# ECOSYSTEM SERVICES OF URBAN TREES AND THE IMPACTS OF URBANIZATION

A Thesis

by

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ABSTRACT

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The University of Texas- Pan American has conducted a complete survey of campus trees in partial fulfillment of the requirements for membership in the International Society of Arboriculture Designation of Tree Campus USA. This tree inventory was accomplished with the help of students whom were trained by faculty and foresters. Other than the completion of the tree inventory, this thesis had two main goals; 1) valuate the ecosystem services provided by campus trees 2) create a unique service learning project that other institutions can model. According to our calculations, the trees on campus have sequestered 568,652 kg of $CO_2$, avoided 749.114 $m^3$/year of water, saved 25,152.2 kWh in energy savings and sequestered 992,229 g of airborne particulates. The students involved in the tree inventory showed strong initiative as well as an increased amount of pride in their work over the course of the semesters. This method showed transformational results and is encouraged by other institutions.

## DEDICATION

The completion of my masters studies would not have been possible without the love and support of my family. My mother, Eliza Cantu, my father, Lauro Cantu, my sister Larissa Cantu, my aunt Roxanna Villarreal, and my wife Star Cantu, wholeheartedly inspired, motivated, and supported me by all means to accomplish this degree. Thank you for your love and patience.

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I will always be grateful to Dr. Alexis Racelis, chair of my thesis committee, for all of his mentoring and advice over the years. I would also like to give my thanks to all 32 Tree Campus students who were all a pleasure to work with and helped us complete a tree inventory of 1,971 trees. My thanks also goes to the Tree Campus Committee members, the group that got this effort together and provided help whenever needed. Last but not least, I say thanks to my committee members, who were not hesitant to help whenever I asked.

I would like to once again say my thanks to everyone, and with everyone's help, we were able to accomplish our goal in transforming UTPA into a Tree Campus USA College®. Congratulations and thank you everyone.

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CHAPTER I

INTRODUCTION

In 1800, only about 3% of the world's population lived in urban areas, but in recent times, it has risen up to 50% (Heilig 2012). These urban areas are densely populated, highly modified systems resulting from destruction, alteration, and fragmentation of the original habitat, or rural lands (Szlavecz, Warren et al. 2011). Urbanization, or rapid increase in population coupled with an increase in per capita energy consumption and landscape modification (Pickett 2003) inextricably spurs the proliferation of impervious structures like buildings, streets, and sidewalks. While urbanization rates differ across the country,  the McAllen metro area in deep south Texas  has one of the fastest rates of urbanization, with an increase in the population living on urban areas of 39% and the urbanized land area increasing by 14% between 2000 and 2010 (Census 2000, Census 2010). The land alteration between 2002 and 2015 for Edinburg, Texas can be seen in figure 1.1. Such a precipitous increase of population and a relatively rapid shift of land use inextricably requires drastic landscape modification.

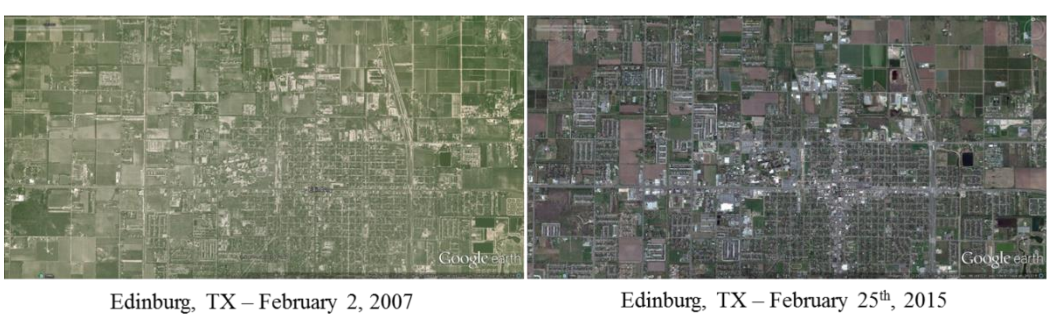


Figure 1.1: Aerial images of Edinburg, Texas from 2002 (left) and 2015 (right)

This project, in partial fulfillment of my master's program, examines generally how landscape modification as a result of urbanization can affect different ecological services. Ecological services (or ES, hereafter), is defined as the set of benefits derived from the environment (as detailed below in section IA). With a specific focus on trees, I analyze and discuss the ecological implications of trees on the Edinburg campus of the University of Texas - Rio Grande Valley, and calculate different ES of campus trees using US-Forest Service modeling tools (i-Tree Eco ™) These data are presented in chapter II, using a format designed for publication in Journal of Ecosystem Services (submission forthcoming).

Chapter III summarizes the context of this work as a service learning project. In the Racelis Urban and Agroecology Lab at UTRGV, master's students are required to contextualize their thesis research as part of a larger service to the RGV community. In collaboration with the Office of Sustainability, City of Edinburg, Texas Forest Service, and the Arbor Day Foundation, Dr. Alex Racelis and I spearheaded an initiative to qualify our campus as a member of Tree Campus USA. This membership is an exclusive designation that signals a campus' pledge toward the sustainable management of trees on campus. One of the five standards required for certification is a service learning project, which was directed by Dr. Racelis through a two or three unit course in Biological Problems (BIO 4201) or Environmental Science Internship (ENSC4300). The class was offered in three consecutive semesters, and I served as the teaching assistant/project leader, where I assisted a total of 32 students to conduct a complete inventory of the 1,971 trees on the Edinburg Campus. The data presented in Chapter III summarizes this experience in the context of service learning, reflecting student experience and the impact of the program.

## Urban Ecology

When a landscape is changed due to urbanization or other event, the processes within the ecosystem are changed. Ecosystem functions are added, removed, or altered. Ecosystem functions are defined as a natural process with the capacity to provide goods and services that can satisfy human needs, directly or indirectly(Sandhu and Wratten 2013). Simply put, any benefits people derive from functioning ecosystems, is considered an ecosystem service (hereby referred to as ES). With this view, it thus is logical to include humans in the functioning of ecosystems, contrary to many contemporary ecologists lens (see for example (Cowles 1899, Forbes 1925)). However, this thought process of humans imbedded in ecological systems is not novel.

Arthur Tansley (1935) wrote a seminal paper where he included humans as part of the complex interactions between organisms and their environment. The reasoning was simple: Humans, as organisms, have the ability to create, destroy, and alter landscapes, and with this reasoning, should be included in ecology, the study of organisms and their interactions with their environments. It is from this early work and a recent resurrection in the Tansley school of thought that the nascent field of urban ecology was founded

Urban ecology is the study of the distribution and abundance of organisms in and around cities, as well as the biogeochemical relationships within that scope (Pickett, Cadenasso et al. 2001). In more simple terms, urban ecology is the study of relationships and interactions amongst organisms that occur within and around cities and urban environments. One of the important relationships urban ecologists observe is the relations between natural (non-human) functions and people. In particular, urban ecologists often focus on how human activity in particular affects natural processes, and vice versa. In particular, recent research has demonstrated how natural processes or ecosystems can impact human activity, particularly focusing on the link between ecosystems functioning and the benefits derived from it (Barbier and Heal 2006, Costanza, Pérez-Maqueo et al. 2008, Engle 2011).

## What are Ecosystem Services?

Ecosystem services are simply defined as the benefits people obtain from ecosystems (Costanza and Folke 1997, Bolund and Hunhammar 1999, Assessment 2005, Sandhu and Wratten 2013). There are several types of ES, including (1) provisioning services, such as raw materials like lumber, food, and fibers (2) regulatory services such as rainwater retention, energy savings, and pollutant sequestration, (3) cultural services like aesthetic, service learning, and spiritual health, (4) supporting services like pollination, habitat, and biodiversity (De Groot, Wilson et al. 2002, Assessment 2005, Sandhu and Wratten 2013).In this study, we focused on the ES by trees in urban areas as with all trees, the most obvious ES is the benefit of conversion of carbon dioxide into oxygen through the process of photosynthesis. However, unlike trees in uninhabited areas, urban trees provide a different set of services, such as energy savings and stormwater mitigation, which often go unappreciated. Urban trees tend to be seen as a money sink, and their many services are often overlooked, yet nonetheless they still provide many benefits to the city and its people (Moro and Castro 2014).

Table 1.1: Classification of ecosystem services (Modified from (Wratten, Sandhu et al. 2013))

| *Ecosystem Services* | *Definition* | *Example* |
|---|---|---|
| ***Provisioning Services*** | | |
| 1 Food production | The portion of primary production that can be extractable as food | Agricultural production of fruits, vegetables, and nuts |
| ***Regulating*** | | |
| 2 Rainwater retention | Dampens the impact of heavy rains to help prevent local flooding | Soil surrounding trees acting like detention structures, storm protection |
| 3 Temperature regulation and energy savings | Regulation of local temperature through evapotranspiration cooling and shade | Tree shade cast on a building during key times of the day, saving energy on cooling |
| 4 Airborne pollutant sequestration | The removal of airborne particulates | Airborne pollution control, harmful pollutant regulation |
| 5 Carbon sequestration | Removal of carbon from the atmosphere, along with other greenhouse gases | Greenhouse gas regulation |
| ***Cultural*** | | |
| 6 Aesthetics | Beauty associated to landscapes, in the eye of the individual or the community | Landscaping, natural parks |
| 7 Spiritual and mental health | Source of spiritual value, beneficial for mental health | Green vegetation as the source of spiritual value |
| 8 Education/ Service learning | Source of education and training | Research and development with students and nature |
| ***Supporting*** | | |
| 9 Pollination | Movement of pollen from anthers to stigma | Bees, butterflies, or other vectors pollinating flowers |

| | | |
|---|---|---|
| 10 Habitat | Provides habitat to local wildlife | Trees as a source of housing to woodpeckers |
| 11 Biodiversity | The diversity of the local plant and wildlife | A tree supporting the life cycles of multiple different species |

## Ecosystem Services

**Provisioning services** are goods that can be taken directly from the natural function. This service represents services like agricultural production, clean water, lumber, and fiber. These services are important because they provide people all over the world with essential human needs, yet it is the poor in many nations that are impacted the most from ecosystem degradation, and the degradation can further exacerbate poverty in a vicious cycle (Mooney, Cropper et al. 2005). To meet the demand of the growing population, agriculture systems are primarily managed to optimize for provisioning services, like food, fiber, and fuel (Zhang, Ricketts et al. 2007).

Agriculture ecosystems cover nearly 40% of terrestrial systems, and are both providers and consumers of ES (Power 2010). As urbanization outpaces agriculture, these services are lost. Agricultural systems try to strike a balance between short-term and long-term benefits, which are catalyzed by human management to provide services like food production, pollination, pest control, genetic diversity, soil retention, soil fertility, and nutrient cycling. Food production, as seen in point one of table 1.1, is a service we can get directly from trees. The picking fruit from trees is straightforward and classic example of provisioning services.

**Regulating services** regulate essential ecological processes, as in the case of carbon sequestration. According to the Millennium Ecosystem Assessment, regulating services are amongst the least understood, yet potentially most valuable services (Assessment 2005, Simonit and Perrings 2011). Regulating services, points two though five in table 1.1, alter the reliability of provisioning services by enabling ecosystems to continue to provide over a range of stresses and shocks (Simonit and Perrings 2011). As seen in table 1.1, trees provide regulating services in the form of rainwater retention, energy savings by shade cast, pollutant sequestration, and carbon sequestration.

With urban trees, the canopy and surrounding soil can hold a large amount of water thus reducing flooding due to water interception by trees (Chen and Jim 2008). Trees function like retention/detention structures (Nowak and Dwyer 2007), ultimately slowing down the rate of runoff. As the amount of impervious surfaces increases with urbanization, it becomes increasingly difficult to mitigate storm water runoff and cost-effective options become limited (Barber, King et al. 2003). Due to urban areas consisting of mostly impermeable structures, rainwater tends to collect and cause flooding. When flooding can be attributed to inadequate city drainage, this can be a result of poor urbanization practices (Pelling 2003).

Another factor that tends to plague urban areas is the fact that they tend to be warmer than the surrounding countryside (Chen and Jim 2008). Urban trees cast shade and can shield from the wind, in which alters the neighboring heat islands which can directly reduce solar heat gain through windows, walls, and roofs (Akbari 2002). Trees also lower surrounding air temperatures through evapotranspiration cooling, which can in turn lead to cooler temperatures and less smog formation (McPherson, Nowak et al. 1997, Akbari 2002). According to Dwyer, McPherson et al. (1992), the annual space air-conditioning and heating cost for a home with efficiently placed trees can be 4% lower, while a home with conflicting placed trees can cost up to 9% more.

Airborne pollutants are also a consequence of urbanization, and the removal of airborne particulates is a health benefit that is of interest (Jim and Chen 2009). These airborne chemicals can be sequestered as well by trees, allowing people to avoid harmful pollutants, which can be seen in a study by Jim and Chen (2008), where the role of trees in urban green spaces is important to help mitigate the pollution issue. If urban forests can be promoted as means of mitigating pollution within the scope of urban sustainability, then they can be used to improve quality of life for people around the world (Escobedo, Kroeger et al. 2011).

The greenhouse effect is one of the most serious concerns of our time, with the rise of carbon dioxide as the leader of this concern (Chapin Iii, et al. 2000,Jo and McPherson 1995, Dewar and Cannell 1992). Trees are a mitigation tool that can be used to help sequester carbon from the atmosphere (Dewar and Cannell 1992, Nowak 1993, Jo and McPherson 1995, Bolund and Hunhammar 1999, McPherson, Simpson et al. 1999, Akbari 2002, Tratalos, Fuller et al. 2007). Trees sequester carbon from the atmosphere during their growing phase. Although trees are not the answer for reducing atmospheric carbon, they work as a short term carbon sink as they grow (Jo and McPherson 1995).

**Cultural services** are more abstract and provide a sense of well-being, spiritual fulfillment, historical integrity, recreation sites, and aesthetics (Sandhu and Wratten 2013). These services are more ambiguous to record, but nonetheless they are important to each community and person varyingly. This type of service is invaluable for urban planning. By knowing the cultural importance of urban green spaces, leaders can choose appropriate decisions and strategies in planning. Willing to pay surveys, do not give an exact number in reality, but they give an estimation of how people view services. In table 1.1, points six through eight highlight a few of the cultural services that can be found on the urban environment.

With their emerald hues, the urban forest creates a covered space where communities can hold events and spend their days in. As time goes by, the urban forest begins to hold meaning to the community. The meaning is different from person to person, and measuring this unique value is important and beneficial to the city. One method to learn this type of information is willingness to pay surveys. Willingness to pay surveys is useful for the city and state to know how the community sees the urban forest. Aesthetic and cultural values are obscure concepts that are difficult to place an importance on. This hedonic pricing method is an easy way to evaluate how the community views nature and how much they are willing to pay to improve their urban forest.

The beautification of everyday sites with greenery can aid in relaxing the community. Individuals who viewed urban scenes with vegetation were shown to have slower heart rates, lower blood pressure, and more relaxed brain wave patterns (Dwyer, Schroeder et al. 1991). In a study done by Maas, Verheij et al. (2006), the amount of urban greenspace had a significant relationship to perceived general health. It was also noticed that elderly, youth, and secondary educated people benefit the most. Personal exposure to nature in everyday life is a major determinant to ones sensitivity to environmental issues (Savard, Clergeau et al. 2000).

Another way trees can provide cultural services is by using them in conjunction with service learning projects. Service learning projects provide an opportunity for students to learn the relevance of certain subjects. By applying world application for different subjects, students can gain a deeper understanding. There are three main points when trying to create a service learning project: 1) create a clear course objective, 2) include a framework for planning assessment, 3) reflection (McDonald and Dominguez 2015). A great example of service learning projects revolving trees is with the University of Texas- Pan American Tree Campus USA project. Students were trained to inventory trees as they learned about the services trees provide to the campus. More on this study can be read in chapter three.

**Supporting services** are a range of services that support the other three types of services. This service is necessary for the production of all other ES (Jansson 2013). As seen in table 1.1 points nine through eleven, this type of service encompasses functions like pollination, habitat, and biodiversity.

Pollination services have become an issue as of late, with the dramatic decrease of honeybee colonies (Kearns, Inouye et al. 1998). Crop pollination is a vital service required in many agricultural systems, and with the alarming regional decline of honeybee populations other sources of this service have become increasingly important (Lonsdorf, Ricketts et al. 2011). Interests in native pollinators have been on the rise, yet due to drivers of change and pressures from agriculture intensification, habitat fragmentation, and land use change (Galic, Schmolke et al. 2012), have played a role in degrading suitable habitat that would sustain healthy populations.

The ability to provide habitat is crucial to many systems in an agricultural standpoint as well as in the eyes of conservation. In agriculture, providing proper habitat in the form of hedgerows, or in natural barriers can increase the amount of beneficial insects (Gliessman 2007), which can ultimately lead to a total decrease in insecticides. As for conservation, the ability to sustain endangered species is vital. Habitats that can provide for a large diversity of species is also important to homeowners and urban planners (Braaker, Ghazoul et al. 2014).

Cataloging these services is important to be able to keep track of services that are lost, gained, or altered in the midst of land change, as what tends to be the case with urbanization. Monitoring the change of services can be difficult at times, since often times the two services being compared are not the same. One method to rank services is by applying a monetary value the services. This act draws controversy at times, but as described by Costanza, d'Arge et al. (1998), choices on ES are made every day, and these choices imply a value. When applying a value to a service, the magnitude of the service can be seen even by the untrained eye. A universal language, money, can help to translate the importance of the services. In chapter two, the study will show a valuation method, as well as the valuation of the University of Texas-Pan American campus trees.

Table 1.2: Generated ecosystem services in unique areas (modified from (Breuste, Haase et al. 2013))

| **Services** | **Street trees** | **Lawns/ parks** | **Urban forests** | **Cultivated land** | **Wetland** | **Stream** | **Lake/ sea** |
|---|---|---|---|---|---|---|---|
| 1 Food Production | | | | x | | x | x |
| 2 Rainwater retention | x | x | x | x | x | | |
| 3 Temperature regulation and energy savings | x | | x | | x | x | x |
| 4 Airborne pollutant sequestration | x | x | x | x | x | | |
| 5 Carbon sequestration | x | x | x | x | x | | |
| 6 Aesthetics | x | x | x | x | x | x | x |
| 7 Spiritual and mental health | x | x | x | x | x | x | x |
| 8 Education/ Service learning | x | x | x | x | x | x | x |
| 9 Pollination | x | | x | x | | | |
| 10 Habitat | x | | x | x | x | x | x |
| 11 Biodiversity | x | | x | | x | x | x |

Different environments provide different services. As seen in table 1.2, different areas have different capacities to provide benefits. Some areas provide a wide array of services, while some are more limited in their scope of services. Some land types, from table 1.2, can be seen to support multiple services like urban forests that are properly supported in cities. In the case when converting a strong urban forest to lawn or park, some services are lost, in this case temperature regulation and energy savings, biodiversity, and habitat. Land use type is important to production of different types of ES.

In this thesis, I focus on regulating services; in particular two through five from table 1.1, and the mechanisms of these services are defined in table 1.3. The cumulative effect of these fours services is greatly impactful to the urban atmosphere (Nowak and Dwyer 2007). These services are crucial now, and will only become more vital as the issues of water shortages, energy, air quality, and greenhouse gases become more stressed.

Table 1.3: Regulating services focused in the study

| Ecosystem Service | Mechanism | Citations |
|---|---|---|
| Stormwater Retention | Trees slow the flow of stormwater from reaching the ground by intercepting and retaining water in the canopy as well as the surrounding soil. | Nowak and Dwyer 2007, Chen and Jim 2008 |
| Climate regulation/ energy savings | With proper placement, trees can block unwanted solar radiation during the summer and can act shield from cooling winds during winter. | Akbari 2002, Chen and Jim 2008 McPherson, Nowak et al. 1997 |
| Pollutant sequestration | Pollutants can be bound by the exterior leaf surfaces or can be taken up and sequestered into the tree through stomata. | Smith 2012, Nowak and Dwyer 2007 |
| Carbon Sequestration | Trees can sequester carbon from the atmosphere by directly storing carbon from $CO_2$ as they grow | Nowak and Dwyer 2007, Dewar and Cannell 1992 |

## Urbanization in the RGV: Potential Pitfalls and Possible Solutions

The Rio Grande Valley is host to about 500 avian species and 300 lepidopteran species (Stanford and Opler 1993, Best 2006). It is also home to the rare habitats, such as the Tamaulipan thornscrub and riverine vegetation in this area provides habitat, for both migratory and permanent residents, and to rare, charismatic fauna such as the ocelot. When lands gets converted through anthropogenic means (agriculture/urbanization, etc.), the remaining native land tends to be fragmented, as is the case for this area (see Figure 1.2).


Figure 1.2 Aerial image of the Rio Grande.

This image of the Rio Grande (yellow line) helps to visualize the impacts of habitat fragmentation. Three parks reside on the river, A) Bentsen State Park B) Anzalduas County Park C) Santa Ana Wildlife Refuge.

Habitat fragmentation is the process in which a large expanse of land is transformed into small patches with a smaller total area (Fahrig 2003). With the loss of total area, there is a loss of suitable habitat as well which in turn comes with many consequences, the most dire is the directional loss of biodiversity (MacArthur and Wilson 1967, Diamond 1969). This loss of biodiversity is a worldwide concern (Krauss, Bommarco et al. 2010), and especially in the Rio Grande Valley where eco-tourism plays an important role in the region’s economy. With increased urbanization and habitat fragmentation come another consequence, invasive species.

Invasive species out-compete native species and further alters ecosystems by negatively impacting other native species (Keane and Crawley 2002, Tallamy, Ballard et al. 2010, Szlavecz, Warren et al. 2011). In a local example, *Arundo donax*, a tall perennial reed-like grass, grows along waterways and has the ability to outcompete local riparian vegetation (Bell 1998). In addition to outcompeting the local vegetation, this invasive weed has been responsible for changing the landscape of riparian areas by changing the hydrology of different sites (Seawright, Rister et al. 2009). One hypothesis as to why invasive species are able to out-compete natives is the enemy release hypothesis. This enemy release hypothesis describes how on introduction to an exotic area, non-native abundance should increase due to the lack of regulation by predators or other natural enemies (Keane and Crawley 2002). This is a great concern on multiple levels, since insects, birds, and the community relies on our native systems.

It has been supported in multiple studies that landscaped dominated by non-native plants are not likely to be supported by the same diversity as native stands (Burghardt, Tallamy et al. 2009, Tallamy and Shropshire 2009). There have been many hypotheses as to why this happens. One theory is how insects and plants coevolved, it is estimated that about 90% of all herbivorous insect species can only reproduce on plant lineages they evolved alongside (Tallamy 2004, Burghardt, Tallamy et al. 2009). Insects develop many adaptations that aid in consuming and living on specific host plant lineages. In the case of lepidopterans, they can be used to monitor change in climate and plant diversity as their life cycles are directly dependent on them (Blair 1999). Thusly, with habitat fragmentation and the rise of invasive species, native species are decreasing further. This decrease will ultimately harm the local insect biodiversity. Avian diversity, similar to lepidopterans, will also be greatly altered by landscape change. Avian species share a similar response to habitat change, and can be considered as surrogates for monitoring conservation areas and climate change (Blair 1999). The diversity of both avian and lepidopteran species becomes particularly important here in the Rio Grande Valley, since their diversity is promoted to help enhance ecotourism tourism estimated to contribute US $463M to the Rio Grande Valley economy (Miller 2009).

Given the implications of a dwindling area of local, native vegetation, the importance and potential for the design and management of urban areas becomes increasingly evident. Urban areas can host a wide diversity of fauna (Bolund and Hunhammar 1999, Melles, Glenn et al. 2003, Zerbe, Maurer et al. 2003, Tommasi, Miro et al. 2004, Ehlers Smith, Ehlers Smith et al. 2015, Elmqvist, Setälä et al. 2015). For example, Italian cities have been shown to hold nearly 50% of all Italian avifauna species (Bolund and Hunhammar 1999). In a study by Loss, Ruiz et al. (2009), it was shown that there is a relationship between avian diversity and neighborhood age, income, and other environmental characteristics. A recent study by Racelis et al (2014) suggests that there native trees in urban south Texas landscaping harbor more insect biodiversity than exotic landscaping trees. Based on this general consensus, the impact that urban landscaping can have on local biodiversity and other ES can be significant. However, few studies actually document quantitatively the relative contribution of urban landscaping in terms of ES in south Texas, one of the most rapidly urbanizing areas in the country. This study helps document the regulating services that take place within a campus setting, focusing on the process to ascertain this valuable information.

Part of the lack of attention toward the maintenance of ES in urban areas can and should be addressed by universities, as institutions of higher learning and surveyors of scientific information. Universities such as Stanford University, University of Delaware, and University of Illinois have research groups that examine this intersection. At the University of Texas- Pan

American, the Racelis Lab in part examines the implications of ES in urban areas of the RGV, as evidenced by this project and other students work (Brush, Racelis et al. 2015, Escamilla, Goolsby et al. 2015). Universities themselves should be at the forefront of thinking about this, not only through research, but as an example to other local institutions. The outcome from this work (See Appendix AI) is that UTPA has received the designation of Tree Campus USA® from the Arbor Day Foundation ®.

In all, there are important implications of how cities and urban areas can be developed to conserve or enhance ES that are important and relevant to the area, especially the RGV. The focus of this work is to develop and elucidate the important role that trees can play in urban environments, and to list the relative contributions of the different trees common to south Texas landscaping. Through this research, I make recommendations for the most important trees on a manicured university landscape in terms of the regulating ecosystems services such as pollutants sequestration (including carbon dioxide and other greenhouse gases), stormwater retention, and energy savings through shade (Chapter II). I also discuss certain cultural services of these urban trees through a service learning project discussed in detail in Chapter III. Finally, in Chapter IV, I talk about the overall implications of these results in the context of urban planning in south Texas, in particular the unique methodology used to learn how the local environment services us, the community.

CHAPTER II

# ESTIMATION OF ECOSYSTEM SERVICES OF TREES ON THE EDINBURG CAMPUS OF UNIVERSITY OF TEXAS RIO GRANDE VALLEY

## Abstract

The tree population within the University of Texas- Rio Grande Valley located in Edinburg, Texas, was inventoried and assessed to explore various ecosystem services these trees provide in the context of a university campus. A total of 1,971 trees were counted and measured for dimensional attributes (height, diameter at breast height, canopy volume), and inputted into i-Tree Eco to calculate regulating ecosystem services including runoff avoidance, energy savings, air pollution removal, and carbon sequestration. The relative contribution of ecosystem services for the 53 tree species found on campus varied greatly. Medium to large trees were shown to provide the greatest amount of services for runoff avoidance, air pollution removal, and carbon sequestration, while small ornamental trees had a larger ranking for energy savings on buildings, likely due to their proximity to buildings. The compensatory value of all the trees on the campus was valued at $5,734,729. An improved understanding of the relative contributions of ecosystem services by a diversity of trees on a university campus can help maximize benefits of trees as assets and make urban landscaping more efficient.

## Introduction

With a steady increase of the world's population now residing in cities, there is greater need to understand how the complex interactions between the natural environment and humans affect ecosystem services on multiple levels, especially for those that are particularly important in the functioning and resilience of urban areas.   Ecosystem services, or the goods or benefits derived from nature, provide mankind with most necessities of life and survival (Brown, Bergstrp et al. 2007, Wratten, Sandhu et al. 2013), and are often divided into separate categories : supporting services (such as water and nutrient cycling), provisioning services (i.e., production of food, fuel, and timber), regulating services (such as rainwater retention, carbon sequestration), and cultural services (aesthetic and spiritual values) (Sandhu and Wratten 2013). The proliferation of urbanized environments inescapably  involves an extensive modification of the landscape (McDonnell and Pickett 1990), alteration of native habitat, and a  manipulation of species assemblages, community composition,  and structure (Savard, Clergeau et al. 2000, McKinney 2002, Krauss, Bommarco et al. 2010), all of which notably disrupt or modify ecosystem services that  are particularly important to urban areas.

There is no greater example of this process than in Hidalgo county of Lower Rio Grande Valley.  With an average of 39% population growth per decade over the last twenty years, this area is considered the fasting urbanizing area in the United States (US Census, 2010.  When combined, agriculture and urban development count for 94% land use in this area (Jahrsdoerfer and Leslie Jr 1988), with, urbanization rapidly outpacing agriculture as the most significant land use (Huang, Fipps et al. 2011). As such, understanding the potential role urban vegetation has in this developed landscape of south Texas is paramount specifically with regulating ecosystem services that are often limiting in these areas: rainwater retention (runoff avoidance), energy conservation  through avoided energy consumption ( cooling through shade), pollutant sequestration including carbon sequestration (Costanza, d'Arge et al. 1998). These services are of specific importance since many city and county governments in urbanized environments often have policies and incentives to deal with these factors (Bolund and Hunhammar 1999).

As of recent events, in May of 2015, flooding events in metropolitan areas in Texas were on the rise. In the Houston area alone, the preliminary damage was estimated to be at least $45 million (Press 2015). Some areas in Houston have a canopy cover ranging from between .8% to 24.% (Rose, Akbari et al. 2003). In 2014, the Hidalgo County Drainage District No. 1, received nearly US$6M from the Texas Water Development Board to help improve the districts drainage system (found in www.twdb.texas.gov). When flooding can be attributed to inadequate city drainage, this can be a result of poor urbanization practices (Pelling 2003).  Urban trees are consistently seen as one tool to mitigate these concerns (Bolund and Hunhammar 1999, McPherson, Simpson et al. 1999, McPherson, Simpson et al. 2005, Jonnes 2011), and although there is an inherent difference in the contribution of different tree species, not much is known about the relative contribution of specific trees in terms of different ecosystem services (Laganière, Pare et al. 2010).  Detailed understanding of the relative contribution by tree species may help guide land managers to more effectively invest resources and effort.  As such, in this project we detail the contributions of different tree species common to a university campus located in south Texas, and discuss these trees in terms of the compatibility of the ecosystem services they provide and the outlook of campus management.

# Methods

## Survey Area

The University of Texas- Rio Grande Valley is located in Edinburg Texas (26.303°, -98.174°), one of four main cities that comprise Hidalgo County   The university acreage accounts for 0.7% of the city of Edinburg.  According to Jahrsdoerfer and Leslie (1988) the pre-exisitng native vegetation, in this area included *Prosopis glandulosa Torr*. (honey mesquite) and *Celtis pallida Torr*. (granjeno) mixed with *Ebenopsis ebano Berl.* (Texas ebony), *Ehretia anacua (Teran & Berl.) I.M. Johnst.* (anacua), and *Condalia hookeri M.C. Johnst.* (brasil), in a vegetation community known as mesquital-chaparral or mid-delta thorn forest (Jahrsdoerfer and Leslie Jr 1988, Brush 2005). As of 2011, the university study site consists of 53% impervious surface, 11% canopy cover, and 36 other (including grass lawns) (Cantu and Brush, unpublished).

## Survey Methods: Tree Inventory and Mapping

The campus was divided into several zones to facilitate a complete inventory of all trees. To be considered for this study, trees had to meet two main criteria: (A) total tree height greater than 4.57m and (B) diameter at breast height (DBH) greater than 2.54cm (consistent with standards from (Nowak, Hoehn et al. 2013)). Upon meeting these criteria, the following parameters were recorded: (1) total tree height (m)(ground to the highest point of the tree); (2) Living tree height (ground to the highest living point of the tree); (3) Crown height (ground to the start of the crown; (4) Crown area; (5) Percent Crown missing, (6) Diameter at breast height, (7) Percent dieback, and (8) Crown light exposure (for more information on the methodology of each parameter, see Nowak, Hoehn et al. (2013). This dimensional data, as well as a georeferenced position (GPS) was recorded for each tree into a Juno Handheld GPS unit (Westminster, CO).

## Ecosystem Services Estimation

To calculate the relative contribution of key ecosystem services for each tree, dimensional data and GPS point was entered into i-Tree Eco (v5.1.7, Kent, OH) available by the USDA Forest Service (www.itreetools.org). This model, formerly the UFORE model, has been used to analyze urban forest structures and functions from across the world (Nowak, Crane et al. 2008, Nowak, Hoehn et al. 2013). This program uses local meteorological data, air pollution data, and the dimensional data from the complete tree inventory to estimate the ecosystem services gathered per tree. Once the services are estimated in relative units, the model then estimates a value of the services using default benefit prices. The compensatory values were modeled from methods of the Council of Tree and Landscape Appraisers (Nowak, Hoehn et al. 2013).

## Relative Rankings

The fifteen most abundant species were used for relative rankings. Only the top fifteen were chosen due to a lack of abundance in the other species. The averages of each of the four key regulating services (avoided runoff, electricity savings, pollution sequestration, and carbon sequestration) were taken on a per tree basis and then compared and ranked against each other species. The rankings used fifteen as the largest average and strongest rank and one as the lowest average.

## Results

Over a total of 157 acres at UTRGV in Edinburg, a total of 1971 trees were tagged and recorded, including 53 different species (see appendix AVII) , Almost 39% of all trees (n=767) were live oaks (*Quercus virginiana)*, by far the most dominate species in the area. The Mexican fan palm *(Washingtonia robusta)*, made up 13.09% (n=258). The total species distributions of campus trees are presented in figure 2.1.

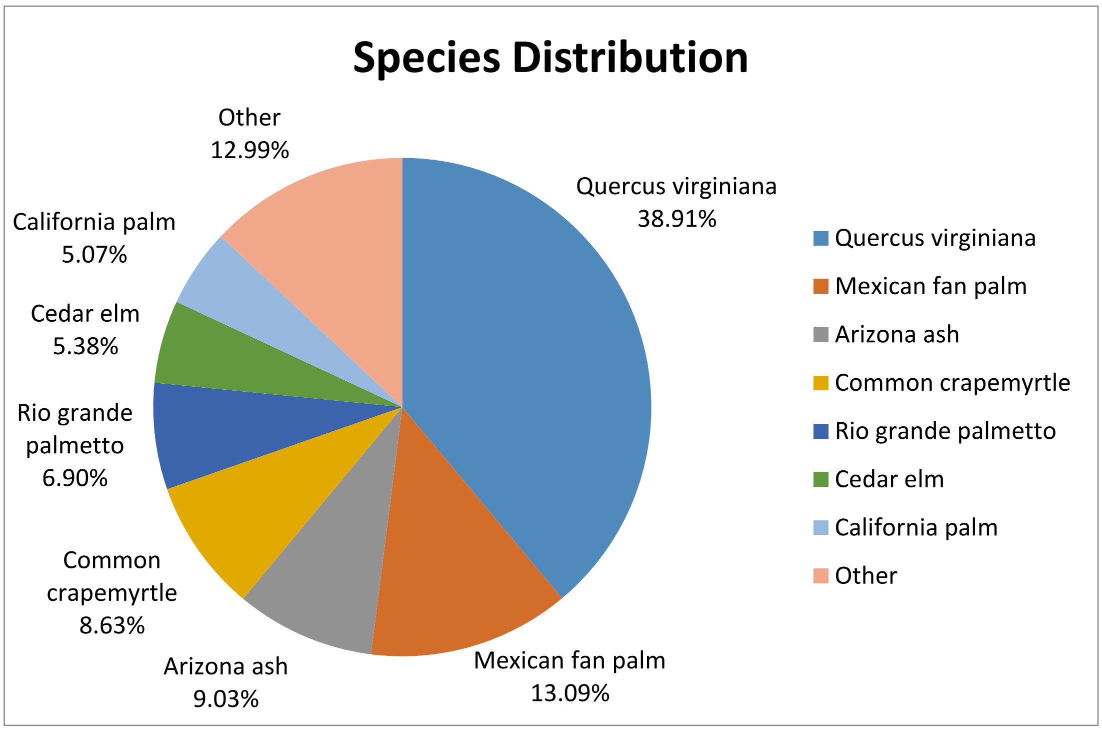


Figure 2.1: The species distribution on the University of Texas- Pan American

### Ecosystem Services

The avoided rainfall data from i-Tree eco can be seen in appendix AVIII. Each year the campus avoids 748.95$m^3$ of runoff, which is valued at $1,761.10. Appendix AX contains the carbon sequestration data. Total and gross carbon sequestration is shown, which was estimated by the model using allometric equations that use both DBH and tree height (Nowak, Hoehn et al.

2013). The replacement value for all the trees on campus is $5.734, 729. The sequestration of airborne pollutants and their removal values are shown in appendix AXI for CO, $O_3$, $NO_2$, PM10, $SO_2$, and PM2.5. PM10 consists of particulate matter that is less than ten microns and greater than 2.5 microns, and likewise, PM2.5 consists of particulate matter fewer than 2.5 microns. The relative rankings can be seen in figure one. The relative rankings are only comparable against other UTPA campus species and should not be ranked against different species from this study.

## Discussion

Live oaks are abundant in this region, and are commonly seen in both housing and business areas (Kroeze and Racelis 2010) . Just as in the city, *Quercus virginiana*, make up a large population of the campus. This species makes up nearly 40% of the species on campus. This high abundance leaves the campus forest at risk from disease or pests, like the infamous oak wilt caused by the fungus *Ceratocystis fagacearum*.

With the data on avoided runoff, as expected, the larger trees species helped avoid more rainwater runoff, since with their larger surface area there is more opportunity to capture and hold rainwater. On average, the *Ficus religiosa* retained the most water with a rate of 2.865 $m^3$/year. The top 16 trees in rainwater retention consist of our larger tree species, The species that are on the lower end of the list tend to be larger shrub or ornamental species that barely met the parameters of the inventory.

Electricity savings was biased towards small ornamental species, which tended to be planted more frequently by buildings. This may be the service the smaller ornamental species can excel at, since planting large trees near buildings could be seen/can be seen as posing structural danger and can be problematic for maintenance. Another factor may be due to the positioning of trees on the UTPA campus. Simply, some trees species may not have been planted near buildings, thus not getting a fair representation on the list. In the case of the Texas ebony, which could potentially offer substantial shading services, the hard seed pods they drop and the resulting “messiness” may discourage its use by landscapers. The Washingtonia palms are relatively low due to the area of the shade cast being a fraction of other trees. The only high ranking palm was the Rio Grande palmetto since it provides a large, dense shade cover due the habit of its growth.

Similar to a study by Cox (2012) larger trees were found to sequester carbon at a higher rate than smaller trees. Smaller trees tend to only sequester a fraction of carbon than larger species. With the exception of *Beaucarnea recurvate,* Ponytail palm, all other palms along with shorter tree species were on the lower end of the average annual carbon sequestration. As for the Ponytail palm, per tree, it sequesters the most with 106.65 kg/ year, with the next closes being *Celtis laevigata,* Sugarberry, with 71 kg/year, and the Texas ebony averages 43.8kg/year of carbon sequestered

. For pollution sequestration, the live oak was the closest to the Texas ebony. The Texas ebony sequestered 824.57g while the Live oak sequestered 814.505g. It is a common result where the medium to large trees are be able to outrank the rest due to their sheer size and volume allowing for higher rates of sequestration (Cox 2012). This trend can also be seen in the average pollution sequestration rankings, since the top trees seemed to be the trees that are medium to large in size. These large tree species ranked the highest in each field except for electricity savings. The top species for electricity savings is a juniper spp., but the results may be inaccurate since we could not identify the juniper down to the species level.

When looking at the compensatory values, if the campus loses all the trees in a disaster, it would cost $5,734,729. Live oaks alone, most abundant species on the campus, amounted to $3,072,772 in replacement value accounting for more than (54%) of the total value of the tree. When comparing live oaks compensatory value to the Mexican fan palm, the second most abundant species, the palm only measures up by a fraction, at $311,692. This is only 5.44% of the overall compensatory value although the palm itself makes up 13% of the population. This value may be due to the difference in measuring compensatory values of woody trees and palm trees. Future projects may benefit more by valuing palm trees using a different algorithm. Overall this compensatory information is useful for businesses and campuses since it provides an accurate estimation on the value of the trees. This can in turn be used in the event where trees are lost or damaged, i.e. a natural disaster, this compensatory data can be used to know what was lost and how much needs to compensated.

When looking at each of the services in figure one, it is important to note that the top ranked species are mainly large tree species. The top five reoccurring tree species are Live oak, Arizona ash, Cedar elm, Burr oak, and Texas ebony. When looking at average avoided rainfall per species, the Texas ebony avoids $.916m^3$/year whiles the closest competitor being Arizona ash at $.736m^3$/year. There were closer competitors, but since they did not number ten or more in abundance, they were not used for the rankings. This is because we felt that few than ten species would not provide an accurate estimation to compare. Although this type of ranking information should only be used for the campus ecosystem, it is still a great asset for the campus. By knowing what a tree can do, the utilities department can make more efficient choices in choosing the right species for the right spot.

The Mexican fan palm scored low in all the services except energy savings, yet this palm is the second most abundant species on the campus.  Although, they are relatively low in the rankings, they may provide other services that have not been collected in this study, one being aesthetics. Aesthetics is an abstract service that is difficult to valuate, and valuating this service is a new project in itself. The Mexican fan palm offer little in services collected in this study, however these palms were not chosen for their shade, or their sequestration properties. The majorities of these palms surround the campus and are lined parallel to the roads. These trees were chosen for a different service, be it the way they look or their easy to maintain properties by the road, when compared to the landscape inside the campus that largely consists of large trees than can provide shade for students.

Trees provide a different quality of services when compared to each other, and finding the right tree for the right service is what is needed to improve our understanding of the quality of services each tree provides. Efficiency in planting should be included in proper urban management practices. The knowledge of the strengths and weaknesses of local and common plant species is invaluable to urban planners. By being able to plant specifically, they can get a greater result for the service they want. Planting a tree is always better than planting no tree, but when landowners know they services they want to get, they should have the resources available to find the right tree for the right spot.

# CHAPTER III

# TREE CAMPUS USA AS A SERVICE LEARNING OPPORTUNITY

## Introduction

The University of Texas- Pan American campus in Edinburg is currently planning to apply for Tree Campus USA® designation created by the Arbor Day Foundation®. The goal of this program is to help universities to establish and sustain healthy community forests (www.arborday.org). To become a Tree Campus College, five standards must be reached. These five standards are: 1) create a tree advisory committee, 2) create a tree care plan, 3) create a tree program with a dedicated annual expenditure, 4) Arbor day observance, and 5) create a service learning project. This project will be to complete both standard two and five. For standard two, the creation of a tree care plan, it was decided that a tree inventory of the campus was needed, since it is nigh impossible to create a strong plan without knowing what trees the campus had. It was soon after decided that the inventory portion of the project will be lead and completed using student volunteers, with the help of faculty, city foresters, and state foresters. The students would be taught about ES while they complete a service learning project for the campus, in fulfillment of standard five. The goal of this project is to teach students the importance of trees and to learn about the services they provide all while completing a well needed tree inventory on campus.

## The Impact of Service Learning

Teaching methods are a constantly improving to ultimately reach the moving target of students' interest and learning patterns. One unique method that will be the focus on this study is service-learning. Service learning is a mixture of both experiential learning and community service, which results with the students gaining hands-on experience and learning (B. Long 2001). This method is impactful to both community and students, since not only are the students completing a community service project for the community, they will also be gaining real world application for their experience (Markus, Howard et al. 1993, Morgan and Streb 2001).

As part of my thesis project, Dr. Alex Racelis and I designed and implemented a series of courses designed as an experiential learning course to train students (1) how to identify and measure trees as part of a tree inventory; (2) to introduce them to the concepts of ES and how trees contribute to overall ES on the university campus and in the Edinburg community at large; and (3) to connect their learning to a product (tree management plan) as part of a service learning project. This direct approach is a contrast to the more traditional teaching approach, the information-assimilation model (Kolenko, Porter et al. 1996). As attractive as this method is, there are some cautions that must be recognized. Distinctions need to be made between the community service and service learning (McDonald and Dominguez 2015). If these distinctions are overlooked, students may not differentiate between the work and learning, turning to working without learning (Kolenko, Porter et al. 1996). Thusly, in our classes, we tried to enforce the service learning model by presenting clear learning outcomes, including the ability to identify the most prevalent trees on campus, the skills to use different technical forestry equipment, and the ability to work in teams, an important skill that is needed when joining the workforce (Kuh 2009).

When using this type of approach, learning becomes multi-dimensional. Students tend to become more interested, and their studies become reinforced through and experiential, hands-on approach (Paris, Yambor et al. 1998). Service learning also expands passed basic objectives, students can enhance skills like critical thinking, problem solving, and communications skills (Bringle and Hatcher 1996). Even after the project is finished, students can feel a sense of accomplishment for their work, and can bring about personal wellness and good work habits.

In this study, we will be looking at an interdisciplinary service project that involves students, staff, and the city. The proposed project involves student volunteers helping faculty in a campus wide tree inventory. As the students complete the campus wide tree inventory, they will learn about the benefits and services of trees.

Trees provide a multitude of services, and these services can range from all types. When a natural function provides a service to the population, we label this as an ecosystem service. These services fall under four types, provisioning, regulating, cultural, and supporting (Sandhu and Wratten 2013). The fruits trees provide are a direct service taken from fruit trees. The casting of shade and the sequestration of carbon is a regulating service. There is even a cultural service in trees when they give a peace of mind to the community (Kuo 2003). Even the act of being habitat for multiple insect and bird species is considered a supporting service. Trees provide a great deal to people and by experiencing the services first hand, we can learn more about the roles they fill in urban landscapes.

## Methods

The campus was divided into two zones which were delineated by the covered walkway on campus commonly called the Bronc Trail. Each semester, for this interdisciplinary study, students from different academic disciplines volunteered to participate in the campus tree inventory. The first week of class consisted of introductory material to the students for why they were gathered. This included information about Tree Campus USA® and why we wanted to aspire for this designation, and lastly it ended on the importance of trees. The students were taught about how trees provide a multitude of services for people, and importance of providing care for trees. For the next few weeks after, city and state foresters trained the student volunteers. The students first learned to properly use basic forestry equipment like diameter at breast height tapes, telescoping poles, metal tree tags, hammers, nails, clinometers, and measuring tapes. The students were also trained to use Juno 3B® handheld units, using a simple how to sheet, as seen in Appendix AII, that were given to each of them. After learning to use this equipment, the city and state foresters taught the students to observe and evaluate tree health. The students learned to predict by when the tree needed maintenance, what type of maintenance the trees needed, bark health, leaf health, and any priority tasks that needed to be known (i.e. building obstruction and sidewalk lifting). The students were also given the task of learning local trees that were likely to be seen on campus, by using a simple guide created by the agroecology lab on campus. This guide, Appendix AIII, and AIV, were used to identify the trees on campus. If the tree species was not on the list, they tree was labeled unknown and then left to the faculty and foresters to identify.

Once trained, the students were divided into groups of three or four for efficiency. A normal tree inventory session for a group consisted of one student standing near the tree gathering gps points and inputting in data into the TerraSync® application. One student would use either the telescoping pole or clinometer, if the tree was perceived to be taller than 15 meters. Another student would nail in a tree tag, then start gathering diameter at breast height, and once completed would transition to be a spotter for the student using the telescoping pole. Once tree height was ascertained using the appropriate gear, the students then measured crown length and width using measuring tapes. Once all the data was gathered into the handheld unit, the students moved on to the next tree. This course was held once a week for four hours, and lasted throughout the semester. At the end of the semester, the students were asked to write a short essay on their views of the course, and any improvements that could be made.

## Results

After three semesters, two long and one summer session, the students completed the 1,971 tree inventory that spanned 157 acres. The data gathered is planned to go to the hands of the facilities management department at the University of Texas- Pan American. Using the gathered data, a complete tree management plan (APPENDIX AV) was designed. This management along with the service learning project helped the University of Texas- Pan American campus fully reach the Tree Campus USA designation (APPENDIX AI).

The students completed the inventory within the time it was estimated to finish. Throughout the course a total of 32 students from various disciplines were credited hours from this course. Some students valued the class greatly and retook multiple times. One student even took the course all three semesters, and described the reasoning as in the pride of seeing this project from start to finish.

We focused on looking at what the students had gained throughout this experience. Looking at figure 3.1, the students' experience throughout the semester is mapped. The students were first trained by foresters, and then were taught about trees and the services they provided. Once taught, the students were able to see some of the services first hand as they completed the tree inventory. As they cooled off and drank water under the shade (regulatory) or picked off a loquat or two as they continued on (provisioning), they were able to see how useful trees could be. Each student wrote a brief report on what they had learned and their outlook on the class. The reports were turned in during the last few weeks of the course and were reviewed for improvements and the student's outlook on the service learning project.

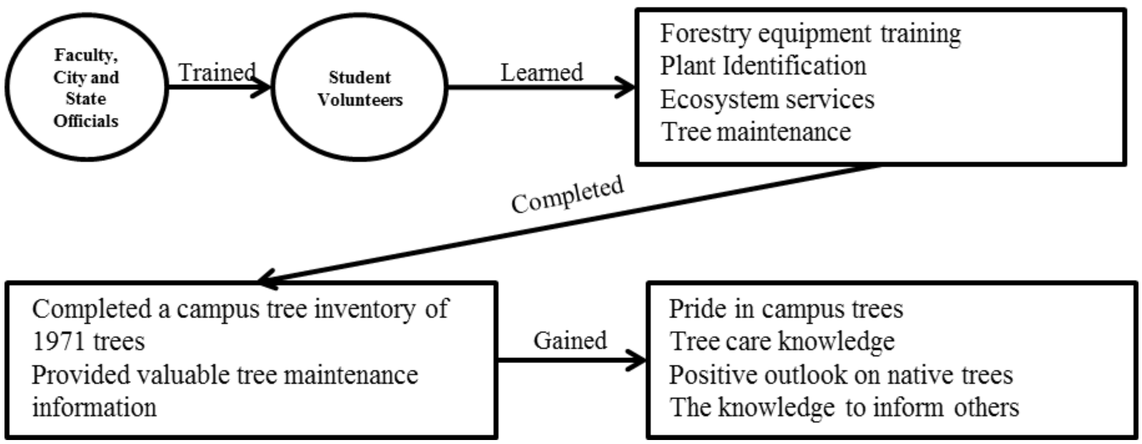


Figure 3.1: A conceptual model of the UTPA service learning project

## Discussion

One of the first observations made was the paradigm shift students had on their outlook on trees. Students were in awe when they first learned about ES, and could not believe a tree can be valued at thousands of dollars. After the initial training, students would start showing greater interest in trees and their health by asking about a trees condition in different scenarios, and what would our recommendation be. Once the students got a handling on estimating tree health, they would start to judge trees they see on their rides home. Many a topics during a typical work day would be discussing tree identification in the cities as well as discussing poor pruning management seen done on other trees.

The student's involvement went above and beyond what we had expected. Students volunteered for this class knowing they will be out in the field once a week for four hours. While they did get course credit, what seems to be a reoccurring trait was the pride they gained in caring for trees. Students were often seen discussing different tree species they have seen in the city, along with critiquing the trees health and improvements the owners can do. The ability to work effectively in groups, one of the most important student attributes according to the National Association for Colleges and Employers, is also enhanced in this project since simple tasks such as measuring tree height requires effective communication between two or three participants.

Another great outcome for the university came when the students came across a row of unhealthy ash trees (*Fraxinus berlandieriana*) on campus. The row of trees showed a noticeable gradient of health, with the center tree being dead, the next trees in proximity were in poor health and as the distance from the dead tree increased, so did the trees health. With recommendation from the city forester, samples from the dead tree were sent to the plant clinic at Texas A&M University for a diagnostic report. It was then learned that the cause of death was from Bacterial Leaf Scorch from *Xylella fastidiosa* (APPENDIX AVI). This information was given to the campus so that damage from this disease can be mitigated and minimalized.

Near the end of the semester, each student was tasked with a short essay commenting on what they have learned or improvements for future years. One quote from a student that took the course for two semesters resonates well with what we wanted to accomplish in this service learning project. As stated by a student "I have shown him (son) some of the trees that myself and my group has surveyed. I have introduced him to the things I have learned through this course and helped him learn things that he would not have experienced anywhere else. That alone is the best outcome I could ever receive through participation in Tree Campus USA."

CHAPTER IV

CONCLUSION

During 2014-2015, the University of Texas Pan - American completed an intensive tree inventory project with the goal to complete standards two and five for the Tree Campus USA designation. Other than the completion of the tree inventory, the valuation of the ES provided by campus trees and the assessment of the service learning project with the campus students were the main objectives for this project.

## Main Goal: Tree Inventory

The goal of this tree inventory was to reach the designation of Tree Campus USA®. This designation (APPENDIX AI) was an intense and amazing experience between every party involved. The tree inventory, not only allows us to receive this designation, but also plays an important role of inventorying the campus trees and their health.

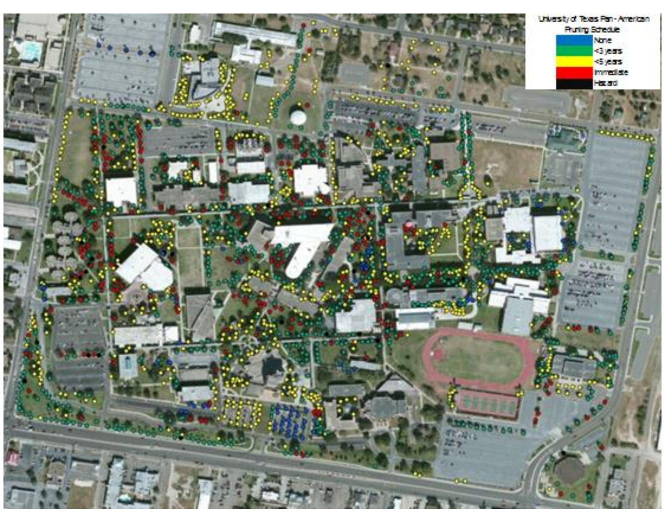


Figure 4.1: Pruning schedule for campus trees

Blue is no foreseeable maintenance, green, is maintenance after 3 years, yellow is maintenance in five years, red is immediate maintenance, and black represents hazard trees.

In figure 4.1, using the data provided from the tree inventory, a pruning schedule was created. The schedule provides the maintenance department with ample knowledge in priority cases and allows for a five year pruning schedule. By using preventative measures guided by the inventory, priority cases can be fixed or removed, allowing for the mitigation of on campus hazards. This can in turn save money from on campus injuries and tree removals due to ill health from lack of pruning.

Tree health is another factor that is gained through the tree inventory. When examining the overall health of the campus trees (Appendix AVII), the tree conditions are either good or excellent. However, 24.9% of trees are fair to dead categories. This is the equivalent of randomly picking one tree out of four and finding a poor to dead tree. Approximately 40% of campus trees are one species, *Quercus virginiana*. This leaves the campus trees with a high risk of infections by forest pests or diseases. Any uncontrolled pest or disease would be able to devastate the campus forest. With the goal of safety and aesthetics on mind, these risks may be too high. This information is essential to properly show upper management the state of their trees. From this point, the next steps can be more accurately created. Tree inventories have several reasons on why to be conducted, from creating a tree management plan, to learning about the services and benefits the trees provide (Wood 1999).

## Objective 1: Ecosystem Services

The four regulating services covered in chapter II are vital to the urban setting. The data gathered from i-Tree Eco, see Appendix AVIII through AXI, provides valuable information in the form of quantitative estimates for the ES provided on campus. Table 4.1 shows the estimations of each of the regulating services for the 15 most abundant species on campus. This is the type of information that is valuable to supporting the planting of more trees. With information on the services values, it provides the abstract services an accurate value, which in turn can help in influencing management decisions.

The total benefits of the ES of campus trees can be seen in figure 4.2. This figure helps to apply the values in relatable terms. For rainwater retention, about 198,000 gallons was avoided on campus, equivalent to six inches of water across an entire acre. With cooling by shade cast, enough power was avoided to power an average size home for 28 months. Enough CO2 was sequestered to remove 120 cars off the road, and every year another 7.5 cars are removed (estimations gathered from epa.gov). One of the essential values of data to business owners and campuses is the structural tree value. This value represents the amount lost in the event of a disaster where all trees are lost. On campus, if a hurricane event occurs, and all the trees are damaged or lost, the campus can give insurance companies and accurate estimation of the values lost. This accurate estimation is increasingly important to areas that are bombarded with natural events.

Table 4.1: Regulating services from the top 15 abundant species

| Species | Number of Trees | | Avoided Rainfall | | Energy Savings | | Pollutant Sequestration[2] | | Carbon Sequestration | |
|---|---|---|---|---|---|---|---|---|---|---|
| | % | Total | $m^3$/year | $/year | kWh/year | $/year | g/year | $/year | kg/year | Compensatory Values ($) |
| *Quercus virginiana* | 38.91 | 767 | 380 | 893 | 7750 | 1,410 | 614,796 | 2,110 | 22704 | 3,072,772 |
| *Washingtonia robusta* | 13.09 | 258 | 28 | 65 | 3808 | 624 | 33,890 | 120 | 221 | 311,692 |
| *Fraxinus berlandieriana* | 9.03 | 178 | 131 | 308 | 424 | 49 | 115,223 | 587 | 5666 | 1,080,612 |
| *Lagerstroemia indica* | 8.63 | 170 | 33 | 77 | 2707 | 287 | 28,043 | 137 | 1645 | 160,370 |
| *Sabal palmetto* | 6.9 | 136 | 31 | 72 | 3506 | 407 | 39,062 | 131 | 53 | 190,641 |
| *Ulmus crassifolia* | 5.38 | 106 | 43 | 101 | 1157 | 129 | 34,532 | 171 | 1119 | 152,285 |
| *Washingtonia fillifera* | 5.07 | 100 | 17 | 41 | 2439 | 301 | 21,085 | 74 | 52 | 88,101 |
| *juniper spp* | 1.57 | 31 | 6 | 14 | 1097 | 160 | 10,869 | 30 | 167 | 35,107 |
| *Cordia boissieri* | 1.52 | 30 | 6 | 15 | 616 | 63 | 5,675 | 28 | 289 | 29,007 |
| *Quercus macrocarpa* | 0.86 | 17 | 6 | 13 | 87 | 10 | 5,972 | 28 | 365 | 50,029 |
| *Quercus rubra* | 0.81 | 16 | 2 | 5 | 71 | 11 | 2,093 | 10 | 142 | 15,284 |
| *Vitex agnus-castus* | 0.71 | 14 | 3 | 6 | n/a[1] | n/a[1] | 3,020 | 12 | 165 | 17,697 |
| *Pistache chinensis* | 0.51 | 10 | 3 | 6 | 37 | 5 | 2,292 | 11 | 124 | 13,048 |
| *Sophora secundiflora* | 0.51 | 10 | 1 | 2 | 24 | 2 | 1,003 | 4 | 97 | 9,316 |
| *Ebonopsis ebano* | 0.51 | 10 | 9 | 22 | 35 | 13 | 8,026 | 40 | 438 | 62,069 |

[1] *No specimens were close enough to buildings to receive a value*

[2] *Pollutants included are CO, $O_3$, $NO_2$, PM10, and $SO_2$*

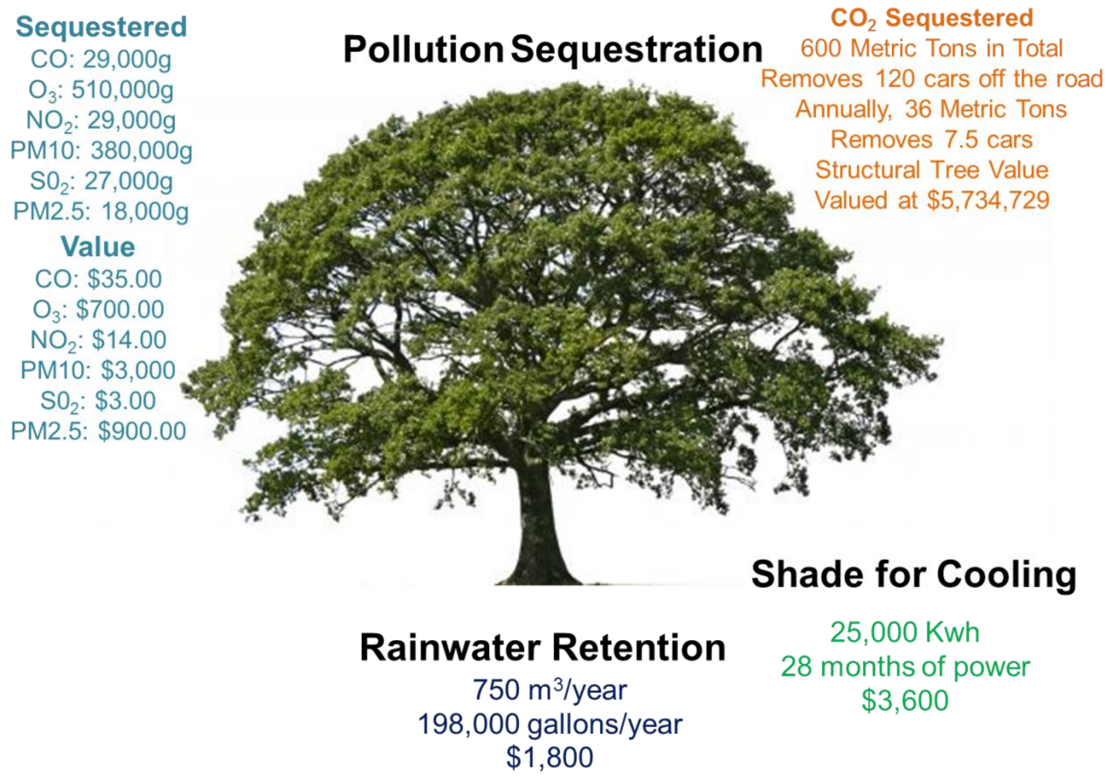


Figure 4.2: The ecosystem services provided by all 1,971 campus trees

With the information learned from trees and their capacity to provide different services, more accurate estimations on what to plant can be made. When planting, by asking the question, "What do I want to get from this tree?" one can look to find an appropriate tree for the role. In table 4.2, future impacts are projected, and what types of trees are recommended to plant, as well as local species recommendations. The recommendation of local species is to only be applied for Lower Rio Grande Valley, since any other areas may have more suitable trees that can fill the role. In general, a tree often adds more ES that no tree at all, but for efficient allocation of resources (especially for cities or university campuses), informed tree planting and management requires basic understanding of the relative contribution of ES for different trees.

Table 4.2: Projected impacts of extreme climatic events. (Modified from Wratten et al. 2008)

| Climate phenomena and their likelihood | Projected impacts on urban systems | Recommendations |
|---|---|---|
| Increase in temperature, raised average temperature, and heat waves *Very likely to certain to occur* | Changes in species composition Increased energy consumption (for cooling) Health concerns due to heat and respiratory stresses | For planting against greenhouse gases: Plant large trees due to their ability to sequester more airborne pollutants For cooling: Trees with large canopies and a larger total leaf area Local recommendations: Texas ebony, Cedar elm, and Arizona ash |
| Increased precipitation events *Very likely* | Changes in species composition Disruption of settlements, commerce, and transportation due to flooding events | Planting against flooding: Large trees or trees with high leaf area Local recommendations: Montezuma cypress, Texas ebony, Honey mesquite |
| Increase frequency and duration of droughts | Water shortages, water becomes more valuable | Planting against droughts: Plant smaller native trees and/or drought tolerant species |
| *Likely* | Loss of drought intolerant species | Local recommendations: Wild olive, Honey mesquite, Brazilian bluewood |

## Objective 2: Service Learning

Building strong bonds between the community and nature is a relationship that is commonly ignored, yet this bond is fundamental to conservation (Moro and Castro 2014). This service learning project was an attempt to unite students, faculty, and the city officials under one goal, Tree Campus USA®. The students showed dedication and pride in their work, and this was seen as the semesters continued. The seed of curiosity was placed with each student, and they are tasked to continue learning and teaching about their community greenspaces. Many of the students gained a new viewpoint. They started seeing different trees in their communities and would constantly ask questions on what species they were. Another commonly discussed topic was their new lens for tree management and health. The students learned to judge tree prunings and commonly voiced their concerns on improperly managed trees they see on their rides home, and has dubbed this new realization the "curse of tree campus." This was not so much a curse, but a paradigm shift or an epiphany. They learned to see the diversity of trees that surround their lives, and now they can instill that knowledge unto others. That should be the outcome that is attempted to reach when undergoing a service learning project.

Although the valuation data gained through this study is useful in the management of trees as assets, the unique methodology of turning a tree inventory into a service learning project cannot be undervalued, and is arguably the most important outcome of this work. With this approach came a trifecta of positive outcomes: The campus gained a comprehensive tree survey with which to effectively manage their tree assets, the city of Edinburg and UTPA increased their sustainability profile with at Tree Campus USA® designation, and most importantly students gained credit hours as well as knowledge on ES and tree health.  Through written testimony, students have had a transformational change in the way they look at trees and better understand their ecological implications. This prized methodology should be worthwhile for campuses in similar situations, that want to show pride in their trees and has a need to create a management plan.

Different species of trees have different implications relative to ES in urban areas. Ecosystem services are extremely diverse, ranging from those that we have the tools to valuate (such as the regulating services included in this thesis) to those that are much more difficult to estimate, such as cultural ES and supporting ES (see chapter I). Given these limitations, additional research is needed to best understand the comprehensive implications of trees in urban areas and in areas such as the RGV undergoing tremendous land use change.  However, this thesis effectively demonstrates that within the context of a university campus or other entity where trees are managed; trees should be seen as assets, and not as time and money sinks. Trees provide specific ecological services that are inherently important to urban areas and colleges that should be integrated into the calculus of sustainable management. To do so, is important to confidently estimate the economic value of such services in a way that can aide us to make informed decisions about how to best inform how to effectively manage these elements that provide these ES.   On the other hand, other valuable ES such as supporting services such as biodiversity and soil formation, and other cultural services such as aesthetics and spiritual value are more difficult to place an economic value, but still should be taken into account using the best information available. Providing this information is the job of urban ecologists. However, whether one is a trained ecologist or not, this old proverb, as this thesis argues, rings true:  “The best time to plant a tree was 20 years ago, the next best time is today.”

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# APPENDIX A

APPENDIX AI

## Tree Campus USA® Designation Letter

Arbor Day Foundation  Tree Campus USA


**Congratulations on Receiving 2014 Tree Campus USA Recognition**

Dear Marianella,

Congratulations to The University of Texas Rio Grande Valley for earning 2014 Tree Campus USA® recognition. Tree Campus USA, a national program launched in 2008 by the Arbor Day Foundation and Toyota, honors colleges and universities and their leaders for promoting healthy trees and engaging students and staff in the spirit of conservation.

To obtain this distinction, The University of Texas Rio Grande Valley has met the five core standards for sustainable campus forestry required by Tree Campus USA, including establishment of a tree advisory committee, evidence of a campus tree-care plan, dedicated annual expenditures for its campus tree program, an Arbor Day observance and the sponsorship of student service-learning projects. Your entire campus community should be proud of this sustained commitment to environmental stewardship.

Two promotional items are being prepared for your campus to help publicize your new recognition. These include a customized press release for your communications contact and ceremonial letter for your president/chancellor (or the contact you listed in your application). Both items will be sent out to the respective individuals in the next 2-3 weeks. Your recognition materials will be shipped to your state coordinator to be distributed to you on or before your state's Arbor Day.

Again, congratulations! Your diligence in improving the environment and quality of life at The University of Texas Rio Grande Valley contributes to a healthier, more sustainable world for us all.

Sincerely,

Mary Sweeney

Mary Sweeney
Program Manager
Arbor Day Foundation

Contact us: treecampus@arborday.org  Forward this to a friend.

APPENDIX AII

## The Trimble® Unit Handout

APPENDIX AIII

**Student's Tree Guide**

**Trees of UTPA**

**Tree Guide**

Leaves Simple or Compound?

Compound

Compound: Are Leaves opposite 

Berlandier Ash

Compound: Is the Fruit a Legum 

Honey Mesquite

Compound: When leaves are crushed, do they smell like almonds? 

Soapberry

Compound: Tiny leaves and may have pneumatophores? 

Montezuma cypress

Compund: Bloated trunk with nodules? 

Floss Silk

Compund: Short tree and long needle-like leaflets? 

Needle-like leaflets: Cycad

Simple Leaves

Margins: Smooth or Toothed? 

Toothed:

Toothed: Asymmetrical leaf base:

Cedar Elm

Toothed: Large spade shaped Leaf:  

Cottonwood

Toothed: Peeling bark:

Mexican Plum

Toothed: Tiny Leaves, red berrie 

Yaupon Holly

Smooth Margins

Smooth: Sandpapery leave 

Anacua

Smooth: Deep indentions, Large fuzzy acorns 

Bur Oak

Smooth: Small to medium sized leaves, tricarpulate f 

Chinese Tallow

Smooth: When leaves are crushed, smell like 

Orange

Smooth: Bark is smooth and tree is multi-trunked? 

Crape Myrtle

Smooth: Leaves are small, fruit is an acorn? 

Live Oak

Smooth: When wounded, does milky sap ooze out? 

Sacred Fig

Smooth: Has large white flowers, leaves are soft?

Wild Olive 

**Anacua - *Ehretia anacua***

Leaves are rough, feel like sandpaper
Leaves are oval shape, small to medium size
Tiny white flowers


**Berlandier Ash - *Fraxinus berlandieriana***

Has opposite leaves
Have compound leaves
Stems have Lenticels
Petioles may have black substance


**Bur Oak - *Quercus macrocarpa***

Large leaves with deep indentions
Acorn is large, has a large fuzzy top

**Cedar Elm - *Ulmus crassifolia***

Asymmetrical or oblique leaves
Serrated margins

**Chinese Tallow - *Triadica sebifera***

Leaves are an important tell
Fruit is Tri-carpalate


**Orange *Citrus - Citrus x sinensis***

Leaves contain citric acid
Leaves have a citrus scent when crushed
Fruit is a hesperidium

**Cottonwood - *Populus deltoids***

Large spatulate leaves
Margins and largely toothed

**Crape Myrtle - *Lagerstroemia indica***

Bark is a large tell
Usually multi-trunk
Smooth bark
Alternate leaves

**Cycad - *Cycas revolute***

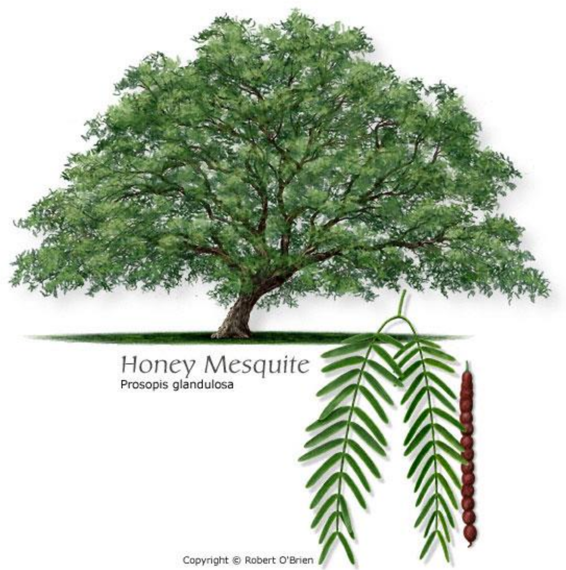
Short ornamental
Long compound leaves, pointed at the ends of each leaflet

**Floss Silk - *Ceiba pentandra***

Large showy flowers
Trunk base has many protrusions
Trunk base may be bloated
Leaves are palmately compound

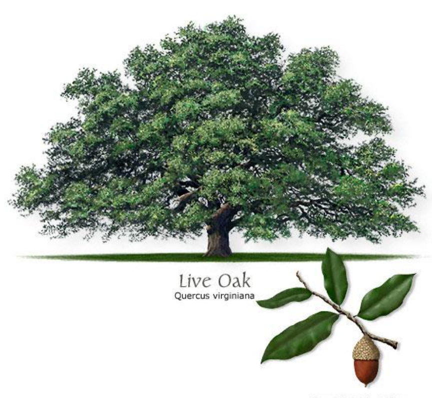
**Honey Mesquite - *Prosopis glandulosa***

Has compound leaves
Fruit is a legume




**Live Oak - *Quercus virginiana***

Small to medium sized leaves
Leaves are can be dark colored
Oval shaped
Smooth Margin



**Mexican Plum - *Prunus Mexicana***

Has peeling bark
Oval leaves with serrated margins
Older branches have silver bandings

**Montezuma Cypress – *Taxodium mucronatum***

Has pneumatophores, or “knees”

Compound leaves, tiny


**Sacred Fig - *Ficus religiosa***

When cut, oozes a white latex
Leaves are large
Leaves are noticeably different


**Soapberry - *Sapindus saponaria***

Has a compound leaf
Fruit is a hard and usually golden

**Wild Olive - *Cordia boissieri***

Large white flowers
Leaves are soft
Large simple leaves

**Yaupon Holly - *Ilex vomitoria***

Bark has white marbling
Fruit is a small red berry
Leaves are small and slightly serrated
Usually multi-trunked


APPENDIX AIV

**Student’s Palm Guide**

Palms of UTPA

Canary Palm - *Phoenix canariensis*

Characteristics

Leaves – Alternate, pinnately compound 12 – 20 in. long.
Stem – Grey – brown, **leaf scars are shaped in a diamond**.

Chinese Fan - *Livistona chinensis*

Characteristics

Leaves - Spiral, **Palmate (Fan shaped), Petioles are toothed near the base**
Stem – Grows upright and does not droop

Corozo Palm - *Attalea cohune*

Characteristics

Leaves – Pinnately compound, usually erect to form a large crown
Stem – Erect without spines, may have rings

Date Palm - *Phoenix dactylifera*

Characteristics
Leaves – Pinnately Compound, 13 – 20 ft long, spines on the petiole
Stem – Has large leaf scars all over the stem

Fan Palm - *Washintonia fillifera*

Characteristics

Leaves – Palmate (Fan shaped), has **long thread like fibers on leaf**
Stem – When the fronds die, they usually stay attached near the crown

Florida Sabal - *Sabal palmetto*

Characteristics

Leaves – Palmate (Fan Shaped), usually wider than they are long
Stem – Leaf bases **may** persist on the stem

Fox Tail Palm - *Wodyetia bifurcata*

Characteristics

Leaves – Pinnately compound, like a **“Fox Tail”**
Stem – Thin smooth stem, has rings

Mexican Palm - *Washintonia robusta*

Characteristics

Leaves – Palmate (Fan shaped), **petioles have hooked spines**
Stem – Usually clean but can have leaf bases, tightly ringed stem

Mexican Sabal - *Sabal mexicana*

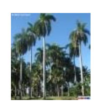
Characteristics
Leaves – Palmate (Fan shaped), petioles are spineless, unfurl
Stem – If not cleaned, stem can be covered in leaf bases

Pygmy Date Palm - *Phoenix roebelenii*

Characteristics

Leaves – Pinnately compound, slightly drooping crown
Stem – **short sized palm growing to about 2 – 3 meters in height**

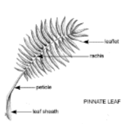
Royal Palm - *Roystonea cubensis*



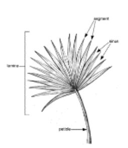
Characteristics
Leaves – Pinnately compound, leaves droop
Stem – Large, smooth columnar stems, grayish white to grayish brown coloured

Keywords:

Pinnately Compound



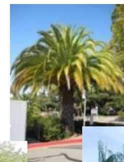
Palmate:



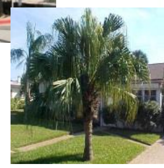
Leaf Base:

Leaf Scars:

**Canary Palm - Phoenix canariensis**



**Chinese Fan -** ***Livistona chi***



**Corozo Palm -** ***Attalea cohune***

**Date Palm -** ***Phoenix dactylifera***

**Fan Palm -** ***Washintonia fillifera***

**Florida Sabal -** ***Sabal palmetto***

**Fox Tail Palm - *Wodyetia bifurcata***

**Mexican Palm - *Washintonia robusta***

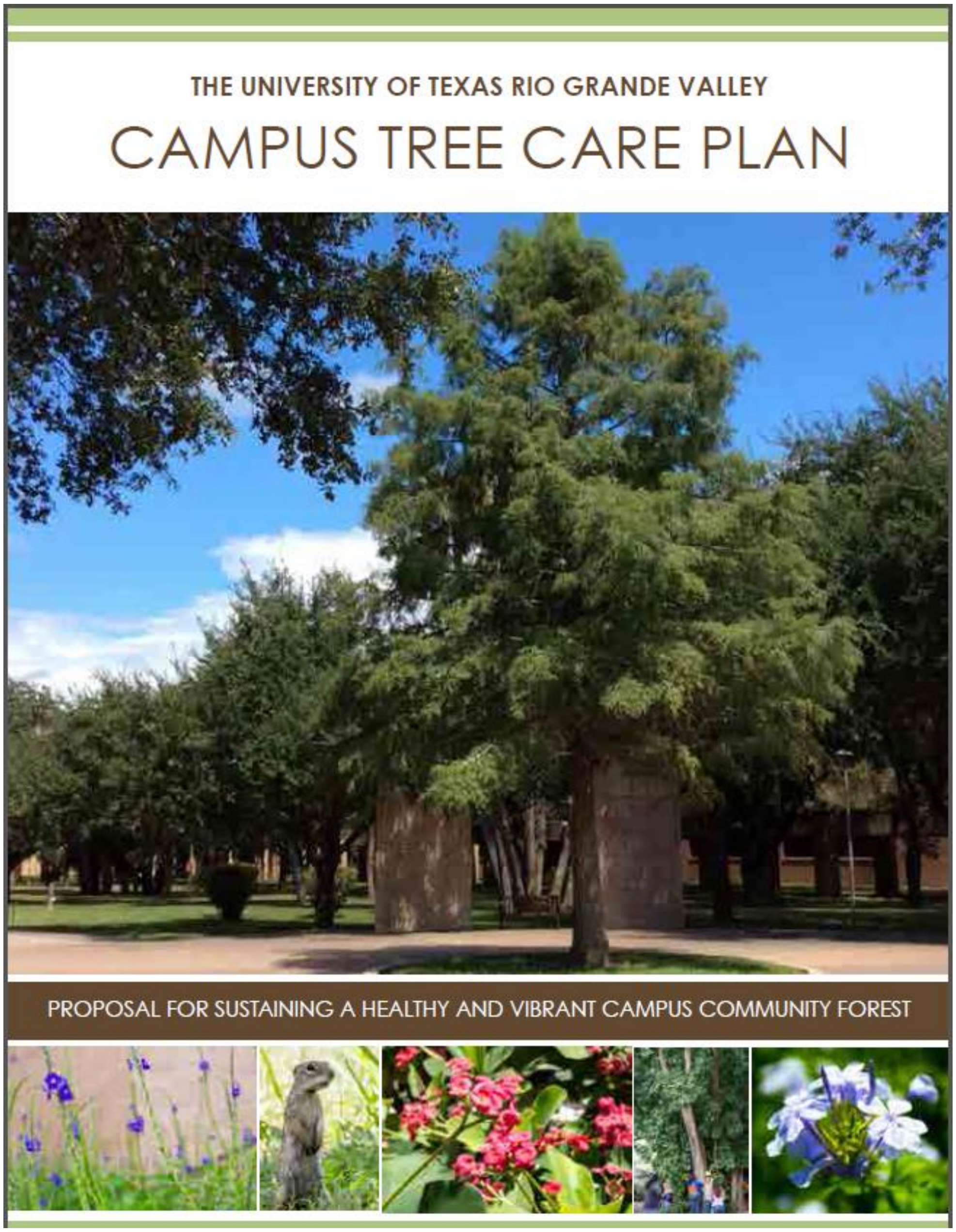
**Mexican Sabal - *Sabal mexicana***

**Pygmy Date Palm - *Phoenix roebelenii***

**Royal Palm - *Roystonea cubensis***

APPENDIX AV

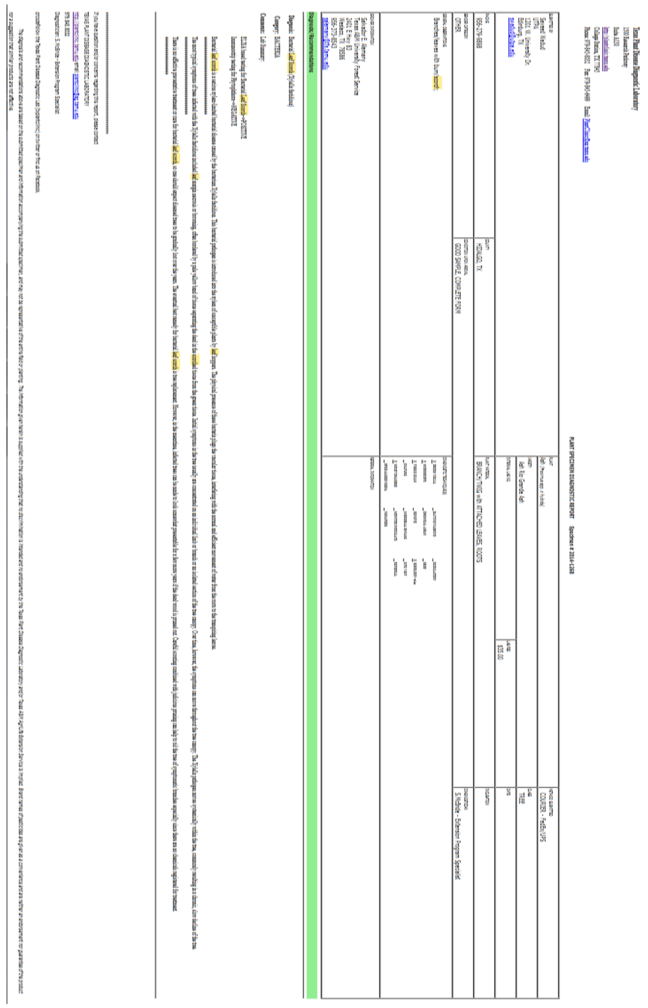
**UTPA Tree Care Guide**




Can be found at http://issuu.com/utpa/docs/sustainability-tree-care-plan

APPENDIX AVI

# Bacterial Leaf Scorch Identification.



APPENDIX AVII

**Tree health conditions taken from i-Tree Eco.**

| Tree Characteristics in University of Texas Pan - American by Species | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Series: TreeCampusUTPA | | | | Time Period: 2015 | | | | | |
| Species Name | Tree Count | % Pop | % Excellent | % Good | % Fair | % Poor | % Critical | % Dying | % Dead |
| Anacahuita | 30 | 1.52 | 50 | 20 | 16.67 | 13.33 | | | |
| Arizona ash | 178 | 9.03 | 30.9 | 44.38 | 14.04 | 8.99 | 1.12 | 0.56 | |
| Berlandier's fiddlewood | 1 | 0.05 | | 100 | | | | | |
| Black willow | 1 | 0.05 | | 100 | | | | | |
| Brazilian bluewood | 1 | 0.05 | 100 | | | | | | |
| Brazilian pepper | 1 | 0.05 | | 100 | | | | | |
| Bur oak | 17 | 0.86 | 29.41 | 47.06 | 11.76 | 5.88 | | 5.88 | |
| California palm | 100 | 5.07 | 63 | 23 | 4 | | 5 | 5 | |
| Canary island date palm | 4 | 0.2 | 50 | | 50 | | | | |
| Cedar elm | 106 | 5.38 | 42.45 | 31.13 | 6.6 | 15.09 | 4.72 | | |
| Ceiba | 2 | 0.1 | | | | 100 | | | |
| Chaste tree | 14 | 0.71 | 100 | | | | | | |
| Chinese fan palm | 1 | 0.05 | 100 | | | | | | |
| Chinese flame tree | 1 | 0.05 | | 100 | | | | | |
| Chinese pistache | 10 | 0.51 | 60 | 10 | 10 | 10 | | 10 | |
| Common crapemyrtle | 170 | 8.63 | 44.71 | 17.06 | 13.53 | 17.06 | 4.71 | 2.94 | |
| Common guava | 1 | 0.05 | 100 | | | | | | |
| Crimson bottlebrush | 2 | 0.1 | | 50 | 50 | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Date palm | 5 | 0.25 | 80 | | | 20 | | | |
| Desertwillow | 4 | 0.2 | | | 100 | | | | |
| Eastern cottonwood | 6 | 0.3 | | 33.33 | 50 | | 16.67 | | |
| English yew | 4 | 0.2 | 50 | 25 | 25 | | | | |
| Golden dewdrops | 1 | 0.05 | 100 | | | | | | |
| gum spp | 1 | 0.05 | | | | | | 100 | |
| Honey mesquite | 8 | 0.41 | 37.5 | 50 | | | | 12.5 | |
| Japanese pittosporum | 3 | 0.15 | | 66.67 | 33.33 | | | | |
| juniper spp | 31 | 1.57 | 45.16 | 19.35 | 16.13 | 16.13 | | | 3.23 |
| Knockaway | 6 | 0.3 | 66.67 | 16.67 | | 16.67 | | | |
| loquat spp | 1 | 0.05 | 100 | | | | | | |
| Loquat tree | 1 | 0.05 | | | | 100 | | | |
| Mescalbean | 10 | 0.51 | 20 | 60 | 10 | 10 | | | |
| Mexican fan palm | 258 | 13.09 | 66.67 | 28.68 | 1.94 | 2.33 | 0.39 | | |
| Mexican plum | 3 | 0.15 | 66.67 | | | 33.33 | | | |
| Montezuma cypress | 8 | 0.41 | 37.5 | 12.5 | 12.5 | 12.5 | 12.5 | | 12.5 |
| Northern red oak | 16 | 0.81 | 31.25 | 18.75 | | 12.5 | 12.5 | 25 | |
| Olive | 8 | 0.41 | 75 | 25 | | | | | |
| pachira spp | 1 | 0.05 | 100 | | | | | | |
| Pecan | 3 | 0.15 | 100 | | | | | | |
| Peepul tree | 2 | 0.1 | 50 | 50 | | | | | |
| Pomegranate | 1 | 0.05 | 100 | | | | | | |
| Ponytail palm | 2 | 0.1 | 100 | | | | | | |
| Quercus virginiana | 767 | 38.91 | 28.94 | 38.59 | 12.78 | 13.43 | 5.22 | 0.65 | 0.39 |
| Rio grande palmetto | 136 | 6.9 | 91.91 | 5.88 | 0.74 | 0.74 | | 0.74 | |
| royal palm spp | 1 | 0.05 | 100 | | | | | | |
| Royal poinciana | 4 | 0.2 | | | | | | 100 | |
| Saffron plum | 1 | 0.05 | 100 | | | | | | |
| Southern magnolia | 2 | 0.1 | 100 | | | | | | |
| Sugarberry | 1 | 0.05 | | 100 | | | | | |
| Tallowtree | 7 | 0.36 | 42.86 | 14.29 | 14.29 | 14.29 | | 14.29 | |
| Texas ebony | 10 | 0.51 | 50 | 50 | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Texas persimmon | 9 | 0.46 | | 22.22 | 55.56 | 22.22 | | | |
| Western soapberry | 1 | 0.05 | | 100 | | | | | |
| Yaupon | 9 | 0.46 | 100 | | | | | | |
| TOTAL | 1971 | 100 | 44.6 | 30.49 | 9.94 | 9.89 | 3.3 | 1.52 | 0.25 |

APPENDIX AVIII

**Regulating Service: Avoided Rainfall**

| Species | | Number of Trees | | Annual Avoided Rainfall | | |
|---|---|---|---|---|---|---|
| | | % | Total | % | $m^3$/year | $/year |
| *Quercus virginiana* | Live oak | 38.91 | 767 | 50.72 | 379.87 | 893.33 |
| *Washingtonia robusta* | Mexican fan palm | 13.09 | 258 | 3.70 | 27.7 | 65.18 |
| *Fraxinus berlandieriana* | Arizona ash | 9.03 | 178 | 17.50 | 131.05 | 308.06 |
| *Lagerstroemia indica* | Common crapemyrtle | 8.63 | 170 | 4.37 | 32.76 | 77.1 |
| *Sabal palmetto* | Rio grande palmetto | 6.9 | 136 | 4.10 | 30.7 | 72.25 |
| *Ulmus crassifolia* | Cedar elm | 5.38 | 106 | 5.75 | 43.05 | 101.25 |
| *Washingtonia fillifera* | California palm | 5.07 | 100 | 2.32 | 17.4 | 40.9 |
| *juniper spp* | juniper spp | 1.57 | 31 | 0.79 | 5.91 | 13.88 |
| *Cordia boissieri* | Anacahuita | 1.52 | 30 | 0.85 | 6.39 | 14.98 |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Quercus macrocarpa* | Bur oak | 0.86 | 17 | 0.76 | 5.72 | 13.42 |
| *Quercus rubra* | Northern red oak | 0.81 | 16 | 0.31 | 2.3 | 5.37 |
| *Vitex agnus-castus* | Chaste tree | 0.71 | 14 | 0.34 | 2.55 | 6.02 |
| *Pistache chinensis* | Chinese pistache | 0.51 | 10 | 0.36 | 2.72 | 6.41 |
| *Sophora secundiflora* | Mescalbean | 0.51 | 10 | 0.12 | 0.93 | 2.15 |
| *Ebonopsis ebano* | Texas ebony | 0.51 | 10 | 1.22 | 9.16 | 21.53 |
| *Diospyros texana* | Texas persimmon | 0.46 | 9 | 0.13 | 1.01 | 2.37 |
| *Ilex vomitoria* | Yaupon | 0.46 | 9 | 0.15 | 1.14 | 2.68 |
| *Prosopis glandulosa* | Honey mesquite | 0.41 | 8 | 1.01 | 7.53 | 17.71 |
| *Taxodium mucranatum* | Montezuma cypress | 0.41 | 8 | 0.74 | 5.56 | 13.06 |
| *Olea europea* | Olive | 0.41 | 8 | 0.15 | 1.11 | 2.6 |
| *Triadica sebifera* | Tallowtree | 0.36 | 7 | 0.49 | 3.66 | 8.64 |
| *Populus deltoides* | Eastern cottonwood | 0.3 | 6 | 0.74 | 5.56 | 13.08 |
| *Ehretia anacua* | Knockaway | 0.3 | 6 | 0.21 | 1.61 | 3.79 |
| *Phoenix dactylifera* | Date palm | 0.25 | 5 | 0.25 | 1.85 | 4.36 |
| *Phoenix canariensis* | Canary island date palm | 0.2 | 4 | 0.19 | 1.42 | 3.34 |
| *Chilopsis sp* | Desertwillow | 0.2 | 4 | 0.13 | 1.01 | 2.39 |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Taxus baccata* | English yew | 0.2 | 4 | 0.13 | 0.94 | 2.2 |
| *Delonix regia* | Royal poinciana | 0.2 | 4 | 0.09 | 0.66 | 1.57 |
| *Pittosporum tobira* | Japanese pittosporum | 0.15 | 3 | 0.05 | 0.38 | 0.9 |
| *Prunus mexicana* | Mexican plum | 0.15 | 3 | 0.05 | 0.38 | 0.88 |
| *Carya illinoinensis* | Pecan | 0.15 | 3 | 0.22 | 1.67 | 3.91 |
| *Ceiba pentandra* | Ceiba | 0.1 | 2 | 0.16 | 1.17 | 2.74 |
| *Callistemon citrinus* | Crimson bottlebrush | 0.1 | 2 | 0.23 | 1.73 | 4.06 |
| *Ficus religiosa* | Peepul tree | 0.1 | 2 | 0.77 | 5.73 | 13.46 |
| *Beaucarnea recurvata* | Ponytail palm | 0.1 | 2 | 0.03 | 0.2 | 0.48 |
| *Magnolia grandiflora* | Southern magnolia | 0.1 | 2 | 0.04 | 0.3 | 0.7 |
| *Citharexylum berlandieri* | Berlandier's fiddlewood | 0.05 | 1 | 0.01 | 0.09 | 0.21 |
| *Salix nigra* | Black willow | 0.05 | 1 | 0.14 | 1.02 | 2.4 |
| *Condalia hookeri* | Brazilian bluewood | 0.05 | 1 | 0.02 | 0.12 | 0.28 |
| *Schinus terebinthifolius* | Brazilian pepper | 0.05 | 1 | 0.02 | 0.14 | 0.32 |
| *Livistona chinensis* | Chinese fan palm | 0.05 | 1 | 0.02 | 0.14 | 0.33 |
| *Koelreuteria bipinnata* | Chinese flame tree | 0.05 | 1 | 0.10 | 0.72 | 1.68 |
| *Psidium guajava* | Common guava | 0.05 | 1 | 0.05 | 0.34 | 0.79 |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Duranta erecta* | Golden dewdrops | 0.05 | 1 | 0.01 | 0.06 | 0.14 |
| *Eucalyptus sp* | gum spp | 0.05 | 1 | 0.05 | 0.34 | 0.79 |
| *Eriobotrya* | loquat spp | 0.05 | 1 | 0.01 | 0.04 | 0.09 |
| *Eriobotrya japonica* | Loquat tree | 0.05 | 1 | 0.03 | 0.19 | 0.44 |
| *Pachira spp* | pachira spp | 0.05 | 1 | 0.04 | 0.27 | 0.63 |
| *Punica granatum* | Pomegranate | 0.05 | 1 | 0.01 | 0.09 | 0.22 |
| *Roystonea sp* | royal palm spp | 0.05 | 1 | 0.02 | 0.16 | 0.37 |
| *Sideroxylon celastrinum* | Saffron plum | 0.05 | 1 | 0.02 | 0.14 | 0.33 |
| *Celtis laevigata* | Sugarberry | 0.05 | 1 | 0.18 | 1.34 | 3.14 |
| *Sapindus drummondii* | Western soapberry | 0.05 | 1 | 0.12 | 0.92 | 2.17 |
| Total | | | 1971 | 100.00 | 748.95 | 1761.08 |

APPENDIX AIX

**Regulating Service: Electrical Savings by Shade Cast**

| Species | Sum of Heating kWh | Value of heating kWh | Sum of Cooling kWh | Value of Cooling kWh |
|---|---|---|---|---|
| Anacahuita | 49.6 | 5.53 | 566.6 | 63.22 |
| Arizona ash | 36 | 4 | 388.4 | 43.34 |
| Berlandier's fiddlewood | 0 | 0 | 0 | 0 |
| Black willow | 0 | 0 | 0 | 0 |
| Brazilian bluewood | 0.8 | 0.09 | 3 | 0.33 |
| Brazilian pepper | 0.8 | 0.09 | 11.1 | 1.24 |
| Bur oak | 3.7 | 0.41 | 83.3 | 9.29 |
| California palm | 415 | 46.27 | 2024.4 | 225.94 |
| Canary island date palm | 38.1 | 4.25 | 105.4 | 11.77 |
| Cedar elm | 143.4 | 15.93 | 1013.2 | 113.07 |
| Ceiba | 0 | 0 | 0 | 0 |
| Chaste tree | 0 | 0 | 0 | 0 |
| Chinese fan palm | 6.3 | 0.71 | 68.7 | 7.66 |
| Chinese flame tree | 3.7 | 0.41 | 13.2 | 1.48 |
| Chinese pistache | 7.4 | 0.82 | 30 | 3.34 |
| Common crapemyrtle | 134.8 | 14.94 | 2572.4 | 287.11 |
| Common guava | 1.1 | 0.13 | 0 | 0 |

| | | | | |
|---|---|---|---|---|
| Crimson bottlebrush | 8.4 | 0.94 | 25.8 | 2.88 |
| Date palm | 10.7 | 1.2 | 0 | 0 |
| Desertwillow | 6.6 | 0.74 | 15.1 | 1.69 |
| Eastern cottonwood | 0 | 0 | 0 | 0 |
| English yew | 10.4 | 1.16 | 90.3 | 10.08 |
| Golden dewdrops | 0 | 0 | 0 | 0 |
| gum spp(Genus) | 26 | 2.9 | 71.5 | 7.97 |
| Honey mesquite | 0 | 0 | 0 | 0 |
| Japanese pittosporum | 2.4 | 0.26 | 64 | 7.14 |
| juniper spp(Genus) | 270.1 | 30.16 | 826.9 | 92.28 |
| Knockaway | 9 | 1 | 90 | 10.05 |
| Live oak | 2793.9 | 311.86 | 4956 | 553.05 |
| loquat spp(Genus) | 0.7 | 0.07 | 9.2 | 1.02 |
| Loquat tree | 5 | 0.56 | 77.6 | 8.66 |
| Mescalbean | 7.5 | 0.83 | 16.9 | 1.88 |
| Mexican fan palm | 1272.4 | 142.09 | 2535.8 | 282.95 |
| Mexican plum | 0 | 0 | 0 | 0 |
| Montezuma cypress | 49.6 | 5.54 | 85 | 9.48 |
| Northern red oak | 21.7 | 2.41 | 49.5 | 5.52 |
| Olive | 6.7 | 0.75 | 27.6 | 3.08 |
| pachira spp(Genus) | 23.5 | 2.62 | 119.4 | 13.32 |
| Pecan | 0 | 0 | 0 | 0 |
| Peepul tree | 0 | 0 | 0 | 0 |
| Pomegranate | 0 | 0 | 0.1 | 0.01 |
| Ponytail palm | 7 | 0.78 | 60.9 | 6.79 |
| Rio grande palmetto | 527.8 | 58.82 | 2978.1 | 332.4 |
| royal palm spp(Genus) | 1.4 | 0.15 | 0 | 0 |
| Royal poinciana | 7.4 | 0.82 | 165.6 | 18.47 |
| Saffron plum | 0 | 0 | 0 | 0 |

| | | | | |
|---|---|---|---|---|
| Southern magnolia | 3.4 | 0.38 | 0 | 0 |
| Sugarberry | 0 | 0 | 0 | 0 |
| Tallowtree | 0 | 0 | 0 | 0 |
| Texas ebony | 35.3 | 3.95 | 0 | 0 |
| Texas persimmon | 7.4 | 0.82 | 25 | 2.78 |
| Western soapberry | 3.7 | 0.41 | 12.5 | 1.4 |
| Yaupon | 7.1 | 0.77 | 3.9 | 0.42 |
| TOTAL | 5966.1 | 665.81 | 19185.9 | 2141.14 |

APPENDIX AX

**Regulating Service: Pollution Sequestration**

| Species | | Sum of Pollutants (g) | Average Pollutants per Tree (g) | Sequestered Values ($) |
|---|---|---|---|---|
| *Quercus virginiana* | Live oak | 624,725.20 | 814.5048 | $2,587.93 |
| *Washingtonia robusta* | Mexican fan palm | 34,466.80 | 133.5922 | $148.04 |
| *Fraxinus berlandieriana* | Arizona ash | 118,509.80 | 665.7854 | $745.64 |
| *Lagerstroemia indica* | Common crapemyrtle | 28,796.30 | 169.39 | $172.88 |
| *Sabal palmetto* | Rio grande palmetto | 39,671.40 | 291.7015 | $160.43 |
| *Ulmus crassifolia* | Cedar elm | 35,481.90 | 334.7349 | $217.07 |
| *Washingtonia fillifera* | California palm | 21,437.00 | 214.37 | $90.92 |
| *juniper spp* | juniper spp | 10,986.80 | 354.4129 | $35.26 |
| *Cordia boissieri* | Anacahuita | 5,832.20 | 194.4067 | $35.86 |
| *Quercus macrocarpa* | Bur oak | 6,122.00 | 360.1176 | $34.89 |
| *Quercus rubra* | Northern red oak | 2,149.10 | 134.3188 | $12.96 |
| *Vitex agnus-castus* | Chaste tree | 3,081.40 | 220.1 | $15.00 |
| *Pistache chinensis* | Chinese pistache | 2,351.30 | 235.13 | $13.79 |

| | | | | |
|---|---|---|---|---|
| *Sophora secundiflora* | Mescalbean | 1,026.10 | 102.61 | $5.44 |
| *Ebonopsis ebano* | Texas ebony | 8,245.70 | 824.57 | $50.27 |
| *Diospyros texana* | Texas persimmon | 915.3 | 101.7 | $5.59 |
| *Ilex vomitoria* | Yaupon | 1,365.80 | 151.7556 | $6.66 |
| *Prosopis glandulosa* | Honey mesquite | 6,796.70 | 849.5875 | $41.48 |
| *Taxodium mucranatum* | Montezuma cypress | 6,726.10 | 840.7625 | $27.35 |
| *Olea europea* | Olive | 991.3 | 123.9125 | $6.00 |
| *Triadica sebifera* | Tallowtree | 3,136.40 | 448.0571 | $18.48 |
| *Populus deltoides* | Eastern cottonwood | 4,702.90 | 783.8167 | $28.20 |
| *Ehretia anacua* | Knockaway | 1,455.20 | 242.5333 | $8.89 |
| *Phoenix dactylifera* | Date palm | 2,365.50 | 473.1 | $9.41 |
| *Phoenix canariensis* | Canary island date palm | 1,804.70 | 451.175 | $7.11 |
| *Chilopsis sp* | Desertwillo w | 884.2 | 221.05 | $5.26 |
| *Taxus baccata* | English yew | 1,166.80 | 291.7 | $4.93 |
| *Delonix regia* | Royal poinciana | 618.2 | 154.55 | $3.84 |
| *Pittosporum tobira* | Japanese pittosporum | 340.9 | 113.6333 | $2.05 |
| *Prunus mexicana* | Mexican plum | 384.7 | 128.2333 | $2.47 |
| *Carya illinoinensis* | Pecan | 1,521.70 | 507.2333 | $9.75 |

| | | | | |
|---|---|---|---|---|
| *Ceiba pentandra* | Ceiba | 1,070.90 | 535.45 | $6.60 |
| *Callistemon citrinus* | Crimson bottlebrush | 1,426.90 | 713.45 | $8.23 |
| *Ficus religiosa* | Peepul tree | 5,427.20 | 2713.6 | $34.08 |
| *Beaucarnea recurvata* | Ponytail palm | 180 | 90 | $1.07 |
| *Magnolia grandiflora* | Southern magnolia | 348.7 | 174.35 | $1.64 |
| *Citharexylum berlandieri* | Berlandier's fiddlewood | 91.9 | 91.9 | $0.60 |
| *Salix nigra* | Black willow | 918.2 | 918.2 | $6.10 |
| *Condalia hookeri* | Brazilian bluewood | 105.1 | 105.1 | $0.62 |
| *Schinus terebinthifolius* | Brazilian pepper | 123.2 | 123.2 | $0.75 |
| *Livistona chinensis* | Chinese fan palm | 183.7 | 183.7 | $0.75 |
| *Koelreuteria bipinnata* | Chinese flame tree | 598.9 | 598.9 | $3.31 |
| *Psidium guajava* | Common guava | 290.3 | 290.3 | $1.72 |
| *Duranta erecta* | Golden dewdrops | 53.6 | 53.6 | $0.33 |
| *Eucalyptus sp* | gum spp | 630 | 630 | $4.22 |
| *Eriobotrya* | loquat spp | 34.5 | 34.5 | $0.21 |
| *Eriobotrya japonica* | Loquat tree | 163.1 | 163.1 | $0.97 |
| *Pachira spp* | pachira spp | 239.4 | 239.4 | $1.46 |
| *Punica granatum* | Pomegranate | 84.7 | 84.7 | $0.51 |

| | | | | |
|---|---|---|---|---|
| *Roystonea sp* | royal palm spp | 201.2 | 201.2 | $0.81 |
| *Sideroxylon celastrinum* | Saffron plum | 126.8 | 126.8 | $0.76 |
| *Celtis laevigata* | Sugarberry | 1,079.00 | 1079 | $6.53 |
| *Sapindus drummondii* | Western soapberry | 792.8 | 792.8 | $4.69 |
| Total | | 992,229.00 | 503.414 | $4,599.90 |

APPENDIX AXI

**Regulating Service: Carbon Sequestration**

| Species | Leaf Area | | Total Carbon Storage | | Gross Carbon Storage | | Replacement Values |
|---|---|---|---|---|---|---|---|
| | Leaf Area | % | kg | % | kg/year | % | $ |
| *Quercus virginiana* | 164,905.80 | 60.89 | 346,256.20 | 63.55 | 22,703.60 | 53.58 | $3,072,772 |
| *Washingtonia robusta* | 12,029.10 | 1.41 | 7,996.70 | 0.62 | 221.10 | 5.44 | $311,692 |
| *Fraxinus berlandieriana* | 62,326.20 | 19.14 | 108,841.30 | 15.86 | 5,665.50 | 18.84 | $1,080,612 |
| *Lagerstroemia indica* | 15,601.30 | 2.11 | 11,988.30 | 4.6 | 1,644.60 | 2.8 | $160,370 |
| *Sabal palmetto* | 13,337.90 | 0.34 | 1,926.20 | 0.15 | 52.90 | 3.32 | $190,641 |
| *Ulmus crassifolia* | 20,486.50 | 1.76 | 10,018.30 | 3.13 | 1,118.60 | 2.66 | $152,285 |
| *Washingtonia fillifera* | 7,556.70 | 0.33 | 1,881.40 | 0.14 | 51.60 | 1.54 | $88,101 |
| *juniper spp* | 2,557.10 | 0.3 | 1,689.40 | 0.47 | 166.50 | 0.61 | $35,107 |
| *Cordia boissieri* | 2,770.50 | 0.32 | 1,791.80 | 0.81 | 289.20 | 0.51 | $29,007 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Quercus macrocarpa* | 2,720.80 | 0.72 | 4,086.80 | 1.02 | 364.80 | 0.87 | $50,029 |
| *Quercus rubra* | 1,087.00 | 0.24 | 1,365.90 | 0.4 | 142.40 | 0.27 | $15,284 |
| *Vitex agnus-castus* | 1,218.00 | 0.19 | 1,054.90 | 0.46 | 165.20 | 0.31 | $17,697 |
| *Pistache chinensis* | 1,299.00 | 0.19 | 1,060.00 | 0.35 | 124.40 | 0.23 | $13,048 |
| *Sophora secundiflora* | 396.20 | 0.1 | 592.40 | 0.27 | 97.20 | 0.16 | $9,316 |
| *Ebonopsis ebano* | 3,975.20 | 1.29 | 7,328.90 | 1.23 | 438.80 | 1.08 | $62,069 |
| *Diospyros texana* | 482.10 | 0.07 | 389.80 | 0.21 | 73.60 | 0.11 | $6,549 |
| *Ilex vomitoria* | 493.10 | 0.04 | 253.20 | 0.16 | 56.60 | 0.1 | $5,513 |
| *Prosopis glandulosa* | 3,584.80 | 1.08 | 6,154.70 | 0.89 | 317.20 | 0.79 | $45,449 |
| *Taxodium mucranatum* | 2,412.00 | 0.23 | 1,301.70 | 0.21 | 73.90 | 0.44 | $25,157 |
| *Olea europea* | 482.60 | 0.16 | 900.90 | 0.31 | 110.80 | 0.21 | $12,170 |
| *Triadica sebifera* | 1,748.80 | 0.75 | 4,245.50 | 0.62 | 220.90 | 0.51 | $28,963 |
| *Populus deltoides* | 2,649.20 | 1.04 | 5,898.20 | 0.78 | 277.40 | 0.62 | $35,542 |
| *Ehretia anacua* | 767.10 | 0.43 | 2,425.40 | 0.4 | 143.70 | 0.36 | $20,611 |
| *Phoenix dactylifera* | 804.50 | 0.02 | 107.60 | 0.01 | 2.10 | 0.17 | $9,714 |
| *Phoenix canariensis* | 618.10 | 0.02 | 107.20 | 0.01 | 2.90 | 0.42 | $24,361 |

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|---|---|---|---|---|---|---|---|
| *Chilopsis sp* | 442.30 | 0.07 | 401.20 | 0.15 | 53.40 | 0.08 | $4,828 |
| *Taxus baccata* | 407.50 | 0.06 | 313.10 | 0.08 | 30.30 | 0.13 | $7,352 |
| *Delonix regia* | 316.60 | 0.06 | 357.50 | 0.02 | 7.30 | 0.01 | $716 |
| *Pittosporum tobira* | 166.00 | 0.04 | 253.70 | 0.1 | 37.00 | 0.06 | $3,690 |
| *Prunus mexicana* | 178.40 | 0.36 | 2,066.80 | 0.35 | 126.60 | 0.24 | $14,013 |
| *Carya illinoinensis* | 791.70 | 0.22 | 1,240.80 | 0.3 | 106.30 | 0.24 | $13,801 |
| *Ceiba pentandra* | 554.70 | 0.82 | 4,653.50 | 0.37 | 132.40 | 0.34 | $19,585 |
| *Callistemon citrinus* | 749.40 | 0.19 | 1,099.70 | 0.21 | 74.50 | 0.16 | $9,221 |
| *Ficus religiosa* | 2,722.70 | 2.07 | 11,799.10 | 0.09 | 31.00 | 1.18 | $67,840 |
| *Beaucarnea recurvata* | 89.20 | 1.13 | 6,431.00 | 0.6 | 213.30 | 0.7 | $40,170 |
| *Magnolia grandiflora* | 128.50 | 0.12 | 665.60 | 0.14 | 49.20 | 0.13 | $7,378 |
| *Citharexylum berlandieri* | 39.20 | 0 | 21.20 | 0.02 | 5.70 | 0.01 | $375 |
| *Salix nigra* | 486.00 | 0.12 | 659.00 | 0.12 | 42.20 | 0.07 | $4,293 |
| *Condalia hookeri* | 52.60 | 0 | 19.40 | 0.01 | 5.30 | 0.01 | $362 |
| *Schinus terebinthifolius* | 59.10 | 0.01 | 44.90 | 0.02 | 8.70 | 0.02 | $876 |
| *Livistona chinensis* | 61.30 | 0 | 11.00 | 0 | 0.40 | 0.02 | $1,015 |
| *Koelreuteria bipinnata* | 340.30 | 0.23 | 1,293.00 | 0.17 | 62.50 | 0.17 | $9,776 |

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|---|---|---|---|---|---|---|---|
| *Psidium guajava* | 146.10 | 0.02 | 102.60 | 0.04 | 13.90 | 0.03 | $1,510 |
| *Duranta erecta* | 28.00 | 0.01 | 39.80 | 0.02 | 8.30 | 0.02 | $884 |
| *Eucalyptus sp* | 146.00 | 0.82 | 4,649.10 | 0.05 | 16.50 | 0.06 | $3,158 |
| *Eriobotrya* | 16.60 | 0 | 11.80 | 0.01 | 4.10 | 0 | $247 |
| *Eriobotrya japonica* | 81.80 | 0.03 | 142.60 | 0.04 | 12.90 | 0.02 | $1,179 |
| *Pachira spp* | 115.50 | 0.06 | 313.60 | 0.08 | 27.20 | 0.06 | $3,315 |
| *Punica granatum* | 44.50 | 0 | 10.70 | 0.01 | 4.00 | 0 | $235 |
| *Roystonea sp* | 67.70 | 0 | 9.20 | 0 | 0.30 | 0.02 | $1,122 |
| *Sideroxylon celastrinum* | 66.90 | 0.01 | 63.00 | 0.03 | 10.80 | 0.02 | $1,145 |
| *Celtis laevigata* | 635.20 | 0.28 | 1,601.00 | 0.2 | 71.00 | 0.15 | $8,492 |
| *Sapindus drummondii* | 438.90 | 0.13 | 715.60 | 0.12 | 44.20 | 0.11 | $6,092 |
| Total | 335,682.00 | 100 | 568,652.00 | 100 | 35,725.00 | 100 | $5,734,729 |
| *kg kilograms of Carbon* | | | | | | | |

# BIOGRAPHICAL SKETCH

Jorge E. Cantu graduated with a B.S. in Biology from Sam Houston State University. During his undergraduate he worked with an invasive plant parasite, *Orobancheae ramosa*, and its distribution in neighboring cities. He actively helped with collections, pressing, and dissecting of the parasitic plants. He also worked with riparian plant communities, focusing on species biodiversity as the geomorphology of the creek changed. Both of these projects helped prepare Jorge for his move back to the valley, 1003 North Nicholson, Apartment 5, Mission, Texas, 78572.Here he worked as a graduate student at the University of Texas- Pan American where he led a campus wide project to help UTPA become a Tree Campus USA® college. After, Jorge Cantu went to gain a Master's degree in Biology from UTPA in August 2015.