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Potential Carbon Storage and Cost-Benefits Analysis of a Small-Scale Community Reforestation Project, Chester County, Pennsylvania

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Abstract

Potential Carbon Storage and Cost-Benefits Analysis of a Small-Scale Community Reforestation Project, Chester County, Pennsylvania

By Jason D. Ferrell

Chairperson: Joy Fritschle

High levels of airborne and waterborne pollutants along with unyielding carbon emissions have become increasingly associated with urban centers throughout the last half century. Environmental restoration in the form of reforestation projects is a cost-effective way to help restore poorly managed ecosystems affected by sprawling urbanization. One such initiative began in 2009 in East Goshen Township, Chester County, Pennsylvania. Its closely monitored development is anticipated to inspire similar sites within the region. In this study, each of the 225 trees on the 1.04 ha reforested field was analyzed to determine carbon stock and pollution remediation for the present-day and projected 5, 25 and 75 years into the future. Current and future tree productivity was measured using the *i-Tree* Eco analysis tool that uses individual tree characteristics to evaluate their pollution removal capabilities, specifically carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), particle matter (PM_{10}) and sulfur dioxide ($S0_2$). The site sequestered 1.02 t C/ha in the 2009 study year, and significantly increased in 2010 to 1.21 t C/ha with an average value of $93.32 per tree. By the time the site has matured in the 75 year projection the trees are expected to have stored a combined 221.41 t C/ha and will remove an estimated $1,912.70 worth of pollutants from the atmosphere each year. Each tree will return an average value of $1,528.61 in benefits for an overall site total of $343,939. Soil samples were also collected from various locations on the site to determine the potential influence of soil chemistry and construction-related compaction on tree growth. Significance testing using single-factor analysis of variance (ANOVA) tests as well as paired one-tailed t-tests found that bulk density and pH did not significantly vary across the site. Significant increases were found in each progressive study year regarding carbon storage, pollution remediation, and the overall monetary value of the site. The remediation properties of the site are projected to substantially outweigh the initial costs of planting and the maintenance costs that continue through the development of the site. The results of this study will aid management practices on site and allow for planning of forest growth and development. The successful maturation of this site is expected to aid in the establishment of similar reforestation efforts throughout the region.

Potential Carbon Storage and Cost-Benefits Analysis of a Small-Scale Community Reforestation Project, Chester County, Pennsylvania

A Thesis Presented to the Faculty of the
Department of Geography and Planning
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In

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INTRODUCTION

Urban forest restoration and management are crucial in maintaining our environmental systems. Significant amounts of forest land within the United States are expected to be transformed by urbanization within the coming decades, and as this trend increases, so does the need for resource planning and management techniques to sustain forest health and productivity (Nowak, 2007). It is widely accepted that rising carbon emissions are responsible for driving climatic changes that we are seeing worldwide, while it has also been proven that forest ecosystems contain approximately 60% of all carbon stored in terrestrial ecosystems (Streck and Scholz, 2006; I.P.C.C., 2011).

The past two decades have given rise to many carbon budget studies that have proven to be of great importance when it comes to implementing efficient forest carbon storing models (Keles and Baskent, 2007). The current carbon sink across U.S. forests is mostly made up of areas of prior land use that have seen some form of ecosystem recovery (U.S.D.A., 2009). Due to this fact, methodologies have been developed to estimate carbon storage across a wide range of forested ecosystems where biomass is lower than normal due to poor historical management practices. Despite the loss of many of the larger tree specimens, regrowth and recovery from past disturbances can contribute to a successful and functioning carbon sink. Significant additions to this national carbon sink can be made through the incorporation of local reforestation efforts that can be systematically placed to reverse poor historical land use (DeLuca et al. 2010; Conway et al., 2011). Approaching the issue from the municipal or township level divides the initiative between several communities within a region, creating a more manageable area for labor-intensive methods such as reforestation to be put in place (U.S.D.A, 2011b).

Thus, it is the aim of this study to examine the carbon sequestering capabilities of a small urban reforestation project in southeastern Pennsylvania, how it can help to combat the ill effects of the land use that surrounds it, and to explore the characteristics that promote healthy and successful forest regeneration. The study objectives are: (1) to determine the carbon sequestering and storage capability of the trees currently at the site and projected into the future, (2) to assess soil characteristics of the site that affect tree growth such as soil taxonomy, bulk density, and pH levels, and (3) to conduct a cost-benefit analysis of the site. The Applebrook Park reforestation project in East Goshen Township in Chester County, Pennsylvania is the first project of its kind within the township. Since this reforestation initiative is new to the local area it is important to examine the benefits that it will provide to the surrounding community.

This thesis will begin with a review of the relevant literature on the need for and benefits of reforestation, the costs and benefits of reforestation projects, and the keys to successful reforestation and management. A description of the study area, methods, and results of the analysis will follow. I will conclude with a discussion of the likelihood of long-term success and benefits of the East Goshen project, and how it might serve as a model for future projects in the region. Specifically, I will highlight the important site characteristics that will either aid or work against forest growth and development. Successful reforestation at Applebrook Park may inspire similar reforestation projects in the area while stimulating East Goshen's ecological restoration initiatives.

The Need for Reforestation

Reforestation comprises one approach among a suite of tools employed in the restoration of ecosystems. The Society for Ecological Restoration defines ecological restoration as the intentional process that initiates the recovery of an altered ecosystem to a state of ecological integrity (Society for Ecological Restoration International Science and Policy Working Group, 2004). Growing population and overharvesting of resources have not followed a course that promotes this recovery in damaged areas. The force of urbanization has been driven by colossal leaps in socioeconomic factors that fuel land development and poor management while significantly changing natural ecosystems worldwide. Land use change, particularly in the U.S., has changed dramatically since World War II due to higher average incomes and a spike in population. Destruction and fragmentation of ecosystems is a direct result of increasing population and poor planning practices that are used to accommodate the masses of citizens (Alig, 2010).

Urbanization and rapid sprawl have led to declining environmental conditions that hamper human health and well-being. Poor air and water quality along with increasing air temperatures are only a few of the adverse affects resulting from mass development and poor planning. The quality and functionality of our urban centers can be increased by the incorporation of ecological processes within areas of high social activity. Natural systems are perhaps the most effective way to remedy environmental damage. The process of trees aiding the filtration of air and water in our urban settings allows for designated landscapes to transform into shades of their former selves. These systems serve as stewards for the cleansing of our environment from unnatural yet accepted development practices. The strategic use of forests within and around cities in the U.S. is an overlooked yet vital blueprint in planning today.

Within Chester County, rising greenhouse gas emissions have become the focus of many programs whose aim is to work toward stabilization and ultimately reduction of high CO^2 levels (e.g., Chester County Greenhouse Gas Reduction Task Force, West Chester Borough Leaders United for Emissions Reduction, West Chester University Climate Commitment Advisory Committee, etc.). Woodlands in the county offer perhaps the greatest potential to reduce greenhouse gas emissions, thus a recent study recommended that reforestation be identified as an important and immediate priority (Allison et al., 2010). Chester County has experienced a loss of 486 ha of forestland per year over the last fifteen years (Allison et al., 2010). This alarming rate of deforestation has led to increased awareness of the importance of preserving existing woodlands and establishing new forested areas. The primary objective of reforestation is to create a community consisting of an adaptive, local species composition that is balanced enough to be considered comparable to similar systems within that particular region (DeLuca et al. 2010). Focusing specifically on East Goshen, ecological restoration is needed to help the flora and fauna revert back to more healthy populations to combat the ill effects of farming and urbanization (Citizens for Pennsylvania’s Future, 2004; East Goshen Township, 2005).

Benefits of Forest Restoration

Urban forest growth is not only important for wildlife resurgence, but it also supports municipal growth as it transitions into a more environmentally conscious framework. Properly placed sites will enhance the quality of surrounding communities through the various benefits that they return.

Restoration of Riparian Buffers

Urban streams account for some of the most environmentally degraded waterways within North America (Hession et al., 2000). Rooftops, pavement and impermeable surfaces drain non-point source pollution directly into our hydrological systems, disturbing water quality, geomorphology and the ecology of such systems. The impact of stormwater runoff from our urban centers has severely impacted the aquatic nature of streams and creeks that surround and infiltrate their boundaries (Hession et al., 2000).

Restoration and management of urban streams and watersheds are critical as increased runoff volume, sedimentation and toxins create a cascade of problems. Riparian buffers have proven to be important features in filtering runoff from urban and agricultural areas. Throughout agricultural and urban areas in the United States, forest buffers can serve to combat sedimentation buildup and non-point source pollution in streams and watersheds (Mayer, 2010). Thus restoration of riparian forests is an important initiative found in many watershed management programs to improve poor stream ecosystems. Their presence is beneficial to the watershed through hydrologic, temperature, light and nutrient regulation, physical habitat, and as a food and energy source (Hession et al., 2000).

Water quality and other environmental characteristics of riparian and aquatic systems illustrate the improvements that systematically placed tree stands can promote. Forest riparian buffers enhance stream habitat, water quality and macroinvertebrate communities. Polluted or disturbed habitats have been recorded to stabilize at intervals congruent with historical levels as the trees mature at 10-15 years old (Orzetti et al., 2010). Buffer restoration projects typically begin with younger trees and see a steady increase in stream water quality until the trees reaches maturity. In fact, buffer age is directly correlated with better stream habitat, water quality and invertebrate survival. As the trees get older, the stream gets healthier (Orzetti et al., 2010).

Riparian zones provide critical services that support society and the economy, making them essential to human health and well being. Their positioning within various landscapes creates pathways and corridors that facilitate a flowing network of ecosystems. These corridors are essential to the sparse patches of parks and green space that surround and are incorporated within our urban centers. The continual depletion of riparian areas is representative of the loss of services from these ecosystems (Mayer, 2010). Agricultural pollution and erosion typically account for most stream water degradation within Chester County (Citizens for Pennsylvania’s Future, 2004). Both pasture and suburban/urban land uses contribute substantial amounts of sediment into streams. This is attributed to the increasing amount of impervious surfaces within watersheds as well as the large amount of grazing land located alongside water sources

(Orzetti et al., 2010). Furthermore, the implementation of riparian buffers has the ability to store and convert nutrients like phosphorous and nitrogen commonly associated with nonpoint source pollution. Managed properly, buffers can trap and convert up to 75% of nitrogen and 70% of phosphorous before it enters the stream (Orzetti et al., 2010).

Testing soil properties and analyzing landscape features among different streams can help in the implementation of riparian buffers. Understanding the landscape patterns and soil distributions in different stream buffer zones is critical to effectively managing riparian areas and reducing pollution in agricultural watersheds. In areas of high agricultural land use, fewer toxins exist within the soil where buffers are present (Kang and Henry, 2009). Though the results may vary somewhat, soil properties are consistent with land use and landscape features such as riparian buffers. Proper landscape distribution patterns along stream networks are helpful in managing different areas of high agricultural activity (Kang and Henry, 2009).

The development of low-density residential and commercial development can result in a 20% reduction in water flow (Tong et al., 2009). Most of the conversion occurs in areas that are experiencing rapid urbanization. Soil nutrient pollution levels drop off as crop rotation ceases and farms do not replenish elements such as nitrogen and phosphorous. However other nutrients (e.g., sodium and chlorides) are introduced into the environment due to the development of roads and parking lots (Tong et al., 2009). At the Applebrook Park reforestation site, historic aerial photographs reveal that agricultural areas nearby have undergone urbanization in the last 80 years (Penn Pilot, 2011). Monitoring future surface runoff and nutrient levels in both the soils and groundwater is important in understanding this urban transition and its effects on stream water quality (Tong et al., 2009).

Carbon Sequestration in Forest Stands

Natural and anthropogenic processes are responsible for constantly cycling carbon through storage pools and the atmosphere (Huang et al., 2004). As trees grow they remove carbon from the atmosphere and store it in the living biomass. Once trees reach maturity, carbon storage is rather consistent from year to year. Eventually as trees die, carbon is deposited back into the atmosphere through decomposition or consumption by other organisms, or is added to the soil composition (Birdsey, 1992). Harvesting transfers carbon to a product pool where most carbon is emitted over time as CO^2 when the wood combusts or breaks down. The rate of emission varies from pool to pool. Thus it is important to allow our forests to sequester as much as possible and restrict the destruction of such sinks, especially in urban areas where development is continually expanding. Offsetting carbon production through urban reforestation efforts, particularly at the local scale, will prove to be very beneficial in the fight against global climate change (U.S.D.A., 2009; Mello et al. 2010).

The United States currently is responsible for about one third of the world's pollutants linked to heat trapping gasses; a portion is caused by fossil fuel combustion and agricultural production, but it is primarily driven by our power and transportation sectors (Huang et al. 2004). As forest communities currently offset about one-eighth of the carbon emissions within the U.S. it would be wise to look further into this resource

(Daniels, 2010). With the U.S. struggling year by year to meet global climate and energy goals, carbon sinks in the form of forest ecosystems could potentially be the most valuable tools to reach such standards (Wayburn and Chiono, 2010).

Forests are able to gather and store carbon through the respiratory and photosynthetic process. By sequestering CO^2 they are not removing it completely from the atmosphere but holding onto it for a period of time that surpasses the life of the individual tree, gradually releasing it back into the environment. Yet long term carbon sinks are threatened by rising taxes, development pressures, forest fires, diseases and pests, etc. that threaten to release the carbon nearly all at once instead of intermittently. The efforts to maintain these carbon deposits must be ongoing to reduce CO^2 emissions in the long term (Daniels, 2010). In exploring the ability of forests to capture much of the atmospheric carbon that facilitates climate change, we find many opportunities to increase the storage of carbon. These opportunities include increasing forest area and productivity of such stands, reducing forest burning and deforestation, increasing biomass production and utilization, planting trees in urban settings, and increasing the use of wood in more durable products (Birdsey, 1992).

Costs vs. Benefits of Urban Reforestation

The urban forest is comprised of all woody vegetation within the environs of human populated areas. The forested land in urban and metropolitan settings makes up 25% of the total forested land within the U.S. (McPherson, 2003b). While urban trees have no value in timber production, they do provide many benefits that can be evaluated both monetarily and aesthetically. Benefits include increasing property values, decreasing energy costs, improving air quality, reducing storm water runoff, decreasing erosion, improving water quality, creating wildlife habitats, increasing community pride, increasing recreational opportunities, reducing noise levels and creating buffer zones (Randolph, 2004).

While the urban landscape holds a significant percentage of the forest canopy in the United States, management practices and forestry techniques have not been properly implemented. The national urban tree deficit is characterized by overdevelopment and the absence of sustainable growth (Randolph, 2004). According to the U.S. Forest Service, an enormous amount of forest land, equaling ~12 million hectares in some areas of the country, will be devoured by urban development over the next decade (Randolph, 2004). The loss of so many trees is unfortunate considering the significant benefits of forest and tree production. Reforested sites, such as the East Goshen project serve as a primary resource in resisting a plague that threatens to significantly diminish the forested landscape over the next few decades.

Over time these new forests will produce many of the benefits previously listed, but there are necessary costs. The initial few years of the site will require more maintenance than the later years as this is the stage when the trees are most vulnerable. The planting, litigation and liability, storm cleanup and administrative costs all require funding (Randolph, 2004). Studies have shown that a tree needs 9-18 years longevity before its benefits will pay off the initial investment costs and start producing positive monetary results (McPherson et al., 1994). Efforts should be taken to achieve longevity throughout each site by ensuring that proper techniques are employed through the various stages of tree development. From ensuring site suitability to planting the appropriate tree species and the maintenance that follows, reforested sites are an investment that produces over time and should be treated as such (McPherson, 2003a).

One problem with measuring the efficiency of a forest is that many of the products a forest has to offer have no market value. In order to measure forest attributes there must be a baseline measure of efficiency. One accepted procedure is to measure the average productivity of labor and use this as a measure of efficiency; however it is inappropriate in forest management as it overlooks all other inputs but labor (Kao and Yang, 1991). Regardless it is imperative that forest managers attempt to show a value on these site products either aesthetically, monetarily or otherwise. For there is a significant investment that reforestation sites require and it is necessary that the benefits of forest growth and protection are provided so that sites are looked at as productive and not as a liability (Randolph, 2004).

Keys to Successful Reforestation

There are certain site characteristics and management techniques that aid in the healthy growth of forest stands. While these variables differ from site to site, knowledge of maintenance techniques that will work with the properties of a site is critical to successful reforestation. Knowing the capabilities of the forest is the important. Coordination of resources among various management techniques can facilitate the productivity of each individual resource without impairment (Kao and Yang, 1991).

Soil Features Congruent with Sustainable Reforestation

The tree species that occupy a site are largely dependent on the soil properties that characterize the area. Soil properties like pH, compactness, and erodibility could be mean life or death for individual trees or entire sites.

Among many soil properties, pH levels influence tree growth and nutrient uptake (Londo, Kushla and Carter, 2006; Wolf, 2009). Soil pH levels are a good indication of the chemical and nutritional status and can be used to estimate the potential growth of the site. Different trees prefer different soils. Pines will grow best in acidic soils while hardwoods will do better in a slightly acidic to neutral soil (Londo, Kushla and Carter, 2006). Nutrients have been known to change their chemical makeup due to reactions in the soil controlled by pH. Trees may or may not be able to utilize them based on this metamorphosis. Soils with a pH of 6.5 – 7.0 normally hold the best growing conditions as vital nutrients are readily available.

Soil pH values at the lower and higher ends of the spectrum (<4.0 and >8.5) can make some nutrients toxic and others unavailable. For example, at a pH level of <4.5, aluminum, iron and manganese are available for mineral uptake while at a higher pH level of >5.5 nutrients like calcium and potassium are over abundant (Londo, Kushla and Carter, 2006; Wolf, 2009). In situations like these, trees can absorb too many of certain nutrients and not enough of others, causing an imbalance leading to toxic conditions.

Along with pH, there are other soil qualities and characteristics that should be considered when working with a reforestation site. Soil organic matter loss and increased soil compaction are the factors most likely to directly impact tree growth in managed forests. The pooling of organic material away from the soil deprives it of the replenishing nutrients that tree and plant species need to grow. This erosion of the topsoil layer is common to areas that have too much open, loosely packed soil as well as sites that have an uneven distribution of trees through the site area (Boussougou et al. 2010). The circulation of heavy equipment common in the beginning stages of a reforestation project has the potential to greatly change the soil structure. Compacted soils are characterized by higher bulk density, greater resistance for root penetration, higher microporosity, increased water retention, and lower air filled porosity; none of which are ideal for successful tree development (Boussougou et al. 2010).

The ability of roots to penetrate soils has a large effect on overall growth. Roots must force their way into the ground as they are only able to support lateral growth in compressible soils (Kozloski, 1985). Individual roots can penetrate only those soil pores that are greater than the root in diameter. Root growth into soils of high bulk density is forced to follow the breaks in the compacted soil. Prevention of root movement into compacted soil depletes the availability of water around the root tip. Capillary movement of water from moist to dry regions in the soil can be a slow process. Therefore, continuous root extension is necessary to obtain water sources. Proper aeration and moisture conditions are required for root growth. Compacted soils do not provide favorable growing conditions for developing trees. Oxygen is needed for aerobic root respiration and this process is used to supply energy needed for mineral uptake, synthesis of protoplasm, and maintenance of cell membranes. Not enough energy is produced and basic root functions cannot be performed in poorly aerated soils. In particular, the smaller absorbing roots and growing root tips contain many living cells that are injured when there is insufficient soil O^2. The lack of energy particularly affects the tree's ability to synthesize new protoplasm, maintain cell membranes and most importantly mineral uptake is severely hindered. As the absorption of minerals decreases, photosynthetic processes slow and cut the tree's ability to properly function, facilitating a loss of ions by leaching through root membranes (Kozloski, 1985).

As a result of this inability to pull nutrients from the earth, deposits of toxic products such as sulfides, methane, ferrous iron and other reduced compounds increase with the tree's dwindling ability to filter them out of the soil. Poor aeration will also stunt tree growth by disrupting its ability to synthesize hormonal growth regulators and nitrogen compounds such as amino acids (Kozlowski, 1985). The results of poor aerobic root respiration illustrate the importance of proper planting techniques of newly established reforestation sites.

Site Management Practices

An understanding of the best management practices in urban forestry is necessary to develop properly functioning forest stands that serve a community's need for environmental remediation and aid in ecological restoration efforts (U.S.D.A., 2011b). Research on forest stands like the East Goshen project will provide a better foundation for improved management techniques. Cost-effective management systems need to be put in place to help promote reforestation benefits in a positive light.

While large-scale studies of forests over entire regions are important in understanding urban tree populations, there is a tendency toward more small-scale reforestation projects. These smaller forest plots allow managers to perfect analysis methods that can be applied to larger forest stands in the future. In these finer-scale studies, ground-based measurements in congruence with remote sensing allow for accurate analysis that can provide more efficient standards applicable in a variety of different environments and populations. Forest managers are given a broader perspective of the processes and approaches needed in maintaining healthy, functioning urban forests through the study of more modestly sized tree stands (U.S.D.A., 2011b). Close monitoring techniques ensure habitat productivity as well as strong community backing and support (DeLuca et al. 2010; Mello et al., 2010).

The forest as a whole should be managed to produce as many benefits as possible without exhausting the resource. At the same time there are many forests including those belonging to the state and federal government that are devoted exclusively to one purpose. Timber extraction and recreational areas are typical foci though some woodland areas are reserved for research and wildlife. Some areas of the forest are better adapted for recreation while others are optimum for timber growth or wildlife and game habitat. This makes it unlikely that every aspect of the forest will be utilized. Management should be able to know how efficiency can affect the output of a site by closely monitoring each section of the forest (Kao and Yang, 1991).

Proper maintenance decisions concerning issues like thinning out tree lots help ensure overall tree health and survivorship. It has been shown that damaged trees and individuals with significant crown die-back have high mortality rates (Ohno et al., 2008). Weakened trees tend to have slower growth rates and thus will be less likely to reach their expected size at maturity. Reforestation sites typically show greater mortality in numbers than in biomass, correlating with a high mortality rate in smaller stems (Lutz and Halpern, 2006). Manicuring and thinning of the site in early development stages is important in reducing competition and allowing healthy trees to flourish (Ohno et al., 2008).

The diversity of the forest site is ultimately determined by the life expectancy of the different species that inhabit it (Lutz and Halpern, 2006). As the forest develops through many generations of growth there will be a transition from the commonality of tree ages seen at the beginning into a diverse grouping of ages based upon the specific lifespan of species (Lutz and Halpern, 2006). Varying the lifespan of the forest and grouping them accordingly through the site will help the forest to regenerate at natural intervals as well as allow those trees with slower growth rates to develop away from those with faster growth rates so they have a better chance to compete for sunlight (U.S.D.A., 2010b).

Forest restoration methods vary from project to project depending on the needs of the operating party and the surrounding community. The Forest Stewardship Council (FSC) is an independent, non-governmental, non-profit devoted to the responsible management of the world’s forests, while the Programme for the Endorsement of Forest Certification Schemes (PEFC) is a similar international group that promotes similar sustainability standards (Forest Stewardship Council, 2011; Programme for the

Endorsement of Forest Certification Schemes, 2011). The FSC promotes reforestation approaches that have been put in place to maintain healthy forest growth from the initial stages of planting. The objectives include using an ecologically appropriate array of native species, the creation of timelines of regeneration, and the proper consideration of artificial and natural regeneration techniques (Forest Stewardship Council 2011).

The demand for voluntary and regulatory action that these two distinct groups promote provides an interesting and unique example of maintaining an appropriate balance between the public and private interests that need to be involved in sustainable forestry practices (Forest Stewardship Council, 2011; Programme for the Endorsement of Forest Certification Schemes, 2011). A similar set of ethics in the promotion of healthy and sustainable forest ecosystems is required to maintain proper management techniques (Soyka, 2011). Similarities in the two groups initiatives include conformance with international and national laws, requirement of forest management to be planned according to environment and local social and natural needs, and the protection of forest biodiversity through the controlled or non-use of fertilizers and pesticides (Forest Stewardship Council, 2011; Programme for the Endorsement of Forest Certification Schemes, 2011).

While there are numerous benefits that result from reforestation, costs will exceed benefits if management practices are not properly maintained. For example, ecosystem restoration over the last century in semi-arid regions of China has relied heavily on afforestation. While small scale and short-term assessments produced the expected benefits, long-term forest sites typically failed, resulting in further environmental degradation through soil erosion, increased desertification and disruption of the biodiversity that adapted to disturbed areas (Cao et al., 2010). Current forestry practice and policy may not be flexible enough to blanket differing environments. Large-scale observation of ecosystem functionality along with forest management approaches are necessary for healthy forest development that exists symbiotically with the existing ecological community (Cao et al. 2010). Several reforestation projects taking place in Brazil, China, Indonesia, Peru, Philippians and Vietnam support this notion of altering reforestation techniques depending on geographical placement. The success of each project relies on the specific management styles adopted for a site that work with the existing conditions. Each may incorporate similar methods into their rehabilitation efforts but experience different results due to widespread factors such as gaps in management expertise, tree species/site compatibility, policy, and funding (Jong, 2010).

Site Preparation and Assessment

The assessment of employed management techniques among reforestation stands is a vital step in determining the level of site progression as well as its economic profitability. As reforestation is relatively well researched, it is necessary to assess the methodologies used in maintaining a sustainable site to deem which practices may be the most important. There are many factors incorporated into successful forest development and one may be more critical than another in changing environments from site to site. However, the process of site preparation is possibly the most important characteristic in all situations (Cao et al., 2010).

Success and failure of a reforestation project is largely dependent on site characteristics and the selection of the tree species that are best suited for those conditions. The relationship between the two should be at equilibrium, whereas the trees do not deplete site resources and the site is able to sustain healthy tree growth (Cao et al., 2010). Site preparation has proven to be congruent with success rates of reforestation efforts. Prepared sites create a more favorable environment for tree establishment. Specifically, it can help improve root-zone temperature and soil moisture problems, reduce frost hazards, control vegetative competition and insects, treat forest pathogens, aerate the soil, and enhance nutrient availability through the incorporation of such methods as scalping, mounding, chemical site preparation, and chemical brushing (Hawkins et al., 2006).

Despite the advantages to site preparation, there is a tendency for most private reforestation projects to practice raw planting (Hawkins et al., 2006). Raw planting is considered a more holistic approach to forestry as it puts less stress on the land and increases the potential site benefits. For example, the use of chemical fertilizers and pesticides is contradictory when planting a site for the use of environmental remediation (Franklin, 1989). Raw planting typically has a greater appeal, as it does not incorporate the use of unnatural synthetics and costs less than chemically prepared sites. Prepared sites can run several hundred dollars per hectare depending on the treatment methods used and site characteristics (Hawkins et al., 2006). Raw planting was seen as a more acceptable form of reforestation for the East Goshen site and it was employed by contractors during site development. While the success rate may not be as high as a prepared site, natural site progression is favored over treatment techniques that involve human intervention and site disturbance (Hawkins et al., 2006).

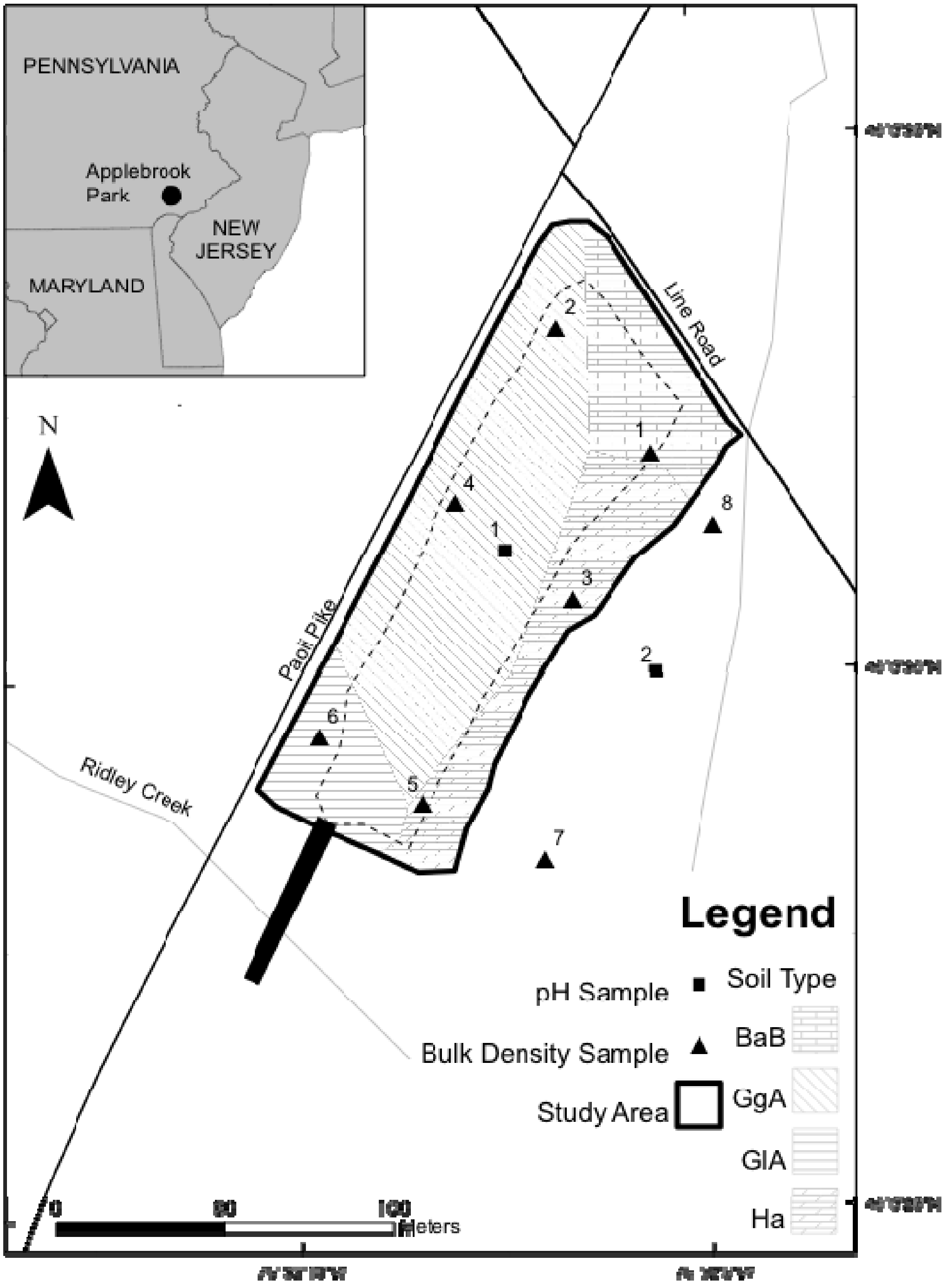
Establishing a strong foundation of knowledge and backing is important before beginning any reforestation project. Each planting location differs in climate, soil type, proximity to urban centers and various other aspects that influence site characteristics and determine the productivity of the forest. Once clear on the proper approach to begin the project, the study area can be populated with the determined number and species of trees.

Study Area

Trees removed during the construction and development of a new YMCA within East Goshen Township were replaced in the park with an equal number of nursery grown trees. `In accordance with East Goshen Township Code Section 205-61E, trees removed during the development process must be replanted on an inch-by-inch basis as measured at diameter at breast height (DBH) by the group responsible for their displacement. The code allows the Township Board the discretion to determine a location off-site for the trees to be planted. Rather than replant trees at the site of the development, an area of the township park was identified for reforestation.

The reforestation area was an approximately 1 ha mowed field bound by Paoli Pike to the northwest, Line Road to the northeast, and branches of Ridley Creek to the southwest and southeast (Figure 1). Historic aerial photos from 1937 to 1971 reveal that the study area was used as cropland until 1971, and was subsequently converted to pasture until the reforestation project began in 2009 (Penn Pilot, 2011).

Figure 1. Applebrook Park Study Area describing site area as well as soil type and sample locations.



Ridley Creek traverses the site parallel to Paoli Pike, a busy collector road. Runoff from the corridor enters the site and filters into Ridley Creek, upsetting the ecological balance and polluting both on-site and farther downstream. The establishment of a riparian buffer system located at the Applebrook Park site could be beneficial to water quality within East Goshen. Runoff from farming practices is generally the most problematic form of non-point source pollution that affects water sources in Chester County, including the East Goshen branch of Ridley Creek (Citizens for Pennsylvania's Future, 2004).

YMCA contractors responsible for the development project planted the trees in June and July of 2009 with the planting and required maintenance (mulch, mowing and watering) overseen by the East Goshen Township Conservancy Board. The grass between the trees is still being mowed; however, the Conservancy Board plans to create an understory once the new trees have become established (G. Hertel, forester, West Chester University, personal communication). The site was planted using clumping methods and when relocated, the 223 trees were 3 inches in diameter and were balled and burlapped. The trees included eleven different native species: *Nyssa sylvatica* (black gum), *Quercus prinus* (chestnut oak), *Quercus rubra* (red oak), *Quercus alba* (white oak), *Ulmus Americana* (American elm), *Carya ovata* (shagbark hickory), *Carpinus caroliniana* (ironwood), *Acer rubrum,* (red maple), *Betula nigra* (river birch), *Plantus occidentalis* (American sycamore), and *Liriodendron tulipifera* (tulip poplar) (Table 1).

No site preparation techniques were used before the introduction of the trees. In addition, the tree locations were laid out so that a trail, that ended southwest of the study

Table 1. Tree characteristics (Grimm, 2002; Arbor Day Foundation, 2011).

Species	Scientific Name	Height at Maturity	Diameter at Maturity	Shade Tolerance	Growth Rate	Life Span (years)
Red Maple	*Acer rubrum*	12-22 m	60-120 cm	Intermediate	Rapid	75-100
River Birch	*Betula nigra*	9-16 m	30-60 cm	Intolerant	Rapid	75-100
Iron Wood	*Carpinus caroliniana*	6-12 m	20-30 cm	Tolerant	Slow	75-100
Shagbark Hickory	*Carya ovata*	16-25 m	30-90 cm	Intermediate	Slow	200-250+
Tulip Poplar	*Liriodendron tulipifera*	24-31 m	60-150 cm	Intermediate	Rapid	100-200
Black Gum	*Nyssa sylvatica*	9-16 m	30-60 cm	Tolerant	Moderate	100-200
Sycamore	*Platanus occidentalis*	31-53 m	90-240 cm	Intermediate	Rapid	200-250+
White Oak	*Quercus alba*	18-24 m	90-150 cm	Intermediate	Slow	200-250+
Bur Oak	*Quercus macrocarpa*	22-24 m	60-120 cm	Intermediate	Slow	200-300
Chestnut Oak	*Quercus prinus*	16-22 m	30-60 cm	Intermediate	Slow	200-250+
Red Oak	*Quercus rubra*	22-28 m	60-120 cm	Intermediate	Moderate	200-250+
American Elm	*Ulmus americana*	23-31 m	60-180 cm	Intermediate	Rapid	100-200

site, could be extended into the reforested area. Overseen by the East Goshen Township Public Works Department, the trail construction began in August 2010 and was completed in late November with the construction of the bridge over Ridley Creek to connect the two park areas.

In 2010, the site changed from an isolated forested plot into a portion of the East Goshen Community Park, complete with a paved circular path and a bridge connecting it with the existing park boundaries. The placement of the path was laid out so that very few of the trees would be affected by its construction. The bridge development was restricted to one location based upon access to the site but it was still anticipated that few trees would be affected. Nine individual trees were moved to random areas of the site as they were in the way of construction. Several other trees were replaced as they were severely damaged in the extraction process. Tree number 141, a *Quercus macrocarpa* (burr oak) was planted as a replacement for a damaged tree while an additional *C. ovata* was planted as well, which boosted the site tree total to 225. As *Q. macrocarpa* is not one of the eleven species that originally occupied the site, it boosted the site species total to twelve from the 2009 study year. Assumingly it was planted by mistake. Another tree bordering Paoli Pike was broken in two at the base by a runaway automobile. The adversity seen through the first year of the site could have affected tree growth by placing significant stress on certain individuals.

The soils at the site are comprised of four different soil types (see Figure 1) (U.S.D.A. 2011c). The Bale silt loam (BaB), which was derived from alluvium over residuum weathered from mica, occupies the northeast corner of the site. Glenelg silt loam (GgA) dominates the site with 63 percent coverage and is composed of weathered mica schist. The Glenelg series consist of deep well drained soils. They have a moderately rapid permeability and are typically characterized by environments consistent with slopes that range from 0-55 percent with a mean annual precipitation of 100 cm and a mean annual temperature of 12°C. In the southwest corner of the site there is the Glenville silt loam (GIA), similarly composed of weathered mica schist. Lastly, the Hatboro silt loam (Ha) is made up of alluvium derived from metamorphic and sedimentary rock, which is congruent with the branch of Ridley Creek that borders the site as it aids in the relocation of soil from place to place (U.S.D.A., 2006; U.S.D.A., 2011c).

METHODS

Field and Lab Methods

In the summer of 2009, West Chester University Biology students, under the direction of East Goshen Township, surveyed the reforestation site at Applebrook Park to collect species identification, tree height, diameter at breast height (DBH = 1.37 m), and to mark each tree individually with an identification number. The information they collected was compiled into a spreadsheet and used by Geography students to locate each tree and tag it with a specific GPS coordinate. In November 2010, I resurveyed the DBH and heights for each tree. I used a standard 5m DBH tape to record tree diameters and a Suunto clinometer to measure tree heights. I also noted the crown base height and width, percent of tree damaged, and sun exposure. Data on sunlight available for each tree was recorded using an index correlated to the number of sides exposed to light (from 0 = full shade to 5 = full sun on all sides and top of tree). All but the trees planted next to the existing buffer received full light from all sides and were classified accordingly.

In December 2010, I collected soil samples at the site and took them back to the lab for testing. Diagnostic methods aided in classification of the soil properties and thus the taxonomic delineation (U.S.D.A., 2006). A hand auger and tape measure were used to take two samples, one from the middle of the site area in the Glenelg silt loam (GgA) and the second from the existing buffer zone at the eastern portion of the site in the Hatboro silt loam (Ha) (see Figure 1). Both samples were taken at a depth of 5cm. Because the soil was disturbed by the original planting of the trees and from the construction of the bridge and path, it was expected that the soil horizons from the site would not match up to those of the buffer zone. It was also anticipated that the disturbed soil would not be as rich with nutrients as the existing soil as much of it was added to the site by the contractors during construction. In the lab, each soil sample was mixed with water to create a slurry, as the water reaches the pH level of the soil rather quickly. A Hanna pHep3 meter was placed into the mixture and the levels were recorded.

I took further samples in February 2011 to determine the bulk density across the entire site. Using a PVC pipe with a 6.35 cm radius, a maul, a shovel, and a tape measure, core samples were taken at depths of 0-5 cm and 5-10 cm at eight sample locations across the site. Six samples were taken in a grid pattern from the area of the site that was planted and experienced soil compaction through the bridge and path development (see Figure 1). The remaining two samples were taken from the northern and southern ends of the existing buffer area bordering Ridley Creek. Bulk density (P) was determined by the weight of the dry soil (Wd) divided by the volume of the ring (V) used to collect the samples (P=Wd/V) (U.S.D.A., 2001). A single-factor analysis of variance (ANOVA) test and a paired one tailed t-test were used to test the null hypothesis that bulk density and pH did not significantly vary across the site.

Current and Projected Carbon Storage

After the completion of fieldwork, the data was compiled into spreadsheets in Microsoft Excel to calculate carbon stock for the present-day (2009-2010) and projected into the future at 5, 25, and 75 years. Calculation of carbon stock followed species-group equations (U.S.D.A., 2011a). The equations used to calculate carbon stock were as follows (Jenkins et al. 2003; Pearson et al. 2007):

Above Ground Biomass (AGB):
$y = \text{Exp}\ (\beta_0 + \beta_1 \text{ Ln } x)$
y = total aboveground biomass (kg)
β_0 and β_1=species specific constants
x = DBH (cm)
Exp = “e” to the power of
Ln = natural log base “e” (2.718282)

Belowground Biomass (BGB):
$y = \text{Exp}\ (-1.0587 + 0.8836 \text{ Ln AGB} + 0.2840)$
y = total belowground biomass density (t/ha)
AGB = aboveground biomass density (t/ha)
Exp = “e” to the power of
Ln = natural log base “e” (2.718282)

Both the AGB and BGB were converted to tonnes (907.18 kg) and the density was calculated (t/ha). For both AGB and BGB it was assumed that fifty percent of all density was carbon (Birdsey et al. 1992). The sum of the total carbon from both the AGB and BGB yielded the carbon stock for the entire site.

Projected future carbon stocks were determined using the Urban Forest Effects Model (UFORE) (U.S.D.A., 2011a). The annual growth rate used by the UFORE model has been standardized based on the number of frost free days in Minnesota and the average calculated growth for street, or open growth, trees using the following equation:

Standardized growth (SG) = 0.83 cm/yr * number of frost free days/153

For the location of the study site, an average value of 195 frost free days per year was used (National Climatic Data Center, 2008). In addition, the SG for a park-like setting was found to be 1.78 times less than that of an open-growth area, so the SG was divided by 1.78. The calculation of the annual growth rate used for the East Goshen site is shown below (U.S.D.A., 2011a):

$$SG = 0.83 \text{ cm/yr} * (195/153)$$
$$SG = 1.0578$$
$$\text{Adjusted Growth} = SG/1.78$$
$$\text{Adjusted Growth} = 1.0578/1.78 \approx 0.5944 \text{ cm/year}$$

The annual growth rate was multiplied by the study time period (5, 25, and 75 years into the future) and applied to the existing DBH values to estimate future DBH values. The carbon stock for each time period was then calculated using methods and equations described above. A paired one-tailed student's t-test was used to test the null hypothesis that carbon stock did not significantly increase over time.

Reforestation site mortality has a critical role in forest development as it contributes to a unique forest dynamic by thinning out tree stands (Lutz and Halpern, 2006). This is taken into account beginning with the 2010 analysis by assigning an overall site mortality percentage to each projection year and randomly selecting species to meet the proper amount to be removed from the study.

The 2010 carbon sequestering capabilities of each tree species was analyzed individually to determine which tree was most productive in the study site and which was the least productive. It should be noted that each species has a different number of individuals representing them. Therefore group a comparison may not represent the actual productivity from one species to another accurately. As a result individual species with similar heights and diameters and trees amounts were selected and compared with one another. In addition, the average carbon stock from each of the twelve tree species was calculated and compared with one another in each study year. This will show which tree species is likely to benefit the site most when it comes to carbon sequestration (McPherson, 2003b).

Assessment of Forest Benefits

I-Tree 4.0 is a peer-reviewed software suite from the United States Forest Service that provides tools to assess urban forests (U.S.D.A., 2011b). This study utilized *i-Tree* Eco, which measures the value that forest stands can potentially provide to the surrounding communities (U.S.D.A., 2011b). Data is entered manually into the application and the program provides baseline data that can be used to make comparisons and set goals for forest growth and development. Analysis of the East Goshen site required measurements of each of the 225 trees to be entered into the program for the current and projected 5, 25 and 75 years to show short and long term benefits.

The *i-Tree* data entry form for a full inventory site (as opposed to an entry form for a sampled site) required DBH and height measurements. For accuracy when evaluating the costs and benefits of a site, the program also required that the crown base height, crown width, percent of tree damaged, and various codes that indicate the amount of sunlight that trees have access to based on distance between each tree and canopy size (U.S.D.A., 2011b). Constants were utilized for the future dates across the entire site in these categories based upon the expected growth rates. As the trees were all in the initial growth stages, the average crown width and base height were very similar from species to species. For the current crown widths, I set a 2 m diameter constant for each tree on the site while the crown base height was set at 1.5 m or average height for diameter measurement. For the three future projected dates of 5, 25, and 75 years, crown measurements and estimated growth rates helped to set projected crown measurements specific to each species (Grimm, 2002; Arbor Day Foundation, 2011). For the projected data, I also estimated the sunlight exposure based on expected size at maturity and growth rate measurements for each species (U.S.D.A., 2010b; Arbor Day Foundation, 2011). In the projected 5, 25 and 75 year periods it is expected that the smaller and slower growing trees like shade intolerant *B. nigra* will be blocked out of the sunlight and therefore will be less likely to survive through maturity (Grimm, 2004; Arbor Day Foundation, 2011).

Tree life expectancy should also be considered when assessing site benefits. It is possible that in some studies, the projected dates exceed the longevity of certain species. As this study only looks as far as 75 years into the future, all the studied species potentially had lifespans through the final analysis date (Grimm, 2002; Arbor Day Foundation, 2011). It is important to also take tree mortality on developing reforestation sites into account. The demographic of a forest is dictated by growth rates and site mortality (Lutz, 2006). For the *i-Tree* analysis to be accurate, I used mortality rates found in comparative urban reforestation analyses and applied a predicted mortality rate of 0.7% to our data for the 5, 25 and 75 year periods (Lorimer et al. 2001; Busing, 2005). Variation in the survival percentages is prevalent in the beginning years of the trees development. Once established however, low mortality is observed across most sites

(Roman, 2006). As the East Goshen site is only in its second year of establishment, observation-based mortality rates are nearly impossible to conjecture.

The *i-Tree* program calculated benefits for each year of the study in terms of the overall value of each tree per year (in dollars) based on township benefits such as increasing property values and various environmental benefits like controlling biogenic emissions (Nowak et al, 2002; Nowak et al. 2006; Nowak et al. 2008). *I-Tree* calculated the pollution capabilities of the forest (in grams/tree and dollar value), specifically removal of carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), particulate matter (PM-10), and sulfur dioxide (SO_2). It should be noted that the *i-Tree* program uses estimates spanning many species and growth rates to create their constants for analysis. Although these values are in fact estimates, they are quite accurate and provide strong foundations for many of the tests and comparisons regarding Applebrook Park. Paired one-tailed student's t-tests were then conducted to test the null hypothesis that these benefits did not significantly increase over time.

I also calculated the 95% confidence interval for the mean DBH of the site. The 95% confidence level is the upper and lower end of the range of the DBH values that occupy the East Goshen site. The lower end is calculated by taking the mean DBH and subtracting (1.96*the standard error of the mean). The higher end is calculated by taking the mean DBH and adding (1.96*the standard error of the mean). The upper and lower DBH values comprise the range of dollar values corresponding to the range of the mean DBH.

Comparative Analysis

It was important to find a sample group of trees similar to the 25-year projection in East Goshen to use for comparison and to test for statistical significance. I wanted to see if the Applebrook Park site will be nearly as productive as a similar urban tree stand with a more diverse range of species and ages by the year 2035. While similar buffers have been recorded to stabilize pollution levels within the first 15 years of planting, it is anticipated that the study site will be somewhat comparable to such an established group of trees. I used a local dataset consisting of nearly 2000 trees that make up West Chester University's North Campus (Welch et al. 2010). This dataset is a comprehensive index of the characteristics of every tree on north campus. To test the null hypothesis that the two population means were equal to one another, I ran a two-tailed t-test.

RESULTS

Carbon Sink Analysis

At the time of the initial survey in 2009, the trees had been planted at the site for less than four months and showed a carbon stock of 1.02 tonnes of carbon per hectare (t C/ha) (Table 2). The second year of study, 2010, showed a significant increase of 19 percent with total carbon stock estimated at 1.22 t C/ha (p-value: 0.00756). In the future, the gap between the aboveground and belowground carbon stock will increase dramatically. Future tree growth was estimated so the increase in carbon storage could be projected for the next 5, 25 and 75 years.

After 5 years (2015), the site is expected to have stored 3.27 t C/ha (a 268% increase from the previous study year, p-value: 0.0314). After 25 years (2035), the site is expected to have stored 26.16 t C/ha (an 800% increase from the previous study year, p-value: 0.0349). The total carbon that this site will have stored in 75 years is estimated to be 221.41 t C/ha (an 846% increase from the previous study year, p-value: 0.0407) (Table 3). In each study year, the null hypothesis that the carbon stock of the site does not increase significantly as the trees age was rejected. It should be noted that the 2009 and 2010 carbon data are observed values and that the 2015, 2035 and 2085 values are projections making them not as precise as the first two study years.

It is clear that there is some discrepancy with this comparison among species based on the varying number of individuals that belong to each group. *Quercus rubra*

Table 2. Current and projected site aboveground, belowground and total carbon stocks.

Study Period	Carbon storage t C/ha	Aboveground Carbon storage t C/ha	Belowground Carbon Stock t C/ha
2009	1.02	0.055	0.046
2010	1.22	0.67	0.55
2015	3.27	1.89	1.38
2035	26.16	16.62	9.54
2085	221.41	153.35	68.06

Table 3. Carbon sequestration significance testing results.

Sample	mean	SD	P-value
2009-2010	0.7	0.09	0.007555333
2010-2015	0.81	1.44	0.031413576
2015-2035	2.18	16.18	0.034937792
2035-2085	17.44	138.06	0.040717563
2085	147.6		

was expected to sequester the most carbon in each of the four projected dates as it was represented by 42 individuals while *Q. macrocarpa* was expected to be the least productive as a species because it has only one representative. Comparisons were made between *N. sylvatica* and *Q. prinus* however. Each species had 20 trees on the site and helped to make for more complete analysis. *Quercus prinus* (current carbon stock = 0.1096 t C/ha) was more productive then *N. sylvatica* (current carbon stock = 0.0630 t C/ha) and the gap between the two will only increase as time goes on. This shows a consistent progression in carbon sequestration through the life of the tree and the comparison of the two species showed the ability of one species to be more productive than another in carbon sequestering capabilities based on specific growth rates.

A more accurate analysis can be made by comparing the average carbon sequestered by each species (Table 4). The comparison of these twelve different averages helped to decipher which species was most productive in sequestering carbon even though there was some variation in measurements among the group. As expected there was variation from species to species in aboveground biomass (AGB), belowground biomass (BGB) and carbon storage. Besides *Q. macrocarpa*, which is several years older then the rest of the trees on site, *Q. alba* was the most productive in carbon storing capacities in each study year when studying species averages. *Quercus prinus*, *Q. rubra*, and *A. rubrum* were also among the leaders in carbon sequestration while *U. americana* and *C. caroliniana* sequestered the least amount of carbon of the species on site.

Table 4. Current and projected average carbon stocks by species.

Species	Number of Specimens	Estimated 2010 Carbon Stock t C/ha	Projected 2015 Carbon Stock t C/ha	Projected 2035 Carbon Stock t C/ha	Projected 2085 Carbon Stock t C/ha
Acer rubrum (red maple)	17	0.16	0.37	2.36	17.16
Betula nigra (river birch)	14	0.05	0.18	1.55	12.91
Carpinus carolinana (ironwood)	18	0.08	0.22	1.81	15.65
Carya ovata (shagbark hickory)	35	0.06	0.31	3.55	34.64
Liriodendron tulipifera (tulip poplar)	11	0.04	0.13	1.1	9.53
Nyssa sylvatica (black gum)	20	0.06	0.2	1.81	16.64
Plantus occidentalis (American sycamore)	21	0.11	0.3	2.24	18.69
Quercus alba (white oak)	4	0.04	0.09	0.63	4.81
Quercus macrocarpa (burr oak)	1	0.02	0.04	0.2	1.34
Quercus prinus (chestnut oak)	20	0.1	0.31	2.61	22.24
Quercus rubra (red oak)	42	0.36	0.89	6.23	49.19
Ulmus americana (American elm)	22	0.06	0.21	2.01	18.39
	Site Average:	0.005	0.014	0.116	0.984

As expected the results from the carbon stock analysis from 2010 showed an increase in sequestered carbon from the previous year. The increase in carbon sequestration through the 2010 year across the entire site was 0.1968 t C/ha. It should also be noted that several trees were replaced after being damaged in the construction of the bridge and pathway that were developed. Tree's number 141 and 223 are not of the original study sample and were placed in the site in October/November 2010. Contractors claim to have planted three new trees but in fact only two were found (*Q. macrocarpa* and *C. ovata*). Tree 71, *C. ovata*, was relocated to the opposite side of the site. Several other trees by the bridge were moved as well. These inconsistencies did not affect this year's analysis.

Results of Soil Analysis

The pH test showed that the sample taken from the middle of the site was a slightly acidic soil capable of supporting a wide array of tree species. For varying pH levels there are corresponding nutrients that are suspended within that soil. At this range of 6.0 – 6.3, the soil more than likely contained higher levels of nitrogen, phosphorous, potassium, sulphur, calcium and magnesium (Pittsburgh Permaculture, 2011). The sample taken from the existing buffer zone showed different results than the sample taken from the middle of the site which was disturbed in the planting process. The pH range of 5.5 – 5.9 revealed a slightly more acidic soil that could have been a result of the sedimentation build-up of different materials from the leg of Ridley Creek nearby. Iron, boron, manganese, copper and zinc are the nutrients that are likely to occupy a soil of this acidity (Pittsburgh Permaculture, 2011). The result of the paired one tailed t-test showed that there was no significant difference between the site and the existing buffer pH values and therefore the null hypothesis that the pH did not significantly vary between samples was accepted (p-value: 0.0674) (Table 5). The top Oa horizon was also still present in this buffer area while its absence in the sample from the middle of the site was the result of soil dispersal in the planting process.

The soil taxonomy of the site was classified as a fine-loamy, mixed, active, mesic Typic Hapludult. The texture of the soil was finely grained and a loam though it tended to have a higher percentage of clay in the lower sub-horizons. It had a mixed mineralogy and an active cation exchange capacity. It was in the mesic temperature regime as the mean temperature was between 8 degrees Celsius and 15 degrees Celsius and the mean summer soil temperature was at least 6 degrees Celsius higher than the mean winter soil temperature. It also had minimum horizon development (hapl), adequate moisture through the year (udic moisture regime) and it was an ultisol (soils that are more weathered, low base saturation <35%-redder, slightly acidic) (U.S.D.A., 2010a). Hydrologic soil groupings were also discovered for each of the four soil series on site to show the infiltration rate and runoff potential on site (U.S.D.A., 1986). The Bale silt loam and the Glenelg silt loam are labeled in group B on the hydrological chart. Group B soils have moderate well drained soils with moderate infiltration rates. The Glenville silt loam is characterized by the hydrological soil grouping C, which has a low infiltration rate due to soil layers consisting of clays that impede the downward flow of water. The Hatboro silt loam is placed in the hydrological soil group D. These soils have high runoff potential

Table 5. pH significance testing results.

Sample	mean	SD	P-value
Buffer 1	5.66	0.2	0.06741
Site 1	6.2	0.17	0.06741

and low infiltration rates when thoroughly wetted. They consist primarily of clays and are often characterized by shallow soils over nearly impervious material (U.S.D.A., 1986).

The average bulk density of the reforested site (samples 1-6) was 1.40 g/cm3 at the 0-5 cm depth and 1.48 g/cm3 at the 5-10 cm depth. The average bulk density of the existing buffer (samples 7-8) was 1.10 g/cm3 at the 0-5 cm depth and 1.25 g/cm3 at the 5-10 cm depth (Table 6). The significance test using a single factor ANOVA accepted the null hypothesis that the bulk density does not vary across the site (p-value: 0.0796) (Table 7).

Table 6. Soil bulk density.

Sample	0-5 cm (g/cm^3)	5-10cm (g/cm^3)
1	1.65	1.50
2	1.44	1.62
3	1.21	1.44
4	1.32	1.30
5	1.42	1.39
6	1.30	1.66
7	1.00	0.90
8	1.20	1.61

Table 7. Bulk density significance testing results.

Source of Variation	mean	SD	SS	df	MS	F	P-value
Between Groups	1.37	0.22	0.5283	7	0.075471429	2.897175761	0.079637662
Within Groups			0.2084	8	0.02605		
Total			0.7367	15			

Forest Assessments and Site Benefits

Quercus rubra was by far the most valuable species on site by returning $91,704 in carbon removal when it reached maturity. *Carya ovata* as a species also provided a larger benefit throughout its lifetime mainly because it was well represented with many individuals (Table 8). The significance test using a one tailed t-test rejected the null hypothesis that the monetary value of the species does not increase significantly as the trees age in each study year (2009 vs. 2010 p-value: 0.0313, 2010 vs. 2015 p-value: 0.0072, 2015 vs. 2035 p-value: 0.0160, and 2035 vs. 2085 p-value: 0.0008) (Table 9). The pollution control qualities of the site were measured by pollution removed (g/yr) as well as a removal value ($/yr) for each compound. The compounds represented were carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), particulate matter (PM_{10}) and sulfur dioxide ($S0_2$). *Quercus rubra*, *U. americana*, and *P. occidentalis* were the most productive trees in pollution removal and combined to control nearly 75% of the pollutants remediated in the 2085 projection (Table 10). Over time, the removal of pollutants will vary across the site (p-value: 0.0090), with significant increases at 25 years (2015 vs. 2035, p-value: 0.0372) and at 75 years (2035 vs. 2085, p-value: 0.03677) (Table 11). However the dollar value of this pollutant removal will not significantly vary as trees age on the site (p-value: 0.0508) (Table 12).

Table 8. Monetary value by species.

Species	2009	2010	2015	2035	2085
Acer rubrum	$1,720	$2,114	$2,001	$2,114	$28,912
Betula nigra	$1,680	$1,314	$1,314	$1,314	$12,270
Carpinus carolinana	$1,372	$1,555	$1,555	$1,555	$11,667
Carya ovata	$2,032	$2,162	$2,100	$2,162	$48,016
Liriodendron tulipifera	$854	$939	$853	$939	$20,252
Nyssa sylvatica	$1,514	$1,705	$1,519	$1,705	$13,932
Plantus occidentalis	$1,500	$2,049	$1,974	$2,049	$34,415
Quercus alba	$532	$631	$631	$631	$12,528
Quercus macrocarpa	N/A	$291	$291	$291	$3,417
Quercus prinus	$1,519	$1,671	$1,671	$1,671	$40,936
Quercus rubra	$4,506	$5,599	$5,446	$5,446	$91,704
Ulmus americana	$946	$969	$969	$969	$26,890
Total	$18,243	$20,999	$20,256	$20,999	$343,939

Table 9. Monetary value significance testing results.

Sample	mean	SD	P-value
2009-2010	1652.27	1040.33	0.019519124
2010-2015	1749.91	1429.096462	0.007225724
2015-2035	1693.66	1388.467596	0.016047881
2035-2085	1737.16	1312.007195	0.000846775
2085	28744.92	23891.00975	

Table 10. Pollution removed from the site in g/yr and $/yr by species.

	Pollution Removed (g/yr)						Removal Value ($/yr)				
Species	CO	O_3	NO_2	PM-10	SO_2	Total	O_3	NO_2	PM-10	SO_2	Total
Acer rubrum											
2009	7	221	47	120	55	448	2	0	1	0	4
2010	6	215	45	116	53	436	2	0	1	0	3
2015	7	207	41	101	51	407	2	0	1	0	3
2035	77	2630	560	1462	643	5371	26	6	10	2	43
2085	167	4724	997	2469	1199	9554	47	10	16	3	76
Betula nigra											
2009	5	162	34	88	40	329	2	0	1	0	3
2010	5	171	36	93	42	347	2	0	1	0	3
2015	6	175	35	85	44	344	2	0	1	0	3
2035	191	6535	1392	3635	1596	13349	65	14	24	4	107
2085	177	5035	1063	2631	1278	10184	50	11	17	3	81
Carpinus carolinana											
2009	6	202	43	110	50	411	2	0	1	0	4
2010	6	188	40	102	46	382	2	0	1	0	3
2015	6	192	39	93	48	378	2	0	1	0	3
2035	48	1639	350	913	400	3350	16	4	6	1	27
2085	65	1833	387	958	465	3707	18	4	6	1	30

Table 10 (cont'd)

	Pollution Removed (g/yr)						Removal Value ($/yr)				
Species	CO	O_3	NO_2	PM-10	SO_2	Total	O_3	NO_2	PM-10	SO_2	Total
Carya ovata											
2009	8	258	55	140	63	523	3	1	1	0	4
2010	9	292	62	159	72	595	3	1	1	0	4
2015	9	280	56	136	70	550	3	1	1	0	4
2035	133	4547	969	2529	1111	9289	45	10	17	3	75
2085	248	7050	1488	3684	1790	14258	70	15	24	4	114
Liriodendron tulipifera											
2009	6	206	44	112	51	418	2	0	1	0	4
2010	6	191	40	103	47	387	2	0	1	0	3
2015	5	178	36	86	44	349	2	0	1	0	3
2035	85	2895	616	1610	707	5913	29	6	11	2	48
2085	155	4418	932	2309	1122	8936	44	9	15	3	71
Nyssa sylvatica											
2009	7	215	46	117	53	437	2	0	1	0	4
2010	6	215	45	117	53	437	2	0	1	0	4
2015	6	199	40	97	50	391	2	0	1	0	4
2035	37	1241	264	691	303	2533	12	3	5	1	21
2085	29	815	172	426	207	1648	8	2	3	1	13

Table 10 (cont'd)

	Pollution Removed (g/yr)						Removal Value ($/yr)				
Species	CO	O_3	NO_2	PM-10	SO_2	Total	O_3	NO_2	PM-10	SO_2	Total
Plantus occidentalis											
2009	12	403	85	219	99	817	4	1	1	0	7
2010	12	376	80	204	93	765	4	1	1	0	6
2015	12	368	74	179	92	724	1	1	0	6	
2035	234	7990	1701	4444	1951	16319	79	17	29	5	130
2085	945	26858	5667	14034	6818	54321	266	56	93	17	433
Quercus alba											
2009	1	32	7	17	8	64	0	0	0	0	0
2010	1	34	7	18	8	69	0	0	0	0	0
2015	1	35	7	17	9	68	0	0	0	0	0
2035	14	487	104	271	119	995	5	1	2	0	8
2085	111	3148	664	1645	799	6367	31	7	11	2	51
Quercus macrocarpa											
2010	0	10	2	6	3	21	0	0	0	0	0
2015	0	11	2	5	3	21	0	0	0	0	0
2035	16	536	114	298	131	1095	5	1	2	0	9
2085	52	1475	311	771	374	2983	15	3	5	1	24

Table 10 (cont'd)

	Pollution Removed (g/yr)						Removal Value ($/yr)				
Species	CO	O_3	NO_2	PM-10	SO_2	Total	O_3	NO_2	PM-10	SO_2	Total
Quercus prinus											
2009	4	149	31	80	37	302	1	0	1	0	2
2010	6	176	37	96	43	357	2	0	1	0	2
2015	6	180	36	87	45	353	2	0	1	0	2
2035	106	3663	779	2037	895	7480	36	8	13	2	59
2085	461	13089	2762	6839	3323	26472	130	27	45	8	212
Quercus rubra											
2009	15	509	108	276	125	1033	5	1	2	0	9
2010	15	489	103	265	120	993	5	1	2	0	8
2015	15	486	98	236	121	956	5	1	2	0	8
2035	254	8732	1860	4856	2133	17835	87	18	32	5	144
2085	813	23087	4871	12064	5860	46697	48	80	14	372	
Ulmus americana											
2009	10	314	66	171	78	638	3	1	1	0	5
2010	9	309	65	168	76	628	3	1	1	0	5
2015	10	316	63	153	79	621	3	1	1	0	5
2035	185	6339	1350	3526	1549	12946	63	13	23	4	104
2085	956	27144	5727	14184	6891	54902	269	57	94	17	438

Table 10 (cont'd)

	Pollution Removed (g/yr)						Removal Value ($/yr)				
	CO	O_3	NO_2	PM-10	SO_2	Total	O_3	NO_2	PM-10	SO_2	Total
Totals											
2009	81	2668	565	1448	658	5419	26	6	10	2	43
2010	81	2666	564	1447	657	5415	26	6	10	2	43
2015	81	2628	527	1275	654	5164	26	5	8	2	41
2035	1381	47235	10057	26269	11536	96477	468	100	174	28	771
2085	4177	118675	25039	62010	30126	240026	1176	248	410	73	1913

Table 11. Pollution removal significance testing results (g/yr).

Sample	mean	SD	P-value
2009-2010	1083.82	1012.25	0.037283454
2010-2015	1083.02	1011.49	0.03738167
2015-2035	1032.8	988.31	0.03716843
2035-2085	19295.42	17998.21	0.0367665
2085	48005.22	44604.65992	

Table 12. Pollution removal significance testing results ($/yr).

Sample	mean	SD	P-value
2009-2010	10.79	10.9	0.107584971
2010-2015	10.79	10.91	0.071479202
2015-2035	10.31	10.84	0.069894274
2035-2085	192.31	193.13	0.073682569
2085	476.7	485.83	

Comparative Analysis

The t-test between the East Goshen site trees in the 25 year projection and the West Chester University North Campus trees showed a p-value of -0.36. The negative value shows that the mean DBH of the East Goshen trees was smaller than that of the WCU North Campus trees. The calculated t score did not exceed the critical value of 1.96 and therefore failed to reject the null hypothesis that the mean values of the WCU North Campus trees' DBH and the 25 year projection of the East Goshen trees' DBH were equal.

The upper and lower 95% confidence levels created a range of 16.85 cm to 20.28 cm with a mean DBH of 19.94 cm in the 25-year projection. The average dollar value of the sample site trees as provided by the *i-Tree* software for the 25 year projection was calculated to be $93.32 per tree. Given the sample data from which this value was calculated, the actual dollar value of the sample site trees fell between $60.75 and $104.41, averaging $84.33 per tree with 95% certainty.

DISCUSSION

The performed analyses provide characteristic information about the current status of Applebrook Park and what it can potentially evolve into. Breaking down such information provides insight into future growth habits or patterns of particular species and how to maintain that growth with proper management practices. It also assists in the construction of a timetable that reflects the costs of the site and how quickly they can be returned through environmental benefits.

Projected Carbon Sink

The 2009 and 2010 carbon stocks were comprised of nearly equal amounts from both above and belowground biomass. The second year of growth at the East Goshen site experienced a significant increase in carbon sequestered in one study year. The initial vulnerable stages of a tree’s life typically show steady progression where aboveground biomass/carbon stock and belowground biomass/carbon stock are very similar. Root systems must be established first in order to support the vertical and lateral growth of the tree. Therefore we will see that both above and belowground biomass will almost mirror each other’s growth through the first years of the site’s progression. Early root development is essential for carbon storage. In all species, shoot growth is faster in the later years of a trees life indicating that the initial stages are devoted to root system development (Udawatta et al., 2005).

At the 5 year projection a small gap is forming between the aboveground and belowground carbon stocks. At 25 years this gap is significantly larger. This shows that the root systems are established and energy can be diverted into growth of the trunks, limb, and foliage. At 25 years it can be expected that majority of the trees are more then halfway to reaching maturity. In the 20-year period between 2015 and 2035, the trees in the study area are expected to increase the amount of carbon sequestered by nine times. *Quercus macrocarpa* however has a life expectancy that nearly doubles other species leaving much room for the tree to increase in size and subsequently, carbon sequestering capacities. At 75 years (2085), most trees are at full maturity and the first generation of growth will nearly be complete. In another 25 years the trees have doubled their carbon sequestering capacity. Until the trees begin to reach their ultimate lifespan and die off, they will continue to sequester relatively the same amount of carbon from year to year from this point forward.

Through each of the four study years that were analyzed for carbon storage, *Q. rubra* was the most productive. *Quercus prinus* and *C. ovata* also showed a steady progression of carbon sequestration through the 75 year projection. Other species showed high rates of carbon sequestration in the initial projection years and leveled off by maturity. *Ulmas americana* and *P. occidentalis* were expected to produce higher results in the 2085 projection based on height and diameter though they are capable of storing carbon values higher than the site average. *Carpinus carolinana* and *L. tulipfera* were two species that showed lower storage capabilities compared to the other species in the study.

This analysis of future 5-year, 25-year and 75-year carbon stocks demonstrates the dramatic increase in sequestered carbon considering the site's overall tree growth.

The progressive increase of the site over the 75 year period shows immense capacities of carbon being stored by the trees on this site, helping to improve the urban setting of East Goshen.

The success of the site in sequestering carbon over the next few decades ultimately relies on the types of trees that occupy the site and the growth capacities that characterize them. While the emphasis is placed on size when it comes to carbon storage, smaller specimens have their place in tree stands as well. Despite inability to sequester as much carbon as their larger neighbors, smaller species contribute to forest diversity, pollution remediation, and wildlife habitat. Every individual counts. The primary concern should be matching tree growth and site characteristics. The connection between these two reforestation factors will be important in promoting tree health while minimizing conflicts with infrastructure and management costs. Proper tree selection will result in the overall productivity of the site and make a sustainable urban forest more attainable.

Soils

Within naturally occurring populations of trees, most species are capable of withstanding alterations that they have become accustomed to through generations of adaptation. Trees in reforestation and relocation efforts however have a chance of being improperly planted in an improper climate, site size, land use area and soil composition. Soil pH tolerance values are important in tree health and vary from species to species. The trees on the East Goshen site are twelve different species all with different pH tolerance values. These values were investigated to discover which trees are best adapted to eastern Pennsylvania soils. As most soils in this area are suited to support a wide array of tree species, soil properties were not expected to greatly affect the reforestation effort; however it is important to be aware of any factor that could affect tree development.

The pH levels that were recorded were consistent with each other as well as with what was expected from the samples. The pH levels all are slightly acidic and are not statistically different across the site despite slight variation from sample to sample. A logarithmic scale is used to measure soil's pH. Each unit in the scale represents a 10-fold change in acidity or alkalinity from one to the next. For example, a soil with a pH of 5.0 is 10 times more acidic then a soil with a pH of 6.0 and 100 times more acidic then a soil with a pH of 7.0. This is why is it important to be aware of the types of soil associated with reforestation projects and the pH levels typically associated with them. These seemingly small changes can have a big impact on the development of the flora on site and can lead to the success or the demise of varying tree species (Mixon, 2010).

The pH range of each species shows the impressive adaptability of these trees. Each tree is capable of surviving in extreme acidic and basic conditions that allows them to occupy a broad range of locations and environments. Clearly these extremes are more detrimental to tree health then a soil with a pH of 6.5 - 7.0, but they still have potential to sustain tree growth.

The tree species with the widest pH tolerance range on the East Goshen reforestation site is *Q. macrocarpa*. It is one of the most tolerant trees of urban conditions and is one of the fastest growing oaks that occupy the site. Unfortunately the site only contains one individual of this species and it is speculated that the tree was planted as a mistake. The tree species that shows the smallest pH tolerance range is also one of the fastest and tallest growing. *Ulmus americana* shows a tolerance range of 7.0 - 8.0. With a preference for the slightly alkaline soil conditions, it naturally occurs in an assortment of conditions especially in floodplains although it can thrive in well drained soils. In more elevated topography it tends to grow closely to streams and rivers (Grimm, 2002).

The bulk density analysis concluded that the soils on site were not subject to over compaction through the course of the planting process. Soil compaction caused by wheel and machine traffic as well as animal grazing potentially reduces soil porosity and hydraulic conductivity. The destruction of pores within the soil restricts trees ability to perform proper nutrient uptake and water absorption. This was not the case on the East Goshen site however as the bulk density across the tree stand conformed with densities of other sites with the same soil series (Boussougou et al., 2010; Zhou et al., 2007). As a result of the congruency of the densities with normal levels it is expected that root functionality and general tree development should continue properly through maturity.

I-tree Eco 4.0 Analysis

The data from the *i-Tree* Eco analysis was effective in breaking down the values and pollution reduction qualities of each species and individual tree represented on site. The values presented from year to year are congruent with tree growth as they steadily increase until the 75-year projection where they increase significantly. For example, *Q. rubra* had an average value of $1,987.25 for the combined 2009, 2010, 2015 and 2035 study years while in the 2085 projection it is valued at $28,912. Similar congruencies in values from year to year are seen in all species supporting the idea that trees are more productive in pollution filtration and storage in the later years of their life. In the years closer to the expected maturity range of each species, growth is more dramatic creating a greater capacity for the trees to absorb pollutants. The gradual increase of toxins removed and money saved for the township was impressive considering the relatively small size of the site. The application of conservative mortality rates hinder a faster return in early tree development stages due to a percentage of trees being removed for each study year.

Quercus rubra is the most productive species on the East Goshen site simply due to its large population. In each of the study years the species had nearly a third or more trees represented on site then any of the others. *Liriodendron tulipifera*, *B. nigra*, *U. americana* and *P. occidentalis* were three other species that have pollution control properties that supersede the rest. While *L. tulipifera*, *U. americana* and *P. occidentalis* are larger trees it is not surprising that they show high remediation capabilities. *Betula nigra's* abilities are significant however despite its growth rate. This species is one of more moderate height such as *N. sylvatica* and *C. ovata* although it's valued as high as the larger trees on site. While most urban areas are in need of proper waterway treatment, this species is capable of removing high amounts of toxins from the ecosystem and maintain healthy growth within floodplain areas making it desirable for such urban reforestation or riparian buffer efforts. Size is a factor in remediation techniques but this demonstrates that no matter what the growth characteristics of the individual tree, their ability to remove pollutants from the environment relies more on the specific species. When planting, it is also important to note the shade tolerance of each species so it is not smothered by faster, larger growing trees (U.S.D.A., 2010b). *Betula nigra* is one tree of concern. This species was planted closely to the stretches of Ridley Creek that border the site to ensure that it would have an adequate water supply. However it is also planted under the existing canopy of the riparian buffer. As *B. nigra* is intolerant to shade, it is not expected to survive under the light consuming branches overhead. It would be wise for future reforestation projects to consider planting patterns as well. Species clumping is not recommended. Random planting helps to promote forest diversity, however it is encouraged that the site design is planned so that species with slower growth rates and certain intolerances (shade, water, sunlight, etc.) are planted with a chance of reaching maturity.

Cost Benefit Analysis

While the data is effective in portraying the characteristics of each species, its true significance is represented in the relationship between pollution control and tree growth between the 2009 and projected 2085 study years (see Table 6). Ensuring the proper growth management techniques through the initial development stages in urban tree stands will increase environmental benefits and money saved by the township in remediation costs as seen in East Goshen Township. In 2010 the pollution removed (CO, O_3, NO_2, PM-10 and SO_2) per year on the site was valued at \$43.30. This averages out to around \$3.60 per species and \$0.18 per tree. Though the trees are still young and their pollution removal rates are minute their overall value is much greater. Other beneficial properties (the generation of oxygen, recycling of water, control of soil erosion, carbon sequestration and storage) and a value from the Council of Tree and Landscape Appraisers (CTLA) (based on a methodology formula to determine the structural value of trees) contributed to an average value of $93.32 per tree per year and a combined $20,999 across the entire site (U.S.D.A., 2011a).

In the projected 5 and 25 years the values are very similar though that may be associated with a constant high mortality rate added to the site in each projected study year. However the trees that were not removed from the study by the projected year 2085 were valued at an average of $2,613.17 per tree per year and combined for $344,939 across the entire site. At this point the trees will have reached full maturity and will be removing a value of $14.48 per tree each year and will combine for $1,912.70 across the entire site. From the 2010 to the projected year 2085, significant growth within the tree stand will provide large monetary benefits toward various types of pollution removal and ecological restoration issues such soil erosion and water quality. As the trees grow they will collect and filter more of the runoff than at the present and disrupt the flow of pollution into Ridley Creek. As the site develops the trees' abilities to capture storm water runoff and improve the water quality are an important benefit that can be used to make a case for further beneficiary results of reforestation practices.

The long-term benefits of the site are worth the initial cost of management and maintenance that take place in the beginning years of the site. The development group associated with the YMCA construction was responsible for planting costs and the replacement of several trees in the first year. However as this site begins to move into a more mature woodland, maintenance costs will be present in the form of invasive control, understory creation, deer prevention, etc. Though these amounts are likely minimal when compared to the return value of the site. Additional benefits include the creation of habitat for native wildlife, biological control of insects and disease, the formation of a strong riparian buffer along Ridley Creek and an aesthetic value for community enrichment.

Management Recommendations

While the Applebrook Park site is primarily used for recreation, it would be wise to incorporate management styles that aid in the growth of other resources. Wildlife habitat in particular should be facilitated to boost environmental benefits on the site. Circumstantially, site management is promoting the development of understory shrubs and grasses by allowing the site to move away from manicured park setting and into natural forest progression. Park management has begun planting an understory of shrubs within the site. As the site is only entering its third year it is suggested that the creation of an understory is withheld until the trees begin to develop a canopy providing adequate shade. Until this point the grass should be mowed several times per year primarily around the walking path so it does not impede upon pedestrians (G. Hertel, forester, West Chester University, personal communication).

Invasive species and control is and will continue to be important issue through the life of the forest. Close monitoring is needed to control and remove invasive plants like *Berberis thunbergii* (japanese barberry) and *Rosa multiflora* (multiflora rose). The understory shrubs that have been planted are already competing with such invasive plants. In addition the shrubs require routine watering being exposed to heavy sunlight and a deer guard or fence to help protect them until they reach more mature states. The creation of an understory will also prove to aid in buffer productivity if planted at the appropriate time (G. Hertel, forester, West Chester University, personal communication). Comparably in forests the understory totals a small percentage of carbon stock and is generally overlooked. While it can contain small amounts of carbon it is believed that biomass peaks in the fifth year of growth if properly maintained (Birdsey, 1992).

Community support can be a strong backing when addressing such issues and can be galvanized by similar success stories such as Chester Creek Restoration completed by East Goshen Township. These projects create positive community awareness and should be publicized to create knowledge and participation of other local conservation issues (East Goshen Township, 2005). Active management and support in the first years is crucial for the survival of this site. It is my hope that the progress of this forest stand over the first initial years will fuel other reforestation efforts in the area and create a community awareness of the benefits of urban forests.

Future Research

The analysis of the projected 5, 25 and 75 years using *i-Tree* Eco was influenced highly by the calculated mortality rate. Being that the site is recently planted, tree mortality is unable to be observed. As the site progresses it will be beneficial to monitor the health and mortality rates from year to year so that they can be applied to carbon, pollution and tree characteristic analyses.

The Pennsylvania Department of Environmental Protection (DEP) has designated Ridley Creek as a high quality watershed. As a result, there are increased standards that the surrounding communities are held to uphold to maintain stream water quality (East Goshen Township, 2005). Because the Applebrook Park reforestation site borders a section of Ridley Creek, water quality tests are encouraged to determine the health of the stream. Sedimentation, erosion, nonpoint source pollution and macroinvertebrate populations should be evaluated and overseen to gauge buffer productivity and to continue to hold high stream water quality standards.

CONCLUSION

This study examined the carbon storing and pollution removal properties of 12 tree species on a small-scale reforestation site in East Goshen. The analysis indicated that site productivity increases dramatically through the maturation of the site, despite the applied yearly mortality rate. The determined existing and future carbon stocks can be used to raise awareness throughout East Goshen about how local carbon emissions can be offset by a small reforestation project. Along with carbon storage, the site showed impressive potential to remove other compounds from the atmosphere. The present-day, 5-year and 25-year study periods yielded similar values and can be attributed to the immaturity of the site and the progressive removal of trees based on the mortality percentage. The 75-year study period produced an exponential increase by nearly 50 times the amount of grams of CO, O_3, NO_2, PM-10 and SO_2 removed per year across the site. This illustrates that the beneficial results will not be as dramatic until the trees begin to move farther into maturity.

East Goshen Township in association with the Conservancy Board and the Board of Supervisors has succeeded in maintaining the Applebrook Park site and contributing to the success of the tree population thus far. The advancement of the project will rely on continued municipal involvement ensuring that the site is managed properly. The sustained and continual improvement of environmental conditions at the municipal level is difficult to uphold due mainly to the lack of immediate results that influence budget and public opinion. However the costs of the site in the initial stages are far outweighed by the benefits associated with urban forest restoration. Care for the site through the next several years will ensure significant environmental and monetary benefits that will save the township thousands of dollars in the decades to come.

One of the goals of this research was to provide East Goshen with detailed site characteristics that will aid in future planning decisions that help to reduce harmful contamination throughout the local region. While East Goshen Township has expressed concern for the protection of the water quality in Ridley Creek in its comprehensive plan (East Goshen Township, 2005), repetition of analyses should be repeated annually to monitor the progression of buffer effects.

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