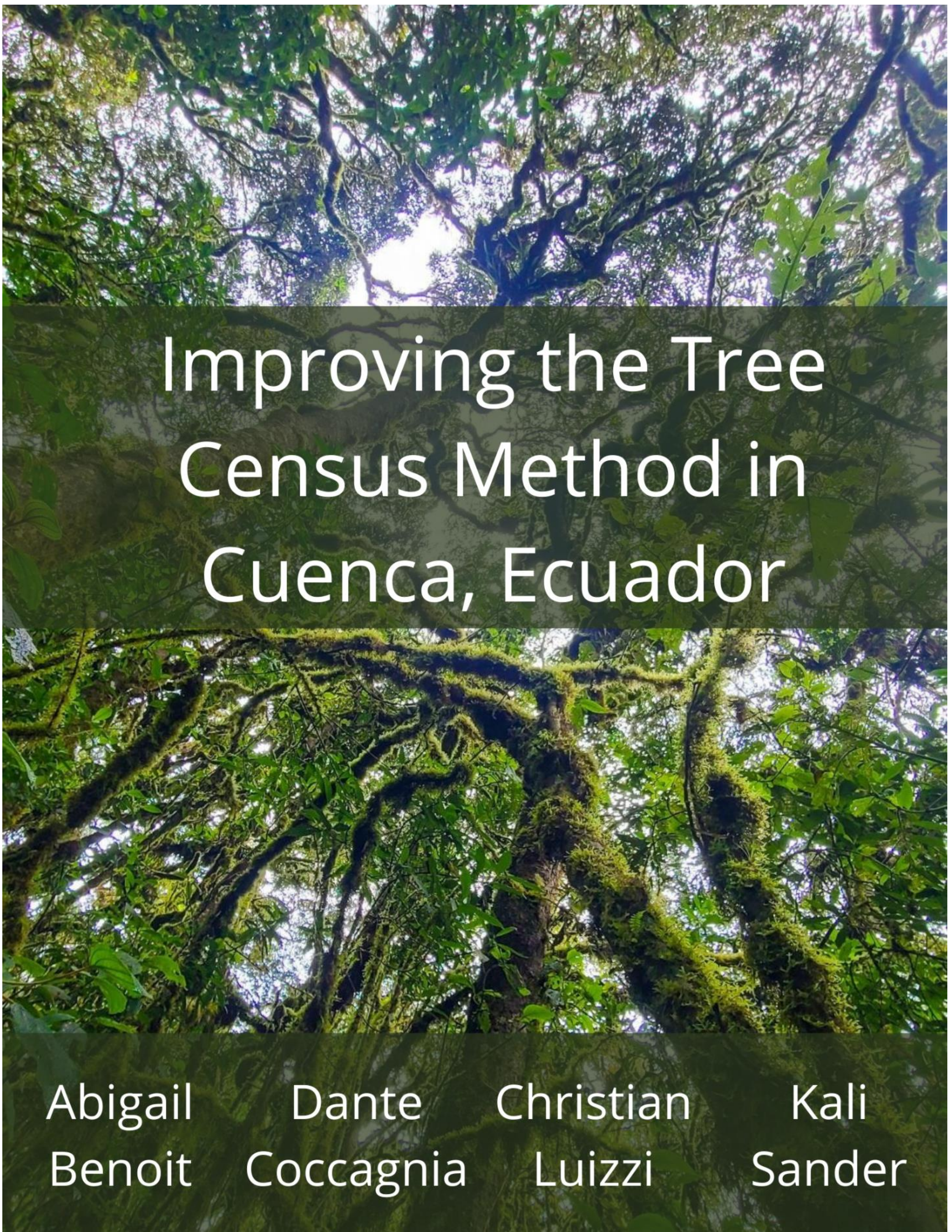

Improving the Tree Census Method in Cuenca, Ecuador

Abigail Benoit Dante Coccagnia Christian Luizzi Kali Sander

Improving the Tree Census Method

in Cuenca, Ecuador

An Interactive Qualifying Project

Submitted to:

The Faculty of Worcester Polytechnic Institute

in partial fulfillment of the requirements for the

degree of Bachelor of Science

Sponsor: Gustavo Morejón, Save.bio Cuenca

Project Advisors: Professor Esther Boucher-Yip and Professor Gary Pollice

Submitted by:

Abigail Benoit

Dante Coccagnia

Christian Luizzi

Kali Sander

Date Submitted: 2 March 2022

ABSTRACT

Climate change has affected Cuenca Ecuador. One effect is increased air pollution. Having an appropriate number of trees is essential to sustain life everywhere. The goal of this project, sponsored by Gustavo Morejón of Save.bio, was to determine the most feasible method to conduct a tree census. Through literature review, interviews, and fieldwork, a methodology consisting of evaluation tools and data organization tools was developed and pilot-tested to collect data for different methods that could be implemented. The results of this project have been recommended to Save.bio with new and improved methods of conducting a census and public education.

ACKNOWLEDGEMENTS

The success of our project depended on the contributions of many individuals over the past four months. We would like to take the time to thank all who have helped and supported us in this process.

First, we would like to thank our sponsor, Gustavo Morejón, for arranging and supervising our project. The guidance and contacts he provided were invaluable for the completion of the project. Our team would also like to thank Nelson Diaz from EMAC for his assistance with our project. We appreciate all of the support and reassurance we were given to complete this project successfully.

Thanks are owed to the community members of Cuenca and the University of Cuenca employees for teaching us Spanish and introducing us to the culture of Cuenca.

Finally, we would like to thank our Worcester Polytechnic Institute Advisors: Professor Gary Pollice, and Professor Esther Boucher-Yip, for their guidance throughout the project. Their feedback and support were constructive for improving our project within the seven weeks. We would also like to acknowledge Professor Courtney Kurlanska, who supplied us with resources and knowledge to prepare for our project, which helped us succeed in Cuenca.

AUTHORSHIP

Section Title	Primary Author(s)	Primary Editors(s)
Abstract	Kali	All
Acknowledgements	All	All
Executive Summary	Dante, Kali	All
1. Introduction	Abigail	Kali, Dante
2. The Environment and Trees	Christian, Kali, Abigail	Dante
2.1 Significance of Biodiversity, Afforestation, and Reforestation	Christian	Kali, Dante
2.2 What is a Tree Census?	Abigail, Christian	Kali, Dante
2.2.1 Definition and Identification of a Tree	Abigail	Christian, Kali, Dante
2.3 Previous Tree Census	Christian, Kali	Dante, Abigail
2.4 Methods of Conducting a Tree Census	Christian	Dante
2.4.1 Citizen Science	Dante	Kali, Christian
2.4.2 Geographic Information System	Kali, Christian	Dante
2.4.3 Global Positioning System	Christian	Abigail, Dante
2.4.4 Drone Technology	Christian	Kali, Dante
2.5 Tree Censuses in Cuenca, Ecuador	Abigail	Christian, Kali, Dante
25.1 Universidad del Azuay	Abigail	Kali, Dante
2.5.2 Save.bio	Abigail	Kali, Dante
2.6 Sponsor Description	Abigail	Dante, Kali
3. Methodology	Dante, Christian	Abigail
3.1 Determine the Most Feasible Options for Conducting a Tree Census	Abigail, Kali	Christian, Dante
3.2 Analyze and Compare Different Technology Platforms	Abigail, Kali, Christian	Dante
3.3 Develop and Test a Protocol Using a Citizen Science Approach	Abigail, Kali	Christian, Dante
3.4 Assessing the Feasibility and Efficiency of the QR Code Tagging Method	Abigail	Christian, Dante

4. Results	Kali, Abigail	Christian, Dante
4.1 Comparing Cuenca Tree Census Structures	Abigail	Christian, Dante
4.2 Results of the Implementation of Different Technology Platforms in a Census	Abigail	Christian
4.2.1 GIS Results	Kali	Christian, Dante
4.2.2 GPS Results Prove Inefficient For City Streets and Parks	Abigail	Christian, Dante
4.3 Citizen Science Census Protocol Results	Kali, Abigail	Christian, Dante
4.3.1 Discussion of the Comparison of Citizen Science and GIS/GPS	Abigail	Christian, Dante
4.4 QR Code Analysis	Abigail	Kali, Christian
4.5 Limitations of the Data	Abigail, Kali	Christian, Dante
5. Recommendations	Abigail	Kali, Christian
5.1 Plans Moving Forward	Abigail	Kali, Dante
5.1.1 Cuenca Tree Area Map	Abigail	Kali, Dante
5.1.2 New Signage System to Rectify the Tagging Method	Kali, Abigail	Christian, Dante
5.2 Project Conclusion	Kali	Christian, Dante
Appendix A	Abigail	Christian, Dante
Appendix B	Kali	Christian, Dante
Appendix C	Abigail, Kali	Christian, Dante
Appendix D	Christian	Kali
Appendix E	Abigail	Kali
Appendix F	Kali	Abigail

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

EXECUTIVE SUMMARY

INTRODUCTION:

Located below the equator in the southern Andes mountains is the city of Cuenca Ecuador, which is home to roughly 700,000 citizens (Data from National Statistics and Census Institute provided by our Sponsor). In a region that is densely populated like Cuenca many resources are required to maintain a healthy and habitable lifestyle, and some of these necessities could potentially be lacking. Oxygen is dependent on the consumption of carbon dioxide from trees which releases oxygen (O2) back into the environment. According to our sponsor's calculations regarding yearly oxygen intake, each individual citizen requires about 7 to 8 trees in order for the city to have a sustainable amount of O2. In order to have an estimate as to how many trees are required, we multiplied 7 (number of trees per person) by the number of citizens in Cuenca, which then yielded approximately 4.5 million trees needed. The question then became, how many trees are in the city of Cuenca? What is the best method of inventorying them? Two censuses were completed prior to our arrival and the results varied drastically. The primary method used in their research was citizen science and that gave results with ranges between 5,000 and 16,000 trees. Because of these inconsistencies in documentation, there is no way of determining specifically how many more trees are needed to fulfill the recommended value of 4.5 million. To improve this system of data collection, we are analyzing former censuses conducted, researching trees in Cuenca, and determining what is economically feasible given resource constraints. The long-term goal of this project is to create a method to accurately assess the tree count in Cuenca which can be implemented globally.

METHODOLOGY:

Through research, data collection, and the implementation of geospatial technologies, and accurate tree count not only directly impacts Cuenca but potentially the future of the environment globally. The objectives we developed to meet our project goal are as follows:

- Determine the most feasible options for conducting tree census in Cuenca
- Analyze and compare different technology platforms
- Develop and test protocol for citizen science approach

- Determine the most feasible and efficient option for tagging trees

To learn more about previous efforts to conduct tree censuses in Cuenca and determine the most feasible option, we interviewed participants of tree inventorying projects prior to our arrival. One of the first interviews we held was with our sponsor, Gustavo Morejón Jaramillo, a biologist specializing in biodiversity monitoring. In March of 2019, Gustavo founded Save.bio, an urban forest inventory, monitoring, and protection system that enables citizens to help tackle climate change. In this interview, we learned more about the structure and methods behind Save.bio and the main goals our sponsor would like to accomplish. Our next interview was with Nelson Diaz, a local municipality worker, in charge of all of the green areas in Cuenca and inventorying eucalyptus in the city. We learned that there is no current system or technology to help with any type of tree census.

To complete our next two objectives, we utilized two different forms of geospatial technology such as Geographic Information Systems (GIS), and Global Positioning Systems (GPS) along with a form of citizen science called ground-truthing. Our sponsor shared GIS files with us which showed maps of all of the green areas and green spaces in Cuenca. To analyze the GIS data, we went to some of the GIS areas recorded in the files and counted the trees as our way of ground-truthing. This allowed us to verify that the GIS files were up to date and had the correct information. In order to analyze GPS data, we used Google Earth images, both aerial and street views, and counted trees in a given location. We then were able to verify our results through citizen science, which allowed us to conduct our own censuses at Parque de la Madre, Avenida Fray Vicente Solano, a location in Turi, Museo Pumapungo, and Parque Lineal 24 De Mayo Bebedero. To do this, we tried multiple methods: counting together as a group, counting in pairs of two, individually counting, implementing our own temporary tagging system, and counting using plot sizes. This taught us that the most efficient method is dependent on the density of trees attempted to be inventoried.

The final objective was to assess the feasibility of the tagging method Save.bio uses. A passion of our sponsor is public education and awareness. Currently, Save.bio is attaching QR Codes on each tree they count in their census as a method of tagging. The purpose of the QR Code is to track trees' health, ensure there is no double-counting, and educate the public. A downfall of this specific method is, over time, codes get lost or broken and are not scanned as much as intended. To determine if this is the most economically efficient tagging method, we scanned trees marked by QR codes at Tres Puentes, recorded the number of people who have scanned, and compared that to how long the tags have been posted.

We also recorded the functionality of the QR tags and any other observations that could impact the usability of this method.

CONCLUSIONS:

Through research, interviews, and data collection, our group was able to use many different methods in various green spaces to determine which methods were the most accurate and in which areas. Our conclusions are as follows:

1. **There cannot be one method of conducting an entire tree census**
   After all data collection was complete, we determined that it is unreasonable and ineffective to complete a tree census using only one method. By using one method, you will not be able to obtain the best results in all of the different areas of the city. Multiple factors go into determining which method to use, and the rationale behind using that certain method.
2. **Green areas along city streets can use citizen science as the main method**
   Since the city streets are not densely populated, it is much easier to use citizen science as the main method for inventorying. When collecting data in these specific areas it was clear that trees were planted in what seemed to be paired with a lot of distance between them. This makes it easy to not double count and be able to move at a decent pace while counting. There is no need for outside resources because it would not be worth the money invested into the equipment since it can be done just as easily by walking down the road where these medians are populated. When applying this method it took our group of four college students no longer than 20 minutes to count a mile-long straight away of 182 trees with great confidence in our results.
3. **Parks and medium density areas can use drone technology/GPS and citizen science ground-truthing**
   Using both drone and GPS technology paired with ground-truthing allows for a more accurate count of the trees in more densely packed areas. By using GPS or drone technology, you are able to quickly count trees in the area through aerial photography. Still, it is difficult to determine if you had already counted or missed a tree from an image. Using citizen science to ground truth, you can obtain more accurate results. Although this may take some time to complete, the results are more accurate than only implementing one method.
4. **Highly dense areas such as forests should use GPS and plot sizes**

In areas of high density, it is much more efficient to use GPS along with plot sizes as a method of estimating the number of trees in an area. By using plot sizes you are able to determine the number of trees in a small highly populated area, and then multiply this plot size by the length of the forest or area to obtain a reasonable quantity of trees, with a margin of error. This method is much faster than going into the forest and tagging or counting each tree individually.

5. **The sole use of citizen science is not feasible for conducting a long-term census or tackling the long-term goal**

   Upon implementing our own citizen science census and utilizing temporary tagging methods in Parque De La Madre it became quite apparent that this was not the ideal method for inventorying over four million trees. Our group of four participants recorded 108 trees in the park which took over an hour of nonstop work. We determined that a group of four participants would need to work five consecutive years to count all 4,500,000 trees. Due to the clear lack of feasibility, further calculations and explanations are not needed.

FINAL RECOMMENDATIONS:

Based on our findings we advise the following recommendations:

- **<u>Implement Multiple Census Methods Throughout Cuenca</u> We recommend utilizing various methods and technologies to conduct the most feasible and accurate censuses throughout the city. From our results, we concluded that citizen science can be solely utilized in city-streets, technological methods combined with citizen science for parks and medium-dense tree populations, and GPS plot sizes for densely-populated tree areas such as forests. We have concluded it is not feasible to solely implement one method.**
- **Improve Citizen Science** Our recommendation for this specific method relates to promoting more participation in citizen science projects and will help quantify the accuracy of this method. With additional participants, pilot programs for these censuses can be conducted, and focus groups can be created to improve census protocols. Increased participation in the first few weeks of the project would allow for the implementation of different methods of utilizing census technologies. Results would then be used to create a feasibility assessment, to compare user-friendliness, economic feasibility, and accuracy.
- **Utilize GPS/Drone Technology** We recommend that using upgraded technology such as GPS and drones would yield better data and results in a much timelier manner. This would be very

beneficial to helping conduct a census in the future, especially in highly dense forest areas. When trees are clustered together, an overhead image may not be able to differentiate all of the trees, whereas different perspectives from drones would allow us to count the trunks of the trees. Having better quality GPS images would also be beneficial because it would allow for a more accurate count when determining the number of trees in that area.

- **Rectify the Tagging Method** In regards to the current tagging method we suggest that instead of having multiple tags on trees that rarely get scanned, have one sign at the entrance of each green space with information about the trees and the area you are observing. This will be more economically efficient than the current QR tags, and potentially be more effective in promoting public education as there is a more visible and functional sign with a single QR code and pictures.

We also have created the following deliverables to present to our sponsor:

- **Create a Cuenca Tree Area Map** Our results regarding which methods worked best lead us to recommend the creation of an interactive tree area map of Cuenca. This map is an interactive interface that shows different densities of trees all over the city. Each area has a different color-coordinated map that determines how dense the area is and what census method would best fit in that area. More specific information such as a description of the area, the code number provided by the municipality, and the overall area will be shown once any given area is clicked on. Through this map, you can use area and size to determine how many trees are in the city. The findings that led us to this recommendation took place throughout our fieldwork. We realized that upon inventorying trees in many different locations that it works best to use a certain method depending on where you are. By creating a map that allows you to see what method to use based on the corresponding color it gives the future employees of the project a sense of direction on how to approach the census.
- **Create a Signage System** This sign would include information about the park in both Spanish and English, the Save.bio logo, and a QR code that would link to the Save.bio website with further information.

If implemented, these suggestions can drastically improve future censuses in the city and can be a start in the right direction to fight climate change. In addition, we hope that our research will elevate past the city of Cuenca and be implemented in different countries across the globe. This research has the potential to educate other cities and countries about the true importance of needing an accurate inventory of trees.

CHAPTER 1: INTRODUCTION

Today, our planet faces a daunting reality. It is experiencing a drastic increase in temperature that could have catastrophic consequences. "Scientists predict that if we keep going along our current greenhouse gas emissions trajectory, climate change will cause more than a third of the Earth's animal and plant species to face extinction by 2050" (California Academy of Sciences, 2020). One of the many reasons for this dramatic change is caused by the increase in carbon dioxide emissions, which puts our planet at a high risk of becoming uninhabitable. There is, however, an effective way to combat some of the damage being caused by climate change and global warming–trees. As trees grow, they remove carbon dioxide from the air, store carbon in their roots, trunks, and branches, and release oxygen into the atmosphere. More trees produce more oxygen, providing us with clean air to breathe. To utilize these natural resources, we need to determine the most reasonable estimate of how many trees are present in a given area. From there, it can be determined if there are enough trees to sustain life.

Cuenca, Ecuador should have approximately four million trees, given the population, to support life properly, but the reality is that there is no accurate estimate available of the number of trees in this area. At best, Cuenca is at a minimum two million trees short. To help combat this issue as well as many others, such as public education, our sponsor, Gustavo Morejón, created a non-profit organization, Save.bio that operates in both Quito and Cuenca. Currently, they use citizen science as their method of counting trees; however, there are discrepancies within their data. Because of these inconsistencies in tree documentation, there is no way to know how many more are needed. To improve this system, we analyzed former censuses conducted, researching trees in Cuenca, and determining what is economically feasible given resource constraints. The long-term goal of this project is to create a method to accurately estimate the tree count in Cuenca. After developing and improving an efficient tree census, we hope it can be implemented globally.

CHAPTER 2: THE ENVIRONMENT AND TREES

Trees have numerous environmental, health, economic, and social benefits. They improve air quality by filtering out harmful dust and pollutants such as ozone, carbon monoxide, and carbon dioxide from the air we breathe. Trees also reduce the amount of stormwater runoff, which decreases erosion and pollution in our waterways and may lessen the effects of flooding. Many species of wildlife also depend on trees for their habitat, providing food, protection, and shelter. Green spaces play a large part in the benefits previously mentioned. A green space can be defined as an open space such as parks that are protected in urban areas.

Researchers have determined that there are approximately 3.04 trillion trees on Earth; this means that there are about 422 trees for every person (Crowther, 2015). Current and historical forest cover maps provided by the United Nations Environment Programme reveal that the global number of trees has fallen by approximately 45.8% since the onset of human civilization (UN, 2020). Afforestation efforts and biodiverse environments can aid in the recovery of the immense loss of trees.

2.1 SIGNIFICANCE OF BIODIVERSITY, AFFORESTATION, AND REFORESTATION

Many government and non-government organizations have engaged in afforestation and reforestation programs to increase biodiversity. Afforestation is the process of introducing trees and seedlings to an area that has not previously been forested. Similarly, reforestation is a form of afforestation, but in areas that have been deforested. Their purposes are to restore an area that has been destroyed due to previous overuse of the land, create forests, and aid in carbon capture (Brack, 2019).

Climate change has significant implications on our planet, and successful afforestation can be advantageous in many ways. It helps reduce the pressure of preexisting natural forests, allows individuals to plant tree species more in demand, allows the natural trees in forests to be conserved, and helps develop and restore long-lost ecosystem areas (Soomro, 2020). Common goals of afforestation are rebuilding soil, preventing erosion, reserving desertification, air purification, and supporting wildlife.

Deforestation is linked to a host of problems, including desertification, increased greenhouse gasses, soil erosion, and fewer crops, which is a pivotal contributor to human-caused climate change. On the other hand, reforestation is the action of repopulating an area that helps eliminate climate change and global warming and helps check for a loss of biodiversity, oxygen-carbon dioxide balance, and restoration of habitats (Madaan, 2017).

One successful reforestation includes a project in a region of Mexico. In this project, the agricultural development (CEDICAM) group learned indigenous farming techniques from Guatemalan immigrants and relied on native tree species (Nuñez & Marten, 2010). CEDICAM planted more than 1,000,000 trees, restored and replicated indigenous hillside terraces, and promoted the use of heirloom seeds, natural composts, and traditional diets. While this was a success, other reforestation attempts involving the eucalyptus species yielded far worse results, negatively impacting the surrounding ecosystem. Although eucalyptus is a fast-growing species and provides oxygen there are many downfalls to introducing it into the ecosystem. While its ability to grow fast and replace empty vegetation sounds enticing during that process it often overgrows in the given area and becomes extremely dangerous due to its weak roots and height. In many places where this plant has been introduced the local governments are now attempting to remove it completely and replace them with the country's native species.

2.2 WHAT IS A TREE CENSUS?

A tree census is an action of taking inventory of size, age, species, and the number of trees within a given area. Tree censuses provide the data necessary to characterize a tree population's structure, function, and value. This information can help with the distribution, species, and health of trees. An essential component of this is collecting data and cataloging sample areas in research plots. This research project will explore the different ways to conduct a tree census most effectively and efficiently.

2.2.1 DEFINITION AND IDENTIFICATION OF A TREE

To begin a tree census, it is crucial to define a tree. A *tree* is defined as a tall plant with woody tissue, typically supporting branches and leaves (USDA FS, 2006). The scientific definition of a tree varies from species to species, and some studies even include shrubs and other plant life in the same category as a tree. To conduct the most accurate tree census, we determined what we believe is a distinct definition of a tree, our definition includes parameters such as height, diameter, presence of leaves or flowering/fruits, species, age, and health.

Through literature review, and our own web research, we found that the most consistent definition of a *tree* is a woody perennial plant, typically large, with a single well-defined stem carrying a more or less definite crown; sometimes defined as attaining a minimum diameter of 1 inch (2.5 cm) and a minimum height of 4.25 ft (1.3m) above ground and a minimum of 15 ft (4.6 m) at maturity (USDA FS, 2006). Maturity height is significant because it determines the oxygen production rates. This is what we used to distinctly define a tree for our project.

2.3 PREVIOUS TREE CENSUSES

The department of the government of New York responsible for maintaining the city's parks, NYC Parks, assembled a volunteer-powered campaign to conduct a tree census. "We trained volunteers to be expert tree counters by providing extensive training and tree guides to make sure that our volunteers were confident and that measurements were as accurate as possible." NYC Parks collaborated with a group called TreeKIT to prototype and test a data entry tool that simplifies the tree mapping process. This prototype was easy to use and generated a representative map of the urban forest. (NYC Parks, 2015)

The United States Department of Agriculture (USDA) is currently conducting a tree census in research plots all over the U.S. "After locating the plot using aerial imagery, crews often hike for miles through difficult terrain just to get to the site." Once there, crew members will measure, catalog damage, and inventory the tree. The USDA also surveys landowners with significant amounts of land. This data collection technique allows for landowner perspectives and plans for the future. This can then be analyzed to build models of what a forest might look like in the future (Avitt, 2021).

Another previous successful tree census was completed by the Morton Arboretum in Chicago IL. In 2020, The Arboretum partnered with the Student Conservation Association to measure 1600 randomized i-tree plots distributed over four land-use types: residential, agricultural, open space, and commercial space. i-Tree is a computer software tool designed to assess and value the urban forest resource, understand forest risk, and develop sustainable forest management plans to improve environmental quality and human health (Nowak, 2020). Through this software, they determined that there are approximately four million trees in Chicago and 172 million in a seven-county region (The Morton Arboretum, 2021). This census was the result of over 10 years of work and dedication.

Another large part of this census was to reduce the amount of air pollution to help improve quality and number of tree canopy's in the city. Through i-tree canopy they determined that the regional canopy has increased from 157 million to 172 million and the canopy coverage percentage has increased from 21% to 23%. Through air pollution removal, and reduced carbon emission, the trees provide $416 million in annual benefits to the people who live and work in the region (The Morton , 2021). This census proves that a successful census can take years to complete and have numerous benefits.

2.4 METHODS OF CONDUCTING A TREE CENSUS

In order to achieve the best estimate on the number of trees in Cuenca our team explored three different methods of inventorying: citizen science and two types of geospatial technologies. Previous tree censuses have been conducted using modern geospatial technology and citizen science. Different software can help make the process easier and make the census faster. Geospatial tools such as geographic information systems (GIS) and global positioning systems (GPS) work well to collect data, analyze, and report information regarding trees in a given area (Ward, Johnson, 2007).

2.4.1 CITIZEN SCIENCE

Citizen science is a data collection technique involving volunteers participating in scientific research by collecting data, monitoring sites, and joining the scientific inquiry (Roy et al., 2012). This method is usually conducted by non-scientists, led by a group of officials or researchers, which relates to a larger research project (Roy et al., 2012). Over the past 20 years, different organizations and scientists have begun to realize the importance of utilizing their community and volunteers.

An advantage of citizen science is that participation is more likely to raise awareness of the issue being studied because engagement leads to learning. This awareness correlates with environmental stewardship and a communitys' preparedness for natural hazards (Walker et al., 2020). There are also negative impacts associated with citizen science. Health and safety issues are significant risks that need to be considered. This could include getting lost, injured, or harmed during information/data collection

(Walker et al., 2020). Another potential drawback to citizen science is error calculations. Because the data is being collected by non-scientists with little to no training, there could be a lack of accuracy in how data was collected. Another risk of implementing citizen science is a lack of engagement (Walker et al., 2020). An accurate well-done tree inventory can take years to conduct.

Citizen science often does not require many resources or training. This can be a benefit when participants utilize instructions properly. In one experiment, expert tree counters and novice tree counters were tasked with determining the number of trees in an urban area (Roman, 2017). Each group was told to walk and count three blocks from their starting point. They recorded the number of trees counted as well as the trees' health and analyzed the data. This is the most common way to use citizen science in order to help conduct a tree census. This experiment demonstrates that it doesn’t take an experienced or qualified scientist to carry out the citizen science portion of a tree census. The end result was a low margin of error on both parts, therefore, proving the previous claim true.

2.4.2 GEOGRAPHIC INFORMATION SYSTEM

Geospatial technology aids in conducting a tree census using Geographic Information Systems (GIS). GIS is a mapping and analysis computer system used to make maps, analyze data, and perform constraint analyses on specific data (Maguire, 2006). GIS is composed of three basic elements: computer software, computer hardware, and data. This data is presented by adding different layers to a map and using these layers to analyze the data (Maguire, 2006). With GIS, one can access workflow-specific apps, maps, and data from around the globe. Internet connection is the only requirement for successful operation. This method is much faster than citizen science, helps eliminate error, and covers an area more accurately (Maguire, 2006).

Initial installation of GIS could cost up to $50,000 (Maguire, 2006). Most cities have access to a national database in which they can access the data for free with either an academic or personal account (Maguire, 2006).

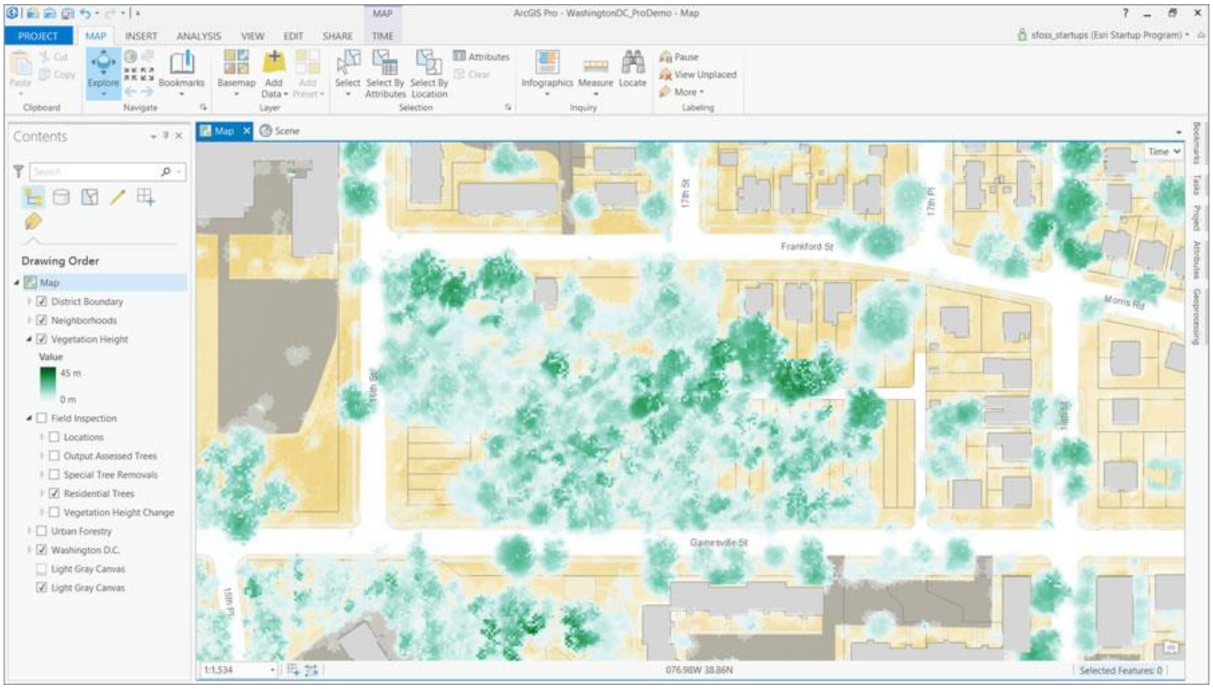

Figure 1: Imagery in ArcGIS Pro that shows the height of trees before deforestation. 2013 (https://www.esri.com/about/newsroom/arcwatch/protecting-urban-forests-the-modern-way/.)

To carry out a tree census using GIS, a data layer of trees is added over the area of study. A data layer can be defined as a collection of geographic data that is acquired from satellite imaging, meaning that when added to a map, specific information about the layer being studied is shown. This will help determine how densely populated specific plots of areas are. GIS allows for the determination of the average number of trees within a specific area. Figure 1 shows different trees and their heights in an urban city. The darker colors refer to trees up to 45 meters, and the lighter colors refer to trees closer to the ground. Then, one can calculate the probable number of trees within a given area with different mathematical formulas. This method is called plotting.

2.4.3 GLOBAL POSITIONING SYSTEM

Global Positioning Systems (GPS) is a satellite-imagery-based navigation system used to compute and track geographic positions (Ward, Johnson, 2007). Three satellites are needed to produce a location on the earth's surface. “The satellite system consists of a constellation of 24 satellites in six Earth-centered orbital planes orbiting at 13,000 miles above the earth and traveling at a speed of 8,700 mph.(GeoTab, 2020) Satellites carry atomic clocks, providing an extremely accurate time, and to take advantage of this precise time, three components are required. (1) Satellites (2) Ground Stations (3) Receivers. These receivers track the satellite and note when they receive the signals transmitted from the satellites. The receiver can determine its distance from the satellite by calculating the time difference between transmission and reception (Kane et al., 1998). To get the most accurate results, four satellites are required. Three satellites are used to calculate distance, a method called triangulation. Then, a fourth satellite is used to eliminate errors.

GPS receivers vary widely in accuracy and can be quite costly, but with the right tools, one can take high-quality images from above. These images can be assessed in two different ways. One can individually count the trees on the picture provided or purchase computer software to count the trees in the photo and inventory them. (Wadman, 2020). This software is generally costly and requires specific equipment.

To conduct a tree census using GPS, data from a website such as Google Earth can be used to determine the number of trees in a specific area. One can zoom into an area of choosing such as a park or street, and count the trees through aerial or street-views. Miscounting may occur, or smaller, shorter trees may not be detected due to a lack of perspective when viewing the images.

Alternatively, one method of GPS is called land surveying which uses a total station and range poles to determine the specific height of a tree or the distance from a certain point (Larjavaara 2013). A total station is a piece of equipment used in surveying that uses a distance meter to read any slope distance from the instrument to any spot, as well as latitude and longitude from satellites above. The total station is placed on the ground, and the lens is pointed at the tree, determining the total height. This is beneficial because determining the size of a tree determines the oxygen production rates and carbon dioxide consumption rates. Figure 2 illustrates this process.

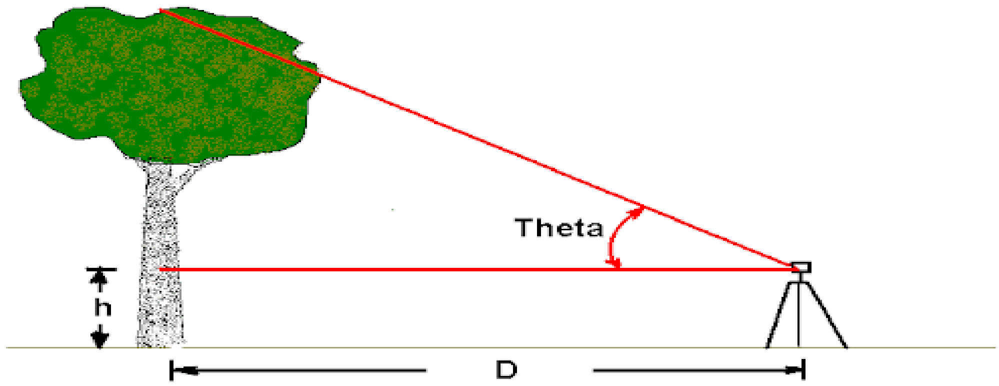

Figure 2: Determination of tree height by using a total station and trigonometry (https://forestryforum.com/members/donp/3treehgtclcs.htm)

2.4.4 DRONE TECHNOLOGY

The term "drone" refers to any unpiloted aircraft and allows for many different uses (Mohan, Silva, Klauberg, Jat, Catts, Cardil, Hudak, Dia, 2017). "Advances in Unmanned Aerial Vehicle (UAV) technology and data processing capabilities have made it feasible to obtain high-resolution imagery and three-dimensional (3D) data which can be used for forest monitoring and assessing tree attributes" (Mohan, Silva, Klauberg, Jat, Catts, Cardil, Hudak, Dia, 2017).

Similar to GIS and GPS, one way to use drone technology is to take high-resolution photos and individually count the trees in the given photograph. This method is very time-consuming, does not allow one to optimize resources, and does not improve planning execution even though images taken from a drone can be a great way to ensure accuracy in certain areas. The second method would be using an innovative company such as Picterra, which utilizes artificial intelligence (AI) software.

Like most methods, there are limitations associated with drone technology. With recent technological advances, there are certain parameters one must follow in order to fly a drone legally. There are height restrictions as well as area restrictions. It is illegal to fly near or around airports, power plants, prisons, military bases, and other areas that could potentially pose a risk. Battery time can prove to be an issue seeing as most of today's drones can fly anywhere from twenty to forty minutes of flight time. This restricts the amount of area that can be covered in a given amount of time. Lastly, an experienced operator with a drone license is required to be able to successfully fly it in a manner that helps the goal of conducting a tree census.

2.5 TREE CENSUSES IN CUENCA, ECUADOR

The city of Cuenca has around 700,000 inhabitants. To keep up with the oxygen needs of the citizens, the city would need around 4,500,000 trees in total (For a further discussion of oxygen production and trees, see Appendix A.). Unfortunately, there are no up-to-date tree censuses that give Cuenca an accurate number of trees. Without an accurate count, Cuenca city employees/managers will not be able to understand the extent of damage their ecosystem is undergoing regarding climate change. Empresa Municipal de Aseo De Cuenca (EMAC) has a program to replace all eucalyptus trees with native species (Morejón 2019). This is because the eucalyptus is an invasive species that is harmful to the city's biodiversity and population due to its attributes and weak nature resulting in wreckage.

2.5.1 UNIVERSIDAD DEL AZUAY

Starting in 2017, the University of Azuay began an effort to carry out the forest inventory of the parks in the city of Cuenca. Around 283 parks are present across Cuenca according to the development plan and land use planning. To conduct their tree census, the University has been implementing orthographic photography through GPS aerial images, drones, and smartphones. They inventory the parks by first grouping them into stages that include 44 parks for each stage. In the inventory, they record descriptive information of the phytosanitary (health of the trees) and georeferencing of each tree (IERSE UDA, 2019). The information they have been collecting in the field is then validated by the staff of the Herbarium of the University of Azuay. The data then goes through a reviewing process in a web form that can be updated based on the results of the samples collected in the field. The University of Azuay has counted approximately 16,000 trees and identified 87 species corresponding to 42 families. They also determined that 59% of the trees inventoried are not native species to Cuenca (IERSE UDA, 2019). To make this information accessible to the public, the University has an up-to-date interactive website, as shown in Figure 3.

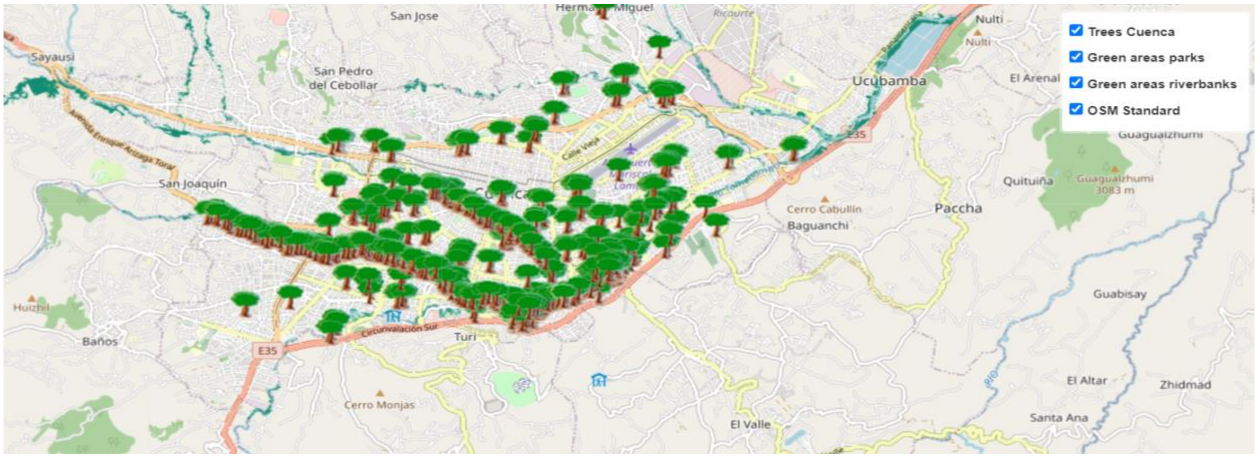

Figure 3: Approximate locations of trees counted in local parks in Cuenca Ecuador during the Universidad del Azuay tree census, (https://vinculacion.uazuay.edu.ec/en/blog/detalle/2490)

2.5.2 SAVE.BIO

Save.bio is a non-profit organization located in Cuenca that utilizes citizen science as its primary method in conducting a tree census. They have tagged over 5000 trees, 151 different species, and ten endangered species to date. They also determined that 47% of the species found were native, and the remaining 53% were introduced (Morejón 2019). The Save.bio website allows any citizen to add a tree to their online map where they can include the condition of the tree, class, diameter at chest height, and identifying factors such as whether there is the presence of leaves, flowers, fruit, pruning, or pests.

To log where a tree is found, an account must be created on the Save.bio website, and then one can select the Cuenca project and drop a pin on a GPS map of where the tree was found. A few questions about the general health and well-being of the tree are then evaluated, as shown in Figure 4 (Morejón 2019).

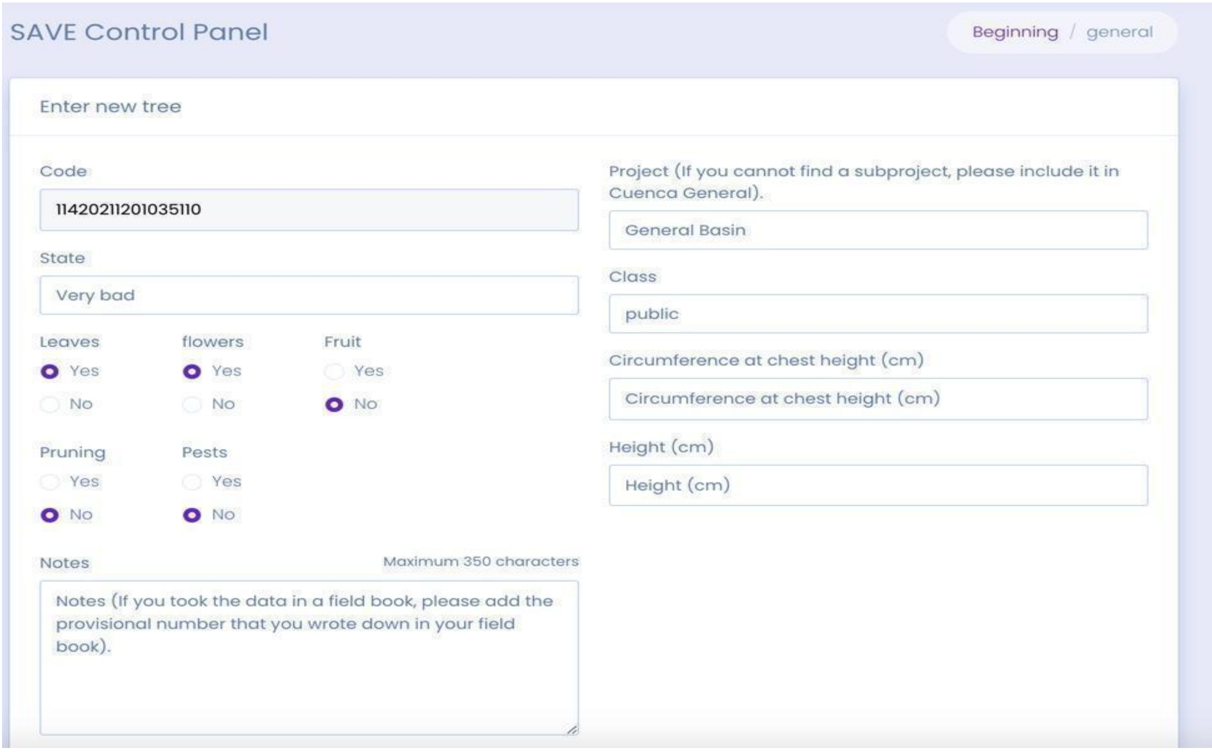

Figure 4: Main page of the tree logging page on the Save.bio website. This allows information to be input about size, health, leaf shape, and other information to help with tree education (https://save.bio/arbolesdecuenca2.php)

After a tree is logged, Save.bio has created a system that uses a tag with a QR code that is then placed around the tree as shown in Figure 5. People can use their smartphones to scan the QR code installed onto the tree. This is a viable tree identification and education method because people always have their phones on them, and the application is easy to use. Once scanned, this QR code will bring users to the Save.bio website where they can learn more about the tree specifically.

An issue associated with this method is that the tags can be removed or torn off. This causes discrepancies between the count on the website and the count in the field. Our sponsor is searching for a better way to keep count of these trees in the field, mentioning that roughly 10% of the codes have been removed either by individuals or from poor weather. With new developments, QR tags are now expected to last between 10-15 years because of higher placement to avoid tampering and new laser engraving technology on metal tags to withstand harsh climates (Morejón 2019). However, new problems have arisen from this proposed development that impacts economic feasibilities and the educational purpose of these tags.

Figure 5: QR code that Save.bio is installing on the trees in Cuenca that have been counted in their census (https://save.bio/arbolesdecuenca2.php)

2.6 SPONSOR DESCRIPTION

Gustavo Morejón Jaramillo is a biologist specializing in biodiversity monitoring and is an expert on the management and programming of biodiversity databases. In March of 2019, Gustavo founded Save.bio, an urban forest inventory, monitoring, and protection system that enables citizens to help tackle climate change. Their operation includes identifying, interacting, tracking, and analyzing trees. They also have environmental education support systems, citizen science participation programs, and tree sponsorship systems. Their project started as a way to understand how many trees are in the city and determine how many more trees are needed to sustain the population.

Despite Save.bio's interactive website and community engagement, there are discrepancies within the data collected. A flaw within the Save.bio website is that anyone can have access and make modifications. Though participation is encouraged for educational benefits, it can sometimes lead to inaccuracy. The problem we are addressing in this project is the reason why we are being tasked with developing efficient methods to conduct a tree census.

CHAPTER 3: METHODOLOGY

The goal of this project was to find a feasible method for documenting an accurate count of the number of trees in Cuenca, Ecuador, as well as helping improve current methods in place. An accurate tree count not only directly impacts Cuenca but potentially the future of the environment globally. The objectives we developed to meet our project goal are as follows:

- Determine the most feasible options for conducting tree census in Cuenca
- Analyze and compare different geospatial technology platforms
- Develop and test protocol for citizen science approach
- Determine the most feasible and efficient option for tagging trees

3.1 DETERMINE THE MOST FEASIBLE OPTIONS FOR CONDUCTING A TREE CENSUS

To achieve our first objective of determining the most feasible option for conducting a tree census, we interviewed the following experts: Gustavo Morejón of Save.bio and Nelson Diaz of EMAC.

We interviewed Gustavo Morejón, of Save.bio. In this interview, we asked questions to gain insight into the methods that he implements to conduct a tree census (Appendix C). To keep our notes organized with all interviews done for this project, we recorded each interview with consent from the subject being interviewed. Each team member simultaneously took notes and compared them at the end to ensure correct results.

We also interviewed a member of the municipality, Nelson Diaz who specifically works in The Green Spaces division of EMAC. This interview allowed us to gain access to how the green spaces in the city are taken care of and maintained. We gained a better understanding of how EMAC inventories all of the trees on the main roads of the city and all of the green spaces such as parks. (Appendix B)

3.2 ANALYZE AND COMPARE DIFFERENT GEOSPATIAL TECHNOLOGY PLATFORMS

Our second objective is to analyze and compare GIS-based technology and GPS-based technology as methods to conduct a tree census. Through fieldwork, we assessed the GIS and GPS data received and determined the accuracies.

To analyze the GIS data, we delved into some of the GIS areas recorded in the files given to our group by our sponsor and counted the trees as our way of ground-truthing. These files were a depiction of the green spaces in the city of Cuenca, given to us through our sponsor. The main goal in attaining these files was to determine the number of trees in given areas that have already been censused or acknowledged. Although these files did not contain what we were hoping they would, having access to green space knowledge allowed us to use ground-truthing to determine if the files were accurate and up to date. We were not able to compare all of the GIS files due to time constraints, inaccessibility, and inability to decipher which areas contained trees and which did not; however, we did select various areas throughout the city with various quantities of trees.

To analyze the data from GPS, we used Google Earth to count trees through aerial and street view photography. Our first area of focus was Parque de la Madre counted the trees inside the track using satellite images as shown in Figure 6. We then used a ground-truthing method of physically counting the trees in person to verify the accuracy of the data. Using temporary tags, we eliminated the chance of double counting trees. More information about ground-truthing can be found in section 3.3.

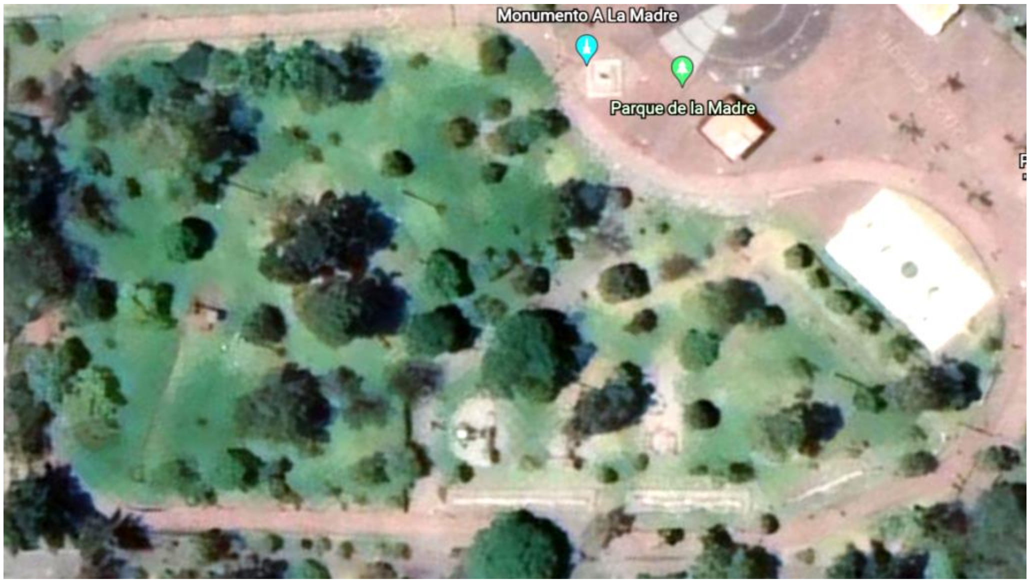

Figure 6: Google Earth Image Depicting Parque De La Madre In Cuenca Ecuador (https://earth.google.com/web/)

Another area our group focused on with GPS technology was the street of Av. Fray Vicente Solano, starting from Tres Puentes Bridge and ending at the round-about by the stadium, on the green areas between both roads. This strip of road is 1546m (0.96 mi). We divided the city street into sections, as shown in Figure 7.

Figure 7: Google Earth aerial views of Av. Fray Vicente Solano divided into sections (https://earth.google.com/web/@0,0,0a,22251752.77375655d,35y,0h,0t,0r)

3.3 DEVELOP AND TEST A PROTOCOL USING A CITIZEN SCIENCE APPROACH

Our third objective is to develop a protocol for ground-truthing. This is designed to confirm GIS/GPS findings and to allow censuses to be continued throughout the years. To develop and test a protocol for citizen science we analyzed past censuses done through Save.bio and the University of Azuay. We also went into the field to conduct our own censuses at Parque de la Madre, Avenida Fray Vicente Solano, a location in Turi, Museo Pumapungo and Parque Lineal 24 De Mayo Bebedero. To do this, we tried multiple methods: counting together as a group, counting in pairs of two, individually counting, implementing our own temporary tagging system, and counting using plot sizes. Through trial and error, we adjusted our citizen science protocol and determined which methods were most efficient and accurate. The first method of temporarily tagging trees was completed in Parque de la Madre. To ensure that trees were not double-counted, we stuck temporary tags on all of the trees within the area. When we were sure all the trees were tagged, we gathered them, met as a group, put all of our tags in a pile, and counted them. This method allowed us to have complete confidence in the number of tags we counted, and since we could physically hold the number of trees in our hands with the tags, we can ensure there is no miscounting. Through simple math (Appendix D) it is evident that solely using citizen science is ineffective and inefficient. It would take four participants approximately five years working 24 hours a day, 7 days a week, 365 days a year.

To conduct the census on Avenida Fray Vicente Solano, we split up into pairs and we started on opposite ends of the street, on each side of the one-ways (each in a corner), counting the trees and met in the middle. As we walked, we recorded the number of trees we counted on each section, similar to Figure 7.

For the censuses completed in Turi and at Museo Pumapungo, we used a 100-foot rope and counted all trees within five feet of the rope. We did this in multiple locations, multiple times in the same area to ensure precise results. By counting 100 feet horizontally and vertically, it allowed us to calculate a plot size of approximately 10,000 square feet. This plot size can be multiplied by the size of the forest to obtain a reasonable quantity of trees, with a margin of error. This is a real-world example of using the materials on hand when encountering complications.

3.4 ASSESSING THE FEASIBILITY AND EFFICIENCY OF THE QR CODE TAGGING METHOD

A passion of our sponsor is public education and awareness. Currently, Save.bio is employing QR Codes on each tree they count as a method of tagging. The purpose of the QR Code is to keep track of the health of trees, ensure there is no double-counting, and educate the public.

To determine the most feasible and efficient method for tagging trees and educating the public we collected data from the QR codes Save.bio has installed. We collected data on how many people are actually scanning these QR codes, to determine if it really is the most economically efficient tagging method. To do this, we scanned trees marked by QR codes at Tres Puentes, recorded the number of people who have scanned, and compared that to how long the tags have been posted. This gave us an idea on if the tags were fulfilling their purpose.

CHAPTER 4: RESULTS

In this chapter, we describe our findings following our research methodology. We created a table of pros and cons from interviews conducted with local census organizers. This allowed us to learn about the different approaches these organizers take to conducting a tree census; what worked and what didn't. We also compared multiple tree census methods and determined which were most feasible and efficient in Cuenca, Ecuador. To do this, we created a table. We included each location for each census conducted, the square footage, number of trees counted, the time it took to complete the census, our confidence of accuracy, and the tree population densities for the given areas. From this, we could easily lay out which method or technology could be implemented to improve the efficiency of future censuses.

4.1 COMPARING CUENCA TREE CENSUS STRUCTURES

To compare the most feasible method for conducting a tree census, our group needed to learn about the structure of each census currently being implemented. To do this, we conducted interviews with Gustavo Morejón, the coordinator of Save.bio, and Nelson Diaz, an architect and green space coordinator at EMAC. Gustavo has conducted a tree census through Save.bio using citizen science, while

Nelson has used citizen science and GIS to aid in his work. The results of these interviews are discussed in Table 1.

TABLE 1: PROS AND CONS LIST FROM INTERVIEW RESULTS WITH SAVE.BIO AND EMAC

	Pros	**Cons**
Save.bio **Interview with Gustavo Morejón**	500 tags distributed to university students, which promotes public education and interests A couple of training sessions are conducted to teach participants how to tag and inventory Save.bio inventory system is interactive and educational	Lack of long-term participant engagement Not time-efficient or feasible QR Tagging is not economically efficient, and not all of the tags are not functional Discrepancies with save.bio inventory count and the QR Tags
EMAC **Interview with Nelson Diaz**	For every eucalyptus tree removed, they plant 10 native species New inventory system records the health, ages, species, and heights of newly-planted native trees	No method of censusing eucalyptus A citizen reports a fallen or near-fallen eucalyptus and that is how EMAC is informed of the tree presence They have no technological resources or technological training No comprehension of the GIS green area files Lack of public education and training of their employees for the inventories

In the interview with Gustavo Morejón, the purpose was to obtain feedback from his citizen science methods and learn about the structure of his census, the challenges, and its benefits. This interview concludes that there has not been any structure over the past few years when determining where and when to tag trees. There are far more than 5,000 trees in the city of Cuenca, and there should be far more tagged and recorded in the census. This leads us to conclude that using citizen science without a structure is ineffective when attempting to do a tree census.

In the interview with Nelson Diaz, the purpose was to obtain feedback from his work with EMAC and their methods in inventorying eucalypti and using GIS. This interview taught us how the municipality is actively working on reforestation and getting an accurate count of all of the green areas in Cuenca. This interview also gave us insight into EMAC's lack of progress. We learned that they really do not have any structure or process to inventory trees in Cuenca. This interview also helped us decipher that the GIS files we obtained are only a visual representation and inventory of green spaces in Cuenca, not the number of trees in each of the respective green spaces.

4.2 RESULTS OF THE IMPLEMENTATION OF DIFFERENT TECHNOLOGY PLATFORMS IN A CENSUS

We completed the next objective of implementing different technology platforms to complete a census. In order to do this, we used multiple technological methods such as GIS and GPS and analyzed GIS files sent to us by our sponsor. We also used different GPS platforms to approximate the count of trees in an area.

4.2.1 GIS RESULTS

We were unable to conduct a complete GIS tree census, we do, however, have existing files that we analyzed. Based on the files that our sponsor sent us, we were able to determine the number of green spaces as well as the total Hectares that the GIS census covered. These files determined that there were a total of 254 green spaces censused over an area of 280.89 Hectares (HA) in the city of Cuenca using Geographic Information Systems shown in Figure 8. The GIS files obtained showed the ID number and location of different green areas rather than the number of trees in a given specific area. While this information does not aid in counting trees, it signifies how large these areas are and how unfeasible it is to solely use citizen science. Additionally, the tree count can be stored in this database once these censuses have been conducted.

Figure 8: Green Area Maps of Cuenca
(https://earth.google.com)

Figure 8 is a map of the green spaces in Cuenca, as determined by EMAC. This map consists of parks, rivers, and streets that contain trees. This data is helpful for the city's layout. However, this information does not provide any count of trees and does not account for privately-owned areas. This map shows the riversides, where there are the most considerable quantities of trees. Most of the trees, however, are Eucalyptus, which we do not want to account for in our census.

4.2.2 GPS RESULTS PROVE INEFFICIENT FOR CITY STREETS AND PARKS

To analyze the GPS data, each group member reviewed aerial satellite images of google maps (geospatial technology). To determine how accurate these images are, we went into the areas we counted using GPS technology and recounted the trees using ground-truthing. Ideally, these areas consist of three different locations being parks, streets, and potentially other unnamed green spaces to give a variety in our collected data.

According to Figure 6, mentioned in section 3.2, of the satellite image of Parque de la Madre, there are approximately 84 trees. This estimate was determined by averaging the number of trees counted by our four-person group and looking at the Google Earth aerial view. This took approximately 50 minutes for one person to count due to double-checking and comparing different perspectives of street view and satellite views. Some challenges we faced when conducting this GPS census included screen mistouches and location changes from changing perspectives, both of which can result in the miscount of trees.

4.3 CITIZEN SCIENCE CENSUS PROTOCOL RESULTS

We conducted our own censuses at Parque de la Madre, Avenida Fray Vicente Solano, a location in the forests near Mirador del Turi, Museo Pumapungo and Parque Lineal 24 De Mayo Bebedero. To do this, we tried multiple methods: counting as a group, counting in pairs, individually counting, implementing our own temporary tagging system, and counting using plot sizes.

TABLE 2: COLOR CODED RESULTS OF CITIZEN SCIENCE CENSUSES

Locations	Area Coverage (ft^2)	Trees Counted	Time to Complete (mins)	Confidence of Accuracy	Tree Density (trees / 10,000 ft^2)
Avenida Fray Vicente Solano	390,544	182	20	Confident	4.66
Parque de la Madre	142,621	108	60	Semi-Confident	7.57
Parque Lineal Rio Tomembamba	10,000	34	20	Confident	34
Museo Pumapungo	10,000	40	15	Confident	40
Forests (3) Averages	10,000	195	25	Semi-Confident	195

In the seven censuses we conducted, we determined our confidence level of tree accuracy after each census. “Semi-confident” meant that we were confident in the number of trees but we may have missed a couple. “Confident” meant that we were 100 percent sure that there was that number of trees in that area. We added this factor because it helps us determine if the method we used was the right method for the given area.

4.3.1 DISCUSSION OF THE COMPARISON OF CITIZEN SCIENCE AND GIS/GPS

At Parque de la Madre, we counted 108 trees in person and 84 using Google Earth. Counting the trees in person took significantly longer than using GPS. Conversely, we feel the data we collected in person is more accurate than the data we collected using Google Earth. Once we determined which protocol to conduct for citizen science at the park through trial and error, it became easier to count trees, and we became more confident with our results.

Along Avenida Fray Vicente Solano, we counted 182 trees in the field and 164 from Google Earth. Going out and physically counting the trees took roughly 20 minutes to conduct, which was more than half the time it took using Google Earth perspectives. The discrepancies between Google Earth and our on-site are likely the result of misinterpreting Google Earth images, or the number of trees and size may have changed since the last Google Earth update. In terms of confidence of accuracy and time comparison, we found citizen science to be more efficient and effective than GPS on this street.

We implemented alternative methods to conduct a tree census utilizing the different resources we had available. We recommended GPS to be used as a method to conduct a tree census in densely populated forests, however, due to poor image quality overviews, and varying heights of trees, it is not feasible to estimate the number of trees in the area. We have determined, based on all of the factors we took into consideration in Table 2, that multiple methods and technologies will need to be implemented to ensure accuracy. Dividing these areas into different categories of methods with corresponding colors shown in Table 2 we have:

- Citizen Science (Yellow)
    - Av. Vicente Fray Solano
- Drone Technology & Citizen Science (Orange)
    - Parque de la Madre
    - Museo Pumapungo
    - Parque Lineal Rio Tomebamba
- GPS & Plot Sizes (Red)
    - Forest Areas

These areas were categorized into these methods primarily based-off of the tree population densities. Av. Vicente Fray Solano has a low-density population, Museo Pumapungo and Parque Lineal Rio Tomebamba have medium-density, and the forest areas have highly-dense tree populations. Although

Parque de la Madre was not a very dense area, the lack of confidence and time consumed using solely citizen science proves that technology can be more efficient.

4.4 QR CODE ANALYSIS

Our final analysis was of the activeness of the QR codes Save.bio has installed. When scanned, the QR codes bring you to the save.bio website where you can see how many times each code has been previously scanned. We wanted to collect data on how many people are actually scanning these QR codes, to determine if it really is the most beneficial approach to public education, and to determine its economic efficiency. To do this, we scanned trees marked by QR codes at Tres Puentes and recorded the number of scanners over a 200 day period.

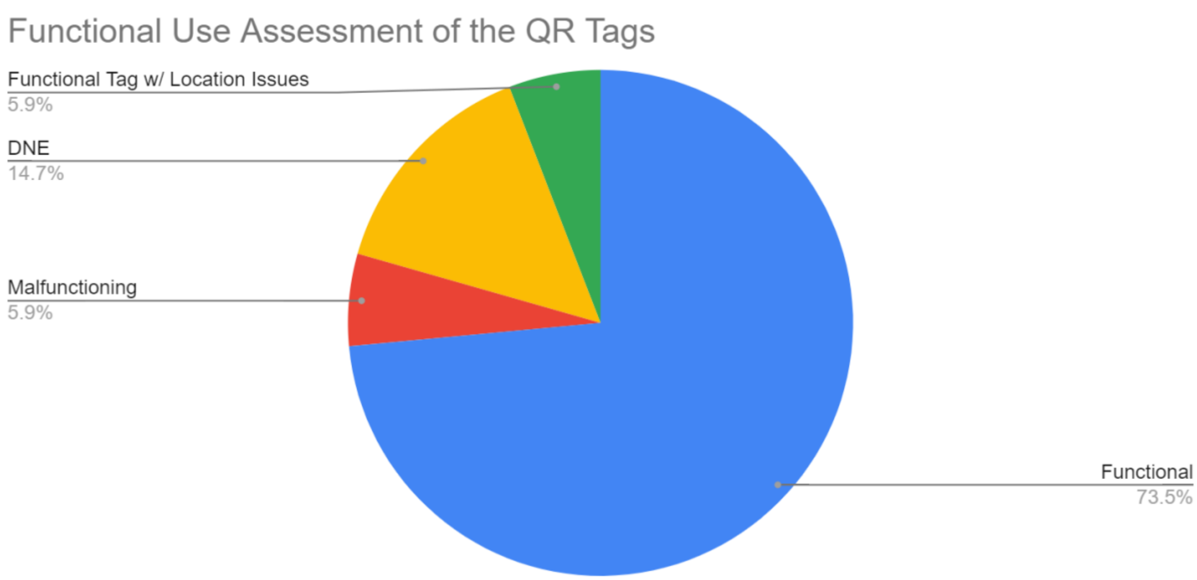

Figure 9: Functional Use Assessment of the QR Tags Pie Chart

Figure 9 signifies the functionality of the QR tags. The chart above shows the number of scans; however, we encountered other issues when attempting to scan the tags in our field assessments. We categorized these issues into four sections: functioning, functioning but with location issues, malfunctioning, and DNE (Does Not Exist).

Tags that we scanned without any issues we categorized in the functioning tag category. We also noticed that sometimes these tags were out of reach for the public or in unsafe areas such as right on a riverbank; we have categorized those in functional tags with location issues. Another category, DNE (Does Not Exist), is when we scanned a tag, but it gave us an error code stating it is not in the Save.bio system. The final category is malfunctioning. We used this to represent all of the tags we either found broken, on the ground or unable to be scanned.

4.5 LIMITATIONS OF THE DATA

For our project, we interviewed people from different organizations in order for us to get the best and the most accurate data possible. We interviewed Gustavo Morejón of Save.bio, and Nelson Diaz of the Empresa Municipal de Aseo de Cuenca, or EMAC. EMAC is part of the municipality that focuses on the environmental impacts of the city.

We were unable to interview Omar Delgado from University del Azuay, due to time constraints and his busy schedule. We were also unable to interview arborists, but our meetings with Gustavo Morejón, and Nelson Diaz, were sufficient to fulfill our requirements. We met on multiple occasions with Mr. Morejón and he provided us with great insight in reference to how Save.bio operates on the application side as well as in the field. By collecting notes and data from his findings our team was able to make necessary assumptions as to how to approach our problem. As for Nelson Diaz, upon exiting our meeting with him it was apparent his organization had no current method or technology in place that could have benefitted our research and helped tackle our problem. That still allowed us to create recommendations for the future of our sponsor's end goal.

CHAPTER 5: RECOMMENDATIONS

In this chapter, we present our final recommendations for conducting a tree census and improving the tagging system. Below are lists of our deliverables and f recommendations with our rationales in the following sections.

Recommendations:

- **Implement Multiple Census Methods Throughout Cuenca** **We recommend utilizing various methods and technologies to conduct the most feasible and accurate censuses throughout the city. From our results, we concluded that citizen science can be solely utilized in city-streets, technological methods combined with citizen science for parks and medium-dense tree populations, and GPS plot sizes for densely-populated tree areas such as forests. We have concluded it is not feasible to solely implement one method.**
- **Improve Citizen Science** Our recommendation for this specific method relates to promoting more participation in citizen science projects and will help quantify the accuracy of this method. With additional participants, pilot programs for these censuses can be conducted, and focus groups can be created to improve census protocols. Increased participation in the first few weeks of the project would allow for the implementation of different methods of utilizing census technologies. Results would then be used to create a feasibility assessment, to compare user-friendliness, economic feasibility, and accuracy.
- **Utilize GPS/Drone Technology** We recommend that using upgraded technology such as GPS and drones would yield better data and results in a much timelier manner. This would be very beneficial to helping conduct a census in the future, especially in highly dense forest areas. When trees are clustered together, an overhead image may not be able to differentiate all of the trees, whereas different perspectives from drones would allow us to count the trunks of the trees. Having better quality GPS images would also be beneficial because it would allow for a more accurate count when determining the number of trees in that area.
- **Rectify the Tagging Method** In regard to the current tagging method we suggest that instead of having multiple tags on trees that rarely get scanned, have one sign at the entrance of each green space with information about the trees and the area you are observing. This will be more economically efficient than the current QR tags, and potentially be more effective in promoting public education as there is a more visible and functional sign with a single QR code and pictures.

Deliverables:

- **Create a Cuenca Tree Area Map** Our results regarding which methods worked best lead us to recommend the creation of an interactive tree area map of Cuenca. This map is an interactive interface that shows different densities of trees all over the city. Each area has a different color-coordinated map that determines how dense the area is and what census method would best fit in that area. More specific information such as a description of the area, the code number provided by the municipality, and the overall area will be shown once any given area is clicked on. Through this map, you can use area and size to determine how many trees are in the city. The findings that led us to this recommendation took place throughout our fieldwork. We realized that upon inventorying trees in many different locations that it works best to use a certain method depending on where you are. By creating a map that allows you to see what method to use based on the corresponding color it gives the future employees of the project a sense of direction on how to approach the census.
- **Create a Signage System** This sign would include information about the park in both Spanish and English, the Save.bio logo, and a QR code that would link to the Save.bio website with further information.

5.1 PLANS MOVING FORWARD

We have concluded that to conduct a comprehensive tree census, drone technology, citizen science, and GPS/GIS plot sizes will all need to be utilized. Implementing citizen science as the primary method of conducting a tree census in Cuenca is not feasible given the copious time it took to count trees in Parque de la Madre. In the parks in Cuenca, drone technology can count trees more efficiently than citizen science and through the use of orthographic photography, drones can achieve more perspectives than GPS, which allows for clusters of trees to be counted more accurately. In city streets, citizen science was found to be the most efficient option as the trees are less densely populated and more accessible. Streets in the city have more people, making public participation easier to achieve. Additionally, people can see trees that aerial perspectives will sometimes be unable to detect. In the forests outside of the city, GPS/GIS plot sizes are the only feasible method of counting the trees. Taking a plot of the forest and counting the trees there, then multiplying that by the size of the forest allows for a quantification of the trees. However, densely populated forests of varying sizes lead to a high likelihood of miscounting the trees, so a margin of error will need to be included. We have also determined that it is not feasible to obtain an exact count of all of the trees in Cuenca. In the pursuit of quantifying the trees, we think that utilizing all these methods and including a margin of error will allow for a complete census. As a result, we will introduce the Cuenca Tree map seen below to our sponsor so he and his company can continue identifying where in the city each method fits best.

Additionally, the tagging system Save.bio is currently using is inefficient, and not very feasible. The tags prove to not be effective in promoting public education with the lack of scans of the QR codes. There are also challenges within the inventory system, supporting our conclusion that this tagging and inventory system is not feasible now, or long-term. More information on other recommendations can be found in Appendices E and F.

5.1.1 CUENCA TREE AREA MAP

Figure 10 shows the map of Cuenca, divided into different sections. Outlined are green spaces, main city streets, parks, and forests. Each section is represented by the colors, yellow, orange, and red. Yellow sections mean trees in that area are not densely populated, and the method of citizen science could be implemented efficiently in these areas. Orange is used in sections that have more densely populated areas, such as Parque de la Madre, and citizen science with a combination of drone technology should be utilized to maximize efficiency. Red sections are the most densely populated tree areas, such as forests. We recommend GPS technology and plot sizes with these areas.

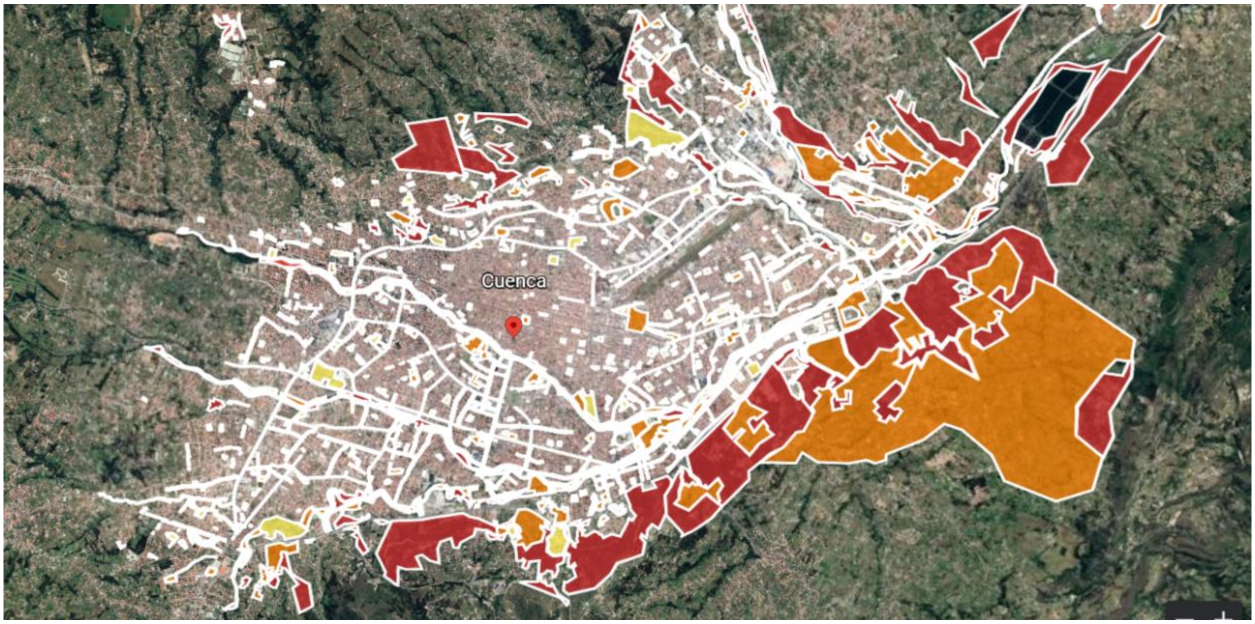

Figure 10: Color-Coded Tree Density Map of Cuenca

Looking closer at the map in Figure 11, if you click on an area of a green space, a description of the area, the code number (provided by EMAC), and the area will appear in a box. Furthermore, in some areas that may not be accessible, this map can be used in place of conducting the tree census. The color-coded density areas can be utilized to estimate the trees in a given space if you multiply the density of the color provided by the area of the space selected. In yellow, orange, and red areas, we have estimated that there are approximately 3, 37, and 195 per 10,000 ft^2 respectively. This estimation was based on the 10,000 square-foot plot censuses we conducted in the field. Ideally, if you utilize this color-coded map and determine the area of each color, you should be able to get an estimate of the number of trees in Cuenca. Using the color-coded densities of the trees, we determine that there are approximately 2.4 million trees in Cuenca.

Figure 11: Zoomed-In Screenshot of the Color-Coded Map including the descriptions

5.1.2 NEW SIGNAGE TO RECTIFY THE TAGGING METHOD

This project aimed to find the most feasible method of conducting a tree census in Cuenca to help combat the ongoing problem of climate change. We found that although there have been two censuses conducted in the city, they have no fundamental structure or program to get an accurate count. There is no actual use of advanced technology here, making it harder to complete the task. To improve the different ways that our sponsor can complete his census, he can start by following and reviewing the recommendations provided. These suggestions will allow for the potential to complete a full census in Cuenca and public education and awareness about trees and their environment.

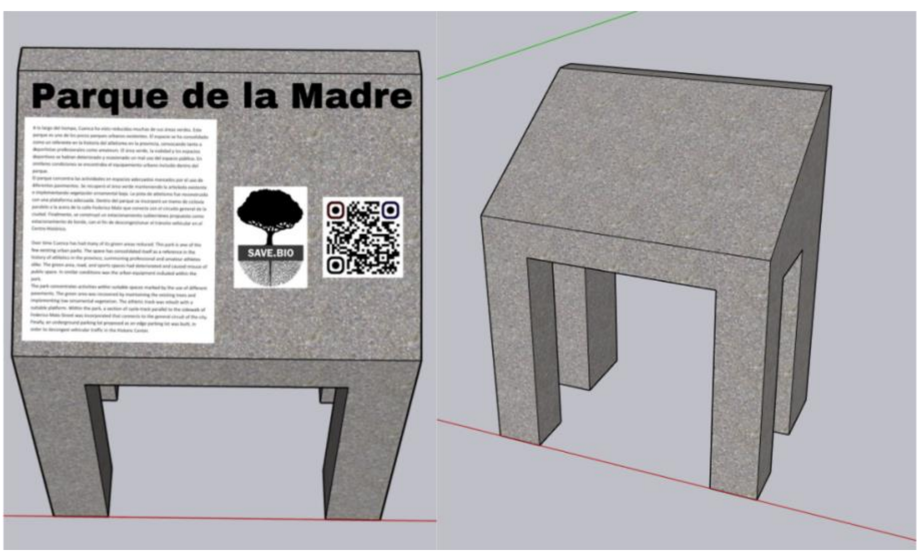

Figure 12: An example of a sign mockup made through SketchUp.

Instead of having multiple tags on trees that rarely get scanned, we recommend having one sign at the entrance of each green space with information about the trees and the area you are in. For example, Figure 12 shows an example of a sign that would be put in Parque de la Madre. This sign would include information about the park in both Spanish and English, the Save.bio logo, and a QR code that would link to the Save.bio website.

Other ideas to promote interest and interaction can include the implementation of augmented reality (AR). With the wide availability of GPS in everyday smartphones, an AR platform can lead an individual on an experience going from tree to tree. Upon arriving at each tree, a prompt will pop up on the smartphone screen educating the interactor on that specific tree. Figure 13 shows a sample of the AR link that the scanned QR code will bring you to. Ideally, this could allow for 360 camera views and inform the user of the tree when pointed at it. This can be implemented for interactive educational use.

Figure 13: Sample of AR in Parque de la Madre

5.2 PROJECT CONCLUSION

The goal of this project was to find the most feasible method of conducting a tree census in Cuenca, in order to help combat the ongoing problem of climate change. We found that although there have been two censuses conducted in the city, they have no effective structure or program to obtain an accurate tree count. There is no real use of advanced technology here which makes it much harder to complete the task. To begin improving the different ways that our sponsor can complete his census, he can start by reviewing and implementing the recommendations provided. These suggestions will allow for the potential to complete a full census in Cuenca or allow for the education of the public about trees and their environment.

WORKS CITED

Avitt, P. by A., Apicello, M. G., & Weaver, B. (2021, July 29). *Tree Census and a wealth of public data*. USDA. Retrieved February 28, 2022, from https://www.usda.gov/media/blog/2020/06/03/tree-census-and-wealth-public-data

Brack, D. (2019, March). *UNFF14 background analytical study - United Nations*. Forests and Climate Change. Retrieved December 8, 2021, from https://www.un.org/esa/forests/wp-content/uploads/2019/03/UNFF14-BkgdStudy-SDG4-10-16-March2019.pdf.

California Academy of Sciences, *Global warming and life on Earth*. Global Warming and Life on Earth. (n.d.). https://www.biologicaldiversity.org/programs/climate_law_institute/global_warming_and_life_on_earth/index.html#:~:text=In%20fact%2C%20scientists%20predict%20that,the%20end%20of%20the%20century

Crowther, T. W., H. B. Glick, K. R. Covey, C. Bettigole, D. S. Maynard, S. M. Thomas, J. R. Smith, et al. “Mapping Tree Density at a Global Scale.” Nature 525, no. 7568 (September 1, 2015): 201–5. https://doi.org/10.1038/nature14967.

GeoTab, *What is GPS?* Geotab. (n.d.). Retrieved February 28, 2022, from https://www.geotab.com/blog/what-is-gps/

IERSE UDA. (2019). Inventario forestal de parques urbanos de Cuenca. Retrieved from https://www.youtube.com/watch?v=gpXrEwbRrvM&t=2s.

Kane, Brian & Dennis, H. & III, P.. (1998). *Locating trees using a geographic information system and the global positioning system*. 24.

Larjavaara, M., & Muller-Landau, H. C. (2013, June 21). *Measuring tree height: A quantitative comparison of two common field methods in a moist tropical forest*. besjournals. Retrieved December 15, 2021, from https://besjournals.onlinelibrary.wiley.com/doi/10.1111/2041-210X.12071 Madaan, A. S. (2017, February 10). *Advantages and importance of reforestation*. Earth Eclipse. https://eartheclipse.com/environment/advantages-and-importance-of-reforestation.html

Maguire, D. J. (2006). *Overview and definition of GIS - Universidad Nacional del Sur*. Retrieved November 30, 2021, from http://lidecc.cs.uns.edu.ar/~nbb/ccm/downloads/Literatura/OVERVIEW%20AND%20DEFINITION%20OF%20GIS.pdf. (Maguire, 2006,)

Mohan, M., Silva, C., Klauberg, C., Jat, P., Catts, G., Cardil, A., Hudak, A., et al. (2017). Individual Tree Detection from Unmanned Aerial Vehicle (UAV) Derived Canopy Height Model in an Open Canopy Mixed Conifer Forest. *Forests*, *8*(9), 340. MDPI AG. Retrieved from http://dx.doi.org/10.3390/f8090340

Morejón, G. (2019). *SAVE.bio Cuenca*. SAVE. Retrieved November 10, 2021, from http://www.save.bio/.

Nowak, D. J., Hoehn, R., & Crane, D. E. (2007). Oxygen Production by Urban Trees in the United States. *Arboriculture & Urban Forestry 2007*. 33(3):220–226 Retrieved November 18, 2021, from https://www.nrs.fs.fed.us/pubs/jrnl/2007/nrs_2007_nowak_001.pdf.

Nowak, D. J. (2020, January 1). *Understanding I-tree: Summary of programs and methods*. General Technical Report NRS-200. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 100 p. Retrieved March 2, 2022, from https://www.fs.usda.gov/treesearch/pubs/61514#:~:text=i%2DTree%20is%20a%20suite,environmental%20quality%20and%20human%20health.

Nuñez, D., & Marten, G. (2010, December). Mexico - Mixteca Region (Oaxaca) – Fighting Desertification With Community Reforestation and Sustainable Agriculture. The EcoTipping Points Project. Retrieved December 13, 2021, from http://www.ecotippingpoints.com/our-stories/indepth/mexico-oaxaca-community-reforestation-mixteca-region.html.

NYC Parks, *How the Tree Census Works*. How the Tree Census Works : NYC Parks. (2015). Retrieved February 28, 2022, from https://www.nycgovparks.org/trees/treescount/about

Roman, L. A., Scharenbroch, B. C., Östberg, J. P. A., Mueller, L. S., Henning, J. G., Koeser, A. K., Sanders, J. R., Betz, D. R., & Jordan, R. C. (2017, February 4). Data quality in Citizen Science Urban Tree Inventories. *Urban Forestry & Urban Greening.* https://www.sciencedirect.com/science/article/pii/S1618866716302680.

Roy, H. E., M. J. O. Pocock, C. D. Preston, D. B. Roy, J. Savage, J. C. Tweddle, and L. D. Robinson. 2012. Understanding citizen science and environmental monitoring. Final report on behalf of UK-EOF. NERC Centre for Ecology and Hydrology, Wallingford, Oxfordshire, UK

Soomro, byA., Soomro, A., Ahsen Soomro, N. (2020, April 22). *Afforestation; importance, Advantages & disadvantages. current efforts!* Environment Buddy. https://www.environmentbuddy.com/plants-and-trees/what-is-afforestation-importance-advantages-disadvantages/

The Morton Arboretum, (2021, May 27). *Chicago Region Tree Census*. The Morton Arboretum. Retrieved November 18, 2021, from https://mortonarb.org/science/projects/tree-census/.

UN, *Human development report 2020 - United Nations Development ...* (n.d.). http://hdr.undp.org/sites/default/files/hdr2020.pdf.

U.S. Department of Agriculture, Forest Service [USDA FS]. 2006. Forest Inventory and Analysis glossary. On file with Pacific Northwest Research Station, Forest Inventory and Analysis, 620 SW Main Street, Suite 400, Portland, OR 97205.

Walker, D. W., Smigaj, M., & Tani, M. (2020, October 12). *The benefits and negative impacts of citizen science applications to water as experienced by participants and Communities*. Wiley Interdisciplinary Reviews. Retrieved December 6, 2021, from https://wires.onlinelibrary.wiley.com/doi/10.1002/wat2.1488.

Ward, K. T., & Johnson, G. R. (2007). Geospatial methods provide timely and comprehensive urban forest information. *Urban Forestry & Urban Greening*, *6*(1), 15–22. https://doi.org/10.1016/j.ufug.2006.11.002

APPENDIX A OXYGEN PRODUCTION OF TREES AND REQUIREMENTS

Net oxygen production by trees is based on the amount of oxygen produced during photosynthesis minus the amount of oxygen consumed during plant respiration (Salisbury and Ross 1978):

Photosynthesis: n(CO_2) + n(H_2O) + light → (CH_2O)n + n(O_2)

Respiration: (CH_2O)n + nO2 → n(CO_2) + n(H_2O) + energy

An average adult consumption rate of oxygen of 0.84kg/day (Perry and LeVan c. 2003) can be used to determine how much human oxygen consumption would be offset from oxygen production of trees annually. Tree oxygen production varies by tree size; an average size tree of diameter 9-12 inches produces about 50 kg of oxygen per year (Nowak et al. 2006b). Based on these calculations, there would need to be six-to-seven trees per person to fulfill the annual oxygen requirements. Cuenca has a population of about 700,000 which means that approximately 4.5 million trees are needed to meet the annual oxygen consumption requirements.

APPENDIX B: MUNICIPALITY INTERVIEW

This participant survey will last approximately 10-15 minutes. The purpose of this survey is to learn how municipality workers keep track of and take care of all of the green spaces and trees on main roads in the city.

This survey will ask you several questions ranging from rating your personal experience with a tree census, how it could have been improved, and your opinions on future directions. By completing this survey you are providing consent for us to use your data to formulate materials and recommendations. If any of these questions make you uncomfortable, you can skip the question as all are optional and can withdraw from the process at any time.

For more information about this research or about your rights as a research participant, please contact any of the involved below:

Researchers: Abigail Benoit, Dante Coccagnia, Christian Luizzi, Kali Sander

gr-treecensusc22@wpi.edu

Project Advisor: Gary Pollice

gpollice@wpi.edu

IRB Manager: Ruth McKeogh

(+1) 508-831-6699, irb@wpi.edu

All of your responses will be anonymous and your identity will remain confidential throughout the entirety of our study.

EMAC Municipality Workers:

What are some techniques of conducting a tree census that you have utilized?

What do you think are the most *efficient* methods of conducting a tree census, and why?

What do you think are the most *accurate* methods of conducting a tree census, and why?

What are some challenges you have faced in regards to tree inventorying/management?

Where do you think the tree census method needs improvement?

What are the techniques of getting the public interested in tree education and conservation?

What does your role look like in the verification process?

APPENDIX C: LOCAL ORGANIZATION INTERVIEW

This participant survey will last approximately 15 minutes. The purpose of this survey is to learn more from local organizations that have implemented citizen science about what was and was not successful.

This survey will ask you several questions ranging from rating your personal experience with a tree census, how it could have been improved, and your opinions on future directions. By completing this survey you are providing consent for us to use your data to formulate materials and recommendations. If any of these questions make you uncomfortable, you can skip the question as all are optional and can withdraw from the process at any time.

For more information about this research or about your rights as a research participant, please contact any of the involved below:

Researchers: Abigail Benoit, Dante Coccagnia, Christian Luizzi, Kali Sander

gr-treecensusc22@wpi.edu

Project Advisor: Gary Pollice

gpollice@wpi.edu

IRB Manager: Ruth McKeogh

(+1) 508-831-6699, irb@wpi.edu

All of your responses will be anonymous and your identity will remain confidential throughout the entirety of our study.

Local Organizations:

What are some data collection techniques that citizen science has utilized?

What are the methods of keeping participants engaged in projects?

What was successful for you?

What was not successful for you?

APPENDIX D: PARQUE DE LA MADRE CALCULATIONS

Appendix A states Cuenca has a population of about 700,000 which means that approximately 4.5 million trees are needed to meet the annual oxygen consumption requirements. It took our team of four, one hour to count approximately 100 trees.

4,500,000 (trees) / 100 (trees counted) ~ 45,000 hours

45,000 (hours) / 8,700 (hours in a year) ~ 5 Years

This results in a group of four participants having to work 5 years straight to count all 4,500,000 trees. Further calculations and explanations are not needed due to the clear lack of feasibility, especially when breaking up these 5 years into eight-hour workdays.

APPENDIX E: IMPROVING CITIZEN SCIENCE

For future tree censuses, promoting participation in citizen science projects will help quantify the accuracy of this method of a census. With additional participants, pilot programs for these censuses can be conducted, and focus groups can be created to improve census protocols. Our team wanted to create focus groups for citizen science participants after creating and piloting a protocol that would teach them how to use the GIS census and inventory system. Increased participation in the first few weeks of the project would allow for the implementation of different methods of utilizing census technologies. Results would then be used to create a feasibility assessment, to compare user-friendliness, economic feasibility, and accuracy. Additionally, more participation allows for censuses to be continued throughout the years.

APPENDIX F: INTRODUCTION OF GPS/DRONE TECHNOLOGY

Another recommendation is the use of GPS drone technology. We reached out to our connections in Cuenca to borrow a drone. We hypothesized that drone technology using orthographic imaging would allow us to count trees faster and more efficiently in clusters. For example, in groups of trees close together, an overhead image may not be able to differentiate all of the trees, whereas different perspectives allow us to count the trunks of the trees. However, we were unable to obtain drone technology due to time constraints and economic feasibility. In the future, if the census has funds, obtaining drone technology could be an efficient method to estimate the number of trees in Cuenca.