Impact of Wildfire Smoke on Seed Germination in Tilden Park

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ABSTRACT

Climate change has caused fire patterns to change across fire-prone areas like the Chaparral. Fires are becoming more frequent and expansive. Man made structures are burning during these huge fires, releasing inorganic chemicals, in addition to organic ones. Believing that inorganic chemicals are notably harmful to the plant biome, I conducted an observation experiment that measured seed germination rates of nonnative and native plates in Tilden Park after different applications of organic and inorganic smoke. My results showed that organic smoke applications through water-smoke, gaseous smoke, and ash smoke lead to a general pattern of germination rate stimulus in native seeds, while inorganic smoke applications lead to an observational average decreased germination rates in native and nonnative plants. This led me to conclude that inorganic smoke released from wildfires could be harmful to Tilden Park seed species, while the organic smoke compounds lead to an increase in the germination rate of only native plants. I believed that native plants were adapted to coexist with natural fires, but nonnative plants weren't, while both types of plants weren't able to evolutionarily deal with the inorganic/toxic compounds released from larger wildfires.

KEYWORDS

plant biota, inorganic, climate change, Easy Bay, observational

INTRODUCTION

Due to climate change, wildfires have been occurring more frequently and devastating on the west coast (Flannigan et al. 2009). Average temperatures are globally rising and the weather is becoming more extreme in biomes like the chaparral (Sokolik 2019). In the chaparral biome, the weather changes are generally observed to correlate to longer dry seasons and heavy rains when it does. During these long dry seasons, the foliage dries out more than usual and becomes prime fuel for multi-thousand-acre fires, many of us have seen on the news (Ghebrehiwot et al. 2011). As human development expansions continue to push into environmental territories, wildfires will have better opportunities to cross burn from natural areas onto human developments (Zavala 2014). This is a huge safety problem. In addition to the obvious danger to human populations living in high risk biomes, wildfires are also dangerous to other living organisms like animals, microorganisms, and plants, due to the creation of smoke.

Fires are dangerous not only because of their ability to burn an expansive destructive area but also because they release a large amount of smoke into the atmosphere. After and during wildfires, smoke in the air can affect surrounding ecosystems for hundreds of miles and for many months (Mojzes and Kalapos 2007). The first obvious effect on human and animal health is that it could lead to the possibility of respiratory issues, especially those with preconditioned diseases like asthma. Months and months without protection from lingering smoke particles in the air led to the development of respiratory diseases. Gaseous smoke can travel for hundreds of miles and affect thousands more even after fires have been extinguished (Zhou et al. 2014). The negative effects of wildfires through gaseous smoke on organisms is apparent, but less studied are alternative ways smoke can affect the surrounding environment.

Smoke-water and ash soil are ways wildfires can further impact the environment. After a wildfire, the smoke can linger for weeks and can even seep into the groundwater sources (Chumpookam et al. 2012). This has effects on surface-based organisms and the plant biota. Different plant species can react differently to the presence of smoke water resulting in stunted or stimulated growth (Ferraz et al. 2013). Plants, like most other organisms, rely on water for basic biotic function, which is why the impact of smoke-applied water should also be considered as a possible harmful factor caused by wildfires. Ash from intensive fires can eventually settle as layers on the ground in soil. Plants and microorganisms can, therefore, be impacted by this form of smoke. Soil quality can be changed due to the persistence of smoke in the air (Flannigan et al. 2009). Wildfires are typically thought of as primarily harmful to large-scale organisms, but these different smoke types show that fire can impact finer organisms, like the plant biota.

The effects of fires on aspects of the environment like plant ecology should be extensively studied because wildfires are becoming an ever more impactful natural disaster. As previously mentioned, wildfires are burning human developments at a higher rate due to them being more innately powerful and the expansion of human development into the natural territories. This led to fires releasing non-organic chemicals in smoke that uniquely impact planted health (Urbanski et al. 2009). Smoke can vary in its chemical makeup. Smoke originating from organic material like plants is chemically made up of carbon-oxygen derivatives, nitrous oxides, methane, and other trace gasses (Urbanski et al. 2009). Smoke originating from inorganic materials can be composed of toxic plastics and cancerous chemicals. Measurement of plant health can be through seed germination rate, which can be stimulated and inhibited (Gama-Arachchige et al. 2020). Different smoke variables can affect seed germination (Markowicz et al. 2012). If wildfire smoke has organic or inorganic fuel can affect seed germination, as well as, the smoke form. While previous research leans towards the positive effect of smoke on seed germination, little research has been done with different smoke or seeds from California's chaparral environment (Keeley 1997). In order to see the effects of wildfire smoke on plant health. I observed the effect of wildfire smoke on seed germination rates in species from Tilden Park.

Objectives

My central research question asks how did Tilden Park plant biota generally react to wildfire smoke through seed germination rates. My sub research questions are how did different smoke applications and concentrations affect seed germination rates, were there differences between native vs nonnative germination, and did organic and inorganic smoke make a difference? I wanted to observe patterns in the effects of wildfire smokes on non-native vs. native seed germination. I elucidated any patterns, through collection of my observational data, on how native vs. nonnative seeds' germination rates react to different applications of smoke: smoke treated water, smoke treated air, and smoke treated soil. After visualizing my data, I had notable patterns that answered my questions. My working hypothesis was that organic wildfire smoke had a positive effect on both native and non-native seed germination, but non-organic wildfire smoke adversely affected both native and non-native seed germination, with a possible proportional correlation to the concentration of smoke applied. For my second sub-research question, my working hypothesis was that organic wildfire smoke water had a positive effect on both native and non-native seed germination, but non-organic wildfire smoke water had negative effects on both types of seed germination, with effects that were proportional to the smoke concentration in water. Lastly, organic wildfire applied soil would also increase the germination of both native and non-native seed germination. The perceived increase in germination will be proportional to smoke concentration. Finally I believed non-organic wildfire applied soil would hinder seed germination. My data generally supported my hypothesis and I developed implications that would have a critical impact on the ability of plants in the Northern Chapparal to be able to deal with inorganic and organic wildfires.

METHODS

Study site

I wanted to understand how Northern Californian plant biota reacted to wildfire smoke. The research site takes place in Tilden Park, which is in the East Bay area of Northern California. The biome of the Bay Area is the chaparral biome. It is commonly known as a Mediterranean climate. The East Bay area is very close to the Pacific Ocean, which allows it to have moderate temperatures. Winters weren't freezing cold and summers weren't blazing hot. Plants in this area are generally known to be able to withstand dry summers and wet winters. In addition, many plants have adapted to the fire cycle through different evolutionary traits that make fires beneficial. However, many nonnative plants also live and thrive in this ecosystem. An aspect of my research measured if there were differences between nonnative vs native seed germination rates from wildfire smoke.

The physical study site took place in a laboratory on the UC Berkeley campus. Specifically, burnings took place under a fume hood in order to help reduce the emission of harmful chemicals. Conditions in the laboratory have very constant temperature and humidity.

Study Species

To determine the impact of smoke exposure on germination, I selected 6 species of plants representing plants that are native and non-native to the San Francisco Bay Area. My native species were *Aesculus californica*, *Rosa californica*, and *Cardamine californic*a. These species were in Tilden Park's plant biota and are very common species in the East Bay area. They are native to the area being studied and are a representation of the natural plant biota in Northern California. My non-native species chosen were *Myosotis latifolia*, *Vinca major,* and *Rubus armeniacus*. These species are in Tilden Park and are common nonnative species in the East Bay area. In general, I chose common species because I believed they represented the Bay area plant life better than non-common species.

Seed and soil collection

I ensured that my study represented wild-grown plant populations in the Northern Californian biome as closely as possible. I collected the seeds mentioned previously by contacting Tilden Park management and landscaping. I reached out to a Tilden Park manager and was given seeds of specific species used in my research. I collected soil from Tilden Park or the hills of Berkeley, to ensure that the soil was representative of the East Bay area. The soils in these areas were used for my experiment and by using soil from a controlled area, I reduced confounding factors from outsourcing soil.

Creation of smoke

Organic and inorganic smoke creation

I created organic smoke by burning wood chips and dead leaves, collected from the hills of Berkeley, in the bee smoker and used the smoker to dispense smoke until the desired concentration was reached. A bee smoker is used to dispense smoke on bees, but I instead dispensed smoke onto plant seeds. Smoke treatment began by placing a smoke concentration detector inside the container and putting the lid on. I used the smoker to smoke the container until the smoke concentration detector reads 100 ppm, 200 ppm, 300 ppm, 400 ppm, or 500 ppm. Each concentration was a separate experimental cycle. To obtain inorganic smoke, I burned pieces of clothing and plastic instead of wood chippings. Inorganic smoke application only varied with fuel usage.

Smoke-water, ash soil, and control

I created smoke water, added smoke and smoke ash by concentration to a closed container with water. I allowed the combination to mix for 24 hours then vigorously shook for 5 mins. Alternatively, I could have used centrifuge-like applications like other studies to simplify the creation of smoke-water (Gama-Arachchige 2020). I then watered seeds using this smoke water mixture, replacing normal tap water. I created smoke soil by adding smoke inside of the closed container with soil and seeds and allowed the smoke and ash to settle for 24 hours. Afterwards, I planted seeds into the soil mixture. The control group of seeds had no smoke applied, was watered every other day, and planted in normal soil from Berkeley/Tilden Park.

General procedures

I determined the impacts of smoke type on seed germination by exposing seeds to preparations of different types of organic and non-organic smoke at different concentrations. Procedures for all the sub-questions are very similar except by the type of smoke being applied.

In order to do so, I filled a relatively small-medium (wide, not high) plastic food container with soil collected from Berkeley 50% full. Next, a hole for the smoker was created, but a bit of connection was left so it acted like a lid to close off the air passage. Separately, thirty seeds of each species (6 total) were planted in each container and label. I applied specific smoke types unique to answer the sub-questions of smoke, smoke applied water, and smoke applied to the soil at specific concentrations. Maintenance was standardized by watering seeds lightly every other day. I monitored seeds daily for 10 days and recorded observations. I repeated the experiment for different concentrations for each type of smoke. After completion, I disposed of materials appropriately and dumped out soil in the same spot soil was taken from, and gathered more soil for each individual trial. Finally, I cleaned out and washed the container and repeated for different smoke applications. Note that for all the variable testing experiments, there was a corresponding control variable experiment that consisted of the species of seeds under no external variables and watered every other day. In general, I expected that there will be varying effects on the germination of each species of seeds with regard to each smoke application and concentration.

Analysis

How were seed germination rates different by native vs nonnative seeds? By application type? The objective of my research was to collect data and visually compare them in bar graphs, in order to find meaningful patterns that elucidate the impact of inorganic and organic smoke on native and nonnative seeds. In addition, smoke application differences were used to compare which were germination cues or even inhibition ones. Because I was one of the first to do this specific research on the effect of wildfire smoke on Tilden Park seeds, I was primarily collecting data and laid out the foundation for further research after I compiled my results. In addition, my graphical analysis showed the negative impacts of inorganic smoke on seed germination in all species in Tilden Park.

RESULTS

Summary

The soil used originated from Tilden Park and the hills of Berkeley. I created each smoke application and applied it to native and nonnative seeds at varying concentrations. I followed my methods to conduct each experiment. To create smoke-water, I mixed smoke ash with water in a closed container and marinated for 24 hours then shook vigorously before pouring on seeds. To create gaseous smoke, use a bee smoker to burn organic materials, locally collected sticks and leaves (cloth and plastic for inorganic applications), then directly applied into the containers with seeds. I created gaseous air and ash and released them in the container with only soil, allowing ash to settle for 24 hours. Afterward, I planted seeds in the soil. I collected data and created visual bar graphs (Figure 1) that showed germination rates with respect to species, smoke application type, and concentration of smoke application. After I created comparative bar graphs isolated by two variables, I was able to observe visual patterns created by smoke applications and native vs nonnative seeds. The questions I answered were if nonnative and native seeds had different reactions to organic smoke applications, if organic and inorganic smoke applications had different effects on native seeds, if different smoke applications had different effects on seed germination, and if concentration of smoke application had an effect on seed germination.

	Day 1	2	3	Total by 10
Aesculus californica	0	0	1	13
Rosa californica	0	3	4	16
Cardamine californica	0	5	6	8

Figure 1. After the smoke application, I collected data on seed germination on each individual species for 10 days. Here is a very small snippet of the data I collected.

Smoke-water

I found that there were visual patterns by species that show how each species' germination rates were affected by organic or inorganic smoke-water at varying concentrations (Figure 2). In order to elucidate the factors of organic vs inorganic smoke-water and native vs nonnative species, I created comparative charts that summarized the different applications of smoke's effect on species based on only two set variables e.g. smoke-water on organic . Visualization using the comparative bar graph, I found that clearer patterns were revealed. Organic smoke water applications were observed to have a positive effect on seed germination rates in native plants (Figure 6) while having little to no effect on seed germination rates in nonnative plants (Figure 8). In addition, I observed that inorganic smoke water had a trend to negatively impact seed germination rates in both native and nonnative seeds (Figure 7, 9).

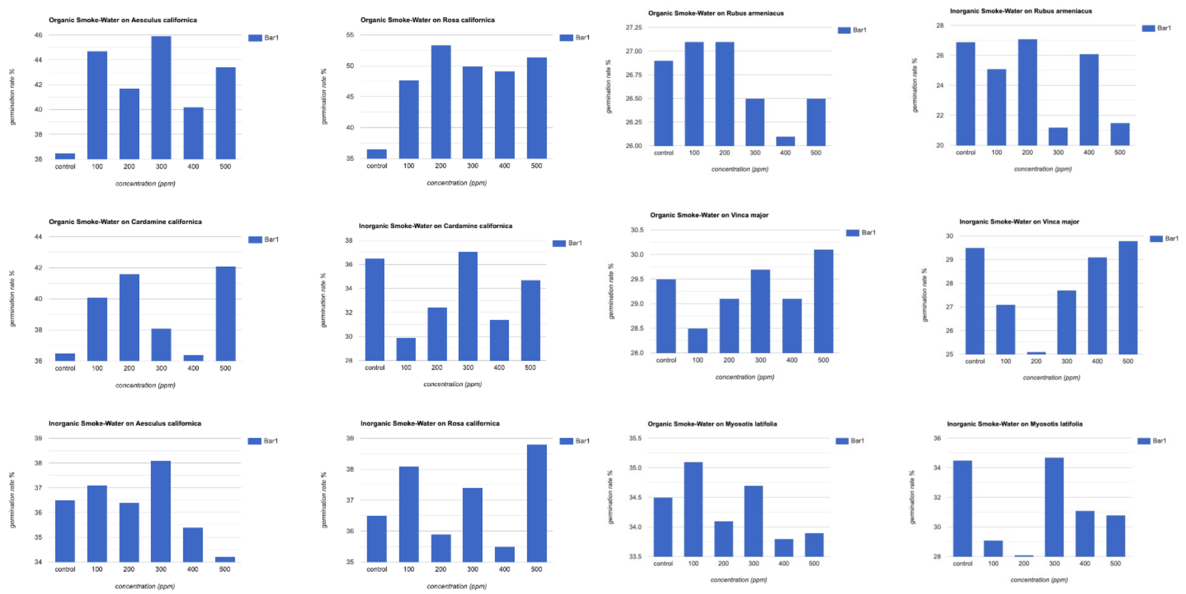

Figure 2. I visualized my collected data into bar charts that show the effects of organic and inorganic smoke-water on the seed germination rates of native and nonnative seed species.

Gaseous smoke

Paralleling smoke-water visual patterns, I found that there were visual patterns by species that show how each species' germination rates were affected by organic or inorganic gaseous smoke at varying concentrations (Figure 3). In order to future elucidate the factors of organic vs inorganic smoke-water and native vs nonnative species, I referenced comparative charts that summarized the different applications of smoke's effect on species based on only two set variables. Organic gaseous smoke applications were observed to have a positive effect on seed germination rates in native plants (Figure 6) while having little to no effect on seed germination rates in nonnative plants (Figure 8). In addition, I observed that inorganic gaseous smoke has a trend to negatively impact seed germination rates in both native and nonnative seeds (Figure 7, 9). I also observed that the positive trend is less extreme when compared to the effects of organic smoke-water and more extreme when compared to the effects of organic ash smoke (Figure 6). In general, I also found that the negative trend is less extreme when compared to the effects of inorganic smoke-water and more extreme when compared to the effects of inorganic ash smoke (Figure 8).

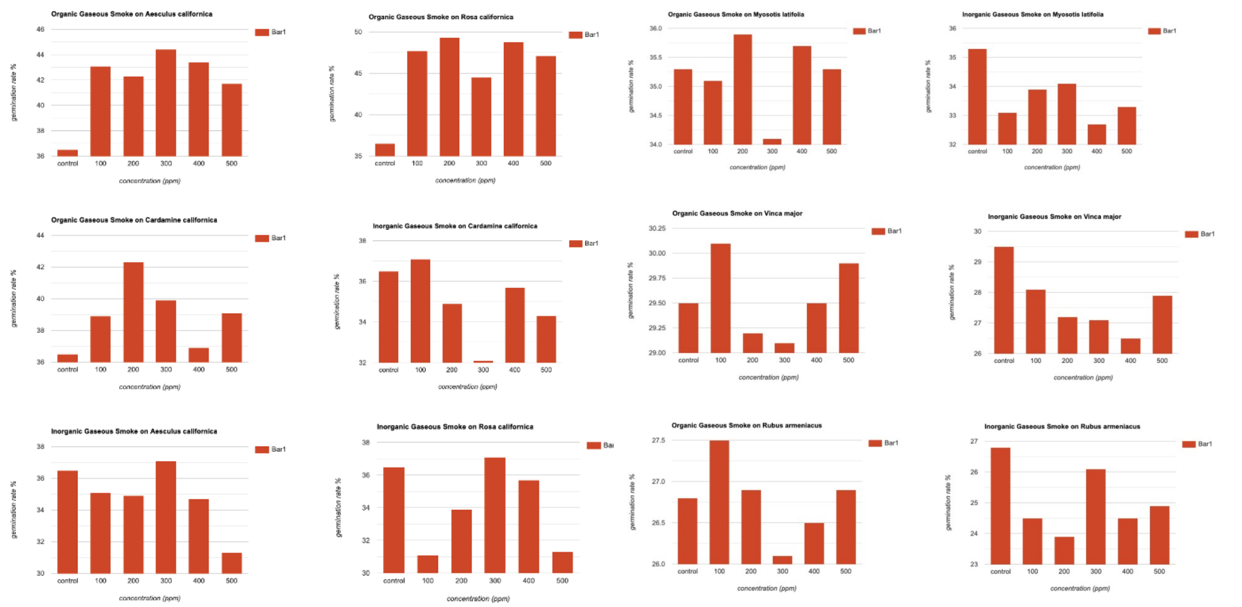

Figure 3. I visualized my collected data into bar charts that show the effects of organic and inorganic gaseous smoke on the seed germination rates of native and nonnative seed species.

Ash soil

Finally, again paralleling the previous two smoke applications, I found that there were visual patterns by species that show how each species' germination rates were affected by organic or inorganic ash at varying concentrations (Figure 3). Again, I referenced comparative charts that summarized the different applications of smoke's effect on species based on only two set variables. Organic ash soil applications were observed to have a positive effect on seed germination rates in native plants (Figure 6) while having little to no effect on seed germination rates in nonnative plants (Figure 8). In addition, I observed that inorganic ash soil has a trend to negatively impact seed germination rates in both native and nonnative seeds (Figure 7, 9). I also observed that the positive trend is less extreme when compared to the effects of both organic smoke-water and gaseous smoke (Figure 6). In general, I also found that the negative trend is less extreme when compared to the effects of both inorganic smoke-water and gaseous smoke (Figure 8).

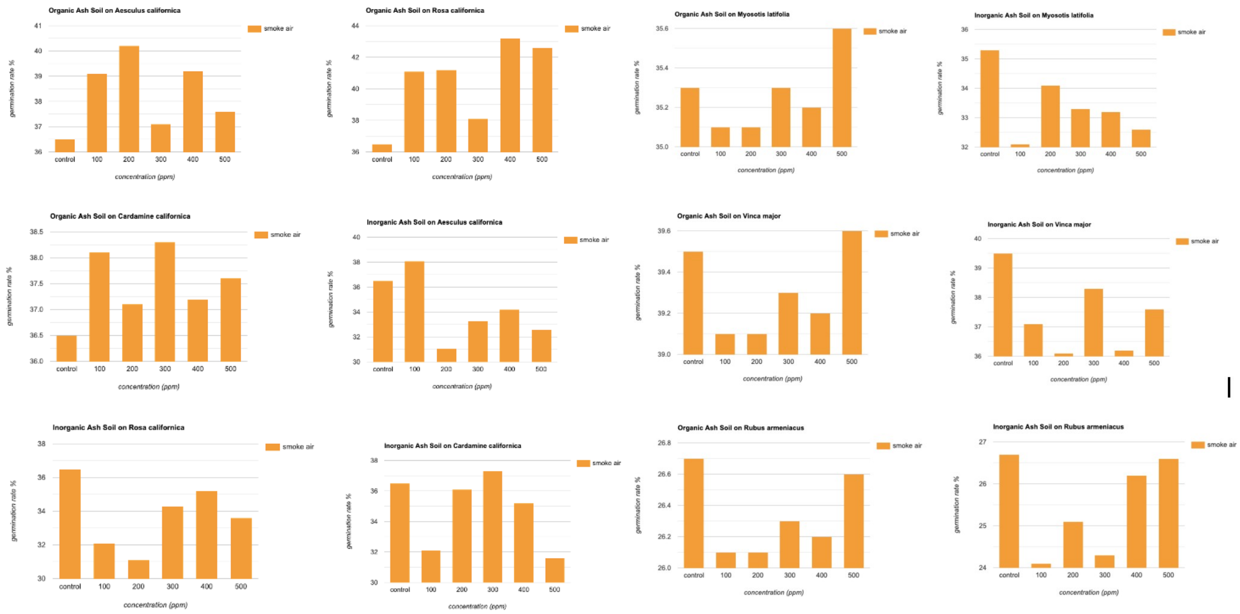

Figure 4. I visualized my collected data into bar charts that show the effects of organic and inorganic ash soil on the seed germination rates of native and nonnative seed species.

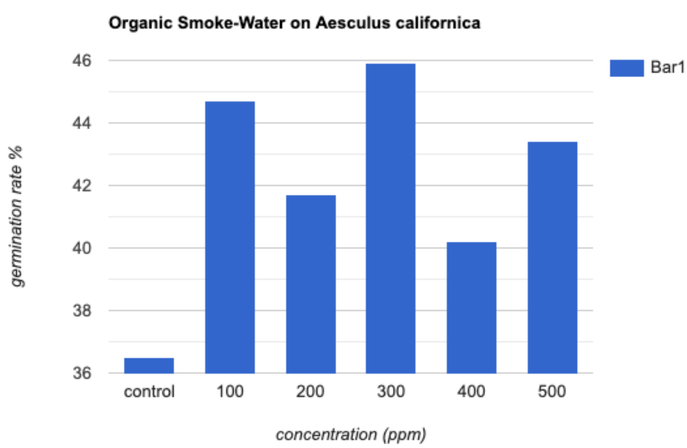

Figure 5. The individual graphs show that there is no correlation between the effects of inorganic and organic smoke application and the concentration of applied smoke.

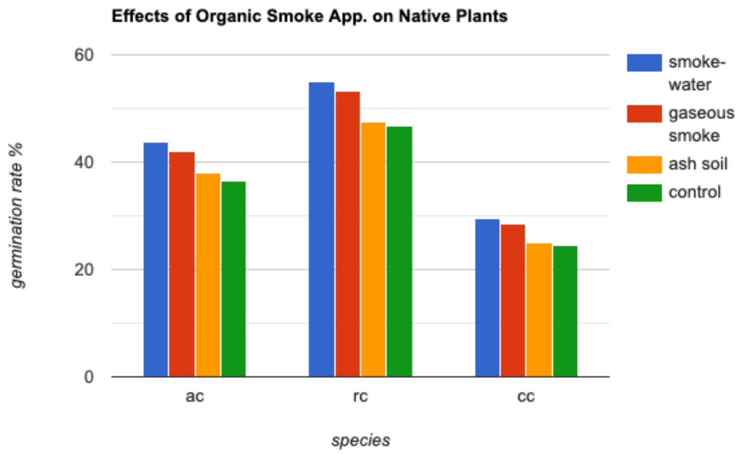

Figure 6. I compiled a comparative bar graph that visualizes the effects of organic smoke-water, gaseous smoke, and ash soil on seed germination rates of native plants.

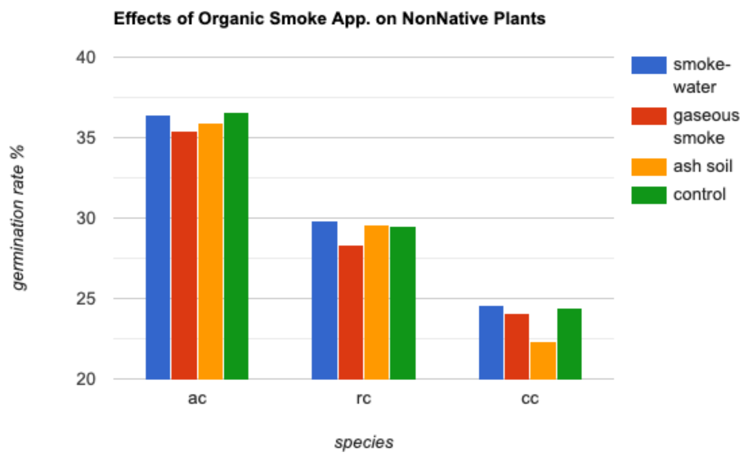

Figure 7. I compiled a comparative bar graph that visualizes the effects of inorganic smoke-water, gaseous smoke, and ash soil on seed germination rates of native plants.

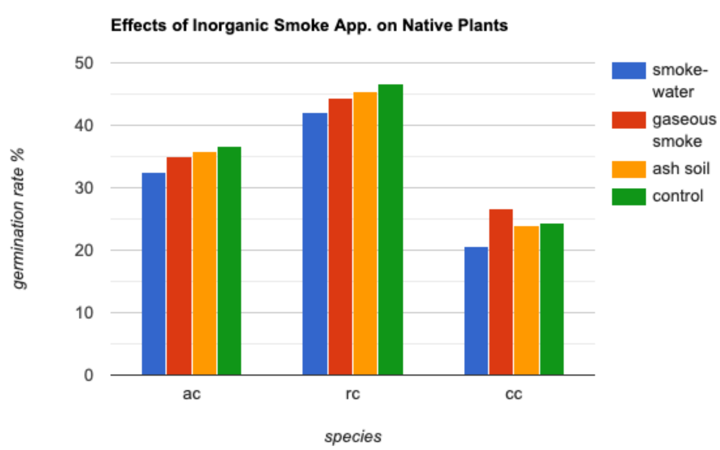

Figure 8. I compiled a comparative bar graph that visualizes the effects of organic smoke-water, gaseous smoke, and ash soil on seed germination rates of nonnative plants.

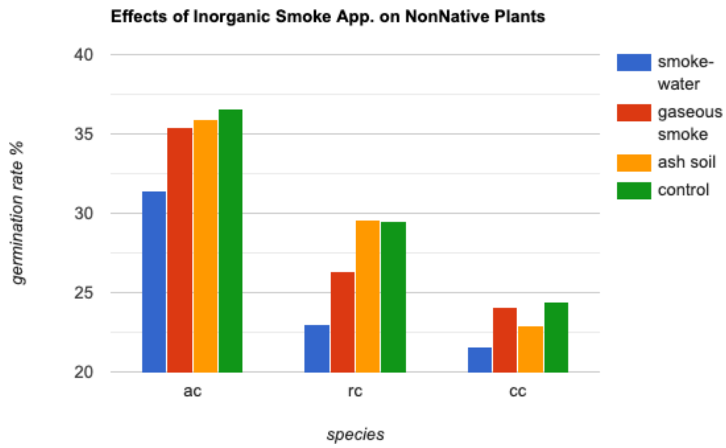

Figure 9. I compiled a comparative bar graph that visualizes the effects of inorganic smoke-water, gaseous smoke, and ash soil on seed germination rates of native plants.

DISCUSSION

The overarching goal of my research is to observe the effect of wildfire smoke on seed germination in Tilden Park. My working hypothesis is that native seed species' germination rates are stimulated by all organic applications of smoke, while inorganic applications of smoke have little to no effect. Past research has mainly only measured the impact of organic smoke-water on seed germination (Baczek-K 2012). My results both support and do not support different aspects of my working hypothesis. I want to note that my hypothesis and research overall are limited to the Tilden Park microbiome. Other research completed only focused on a specific species, papaya seeds, or region like the Mediterranean (Crosti 2004, Chumpookam 2012). Overall, my data collection and visualization help close the knowledge gap of general research done in Tilden Park about the impacts of wildfire smoke, specifically how nonnative and native seeds react differently to organic and inorganic smoke applications.

Smoke water's observed effect

My results support the aspect of my hypothesis that states that organic seed germination rates in Tilden Park are stimulated by organic smoke-water. My results show that there is an observed pattern that shows that organic smoke water has a positive effect on seed germination rates in native plants (Figure 6). This stimulatory effect does not follow to nonnative seeds where there is little to no effect on seed germination rates (Figure 8). Additionally, inorganic smoke water hurts germination rates in both native and nonnative plants (Figure 7,9). However, there is no indication that the concentration of smoke water has any association with positive or negative effects (Figure 5). Through comparison, it is observed that organic smoke-water has the most effect on seed germination, with the most increase and decrease in average germination rates (Figure 6, 7, 9). In Baczek's research done on farming crops in central Europe, it is shown that seed germination rates increase after the implementation of smoke water (Baczek-K 2012). In Chumpookam's research done on papaya seeds, the application of smoke-water on papaya seeds also increases seed germination rates at low concentration (Chumpookam 2012). Overall, both research conclusions support my smoke water sub-hypothesis. Although it is important to note that Chumpookam's conclusion has the caveat of influence by concentration level and my doesn't. In addition, they measured different species of seeds, which is important because there could be a species-specific reaction confounding variable (Sokolik 2019). Sadly, I found no studies on the effect of inorganic smoke on seed germination, which means I don't have papers to reference my finds with. In general, it can be stated that I observed a trend where organic smoke-water stimulates native seed germination, not native, while inorganic smoke-water has a harmful trend on both native and nonnative plants (Mojzes 2007). Implications of my observations are that organic smoke-water can be a germination cue in native Tilden seeds (Zhou 2014). In addition, inorganic smoke-water can inhibit seed germination in many seed species. This is important because the growing severity of fires is burning more human-made structures, creating inorganic compounds in smoke that can impact the environment for hundreds of miles.

Gaseous smoke's observed effect

My results support the aspect of my hypothesis that states that organic seed germination rates in Tilden Park are stimulated by organic gaseous smoke. My results show that there is an observed pattern that shows that organic gaseous smoke has a positive effect on seed germination rates in native plants (Figure 6). This stimulatory effect does not follow to nonnative seeds where there is little to no effect on seed germination rates (Figure 8). Additionally, inorganic gaseous smoke also has a negative effect on germination rates in both native and nonnative plants (Figure 7,9). However, like smoke-water, there is no indication that the concentration of smoke water has any association with positive or negative effects (Figure 5). Through comparison bar graphs, it is observed that organic gaseous smoke has the second most impactful effect on seed germination, with the second most increase and decrease in average germination rates out of the three smoke applications (Figure 6, 7, 9). In Crosti's research, it is shown that plant-derived smoke can increase germination rates in native Mediterranean seeds across all seeds studied (Crosti 2004). However, in Gómez-González's research on Chilean sources of seeds, research showed that organic smoke has an inhibitor effect on seed germination rates (Gomez 2007). These conflicting studies are a problem because there are mixed results on the effects of organic smoke. In Gomez's research, they hypothesize that although Chilean seeds are in a Mediterranean region, which is known to have regular fires, there is a marked lack of fires in that region, which they believe correlates to the negative effects of smoke on seed germination rates (Gomez 2007). This study allows me to hypothesize that because native seeds in Tilden are used to regular fires, organic gaseous smoke is an evolutionary germination cue that stimulates seed germination rates. This hypothesis can be used in future studies that focus on the genus differences in seeds (Sokolik 2019). The result of such a study will help my study in retrospect because seed species-genus connections can be a confounding factor (Zhou 2014). Despite the noticeable concerns with previous studies and confounding factors, I observed a trend where organic gaseous smoke can act as a germination stimulus in native Tilden Park seeds, showing the possibility of environmental influence on reaction to organic smoke, meaning fire-prone native species may have evolved to have a possible react to organic fire smoke.

Ash soil observed effect

Lastly, my results support the aspect of my hypothesis that states that organic seed germination rates in Tilden Park are stimulated in organic ash soil. My results show that there is an observed pattern that shows that organic ash on soil has a positive effect on seed germination rates in native plants (Figure 6). Like other smoke applications, this stimulatory effect does not follow to nonnative seeds where there is little to no effect on seed germination rates (Figure 8). Additionally, inorganic ash soil also has a negative effect on germination rates in both native and nonnative plants (Figure 7,9). However, like smoke-water and gaseous smoke, there is no indication that the concentration of smoke water has any association with positive or negative effects (Figure 5). Through comparison bar graphs, it is observed that organic ash soil has the second least impactful effect on seed germination, with the least increase and decrease in average germination rates out of the three smoke applications (Figure 6, 7, 9). This leads me to the idea that ash soil can be the least potent germination out of the three smoke applications. It has the possibility to least affect seed germination rates (Keely 1997). In Bargmann's research in Norway on ericaceous dwarf shrubs, graminoids, and herbs, the study concluded that smoke ash might be a germination cue because it helps increase germination rates, by decreasing the time to germinate (Bargmann 2014). This study is the model study for my smoke ash soil subquestion and the fact that our results support one another helps build confidence in our individual results. In addition to studying germination rates, the research also studied growth after germination rate, which follows the trend of being stimulated by organic ash (Bargmann 2014). My study doesn't measure how specifically germination rate is increased or decreased, but it opens the possibility for future research to dive into the cellular level of how ash can be a germination cue (Ferraz 2013). This can be branched into another study that prevents the inhibition of germination by inorganic ash, which my study shows in native and nonnative species in Tilden Park.

Limitation and future direction

As mentioned before, the location of my reach is also my limitation. The native and nonnative species of seeds I chose are active in Tilden Park; therefore, my conclusions and patterns I formulate can only be applied to the specific seeds in Tilden Park. This is an obvious double edge sword because although I know more about how specific seed species in Tilden Park generally react to different smoke applications, I don't have data of other microbiomes around the Bay or even in a bigger picture context. Conclusions made from research on South African seeds can't be extrapolated to other seed species (Ghebrehiwot 2011). Methodologically, I adapted creation smoke applications in order to make it as reproducible and accurate as possible given my situation. An example of my adaptation is having to marinate, then shake water and ash/smoke combination in order to make smoke-water. This is different from using a bubbler to create smoke water (Ferraz 2013). Small differences shouldn't alter my results too much but is still a noticeable difference in methodology (Crosti 2006). As mentioned before, no research had been done to measure the effect of inorganic smoke applications, so I can reference other sources when creating the fuel for inorganic smoke and analyzing my results (Markowicz 2012). This is obviously a sizable problem because science is based on precedent and building up from the past and I have no past to work on, which might lead to an unoptimized experimental methodology. My experiment had a possibility of not answering my hypothesis as accurately as it should. I tried to reduce this problem by mimicking the creation of organic smoke, which is well precedented (Crosti 2006).

Future research done can acknowledge the limitations of my study. My research is an observational study and doesn't rely on heavy statistical analysis. I noted that there wasn't a plethora of research done on the Bay area biome or microbiome, so I set out to record data and visualize it for a base understanding of how Tilden Park's microbiome reacts to smoke applications. Future research can be done that uses complex statistical analysis methods that confirm my conclusions. In addition, research needs to be done on another subsect of seeds in Tilden Park to see if my native vs. nonnative conclusion can be replicated, as replication of results is key to give my conclusion extra validity. In the far future, experiments can be done to answer the whys of our conclusions. This will take place at a cellular level and is currently out of the scope of much research. Results from this can give more concrete organismal pathways that explain seed germination reaction to the smoke. Another key goal of my research was to show the harm of inorganic smoke, which I was able to observe in both native and nonnative seeds in Tilden Park. Research in the far future can innovate ways that can neutralize the harmful elements in inorganic smoke, so we can soften the negative effects of the ever-growing fires on the plant environment in regions like California.

Conclusion

My research objective was to collect data in order to observe the effect of organic and inorganic wildfire smoke on native and nonnative seed germination in Tilden Park. The species I chose were representative of native and nonnative species in Tilden Park. The three smoke applications of smoke-water, gaseous smoke, and ash soil are used to replicate fire conditions in order to measure seed germination rates (Urbansli 2009). My results show that organic smoke applications stimulate seed germination in native species, while inorganic smoke applications generally inhibit seed germination in nonnative species. My observation on the harmful inorganic smoke on seed germination shows that the increased rate and extremity of fires will harm plant biomes for hundreds of miles due to the burning of man-made inorganic/toxic structures (Keeley 1997). Climate change is changing the fire culture in biomes like the Mediterranean environment, making them more frequent and destructive (Ferraz 2013). Although many native plant species have evolved to coexist symbiotically with fire, the inorganic chemicals released by the more destructive fires can be harmful to plant biomes (Markowicz 2012). In addition, nonnative plants from not-fire-prone areas have the possibility to be further affected by fires (Flannigan 2009). This is crucial to the agricultural market because, in areas like California, crops are typically not native; therefore, they have the possibility to not be equipped to deal with inorganic smoke from fires. Future research to prevent the harmful nature of inorganic smoke through the cellular level or inactivation of harmful chemicals needs to be invested in, in order to protect the plant biome and crops as climate change shows no signs of stopping.

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