C. C., Donner, D. M., Miesel, J. R. (2020). Prescribed burn frequency, vegetation cover, and management legacies influence soil fertility: Implications for restoration of imperiled pine barrens habitat, Forest Ecology and Management, Volumes 470–471, 118163, ISSN 0378-1127, https://doi.org/10.1016/j.foreco.2020.118163.

Robinson, D. (2007). Implications of a large global root biomass for carbon sink estimates and for soil carbon dynamics. Proceedings of the Royal Society B: Biological Sciences, 274(1626), 2753–2759. https://doi.org/10.1098/rspb.2007.1012

Shah, V., Shah, S., Kambhampati, M. S., Ambrose, J., Smith, N., Dowd, S. E., McDonnell, K. T., Panigrahi, B., & Green, T. (2011). Bacterial and Archaea Community Present in the Pine Barrens Forest of Long Island, NY: Unusually High Percentage of Ammonia Oxidizing Bacteria. PLoS ONE, 6(10), e26263. https://doi.org/10.1371/journal.pone.0026263

Siefert, A. (2005). *Effects of Changes in Canopy Cover on Understory Vegetation in the Long Island Pine Barrens*. https://www.bnl.gov/esd/wildlife/files/research/pdf/siefert_paper_2005.pdf

Sofo, A., Mininni, A. N., & Ricciuti, P. (2020). Soil Macrofauna: A key Factor for Increasing Soil Fertility and Promoting Sustainable Soil Use in Fruit Orchard Agrosystems. Agronomy, 10(4), 456. https://doi.org/10.3390/agronomy10040456

Waring, B. G., & Powers, J. S. (2017). Overlooking what is underground: Root:shoot ratios and coarse root allometric equations for tropical forests. *Forest Ecology and Management*, *385*, 10–15. https://doi.org/10.1016/j.foreco.2016.11.007

Figures

Figure: Root biomass sample data

Green boxes indicate that the samples were collected in batches of three

Treatment	Weight of dry roots (g)
Frequent	2.9
Frequent	1.1
Frequent	2.1
Frequent	1.5
Frequent	3.7
Frequent	5.3
Frequent	1.1
Frequent	3.1
Frequent	1.1
Frequent	2.8
Frequent	5.933333333
Frequent	5.933333333
Frequent	5.933333333
Frequent	2.2
Frequent	2.2
Frequent	2.2
Control	2.7
Control	1.6
Control	1
Control	2.4
Control	2.033333333
Control	2.033333333
Control	2.033333333
Control	2.566666667
Control	2.566666667
Control	2.566666667
Infrequent	5
Infrequent	3.2
Infrequent	2.933333333
Infrequent	2.933333333
Infrequent	2.933333333
Infrequent	4.066666667
Infrequent	4.066666667
Infrequent	4.066666667

Infrequent	2.033333333
Infrequent	2.033333333
Infrequent	2.033333333