Inventorying Trees on the Northern Arizona University Campus for Policy Decisions and Carbon Sequestration Totals

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Introduction

In 1856, during the annual American Association for the Advancement of Science conference (AAAS), Eunice Foote's paper 'Circumstances Affecting the Heat of the Sun's Rays' was presented by Professor Joseph Henry of the Smithsonian Institution (Sorenson 2011). Eunice was the first scientist to suggest that changing the proportion of carbon dioxide (CO_2) in the atmosphere would change atmospheric temperatures. Forty-three years later in 1896, Swedish scientist Svante Arrhenius was the first to claim that fossil fuel combustion may eventually result in enhanced global warming as indicated by the relationship between atmospheric CO_2 concentrations and temperature (NASA "World of Change").

The burning of fossil fuels provides energy and as a byproduct, the release of CO_2 (EPA 2017). The CO_2 accumulates in the atmosphere where it interacts with energy from the sun (NASA 2019). Other causes of increased CO_2 come from natural sources such as wildfires, volcanic eruptions, plant respiration, and decomposition of organic matter (NASA "World of Change"). In 1956 Gilbert Plass summarized that an increased amount of atmospheric CO_2 resulted in more absorption of infrared radiation (Plass 1956). He concluded that adding more carbon dioxide to the atmosphere would intercept or trap infrared radiation from the sun as it reflected back from the earth's surface; warming the earth's temperature (Plass 1956). It is this increase in temperature which can lead to negative consequences (IPCC 2018). Scientists have been studying the melting of glaciers and ice caps at the earth's poles and believe it to be the result of global warming due to increased atmospheric CO_2 (Lal 2008). Water levels rising around the world, loss of habitat and prolonged wildfire seasons have all been partially attributed to global warming (IPCC 2018).

Mitigating the effects of global warming can be done through the process of carbon sequestration (Bauer 2015). Carbon sequestration is the process of capturing atmospheric CO_2 or CO_2 that would be released into the atmosphere and storing that carbon in safe locations that does not allow the carbon to be released again (Lal 2008). Northern Arizona University (NAU) committed itself in 2007 by aspiring to be carbon neutral by 2020 (CEFNS.NAU). The idea behind carbon neutrality is to sequester CO_2 in the amount equal to the CO_2 released as a result of activities by a person or entity (USGS "What is carbon sequestration".gov). Recent efforts NAU has employed to reduce electrical usage, thereby reducing CO_2 output to the atmosphere, are solar panels and natural lighting (CEFNS.NAU). Additionally, by using reclaimed water and low volume flush toilets, NAU has reduced the energy normally required to provide usable water (CEFNS.NAU). One final but important piece of the university becoming carbon neutral is to quantify the volume of CO_2 sequestration provided by the trees on campus.

Maintaining healthy trees supports improved capacity for trees to sequester CO_2. To understand the maintenance needs (limbing, removal of dead branches, or complete removal) of the trees on campus, a partial inventory was conducted in two phases. Two inventories, one in 2014 and the other in 2018 (Phase I and Phase II, respectively) were conducted to start, and then continue, a baseline assessment of the total number of trees on campus and their health. The main focus of Phase II was to continue the inventory to gauge the health of trees for their ability to sequester CO_2. Trees use CO_2 available in the atmosphere through photosynthesis for the production of glucose, which is a major building block for plant cells, roots, and seeds (Rsc.org). Up to 40% of the CO_2 used in photosynthesis is stored or sequestered by the structural components of the tree. When trees are not competing with one another, and are provided with enough nutrients and water, photosynthetic rates can increase and the greatest potential of CO_2 sequestration can occur (Kocher 2007).

The goals for the 2018 tree inventory were to continue gathering tree data, and to calculate the total amount of CO_2 sequestered by the trees in the inventory. The only distinction between Phase I and Phase II was the addition of the CO_2 calculation in Phase II. NAU's 2020 carbon neutral goal is less than one year away and with so many trees on campus, knowing the amount of CO_2 that has been sequestered, is essential information. The following information must be known to calculate carbon neutrality. The first is the amount of energy used in a year, and secondly, the amount of carbon saved or sequestered (offset). Energy used is reduced by the amount of offset to arrive at net carbon footprint. If the subtraction result is zero, neutrality is met. If the subtraction result is a negative number, the institution is a sink (EPA 2018). Without a total of sequestered CO_2 known to campus officials, a significant piece of the carbon neutrality calculation is missing, leaving officials to guess whether or not NAU is truly a carbon neutral university.

Literature Review

Introduction

Today's CO_2 levels are at the highest they have been in three million years (Lindsay 2018). Carbon dioxide levels in the atmosphere go through a natural exchange of rising and falling concentrations through a process called The Carbon Cycle (NOAA 2019). The carbon cycle is the process by which carbon compounds are interconverted among five different pools in the environment, involving the incorporation of carbon dioxide into living tissue by photosynthesis and its return to the atmosphere through respiration, the decay of dead organisms, and the burning of fossil fuels (Lal 2008). There are five major pools of carbon: ocean, fossil fuels, terrestrial carbon, atmospheric carbon, and soil carbon. Each pool has a mechanism of sequestering carbon and ways to release carbon into another pool (Lal 2008 and NOAA 2019). These mechanisms encompasses two smaller subsets of carbon within each five major carbon pool. The two subsets of carbon are housed within each major pool as abiotic (non-living) and biotic (living) carbon.

The scientific community firmly believes the problem with today's rising CO_2 levels stem from mankind's use of fossil fuel (Asselt 2015). Fossil fuel is normally stored underground where it falls out of the carbon cycle (Lal 2008). With the collection and burning of fossil fuel, the CO_2 trapped underground is released back to the carbon cycle (NOAA 2019 and Lal 2008). Over time, this increases the amount of CO_2 in the atmosphere that was previously taken out of the carbon cycle millions of years ago (NOAA).

To combat the problem of the added CO_2 from the burning of fossil fuels, carbon sequestration and the improvement of artificial sequestration technology is being studied and improved. Currently, two possible subsets of the oceanic and soil carbon pools are being studied to see if boosting their sequestration rate is possible (Falkowski 2000). These two subset pools are the abiotic (non-living *i.e*. oceans and geological formations) and biotic (living *i.e.* plants, animals) pools. The abiotic pool is the pool of carbon naturally stored in non-living things like the ocean and the soil of the earth (Lal 2008). The biotic carbon pool encompasses all living species on the earth. Artificial carbon sequestration works by increasing the rate of carbon sequestration in both abiotic and biotic carbon pools. This artificially can occur after the capture of CO_2 from fossil fuels sources and storing the carbon in abiotic structures (*i.e.* the ocean floor or deep underground) or by increasing the photosynthetic rate of plants (Kambale and Tripathi 2010).

Related Study

A study conducted in 2013 considered 11,944 scientific articles published between 1991-2011 which looked at the effects of global warming (Cook et al 2013). This study indicated a consensus among the scientific community regarding the effects of human caused CO_2 emissions (Cook et al 2013). Knowledge of human-caused CO_2 emissions and its effects on the environment increased the desire to find ways carbon sequestration can lower CO_2 levels in the atmosphere (Houghton et al 2001). In 1996, Norway's state-run oil company pioneered efforts to artificially sequester CO_2 released as a result of extracting natural gas from the earth's geological structures (Jain et al 2012). From that point, the idea of artificial carbon sequestration had begun, but the full potential was not realized until a several decades later (Jain et al 2012).

The following section of this professional paper details the current scientific understanding about the rise atmospheric CO_2, along with the potential solutions to combat the rise of CO_2

Current CO_2 Level

Carbon dioxide levels in the atmosphere in 2017 were 405.0 ppm (parts per million) which was an increase of 18% over the last 35 years (Lindsay 2018). Since 1880, global temperatures have increased an average of 0.8 degrees Celsius with 66% of this temperature increase occurring since 1975 (Figure 1) (NASA "World of Change"). This change is thought to be a result of increased burning of fossil fuels which release CO_2 into the atmosphere causing a warming of the earth's surface (IPCC 2018). During the last three million years, the atmospheric levels have fluctuated up and down periodically as natural sources and sinks of carbon dioxide capture and release CO_2, respectively (Lindsay 2018). But not until the industrial revolution, in the mid-1700s, did humans start to increase CO_2 output into the atmosphere faster than what naturally occur (Figure 2) (Lindsay 2018). Fossil fuels, which took millions of years to create and rested deep in the ground, started being extracted and burned at a greater rate than ever before thus causing CO_2 to be released into the atmosphere much faster than the rate of sequestration (Lindsay 2018).

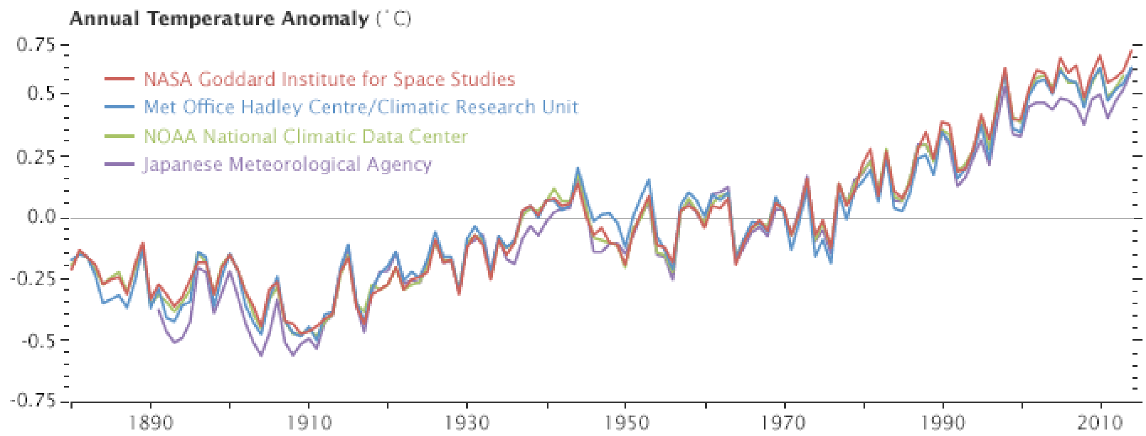

Figure 1. World temperature changes above and below an average since 1880 (NASA "World of Change")

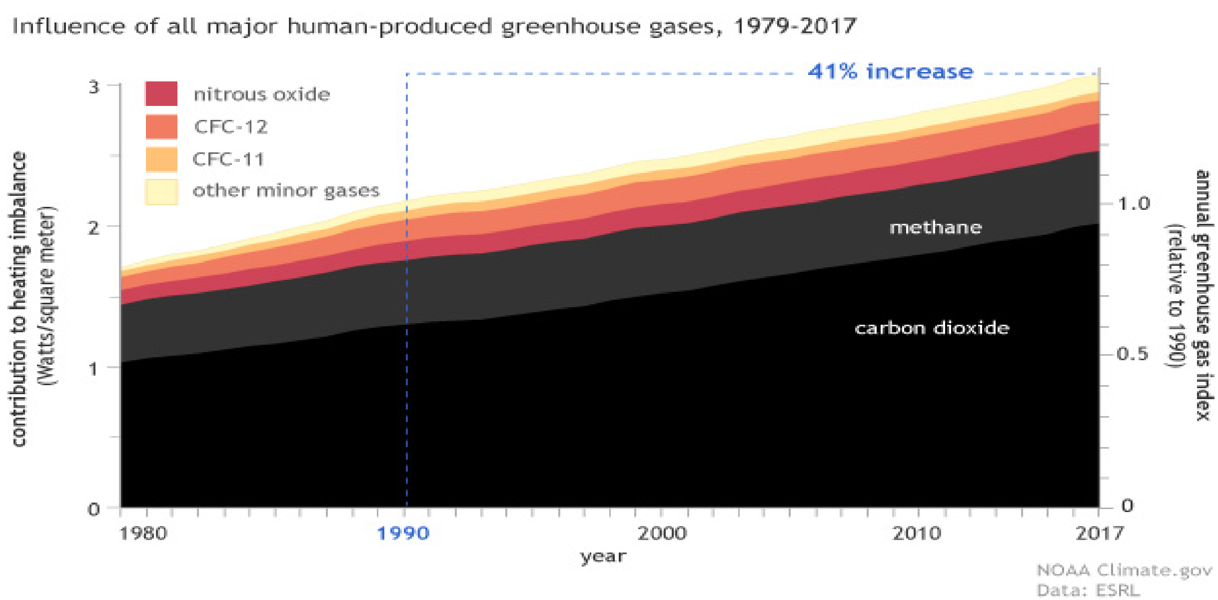

Figure 2. CO_2 increase along the annual greenhouse gas index levels since 1979 (Lindsay 2018). Annual greenhouse gas index describes the Earths ability to absorb and hold heat from solar radiation.

Even with advancements over time in cleaner and more fuel-efficient technologies, CO_2 concentrations in the atmosphere today have increased faster than the prior decade (Figure 2.) (Smith 2016). A major component of this increase stems from China and India increasing production to grow their economy and standard of living

(EPA 2017). Increase in gross domestic product production means more burning of fossil fuels to meet the increased economic development (EPA 2017). Although advancements in technology have occurred to take carbon from the air and sequester it into different natural “sinks” such as the soil or ocean, these advancements are extremely expensive and therefore inaccessible to second world countries (Renforth and Henderson 2017, Smith 2016).

World’s Carbon Storage

The United States Geological Survey defines carbon sequestration as “…the process of capturing and storing atmospheric carbon dioxide” (USGS “What is carbon sequestration”). The earth goes through a natural rise and fall of atmospheric CO_2 which stems from carbon transitioning between five connected sources and sinks (Figure 3) (Batjes 1996, Falkowski 2000, Pacala and Socolow 2004, Houghton et al 2001, Lal 2008). The main storage or **largest pool** of carbon resides in the **world’s oceans**. The ocean carbon pool contains 38,400 peta-grams (Pg) of carbon and that total increases by approximately 2.9 (+- 0.2) Pg C per year (one peta-gram is a unit of measurement that equals 10^15 or 1,000,000,000,000,000 grams). This is equivalent to the weight of 100 Hoover Dams. Oceans house carbon at the surface layer (670 Pg C), deep layer (36,730 Pg C), and in the totality of organic life that reside in the oceans of the world (1,000 Pg C) (Lal 2008).

The **next largest pool** is the **geological pool** comprised of fossil fuels and is estimated at 4,130 Pg C. The burning of fossil fuel adds 7 Pg C a year to the atmosphere (Lal 2008)

The **third largest** of the five carbon pools and the **largest terrestrial pool** are the **earth's soils**, which holds 2500 Pg C (Lal 2008). The total amount of carbon comes from organic matter from the earth's surface and with the weathering of carbonic minerals. The soil pool absorbs 60 Pg C a year from terrestrial organic life but releases 60-61.2 Pg C back into the atmosphere from the decomposition of organic matter. Soil carbon is also responsible in depositing 0.6 +-0.2 Pg C a year into the ocean, through soil erosion and runoff.

The **atmosphere**, which is the **fourth largest carbon pool**, receives the highest amount of CO_2 than the four other carbon pools combined (Figure 3). The atmosphere holds 760 Pg C and increases at a rate of 3.5 Pg C a year (Lal 2008).

Finally, the amount of carbon from **organic material** (plants and animals) is equal to 560 Pg C and is the **smallest of the five pools** (Lal 2008). The earth's plants take up 120 Pg C a year from the atmosphere by photosynthesis, but returns 60 Pg C back to the atmosphere through the process of plant respiration. The other 60 Pg C is stored in these plants and animals until such time decomposition has occurred.

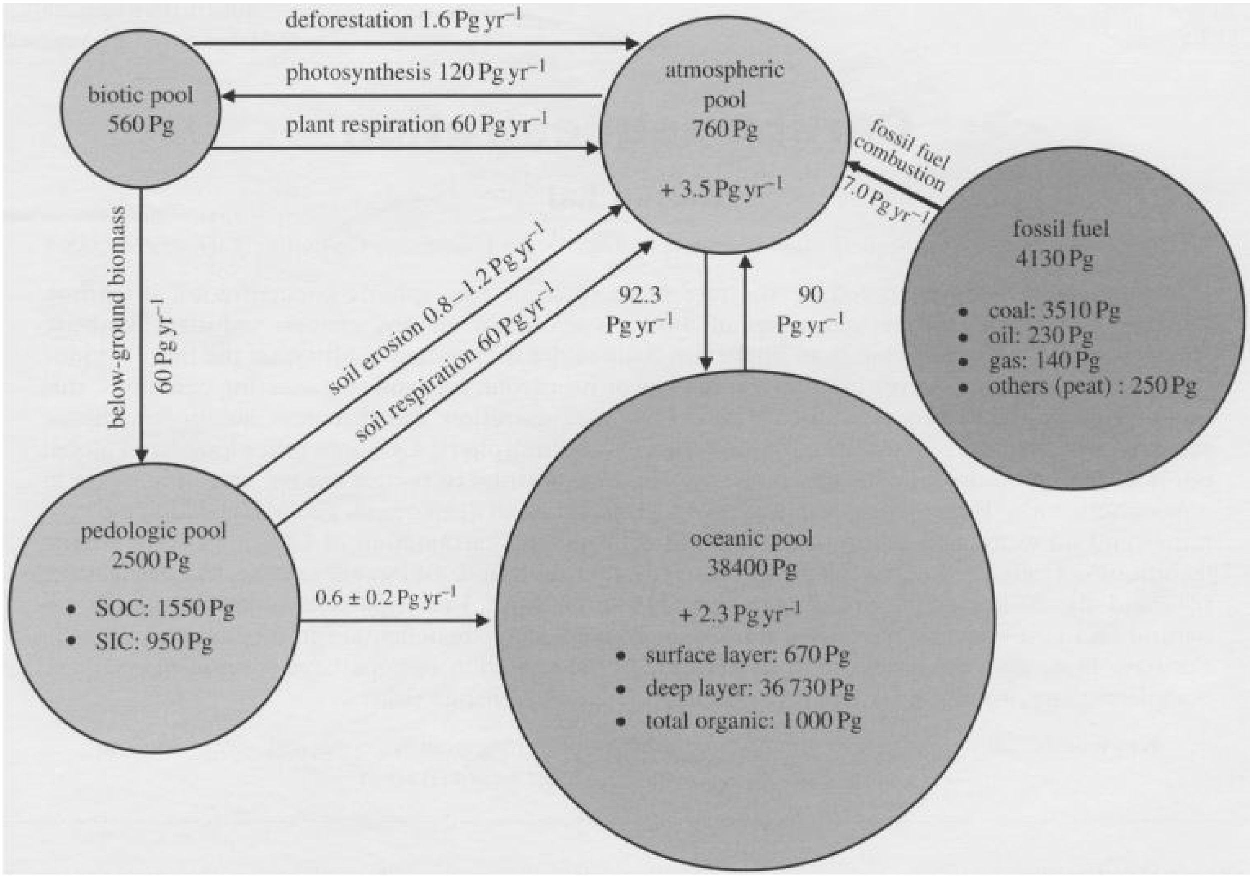

Figure 3. Visual representation of the five carbon pools and the movement between each pool (Lal 2008)

Carbon Sequestration

The burning of fossil fuels is the largest single contributor of the increase in the CO_2 levels in the atmosphere. Emission rates of fossil fuel combustion increased by 40% between 1980-2000 and in 2018 the emission rate increased by 2.8% (Lindsay 2018). This is the largest increase in the last seven years (Wofsy 2001). Even with this increase, the total amount of carbon in the atmosphere did not spike considerably in concentrations because additional carbon was captured by the oceans, forests, soils, and other ecosystem services (Battle et al 2000). In addition, Fung (2000) and Pacala (2001) hypothesize that these sinks had the potential to store even larger quantities of carbon. Because of the potential for housing more carbon in these sinks, Lal (2008) called for more research into ways for humanity to fill the sinks artificially with atmospheric carbon. Carbon sequestration could be achieved using two the different types of subsets of carbon sinks: abiotic (non-living *i.e*. oceans and geological formations) and biotic (living *i.e.* plants, animals) (Lal 2008). Each type of sink has advantages and disadvantages in the amount of carbon sequestration that can occur.

Abiotic Sequestration

Abiotic sequestration, the process of capturing CO_2 and depositing it into geological structures, has received considerable attention for its theoretical capability to sequester vast amounts of carbon (Freund & Ormerod 1997, Lal 2008). The three main technologies that capture CO_2 emitted from the burning of fossil fuels are oxy-combustion, pre-combustion, and post-combustion processes. Oxy-combustion uses pure oxygen as the air source at the time of combustion of the fuel. After combustion, the resulting exhaust is H_2O and CO_2 (Zak et al 2013). The H_2O is separated from the CO_2 gas through condensation and the result is pure CO_2 that is sequestered at a later time (Zak et al 2013). Pre-combustion is the process of converting fossil fuel sources into hydrogen (H_2) and CO_2 prior to combustion which allows for early capture of CO_2 (Jansen et al 2015). The carbon and hydrogen in the fuel source is separated from the fuel when injected with an oxygen-steam mixture to create H_2 and CO_2 (Jansen et al 2015). The H_2 is used as an energy producing fuel for the facility and the CO_2 is captured for storage and future sequestration (Jansen et al 2015). Finally, post-combustion carbon capture occurs after the burning of coal or natural gas. The exhaust is piped to a conditioner, which uses membrane filters or solvents to capture the CO_2 before the cleaned exhaust leaves the plant (Roussanaly et al 2016). In the conditioner, the CO_2 is put under 110 bars of pressure in order to liquefy it for transportation to storage tanks.

All three carbon capture technologies stop CO_2 from being released into the atmosphere and enable storage of CO_2 for later sequestration at appropriate sites (Mai et al. et al 2018). The liquefied CO_2 can then be injected into the ocean at a depth of 1000 meters (m) where it remains partially stable (O'Connor et al. 2001, Lal 2008). Alternatively, the liquid CO_2 can be injected at an even greater depth of 3000m. At this depth, CO_2 is believed to be completely stable and does not dissolve back into a gas (Lal 2008). A concern with this method of carbon sequestration, however, stems from a rise in carbonic acid that forms with an increase in CO_2 concentration (Seibel BA and Walsh 2001). A sharp rise in carbonic acid can pose negative effects that may occur on the oceanic life at the injection site (Seibel and Walsh 2001). More studies would need to be done to understand the full effects of artificial injection into oceans, but as the world's largest sink, the benefits may outweigh the risks.

A possibly less invasive method of carbon sequestration to organic life can occur from injecting liquefied CO_2 underground, but more specifically, into old coal mines, oil wells, or saline aquifers (Tsang et al 2002, Klara et al 2003, Baines & Worden 2004, Gale 2004, Lal 2008, and Fernandez 2019). Coal mines and oil wells have already been highly disturbed and the liquid CO_2 dissolves well in these environments (Lal 2008). The use of saline aquifers is promising because of the low risk of the liquid CO_2

mixing with freshwater, which typically reside above the saline aquifers and protects the fresh water with a non-permeable layer of rock (Klusman 2003, Lal 2008). This separation ensures that any potential leak of CO_2, which is mixed in with the saline solution, will not seep into the freshwater above.

Biotic Sequestration

Biotic sequestration is the management of plants and other microorganisms to remove CO_2 from the air and sequester the carbon into the ground and into the structure of the plants (Lal 2008). One possible way to speed up the process of carbon sequestration goes back to the potential of our world's oceans. The world's oceans are home to 1 billion tonnes (metric tonnes=2204 pounds) (equivalent to 3,000 Empire State buildings) of phytoplankton (Falkowski 2012). The annual oceanic photosynthesis rate for plankton alone is calculated at 45 Pg C or 45 times the planktons' total weight (Falkowski et al 2000 and Falkowski 2012). When the plankton die, a portion of the total amount of dead plankton finds its way to the bottom of the ocean where it becomes sequestered by additional layers of dead organics and sediments (Raven JA and Falkowski PG 1999). If managed, the process of photosynthesis can be increased by adding iron (Fe), a nutrient sparsely available in the world's oceans (Martin and Fitzwater 1988). With more Fe in the water, plankton increase their photosynthetic rate which can speed up carbon sequestration with more organic particulate matter falling to the ocean floor as the plankton dies off. However, this process contains many unknowns as to how it may affect the ocean's environments (Rizwan et al 2017). Increased plankton resulting from increased (Fe) could cause a bloom that would result in a higher atmospheric CO_2 concentration due to decomposition being larger than what is sequestered (Rizwan et al 2017).

Wetland soils (subset) are the largest sink within the soil carbon pool (Figure 3.). Wetland soils (histosols) in the Northern regions of the world hold an estimated 450 Pg C (equivalent to 30,000 Empire State buildings) or 18% of the world's soil carbon (Gorham 1991, Warner et al 1993). In these northern regions where permafrost comes into play, wetlands have low oxygen levels in the soil which hinders decomposition and respiration of CO_2 back into the atmosphere (Kobak et al 1998 and Lal 2008). Considering the lower temperatures and low oxygen levels, any organic matter that falls into a wetland environment does not have the opportunity to decompose. This allows the small amount of organic carbon to accumulate at a rate of 0.1 Pg C per year. This accumulation has occurred over a long period of time (over 19,000 years) since the last ice age. During this time, 0.1 Pg C released per year in the northern wetlands has added up to an amount almost 200 times the total carbon of all vegetation growing on the wetlands (Garnett et al. 2001).

The carbon that has been sequestered into the wetlands will remain static until it is disturbed and decomposition is able to occur. Whenever wetlands are converted to farmland or other development, the stored carbon is released back into the atmosphere in the form of CO_2 (IPCC 2018). From 1970-2015, 35% of the world's wetlands were converted for development or lost due to global warming impacting the natural sequestration process. This wetland mass conversion is equivalent to an area the size of India or 1,269,210 square miles (sq. mi.) (IPCC 2018). By preserving wetlands, we can ensure a steady deposit of carbon into the ground and make sure the carbon already in the ground is not released back into the atmosphere.

A second biotic solution to carbon sequestration comes in the form of biochar (Fowles 2007). Biochar is created by burning woody plant material in a low oxygen environment that provides energy for the processing facility and creates a byproduct of stable carbon usable as an alternative to commercially bought fertilizers (Fowles 2007 Debiagi et al 2018). The process of sequestering biochar is less costly and time consuming than injecting liquid CO_2 in the ocean or saline water reservoirs underground as biochar only has to be buried 0.5 – 1m underground (Lal 2008). Biochar is completely stable and an excellent source of nutrients for soil life. Biochar is a cheap solution for depositing atmospheric CO_2 and a great fertilizer for soil environments (Smith 2016).

The world's forests, constitute a third biotic solution with an annual carbon sequestration rate of approximately 1.7 Pg C per year (Fan et al 1998). The carbon is stored in any harvested material, woody debris, and any produced wood products (Wofsy 2001). Estimates indicate that the United States could increase sequestration through afforestation by 117 Tg C per year (Tg= teragram or 10^12 grams) (IPCC 2018). Afforestation has been shown to work; from 1970 to 1998, China increased carbon sequestration rates by 21 Tg C per year through a combination of afforestation and the annual growth of existing trees (Fang et al. 2001).

Trees are a very important tool in combating rising atmospheric CO_2 levels. Their ability to continually grow and sequester carbon into both the soil and into their overall structure is a natural sequestration process (Lal 2008, Nowak and Crane DE 2002). Arguments do exist, however, against relying heavily on trees because when a tree dies the carbon is released back into the environment through decomposition (Silva 2017). Silva argues this is true for single trees but the argument does not look at the influences single trees have on the local soil environment (Silva 2017). When a tree dies, it releases carbon back into the atmosphere but it also releases carbon into the soil and onto the forest floor (Silva 2017). The released carbon can be shared with other trees and plant species via “root-microbial networks” (Silva 2017). These networks in the presence of carbon speeds the weathering of minerals in the soil and in this biological process uses CO_2 to fuel this interaction (Silva 2017).

Carbon Neutrality

Carbon neutrality is the overarching goal of most countries of the world and many different universities across the United States (Asselt et al 2015, Saral et al 2017, Song et al 2017). The definition of carbon neutrality is having a net zero carbon footprint where the amount of carbon released by the burning of fossil fuels is balanced by the carbon sequestered or saved using renewable energy (go-green.ae). The process of offsetting carbon comes from using alternative energy sources not derived from fossil fuels. Alternative energy can come from electrical power generated by solar panels and wind turbines (Chu et al 2017). Recycling paper and other reusable material, planting and maintaining trees, and using updated insulation in buildings are additional ways to mitigate the carbon footprint.

NAU has a goal of carbon neutrality by 2020 as expressed by then NAU President John Haeger. Dr. Haeger signed the American College and University Presidents' Climate Change Commitment in 2007, which called for universities to be carbon neutral by 2020 (CEFNS.NAU). NAU approached this goal in multiple ways. First, NAU followed the Leadership in Energy & Environmental Design (LEED) program for new building design, construction, and overall campus operations. Part of the NAU LEED projects' requirements was to install electrical meters to monitor energy use (CEFNS.NAU). This was required on all buildings constructed after 2007 and natural lighting was implemented to decrease energy usage. Many of the sprinklers on campus use reclaimed water as a way to reduce the need for water treatment which in turn reduces energy consumption (Schouten et al 2013). Solar panels have been installed on the rooftop of one of the parking garages and low flow toilets have been installed about the campus. Anytime NAU can use renewable (sun or wind generated) energy or deploy recycling efforts, they are taking steps toward carbon neutrality.

Phase II of the tree inventory was the first time NAU's Campus Tree Committee looked at the natural CO_2 sequestration by campus trees. In 2014, NAU joined Tree Campus USA whose main goal is to sustain healthy community forests across universities and colleges in America (Tree Campus USA Standards). In joining Tree Campus USA, a committee was created and comprised of NAU faculty and staff as well as a forester from the city of Flagstaff. In 2015, the committee reestablished a goal to complete the campus wide tree inventory that began in 2014 (Phase I). The inventory would not be looked at again until Phase II, which happened the summer of 2018.

Calculating the amount of carbon the inventoried trees on NAU's campus have sequestered, was added to the data collection of the Phase II inventory. With NAU's goal of being carbon neutral by 2020, the Campus Tree Committee determined that calculating the total carbon sequestered by the trees on campus provided a truer picture of where the university was in their desire to be carbon natural (CEFNS.NAU)

With the scientific research clear on the success of sequestration provided by trees (Lal 2008, Fargione 2018), and with NAU's goal of being carbon neutral, the methods laid out below serve as a guide for calculating the total pounds of CO_2 campus trees sequester. The Phase II effort to complete a campus tree inventory and related sequestration provided NAU with additional information to use in determining what level of carbon neutrality the campus possesses.

Methods

The goal for the Phase II inventory, the foundation of this professional paper, was to add to the data captured in Phase I, with the eventual goal of having all campus trees inventoried. The 2018 inventory (Phase II) was conducted in the area North of University Drive, West of Beaver Street, and South of Blome Drive. The ultimate goal of the Phase II inventory was completing the entire northern part of campus (University Street to Butler Street). To maintain consistency within the Phase I inventory, the 2014 protocols were utilized (Appendix A).

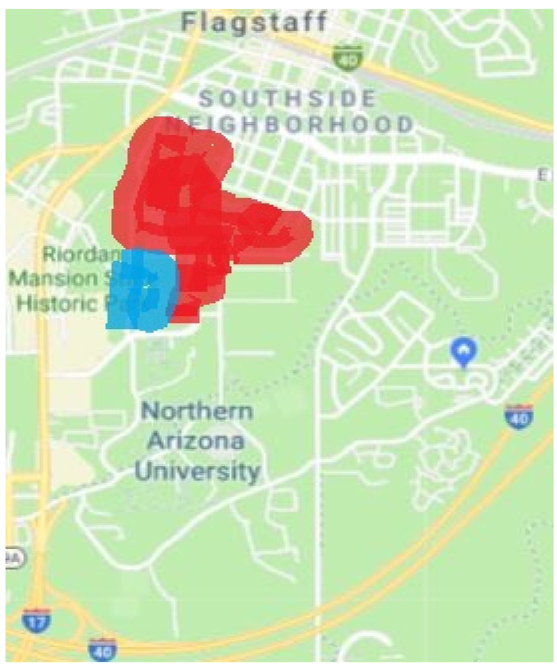

Figure 4. Map of Northern Arizona University showing Phase I (red) and Phase II (blue) locations captured in the inventory

The Phase I inventory of NAU trees started on February 2, 2014 and ended on June 22, 2014. The Campus Tree Committee hired a consulting arborist from the City of Flagstaff to conduct the inventory on behalf of the committee. The goal of the first inventory was to comply with the Campus Tree Committee's effort to have all the trees on campus counted and tallied (NAU's Tree Campus Plan 2015). With Phase I of the inventory, the arborist selected 11 variables, as described below, because they are fundamental for gauging the health and quality of the trees on campus (fia.fs.fed).

Below are the eleven variables collected for the inventory:

- Species: both scientific and common name recorded;
- Height: measured to the nearest foot using a clinometer;
- DBH: measured to the nearest 0.1 inch using the diameter side of the logger's tape;
- Condition: based on seven visual criteria (*i.e.* trunk condition, missing branches, pests present, yearly growth, ect.) all of which have point values associated with them to provide the overall health condition of the tree (Appendix A);
- Condition Class: the percent value of the condition of the tree *i.e* (a tree with a good condition will have a condition class of 80%) (Appendix A);
- Hazard Level: is based on the seven criteria (trunk condition, and pests present) from the condition. Hazard level takes the condition of the tree and the potential danger the tree may have to the public (scale 100=no danger 0=extremely dangerous) (Appendix A);
- Hazard Rating: similar to condition class, hazard rating is the value of hazard level *i.e* (1=no danger 10=extremely dangerous);
- Trunks: number of stems above breast height;

- Species Rating: falls within a percentage rating of 0-100% based on environmental factors such as: growth characteristics, maintenance needs, structural qualities, and longevity. Each tree species has their own designated percentage rating which is used to calculate the appraisal value of the tree (the complete list can be found in Appendix A);
- Location Class: is used for the appraisal of trees to access the value. The location class of the tree is based on a scale from 20-100 *i.e* (historical tree=100, park tree=60, and a tree in the woods=20) (Appendix A);
- Maintenance: this criterion is any suggestion given to maintain the tree, i.e. (limbing of dead branches, thinning a portion of trees in a group, and removing a tree)

(A complete description of the variables is in Appendix A)

All field data were collected on an Android tablet device. To aid in the data collection, an app was developed in 2014 by the School of Informatics, Computing, and Cyber Systems (SICCS) at NAU. Matthew Tafoya, who is the Systems Analyst oversaw the creation of the app used for both Phase I and Phase II. The app created a set of dropdown menus for each data field that increased the efficiency of the field data collection and reduced data entry errors. This also allowed real-time live data entry to a copy of the master database housed at SICCS.

The 2018 inventory was conducted from June 11th to August 26th using the same protocols as Phase I. However, with an improvement to the app, the amount of carbon sequestered in each tree was automatically calculated and updated in the database. In

Phase II, CO_2 sequestration was added to the inventory data set. Once the dbh and height were collected, the app automatically calculated the above ground CO_2 that was sequestered (lbs.). This equation line was applied to both Phase I and Phase II inventories which provided sequestration totals for both inventories. The sequestration calculations were based on tree height, and dbh. The equation line is, CO_2 sequestered = 0.20*(DBH^2) * Height * (0.725) * (0.5) * (3.6663)

where (0.725=Dry weight, 0.5=Weight of Carbon, 3.6663=atomic weight of CO_2). This equation calculates the total above ground carbon a single tree has sequestered from its germination to when the tree was inventoried (Villiers et al 2014). For Phase II, I chose this equation because it is an estimate of carbon sequestration by average wood density across tree species (Villiers et al 2014). This provides an overall good equation to estimate sequestration over many different tree species, which applies to NAU's campus.

With the knowledge of the total CO_2 sequestered, informed decisions can be made to properly maintain campus trees. Access to this data will allow policy makers, without requiring numerous rounds throughout the campus, to provide direction to groundskeepers on which trees should be removed to protect the community; which trees need maintenance to boost aesthetics and overall health; or need to be removed for campus building-ground disturbance and-or modifications.

Results

Phase I and Phase II of the inventory totaled 1741 trees on campus with Phase II accounting for 209 trees (12% of the total) with more than 2-3rds of the campus still needing to be inventoried. To-date, 1741 trees have sequestered a total of 3,186,187lbs of CO_2.Below is a table of all of the tree species on campus with the average and range in dbh, height, and CO_2 sequestered.

Table 1. Average dbh, height, and CO_2 sequestered along with the total number of trees and their total percentage of the 1741 trees inventoried. (*) was added to common name if missing complete scientific name, as it was not collected by the arborist during Phase I or in Phase II

Common name	Scientific name	Trees		dbh (in)		Height (ft)		Carbon Sequestered (lbs)		
		Number	% of Total	Average	Range	Average	Range	Average CO_2 lbs. per tree	Range	Total
Alligator Juniper	*Juniperus deppeana*	3	0.2	15.8	5.9 - 22.8	26	18 - 32	2,439	166 - 4,145	7,317
American Elm	*Ulmus americana*	17	1	17.1	2.8 - 33.3	42	7 - 75	6,170	14 - 22,106	104,905
Apache Pine	*Pinus engelmannii*	1	0.1	3.4	0.00	17	0.00	52	0	52
Arixona Walnut	*Juglans major*	1	0.1	2.2	0.00	15	0.00	19	0	19
Aspen	*Populus tremuloides*	253	14.5	4.4	1.0 - 21.8	22.9	5 - 52	251.1	1.4 - 4,294	63,533
Austrian Pine	*Pinus nigra*	122	7	10.4	1.0 - 22.5	25.1	6 - 46	1,061.3	1.5 - 5,088	129,484
Bigtooth Maple	*Acer grandidentatum*	1	0.1	2.4	0.00	13	0.00	19	0	19
Birch	*Betula occidentalis*	28	1.6	6.4	1 - 15	25	11 - 14,649	459.3	2 - 2,033	12,860
Black Cherry	*Prunus serotina*	1	0.1	14.4	0	30	0.00	1,653	0	1,653
Black Locust	*Robinia pseudoacacia*	10	0.6	15.9	8.8 - 30.7	51	35 - 64	4,525.9	787 - 15,031	45,259
Blue Atlas Cedar	*Cedrus atlantica*	1	0.1	5.8	2 - 33.2	18	0.00	160	0	160
Blue Spruce	*Picea pungens*	183	10.5	9.7	0.00	26.2	6 - 63	1,563.1	11 - 14,770	286,063
Boxelder	*Acer negundo*	4	0.2	5.5	4 - 6.4	16.3	12 - 25	138.3	51 - 215	553
Bristlecone Pine	*Pinus aristata*	4	0.2	4.5	2.5 - 6.6	13.3	8 - 17	95	13 - 196	380

Common name	Scientific name	Trees		dbh (in)		Height (ft)		Carbon Sequestered (lbs)		
		Number	% of Total	Average	Range	Average	Range	Average CO_2 lbs. per tree	Range	Total
Cherry*	*Prunus*	1	0.1	14.1	0.00	23	0.00	1,215	0	1,215
Chokecherry	*Prunus virginiana*	26	1.5	3.1	2.1 - 4.6	16.4	1 - 23	46.9	14 - 168	1,218
Cottonwood	*Populus fremontii*	19	1.1	18.1	2 - 48.2	45.1	14 - 98	10,977.2	14 - 50,430	208,567
Crabapple*	*Malus*	78	4.5	5.7	1 - 15.8	15.9	4 - 28	236.9	1 - 1,857	18,474
Domestic Apple	*Malus domestica*	14	0.8	10.4	1 - 21.2	23.3	10 - 39	1,168	2 - 4,539	16,352
Douglas Fir	*Pseudotsuga menziesii*	9	0.5	18.4	13.1 - 24.2	46	34 - 59	466.9	1,642 - 8,561	41,993
Eastern Hemlock	*Tsuga canadensis*	2	0.1	5.5	2 - 8.9	22.	11 - 33	352.5	11 - 694	705
Engelmann Spruce	*Picea engelmannii*	12	0.7	28.6	21 - 38	68.7	61 - 78	15,358.8	7,150 - 26,867	184,306
European White Birch	*Betula pendula*	1	0.1	15.5	0.00	50	0.00	3,193	0	3,193
Gambel Oak	*Quercus gambeii*	20	1.1	1.6	1 - 9.1	9.5	6 - 31	48.7	1 - 682	973
Giant Sequoia	*Sequoiadendron giganteum*	2	0.1	12	11.2 - 12.8	24.5	2 - 26	949	766 - 1,132	1,898
Green Ash	*Fraxinus pennsylvanica*	31	1.8	7.1	1 - 23.8	24.1	7 - 61	1,043.5	1.8,063	32,349
Hawthorn*	*Crataegus*	12	0.7	9.1	2.7 - 20.2	25.8	12 - 41	929.8	26.2,928	11,158
Honey Locust	*Gleditsia triacanthos*	76	4.4	8	1 - 25.7	24.5	1 - 66	849.7	2 - 8,073	65,579
Limber Pine	*Pinus flexilis*	2	0.1	11.5	10.7 - 12.2	37	36 - 38	1,299	1,095 - 1,503	2,598
Linden*	*Tilia*	10	0.6	9	2.8 - 11.8	25.5	12 - 32	674.3	25 - 1,086	6,743
Mountain Mahogany*	*Cercocarpus*	1	0.1	1.8	0.00	15	0.00	12	0	12
Narrowleaf Cottonwood	*Populus augustifolia*	1	0.1	20.2	0.00	52	0.00	5,639	0	5,639
New Mexican Locust	*Robinia neomexicana*	1	0.1	1.2	0.00	8	0.00	3	0	3
Norway Maple	*Acer platanoides*	1	0.1	5.4	0.00	21	0.00	162	0	162
Norway Spruce	*Picea abies*	1	0.1	6.2	0.00	18	0.00	18	0	183
Peach	*Prunus persica*	1	0.1	5.2	0.00	10	0.00	71	0	71
Pear*	*Pyrus*	105	6	2.8	1 - 14	12.5	7 - 35	72.2	2 - 1,562	7,578
Pinyon	*Pinus edulis*	4	0.2	7.3	3.5 - 15	20.5	9 - 39	666.3	31 - 2,332	2,665

Common name	Scientific name	Trees		dbh (in)		Height (ft)		Carbon Sequestered (lbs)		
		Number	% of Total	Average	Range	Average	Range	Average CO_2 lbs. per tree	Range	Total
Plum*	*Prunus*	54	3.1	4.8	1 - 15.5	15.1	6 - 36	177.4	1 - 1,468	9,579
Ponderosa Pine	*Pinus ponderosa*	173	10	17.1	1 - 37.6	44.9	4 - 91	5,810.7	1 - 27,960	1,005,257
Red Maple	*Acer rubrum*	169	9.7	3.3	1.7 - 10.9	18.4	10 - 28	67.2	9 - 884	11,357
Red Oak	*Quercus rubra*	6	0.3	8.6	4.8 - 16.5	29.8	25 - 39	813.2	159 - 2,822	4,879
Red Spruce	*Picea rubens*	3	0.2	13.7	10.6 - 19.8	39.7	31 - 56	2,571.7	925 - 5,835	7,715
Riles Rose*	*Rosa*	1	0.1		0.00		0.00		0	0
Rocky Mountain Juniper	*Juniperus scopulorum*	4	0.2	5.6	1 - 9.5	15.5	6 - 22	232	1 - 527	928
Russian Olive	*Elaeagnus augustifolia*	11	0.6	10	2.7 - 24.5	26.7	18 - 41	1,289.6	34 - 6,541	14,185
Scots Pine	*Pinus sylvestris*	12	0.7	10.1	3 - 20.1	21.3	9 - 27	807.7	21 - 2,899	9,692
Siberian Elm	*Ulmus pumila*	123	7.1	18.2	1 - 47.3	38.2	11 - 65	4,464	2 - 32,707	666,945
Silver Maple	*Acer saccharinum*	8	0.5	11.8	3.1 - 28	29.4	19 - 46	2,330.5	51 - 8,960	18,644
Southwest White Pine	*Pinus strobiformis*	9	0.5	5.2	2.4 - 12.5	17.1	10 - 30	226	18 - 1,245	2,034
Spanish Fir	*Abies pinsapo*	1	0.1	3.1	0.00	10	0.00	25	0	25
Subalpine Fir	*Abies lasiocarpa*	2	0.1	12.5	7.6 - 17.4	35	30 - 40	1,839.5	460 - 3,219	3,679
Sugar Maple	*Acer saccharum*	1	0.1	6.4	0.00	35	0.00	381	0	381
Sycamore	*Plantanus wrightii*	17	0.9	7.9	4.5 - 19.7	27.9	23 - 40	770.1	139 - 3,797	9,790
Sycamore Maple	*Acer pseudoplatanus*	1	0.1	19.7	0.00	32	0.00	3301	0	3,301
Utah Juniper	*Juniperus osteosperma*	25	1.4	7.5	1 - 17.8	19.3	4 - 34	527.2	1 - 2,442	13,180
White Fir	*Abies concolor*	9	0.5	9	4.5 - 12	27.3	17 - 41	723.1	91 - 1,569	6,508
White Mulberry	*Morus alba*	1	0.1	17	0.00	15	0.00	1,152	0	1,152
White Poplar	*Populus alba*	4	0.2	25.6	20.5 - 32.3	52.3	45 - 66	9,773.8	5,473 - 18,302	39,095
Willow*	*Salix*	5	0.3	33.8	15.1 - 50.8	46.6	36 - 59	18,193.6	2,181 - 40,471	90,968

Below I have summarized the main results from both inventories (Phase I and Phase II) of NAU's campus' trees. Without this inventory, NAU's policy makers would have to rely on guess work when making decisions about the aesthetics and maintenance of the trees on campus.

Top five tree species with the highest recorded number of trees:

- Aspen-253
- Blue Spruce-183
- Ponderosa Pine-173
- Red Maple-169
- Siberian Elm-123

Top five tree species with the largest average dbh (in):

- Willow-33.8
- Engelmann Spruce-28.6
- White Poplar-25.6
- Narrowleaf Cottonwood-20.2
- Sycamore Maple-19.7

Top five tree species with the largest average height (ft):

- Engelmann Spruce-68.7
- White Poplar-52.25
- Narrowleaf Cottonwood-52

- Black Locust-51.2
- European White Birch-50

Top five tree species with the largest average CO_2 sequestered (lbs):

- Willow-18,193
- Engelmann Spruce-15,358
- Cottonwood-10,971
- White Poplar-9,773
- American Elm-6,170

Top five tree species with the largest total amount of CO_2 sequestered (lbs):

- Ponderosa Pine-1,005,257
- Siberian Elm-666,945
- Blue Spruce-286,063
- Cottonwood-208,567
- Engelmann Spruce-184,306

The results show that ponderosa pine has sequestered more CO_2 than any other inventoried tree species on campus. This stems from two main reasons, the first is ponderosa pine is the third most abundant tree species on the north campus. The second reason is ponderosa pine sequesters 5,800 lbs. of CO_2 on average. Based on this information, the drawn conclusion is that ponderosa pine is the most important tree species to the NAU campus for CO_2 sequestration.

Discussion

The goal of Phase I was to establish an inventory of the trees on NAU's campus. This was done by the Campus Tree Committee working with ICCS to develop an app that would ease the work for the arborist rather than writing out the data to transfer it to a spreadsheet. Through the work done by the ICCS, this goal was met. With the Phase II continuation of the project, under Dr. Kolb's direction, it was determined the most important aspect of this Phase was CO_2 sequestration. Therefore, the goal was established to develop a way in which the Campus Tree Committee could look at a tree on the map and know, based on data the amount of CO_2 the tree has sequestered.

What could be added to this inventory is a yearly sequestration rate of the trees on campus. The total of 3,186,187lbs of CO_2 is for all of the inventoried trees through their lifetime. This total could be used for a yearly sequestration rate if the ages of the trees are known and documented. For example, if the average age of the trees along S. Knoles Dr. were calculated, it would reduce the time of aging each and every tree to obtain a yearly rate of CO_2 sequestration. If the average age of the trees is 12 years, that average age variable could be used by the app's equation line and divide each trees CO_2 by the age. After running the equation for these seven trees, the yearly CO_2 sequestration rate is 57.9lbs of CO_2 per year. Once the average tree age is calculated, a yearly CO_2 sequestration would be known and deducted from the CO_2 emissions NAU produces. This would help NAU in completing the policy goal of carbon neutrality by offsetting a large amount of CO_2 from its yearly emissions.

Therefore, if groundskeepers planned to construct a storage shed or a picnic bench in a location where trees have been inventoried, with the overarching goal of keeping campus carbon neutral, they would have to make a decision on which trees to remove for new structures. Groundskeepers could look at the inventory map and select which trees to remove to accommodate campus modifications and new structures depending on the objectives of what trees should be saved *i.e.* (health conditions, dbh, location class, etc.) based on the inventory data associated with each tree. If keeping the most amount of CO_2 on the ground is the main objective, knowing the per tree carbon values gives more power to policy makers in knowing that their decisions are in alignment with NAU's stated goals. We can expand this example to an entire construction site. If a new building is being constructed and there are a total of 35 trees on that site all of which would be removed, the total amount of CO_2 removed can be calculated and removed from yearly sequestration rate total. This would allow the Campus Tree Committee to know how many trees need to be planted to compensate for the trees that were removed from campus to make way for a new building.

Conclusion

This project has made great strides from its initial start in 2014. Originally, it was a project started by the Campus Tree Committee to document the number of trees the committee had to manage. In Phase II, the goal was to continue the Phase I inventory along with adding the CO_2 sequestration totals on campus. As stated in the results, the total amount of CO_2 that has been sequestered was 3,186,187lbs. This amount averaged over the 1741 trees inventoried is 1830lbs of CO_2 per tree. With only one-third of the trees on campus being inventoried, there is still a significant amount of sequestered CO_2 unaccounted for. Most of the trees inventoried are smaller species of trees which include aspen, cherry, and plum, for example. These smaller species do not have the capability to sequester large amounts of CO_2 (Bourg-Meyer 2017). The reason small tree species cannot sequester large amount of CO_2 comes from the fact they do not put on much biomass to grow big and tall (Bourg-Meyer 2017). Given the lower biomass and growth rate, these trees are less efficient in CO_2 sequestration. With a visual observation, most of the trees south of University St are large ponderosa pine that currently hold large amounts of CO_2. Table 1 shows ponderosa pine have an average of 5,800 lbs. of CO_2 sequestered. Therefore, with two-thirds of campus not included in the Phase I and II inventories, most of which are ponderosa pine, there is a large amount of CO_2 not recorded. Without actually making measurements, it is safe to say that these trees must be inventoried or use remote sensing to estimate CO_2 sequestration. Once these trees are inventoried, an accurate CO_2 total can be calculated for campus policy makers. With this information, new steps can be taken to get NAU closer to its goal of carbon neutrality. Additionally, with the data from the newly inventoried trees, NAU could show it is sequestering more CO_2 than it is emitting. Should this be the case, NAU should celebrate exceeding their goal and going beyond what they originally set out to do. This information will allow NAU to make positive, informed decisions and shape future policy desires for the betterment of the University and the community it inhabits.

The inventory of the trees on NAU's campus follows the first code of ethics established by the Society of American Foresters (SAF). The first code of ethics states, "Foresters have a responsibility to manage land for both current and future generations. We pledge to practice and advocate management that will maintain the long-term capacity of the land to provide the variety of materials, uses, and values desired by landowners and society". My personal ethics mimics SAF's first code of ethics in the fact that I believe it is my job to ensure future use and enjoyment in all the forests I have the privilege to work in. Based on the objectives laid out before me, I will base my decisions on completing and fulfilling the objectives and with the goal of sustainability of the land at the forefront of my mind.

This first code also encompasses the project as a whole. The desired outcome from the project was to inventory the trees on campus along with totaling the amount of CO_2 campus trees have sequestered. The value the Campus Tree Committee determined the trees on campus hold is their ability to sequester CO_2.

In 2007, NAU established the ethical view that the campus was to be carbon neutral by 2020 and to reach this goal, research needed to be done on the trees on campus. With this decision, the Campus Tree Committee was created in 2014 along with the committee starting Phase I and later Phase II of the inventory. One ethical decision started a ripple effect on what should be done to manage campus trees in the present and in the future.

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Appendix A.

This data is the complement of articles and reports used to help in the data collection of the inventory variables.

Utah Forest Facts
UtahStateUniversity COOPERATIVE EXTENSION
Urban Community Forestry NR-FF-001 (updated February 2012)

Species Ratings for Landscape Tree Appraisal in Utah

Mike Kuhns, Extension Forester,

in cooperation with the Utah Community Forest Council & Utah Chapter ISA

This fact sheet establishes species ratings to be used by tree appraisal experts with the trunk formula method for appraising the monetary value of trees in Utah.

Species Ratings and the Trunk Formula Method

The dollar value of a landscape tree occasionally needs to be determined for insurance purposes, condemnation, real estate transactions, or tree inventories. For larger trees the trunk formula method often is used for establishing these values. This method starts with calculation of a basic value and adjusts that value for the species, condition, and location of the tree.

This fact sheet establishes species ratings for nearly all trees likely to be found in the Intermountain West, with a particular focus on Utah. These species ratings are for use with the trunk formula method of tree appraisal. These ratings are not to be used with the replacement cost method since they are already reflected in the cost of the replacement tree.

The complete tree appraisal procedure is described in detail in the "Guide for Plant Appraisal" prepared by the Council of Tree and Landscape Appraisers and published by the International Society of Arboriculture (9th edition, available from ISA, P.O. Box 3129, Champaign, IL 61826; phone (217)355-9411; www.isa-arbor.com.

Uses and Limitations

Species ratings in this guide are given by Latin name and common name and are expressed as percentages, with a maximum possible value of 100% and a minimum value of 5%. Latin names are used to keep like species together in the table. These ratings are subjective, based on a tree's adaptability to environmental factors, growth characteristics, aesthetics, maintenance needs, structural qualities, longevity, and allergenic properties.

Each species is given a rating range of about 10 to 20 points, within which most trees of that species will likely fall. Ratings should be adjusted within or even outside of the given range if local conditions require. For example, a species planted on a site where it is poorly adapted might get a lower species rating, and an otherwise poor species planted in an especially harsh area where nothing else will do well might get a higher species rating. Species ratings should be based only on overall species-related factors, without regard to condition or location factors that are tied to a specific tree and its site.

These species ratings and the related appraisal methods generally are for trees in cultivated or developed landscapes where the tree lends considerable aesthetic and functional contribution to the site. They generally should not be used for appraising trees in undeveloped, unpopulated rural areas. Such trees may be better evaluated using forest timber appraisal techniques. Better appraisal techniques also exist for shrubs, windbreak trees in rural, non-residential situations, and for appraisal of orchard trees or Christmas trees.

Knowledge Is Essential

Appraisal of landscape trees and adjustment of the species ratings included in this fact sheet should only be done by persons who are experts in use of the appraisal techniques. These persons also must be knowledgeable about the species involved, site conditions, and about trees and tree biology.

The species ratings in this fact sheet are based on the knowledge and opinions of the author and of several experts involved in community forestry in the area. We welcome input and advice. Contact Mike Kuhns, Extension Forester, Utah State University, Logan, UT 84322-5230, or send e-mail to mike.kuhns@usu.edu.

Other Appraisal Factors

The following factors are needed for conducting tree appraisals (see the "Guide to Plant Appraisal") and were derived from a 2012 survey of nurseries in Utah. They will change regularly. For up-to-date figures, or for other community forestry assistance, contact the Utah Community Forest Council at www.utahurbanforest.org.

Largest commonly available transplantable tree size

– the average size of the largest normally available tree for the surveyed nurseries: **2.4-inch trunk caliper (4.52 square inches)**

Replacement cost – the cost to buy the largest normally available tree (see above), including warranty: **$260**

Installation cost – including delivery and planting: **$153**

Installed tree cost – including tree, delivery, and planting:

$413

Unit tree cost – the cost per square inch of trunk area (not including installation): **$58 per square inch**

Wholesale tree cost – the wholesale cost to buy the largest normally available tree for the surveyed nurseries (generally reflects a discount given to landscapers): **$218**

Species Ratings

<u>**Species**</u>	<u>**Rating**</u>
Gymnosperms (mostly with needle or scale foliage)	
❖ *Abies concolor* — white or concolor fir	75-95%
❖ *Abies lasiocarpa* — subalpine or alpine fir	60-80%
Calocedrus decurrens, Libocedrus decurrens — incense-cedar	75-95%
Cedrus atlantica, deodara, libani, etc. — true cedars	90-100%
Chamaecyparis obtusa — Hinoki falsecypress • Hinoki cypress	75-95%
Cupressus arizonica — Arizona cypress	75-95%
Cupressus sempervirens — Italian cypress	75-95%
Ginkgo biloba — ginkgo • maidenhair tree (male only; female 10-30%)	90-100%
Juniperus chinensis, ❖*osteosperma,* ❖*scopulorum, virginiana,* etc. — junipers	55-75%
Larix decidua, kaempferi, etc. — larches	80-100%
Metasequoia glyptostroboides — dawn redwood	80-100%
Picea abies — Norway spruce	75-95%
❖ *Picea engelmannii* — Engelmann spruce	70-90%
Picea glauca — white or Black Hills spruce	75-95%
Picea glauca 'Conica' — dwarf Alberta spruce	50-70%*
Picea omorika — Serbian spruce	75-95%
❖ *Picea pungens* — blue or Colorado blue spruce	75-95%
Pinus bungeana — lacebark pine	90-100%
❖ *Pinus contorta* — lodgepole pine	60-80%
Pinus densiflora — Japanese red pine	70-90%
❖ *Pinus edulis* — pinyon • Colorado pinyon	65-85%
Pinus eldarica — Afghan pine	70-90%
❖ *Pinus flexilis* — limber pine	80-100%
Pinus halepensis — Aleppo pine	60-80%
Pinus heldreichii — Bosnian pine	70-90%
❖ *Pinus longaevea, aristata* — bristlecone pine	80-100%
❖ *Pinus monophylla* — singleleaf pinyon	75-95%
Pinus monticola — western white pine	70-90%
Pinus mugo — Mugo or Swiss mountain pine	50-70%*
Pinus nigra — Austrian pine	70-90%
Pinus parviflora — Japanese white pine	75-95%
❖ *Pinus ponderosa* — ponderosa pine	70-90%
Pinus strobiformis — southwestern white pine	80-100%
Pinus strobus — eastern white pine	50-70%
Pinus sylvestris — Scotch or Scots pine	75-95%
Pinus thunbergiana — Japanese black pine	70-90%
Pinus wallichiana — Himalayan or Bhutan pine	70-90%
❖ *Pseudotsuga menziesii* — Douglas-fir	65-85%
Sequoiadendron giganteum — giant sequoia	85-100%
Taxodium distichum — baldcypress	80-100%
Thuja occidentalis — northern whitecedar • eastern arborvitae	65-85%

*Often shrubby; ❖Utah native

Thuja or *Platycladus orientalis* — Oriental arborvitae... 45-65%

Thuja plicata — western redcedar................................ .. 70-90%

Angiosperms (mostly broadleaves)

Acer buergeranum — trident maple 75-95%

Acer campestre — hedge maple 75-95%

Acer ginnala — Amur maple • Ginnala maple 50-70%*

❖ *Acer glabrum* — Rocky Mountain maple.................. .. 75-95%

❖ *Acer grandidentatum* — canyon or bigtooth maple .. 90-100%

Acer griseum — paperbark maple 85-100%

❖ *Acer negundo* — boxelder • ash-leaved maple 50-70%
• Manitoba maple

Acer nigrum — black maple... .. 80-95%

Acer palmatum — Japanese maple............................. .. 75-95%

Acer platanoides — Norway maple............................. .. 60-80%

Acer pseudoplatanus — sycamore maple.................... .. 65-95%

Acer rubrum — red maple 50-70%

Acer saccharinum — silver maple 40-60%

Acer saccharum — sugar maple.................................. .. 70-90%

Acer tataricum — Tatarian maple 75-95%

Acer truncatum — purpleblow or Shantung maple 75-95%

Aesculus californica, glabra, hippocastanum.............. .. 60-80%
— buckeyes, horsechestnuts

Aesculus x *carnea* — red horsechestnut...................... .. 70-90%

Ailanthus altissima — tree-of-heaven • ailanthus....... .. 35-55%

Albizia julibrissin — mimosa • silk-tree • albizia.......... .. 65-85%

Alnus glutinosa — European or common alder 60-80%

❖ *Alnus tenuifolia* — thinleaf or mountain alder......... .. 65-85%

❖ *Amelanchier alnifolia* — Saskatoon • western 75-95%*
serviceberry

Amelanchier arborea — downy serviceberry............. .. 80-100%

Amelanchier x *grandiflora* — apple serviceberry....... .. 80-100%

❖ *Amelanchier utahensis* — Utah serviceberry 65-85%*

Betula nigra — river birch.. .. 60-80%

❖ *Betula occidentalis* — water or river birch 60-80%

Betula papyrifera — paper birch 55-75%

Betula pendula — European white birch........................ 55-75%

Carpinus betulus — European hornbeam 80-100%

Carpinus caroliniana — American hornbeam............... 85-100%
• musclewood

Carya illinoensis — pecan.. 60-80%

Castanea mollissima — Chinese chestnut...................... 70-90%

Catalpa bignonioides, speciosa, etc. — catalpas 50-70%

Celtis occidentalis — hackberry • common.................... 75-95%
hackberry

❖ *Celtis reticulata* — netleaf hackberry 75-95%

Cercidiphyllum japonicum — Katsuratree 65-85%

Cercis canadensis — eastern redbud • Judas-tree 80-100%

❖ *Cercis occidentalis* — California redbud.................. 90-100%*
• western redbud

❖ *Cercocarpus ledifolius* — curlleaf mountain-mahogany 70-90%*

❖ *Chilopsis linearis* — desertwillow 45-65%*

Chionanthus virginicus — fringetree • white fringetree 80-100%

Cladrastis kentuckea or *C. lutea* — yellowwood.......... .. 70-90%

Cornus alternifolia, florida, etc. — dogwoods 65-85%

Cornus kousa — Kousa dogwood................................ .. 75-95%

Cornus mas — pagoda or alternate leaf dogwood 75-95%

Corylus americana, colurna, cornuta, etc. — hazelnuts • filberts 70-90%

Cotinus coggygria, obovatus, etc. — smoketrees...... .. 60-80%*

❖ *Cowania mexicana* — cliffrose • quininebush........ .. 75-95%*

Crataegus crusgalli, ❖*douglasii*, laevigata,* x *lavallei, phaenopyrum, viridis,* etc. — hawthorns 70-90%

Cydonia oblongata — quince...................................... .. 60-80%

Elaeagnus angustifolia — Russian-olive 5-30%**

Eriobotrya japonica — loquat 60-80%*

Fagus grandifolia, sylvatica, etc. — beechs 80-100%

Fraxinus americana — white ash................................ .. 70-90%

❖ *Fraxinus anomala* — singleleaf ash • dwarf ash..... .. 70-90%*

Fraxinus excelsior — European ash............................. .. 35-55%

Fraxinus pennsylvanica — green ash 60-80%

Fraxinus quadrangulata — blue ash 65-85%

❖ *Fraxinus velutina* — velvet ash • Modesto ash 40-60%

*Often shrubby; ❖Utah native

Gleditsia triacanthos — honeylocust 70-90%

Gymnocladus dioicus — Kentucky coffeetree 80-100%

Ilex opaca — American holly 80-100%

Juglans cinerea, major, nigra, regia— walnuts and butternut 65-85%

Koelreuteria paniculata — goldenraintree.................... 70-90%

Laburnum x *watereri* — goldenchain tree • Waterer laburnum... .. 65-85%

Lagerstroemia indica — crapemyrtle 65-85%*

Liquidambar styraciflua — sweetgum • American sweetgum 60-80%

Liriodendron tulipifera — yellow-poplar • tuliptree • tulip-poplar....... 70-90%

Maclura pomifera — Osage-orange 70-90%

Magnolia acuminata, grandiflora, kobus, x *loebneri,* x *soulangiana, stellata,* etc. — magnolias 75-100%

Malus pumila — apple 50-70%

Malus spp. — crabapple.. 65-90%

Melia azedarach — Chinaberry..................................... 30-50%

Morus alba, rubra, etc. — mulberries 60-80%

❖ *Ostrya knowltonii* — Knowlton hophornbeam 75-95%

Ostrya virginiana — Eastern hophornbeam • ironwood................ 80-100%

Phellodendron amurense — Amur corktree 70-90%

Pistacia chinensis, vera — pistachio, pistache................ 75-95%

*Often shrubby; **May be a noxious weed; ❖Utah native

Platanus x *acerifolia, occidentalis* — planetrees, ... 65-95%
sycamores

Populus x *acuminata* — lanceleaf cottonwood 40-60%

Populus alba — white poplar...................................... .. 40-60%

❖ *Populus angustifolia* — narrowleaf cottonwood 40-60%
❖ *Populus balsamifera* — balsam poplar..................... .. 45-65%
Populus x *canadensis* — Carolina poplar and other..... .. 40-60%
hybrid poplars

Populus candicans — balm-of-Gilead 45-65%

Populus deltoides — eastern cottonwood................... .. 50-70%

❖ *Populus fremontii* — Fremont cottonwood............. .. 60-80%
Populus nigra var. *italica* — Lombardy poplar............. .. 35-55%

❖ *Populus tremuloides* — quaking or trembling aspen... 45-65%
❖ *Populus trichocarpa* — black cottonwood 50-70%
❖ *Prosopis glandulosa* or *P. juliflora* — honey 60-80%*
mesquite

Prunus armeniaca — apricot 60-80%

Prunus avium — sweet cherry • mazzard.................... .. 50-70%

Prunus cerasifera — purpleleaf plum • cherry plum 45-65%
• Myrobalan plum
Prunus cerasus — sour cherry..................................... .. 50-70%

Prunus domestica — common plum............................ .. 50-70%

Prunus padus — European bird cherry • May Day tree . 60-80%

Prunus persica — peach... .. 40-60%

Prunus sargentii — Sargent cherry 65-85%

Prunus serrulata — Japanese flowering or Oriental..... .. 70-90%
cherry

Prunus subhirtella — Higan cherry............................... .. 70-90%

❖ *Prunus virginiana* — common chokecherry 55-75%*
Prunus x *yedoensis* — Yoshino cherry 70-90%

❖ *Ptelea angustifolia* — common hoptree • wafer- 70-90%*
ash • western hoptree

Pyrus calleryana — Callery pear (wide variation by 65-90%
cultivar; 'Bradford' 50-70%)

Pyrus communis — common pear 50-70%

Pyrus ussuriensis — Ussurian pear 65-85%

Quercus acutissima — sawtooth oak 75-95%

Quercus alba — white oak... 80-100%

Quercus bicolor — swamp White oak.......................... 90-100%

Quercus cerris — turkey oak.. 75-95%

❖ *Quercus gambelii* — Gambel, scrub, or Rocky Mountain white oak 70-90%*

Quercus imbricaria — shingle or laurel oak 60-80%

Quercus macrocarpa — bur or mossycup oak 90-100%

Quercus muehlenbergii — chinkapin oak................... .. 80-100%

Quercus palustris — pin oak 35-55%

Quercus robur — English oak 80-100%

Quercus rubra — northern red oak............................. .. 75-95%

Quercus shumardii — Shumard oak........................... .. 80-100%

❖ *Quercus turbinella* — shrub live oak....................... .. 65-85%*
❖ *Quercus undulata* — wavyleaf oak 65-85%*
Robinia x *ambigua* — Idaho flowering locust 40-60%

❖ *Robinia neomexicana* — New Mexican locust.......... .. 50-70%
Robinia pseudoacacia — black locust 40-60%

❖ *Salix amygdaloides* — peachleaf willow................... .. 50-70%
Salix babylonica — weeping willow 35-55%

Salix fragilis — crack willow... .. 30-50%

Salix matsudana — Hankow willow cultivars,.............. .. 25-45%

including globe Navajo willow

Salix nigra — black willow 40-60%

❖ *Sambucus cerulea* — blue elder 60-80%*
Sophora japonica — Japanese pagodatree.................. .. 60-80%

• scholar-tree
Sorbus alnifolia — Korean mountain-ash 55-75%

Sorbus americana — American mountain-ash............. .. 50-70%

Sorbus aucuparia — European mountain-ash • rowan... 45-65%

❖ *Sorbus scopulina* — Greene mountain-ash 60-80%*
Syringa reticulata — Japanese tree lilac 80-100%

Tamarix parviflora, ramosissima — tamarisk........... ..5-20%*,**

• salt-cedar
Tilia americana, cordata, x *euchlora* — lindens, ... 65-85%

basswoods

Tilia tomentosa — silver linden.................................... .. 75-95%

Ulmus americana — American or white elm 35-65%

Ulmus glabra — Camperdown elm.............................. .. 75-95%

Ulmus parvifolia — lacebark or Chinese elm.................. 65-85%

Ulmus procera — English elm • elm hybrids 55-75%

Ulmus pumila — Siberian or Chinese elm 25-45%

❖ *Yucca brevifolia* — Joshua-tree 60-80%*
Zelkova serrata — Japanese zelkova 65-85%

*Often shrubby; ❖Utah native

*Often shrubby; **May be a noxious weed; ❖Utah native

Acknowledgments: I thank the Utah Community Forest Council for their support, and several anonymous reviewers who advised me on the species ratings. And thanks to the nurseries that contributed price and other data.

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GUIDE TO JUDGING THE CONDITION OF A SHADE TREE[1]

by **Bruce** L. **Webster**

Abstract. The high degree of subjectivity involved in judging the condition of a shade tree pointed to a need for a method that would help quantify tree condition. The method described utilizes 6 factors involved in tree condition. Each factor is given a rating, and the sum of the ratings gives a numerical value equatable *to* a condition class. The method is useful when introducing shade tree condition *to* traditional foresters who may be unfamiliar with urban forestry, and may also be useful *to* individuals wt10 need precise data of tree condition.

As most people dealing with urban forestry are aware, trying to arrive at an accurate appraisal of tree condition can be highly subjective. What one individual may judge as a tree in fair condition, another may place in the good category. Or worse yet, in some cases there can be a disparity of 2 or more condition classes.

The Forestry Division of the South Dakota Game Fish & Parks faced this problem in 1973 when the community forestry program was launched. We were in a position of hiring a summer forestry stu- dent to conduct street tree surveys. Those surveys required the student to note species, size, and condition. Since most upper level students have had dendrology, species identifica- tion posed little problems. Likewise, size or diameter was easy to determine. But condition class proved to be difficult to demonstrate.

By 197 4, however, we had devised a formula for determining condition. This formula utilized 5 factors, and assigned a rating for each. These fac- tors were directly related to visibly identifiable characteristics of a shade tree. The use of this for- mula helped to establish more consistency among surveyors. The method was revised in 1975, and then again in 1 977, the latter revision designed to be used with the *Guide to the Professional Evalua- tion of Landscape Trees, Specimen Shrubs and Evergreens* produced by ISA, AAN, and other organizations.

The Condition Guide

The guide to judging shade tree condition utilizes 6 factors: trunk, growth rate, structure, in- sect and disease problems, crown development, and life expectancy. Each factor is given a rating between either one and three or one and five, with the higher number being the better rating. These ratings are based on easily identifiable visual characteristics assigned to each factor.

The trunk factor, rating 1-5. A tree trunk that is sound and solid tt1roughout, has no visible deterioration present, and no visible damage to bark and cambium would receive a rating of 5. A rating of 4 may *be* assigned when there is minor cambium damage to an otherwise sound and solid trunk. A tree that is showing early signs of decay either by presence of a conk or other means would rate a 3. Likewise, bark and cambium damage, either through auto or construction damage would also rate a 3. A rating of two would combine the characteristics of extensive decay, hollowness, and some bark and cambium damage, although the overall cross-section of the trunk remains a circle. When there is extensive decay, very large sections of bark missing, the tree is hollow, and the cross-section is more of a half-circle rather than a full circle the rating assign- ed is a one.

Growth rate, rating 1-3. Growth rate is deter- mined by measuring annual twig elongation. If

[1] Presented at the annual conference of the International Society of Arboriculture in Toronto, Ontario in August of 1978.

growth rate exceeds 6 inches it is given a three. If it ranges from 2-6 inches, it is given a 2. If growth rate is less than 2 inches, it receives a rating of one.

These are general recommendations for many medium growth trees. Species that are either very fast or very slow growing have to be considered individually and may require the use of a different range of growth rate values.

Structure, rating 1-5. The structure of a tree ad- dresses the development and placement of the major limbs and branches. In horticulture, this fac- tor would be termed the scaffold. The rating is determined by 3 characteristics, radial placement of limbs; dead, broken or missing limbs; and nar- row crotch angles.

A top rating of 5 means that there are no major limbs dead, broken or missing, no narrow crotch angles, and good radial distribution of branches. A tree with good radial branch distribution, but one that has a narrow crotch angle would receive a 4. A rating of 3 indicates that one of the major limbs is dead or broken, destroying the radial balance of the structure. If a tree has 2 or 3 major branches forming narrow crotches with at least one being broken, a rating of 2 is assigned. Finally, if 2 or more major limbs are dead, broken or missing, and there are several narrow crotch angles present, there can be no good radial placement of bran- ches and the rating is one.

Insects and diseases, rating 1-3. If there are no pests present the tree would receive a 3. If there are one or two minor insect or disease problems present, such as leaf feeders or leaf diseases, the rating would be a two. If the insect or disease pro- blem is serious, such as a canker disease, wilt disease, bark beetles or wood borers, the rating is one.

In addition, environmental considerations may also be involved in determining the pest rating.

rating of 5 indicates a dense leafy crown that is evenly balanced on all sides. If a tree is slightly un- balanced with crown development extended slightly in one direction, it rates a 4. A three would indicate a thin crown or a severe imbalance. One often sees this condition when street trees are overcrowded. A tree that has a slight imbalance combined with a thin crown would receive a 2, whereas a thin crown and severe imbalance would rate a one.

Life expectancy, rating 1-5. Life expectancy is the factor that is still rather subjective, because it is based on prediction, and as we all know, predic- tions can turn out to be false.

Life expectancy is a summary or catch all factor. It is related to all of the previous factors. For in- stance, one would hardly expect a high rating on life expectancy if the trunk is hollow and the struc- ture is broken.

Some characteristics that influence life expec- tancy might be historical data about the tree or Such problems as air pollution, herbicide damage, leaf scorch, drought, flooding, etc. could be as serious and damaging as an insect or disease problem.

Crown development, rating 1-5. Crown development is based on balance and crown den- sity, and indicates such problems as over- crowdedness, competition, dominance, etc. A the care a tree has received. A tree with a history of defoliation might have a lower rating in life expec- tancy, even though all other fctors point to a highly rated tree. On the other hand, a narrow crotch angle likely to break could be cable braced, thus increasing the life expectancy.

The ratings for life expectancy are 5 for over 30 years, 4 for 25-30 years, 3 for 15-20 years, 2 for 5-1 O years, and 1 for 5 years or less.

Rating for Condition Classes

In reviewing the six factors of condition just discussed, one notes that the total for all factors combined range from 26 to 6. This range is distributed over the five condition classes as follows:

GUIDE FOR JUDGING THE CONDITION OF A SHADE TREE

A. Trunk Condition

Sound & Solid	Sections of bark missing	extensive decay & hollow
5	3	

B. Growth Rate (consider species)

more than 6" twig elongation	2-6" twig elongation	less than 2" twig elongation
3	2	

C. Structure

Sound	one major several minor limbs dead, broken, missing	2 ormore *major* limbs broken, dead, missing
5	3	

D. Insect & Disease

No pests present	1 pest present	2 or more pests present
3	2	

E. Crown Development

Full & Balanced	full butunbalanced	unbalanced & lacking a full crown
5	3	

F. Life Expectancy

over 30 years	15-20 years	less than 5 years
5	3	1

Condition Class:	*Percent*	*Rating*
Excellent:	80-100%	26-23
Good:	60-80%	22-19
Fair:	40-60%	18-14
Poor:	20-40%	13-10

To illustrate how this determination of condition class works, let's consider some specific ex- amples.

being broken (3). There is a *leaf disease present (2), and the crown* is *relatively balanced but thin*

(3). Life expectancy is 15 years (3).

The total rating of these six factors for tree two is 17, hence it has a classification of 40-60% or Fair condition class.

Example #3. *The third tree is split open and hollow (1). Its growth rate is **4"** (2). There are two major limbs missing and another with* a *narrow crotch angle (1). Wood borers and a canker*

disease are present (1). What little crown does exist is fairly dense, but is very lopsided (2). Life expectancy is *5 years (1).*

The ratings for tree three add up t 8, putting this tree into fhe very poor or 0-20% condition class.

At the outset, the notation that tree condition can be highly subjective was made. This method of using numerical ratings does not claim to eliminate subjectivity, but it has helped reduce it. This method has been an effective training tool for summer forestry students and professional district foresters who may not be familiar with urban tree

*Example #1. Tree one has a sound trunk with un- damaged bark (5). Its growth rate is **4"** (2), and the structure or scaffold has no narrow crotch angles or broken, dead or missing limbs (5). There is a leaf chewing insect present (2),* *and the crown is well balanced and quite dense (5). Its.life expectancy is 25 years* ***(4).***

The sum of the ratings for the six factors is 23, hence it falls into the 80-100% or Excellent con- dition class.

Example #2. Tree two has a sound and solid trunk (5), but growth rate is less *than 1" per year (1). The structure is good except for one major limb*

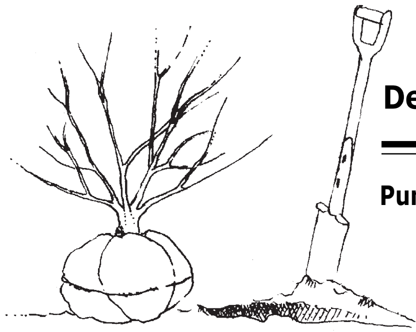
needed, the method is used. To date, this method has not been tested in court.

Finally, there is considerable variation of opinion as to what factors should be included in condition, and in the relative weight each factor should have. This author realizes that others may modify or add to this system to better fit their needs. However, if those who are interested in a system of quantify- ing tree condition are aided and stimulated, then the time and effort spent on this method is wor- thwhile.

Urban Forester Nebraska Forest Service

Lancaster Co. *Extension Office*

Lincoln, Nebraska



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Landscape Tree Appraisal

Michael N. Dana

Appraising the Monetary Value of Landscape Plants

Landscape plants serve functional and esthetic roles in rural, urban commercial, or residential landscapes. Such plants have market value much like real estate, but that value is often difficult to determine. In the case of loss of landscape plants, however, it may be neces- sary to establish a monetary value to validate an insur- ance claim or to justify a loss to the Internal Revenue Service.

Appraisal of landscape plants is not a precise process. Often, the opinion of an expert plantsman or consulting arborist is required, especially in the case of claims, which are decided through litigation. However, homeowners can get some idea of the value of their landscape plants by following the procedures outlined in this bulletin. In some cases, a value determined by the homeowner may be sufficient to settle a claim, or to satisfy the IRS.

Three different methods are used by professionals to arrive at a value for landscape plants. Select the simplest method, which is appropriate to the size and number of landscape plants for which a value is re- quired.

Decrease in Assessed Value of Real Estate

When many plants are affected on a piece of property, or when a dominant landscape element is lost, then the change in assessed valuation may be the best indicator of value. Ask a realtor or land appraiser to assess the property with and without the plant or plants affected. A good, recent photograph of the landscape is valuable in establishing the property status before the loss.

Replacement Cost

Small trees or shrubs that are easily transplanted at their full size can be appraised by determining the cost of replacement. A local nurseryman can quote replace- ment costs, which should include removal of the dead or damaged plant, installation, post-transplanting care, and a survival guarantee. If the plant was in poor condition prior to the loss, the appraised value may be less than the full cost of replacement.

Formula Computation

The formula method is in widespread use for large, individual trees, which exceed the size that is usually transplanted. It is a hybrid of the replacement cost method and a process of extending that cost to larger plants. The guidelines for this method are distributed by the Council of Tree & Landscape Appraisers and are accepted by professionals in the landscape industry and the real estate and legal disciplines.

The formula is as follows:

Tree Value = Base Value × Cross Section Area × Species Class × Condition Class × Location Class

Base Value

Base Value is the dollar amount assigned to one cross- section unit (square inch or square centimeter) of a tree's trunk cross-section area. It is based on the cost of the largest available replacement plant of similar spe- cies. To compute the base value, find the cost (usually the installed price) of a replacement-size tree from a local nursery or landscape company. Then, divide that amount by the trunk cross-sectional area of the replace- ment tree. That amount is the base value for that cross- sectional unit. For example, if a 2 inch trunk diameter replacement tree will cost $150 installed, then divide $150 by 3.1 sq.in. (from Table 1) to determine that one square inch of cross-sectional area is valued at $48.40 (rounded to the nearest dime).

Table 1. Diameter and Cross Section Area of Tree Trunks.

Inches		**Centimeters**	
Trunk Diameter	Cross-Section Area	Trunk Diameter	Cross-Section Area
2	3.1	5	19.6
4	12.6	10	78.5
6	20.3	15	176.7
8	50.3	20	314.2
10	78.5	25	490.9
12	113.1	30	706.9
14	153.9	35	962.1
16	201.1	40	1256.6
18	254.5	45	1590.4
20	314.2	50	1963.5
22	380.1	55	2375.8
24	452.4	60	2827.4
26	530.9	65	3318.3
28	615.8	70	3848.5
30	706.9	75	4417.9
32	804.3	80	5026.6
34	907.9	85	5674.5
36	1017.9	90	6361.7
38	1134.1	95	7088.2
40	1256.6	100	7854.0

Cross-Section Area

Cross-Section Area is used to express tree size. It is the cross-sectional area of the tree trunk measured about one foot (30 cm) above ground level for trees with trunk size up to 12 inches (30 cm) in diameter, or at about 4 1-2 feet (140 cm) above ground level for trees with greater than 12 inch (30 cm) trunk diameter. Cross-section area can be calculated from trunk diameter by using the formula diameter^2 x 0.7854. It can be computed in either square inches or square centimeters. Cross-section areas for trunk diameters ranging from 2 inches to 40 inches and 5 cm to 100 cm are listed in Table 1.

Abnormal trunk structures such as low-branch crotches or forked trunks, burls, or wound scars at the prescribed location for diameter measurement require that the measurement be taken at a different location. Typically, such measurements are made 6 to 12 inches (15 to 30 cm) below the abnormality.

A multi-stemmed tree is measured as separate trunks and then a combined size value is computed. Compute the cross-section areas for all but the largest stem, add them together, and multiply that total by 0.50. Add that value to the cross-section area of the largest stem. The result is a multi-stemmed cross section areavalue.

Species Class

Species Class is an assigned value based on all the landscape merits of a landscape tree species and its accompanying potential for problems. Criteria used in determining species class include form, color, growth habit, flowering and fruiting characteristics, structural strength, longevity, insect and dis- ease resistance or susceptibility, and maintenance require- ments. Each tree species can be assigned any value from 1% to 100% but for practical simplicity, species are usually placed in one of five percentage classes (100, 80, 60, 40, 20). Table 2 is a listing of species class values for many common landscape trees of Indiana. Express the class as a decimal for use in the formula. Thus, 80 becomes 0.80, 100 becomes 1.00, etc.

Condition Class

Condition Class is a factor indicating the health, vigor and life expectancy of a tree, as well as its quality of form relative to a "perfect specimen" of that species. This value can be any percentage from 1% to 100%, but is commonly expressed as one of five percentage categories (100, 80, 60 to 40, 20, 0). The rating is based on such defects as wounds, decay, storm damage, insect or disease damage, and poor form. Very few trees are perfect specimens. However, it is possible to improve condition class if proper cultural treatments are given.

The accuracy of the value assigned for tree condition is dependent on the expertise of the appraiser. It is this judgement which may be most difficult for the nonprofessional to make. Damage to the trunk, for example, may significantly reduce a tree's life expectancy, or the damage may be superficial; and while unsightly, it may not indicate a poorer condition and shortened life span. Professional consultation may be necessary to determine this factor. Table 3 can serve as a guide in assigning condition class values.

Location Class

Location Class is based on the functional and aesthetic contribution, which the tree makes to the site, the placement of the tree on the site, and the importance of the location in the landscape context of the community. This factor can be rated at any percentage from 1% to 100 %. Table 4 can be used as a beginning point by assigning a value based on location. Judgement will be required to incorporate functional, aesthetic, and placement quality into the value. Use these considerations to determine a specific value from the ranges pre- sented in the table. The elements of location class are:

1. Site location. Identical trees on two different sites may be valued quite differently. For example, a large, healthy tree in a remote location on a golf course fairway would not rate as highly as the same tree in a residential yard.

2. Functional and aesthetic value. Trees function as visual screens, windbreaks, climate moderating elements, architectural elements, sculpture, background, framing and unifying elements, in air purification, and can provide cover for wildlife. An evaluation of the tree's role in the landscape is essential to accurately assign a location value.

3. Plant placement. A plant's value may be diminished by a location, which interferes with utility lines, is deleterious to other trees, or is a safety hazard or public nuisance.

Table 2. Species Class Values for Some Indiana Landscape Trees.

Common Name	Botanical Name	Species Class
Evergreen Conifers		
Arborvitae (White Cedar)	*Thuja* spp.	60
*Cedar of Lebanon	*Cedrus libani*	100
Douglas Fir	*Pseudotsuga menziesii*	100
*False Cypress	*Chamaecyparis* spp.	80
Fir, Balsam	*Abies balsamea*	40
Fir, White	*Abies concolor*	100
Hemlock, Canada (eastern)	*Tsuga canadensis*	100
Juniper, Chinese	*Juniperus chinensis*	40
Juniper, American (red cedar)	*Juniperus virginiana*	60
Pine, Austrian	*Pinus nigra*	60
Pine, Eastern White	*Pinus strobus*	80
Pine, Jack	*Pinus banksiana*	20
Pine, Red (Norway)	*Pinus resinosa*	60
Pine, Scots	*Pinus sylvestris*	40
*Pine, Virginia	*Pinus virginiana*	20
Spruce, Black Hills	*Picea glauca* "Densata"	80
Spruce, Colorado Blue	*Picea pungens*	100
Spruce, Norway	*Picea abies*	100
Spruce, Serbian	*Picea omorika*	80
Spruce, White	*Picea glauca*	80
Yews	*Taxus* spp.	80
Broad-Leaved or Deciduous Trees		
Alder, Black	*Alnus glutinosa*	60
Ash, Blue	*Fraxinus quadrangulata*	80
Ash, Green	*Fraxinus pennsylvanica*	60
Ash, Green, Seedless	*Fraxinus pennsylvanica*	
and Cultivars	*subintegerrima*	80
Ash, White	*Fraxinus americana*	80
Bald Cypress, Common	*Taxodium distichum*	100
Beech, American	*Fagus grandifolia*	100
Beech, European	*Fagus sylvatica*	100
Birch, Cutleaf European	*Betula pendula* "Gracilis"	20
Birch, European White	*Betula pendula*	20
Birch, Paper (White)	*Betula papyrifera*	20
Birch, River	*Betula nigra*	80
Blackhaw	*Viburnum prunifolium*	80
Boxelder (Male Tree)	*Acer negundo*	40
(Female Tree)		[illegible]

Table 2. (continued)

Common Name	Botanical Name	Species Class
Broad-leaved or Deciduous Trees (continued)		
Hornbeam, American	*Carpinus caroliniana*	100
Horsechestnut, Common	*Aesculus hippocastanum*	80
Horsechestnut, Red	*Aesculus carnea*	80
Ironwood	*Ostrya virginiana*	80
Katsura Tree	*Cercidiphyllum japonicum*	100
Larch, Eastern (Tamarack)	*Larix laricina*	40
Larch, European	*Larix decidua*	100
Larch, Japanese	*Larix kaempferi*	100
Lilac, Japanese Tree	*Syringa reticulata*	80
Linden, American (Basswood)	*Tilia americana*	60
Linden, Greenspire	*Tilia cordata* "Greenspire"	100
Linden, Littleleaf	*Tilia cordata*	80
Linden, Redmond	*Tilia x euchlora* "Redmond"	100
Locust, Black	*Robinia pseudoacacia*	20
Magnolia, Saucer	*Magnolia soulangiana*	60
*Magnolia, Southern	*Magnolia grandiflora*	80
Magnolia, Star	*Magnolia Stellata*	100
Maple, Amur	*Acer ginnala*	80
Maple, Black	*Acer nigra*	100
Maple, Hedge	*Acerr campestre*	100
*Maple, Japanese	*Acer palmatum*	100
Maple, Norway & Cultivars	*Acer platanoides*	100
Maple, Red and Cultivars	*Acer rubrum*	80
Maple, Silver	*Acer saccharinum*	40
Maple, Sugar	*Acer saccharum*	100
Maple, Sycamore	*Acer pseudoplatanus*	60
Maple, Tatarian	*Acer tatarica*	80
*Maple, Trident	*Acer buergeranum*	100
Mountain Ash, American	*Sorbus americana*	60
Mountain Ash, European	*Sorbus aucuparia*	40
Mulberry, Red	*Morus rubra*	20
Mulberry, White (Fruiting Tree)	*Morus alba*	20

(Fruitless Cultivar)		60
Nannyberry	*Viburnum lentago*	80
Oak, Black	*Quercus velutina*	80
Oak, Bur	*Quercus macrocarpa*	100
Oak, Chestnut	*Quercus muehlenbergii*	100
Oak, Northern Red	*Quercus rubra*	100
Oak, Pin	*Quercus palustris*	80
*Oak, Post	*Quercus stellata*	60
Oak, Red	*Quercus rubra*	100
Oak, Scarlet	*Quercus coccinea*	80
Oak, Shingle	*Quercus imbricaria*	100
Oak, Shumard	*Quercus shumardii*	80
Oak, Swamp Chestnut	*Quercus michauxii*	80
Oak, Swamp White	*Quercus bicolor*	100
Oak, Upright English	*Quercus robur* "Fastigiata"	60
Oak, White	*Quercus alba*	100
*Oak, Willow	*Quercus phellos*	80
Osage Orange	*Maclura pomifera*	40
Pawpaw, Common	*Asimina triloba*	60
*Peach, Flowering	*Prunus persica*	60
Pear, Callery Cultivars	*Pyrus calleryana*	80
Persimmon, Common	*Diospyros virginiana*	60
*Planetree, London	*Plantanus x acerifolia*	40
Plum, American	*Prunus americana*	40
Poplar, Bolleana	*Populus alba* "Bolleana"	40
Poplar, Lombardy	*Populus nigra* "Italica"	20
Poplars	*Populus* spp.	40
Purple-leaf Sand Cherry	*Prunus* x *cistena*	40
Redbud, Eastern	*Cercis canadensis*	40
Redwood, Dawn	*Metasequoia glyptostroboides*	100
Russian-olive	*Elaeagnus angustifolia*	40
Sassafras, Common	*Sassafras albidum*	80

Scholar Tree, Chinese	*Sophora japonica*	80
Serviceberry	*Amelanchier* spp.	80
Sourwood	*Oxydendrum arboreum*	80
Sumac, Staghorn	*Rhus typhina*	80
Sweet -gum	*Liquidambar styraciflua*	80
Sycamore, American	*Platanus occidentalis*	40
Tree-of-heaven	*Ailanthus altissima*	20
Tulip-tree	*Liriodendron tulipifera*	60
Walnut, Black	*Juglans nigra*	80
Willows	*Salix* spp.	20
Yellowwood, American	*Cladastris lutea*	60
*Zelkova, Japanese	*Zelkova serrata*	80

Table 3. Condition Class for Shade and Ornamental Trees.

Condition	**Description**	**Condition Class**	**Values for use in formula**
Excellent	Perfect specimen. Excellent form and vigor for species. No pest problems or mechanical injuries. No corrective work required. Minimum life expectancy 30 years beyond the time of inspection.	100	1.0 range 1.0-0.9
Good	Healthy and vigorous. No apparent signs of insect, disease, or mechanical injury. Little or no corrective work required. Form representative of species. Minimum life expectancy 20 years.	80	0.8 range 0.9-0.7
Fair	Average condition and vigor for area. May be in need of some corrective pruning or repair. May lack desirable [illegible]	60 or 40	0.6 or 0.4 range [illegible]

Table 4. Site Location Values for Shade and Ornamental Trees.

Site Location	Location Class	Values for use in Formula*
Specimen or historical trees	100	0.9-1.0
Average residential, landscape trees	80-90	0.8-0.9
Malls and public area trees	70-80	0.7-0.8
Arboretum, park and recreation trees	60-80	0.6-0.8
Golf course trees	60-80	0.6-0.8
City street trees	60-80	0.6-0.8