Urban Forest Inventory at Principia College

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2019 Final Sustainability Project

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Abstract

The first comprehensive inventory of trees on the core campus (approximately 100 acres) of Principia College has identified 1,499 trees representing 65 species (two percent of trees could not be identified to species). Using ESRI's iPhone app *Collector for ArcGIS* (version 19.0.1), a database and map were created to identify and locate all planted, landscape trees. Fifty-four percent of the trees inventoried are native to the region; native and non-native species inter-mingle across the campus. Average DBH was 30.6 cm (range: 2.0-152.8 cm). Average crown height ranged from 16-32 feet high; on average, the tallest species were Pin Oak, American Sycamore, Eastern Cottonwood, Shagbark Hickory, and Eastern White Oak. Seven species comprise more than half of all campus trees: Eastern White Pine, Eastern Redbud, Eastern Redcedar, Sugar Maple, Blue Spruce, Flowering Dogwood, and the Ornamental Flowering Peach. Thirty-one percent of trees have impacts to their critical root zone, most commonly due to pavement, but 18 other causal factors were identified, including buildings, retaining walls, light posts, and benches.

The Principia College "urban forest" provides a wide range of essential environmental, economic, and social benefits including, among others, providing wildlife habitat, air pollution removal, stormwater management, soil stabilization, carbon sequestration, cost savings (e.g., reduced energy requirements for buildings), and mitigating the urban "heat island effect", as well as contributing to human well-being (e.g., lowered stress levels, aesthetic beauty, artistic inspiration) and property value. The total overall benefits, summed across the 1,499 trees, was monetized using an online tool (National Tree Benefit Calculator) and estimated to be $76,141 annually. Native species, especially Eastern Black Oak, Eastern White Oak and Northern Red Oak, contribute by far the most overall economic benefits per tree per year.

There are several change forces that could impact the urban forest's structure, health, and provision of essential services in the future. For instance, tree breakage due to windstorms and/or aging and loss of larger trees can alter the abundance and distribution of trees. The inventory revealed that the most common large diameter tree species are under-represented among the smaller diameter trees, raising the concern that large, ecologically significant trees may disappear over time without thoughtful intervention (e.g., new plantings) by landscape managers. Recommendations going forward include reducing risk, including taking care to safeguard critical root zones and to prune (or remove) sick or injured trees; documenting maintenance, complaints, site visits, inspections, and action(s) taken; and prioritizing native plantings.

Native species complement the surrounding forest ecosystem, provide the most economic benefits, and reduce the threat posed to Principia's urban (and surrounding) forest by exotic and often invasive species. Characteristics such as benefits to imperiled pollinators, plantings that support academic courses, and trees that aesthetically complement the built environment should be prioritized. Signage designed to increase awareness of the significant value of campus trees, including the apple orchard, should be developed. Finally, this inventory provides a baseline for long-term management and it should be revised and updated, as needed.

Introduction

An "urban forest" refers to a forest within a developed urban area. An urban forest includes all community trees, shrubs, herbaceous low-growing perennial vegetation, and soil (Penner 2015). Through planned connections of green spaces, urban forests form the green infrastructure upon which communities depend (Birch and Wachter 2008, U.S. Department of Agriculture 2018). Trees offer a wide range of benefits to the environment and supply beauty for the enjoyment of human communities (International Society of Arboriculture 2011). In addition to supporting important ecological processes, healthy urban forests provide economic returns and boost community well-being (Penner 2015).

The natural processes of trees deliver ecological services that will benefit the community and the surrounding environment for generations. For example, trees provide wildlife habitat, aesthetic appeal, and visual barriers. They also benefit the environment by reducing the air temperature, improving air and water quality, sequestering carbon, and mitigating air and noise pollution (Nowak et al. 2016). At Principia College, professors take advantage of trees for research and teaching purposes (e.g., species identification, dendrology). Campus trees also provide products such as apples, nuts, and maple syrup (Center for Sustainability 2013, 2016).

According to the National Tree Benefit Calculator[1], not only do trees benefit the environment, but they are a wise economic investment. In urban environments, studies have shown that trees are effective in improving property value (e.g., Escobedo et al. 2015) and contributing to the economic well-being of a community by reducing pressures on stormwater infrastructure (Penner 2015).

Developed areas are generally warmer than their rural surroundings, a phenomenon often referred to as the Heat Island Effect (Mohajerani et al. 2017). The shade provided by trees cools buildings; according to the Alliance for Community Trees, a few trees located strategically around a building can reduce summer cooling costs by 30-40%. Between 1900 and 2010, the average air temperature in the Midwest increased by more than 1.5°F and the "rate of increase in temperature has accelerated in recent decades" (Melillo et al. 2014). With a warming climate, air conditioning will likely increase. Ironically, burning more fossil fuels to stay cooler will warm the atmosphere further. Trees are a renewable source of cooling to aid in decreasing energy use and cost (Alliance for Community Trees n.d.).

Trees foster a healthier society by improving air quality through reducing air pollutants. Urban vegetation has also been linked to reduced crime rates, enhanced psychological well-being, and expanded outdoor recreation and fitness opportunities (Penner 2015). Indeed, "urban ecosystems are increasingly recommended by National and State environmental protection agencies to mitigate the harmful impacts of air and water pollutants, harmful emissions, and the

[1] The National Tree Benefit Calculator was developed by Casey Trees and Davey Tree Expert Co. (undated), and can be accessed at http://treebenefits.com/calculator/. Throughout this paper the tool will be referenced simply as the "National Tree Benefit Calculator."

negative effects of urban heat and noise" (Wolf and Robbins 2015). Not only do trees improve the livelihoods of individuals, they strengthen social cohesion and revitalize communities. For example, social cohesiveness improves in communities with more trees because social interaction increases substantially (Penner 2015). In summary, trees add significant value to the landscape and are an integral component to any community's environment (Davey Resource Group 2016).

The Principia College Campus Tree Care Plan (CTCP) (Center for Sustainability 2013) provides stakeholders with a framework for tree management in our core campus area. With the overall goal of ensuring a safe, attractive, healthy and sustainable campus tree population, the CTCP is a tree care guide for designers, construction managers, landscaping personnel and other members of the college community. These guidelines provide the tools needed to minimize any potentially negative impacts on the College's tree population. My project is designed to address the following gaps identified by the CTCP (Center for Sustainability 2013:6):

> **Campus Tree Plan Goals and Targets**
> *Campus Forest Ecology*: The proportion of native to non-native tree species is unknown, nor can we accurately characterize the ecological services (e.g., provision of essential habitat for endangered species) provided by our trees. Our goal is to ground truth our ArcGIS data to complete: (i) a tree species inventory, (ii) research and identify ecological services provided by our trees (and potential threats posed by invasive/exotic trees), and (iii) make species-level recommendations to inform and guide tree planting and replacement efforts.

To achieve a more comprehensive picture of which campus trees are a priority for conservation (e.g., healthy trees, native trees, trees that provide food resources to wildlife or to the campus community), I will conduct a comprehensive tree species inventory designed to inform and guide planting and replacement efforts. The inventory will include a field survey of the core campus, ground-truthing of existing databases, and research into ecological services provided by the trees. The project will also highlight the sustainability values expressed by the Principia College campus trees, including carbon sequestration, water conservation, and human well-being.

Methods

Site Description

Principia College purchased approximately 2,500 acres of land in Jersey County, Illinois in 1930 (Hosmer and Williams 1986). The land is situated in the temperate/humid biome within the Central Mississippi River valley. The average temperature ranges from 29.9°F in the winter to 74.4°F in the summer (Natural Resource Conservation Service 2003); annual precipitation averages 38.41 inches, 21.5 inches of which comes during the growing season (Lovseth 2018). "Goss-Menfro complex" soils in Jersey County, including Principia College, are primarily silty clay loam (Natural Resource Conservation Service 2017).

The core of the college campus (approximately 100 acres) is defined by the built environment, and is located on limestone bluffs overlooking the Mississippi River and the Historic Village of Elsah, Illinois. The core campus supports 43 named buildings, more than a dozen parking lots, and a variety of athletic fields, all connected by walking paths (Figure 1).

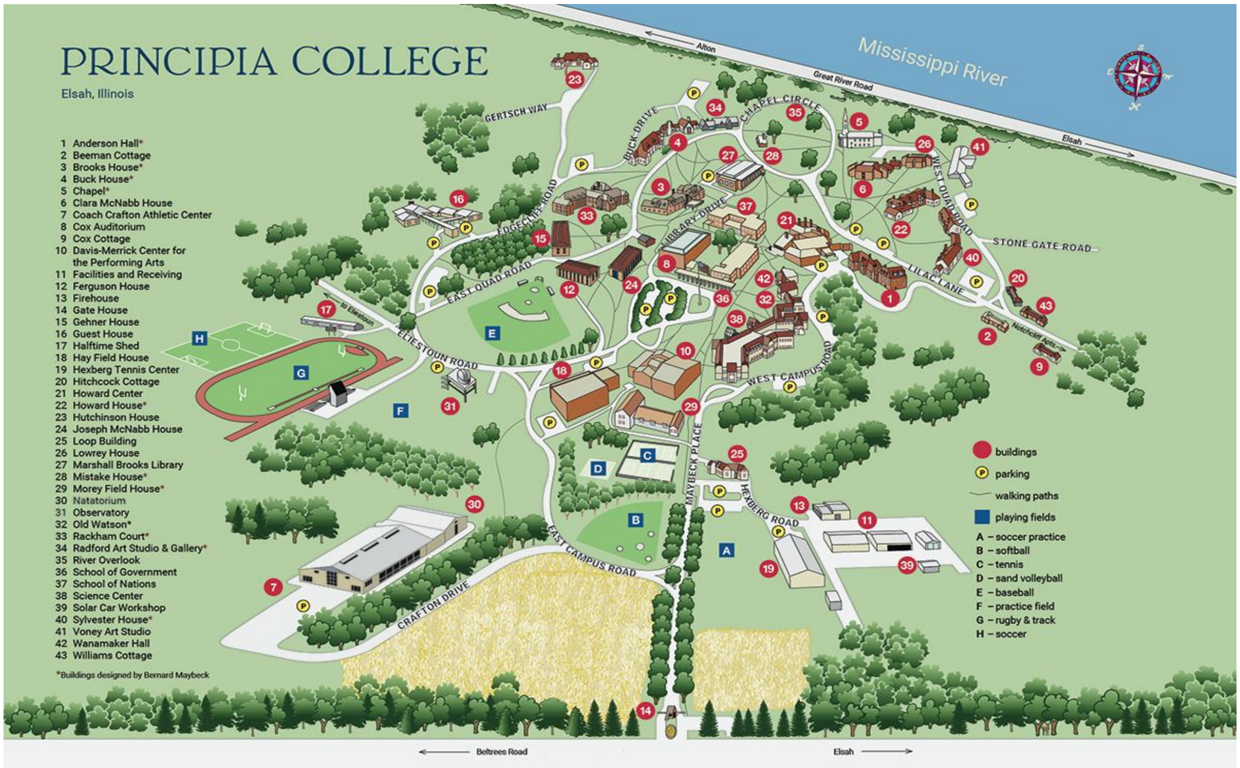

Figure 1. *The built environment ("core campus") of Principia College, Elsah, IL.*

Field Measurements

Field data collection occurred between February and April 2019. The core campus was surveyed on foot, beginning at Cox Cottage (#9 in Figure 1) and continuing roughly eastward through the West Residential Quad, Chapel Green, and East Residential Quad. All planted, landscape trees on the core campus were identified to species, located using GPS coordinates (latitude, longitude), and characterized by DBH ("diameter at breast height" measured 4.5 ft from the ground) and crown height.

Sibley (2009) was used to identify tree species. A *Forestry Suppliers Inc.* DBH-tape and Merritt Hypsometer were provided by the Principia Biology and Natural Resources Department for measuring DBH (cm) and crown height (ft). The Merritt Hypsometer is typically utilized by foresters and is designed to measure height by 16-ft "logs". Therefore, crown height was categorized by numbers 1 through 5, each representing 16-ft height categories. In some cases, tree height and DBH were approximated due to time constraints and/or difficulty accessing the trunk. Any impacts to the root zone of the tree or observable rot/decay were recorded.

All data, including GPS coordinates, were collected through ESRI's iPhone app *Collector for ArcGIS* (version 19.0.1). This app allows for easy data collection in the field that can be integrated seamlessly into ArcGIS Online. ArcGIS is a computer software program that can be used to collect and manage spatial data. ArcGIS is necessary for the creation of maps and performing spatial analysis.

Data Analysis

The National Tree Benefit Calculator, developed by Casey Trees & Davey Tree Expert Co., was utilized to approximate the benefit of individual campus trees. The National Tree Benefit Calculator is based on i-Tree's street assessment tool[2] and makes it easy to approximate the benefits of individual street-side trees. By entering your zip code, tree species, DBH, and surrounding land-use information, you can quickly learn what benefits an individual tree provides. Benefits are quantified as money saved from stormwater runoff interception, increase in property value, energy conservation, air quality improvement, and atmospheric carbon reduction.

The National Tree Benefit Calculator limits its analysis to a 45 cm DBH maximum – if the average DBH is well above 45 cm, estimates for those species will be a less accurate. It is difficult to quantify the social and communal health benefits of trees. The specific geography, climate, and interactions with humans/infrastructure are variable. Taking all of this into account, we view the results provided by The National Tree Benefit Calculator as general indications of the benefits produced by urban trees. We also recognize that these benefits do not include the costs associated with a tree's long-term care and maintenance.

Additional analyses (e.g., proportion of native/non-native trees, species distribution, tree condition, root zone impacts) were performed using Microsoft Excel and ArcGIS.

Results

Inventory

A total of 1,499 trees were inventoried, representing 65 species. Using ESRI's iPhone app *Collector for ArcGIS* (version 19.0.1), a map was created to identify and locate all planted, landscape trees on the core campus of Principia College (Figure 2).

[2] Since 2006, i-Tree has been a cooperative effort between the USDA Forest Service, Davey Tree Expert Company, Arbor Day Foundation, Society of Municipal Arborists, International Society of Arboriculture, Casey Trees, and SUNY College of Environmental Science and Forestry: https://www.itreetools.org/

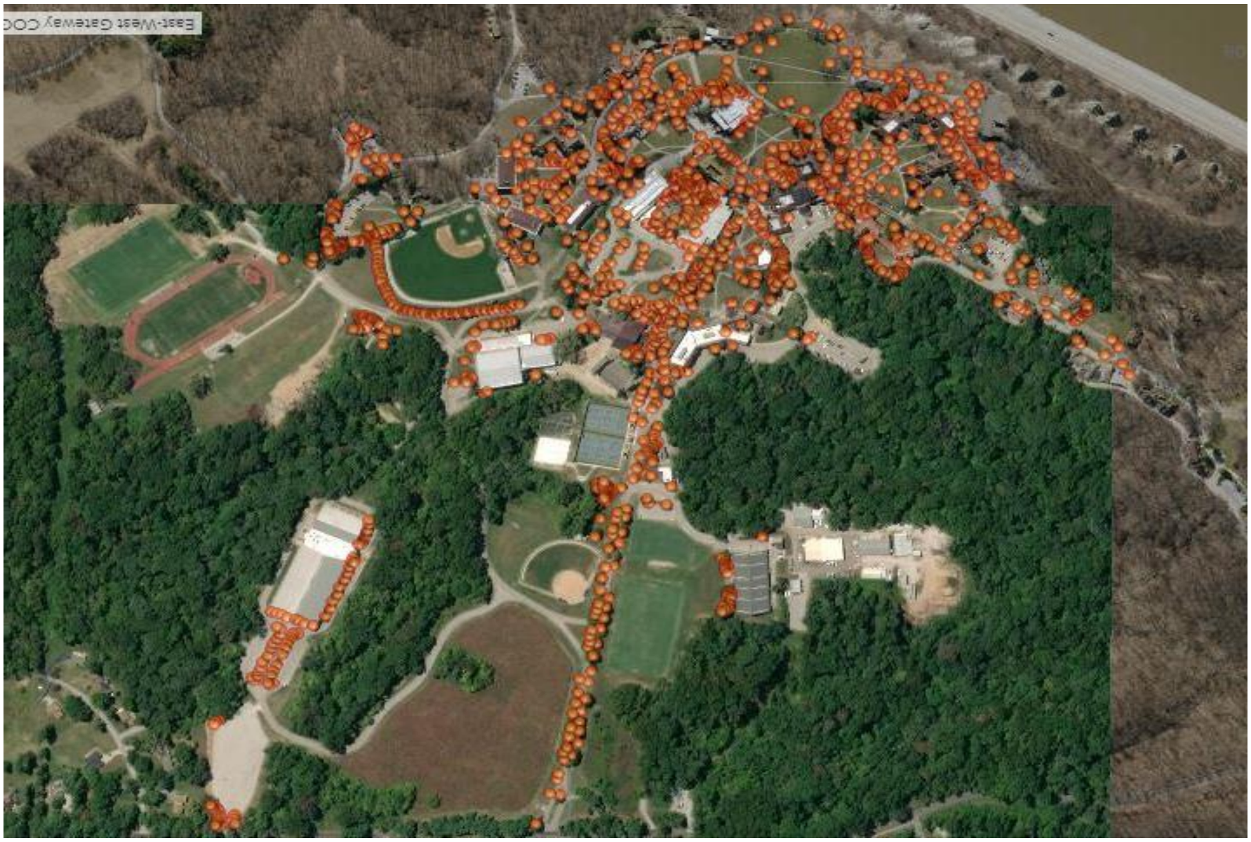

Figure 2. *The distribution of 1,499 trees inventoried on the core campus of Principia College. Special thanks to Dr. John Lovseth (Land Stewardship Manager, Biology and Natural Resources Department at Principia College) for help with this analysis and visualization.*

The most common tree species are the Eastern White Pine, Eastern Redbud, Eastern Redcedar, Sugar Maple, Blue Spruce, Flowering Dogwood, and the Ornamental Flowering Peach. These seven species alone comprise more than half of all of Principia College's campus trees (Figure 3).

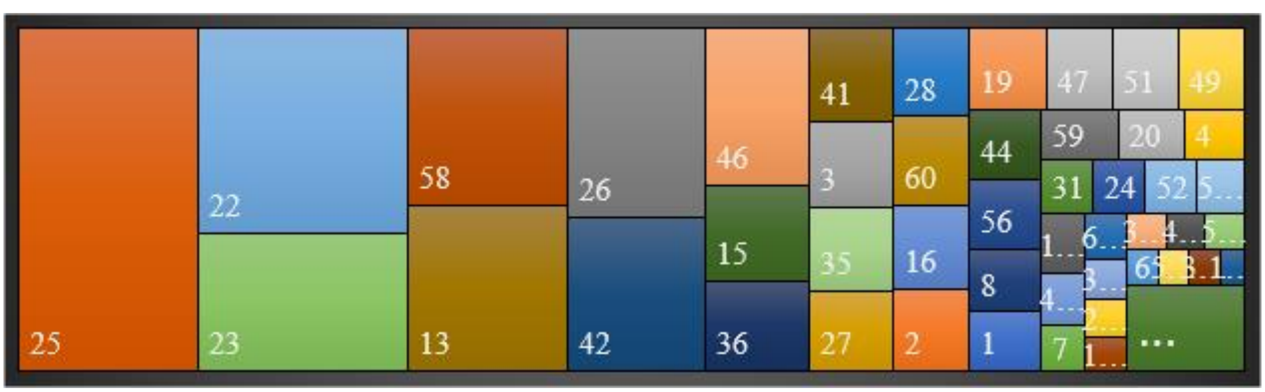

Figure 3. *The proportion of each tree species (n=65 + an "unknown" category) occurring on the core campus of Principia College, with a corresponding key below (additional detail in Appendix 1).*

1	American Beech	23	Eastern Redcedar	45	Paper Birch
2	American Elm	24	Eastern White Oak	46	Pin Oak
3	American Holly	25	Eastern White Pine	47	Princeton Elm
4	American Sycamore	26	Flowering Dogwood	48	Red Maple
5	American Witch-hazel	27	Ginkgo	49	River Birch
6	Amur Cork	28	Green Ash	50	Sassafras
7	Amur Maple	29	Hawthorn	51	Saucer Magnolia
8	Apple	30	Honeylocust	52	Serviceberry
9	Austrian Pine	31	Ironwood	53	Shagbark Hickory
10	Black Cherry	32	Japanese Tree Lilac	54	Silver Maple
11	Black Walnut	33	Japanese Zelkova	55	Southern Magnolia
12	Black Willow	35	Kwanzan Flowering Cherry	56	Spring Snow Crabapple
13	Blue Spruce	34	Maple (unknown)	57	Star Magnolia
14	Box Elder	36	Mockernut Hickory	58	Sugar Maple
15	Bradford Pear	37	Northern Hackberry	59	Sweetgum
16	Crabapple ('Sweet')	38	Northern Red Oak	60	Unknown
17	Chinkapin Oak	39	Northern White-cedar	61	Weeping Cherry
18	Crabapple	40	Norway Maple	62	Weeping Redbud
19	Eastern Black Oak	41	Norway Spruce	63	Weeping Willow
20	Eastern Cottonwood	42	Ornamental Flowering Peach	64	White Spruce
21	Eastern Hemlock	43	Osage Orange	65	Whitebud
22	Eastern Redbud	44	Pacific Yew	66	Winged Elm

Fifty-four percent of the 1,499 trees inventoried are native to this region; forty-four percent are non-native; two percent could not be identified (Figure 4). Similarly, of the 65 identified species, fifty-five percent (n=36) are native and forty-five percent (n=29) are non-native. For a complete listing, see Appendix 1.

The Eastern White Pine thrives in the Great Lakes region and east into Appalachia. It has been labeled as non-native because it is not known to occur naturally in Principia College's surrounding forest, although some do consider it to be native to our area (Natural Resource Conservation Service 2002).

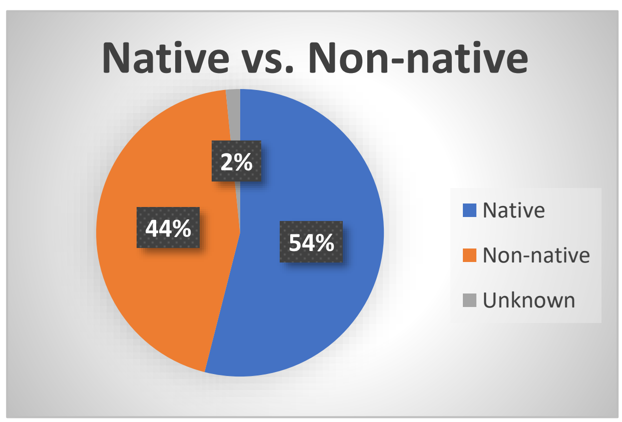

***Figure 4**. Proportion of native vs. non-native trees inventoried on the core campus of Principia College.*

Mature trees – many, if not most, intentionally planted for landscape purposes – are broadly distributed across the core campus. Native and non-native plantings intermingle; notwithstanding, the inventory reveals certain patterns. For example, the inner reaches of the core campus are more likely to be non-native species, increasingly favoring native species toward the campus edges (Figure 5).

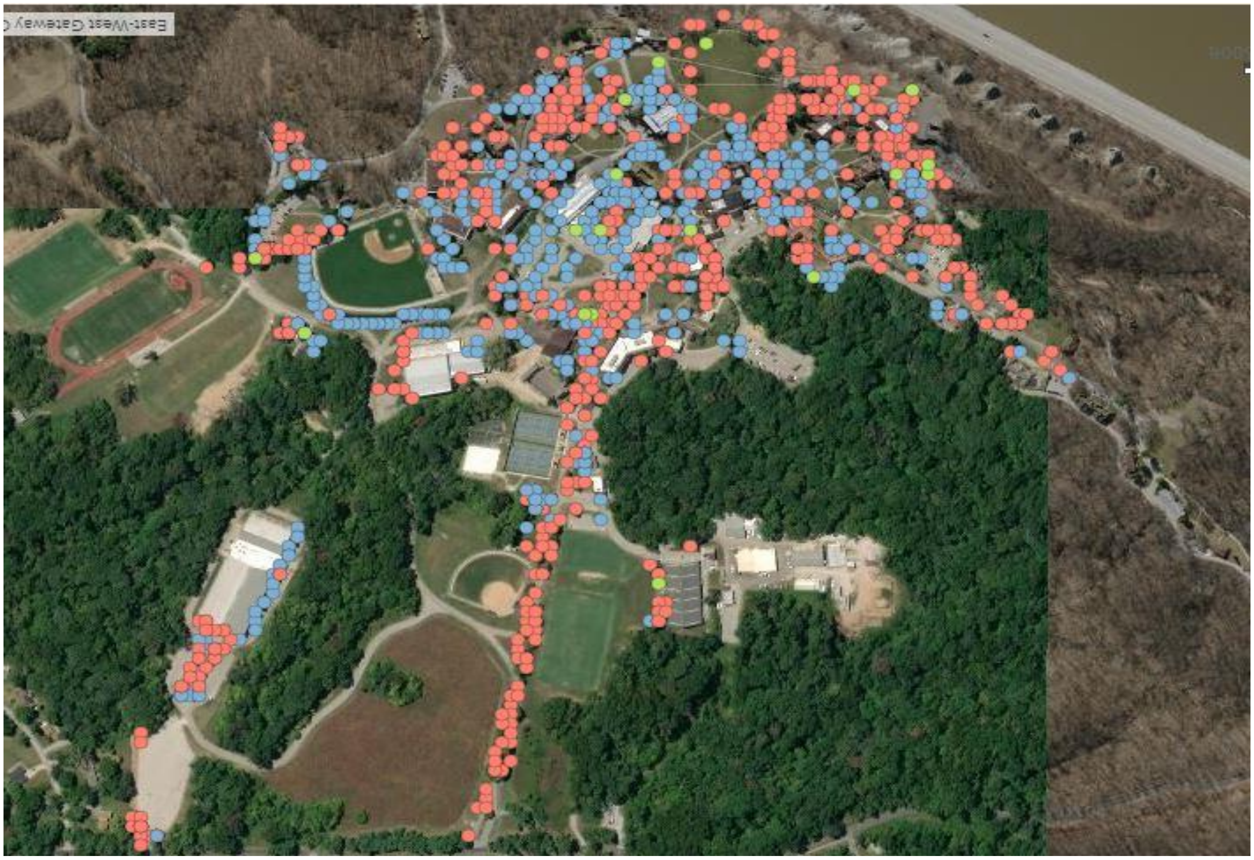

Figure 5. *The distribution and abundance of native (pink) vs non-native (blue) tree species occurring on the core campus of Principia College. Green dots are trees that could not be identified to species.*

Demographics

The average DBH of all inventoried trees was 30.6 cm; the range was 2.0 to 152.8 cm. The sum total DBH for all inventoried trees was 45,771.6 cm. When analyzing the sum of the DBHs for each species, which positively correlates to biomass (e.g., Devine et al. 2013), the five tree species with the largest collective biomass were Eastern White Pine, Sugar Maple, Blue Spruce, Eastern Redbud, and Eastern Redcedar[3].

[3] The five species with the highest average DBH are the Eastern Cottonwood, Pin Oak, Black Willow, Osage Orange, and Norway Maple – but these are not as well represented on campus as the Eastern White Pine, Sugar Maple, Blue Spruce, Eastern Redbud, and Eastern Red Cedar; hence, the latter group rises to the top when *collective* biomass is reported.

The five species with the smallest collective biomass were Ornamental Flowering Peach, Weeping Redbud, American Witch-hazel, Chinkapin Oak, and Winged Elm.

The average height of the trees inventoried was a category 2, translating to a crown height between 16 and 32 feet tall. On average, the five tallest species were Pin Oak, American Sycamore, Eastern Cottonwood, Shagbark Hickory, and Eastern White Oak. The five shortest species were Saucer Magnolia, Serviceberry, Spring Snow Crabapple, Weeping Redbud, and Winged Elm.

Thirty-one percent of all inventoried trees have impacts to their root zone. Figure 6 provides a list of all types of observed root zone impacts with the corresponding quantity of affected trees. In addition, the inventory revealed that eleven trees (mostly Eastern Redbuds) were hollow on the inside. Forty-five trees had a significant level of tilt or lean, and twenty-one trees had had their tops broken off, most likely due to high winds.

The Principia Apple Orchard, located in the West Residential Quad, became the responsibility of the Center for Sustainability in 2015. The orchard had been untended for many years, there was evidence of disease and other weaknesses is some trees, and all mature trees were in "desperate need of pruning" (Center for Sustainability 2016).

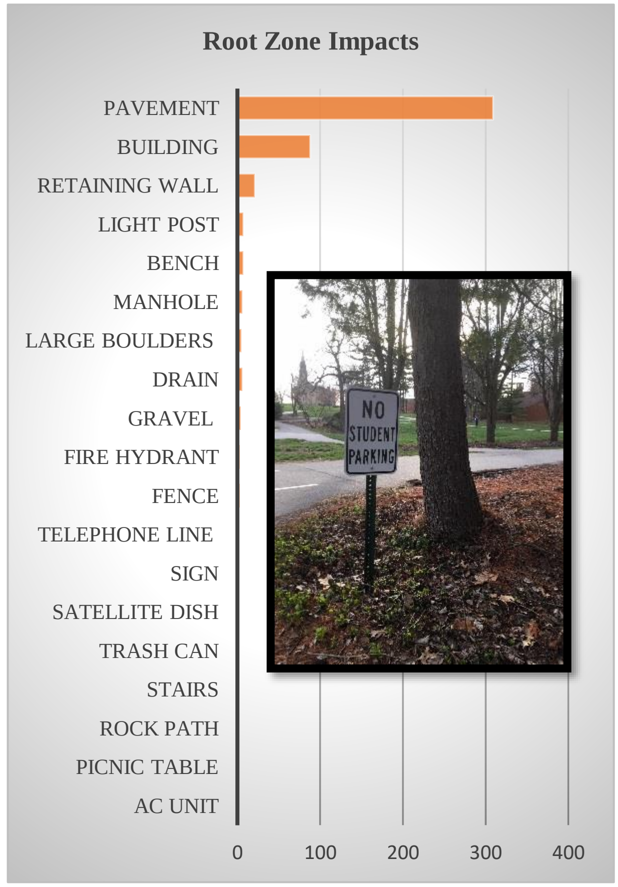

Figure 6*. The number of trees that have impacts to their root zone corresponding to the type of impact.*

In 2016, there were 24 apple orchard trees. This inventory project has revealed that trees 4, 6, 8, 9, 11, 14, 15, 20 and 22 are no longer present (Figure 7), having been lost during severe storms in recent years. Existing domestic apple (*Malus domestica*) varieties include Enterprise, Golden Delicious, Jonafree, Jonathan, and Royal Gala (trees 3, 5, 7, 13, and 19 are unknown varieties). While progress has been made in orchard care, including a regimen of annual pruning and harvest, there continues to be a need for pruning of these mature trees, a few trees need staking, and young trees growing nearly horizontally should probably be removed (see *Management Recommendations*).

Figure 7. *(l) GIS map (superimposed on a Google Earth® image) of 24 existing apple orchard trees (PINK) and 11 proposed plantings (BLUE) (Center for Sustainability 2016). (r) Snip from ESRI map of trees inventoried in 2019 (present study).*

Ecosystem Services

Using the National Tree Benefit Calculator, ecological services provided by trees inventoried in Principia College's core campus were estimated. These services include mitigating storm water runoff, enhancing property values, absorbing or intercepting pollutants, and sequestering carbon. The species that contribute most to storm water runoff interception are the Eastern Black Oak, Eastern White Oak, and Northern Red Oak. A single one of any of these top performing trees can intercept more than 15,000 gallons of water per year. The species that contribute most to increased property value in our zipcode (62028) are Chinkapin Oak, Ironwood, and Paper Birch, with a maximum of a $62 increase per tree per year.

Eastern Black Oak, Eastern White Oak, and Northern Red Oak were the top species with regard to energy conservation, with a maximum of 227 Kilowatt hours saved per tree per year. These same species contributed the most to improving air quality. The tree accomplishes this by absorbing or intercepting pollutants, as well as lessening the need for the creation of said pollutants by reducing energy use. The tree species at Principia College that sequester the most atmospheric carbon per year are the Eastern Black Oak, Eastern White Oak, and Northern Red Oak, with top performing trees sequestering as much as 1,560 pounds of atmospheric carbon per tree per year. Not surprisingly, Eastern Black Oak, Eastern White Oak, and Northern Red Oak contribute the most overall benefits, with an average savings of $177 per tree per year.

Taking these and other ecosystem processes cumulatively into account, the total overall benefits can be monetized by the National Tree Benefit Calculator for the entire urban forest at Principia College. The result is that the 1,499 trees landscaped on the core college campus provide an estimated $76,141 in essential ecological services annually.

Discussion

Overview

This project created a tree inventory of the approximately 100 acres that comprise the core Principia College campus. The inventory counted 1,499 individual trees, representing 65 species, and resulted in a data spreadsheet that will serve as a living record[4] of Principia College's "urban forest". The assembled data was used to characterize the composition of the campus tree community, including location, proportion of native vs. non-native trees, species and biomass distribution, tree height, root zone impacts, and tree condition. Using the National Tree Benefit Calculator, ecological services provided by the trees were monetized as they relate to stormwater runoff interception, increase in property value, energy conservation, air quality improvement, and atmospheric carbon reduction (based on a calculated average DBH for each species). Support for native pollinators is also discussed under *Management Recommendations*.

Native and non-native species intermingle on the landscape and occur in roughly equal proportions. Non-native species can be problematic – outcompeting native species, removing resources from the surrounding ecosystem, and providing little or no nutrition to wildlife. In contrast, native trees contribute significantly to the environment – and benefit the human community in terms of carbon sequestration, energy savings (e.g., provision of shade), and overall well-being. Managers should be aware when stewarding an urban forest that changes have the potential to impact the structure and composition of the urban forest, and thus the provision of environmental benefits. Possible sources of change include tree size distribution, native : non-native ratios (especially as regards invasive species), and potential pest infestations (Nowak et al. 2016). One way to anticipate change is to monitor the ratio of young (small) to older (larger) trees, to monitor patterns of illness and storm damage, and to be aware of the cumulative effects of aggressive invasive species, such as Asian/Amur Honeysuckle (*Lonicera maackii*).

The inventory revealed that the most common large diameter tree species are under-represented among the smaller diameter trees, raising the concern that large, ecologically significant trees may disappear over time without thoughtful intervention by landscape managers. Among the most common species on campus – e.g., Eastern White Pine, Sugar Maple, and Blue Spruce – also make up most of the biomass, meaning there are many of these trees and they are large. In contrast, native Eastern Cottonwood, Pin Oak, Black Willow, and Osage Orange trees have the highest average DBH, but there are very few of these trees. The same occurs in the height analysis; the tallest species are relatively uncommon. Serviceberry, Weeping Redbud, and Crabapple dominate the smaller diameter trees. These ratios should be documented and acknowledged, and planting should be intentional with regard to species composition over the long term.

[4] The spreadsheet and resulting maps were enabled by ESRI's iPhone app *Collector for ArcGIS* (version 19.0.1), which allows for easy data collection in the field that can be integrated seamlessly into ArcGIS Online.

Ecosystem Services

Trees have a remarkable capacity to improve a community; however, trees are often underrated and undervalued because it can be difficult to quantify their benefits (Penner 2015). The National Tree Benefit Calculator (Casey Trees and Davey Tree Expert Co. n.d.) provides a unique and site-specific tool to assist in estimating – and even monetizing – the social, ecological and economic value of trees.

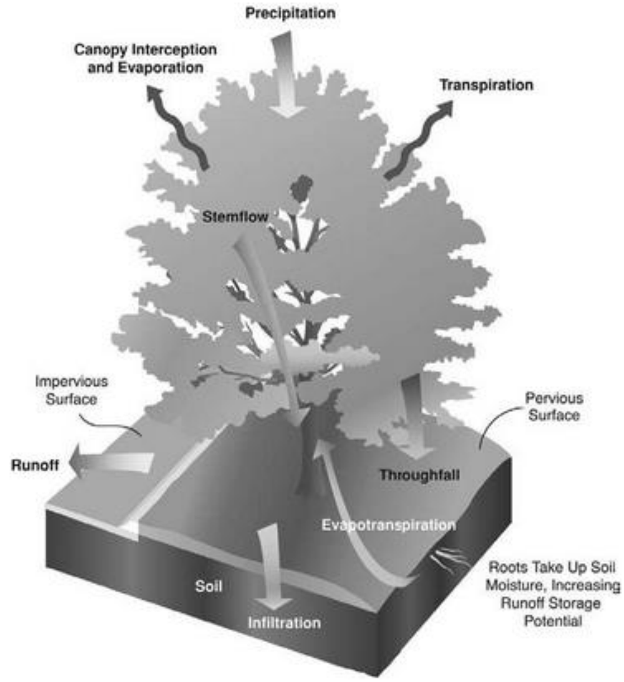

Figure 8. *How trees intercept stormwater runoff. Source: National Tree Benefit Calculator*

Stormwater runoff in urban settings carries chemicals (oil, gasoline, salts, etc.) and litter into streams, wetlands, rivers, and oceans. The more impervious the surface, the quicker pollutants will wash into community waterways. This adversely affects drinking water, aquatic life, and the health of the entire ecosystem. Trees intercept precipitation, while their root systems promote in-filtration and water storage in the soil (Nowak et al. 2016). By slowing down the impact of rainfall, trees also help reduce soil erosion (Figure 8). According to the National Tree Benefit Calculator, the species that hold rainwater the most effectively at Principia College are those which are native to the region; in particular, our native oaks: Eastern Black, Eastern White, Northern Red.

Research shows that trees increase the “curb appeal” of a property and thus the sale price. In a recent study of four cities across Florida, including “congruent parcel tract-level home attributes and appraised property values from single and multi-family units”, Escobedo et al. (2015) concluded that “more trees with greater Leaf Area Indices (LAIs) add to property value, while biomass and tree–shrub cover have a neutral effect, and replacing tree with grass cover has lower value. On average, property value increased by $1,586 per tree and $9,348 per one-unit increase in LAI, while increasing maintained grass from 25% to 75% decreased home value by $271.” Similarly, the National Tree Benefit Calculator uses a tree’s Leaf Surface Area (LSA) to determine increases in property value. Built environments with more trees, and more LSA, have a higher value than those with fewer trees and lower LSA. According to the National Tree Benefit Calculator, Chinkapin Oak, Ironwood, and Paper Birch have the highest LSA at Principia College.

Urban trees are vital for reducing heat stress and mitigating the urban “heat island effect”, which is caused by the dominance of impervious surfaces and energy-absorbing materials in urban environments (Mohajerani et al. 2017). When trees are connected, the flow of cool air is improved (Zupancic et al. 2015). Every 10 percent increase in overall urban tree canopy generates a 2 °F (0.6 °C) reduction in ambient heat (Wolf and Robbins 2015). These ecological services also conserve building energy; specifically, shade provided by trees reduces the amount of heat absorbed and stored by buildings, evapotranspiration cools the air by using the sun to convert liquid water into vapor, and trees reduce wind speeds and decrease the amount of heat lost from a building (Figure 9). Native species conserve energy most efficiently on Principia's campus; in particular, our native oaks: Eastern Black, Eastern White, and Northern Red.

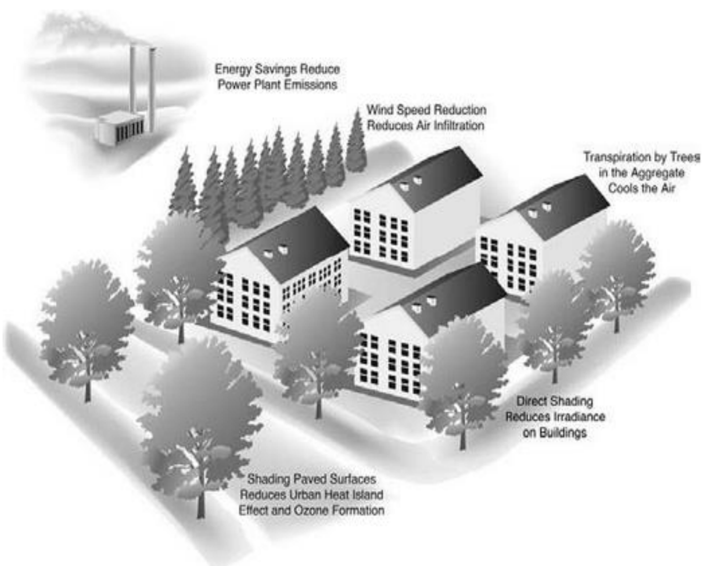

***Figure 9**. How trees conserve energy. Source: National Tree Benefit Calculator*

According to the National Tree Benefit Calculator, urban trees also mitigate the adverse health effects of air pollution by absorbing pollutants through their leaves and intercepting particulate matter like dust, ash, or smoke. Through the added benefit of reducing the air temperature, trees indirectly reduce energy needs for cooling surrounding buildings and associated pollutant emissions from power plants (Nowak et al. 2016). Trees, like any other plant, release oxygen through photosynthesis, which makes the air more breathable for us. Again, native oaks (Eastern Black, Eastern White, and Northern Red) are the top performers on our campus.

Climate change caused by the burning of fossil fuels is having far-reaching effects in the Midwest, including extreme heat, heavy downpours, and flooding, which "will affect infrastructure, health, agriculture, forestry, transportation, air and water quality, and more" (Melillo et al. 2014). We all contribute to these changes; e.g., according to the U.S. Department of Transportation Federal Highway Administration, we drive an average of 13,476 miles per year (Megna 2016), with transportation generating 29% of climate altering emissions (EPA 2017). We all contribute to the solution, as well – and from a management standpoint, it's important to know that our native trees outperform our non-native trees in carbon sequestration.

Carbon sequestration is a process that is accomplished naturally by plants. Trees grow by taking carbon from the air through photosynthesis. Carbon is trapped in roots, trunk, stems, and leaves as they grow, and then released when the tree dies (e.g., Nowak et al. 2016, Bravo et al. 2017). Trees can also reduce atmospheric carbon by shading buildings, thereby reducing heating and air conditioning demands and corresponding emissions associated with power production (Wolf and Robbins 2015).

In summary, trees beautify the landscape, enhance biodiversity, provide food and/or shelter to birds and other wildlife, stabilize the soil, reduce the Heat Island Effect, lower pollutant levels, sequester carbon (thus mitigating climate change and lowering energy costs), and perform a myriad of other services. Principia's urban trees and other natural systems also improve community health, cohesion, and resilience. Humans are naturally social, but modern life is increasingly isolated and disengaged (Harraka 2002). Research has shown a positive relationship between social cohesion and green space – and the quality of green space (variety of plants, maintenance, orderly arrangement, absence of litter, etc.) matters more than the quantity of green space in promoting social cohesion in neighborhoods (de Vries et al. 2013). This should be considered when developing management recommendations, including removing or planting campus trees.

Management Recommendations

Principia College's Campus Tree Care Plan (Center for Sustainability 2013) gives "General Care Guidelines" related to tree planting, landscaping, watering, maintenance and removal, pruning, mulching and prevention of mower damage, fertilization, pests and diseases, and managing for destructive events. These will not be repeated here. The Plan also notes that "The proportion of native to non-native tree species is unknown, nor can we accurately characterize the ecological services (e.g., provision of essential habitat for endangered species) provided by our trees" and prioritizes the need to complete a tree species inventory, research and identify ecological services provided by campus trees, and make species-level recommendations to inform and guide tree planting and replacement efforts. My project aimed to fill these gaps, and in this final section I summarize management recommendations suggested by my research, as well as some thoughts on next steps.

Recognize and Manage Risk

Recognizing and reducing risk associated with planted trees will increase community safety and improve the health and longevity of trees. Therefore, along with species inventory records, documentation of maintenance, complaints, site visits, tree inspections, etc. should be kept. Liability for damage or injury is reduced when it can be shown that a municipality has not neglected its responsibility for its trees (North Carolina Forest Service 2017).

Trees provide significant benefits to communities, but when they fall, injure people, or damage property they become a liability. It is important to understand and address risk to maintain a safe environment and prolong tree life. The International Society of Arboriculture's brochure titled "Recognizing Tree Risk" is useful for identifying the common defects associated with tree risk (International Society of Arboriculture 2011). Evaluating the seriousness of these defects is best done by a professional arborist; once a risk is identified, steps can be taken to reduce the likelihood of the tree falling.

The following are defects or signs of possible defects in urban trees (Figure 10) (International Society of Arboriculture, 2011):

1. Regrowth from topping, line clearance, or other pruning
2. Electrical line adjacent to tree
3. Broken or partially attached branches
4. Open cavity in trunk or branch
5. Dead or dying branches
6. Branches arising from a single point on the trunk
7. Decay and rot present in old wounds
8. Recent change in grade or soil level, or other construction

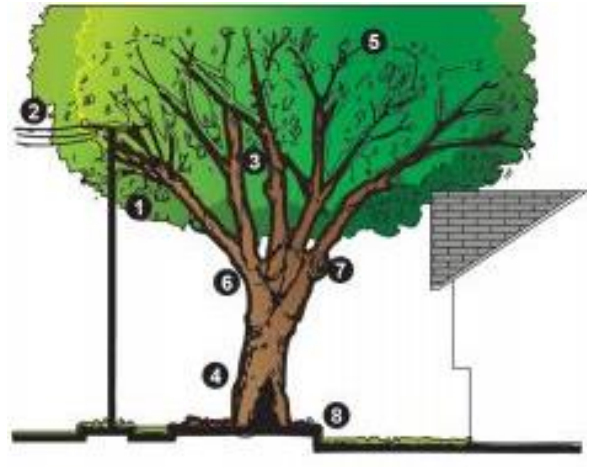

Figure 10. *Defects or signs of possible defects in urban trees. Source: International Society of Arboriculture (2011)*

The following are options for managing risk:

1. Pruning: Should be done on a regular basis to remove defective branches. Inappropriate pruning may weaken a tree.
2. Provide physical support: for young trees or weak branches to increase their strength and stability. This is not a guarantee against failure.
3. Provide routine care: with water, nutrients (in some cases), mulch, and pruning as dictated by the season and their structure.
4. Remove the tree: if the levels of risk are unacceptable. Plant a new tree in an appropriate place as a replacement, prioritizing native species.

Safeguard Existing Trees

Trees are unique ecological and economic assets; they deserve the best possible care (International Society of Arboriculture 2011). Principia values its campus trees both for their beauty and for their essential services (e.g., erosion control, temperature moderation) (Center for Sustainability 2013). The Campus Tree Advisory Group aims to protect trees from unnecessary damage; however, during necessary construction or maintenance, some trees may be compromised or lost. To guide decision-making, the Group provides points of guidance in the Campus Tree Protection Policy and the Campus Tree General Care Guidelines, all of which are provided in the Campus Tree Care Plan (Center for Sustainability 2013).

When a tree's roots, bark, trunk, and/or crown are damaged the tree may become vulnerable to pests, disease, or debilitation, not to mention compromising its aesthetic qualities. Root impaction, in particular, can be harmful for trees so planting in high traffic areas should be avoided. That said, it is challenging to achieve this in an urban setting and nearly one-third of all trees at Principia College experience some form of root zone impact, generally from pavement but also through proximity to buildings, retaining walls, light posts, and benches (Figure 6). Contractors are expected to make every effort to protect the Critical Root Zone (CRZ), defined by the Illinois Department of Natural Resources as one foot outside the perimeter of the leaf canopy of the tree. The CRZ is the most sensitive area of the tree's roots, and special care should be taken to avoid damaging this zone (summarized in Center for Sustainability 2013).

When trees have been damaged or compromised beyond repair, they should be removed. For example, the Apple Orchard includes several trees that are growing nearly horizontally due to wind damage. It should be a priority both to remove these trees and to replace them with larger specimens better able to withstand the bluff winds. Replacements in general (not just in the orchard) should prioritize native species (see Appendix 1), consider the needs of pollinators (see below), and seek to enhance existing (or provide new) educational opportunities. For example, when the temporary gravel parking lot next to Clara House is removed and the site renovated, this may provide an opportunity to plant native oak species. It would benefit our students' forestry education to have a clustered group of different oak trees to learn and compare in situ. Existing educational opportunities for tree species identification exist at the back of West Residential Quad, behind the houses; there is a lot of species diversity clustered there.

Minimize Non-Native Plantings

A few species on campus are common but problematic in urban environments. Bradford Pear, for example, is a landscape favorite for its fast growth and spring flowers. But rapid growth brings characteristically higher potential for breakage, not to mention it is non-native and provides no benefits to the surrounding ecosystem. In contrast, this inventory has highlighted that native species – especially oaks – support the surrounding ecosystem and at the same time provide a wealth of economic benefits to urban communities. Another reason to carefully steward and prioritize our native trees is that current research suggests that non-native plant species may be better at shifting their flowering time compared to native plant species, and these differences are thought to influence a species' success both now and in future warmer environments (Zettlemoyer et al. 2019) – meaning that without management intervention, our native species may be outcompeted in an era of climate change.

Not all native species are suitable for planting near built infrastructure. Tree characteristics should be taken into account during landscape planning. For example, while Sweet Gum is native, the seed balls are large and plentiful and it is easy to slip on them when they land on pavement. Native Silver Maple and Eastern Cottonwood are fast growing but weak trees, prone to breakage and rot. Unfortunately, the campus currently hosts every species found on the Campus Tree Care Plan's *Not Recommended List* (Appendix 2). As these trees age and die, they should be replaced with trees on the *Recommended Species List* (Appendix 2) (Center for Sustainability 2013).

Trees that were in poor condition on campus were mostly Redbuds, which is common for this species.

Consider Pollinator Landscapes

Due to their dense supply of flowers, trees can be an important food source for imperiled native pollinators. Trees are also good nesting places for bees; e.g., the Eastern Carpenter Bee relies solely on trees for nesting. Some of the most common flowering trees on Principia's campus are the Flowering Dogwood and Eastern Redbud. Both attract insects, including bees, wasps, flies, skippers, and beetles (Pollinator Partnership 2016). It is important to provide habitat and foraging grounds for pollinators because they have experienced sharp population declines in recent years (e.g., Ghazoul 2015). Care should be taken to provide corridors of flowering trees through the Principia campus for the benefit of native pollinators, and this would also provide an excellent educational resource. A variety of research studies and management guidelines are available from organizations such as The Xerces Society (e.g., Hatfield et al. 2012).

Next Steps

The species composition, location, condition, and size of trees all impact management decisions; therefore, this tree inventory provides an essential tool for landscapers and stewards. Moving forward, the inventory should be repeated at regular intervals in order to evaluate the success of urban forest management programming. Gaps in the current inventory include a handful of trees that could not be identified to species, as well as the need to further refine diameter and height data (there are tools available in the forestry program at Principia College to measure height with greater precision). The Campus Tree Care Plan (Center for Sustainability 2013) also has a goal of ground-truthing the canopy cover provided by the campus trees. Based on research into other urban forest inventories, I recommend that this be done using the i-Tree software program provided by the USDA Forest Service. Perhaps an evaluation of the utility of this tool could form the basis of a future student project.

The value of our campus trees is likely to be underappreciated by the campus community. Creating outreach assets, perhaps as simple as some creative signage, could form the basis of a future student project. It's worth repeating – and sharing more broadly – that the ecological services provided by the 1,499 trees landscaped on the core college campus provide an estimated $76,141 in essential ecological services *annually*. We can further increase this benefit by planting more native oaks, which outperform other tree species on nearly every metric.

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Appendix 1. Species list (with scientific names) of trees inventoried on the core campus of Principia College, Elsah, Illinois. Of 65 identified species, 36 (shaded in **bold face**) are native.

Common Name	Scientific Name		Common Name	Scientific Name
American Beech	*Fagus grandifolia*		Japanese Zelkova	*Zelkova serrata*
American Elm	*Ulmus americana*		Kwanzan Flowering Cherry	*Prunus kanzan*
American Holly	*Ilex opaca*		Magnolia (Saucer)	*Magnolia soulangiana*
American Sycamore	*Platanus occidentalis*		Magnolia (Southern)	*Magnolia grandiflora*
American Witch-hazel	*Hamamelis virginiana*		Magnolia (Star)	*Magnolia stellata*
Amur Cork	*Phellodendron amurense*		**Maple (unknown)**	*Acer sp.*
Amur Maple	*Acer ginnala*		**Mockernut Hickory**	*Carya tomentosa*
Apple	*Malus domestica*		**Northern Hackberry**	*Celtis occidentalis*
Austrian Pine	*Pinus nigra*		**Northern Red Oak**	*Quercus rubra*
Black Cherry	*Prunus serotina*		Northern White-cedar	*Thuja occidentalis*
Black Walnut	*Juglans nigra*		Norway Maple	*Acer platanoides*
Black Willow	*Salix nigra*		Norway Spruce	*Picea abies*
Blue Spruce	*Picea pungens*		Ornamental Flowering Peach	*Prunus persica*
Box Elder	*Acer negundo*		**Osage Orange**	*Maclura pomifera*
Bradford pear	*Pyrus calleryana*		Pacific Yew	*Taxus brevifolia*
Chinkapin Oak	*Quercus muehlenbergii*		Paper Birch	*Betula papyrifera*
Crabapple	*Malus pumila*		**Pin Oak**	*Quercus palustris*
Crabapple ('Spring Snow')	*Malus 'spring snow'*		**Princeton Elm**	*Ulmus americana*
Crabapple ('Sweet')	*Malus coronaria*		**Red Maple**	*Acer rubrum*
Eastern Black Oak	*Quercus Velutina*		**River Birch**	*Betula nigra*
Eastern Cottonwood	*Populus deltoides*		**Sassafras**	*Sassafras albidum*
Eastern Hemlock	*Tsuga canadensis*		**Serviceberry**	*Amelanchier arborea*
Eastern Redbud	*Cercis canadensis*		**Shagbark Hickory**	*Carya ovata*
Eastern Redcedar	*Juniperus virginiana*		**Silver Maple**	*Acer saccharinum*
Eastern White Oak	*Quercus alba*		**Sugar Maple**	*Acer saccharum*
Eastern White Pine	*Pinus strobus*		**Sweetgum**	*Liquidambar styraciflua*
Flowering Dogwood	*Cornus florida*		Weeping Cherry	*Prunus pendula*
Ginkgo	*Ginkgo biloba*		**Weeping Redbud**	*Cercis canadensis*
Green Ash	*Fraxinus pennsylvanica*		Weeping Willow	*Salix babylonica*
Hawthorn (unknown)	*Crataegus sp.*		White Spruce	*Picea glauca*
Honeylocust	*Gleditsia triacanthos*		**Whitebud**	*Cercis canadensis*
Ironwood	*Carpinus caroliniana*		**Winged Elm**	*Ulmus alata*
Japanese Tree Lilac	*Syringa reticulata*			

Appendix 2. Tree species selection for Principia College (Center for Sustainability 2013).

Recommended Species		Copper beech (*Fagus sylvatica*)
White Oak (*Quercus alba*)		Silverbell (*Halesia tetraptera*)
Post Oak (*Quercus stellata*)		Black walnut (*Juglans nigra*)
Chinkapin Oak (*Quecus muhlenbergii*)		Cucumber magnolia (*Magnolia acuminata*)
Sugar Maple (*Acer saccharum*)		Dawn redwood (*Metasequoia glyptrostroboides*)
Eastern Redbud (*Cercis canadensis*)		Ironwood (*Ostrya viriginiana*)
Flowering Dogwood (*Cornus florida*)		Quaking aspen (*Populus tremuloides*)
Pecan (*Carya illinoinesis*)		Japanese flowering cherry (*Prunus serrulata*)
Allegheny serviceberry (*Amelanchier laevis*)		Swamp White oak (*Quercus bicolor*)
Shortleaf Pine (*Pinus enchinata*) [native pine]		Scarlet oak (*Quercus coccinea*)
White fir (*Abies concolor*)		Hill's oak (*Quercus ellipsodalis*)
Black maple (*Acer nigrum*)		Shingle oak (*Quercus imbricaria*)
Sycamore maple (*Acer pseudoplatanus*)		Burr oak (*Quercus macrocarpa*)
Ohio buckeye (*Aesculus glabra*)		Red oak (*Quercus rubra*)
Yellow buckeye (*Aesculus flava*)		Chestnut oak (*Quercus prinus*)
River birch (*Betula nigra*)		American Linden (*Tilia americana*)
Bitternut hickory (*Carya cordiformis*)		
Shellbark hickory (*Carya lasiniosa*)		**Not Recommended Species**
Pignut hickory (*Carya glabra*)		Ginkgo (*Ginkgo biloba*)
Mockernut hickory (*Carya tormentosa*)		Princess Tree (*Paulownia tomentosa*)
Shagbark hickory (*Carya ovata*)		Silver Maple (*Acer saccharinum*)
Northern Catalpa (*Catalpa speciosa*)		Bradford Pear (*Pyrus calleryana*)
American Yellowwood (*Cladrastis kentukea*)		Eastern Cottonwood (*Populus deltodies*)
Common Persimmon (*Diospyros virginiana*)		Sweetgum (*Liquidambar stryciflua*)
American beech (*Fagus grandifolia*)		Asian/Amur Honeysuckle (*Lonicera maackii*)