It's Raining Seeds! Hallelujah!

New Mexico Supercomputing Challenge
Final Report
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Team 16
Eldorado High School

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Executive Summary

As New Mexico is a very dry state, it is very prone to large and damaging forest fires. When damaged, our vast pine forests will certainly not recuperate in our lifetimes if left alone. Ponderosa pines can live for five hundred years or more. According to the New Mexico State Forestry, humans cause about 55% of wildfires, from defective power lines, untended campfires, fireworks, or smoking. There have been many responses to this crisis, one of which we have chosen to study more in depth.

Companies such as BioCarbon Engineering, Droneseed, and Flash Forest have all adopted the method of using drones to shoot tree seeds into recovering areas. This method is significantly more effective than hand planting. Instead of a large team planting one seed at a time, one person can fly a drone over a much wider area much faster.

Such initiatives have received a lot of attention and already replanted acres of land damaged by farming, erosion, and fires. However, we are interested in how this process can be improved and adapted to fit New Mexico's unique needs. To test our improvements, we have created a NetLogo simulation of the drones interacting with an environment modeled after a New Mexican terrain.

Our simulated drones will be completely autonomous, and will have the ability to locate optimal spots for seeds to be planted, and deliver them from a certain elevation while still in motion.

These modifications will suit the specificities of New Mexico especially, but can in general drastically improve not only the speed of delivery, but the effectiveness of the operation in the long run, by creating a greater chance of survival during the crucial first few years of life.

Introduction

Our goal with this project is to conceptually design an improved method of reforestation using drones that is specifically adapted to New Mexico, and then to test its effectiveness using a NetLogo model.

It is important to understand that our project is purely conceptual, and has no physical implementation. We are concerned with the impacts of drone reforestation, not the robotics of drones, although we have studied basic drone concepts for background.

In order to apply this project to New Mexico and more specifically analyze its impact, we have decided to only model the planting of Ponderosa Pine trees, This is an extremely common tree type in New Mexico's forest, and is therefore often what is burned in forest fires. Focusing on only one type of tree simplifies the ecological considerations in our model, but in the future a greater biodiversity could be incorporated, such as the similarly common Pinyon Pine.

Our model will be a fully customizable simulation of a swarm of drones that will divide up a given terrain between them. Once given their area, each drone will scan the vegetation density beneath them and identify points where a seed can be planted. Then each drone will plot an optimal path between the points autonomously and travel along that path delivering seeds without stopping.

To verify that our adjustments will make a difference in the long run, we will also run our drones over the same terrain, but not use the scanning and pathfinding method. Instead, each drone will simply deliver seeds with a radius of two meters regardless of plant density. This experiment is meant to be a control. Based on these results, we have analyzed the chances of success of the seedlings over the course of 10 years to determine whether using our method is more effective than the method of existing companies.

Our model can be adapted to different circumstances, such as different terrain, wind strength and direction, and number of drones. We will have a random terrain generator that will create patches of rock, undergrowth, and burnt trees for the drones to scan, and we will have a physics engine to determine how the drone should adjust its drop location according to the wind.

As a note of background, there are many ongoing debates about whether reforestation is necessary. It is widely known that wildfires can be helpful to an environment, and the forest will naturally recuperate over time. However, as wildfires are becoming more and more common, as well as more severe, the forests are less and less able to recover, therefore necessitating reforestation projects such as this.

Research

Impact of Forest Fires

The ponderosa pine, as well as many other species, is unique in its ability to weather fires provided they are relatively fast moving. Its thick bark and deep roots protect the essential parts of the tree. However, as forest fires increase in severity and frequency, many trees are killed by fires and if possible, returning ground cover is sparse. Such damaged areas that need reforestation are in fact prime candidates to reintroduce ponderosa seeds.

> “Ponderosa pine forests appear to have evolved with fire and many authors have suggested that their composition and structure are dependent on the vegetation’s relations with fire (Covington and Moore 1994, Everett and others 2000, Hann and others 1997, Harvey et al 1999). However, when wildfires burn altered ponderosa pine forests, the extent or area burned is similar to historical times but they tend to burn more severely (Graham 2003, Graham and others 2004, Hann and others 1997, Kaufmann and others 2001). They often kill large continuous expanses of vegetation, consume the forest floor, volatilize nutrients, provide for exotic species introductions, increase soil erosion, and, in general, create forest conditions that may not be favorable to society (fig. 13). The long-term consequences are not well understood for issues such as water quality and wildlife habitat. Nor will the sense of place that forests often provide which, in some cases, will not be replaced for many generations (Galliano and Loeffler 1999, Kent and others 2003, Schroeder 2002).” (Graham)

Drone Reforestation

According to Droneseed, swarms of four foot long drones are deployed, each equipped with seeds. To ensure the seeds' survival, each is encapsulated in a small, biodegradable cone with nutrients and a shield from possible predators. These cones are shot out of the drones at extremely high velocities (between 150 and 300 meters per second) to implant them into the ground.

The comparative speed of the drones to humans is significant. Drones can travel six to ten times faster than a human, and according to BioCarbon Engineering, they can plant 100,000 seeds in a single day, while humans can only plant 2,500 per day on average.

Tree Survival

What was left unclear, however, was if these efforts are doing any good. In traditional, government-sponsored tree planting projects, more established saplings are transplanted from a nursery where they have grown in optimal conditions for years rather than starting the trees from seed. While this is more expensive, it greatly increases the chance of survival of the tree.

In the case of ponderosa pines, this extra care could make the world of difference. While pines are quite hardy plants, able to thrive in subpar soil, they are extremely shade and competition intolerant. During the time it would take for the seed to germinate and sprout, fast-growing shrubs and groundcover would quickly take over. Fig. 2 is a demonstration of shrub density has a negative impact on the number of pines.

In an experiment by the US Forest Service, the growth of pine trees was monitored over several years in relation to the number of shrubs nearby. This chart demonstrates the drastic negative effect shrubs have on the growth of pines. Another disconcerting discovery was that, “insect damage tended to increase with increasing shrub density. Damage to terminal buds by the gouty pitch midge and possibly other insects occurred almost annually, occasionally reaching near-epidemic status. In 1973, for example, the proportion of damaged trees was 2 percent in the no-shrub plots, 1 percent in light shrub, 12 percent in medium shrub, and 31 percent in heavy shrub plots.”(McDonald) During the first five years of life, shrubs and grasses have a significant advantage over the pine seedlings, as evident in Fig 1.

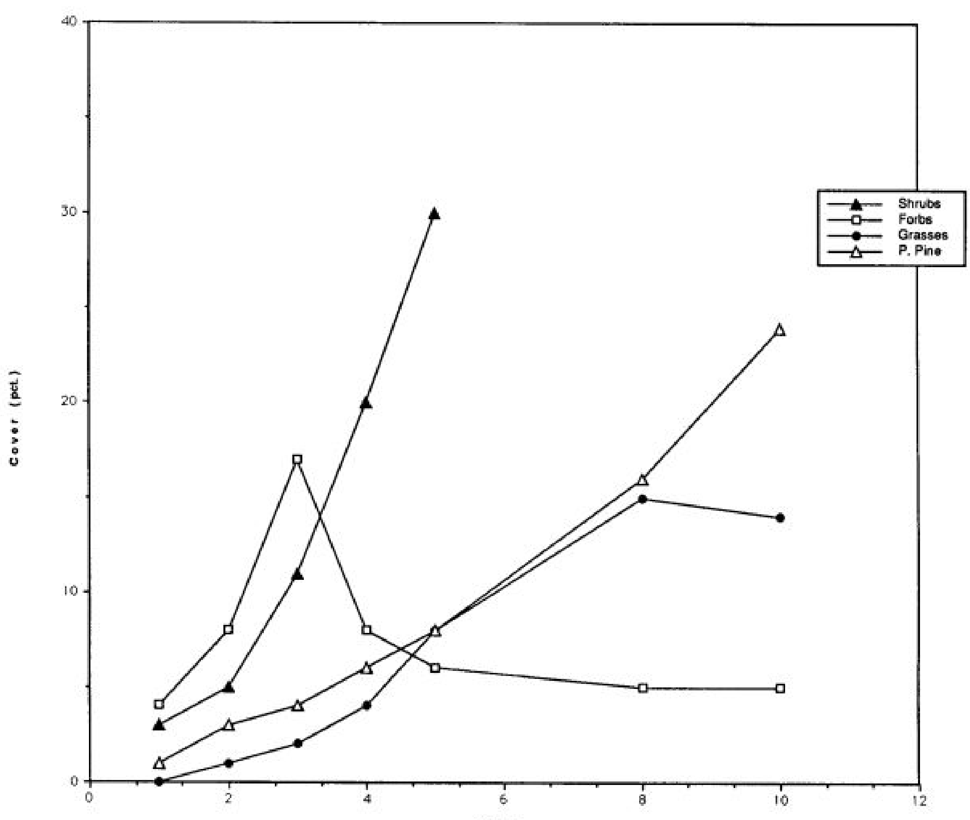


Fig 1 - Percent ground cover by plant type over 10 years (McDonald)

Density class	Density	Cover	Height	Diameter
	no./acre	*pct*	*ft*	*inches*
No shrubs	1000	46	16.5	5.1
Light shrubs	1000	29	12.0	3.9
Medium shrubs	1000	23	9.3	2.9
Heavy shrubs	750	8	5.8	1.4

Fig. 2 - Ponderosa pine values by shrub density class (McDonald)

These discoveries led us to designing drones that can identify the best places to place seeds, and deliver them exactly in those places, unlike the blanket approach of drone companies. Too dense of an area will destroy the tree before it matures, meaning it's only chance of success is to plant in clear areas. In the case of recently burned areas the amount of competing vegetation is severely lessened, but if the area has begun to recover this tactic is very necessary, even if the land is cleared by hand.

Another consideration we took into account was the weather and the movement of the drone. If we want our seed to land precisely, the drone will have to release the seed in a position relative to any wind and the movement of the drone. This calls for a physics engine to determine the correct dropping spot as the drone is in movement. However, this may not have the most significant impact on the delivery of seeds since they are being shot at such a high speed.

After conducting more research on ponderosa planting instructions, we have decided to plant our pines two meters apart, since adult pines need significant space around them to avoid crowding, but there is a high likelihood of not every seed surviving to that size.

Mortality Rate

Our next phase of research was concerning the next phases of life for the newly planted trees. We needed an approximate rate of survival for these saplings over a certain time frame, and therefore needed to define what criteria we would be basing these mortality rates on. First, we needed to consider the time span over which survival would be measured, and how this would impact the size of our tree. We decided on a 10 year overview, since this time span would allow for the saplings to reach a size sufficient to withstand competition that was so harming earlier in life. Having a shorter timespan would also focus the mortality rates as a function of whether or not our improved drone method was applied, rather than as a function of possible wildfires or infestations.

A USDA study on the mortality of post-fire pines indicated that “mortality in unburned transects on the four study sites averaged 2% over the 3 years.” (Sieg), meaning that for established forests, an average of 2% mortality per year was observed.

In Fig. 2, we see that in areas with high shrub density, approximately 25% fewer trees grew. We chose to consider a recovering burn area a high shrub density, since immediately following fires, undergrowth begins to sprout rapidly and in abundance. This study was conducted over a plot of 18-year old trees, but such a high mortality rate is only realistic for trees under five years old.

Lastly, we needed to consider the impact of insects or animals to the saplings. As mentioned earlier, burned areas are more prone to insect attacks. Fig 3 shows the relationship between total crown damage (amount of the tree burned) and mortality because of insect attack. While the planted trees will not be nearly as susceptible to beetles as the damaged trees, their proximity to the damaged trees puts them at risk. However, as we can see by the graph, this risk is still not even 1%. We chose to set the mortality to 1%, to account for animals as well as beetles.

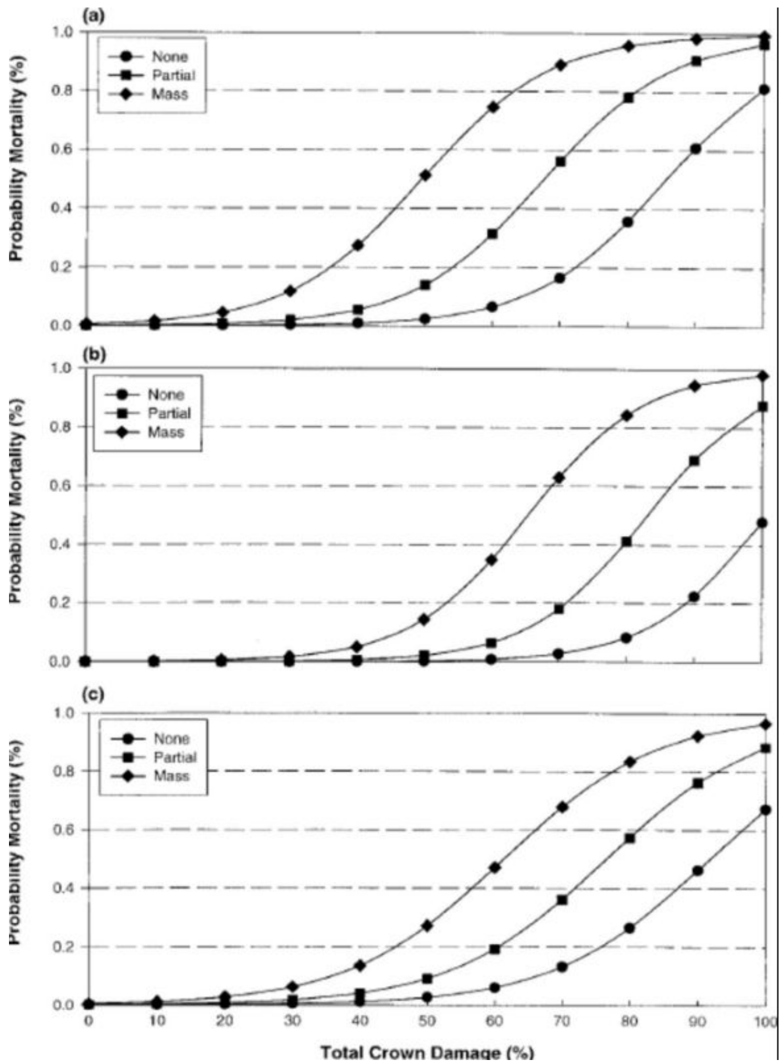


Fig 3 - Percent of total crown damage in relation to mortality following various intensities of insect attack (McHugh)

This gives us a total mortality of 28% for the first five years of life. While this number is highly subjective, according to the intensity of the previous fire, geography, weather conditions, and many, many other factors we can't incorporate at this state, 28% is a good base number for the mortality of seeds without a consideration for seed placement. This number could reasonably be lowered to 5% for the next several years, barring another fire, which such young trees couldn't survive at all.

If we incorporate precise seed delivery, we can drastically reduce mortality based on competition. It may be unrealistic to assume that this number would shrink to 0%, since invasive plants could, over the vulnerable five years, spread towards the saplings. We consider it safe to say that this mortality rate could shrink to 15%, leaving the total mortality for trees using our method at 18% for the first five years, and still 3% after the critical first five years.

Problem Solution

Outline

In order to solve our problem, we needed to create an accurate, feasible model of the drone and its environment. After our research, we determined what parameters would affect the planting of ponderosa seeds.

First, the terrain. We considered using New Mexico GIS data to create a model of terrain on which to run our program, but this would have meant we would be unable to use recently burned terrain. We also ran into hurdles figuring out how to transfer the data to our program, as it was comprised more of visualizations than data points. Instead of this, we created a random terrain generator that will supply dead trees, already grown or existing undergrowth, and patches of rock which the drone will have to identify and place seeds sufficiently away from. Since ponderosas are adapted to New Mexico's soil types, we did not need to factor that in. Our terrain generator creates a plane of small cubes, each representing one meter cubed. Obviously this is a very simplified approach, but can be improved in the future.

Second, the velocity of the travelling drone and any wind. To increase effectiveness, it is important for the drone to keep moving, but still maintain its precise dropping. Even though the seed cones will travel very fast, therefore negating most of the effects its forward momentum will have on where it lands, we want to make it as accurate as possible, even in bad weather conditions. The velocity of the drone and of the wind can be implemented as force vectors on the seed capsule, impacting its flight path. (For the sake of simplicity, we will only take into account the horizontal force of wind, not any vertical component.)

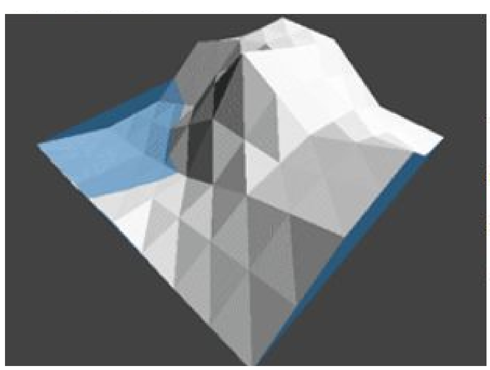
Third, the number of drones. This number will be a variable, and will only change how the simulation operates in that it changes the number of partitions the terrain will be divided into, thus lengthening the process of dropping seeds. This variable gives the user greater control of the situation, but does not change the effectiveness of the operation in terms of seed survival.

Fourth, the control. Since the drone companies are privately operated and relatively new, it was very difficult to find grounded statistical data about the success of their operations, especially in regards to forest fire recovery. Therefore, we decided to analyze their results through our own simulation. This was a simple process of not including the drones scanning and pathfinding instructions, but planting seeds evenly with a radius of two cubes (two meters) around them, regardless of terrain. This method is closer to what is currently being done.

Fifth, the ecological considerations of the ponderosa. This includes the aforementioned planting radius, which is made easy since the scale of our project is one block to one meter. Other techniques could be applied when it comes to the actual, rather than simulated, planting, but as far as our simulation goes, the seeds will not be given extra support such as weed killer or ground clearing.

Code

The terrain is generated using the diamond square method, which requires first setting four random

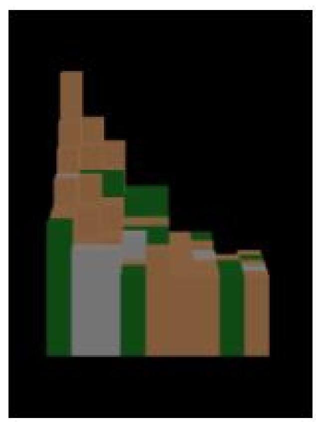


Visualization of the Diamond-square method in action with slight randomization (Center point and center of edges set initially) initial altitudes for the corners and the center of the terrain plot. From there, the new corners and center formed in the squares created in the first step are again randomized. This process is repeated as many times as needed to create realistic looking random terrain.

```
let val1 matrix:get m (starting_value_x + half_step_size) starting_value_y
set summation summation + val1
set num_additions num_additions + 1
```

This is one portion of the square step, which looks somewhat like a cross to find the point being modified. It takes a starting value in and goes up, down, and each side the same distance in order to find the average value. Since not all points have these kinds of edges (being on borders), we need to know how many values are being added in order to get the average properly.

The drones are moved around this 3D space by changing their velocity constantly to move them at different speeds depending on where they need to go. They shoot the seeds directly downward just like the drones do in real world applications. By moving around carefully and only shooting when at certain destinations, the drones are able to be incredibly precise in where the seed ends up landing.



Possible output of our Terrain generation in Netlogo 3D

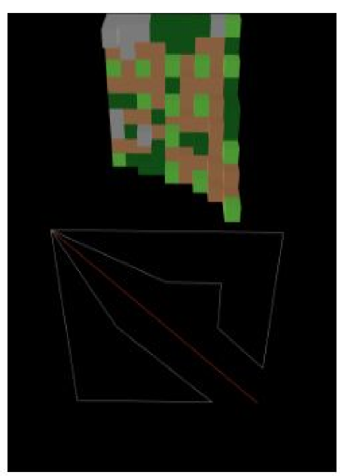
The seed shooting mechanism in our simulation is actually based off of a modified fireworks program, from the net logo 3D models library. The model already had the capability to apply certain x y and z velocities to the seeds (firework trails) as well as gravity affecting them. We added the vertical velocity to make the seed go directly down, rather than arc and fall like the firework trails. The gravity function on the seeds has little impact on them, since they are already being shot at high velocities, but is still present.

The drones all launch from the same corner but each is assigned a specific slice of the total area, the size of the slice changing depending on how many drones are present.

The motion of the drones is fairly simple. The move-to-point function takes two values and sets them to be the velocity of the drone on two axis, with a maximum speed of three meters per second. Then, the drone sets those values as it's speed in the form of a vector, and moves toward that point. Since these values are always updating, the drone will not move if it is given information for a point it is already on.

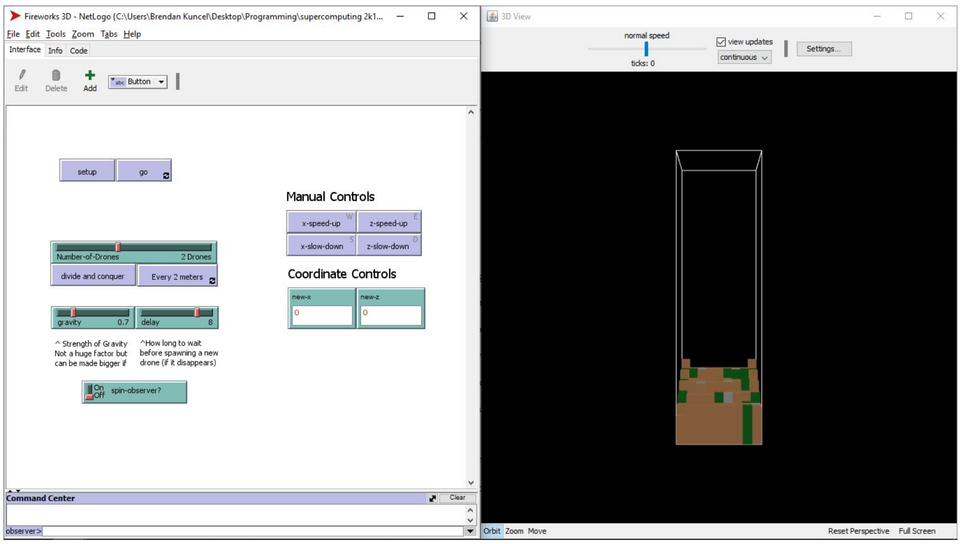
```
move-to-point new-x new-z
set x-vel initial-x-vel
set z-vel initial-z-vel
```

The path of the drones is determined using a simple pathfinding algorithm between the planting points. This algorithm finds the nearest seed in a specific slice to the starting point of the



Example of a path for 2 drones compared to where the seeds should go (shown in light green) drone. It repeats this process of finding the nearest point in the same slice to that seed, making sure that it does not block the path back to the start, until the drone travels back at the start for refilling.

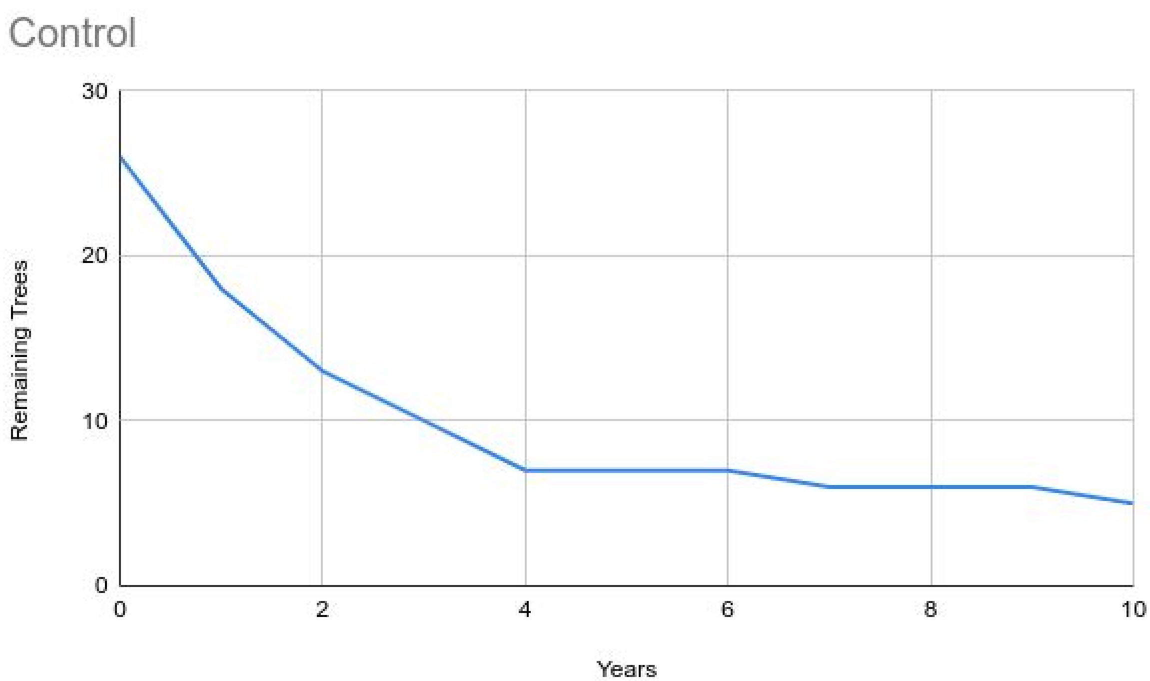
Shown - Interface for controlling drones/ starting the different methods of delivery

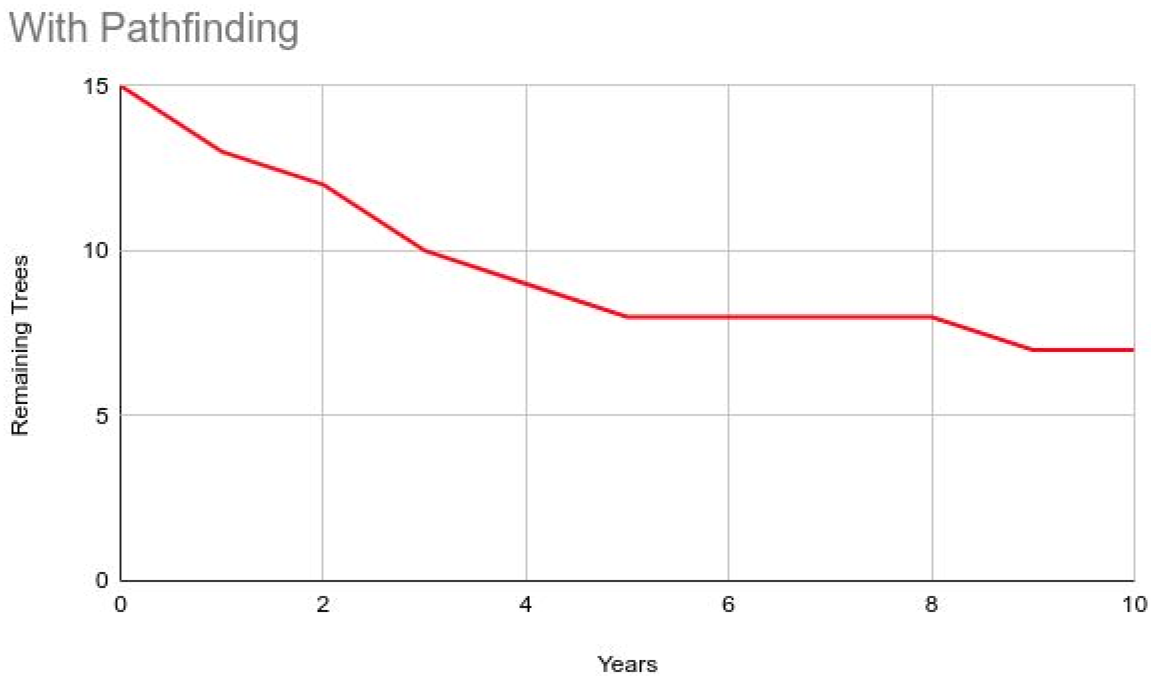


Conclusion

Results

As we ran our simulation over different terrains, we recorded the time each method of seed delivery took, and as hypothesized, pathfinding between delivery points was significantly faster than a blanket delivery approach. Different terrains afforded different numbers of possible seed locations. Based on these and the mortality rate statistics we found earlier, we were able to create graphs of how effective our improved model is compared to existing drone techniques over the period of 10 years. The following graphs reflect how many trees will survive with our improved detection method.





Our model was successfully created according to the parameters we laid, and is a valuable resource for experimenting with the future of drone reforestation.

Analysis

It is clear that using sensing technology and precision dropping can not only reduce the number of seeds expended and the time spent planting, but maximize the survival of the ponderosas. Although fewer seeds were planted using our method, more seeds were able to make it to adulthood, or at least out of the fragile first five year period. In our control, more seeds were planted, but many of them were quickly overrun by other vegetation or unable to grow among rocks.

It may be inaccurate to place an exact percentage of the advantage our method has on the blanket method until this experiment is repeated in the real world, but based on our data, the pathfinding method was approximately 40% more successful.

Sources of Error and Future Development

This experiment and its results are meant as a baseline for future development. A major area of improvement would be to incorporate more accurate terrain, perhaps even from a recently burned area so that the drone paths simulated could be applied in real life. Improving the quality and specificity of vegetation would allow the drones to more accurately determine where to deliver seeds.

Because of the basic terrain, simplified wind patterns, and variable mortality rates, the survival rate graphs may have a margin of error, which could be improved with better information regarding specific geographic regions and the conditions the seeds are being planted in.

Our data may have been more accurate with better statistics on survival rates. The rates we derived were not geographically specific, but more species specific. If this method was used in New Mexico, other factors may contribute, such as the presence of competing pines, the lack or abundance of rainfall, or the soil composition. While estimates can be made, the only way to be completely accurate is a field test.

Finally, if this conceptual project were applied in real life, other considerations may arise. For example, how would spraying a pesticide or a weed killer over the burned area improve the saplings chances? How would planting right after rain, or at varying times following the forest fire affect the growth? All of these are projects for another day.

Acknowledgements

We would like to thank Mrs. Glennon for her support throughout the years. She has been an invaluable resource and always there for us to bounce ideas off of. We would also like to thank Patty Meyer for her ideas and interest in our project. Both are endlessly caring and we couldn’t complete the project without them.

Team Information

Brendan Kuncel, a senior from Eldorado High School, was the programmer for this project. His greatest achievement for the project was managing to get the code back up and running since it somehow got corrupted for the second year in a row right before interim reports (He should get another computer since his current one is 6 years old). That was a very stressful time (He also just realized that he never told his partner about that happening).
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Savannah Phelps, a junior from Eldorado High School, was the researcher and writer for this project. Her biggest achievement was the extensive research conducted for this project. In all of its phases, research was a big priority.
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