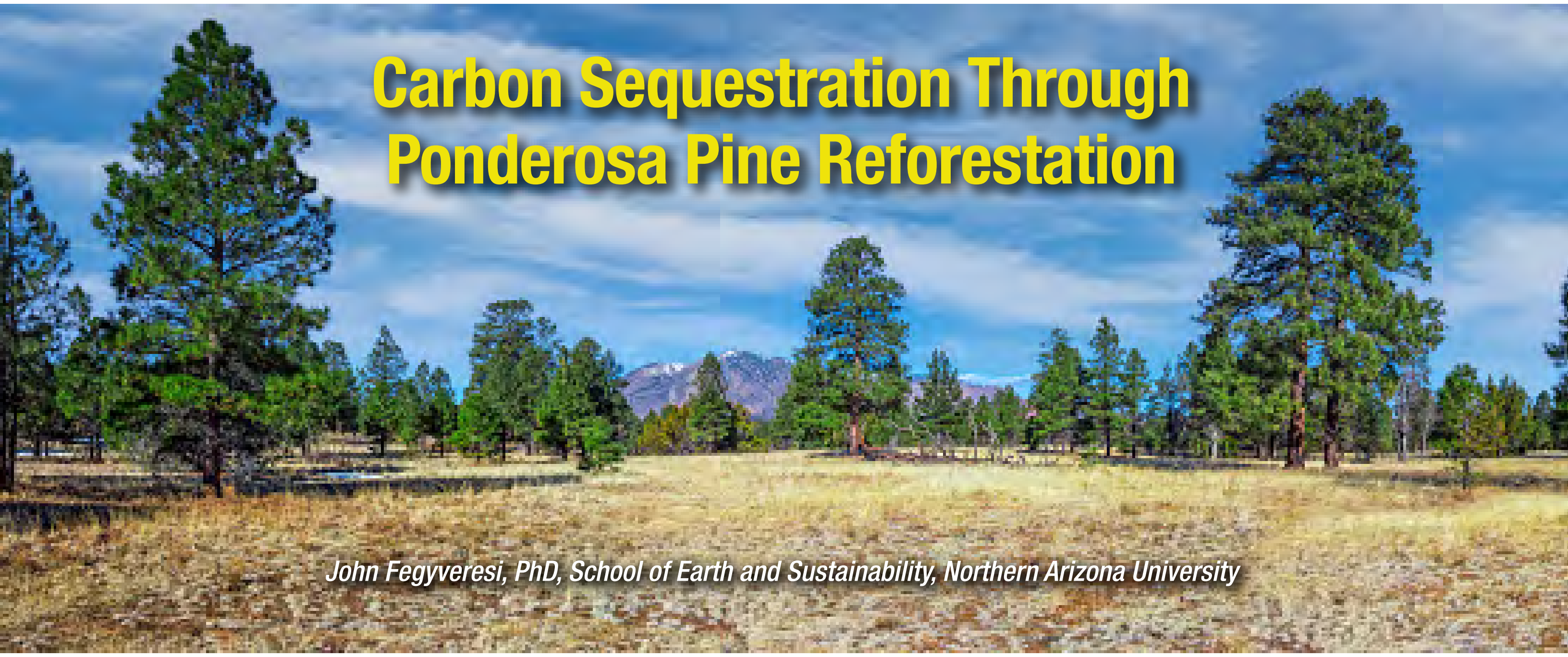

Carbon Sequestration Through Ponderosa Pine Reforestation

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Abstract

Reforestation efforts are often cited as one of the 15 most important and effective strategies that can be implemented to reduce atmospheric CO_2 (Hawken, 2017). The project detailed here, is a small-scale, proof-of-concept initiative for a much larger and future reforestation campaign in Northern Arizona. This project allowed for broad student involvement in what will ultimately be a multi-year effort for sequestering CO_2. In addition, this project serves as a first step in a potential larger Carbon Offset initiative that would be sponsored and championed by all three of the State Universities of Arizona (ASU, UofA, and NAU). As part of this NOAA Climate Stewards funded project, two-dozen graduate students from the NAU Climate Science and Solutions (CSS) graduate program successfully completed a small-scale (2-acre) Ponderosa Pine reforestation initiative in the Fall of 2020. These students planted ~200 Ponderosa Pine saplings on previously burned National Forest land. Future graduate students will subsequently monitor survival rates and carbon sequestration. It is hoped that the long-term project will ultimately result in over 1 million total newly planted trees (approximately 10,000 acres) in the next five years.

Introduction

Global climate change is not a single-solution problem to society and has even earned the nickname, “the wicked problem” (Murphy et al., 2012). As crucial players in the global CO_2 cycle, forests and trees can help offset emissions by naturally increasing carbon sinks. In a CRS Report to Congress (Gorte, 2009), tree planting was deemed to have a greater carbon sequestration potential than other land use practices, and serves multiple purposes when implemented in areas where tree biomass has been lost. Specifically, it is estimated that on average, reforestation can result in the sequestration of between 1.1 and 7.7 metric tons of CO_2 per acre, per year (Table 1; Brown et al., 1996).

Among the different terrestrial ecosystems, conifer forests are considered major carbon reservoirs. Their contribution to climate change mitigation is established in their large

Table 1. Estimated Sequestration Potential for Selected U.S. Land Use Practices. Adapted from Brown et al., 1996
(in metric tons of CO2 per acre per year)

Activity	EPS (2005)	USDA (2004)
Afforestation (previously cropland/pasture)	2.2 - 9.5	2.7 - 7.7
Reforestation	1.1 - 7.7	—
Riparian or conservation buffers (non-forest)	0.4 - 1.0	0.5 - 0.9
Reduced/conseration tillage	0.6 - 1.1	0.3 - 0.7
Grazing management	0.1 - 1.9	1.1 - 4.8

Sources: EPA: U.S. Environmental Protection Agency, Office of Atmospheric Program, *Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture,* EPA 430-R-05-006, Washington, DC, November 2005, Table 2-1, https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100GO8M.TXT. **USDA:** Jan Lewandrowski, Mark Peters, and Carol Jones et al., *Economics of Sequestring Carbon in the U.S. Agricultural Sector,* USDA Economic Research Service, Technical Bulletin TB-1909, Washington, DC, April 2004, Table 2.2, https://www.ers.usda.gov/webdocs/publications/47467/17126_tb1909_1_.pdf.

storage capacity and their ability to uptake carbon dioxide from the atmosphere through photosynthesis (Laclau, 2003). As such, one common species of tree found in the forests of Northern Arizona, is the Ponderosa Pine.

Based on the EPA's Carbon Footprint Calculator (https://www3.epa.gov/carbon-footprint-calculator/), an average American household in Flagstaff produces between ~8-12 metric tons of CO2 per year. Thus, an acre of Ponderosa Pines planted as part of a reforestation strategy in Flagstaff could nearly offset the carbon output of an entire single-family home. The projected 10,000 acres of planned new growth as part of this greater project, could offset approximately 21% of all carbon emissions from Flagstaff county homes. Furthermore, Ponderosa Pine stands at full maturity, could sequester up to 175.1 metric tons of CO_2 per hectare. In addition to significant biomass loss due to the various local and regional wildfires in Coconino County (e.g., the 1996 Horseshoe Fire), the already delicate Ponderosa Pine forests near the margins of the Colorado Plateau are losing several thousand additional acres per year due of the impacts of climate change and average warmer temperatures. This project aimed to address a portion of these losses. Data collected by future graduate classes will also be shared with the School of Forestry and the National Forest Foundation in order to inform the larger reforestation project, as well as evaluate the success, feasibility, and efficiency of the project.

Figure 1. Field location map created in QGIS by the author, using open-source satellite imagery.

At the onset of this project, Northern Arizona University Graduate students within the CSS program took a required class specific to Climate Change Mitigation in the Fall of 2020 (course: ENV 675). As part of their class project, they were broken up in to seven specific teams for the purposes of project preparation, field methods and operations, data collection, and report synthesis (as detailed in subsequent sections below). These teams were: *Literature Review, Site Summary, Outreach and Fundraising, Aerial Drone Imagery, Automatic Meteorological Station, GPS Tagging, and Soil Sampling.*

Background and Site Summary

The planting site is located within the Horseshoe Fire (1996) burn scar (Figure 1), approximately 25 miles NNW of Flagstaff, Arizona. It is characterized by high elevation (~8,000 ft), mean annual precipitation of ~20 inches, moderate humidity (<50%), and four distinct seasons (with wide ranges in diurnal temperatures).

The growing season in this area is relatively short, with the final spring freeze often occurring as late as June, and the first fall freeze as early as September. There are two main seasons of precipitation in the area, a summer monsoon (rainy) season, and a winter precipitation, or snowfall season (Staudenmaier et al., 2014).

Low precipitation conditions in the area may become the new normal as climate change increases the mean annual temperatures of the region, and decreases annual precipitation. The 4th National Climate Assessment indicates that the Southwest U.S. should expect intensifying droughts all while the population increases in the region, and already limited water resources continue to diminish (Gonzalez et al., 2018). Based on projections from the U.S. Climate Explorer Toolkit (https://toolkit.climate.gov/tool/climate-explorer-0), the planting site should expect a mean daily max temperature increase of nearly 10˚F by the end of the 21st century if as a society we continue on the "business as usual" pathway (IPCC – SSP5-8.5 scenario) of emitting greenhouse gases around the globe (Figures 2, 3). Based on these predicted changes in temperature and precipitation for the region, it is imperative that we regularly consider the suitability of Ponderosa Pine to inhabit this historically Ponderosa-dominated landscape in future planting initiatives.

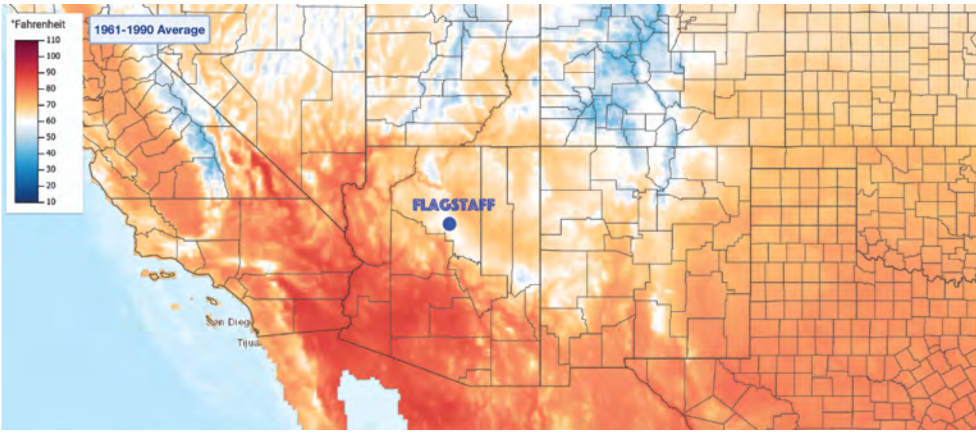

Figure 2. Historical 1961-1990 mean daily max temperature for Northern Arizona. U.S. Climate Resilience Toolkit. https://toolkit.climate.gov/tool/climate-explorer-0

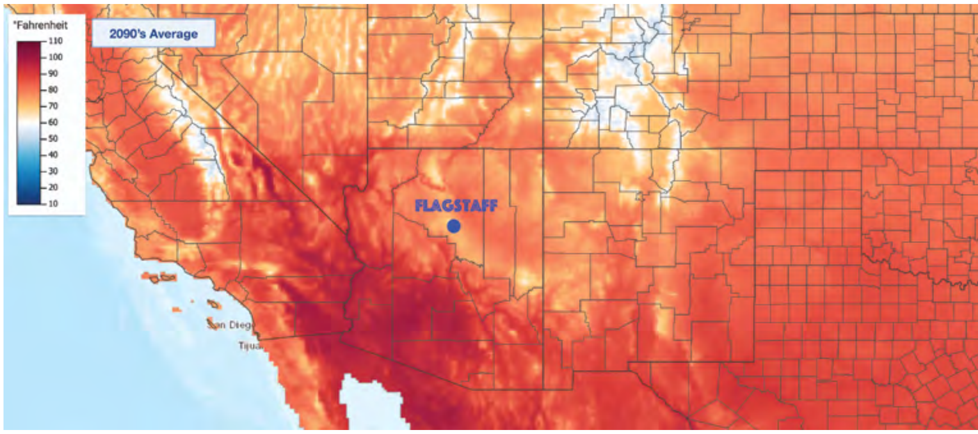

Figure 3. Projected 2090 mean daily max temperature for Northern Arizona under the high emissions (SSP5-8.5) scenario. U.S. Climate Resilience Toolkit. https://toolkit.climate.gov/tool/climate-explorer-0

Initial Site Data and Observations

Many aerial photographs and videos of the planting site were taken during the planting campaign (Figure 4). During the on-site tree planting, the ambient temperature, soil moisture, solar radiation, soil pH, and soil nutrient level were all measured by various team members. In addition, a Meteorological (*ONSET*) data logger weather station were configured to continually monitor local conditions at the site.

Figure 4. Aerial drone imagery of the project planting site on the Horseshoe Fire burn scar. Photo credit: John Fegyveresi

Aerial Drone Methods and Data

A designated drone team gathered aerial imagery of the site in an effort to create high-resolution figures of the planting area. Images gathered were made available to all other project teams in order to combine and/or

Figure 5A. (top) DJI Phantom 4 drone and components used for aerial imagery and site surveying. Photo credit: John Fegyveresi

Figure 5B. (bottom) Students preparing DJI Phantom drone for flight and image capture. Photo credit: John Fegyveresi

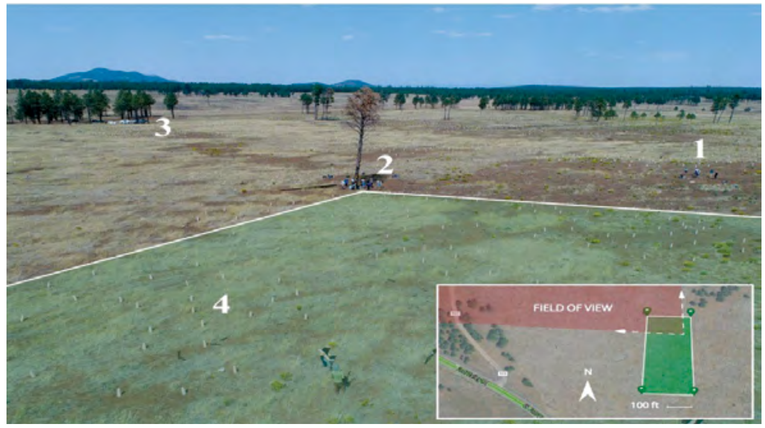

Figure 6. View from the NW corner of the planting site. 1) Location of drone deployment; 2) Location of ONSET Weather Station and main rendezvous point; 3) Parking area; 4) Partial view of tree cluster #1. Photo credit: John Fegyveresi

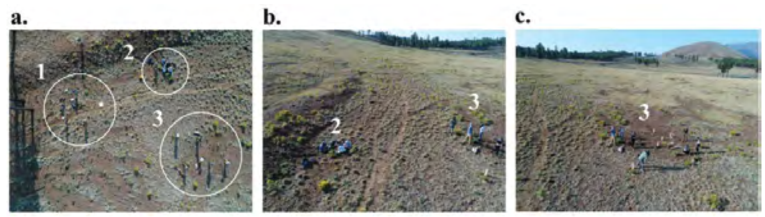

Figure 7. (a) Examples of three different student teams near the NE corner of the planting site; 1) Original location of Drone Team; 2) Soil/Solar Team collecting sample; 3) Tree Planting Team. (b) Soil/Solar Team (left) and Tree Planting Team (right). (c) Tree Planting Team working cluster #1. Photo credit: John Fegyveresi

incorporate them with their gathered data sets (See also Figures 5 – 7). The obvious advantage of using a drone for the site imagery, was that it was capable of giving a more complete picture of the specific site location as compared to traditional ground-based imagery. Additionally, larger-scale aerial images give a better sense of scale for the burn scar and planting area.

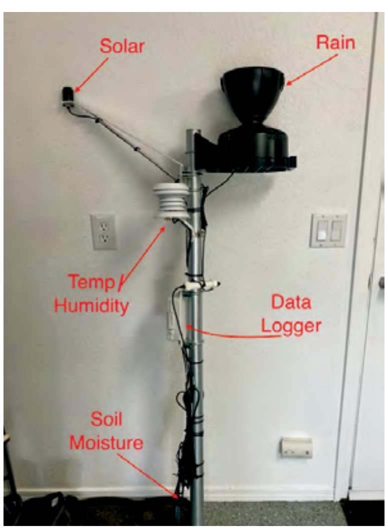

Figure 7. ONSET Meteorological Station installed at the planting site. Data logger and individual sensors are identified.
Photo credit: John Fegyveresi

ONSET Meteorological Station Methods and Data

Introduction

The *ONSET* Sensor Station team installed and configured an automated meteorological sensor station and data logger at the planting site (Figure 8). This team was responsible for downloading all collected sensor data from the planting day, as well as data captured over a 10-day period following the planting in order to evaluate any possible longer-term trends. The *ONSET* sensor Station included sensors for detecting rainfall (inches), soil moisture content (m^3/m^3), solar radiation/Insolation (W/m^2), temperature (°F), and humidity (%). The station was positioned near an existing snag (dead tree) at the primary planting area rendezvous point, and was programed to continuously record data at 1-minute intervals.

GPS Methods and Data

The GPS Measurement team gathered and documented all location specifics for the two-acre planting site through GPS latitude and longitude waypoints (e.g., Table 2). These measurements included GPS Coordinates bounding the entire site itself, as well as coordinates for all individual planted trees, any on-site instruments installed (i.e., the *ONSET* station), and any direct measurements made (i.e., soil measurements).

Soil Methods and Data

The Soil Measurements team set out to gather various data relevant to the health and condition of the soil in the planting area. In order to get an accurate and in-depth analysis of current soil conditions at the planting site, they used four different instruments. These included the *Rapitest* Soil Test Kit, *Rapitest* Digital 3-way, the Atree 3-Way Meter, and standard Toulifly pH strips. Four sampling sites were selected to best represent the integrated soil composition and conditions across the planting site. Measurements of nitrogen, phosphorus, potassium, and soil pH, were carried out using the *Rapitest* Soil Test Kit (Figure 9).

At each site, the GPS coordinates were recorded before the soil analysis, and soil was sampled from a depth of approximately six inches.

Table 2. GPS Site Locations

Site Identifiers	Longitude	Latitude
Site Corner 1	35.445203	-111.761341
Site Corner 2	35.446414	-111.761267
Site Corner 3	35.445178	-111.760622
Site Corner 4	35.4464	-111.760671

Instruments	Longitude	Latitude
ONSET Sensor Station	35.446517	-111.761240

Soil Sample Identifier	Longitude	Latitude
Sample 1	35.446389	-111.760639
Sample 2	35.445667	-111.761333
Sample 3	35.445639	-111.760972
Sample 4	35.446278	-111.760861

Figure 9. Students in the Soil Sampling team taking soil chemistry and pH measurements at the planting site.

Photo credit: John Fegyveresi

Ponderosa Pine Growth

Fortunately, Ponderosa Pines are fairly tolerant of varying soil conditions, however they still do prefer soils with a pH of between 6.0 to 7.0, and growing best in zones with 30 to 60 cm average annual precipitation on well-drained soils. Once established Ponderosa Pines can also survive in hot and dry conditions, exhibiting medium drought tolerance (Ganey and Vojta, 2011). When compared to other species of pines, Ponderosa Pines are able to tolerate less fertile soils, requiring lower soil nitrogen and phosphorus in order to survive. In addition, though higher potassium levels are not necessary for growth and survival, there is some evidence that potassium fertilization can lead to decreased mortality in ponderosa pine (Garrison-Johnston et al., 2005). The biggest concern for the soil conditions is that the annual rainy ("monsoon") season did not bring adequate rain totals for the year, leaving the soil conditions exceptionally dry. And though an established Ponderosa Pine tree can survive in such dry conditions, a young sapling needs additional moisture to properly establish. These dry conditions may ultimately lead to a higher mortality rate.

It is reasonable to conclude that our saplings can grow with the available nutrients of nitrogen, potassium, and phosphorus and the pH recorded for the planting site. Mean pH reading across all sampling sites and methods, was 5.7. This value is just under the ideal threshold of 6.0 (slightly more acidic). The nitrogen reading found in each testing location also showed that the levels were depleted. Our phosphorus readings varied at each testing site from depletion, to adequate, with two readings not clear enough to record an accurate interpretation. Though nitrogen levels were depleted and phosphorus readings were not consistent, it is still likely that the conditions are sufficient for tree growth. Lastly, two of our testing locations found a surplus of potassium while the other two found an adequate level of potassium. Despite the dry conditions, and based on the collected data however, the results should indicate a relatively satisfactory survival rate among the saplings (at least 20-30%).

Conclusions

In total, ~200 new Ponderosa Pine saplings were planted and catalogued on a previously burned portion of National Forest land, ~26 miles north of Flagstaff Arizona, within the Coconino National Forest. At the planting site, several measurements were made, and many instruments were used in order to document an ensemble of relevant data. These included drone photography, soil moisture and pH measurements, GPS waypoints and coordinates, and various meteorological and solar data. As a part of this campaign, a fundraising and social outreach effort was also carried out in an effort to raise awareness and funding for future project support. In total, over $500 dollars were raised through these efforts. In future years, this planting site will be further monitored by CSS graduate students to estimate overall tree survival rates, as well as total sequestered carbon. It is hoped that through this experience, and with the collaborations and partnerships built through it, that this initial proof-of-concept, small-scale planting campaign, will evolve into a much larger and continual reforestation and carbon mitigation effort. Following the project, the NAU School of Earth and Sustainability and School of Forestry, have teamed up to promote a larger tree-planting fundraising campaign on the NAU campus. We have established a NAU Foundation charitable fund through the University that will allow for open donations to this campaign. Long term, the multi-year extended plan for this project is to plant over 1 million trees over the next five years (~10,000 acres).

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About the Author

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Contributions to this article were made by the following MS graduate students in the NAU Climate science program under the supervision of John Fegyveresi, PhD:

Anabeth Avila Arenas; Bryce Beck; Jamie Blatter; Samuel Blustein; Caitlin Brogan; Dylan Chandler; Jenna Decker; Katie Dickinson; Jack Dugan; Katherine Dunlap; Sebastian Espinosa; Jillian Goulet; Stephannie de Souza Fernandes; Brianna Lovato; Christopher Moreno; Marie Nabors; Xuechen Niu; Mitchell Riner; Bennett Rosenow; Crystal Routhe; Maya Shimoni; Virgil St Aime; Chelsey Trejo; Ryan Tsingine; Hailey Weinberg; Isabelle Wilhelm; Alex Wilson; Iris Wu; Taylor Wyum