Comparison of Carbon Sequestration Methodologies for Use by Academic Institutions in Texas

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Abstract

As natural areas are continuously converted for anthropogenic use, it is important to quantify the loss of ecosystem services to the nearby communities. Until recently, the study of these services in urban areas has been limited. However, efforts to preserve these lands would be better supported if methodology was easily accessible to quantify the ecosystem services. Specifically, carbon sequestration is critical to climate regulation. Therefore, our objectives were: 1) to compare two sets of methodology for quantifying carbon sequestration based upon ease of use, cost, time requirement, and accuracy: data provided by remote LiDAR technology and field measurements incorporated into the i-Tree Eco software system, and 2) to provide recommendations to promote biodiversity protection on lands in close proximity to urban areas. We quantified carbon sequestration at Wild Basin Wilderness Preserve in Austin, Texas. We used five plots, varying in ecosystem structures across the preserve, and measured the number of trees per species, as well as DBH and height for each tree. These data were then entered into i-Tree Eco for an estimate of carbon sequestration. These field-based estimates were then compared to estimates provided by remote LiDAR data. We found a strong positive correlation between average canopy height and amount of carbon being sequestered at each plot (rho = 0.90 p = 0.037). By improving access to different methodologies, more land potentially will be conserved and restored, which may increase protection of urban biodiversity and enhance the health and well-being of city residents.

1.0 Introduction

Research on ecosystem services has been growing in recent years, but interactions among multiple ecosystem services across different landscapes are still poorly understood (Qui, 2013.) Ecosystems provide many basic services for all humans, and the term ecosystem services can be defined as the conditions and processes through which natural ecosystems, including the species that make them up, sustain and fulfill human life (Daily, 1997). Ecosystem services can benefit human populations directly and indirectly (Costanza et al., 1997). The vertical structure of a forest ecosystem is complex and multilayered. The biodiversity of species may add to this complex situation (Kenzo, 2006). There is a pressing need for better understanding of the dynamics of tree communities In addition to the great biodiversity that they harbor, some species are disproportionately important in the world carbon budget (Clark, 2001). Further, recent modeling and empirical studies of these forests suggest that they are highly responsive to climatic variation and thus could significantly shift their net carbon balance with on-going global climate change (Clark, 2001).

In 2005, the Millennium Ecosystem Assessment identified categories for ecosystem services, which include provisioning, regulation, cultural and supporting services. Provisioning services are any type of benefits people can extract from nature such as drinking water, natural gas or oil, and medicinal benefits. Benefits obtained from regulation of ecosystems processes, such as pollination, water purification, and carbon storage fall under the category of regulating services. Cultural and supporting services include any nonmaterial benefits gained from ecosystems. Some examples are spiritual and religious benefits, ecotourism and education. Although research and policy interests towards ecosystem services have grown considerably in recent years, ecosystem services in cities and in urban regions remain areas of limited research (Niemela, 2010). It is important to assess their value because urban ecosystem services have a large positive impact on the long term sustainability for regions and the overall quality of life for humans (Gomez-Baggethun & Barton, 2013). Furthermore, "conserving and restoring ecosystem services in cities and urban regions can reduce ecological footprints and the ecological debts of cities while enhancing resilience and health for their inhabitants" (Gomez-Baggethun & Barton, 2013).

Climate regulation, specifically carbon sequestration, is categorized under the supporting service established by the Millennium Ecosystem Assessment. Forests, one of the important terrestrial ecosystems, play a key role in carbon sequestration and have an important role in the global carbon cycle (Zhou et al., 2014). Forests are valued globally for the services they provide to society (Pan et al., 2011). Forests account for 85–90% of the biomass of all global terrestrial vegetation, and for 90% of the carbon exchange with the atmosphere, via photosynthesis and respiration, decomposition and combustion (Zhou et al., 2014). It is suggested that there are extensive areas of relatively young forests with the potential to continue sequestering carbon into the future in the absence of any accelerated natural disturbance, climate variability, and land-use change (Pan et al., 2011). However, trees and forests in urban areas are often ignored because their ecosystems are not well understood (Nowak, Greenfield, Hoehn, & Lapoint, 2013).

Urban trees have the capability of storing large amounts of carbon, as well as regulating air temperatures, air pollution and energy usage from buildings (Nowak, 1993). Studying these regulations is useful for understanding carbon emissions and also for preparing greenhouse gas inventories for any given city (Nowak, Greenfield, Hoehn, & Lapoint, 2013, p. 229). Many universities around the world are beginning to make efforts to become climate neutral in order to combat global warming (Baehr, 2015.) Some Texas universities have become interested in obtaining carbon credits, which are permits that allow a country or organization to produce an amount of carbon emissions that can be traced if not used fully. Carbon Offsetting is the use of carbon credits to enable organizations to compensate for their emissions, meet their carbon reduction goals and support the move to a low carbon economy. Specifically Rice University in Houston, Texas offset 57,640 metric tons of CO2 in 2012 (Johnson, R. 2007). Universities which have large urban nature areas may be able to offset their carbon emissions in this manner.

We focused our study on carbon sequestration at Wild Basin Wilderness Preserve (Wild Basin), an urban park located in Austin, Texas, and managed by St. Edward's University. Assessing the value of ecosystem services provided by Wild Basin and the greater Balcones Canyonland Preserve (BCP) system can provide a better understanding of its importance for the city of Austin, Texas. We assessed the most prevalent ecosystem services provided by Wild Basin and quantified the amount of carbon being sequestered at the Wild Basin. There

were two objectives to our research study. The first objective was to compare two methods for quantifying carbon sequestration based upon ease of use, cost, time requirement, and accuracy using data provided by remote LiDAR technology and field measurements incorporated into the i-Tree Eco software system. The second objective was to provide recommendations to promote biodiversity protection on lands in close proximity to urban areas. As more and more natural areas are being converted to cropland and building structures, it is important to know what is being lost in the area of ecosystem services. Quantifying the value of carbon sequestration provided by Wild Basin and Balcones Canyonland Preserve could greatly increase current and future support for this nature preserve. Furthermore, this research could be used to assess the benefits that carbon sequestration provides St Edward's University, the Austin community and Travis County.

2.0 Methods

2.1 Study Area

Our study was conducted at Wild Basin, an area located along the Capital of Texas Highway approximately 16 km west of downtown Austin, Texas. Wild Basin is an ideal area to study due to its close proximity to the center of the city. The 92 hectares preserve is managed by the BCP and jointly owned by Travis County and St. Edward's University. Wild Basin provides a habitat for vulnerable and endangered species such as the Golden-cheeked warbler and also serves as an area for visitors to hike trails and enjoy the outdoors ("Wild Basin Wilderness Preserve," n.d.). In addition, Wild Basin Creative Research Center functions as an information center for the public and research facility for students ("Wild Basin Creative Research," n.d.).

Within the preserve we looked at five plots from a grid of points across the preserve previously established by Wild Basin. We chose plots 2, 3, 5, 7, and 9 because they best represented the three prevalent ecosystems in the preserve: Semi-Open Grassland, Woodland, and Streamside Community (Fig. 1, Walther, J., 1981). Of these ecosystems, we were able to represent two plots from each, except the streamside community. We only managed to get one plot of this type due to time and weather constraints. We measured a 5.64 meter (0.01 hectare) radius, the minimum requirement for i-Tree Eco, from the center of the each plot to establish our study area.

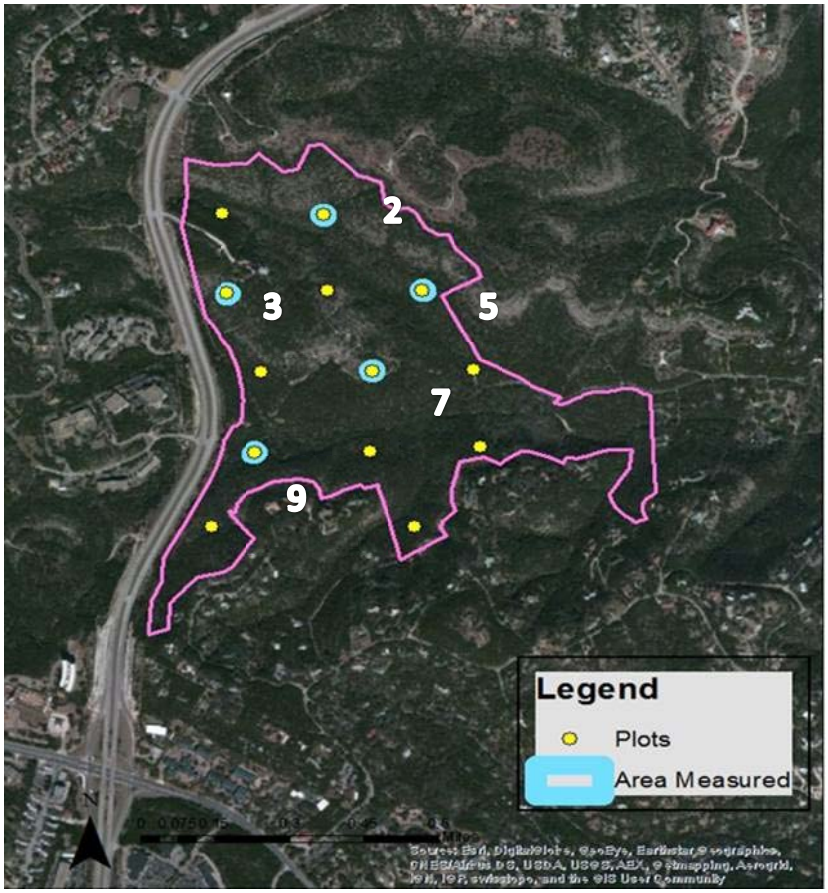

Figure 1 Map of Study Site

2.2 Technology Used

LiDAR and i-Tree Eco were the methods we used for measuring average maximum canopy height within our five plots. We decided to use these two methods because both are methods that universities can get access to in order to measure tree height. Though i-Tree Eco is much more time intensive, LiDAR requires getting the data files, if they exist for that region.

LiDAR (Light Detection and Ranging) is a technology that utilizes infrared light beamed down from a low-flying plane or helicopter to measure height of tree canopy in comparison to ground elevation (NOAA. n.d.; ESRI, 2011). The intensity of the beams sent out result in a better signal back, making it possible to acquire three-dimensional information and extrapolate a more in depth analysis. (ESRI, 2011). LiDAR has been used to measure for such purposes as forestry mapping, tree density and biomass, and even to determine how forest fires will act in an area (Peterson et al., 2005).

The i-Tree Eco software is used by the US Department of Forestry to take ground data input, local hourly pollution, and meteorological data to calculate carbon sequestration ("i-Tree Eco," n.d.). The manual was an excellent guide for us in the field to know what data we needed to collect from the plot. This software was straight forward to use (especially with the manual), but it does require a large amount of time entering data into the computer program as well as in the extensive field time for measuring trees.

2.3 Measurements

To calculate the average canopy height surrounding our plots, we used LiDAR data, processed by Travis County, and ArcGIS. We added a 5.64 meter buffer, to account for our plot radius, to a sampling grid of Wild Basin. Then we used Zonal Stats as Table tool to calculate statistics for average canopy height in each buffer. Percent canopy cover was calculated using a similar method. A 5.64 meter buffer was added to the Tree Canopy 2010 GIS/Map obtained through the city of Austin. The percent canopy values were also obtained using Zonal Statistics as a Table tool.

For our field measurements, we followed the recommended data collection from the i-Tree Eco manual. For each plot, we first marked out the boundary and identified shrub species in the area. We also collected the average height of each shrub species identified. We then tagged each tree with an ID number, determined its species and took DBH measurements for all trees over 2.54 cm.

Our tree height measurements, tree height, height to live top, and height to crown base, were obtained using a clinometer (Clinometer Quick Guide, 2012). This is a simple mechanical tool we used in the field that has two different scales for taking measurements based on angles. We used the percentage scale to take readings at the top and base of each tree as well as the crown base. These readings were then used to calculate the above mentioned heights. We used the averages of these tree height measurements within each plot to compare to our LiDAR results.

We also determined percent crown dieback, percent crown missing, and the amount light exposure. These more subjective measurements were determined by all three researchers to make our measurements as accurate as possible. All trees were recorded as ingrowth, and being located in the park. These data were then entered into i-Tree Eco software to produce the total carbon sequestered in Wild Basin Wilderness Preserve.

3. Results

3.1 Remote Sensing Data

The zonal statistics generated through ArcGIS provided us with the average canopy height with standard deviation and percent canopy cover for each site (Table 1).

Plots	Average Canopy Height	SD Average Canopy Height	% Canopy Coverage
2	5.69	0.95	100
3	2.30	1.70	16.95
5	4.97	1.32	100

7	1.89	1.71	0
9	7.34	2.25	96.69

Table 1 Average canopy height and percent canopy cover for each site

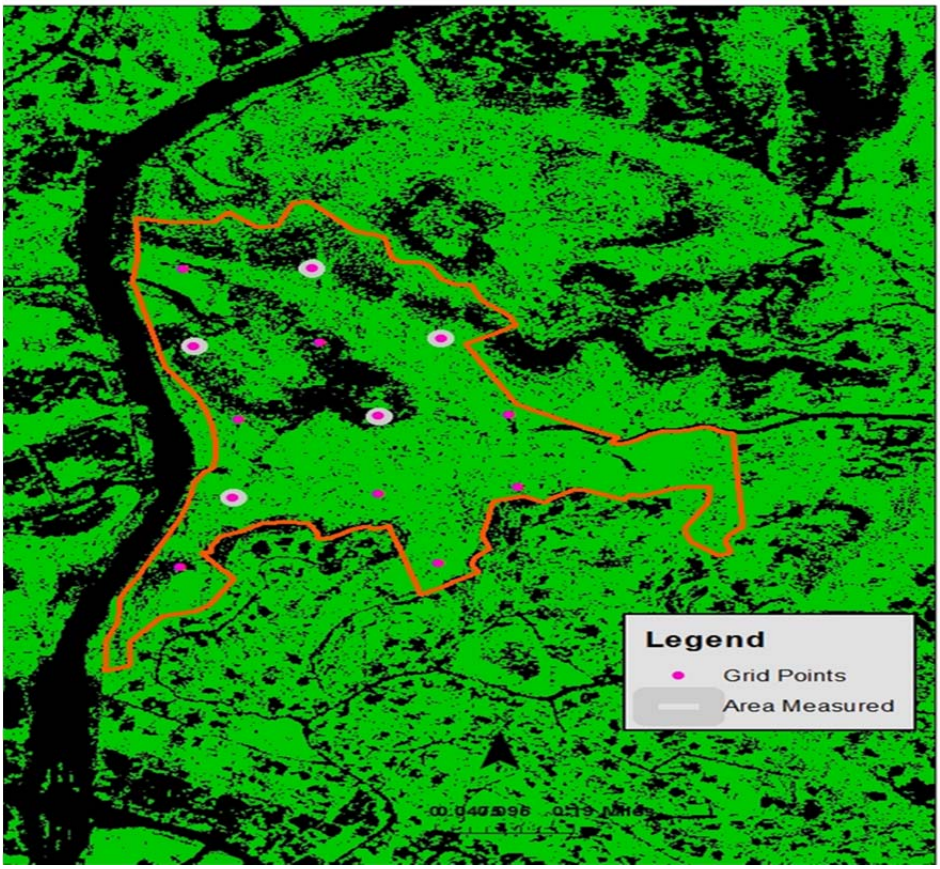

Figure 2 Canopy coverage of Wild Basin using Tree Canopy 2010 GIS data from City of Austin

3.2 Comparison of Methodologies

A paired t-test was used to compare the average canopy height obtained from LiDAR data and field measurements (Figure 3). There was no significant difference between tree height from field measurements and Lidar ($p = 0.667$), but there was also no significant correlation between the two measurements ($p = 0.755$).

To determine a relationship between the average canopy height obtained through LiDAR and amount of carbon sequestered given by i-Tree Eco, we ran a Spearman's Rank Correlation (Figure 4). There is a strong positive relationship between both variables.

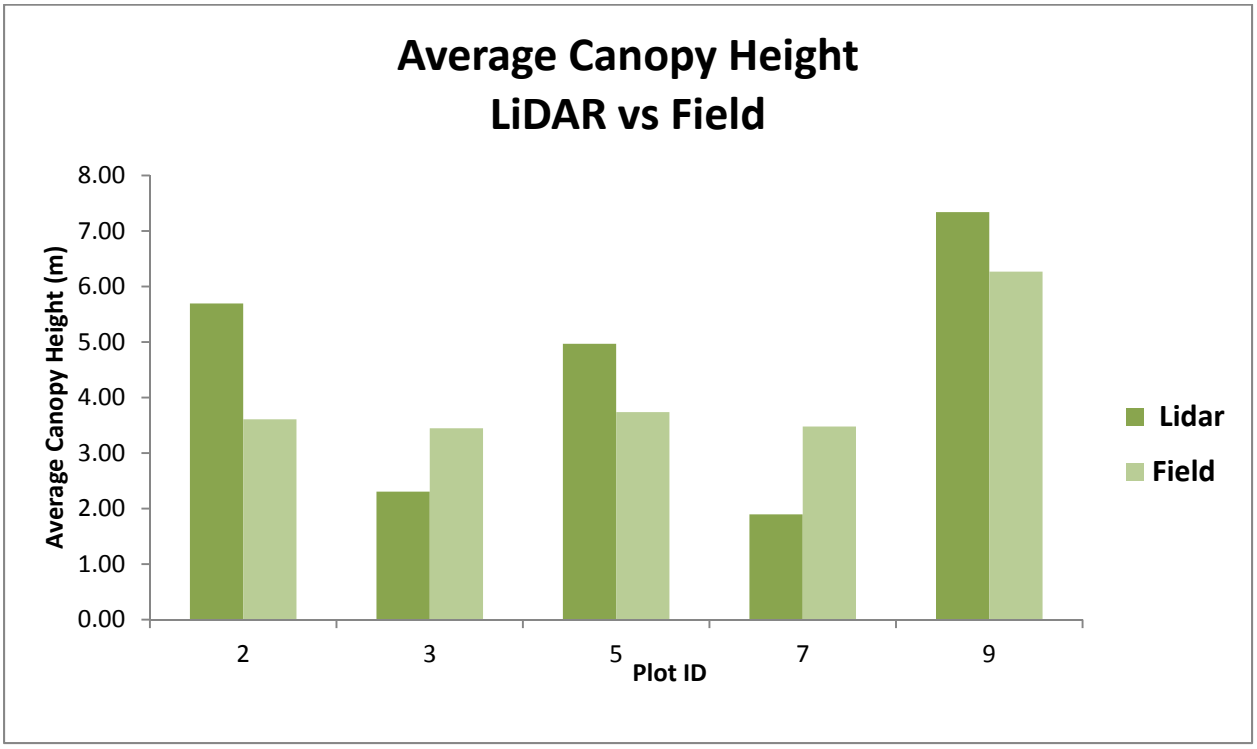

Figure 3 Comparison between average canopy heights from both methods at each plot

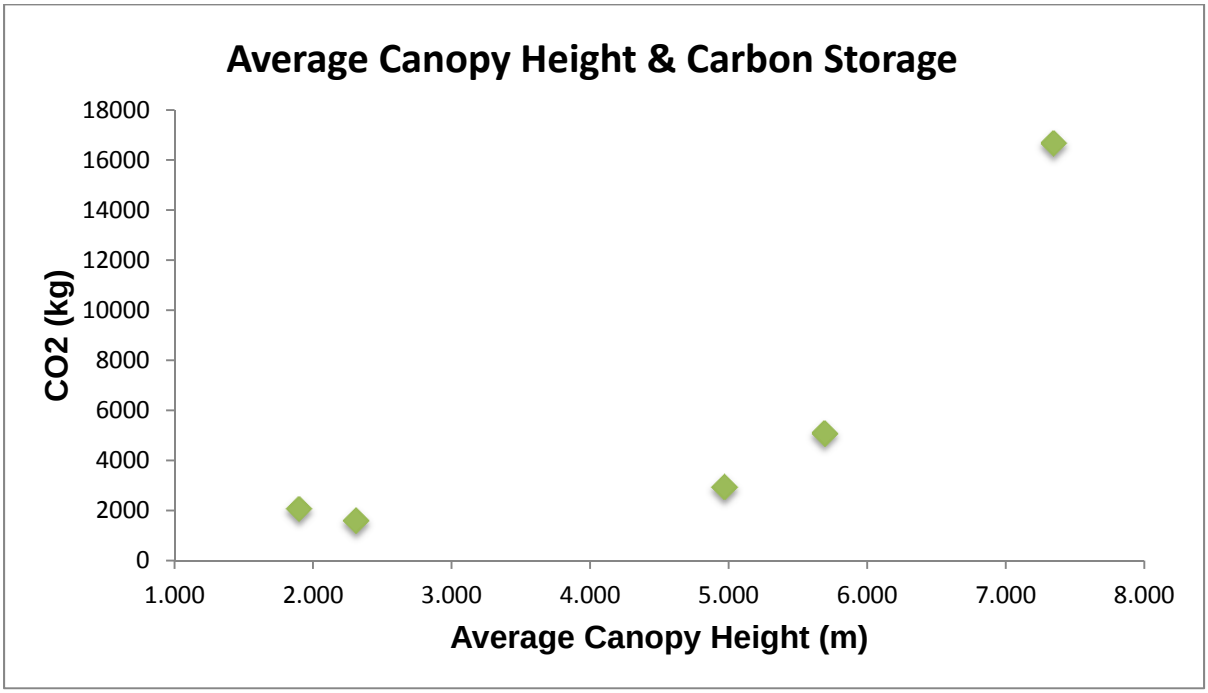

Figure 4 Average canopy height obtained through LiDAR and carbon sequestration given by i-Tree Eco (rho = 0.900 p = 0.37).

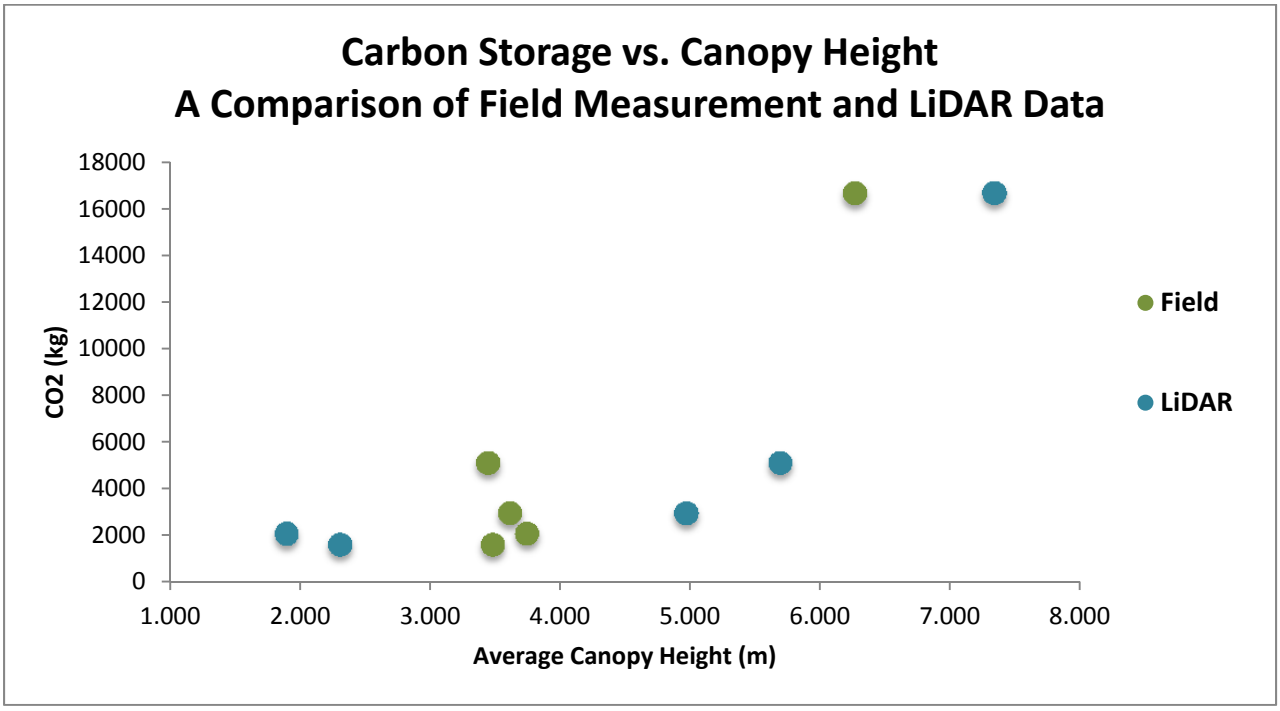

Figure 5 Average canopy height and the quantity of carbon storage from both measurements

3.3 Carbon Sequestration at Wild Basin

Based on both measurements, the amount of carbon being sequestered typically increases as average tree height increases (Figure 5). The results from i-Tree Eco indicate that Wild Basin stores 522,706 metric tons of carbon dioxide with a standard error of 25,933.6 metric tons. Overall, Wild Basin is valued at $344,062,842 with a standard error of $144,016,567.

3.4 Biodiversity at Wild Basin

From our data collection in the field, we identified the species of trees in each of our plots. This data allows us to see what the biodiversity looks like in the preserve based on our sample size. Below are the breakdowns of the species and their representation in each plot by percentages.

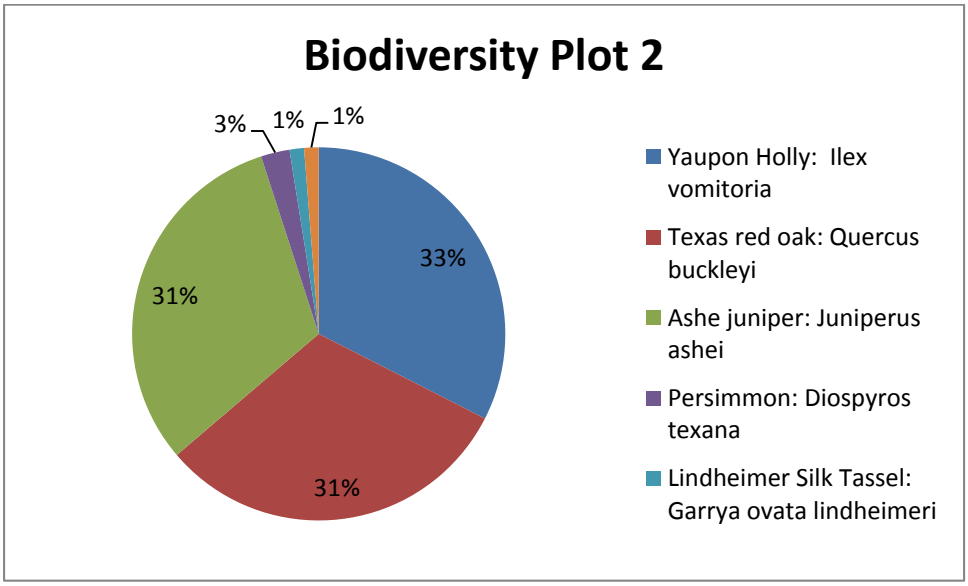

Figure 6 Biodiversity Plot 2

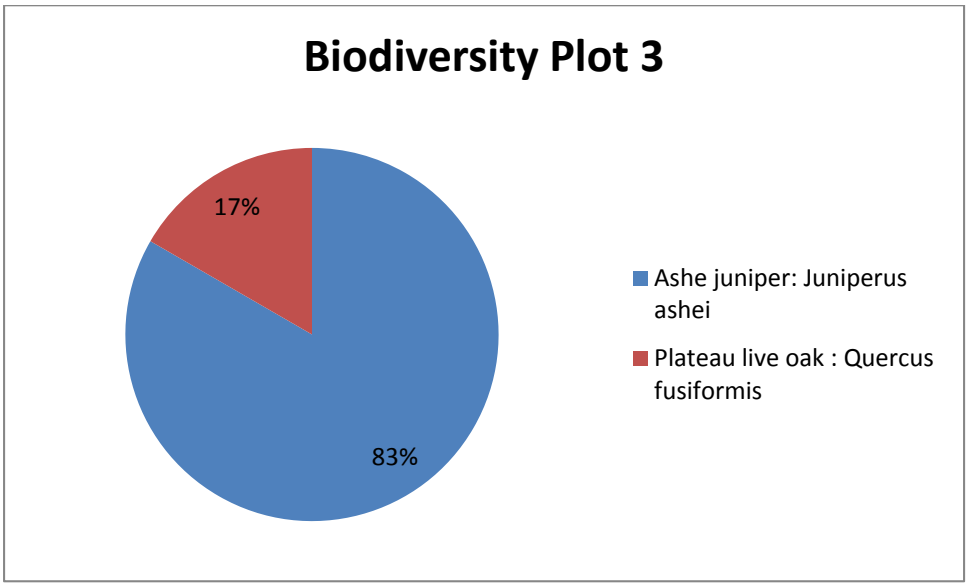

Figure 7 Biodiversity Plot 3

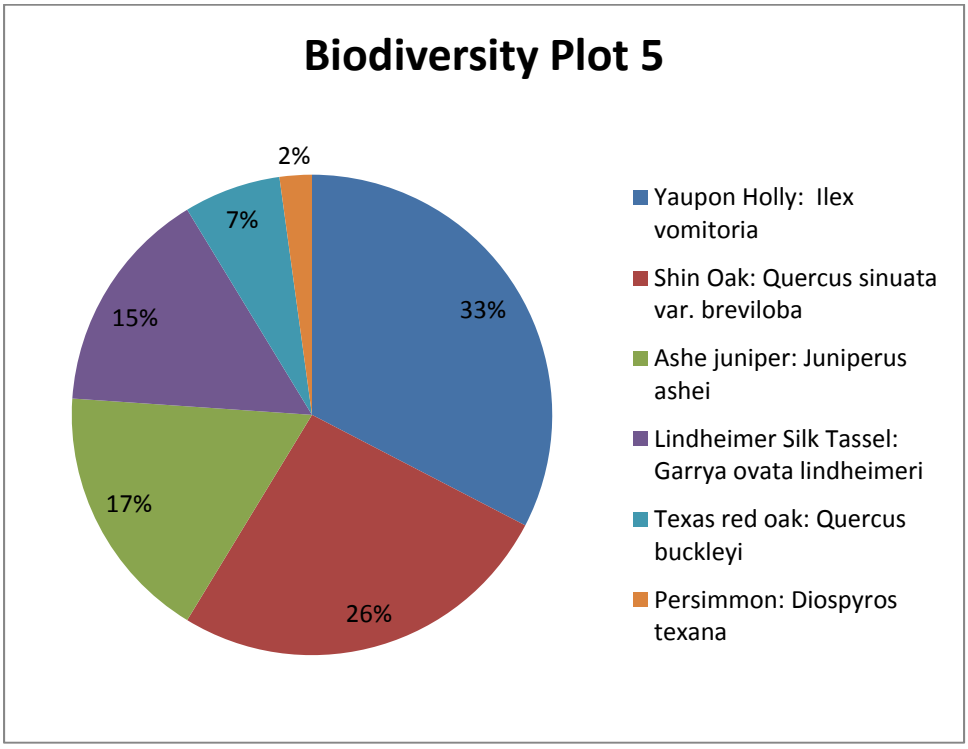

Figure 8 Biodiversity Plot 5

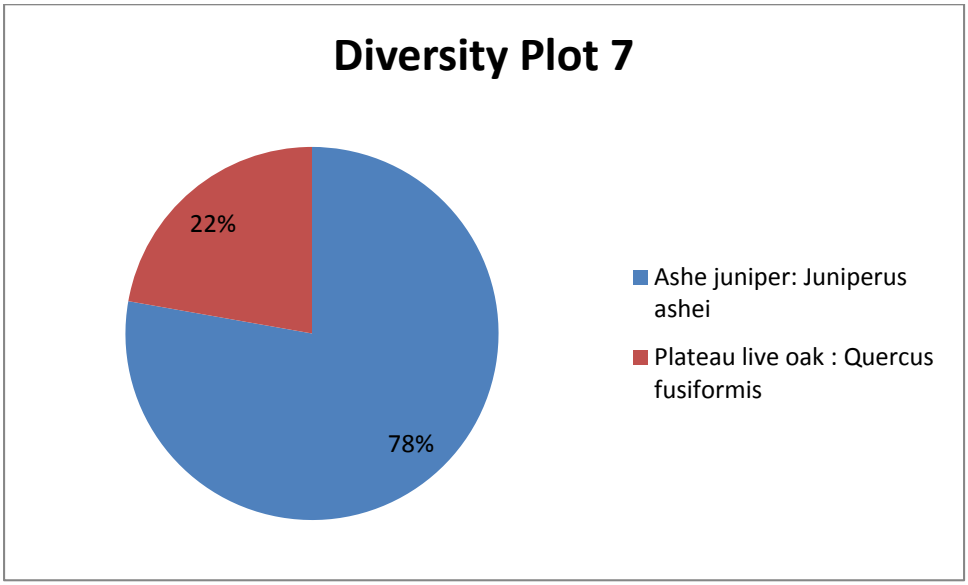

Figure 9 Biodiversity Plot 7

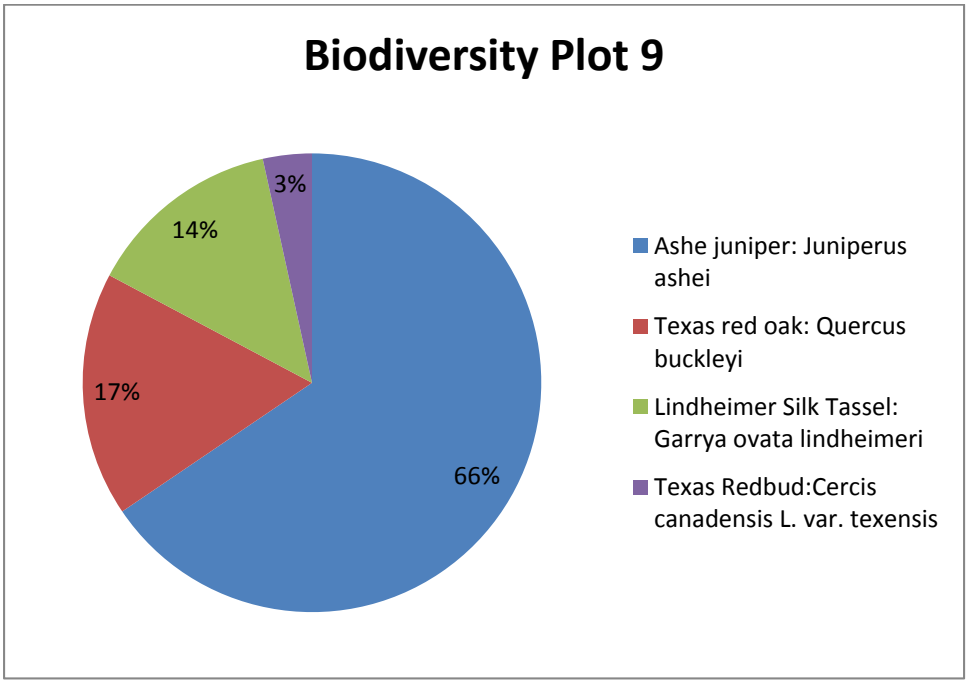

Figure 10 Biodiversity Plot 9

4.0 Discussion

Our results indicate that there was no significant difference between LiDAR and our field data for average canopy height. However, there is no significant correlation between the two methods, since LiDAR over estimated average canopy height for most of our plots. It is possible that a larger sample size will strengthen the correlation between both variables. Based on our field measurements, we also found that remote sensing was limited in estimating the canopy coverage in our plots. For example, percent canopy coverage for plot 7 was estimated at zero, though our field estimates indicated there was canopy coverage at this area. Additionally, Plots 2 and 5 were overestimated at 100 percent canopy coverage. It is possible that the area of the plot may have been too small for canopy detection and or the canopy coverage has changed over the last five years.

We found a significant relationship between average canopy height obtained through LiDAR and the amount of carbon sequestered provided by i-Tree Eco. This relationship can be further explored, as remote sensing techniques could replace field methods for measuring tree height, thus decreasing the time spent on the field. However, it is important to point out that given our small sample size, it was not possible to obtain the amount of carbon sequestered using LiDAR exclusively. Perhaps after further research, with larger plots and a larger sample size, this relationship will be strong enough to make using remote data a possible stand in for estimating carbon sequestration

The i-Tree Eco software provided the value of carbon sequestration with a relatively large standard error. The relative standard error we encountered is most likely due to our sample size, as the accuracy of this methodology tends to decrease with reduced plot and sample size (Nowak, Walton, Stevens, Crane & Hoehn, 2008). Additionally, i-Tree Eco utilizes other measurements in the field such as tree species, dieback and crown size when calculating carbon values. For example, Plot 9 had a tall Cedar Elm (*Ulmus crassifolia)* that provided a

large portion of carbon being stored at this site. However, it is important to note that i-Tree Eco provides information beneficial to any preserve. It also provides information in addition to carbon sequestration that would be useful for preserve, universities, and other organizations interested in determining the value of ecosystem services in urban areas.

The summary provided by i-Tree Eco not only gave values of carbon being sequestered in tons and the monetary value of the service, but it also provided values for avoided runoff, pollution effects, and species condition. This makes the software valuable for areas like Wild Basin which are undeveloped, provides numerous ecosystem services to nearby cities, and wants to make the value of these services known to those who want to develop the land. Being able to put values on these services with relative ease, even estimations in dollars, aids in conveying the importance of keeping the land intact.

In looking at the biodiversity within our plots, we were not able to establish a relationship between species diversity and average canopy height. It is entirely possible that our plot size or sample size was too small. Realistic forest dynamics models of these ecosystems will be needed for understanding of how these complex communities function and how they will respond to future environmental change (Clark, 2001). Tree diversity is an important driver of forest ecosystem functioning, and may enhance tree growth. (Haase, 2015). One study found that canopy openness increased significantly with tree height and that leaf properties had simple and significant relationships with tree height, with few intra- and interspecies differences (Kenzo, 2006). Understanding the diversity of canopy and leaf properties could result in developing models that can accurately estimate carbon dioxide flux and biomass production in forests. Our recommendation to the Wild Basin is for continued research in this area.

Overall our results suggest that Wild Basin provides an economic value to the city of Austin as undeveloped land. We would like to emphasize the importance of this service to the surrounding community, the city of Austin, Texas and Travis County. This information could be helpful in providing carbon credits, lowering emissions of greenhouse gases and lowering pollution levels. These benefit the health of the residents, the economy and the environment. The monetary value of this preserve, based on the ecosystem services, should be taken into consideration when making environmental management decisions. We hope that our data can be used as a basis with which to develop a long-term monitoring plan for Wild Basin. Furthermore, Wild Basin could benefit from studying other ecosystem services provided by this area. Having the values and data for many, if not all, the ecosystem services would provide much insight into the value of the urban ecosystem services at Wild Basin. Table 2 provides a list of these other services and suggested methodologies for future research.

Service	Suggested Methodologies	Reference
Moderation of Environmental Extremes	Identify extremophiles at Wild Basin	Rothschild and Mancinelli, 2001
Temperature Regulation	Looking at possible correlations between landscape characteristics and land surface temperature is recommended. Analyze the heat island magnitude and characteristics of	Connors, Galletti, & Chow, 2013

	other cities in Texas compared to Austin.	
Air Purification Pollution Control	USDA Forest Service I-Tree Eco (pollution removal)	I-Tree Eco User's Manual, n.d
Noise Reduction	Measuring decibels at points throughout preserve	Maisonneuve, Stevens, Neissen, & Steels, 2009
Pollination	The distance from local gardens to Wild Basin in relation to pollination measurement. Abundance and biodiversity of pollinators at Wild Basin Determine pollinators pollinating specific endangered species/ invasive species may be helpful.	Carvalheiro, Seymour, Veldtman, & Nicolson, 2010 Morandin & Winston, 2006
Soil Quality	Soil Carbon Coalition: Measuring Soil Carbon Change: A flexible, practical local method is a guide with a good technique for soil analysis.	Donovan, 2013
Water	USDA Forest Service I-Tree Eco (run-off)	I-Tree Eco User's Manual, n.d
Population Management	Biodiversity counts using camera traps	Rowcliffe, J.M. et al, 2008
Education & Recreation	A multitude of articles on this topic, mainly using self-reporting or surveying to analyze this service. Some like this one suggested using GIS mapping as well.	Brown, Schebella, & Weber, 2014

Table 2 List of ecosystem services provided by Wild Basin with suggested methodologies obtained to literature review

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