Enhancing Resiliency in Baltimore's Urban Forest

2014 SNRE Master's Project

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Executive Summary

The City of Baltimore, as part of their climate adaptation strategy, has pledged to double their tree canopy by 2017 in the hopes of mitigating a variety of climatic hazards that are projected to worsen in the future. These hazards include the length and magnitude of heat and precipitation events, sea-level rise, and increased prevalence of extreme weather events such as tornados and coastal storms. In keeping with this goal of forest expansion, one of the strategies (strategy NS-2) put forth in Baltimore's Disaster Preparedness and Planning Project (DP3) is to "increase and enhance the resilience and health of Baltimore's Urban Forest." To help the City of Baltimore meet their goal of successfully and sustainably expanding their urban forest, we have completed a five-staged approach centered around the creation of an interactive spatial decision support tool: (1) identification of urban forestry best practices and analysis of precedence to inform successful tree selection and planting; (2) a review of existing urban forestry practices and policies in other cities to identify cities leading the way on planning and growing a resilient urban forest and synthesizing lessons, strategies implemented, and challenges in these locations, (3) the integration of the USDA vegetation database outlining the preferred growing conditions and a variety of other attributes for the majority of eastern hardwood species, with a spatial database that includes site-specific environmental, situational, and risk factors; (4) the creation of a user-friendly interactive tool that ranks trees from the vegetation database based on site-specific characteristics; and (5) beta-testing of the tool with a variety of Baltimore stakeholders to generate buy-in, ensure its usability and longevity as a solution, and provide recommendations for future iterations of this model. Throughout the tool development process, we aimed to create an interface that is replicable across other cities, given the amount of need we have identified for a tool of this caliber, specificity, and integrated considerations. Based on beta-testing results with 17 stakeholders, carried out in Baltimore in late March, 2015, our tool was well-received and supported, and we anticipate that Baltimore officials will work to publically implement the tool in the coming months.

Acknowledgements

First and foremost, we would like to thank our advisor Dr. Dan Brown for his expertise and support throughout this project. His insight has proved invaluable to us throughout the past 18 months, and his high standards and trust in our abilities have helped us to produce what we believe to be a high-quality product. Secondly, we would like to thank our client, Kristin Baja, for proposing this project, providing guidance, honest feedback, and coordinating the beta-testing sessions in Baltimore in March 2015. Finally, the help of Michael Bommarito (University of Michigan) and Alex Redkin (our web developer) were instrumental in building our user-interface and hosting our tool online. Their boundless computer wizardry continually shocked us all, saved our sanity on multiple occasions, and allowed us to share the tool with a geographically and professionally diverse audience.

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Chapter 1: Introduction

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1.1 Project Overview, Goals, and Defense

This project consists primarily of two components: (1) an in-depth policy analysis of current urban forestry management plans to characterize the gaps, overlaps, or the coincidence of urban forestry policy and climate adaptation policy; and (2) the creation of a spatial decision support tool to rank tree species survivability and suitability at a specific site within the City of Baltimore given a suite of current and projected site-specific conditions. The overall goal of this project is to help Baltimore create and maintain a healthy and resilient urban forest. By combining a study of current urban forestry practices with in-depth research on urban forestry, climate change, and tree species selection, it is our hope that this tool will not only place Baltimore on the forefront of climate adaptation technology, but also increase the health and resilience of Baltimore's urban forest for the years to come.

To meet our project goals, we examined the intersection of two growing trends in urban sustainability: urban forestry and climate adaptation. Trees have been found to provide a vast array of ecosystem services in urban systems, including the filtration of harmful particulate matter from the air (Nowak, 2013; Nowak et al., 2006), the provisioning of shade to relieve heat stress due to the urban heat island effect (Cummins & Jackson, 2001; Nowak et al., 1998; Rosenfeld et al., 1998), noise control (Anderson et al., 1984; Cook, 1978), reduced energy costs (Akbari et al., 2001, 2002), flood/erosion control (Tyrväinen, 1999 in *Urban Forests and Trees: A Reference Book*), the provisioning of habitat for wildlife (Howenstine, 1993), and increased infiltration rates of stormwater (Bartens et al., 2008; Gregory et al., 2006). However, urban areas are high stress environments for trees; the amount of impervious surface found in these areas affects water cycling and surface temperatures, generally leading to dry conditions and more intense heat year-round. As explained in one study, "amounts of water available to trees at various locations are… often not correctly represented by annual or seasonal precipitation and the evapotranspiration ratio" (Sæbø et al., 2003).

Warmer winter temperatures can increase the likelihood of winter kill, where trees prematurely circulate water and nutrients in vascular tissue, which can cause tissues to freeze, damaging or killing trees (Safford et al, 2013). These warmer winter temperatures also create favorable environments for tree pests and diseases (Tubby & Webber, 2010). More frequent windstorm events can blow trees over and break branches, while increasing intensity of winter storms can damage tree limbs. More extreme precipitation events will also cause flooding and erosion which may uproot trees or damage root systems (Cullington and Gye, 2010). These vulnerabilities require targeted urban forestry planning to ensure that trees are planted effectively in order to adapt to and mitigate climate change. Additionally, tree species that are well suited to existing conditions, but not of the climates in decades to come, will become maladapted to new climate conditions (Howe, 2003), making them poor investments and less effective in adapting to climate change.

Climate adaptation strives to manage the unavoidable changes and avoid unmanageable challenges by taking proactive steps to prepare for future changes in the climate (Bierbaum et. al 2013). While reducing greenhouse gas emissions and efforts to mitigate climate change are generally global challenges, adaptation has drawn the climate change conversation down to the community level. Adaptation strategies often include co-benefits like increasing energy efficiency, saving money, improving quality of life, and creating jobs (ICLEI). No-regret measures are strategies that can address climate uncertainty and yield benefits even in the absence of the impacts of climate change (Hallegatte, 2009). Many municipalities are increasingly looking toward the expansion of urban forests as a no-regrets strategy to reach their sustainability goals, increase quality of life, and decrease human health and safety risks associated with increased heat, wind, and flooding.

1.1.1 Policy Analysis

To contribute to the project's overarching goal of enhancing Baltimore's urban forest management, the policy analysis aims to identify cities that balance urban forestry challenges posed by climate change with strategies that increase the adaptive capacity of municipalities through the use of tree planting and urban forests. Cities are planting more trees in urban areas to lessen the impacts of climate change; but climate change now is impacting urban forests which may reduce their mitigative effects (Ordóñez, 2015). The policy analysis reviewed the urban forest and climate action planning documents of 30 cities that currently have climates similar to Baltimore's projected climate, are reputable leaders in urban forestry management planning, or have a population greater than 500,000 reflecting a scale of planning comparable to that of Baltimore. Urban forestry plans were reviewed for explicit discussion on the role of urban forestry in municipal responses to climate change, and for consideration of how climate change increases stresses on city trees. Climate change planning documents were reviewed for 'tree-centric' approaches to adaptation, such as an increase in tree canopy (Cullington and Gye 2010). Finally, interviews with urban forestry professionals highlighted climate change associated challenges in the field, and changes in practices since the publication of their urban forestry plans. In this section, we set out to identify model cities and adaptation strategies for Baltimore as it addresses the management of climate resilient urban forests. The policy section as a whole analyzes existing urban forestry and adaptation policy and practice to determine if other cities consider climate resilient forests to be a goal, measure the progress of other cities in addressing this question, and determine if Baltimore can learn from other cities, or if the city's approach is a leader in the field.

1.1.2 Spatial Tool

After reviewing the various online tree-selection tools that are currently available to urban foresters, we found that three elements were lacking from those tools: the tools do not provide an automated method for determining site-specific characteristics, very few incorporated climate change impacts on future growing conditions, and none allowed for the pooling of institutional knowledge that is required for an urban forestry program that spans many organizations, as Baltimore's does. Each of these factors is discussed below.

Many tools recommend a site analysis in order to be used, which is not realistic for the scale at which Baltimore will need to conduct plantings in order to reach their target planting goals. Other tools do not consider site-specific information at all, which is an important factor in determining tree survival. For this reason, we aim to create a spatial tool that harnesses the power of geographic information systems (GIS) to allow users to incorporate site-specific characteristics into their tree selection decisions without needing to leave their computer. In addition, many of the site characteristics (i.e. average summer surface temperature and number of sun hours in a day) incorporated into our model require expensive equipment for data acquisition and long time periods to analyze. Because we were able to include these factors, this model is perhaps more specific than many of those currently in use.

While several scientists have proposed methods for integrating climate change into urban tree species selection (Yang, 2009; Roloff, 2009), we were unable to find existing models that comprehensively considered climate change impacts, and none that considered the unique risks that Baltimore is facing due to its location along the coast. For this reason, we set out to create our own spatially-explicit tool that considers the many facets of climate and resilience planning, including increasing temperatures, changing precipitation patterns, increased storm frequency, and the social repercussions of these changes. As Sæbø (2003) stated, "the management program, the choice of plants, and the placement of trees all must be decided by planners taking into account extreme situations and the frequencies of their occurrence."

Finally, numerous organizations are involved in Baltimore's urban forestry program, and they encompass a vast breadth of interests. These organizations include (but are not limited to) the City of Baltimore Office of Sustainability, Department of Parks and Recreations, Department of Public Works and Transportation, TreeBaltimore, Cleaner Greener Baltimore, The Baltimore Tree Trust, Tree-mendous Maryland, the Maryland DNR, The Forest Service, Blue Water Baltimore, and the Parks and People Foundation. Due to the variety of stakeholders, we aim to create a tool that can act as a central repository for the range of institutional knowledge that is currently sequestered individually within each of these organizations - or "functional silos," as they have been referred to in the literature (Yaffee, 1997). As Nerys Jones (2005) explains,

Urban forestry needs to be delivered at a strategic scale if it is to provide a full range of environmental, social and economic benefits to the urban dweller. Therefore, there needs to be an effective and integrated working relationship across public, private, voluntary and community sectors – with contributions of land, skills and finance from the widest possible range of partners (187).

According to a survey of 25 interest groups and collaborators with the TreeBaltimore Initiative coordinated by Locke et al. (2013), these agencies have many overlapping interests. Their study used hierarchical clustering algorithms to show that there were many opportunities for collaboration by groups with similar goals, which is a finding that could be very useful to Baltimore in the future as they continue to work on urban forest expansion. They also generated tree planting prioritization maps for each stakeholder involved in the survey process using GIS technology, based on their individually reported interests and goals for tree planting. These maps not only helped individual organizations define their goals and prioritize areas for tree planting, but also when combined and averaged together, provided the city with a comprehensive prioritization map based on input from 25 stakeholder groups and their ranking of 18 criteria for choosing areas to complete greening projects.

1.2 Our Team and Client

The project client is the City of Baltimore Office of Sustainability, which is housed within the Department of Planning. Our point of contact is Kristin Baja, the City's Climate and Resilience Planner. Our team consisted of four M.S. Candidates at the University of Michigan School of Natural Resources and Environment (SNRE): Rebecca Robinson (M.S. - Environmental Informatics), Wing Sze Poon (M.S. - Environmental Informatics; Conservation Ecology), Kristiane Huber (M.S. - Environmental Policy and Planning), and Dania Gutierrez (M.S. - Behavior, Education, and Communication; Environmental Policy and Planning). This team chose this project from a variety of proposals as their capstone project in partial fulfilment of their graduate requirements, and were especially excited to work with Kristin, who is an alumna of SNRE.

1.3 Study Area

Baltimore, Maryland encompasses 80 square miles at the mouth of the Patapsco River where it meets the northern reaches of the Chesapeake Bay. With a population of 622,104 residents as of the 2013 U.S. Census, it is the largest city in Maryland and the 26th largest in the United States. Baltimore began as an industrial and manufacturing hub due to its accessibility by water and proximity to Midwestern cities, but shifted to a service-oriented economy with the founding of John Hopkins University (in 1876) and Hospital (in 1889), now the city's two largest employers according to the Baltimore Development Corporation (http://www.baltimoredevelopment.com/). Baltimore currently experiences a temperate climate with four distinct seasons characterized by warm, humid summers and damp, cool winters, but the climate is expected to change drastically due to climate change. Its location along the coast further compounds the climatic risks the city will face in the future.

1.3.1 Climate Change Risks

Baltimore is situated along 60 miles of Chesapeake Bay waterfront, which has led to a booming seaport and tourism industry. According to the city's Disaster Preparedness and Planning Project (DP3), however, this resource also leaves Baltimore much more vulnerable to sea level rise – in all, 1.33% of Baltimore City's land area falls within an inundation zone based on sea level rise projections (63). Additionally, the highly developed shoreline exacerbates vulnerability to heat events, coastal storms, high winds, and flooding, all of which are predicted to worsen with climate change.

Average annual temperatures in Baltimore are predicted to increase by 12 degrees °F by 2100, yielding a climate similar to New Orleans, LA, and the number of days where the temperature exceeds 90 degrees Fahrenheit is expected to increase to between 38 and 41 days by the end of the century (DP3, 84). Sensitivity to extreme heat is compounded by the lack of green cover in Baltimore (DP3, 142), which not only provides less tempering of the climate, but also negatively affects air quality, both of which increase health risk during heat events. As an illustrative example, Baltimore received a D grade on their 2013 Air Quality Report Card from the American Lung Association (DP3, 88).

Generally, precipitation events are projected to increase in frequency and intensity, meaning that while average precipitation is expected to increase by 10% due to more frequent heavy storm events, the periods between these storms will be much drier. Droughts, according to the DP3, are difficult to predict, though other studies have concluded that the metropolitan regions of the southeast are at greatest risk of ecological change due to increasingly arid conditions and loss of tree cover (Greenfield and Nowak, 2013). The average duration of dry spells in Maryland is projected to increase by two days (DP3, 77).

Winter storm precipitation in Baltimore is projected to increase by 40%, though due to an expected increase in winter temperature between 7.4 and 10.6 degrees °F by the end of the century (DP3, 73). This precipitation will fall as rain more often than snow. Sea level is projected to increase an additional 13 inches by 2050, having already risen 13 inches between 1902 and 2006. By the end of the century, sea level could rise by as much as 48 inches (DP3, 36). Sea level rise is further compounded by land subsidence, or the gradual sinking of land surface. In Maryland, subsidence rates are approximately 1.5 mm/year, and scientists estimate a 6-inch drop over the last century.

1.3.2 Baltimore's Urban Forest Benefits

Baltimore's current urban forest provides measurable benefits to Baltimore's residents. Based on an analysis of the iTree model output for Baltimore, every year the canopy removes 12.7 tons of fine particulate matter ($PM_{2.5}$ – the most harmful type of air pollution for human respiratory health) at a value to society of $7,780,000 per year. This corresponds to a 9% average improvement in air quality and a 1% reduction in $PM_{2.5}$ concentrations (Nowak, 2012). According to TreeBaltimore, the city's "umbrella organization" for organizing the many stakeholders interested in increasing Baltimore's tree canopy, Baltimore's 2.8 million trees provide $3.3 million in energy savings through shading and wind protection, $10.7 million per year by storing 527 tons of carbon, $3.8 million per year in air quality improvements corresponding to the removal of 700 metric tons of air pollution (this includes the aforementioned $PM_{2.5}$), and $1.6 million annually by removing 244 metric tons of ozone, which causes asthma and smog. Over its lifespan, a single tree is estimated to provide $57,000 in economic and environmental benefits (http://treebaltimore.org/about/). Additionally, trees have been shown to reduce heating costs by 10-50% due to wind mitigation (Maryland Department of Natural Resources) and increase home value by 7-10% (Susan Wachter, 2005; Anderson et al., 1988; Donovan et al., 2010). A single tree is estimated to store 50-100 gallons of water during large storm events, therefore reducing stormwater runoff into the Chesapeake Bay (Fazio, Tree City USA Bulletin). An increased tree cover has also been correlated with decreased crime rates in Baltimore: a 10% increase in canopy cover is associated with an approximate 12% decrease in crime (Troy et al., 2012). This statistic is particularly interesting because

Baltimore had the 5th highest murder rate in the country in 2013, according to the Baltimore Sun, a local newspaper (Fenton, 2014).

1.3.3 The Current State of Baltimore's Urban Forest

According to recent studies, Baltimore's tree canopy is struggling. Total tree cover in Baltimore decreased from 30.4% in 2001 to 28.4% in 2005 (Nowak et al., 2012a), while the impervious surface cover has increased by 2.1% in that period. When comparing Baltimore to the 19 other cities in Nowak's study (2012a), both of these statistics were worse than the average (1.5% average decrease in canopy and 1.3% average increase in impervious cover). Estimates on the number of trees in Baltimore vary, though the Department of Parks and Recreation estimates 2.8 million trees in total, 100,000 of which are street trees (treebaltimore.org/about). According to the Department of Recreation and Parks, while Baltimore's forest is relatively diverse, it is dominated by a few tree species: while the street tree population includes 95 different species, 31% of the population is one of three species: Silver Maple (*Acer saccharinum*), Linden (*Tilia americana*), or Norway Maple (*Acer platanoides*).

A different study by Nowak completed a stratified random sample of Baltimore's complete canopy (comprised of street, park, and residential trees) to measure the proportion of invasive trees in Baltimore's urban forest. The study illustrated that Baltimore is currently being invaded by *Ailanthus altissima*, or Tree-of-Heaven, which comprised 10.1% of a stratified random sample of the city's canopy in 2012 (Nowak et al., 2012b). This was second in abundance only to the native tree, American Beech (*Fagus grandifolia*), which comprised 18.2% of the same sample. According to the same study, 58% of new trees between 2004 and 2009 were native, while 14% were invasive. The remaining 28% of new trees are believed to have regenerated naturally (Nowak et al., 2012b).

In a study by Nowak et al. in 2004 based on re-measurements of urban forest plots between 1999 and 2001 and the outputs from the Forest Service's iTree (formerly UFORE) model, Baltimore's trees experience an annual mortality rate of 6.6%, resulting in a net negative change of 4.2% in overall cover: from 2,535,600 live trees in 1999 to 2,210,200 in 2001, despite plantings of approximately 42,650 trees per year. Nowak found that only 60% of dead trees were removed, leaving approximately 130,000 dead trees standing throughout the city, creating risk to residents and infrastructure alike. He found that four factors significantly affected mortality rates: tree size, tree health, tree species, and land use. Nowak found that mortality rates differed by the type of land use on which trees were found, with trees on land designated for transportation (street trees) experiencing the highest mortality (20.2%) and trees in low to medium density residential areas experiencing significantly lower mortality rates than all other land uses (2.2%). Additionally, he found that smaller trees (in terms of diameter at breast height, or dbh) exhibited significantly higher mortality rates than larger trees and that different species had different mortality rates, though varying distributions of tree sizes and land use locations within species types complicated these relationships. Due to this observation, Nowak suggested that better management of young trees could significantly decrease mortality rates, reporting that reducing the mortality rate of trees with a diameter at breast height (dbh) less than 30.5 cm by 3% would result in a doubled average lifespan for urban trees: from 15 to 33 years (145).

Nowak ran simulations based on various combinations of tree-planting and tree-mortality scenarios and found that the amount of tree cover over time was very sensitive to mortality rates, indicating that better management, especially for mortality-prone young trees, would be most effective in helping Baltimore expand their urban forest.

1.3.4 Background on Urban Forestry, Climate Adaptation, and Resilience Planning

In order to address some of their concerns about climate change, Baltimore adopted the Sustainability Plan in 2009, the Climate Action Plan in 2012, and the Disaster Preparedness and Planning Project (DP3) in 2013. Each plan expands on a need described in the previously adopted plan, yielding three policy documents that are increasingly detailed and specific in their strategic recommendations. While these policy documents are relatively comprehensive in their recommendations for a variety of issues, ranging from storm water management to quality of life to infrastructural integrity given climate risks, a common theme running throughout these documents is that the expansion of their urban green space will constitute an integral part of any future planning.

The *Sustainability Plan* was adopted in 2009 as an element of the Comprehensive Master Plan for Baltimore, completed by the Baltimore City Planning Department in 2006. It was the first document to express Baltimore's now-widely publicized goal of doubling their tree canopy cover from 20% to 40% by 2037 through the implementation of the TreeBaltimore Initiative. The recommendations in this plan are organized into seven categories: *Cleanliness, Pollution Prevention, Resource Conservation, Greening, Transportation, Education & Awareness,* and *Green Economy*. Alongside inventory, assessment, and communication goals set forth in the "Greening" category of this document, the plan also proposes increased tree planting on public lands and the identification and pursuit of opportunities for planting on private land. This proposition is especially important, given that if Baltimore is to meet the urban forestry goals set forth in this plan, the majority of tree plantings will have to occur on private lands; if all available public lands – including right-of-way areas and parks – were forested to 100% cover, Baltimore would only be able to reach approximately 10% of their 40% forest canopy expansion goal (Galvin et al., 2006; O'Neil-Dunne, 2009).

To help meet the goal of a 15% greenhouse gas (GHG) reduction by 2015 put forth in the Sustainability Plan, the *Climate Action Plan* (CAP) was conferred three years later (2012), and outlines three specific action areas for emissions reduction. One such action area is titled "Growing a Green City" and is estimated to have a reduction potential of 38,935 million tons of CO_2 emissions annually, or 3% of the total GHG reductions outlined in the CAP (CAP, 54). It is interesting to note that while this greening initiative is estimated to sequester a relatively small proportion of Baltimore's emissions, this is the strategy most-favored by participants of a climate adaptation Town Hall meeting. While carbon sequestration is the main focus of this strategy, the other positive benefits of urban forestry are briefly mentioned. The plan proposes to coordinate existing city ordinances and the many city agencies, organizations, and initiatives interested in urban greening to (1) protect trees, (2) increase the number of trees, and (3) improve the health of the trees. Additionally, the plan suggests the creation of tree planting standards with the Bureau of Water and

Wastewater (BWW) to enhance stormwater mitigation effects while also maintaining the integrity of existing stormwater infrastructure.

The *Disaster Preparedness and Planning Project* (DP3) fulfills the Climate Action Plan's call for an integration of climate adaptation into the All Hazards Mitigation Plan (AHMP) – a plan that is required of every local jurisdiction by the Federal Emergency Management Agency (FEMA). The project was "created by the Department of Planning as an effort to address existing hazards while simultaneously preparing for predicted hazards due to climate change. This project develops a program that integrates hazards mitigation planning, floodplain mapping, and climate adaptation planning." The professed goals of this analysis are (1) to protect the health, safety, and welfare of residents and visitors, (2) prevent damage to structures and infrastructure, (3) enhance adaptive capacity, and (4) promote awareness and education (DP3, 152). The DP3 is the most detailed of the three documents, specifically quantifying risk and vulnerability to six climate change hazards as well as suggestions for protection/prevention strategies. The hazard categories considered are flooding, coastal hazards, precipitation variability, wind, extreme heat, and land (includes earthquakes, landslides, and sinkholes). The DP3, like the other plans, organizes their strategies and recommendations by category: infrastructure, buildings, natural systems, and public services.

The importance of expanding and maintaining green infrastructure in Baltimore is a common theme throughout these three documents. Most notably, it constitutes one of the main categories in each: "Greening" in the Sustainability Plan, "Growing a Green City" in the CAP, and "Natural Systems" in the DP3. While the use and protection of green infrastructure is understandably the most prevalent recommendation within these specific categories, it is interesting to note that recommendations of urban greening comes up relatively frequently within the other categories as well. Most notably, in the DP3, five recommendations for protecting Baltimore's infrastructure (of 22) explicitly recommend deploying urban forestry, one of ten strategies within both the "buildings" and "public services" categories mention urban greening, and all eight recommendations within the "natural systems" category pertain to either the protection, expansion, or utility of the urban forest. Altogether, 30% of the strategies put forth in the DP3 suggest the use of urban greening in some way, illustrating the idea that Baltimore's forest plays an integral role in protecting the city in the face of environmental hazards, vulnerability to climate change, and health risks such as air pollution. Chapter 2 will further explore Baltimore's leadership in this field when compared with other cities planning for climate change and planning to increase the size of their urban forests.

References

Akbari, H. "Shade trees reduce building energy use and CO2 emissions from power plants." *Environmental Pollution* 116 Suppl 1 (2002): 119-126.

Akbari, H., M. Pomerantz, and H. Taha. "Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas." *Solar Energy* 70, no. 3 (2001): 295-310.

Anderson, L.M., and H.K. Cordell. "Influence of trees on residential property values in Athens, Georgia (U.S.A.): A survey based on actual sales prices." *Landscape and Urban Planning* 15, no. 1 (1988): 153-164.

Baja, Kristin, and Megan Griffith. *Disaster Preparedness and Planning Project.* Rep. Baltimore Office of Sustainability. October 2013. (accessed November 2014).

Bartens, Julia, Susan D. Day, J. Roger Harris, Joseph E. Dover, and Theresa M. Wynn. "Can Urban Tree Roots Improve Infiltration through Compacted Subsoils for Stormwater Management." *Journal of Environmental Quality* 37, no. 6 (2008): 2048.

City of Baltimore Department of Recreation and Parks. "Street Survey". http://bcrp.baltimorecity.gov/Recreation/SpecialPrograms/TreeBaltimore/StreetSurvey.aspx (accessed April 21, 2015)

Cook, D.I. "Trees, solid barriers, and combinations: alternatives for noise control." Edited by G. Hopkins. *National Urban Foresty.* SUNY College of Environmental Science and Forestry, Syracuse, NY, 1978. 330-339.

Cummins, Susan Kay, and Richard Joseph Jackson. "The built environment and children's health." *The Pediatric Clinics of North America* 48, no. 5 (2001): 1241-1252.

Donovan, Geoffrey H., and David T. Butry. "Trees in the City: Valuing Street Trees in Portland, Oregon." *Landscape and Urban Planning* 94, no. 2 (2010): 77-83.

Fazio, James R. *How Trees Can Retain Stormwater Runoff.* Tree City USA Bulletin 55, Arbor Day Foundation, n.d.

Fenton, Justin. *New FBI statistics: Baltimore No.5 in murder rate.* The Baltimore Sun. November 10, 2014. http://www.baltimoresun.com/news/maryland/crime/blog/bal-new-fbi-statistics-baltimore-no-5-in-murder-rate-20141110-story.html (accessed November 7, 2014).

Gao, Y., J.S. Fu, J.B. Drake, Y. Liu, and J-F Lamarque. "Projected changes of extreme weather events in the eastern United States based on a high resolution climate modeling system." *Environmental Research Letters* 7, no. 4 (2012).

Gregory, J.H., M.D. Dukes, P.H. Jones, and G.L. Miller. "Effect of urban soil compaction on infiltration rate." *Journal of Soil and Water Conservation* 61, no. 3 (2006): 117-123.

Grove, J.M., J. O'Neil-Dunne, K. Pelletier, D. Nowak, and J. Walton. *A report on New York City's Present and Possible Urban Tree Canopy.* Northwestern Research Station, Syracuse, NY: New York Department of Parks and Recreation, USDA Forest Service, 2006.

Hallegatte, Stéphane. "Strategies to adapt to an uncertain climate change." *Global Environmental Change* 19, no. 2 (2009): 240-247.

Howe, Glenn T., et al. "From genotype to phenotype: unraveling the complexities of cold adaptation in forest trees." *Canadian Journal of Botany* 81, no.12 (2003): 1247-1266.

Howenstine, W.L. "Urban forests as part of the whole ecosystem." Edited by C. Kollin, J. Mahon and L. Frame. *6th national urban forest conference.* Washington, D.C.: American Forests, 1993. 118-120.

ICLEI. *What Can Local Governments Do?* http://www.icleiusa.org/climate_and_energy/Climate_Adaptation_Guidance/what-can-local-governments-do (accessed April 16, 2015).

Locke, Dexter H., J. Morgan Grove, Michael Galvin, Jarlath P.M. O'Neil-Dunne, and Charles Murphy. "Applications of urban tree canopy assessment and prioritization tools: Supporting collaborative decision making to achieve urban sustainability goals." *Cities and the Environment* 6, no. 1 (2013): 7.

Meehl, Gerald A., Francis Zwiers, Jenni Evans, and Thomas Knutson. "Trends in extreme weather and climate events: Issues related to modeling extremes in projections of future climate change." *Bulletin of the American Meteorological Society* 81, no. 3 (2000): 427-436.

Nilsson, Kjell, Thomas B. Randrup, Jasper Schipperijn, and Cecil Konijnendijk. *Urban forests and trees.* Berlin: Springer-Verlag Berlin Heidelberg, 2005.

Nowak, David J. "Contrasting natural regeneration and tree planting in fourteen North American cities." *Urban Forestry & Urban Greening* 11, no. 4 (2012): 374-382.

Nowak, David J., and Eric J. Greenfield. "Tree and impervious cover change in US cities." *Urban Forestry & Urban Greening* 11, no. 1 (2012): 21-30.

Nowak, David J., Satoshi Hirabayashi, Allison Bodine, and Robert Hoehn. "Modeled PM2.5 removal by trees in ten U.S. cities and associated health effects." *Environmental Pollution* 178 (2013): 395-402.

Ordóñez, C., and P. N. Duinker. "Climate change vulnerability assessment of the urban forest in three Canadian cities." *Climatic Change* (2015): 1-13.

Roloff, and A. Roloff. "Bäume in der Stadt – was können sie fernab des Naturstandortes ertragen?" *Forest und Holz* 61 (2006): 350-355.

Roloff, Andreas, Sandra Kom, and Sten Gillner. "The Climate-Species-Matrix to select tree species for urban habitats considering climate change." *Urban Forestry & Urban Greening* 8, no. 4 (2009): 295-308.

Rosenfeld, Arthur H., Hashem Akbari, Joseph J. Romm, and Melvin Pomerantz. "Cool Communities: Strategies for Heat Island Mitigation and Smog Reduction." *Energy & Buildings* 28, no. 1 (1998): 51-62.

Sæbø, Arne, Thorarinn Benedikz, and Thomas B. Randrup. "Selection of trees for urban forestry in the Nordic countries." *Urban Forestry & Urban Greening* 2, no. 2 (2003): 101-114.

Troy, A., J.M. Grove, and J. O'Neil-Dunne. "The relationship between tree canopy and crime rates across an urban-rural gradient in the greater Baltimore region." *Landscape & Urban Planning* 106, no. 3 (2012): 262-270.

Yaffee, Steven L. "Why Environmental Policy Nightmares Recur." *Conservation Biology* 11, no. 2 (1997): 328-337.

Yang, Jun. "Assessing the impact of climate change on urban tree species selection: a case study in Philadelphia." *Journal of Forestry* 107, no. 7 (2009): 364-372.

Chapter 2: Policy Analysis

In this chapter:

2.1 Introduction

The policy analysis portion of our project aims to contextualize the on-line decision support tool within the challenges and needs of the urban forestry and climate adaptation fields. Baltimore's consideration of climate change impacts on its urban forest and its simultaneous integration of canopy targets are complex approaches to climate adaptation that acknowledge the dynamism of urban forests in adapting to climate change. Climate change will likely intensify the above stressors while adding other challenges related to drought, average surface temperatures, and saltwater intrusion from rising sea levels and storm surges (DP3, 5). Given this dynamic relationship between climate change and urban forests, this analysis aims to determine how municipal policy relating to the two fields aligns. The analysis considers the following study questions:

a) How do climate action and adaptation plans integrate urban forestry into their targets and strategies?

b) How do urban forestry management and master plans consider the impacts of climate change and its impacts on planting and management practices?

c) Are these climate adaptation plans and urban forestry policies representative of the challenges practitioners face each day and changes in practice in Urban Forestry departments across the country?

2.1.1. Definitions

*Urban forestry document*s: refers to urban forestry master plans, urban forestry management plans, or external reports with some elements of resource assessment, urban forestry goals, strategies, or consideration of urban forestry policy implementation.

Urban Forestry Master Plans: Often incorporates a historic and/or environmental assessment of the conditions in the community (APA, 37). This process creates long-term planning for a city's trees. Based on the policy review, master plans generally include goals to align objectives with existing policies in a city and rely on public engagement to a greater extent than management plans.

Urban Forestry Management Plans: Often developed through collaborative efforts of staff members and/or consultants and can have a relatively narrow or broad scope. A number of the management plans reviewed integrated similar planning principles as the master plan, including longer planning horizons of decades instead of years and opportunities for stakeholder input.

2.2 Methods

30 cities were initially selected for review of relevant urban forestry and adaptation policies if they met at least one of the following three criteria:

a) *A population of 500,000 or greater*: The City of Baltimore has a population of 622,104 (Wood & Burris, 2014). Cities with large populations face unique challenges in managing urban forests and adapting to climate change on a large scale. This criteria was selected based on conversations with our client, in which city size and scale of planting were discussed as challenges in Baltimore.

b) *Geographically located in the southeastern United States*: Based on feedback from our client, there was particular interest in tree species prevalent in the southeast because of the projected northward range expansion of tree species under climate change. Some of the impacts of climate change Baltimore already experiences, including an increase in the frequency and intensity of heat waves, increased intensity of extreme weather events and an average increased temperature of 1.8°F (Baltimore DP3, 34), are climate characteristics already faced in southeastern cities.

c) *Leadership in urban forestry management*: To identify model cities for Baltimore's urban forestry, cities were selected based on their reputation for having a healthy urban canopy or robust urban forest planning process. These cities were identified using American Forests' list of *10 Best Cities for Forests* as well as Google and Database searches for "urban forest master plan", "urban forest management plan", and "urban forestry climate change". Cities selected have (1) management and master plans that were less than 15 years old or were accompanied by evaluation and policy updates; and (2) some form of a climate action plan, sustainability plan with a climate change chapter, or a climate adaptation plan.

We reviewed the most recent urban forestry planning documents and climate adaptation reports or sustainability reports with climate adaptation considerations from each city (see Appendix B for the full list of cities and reports reviewed). Our analysis involved reviewing each urban forestry planning document for evidence that the city is or will be considering climate change adaptation in the management of its urban forest. This evidence was either in the form of an explicit discussion or indirect reference to climate change-related issues such as resilience or uncertainty. In this analysis, urban forestry planning documents that describe how urban forests may be benefited or impacted from climate change were also considered as a document integrating climate change adaptation. For example, urban forestry planning documents that discussed the benefits of urban forestry for reducing urban heat island effects and described the possibility of this phenomenon worsening in the future, were considered as examples of a city acknowledging the impacts of future uncertainty. Climate adaptation or sustainability planning documents were then reviewed to determine how urban forestry was incorporated. Goals and strategies in these documents were then compared to the city's urban forestry planning documents.

All of the large cities and urban forestry leading cities selected have climate action plans as well as an urban forestry management or master plans. For the remaining cities, information from websites were substituted for formal plans, though this approach was limited as they does it not provide the detailed found in planning documents. Interviews also served as a way to supplement gaps in information. Southeastern cities were largely lacking in both formal urban forestry plans and adaptation plans. Climate change is generally omitted from sustainability information on southeastern cities' websites. The cities selected for their southeastern location generally have smaller populations than other selected cities, and likely because of this, those cities lack formal urban forestry management plans, with forestry divisions or parks departments' websites serving the purpose of communicating to the public on reporting storm damage and providing general planting recommendations (City of Raleigh; Norfolk Recreation, Parks & Open Space; City of Charleston).

Cities selected in this policy analysis were contacted for interviews via e-mail and phone calls. The team reached out to 20 city governments for interviews based on their similarity in climate change vulnerability and goals in canopy sizes as Baltimore. We were only able to successfully interviewed eight cities listed in Appendix C. Interviewees were asked if and how climate change affects urban forests in their city, how their management plans are used and changed, and if they were making any adjustments in practice based on climate change impacts in their cities. See Appendix D for a list of interview questions and detailed description of the interview procedure.

2.3 Results

2.3.1 How are forestry plans integrating climate change?

Of the 30 cities selected, 25 have urban forestry plans documents. The urban forestry plans broadly focus on the mitigative benefits of urban forests like sequestering carbon and offsetting greenhouse gas emissions. Gresham, Oregon's Urban Forestry Management Plan (2011, 26) states "Urban forests help moderate global climate change and can be a cost-effective method of greenhouse gas reduction". This is representative of the economic and ecological benefits from climate change expressed in forestry plans that mention climate change, which are often from cities that signed the U.S. Conference of Mayors Climate Protection Agreement between 2005 and 2007 (United States Conference of Mayors).

Climate adaptation in urban forestry management practices is largely omitted from the plans reviewed. Twelve of the 25 plans considered the adaptive benefits of trees. Of those 12, however, seven cities further consider climate impacts on urban forests and how to manage for these challenges.
The plans that considered climate change adaptation most commonly identifies two benefits regardless of geographic location and city size:

a) Tree canopy decreases urban heat island effect by shading sidewalks, buildings and streets.
b) The use of trees as an element of larger green infrastructure systems that improve stormwater management to prepare cities for more extreme precipitation events.

The identified challenges of climate change in urban forest plans are quite similar across cities despite their geographic location and climates:

a) Increased storm intensity may cause greater tree damage which will contribute to more debris in streets after storms.

b) Higher temperatures will increase heat stress for trees, especially in the summer.

c) Hardiness zones will shift north meaning that many urban trees currently growing in cities will be growing further outside of their hardiness zone throughout the century. Current trees planted will be growing in less suitable environments in the future.

d) Warmer temperatures and milder winters could result in a greater number, or a shift in, diseases and pests.

The most common integration of climate planning or planning for uncertainty was to set or report having reached city-wide species diversity goals. 14 of the 25 cities with urban forestry management documents mention diversified plantings as a strategy to grow a more resilient urban forest. Most cities' existing diversity goals are based on tree diversity recommendations of Moll (1989) that no more than 10% of trees in a community be of the same genus and less than 5% be in the same species. A number of plans also require that no more than 20% of the trees be in the same family. These diversity goals were put in place before climate change was a challenge, and seem to set a helpful precedent or basis for increasing diversity going forward. Most of the plans, while generally encouraging more plant diversity, shy away from detailed descriptions of how species should be selected to add to diversity. Few cities struggle on how to diversify urban forest plantings, whether to increase diversity with more native plants that are well adapted to the given area, or introduce plants from areas with similar climate as the projected climate at that location.

2.3.2 Climate adaptation plans integrating urban forestry

Of the 30 cities selected, 22 have formal citywide climate adaptation plans, and an additional four have climate action or sustainability plans with mention of the impacts of climate change. Adaptation plans considered urban forests from two perspectives: in their climate vulnerability assessments, and in steps, actions or strategies for adaptation. Most plans focus on forests as an adaptation strategy, but a number of cities in our list also consider managing urban forests for climate change. For example, Vancouver's Climate Change Adaptation Strategy considers the increase in climate change impacts to urban forests (22) while also strategizing to increase the long-term health of the forest (26).

<u>Urban Forestry Vulnerability</u>

Of the cities reviewed, only six adaptation plans specifically acknowledge the stress that climate change might put on an urban forest, and there is little discussion of what those vulnerabilities are and how they might affect the city's ability to reach its canopy goals, maintain canopy, or reach other sustainability targets in terms of greenhouse gas emissions offset, reducing urban heat island effects, or reducing stormwater runoff with green infrastructure. For instance, the City of Alexandria's sustainability plan sets a 40%

increase in canopy as city goal (23) and discusses how trees "combat climate change" but does not mention the urban forests vulnerability to climate change.
The City of Chicago's Climate Action Plan is very strong in its discussion of climate change vulnerability and specifically discusses Chicago's shifting plant hardiness zone, which has already shifted to that of central Illinois as of 1990. The report warns that the city's plant hardiness zone could be equivalent to northern Alabama or southern Missouri by the end of the century (City of Chicago, 40). The plan also proposes strategies to overcome these challenges discussed in the Section 2.3.4.

The most common vulnerability concern about the urban forest is related to tree mortality and damage from increased intensity and occurrence of storms. Melbourne, Australia's climate adaptation plan considers the importance of a resilient forest in its adaptation plan because of a concern about increased debris complicating disaster response and falling branches as they damage utilities, roads, and threaten human lives (City of Melbourne Climate Change Adaptation Strategy, 33). Instead of increasing response crews after storms, the plan calls for a healthier and more adapted urban forest that can withstand these impacts (City of Melbourne Climate Change Adaptation Strategy, 64). The City of New York also integrates this concern about urban forest resilience to increasingly violent storms, drawing on the city's experience with Hurricane Sandy in 2012. *A Stronger More Resilient New York* discusses improving the health and resiliency of the urban forest due to storm surge, wind, and changes in temperatures (200). This is also apparent in Vancouver's plan, where concern is expressed about increased maintenance and replacement costs for forests from extreme temperatures and wind storms (Vancouver Climate Adaptation Strategy, 15).

The plans largely leave out a number of more complex or challenging impacts of climate change. Drought is acknowledged, but with the exception of Toronto, few adaptation plans consider more technical solutions for irrigation or retaining water for trees to access. Only New York (194) considers the challenges of saltwater inundation and the need for saline-tolerant trees and plantings. Similarly, consideration of flood impacts on trees is only considered explicitly in Atlanta and New York's adaptation plans.

Urban Forestry as a Strategy for Adapting to Climate Change

The 26 climate action plans that include climate adaptation sections and strategies incorporate a canopy goal or tree planting targets (i.e. New York's Million Trees program), mainly with the goal of reducing urban heat island effects. The other most common discussion of trees or an urban forest as an adaptation measure is reducing stormwater runoff and increasing water retention in cities. Ann Arbor, Michigan's Climate Action Plan serves as a good example of this trend in its goal to reduce urban heat island effect through increasing the forest canopy. It also highlights the trees' interception of 65 million gallons of stormwater each year (City of Ann Arbor, 142). We see this emphasis on urban heat island reduction and flood control in a number of plans - across city sizes, regions, and leadership categories.

New York City looks to urban trees for reducing storm impacts based on observations that forests and parks acted as a barrier from storm surges in the Brooklyn-Queens Waterfront and in Staten Island (A Stronger, More Resilient New York, 265 & 286). This integration of trees as a living storm barrier was unique to New York City in our analysis.

Alignment of Urban Forestry and Climate Adaptation Planning

Of the 30 cities reviewed, 15 (mostly fitting the "urban forestry leader" and large city criteria) have urban forestry and climate adaptation plans that involve cross-sectoral communication and planning. These urban forestry plans consider the impacts of climate change as well as the benefits of urban forestry for addressing climate challenges. In these 15 cities, canopy targets are consistent between adaptation and urban forestry plans, and adaptation plans acknowledge the vulnerability of urban forests or mention that urban forestry would need increased resources or information to adapt their practices. Of these 15 cities, six cities (Alexandria, Charlottesville, Charleston, Gresham, Minneapolis and Syracuse) have robust urban forestry plans in place that consider climate impacts, but adaptation plans that do not feature or emphasize urban forests as an adaptation strategy. With forestry divisions already working to grow resilient urban forests, these forests will help cities reach canopy cover goals, and might lay the framework for the green infrastructure-focused climate adaptation plans in the pipeline.

2.3.3 Themes of Interviews

When asked about concerns related to climate change or perceived changes in climates, interviewees discussed observed changes, mostly in increases in extreme summer heat and drought conditions or in extreme winter cold and precipitation. Most interviewees discussed concern about increased pests and disease due to warmer temperatures, and increased stress on trees making them more susceptible to disease. Our interview subject from South Carolina said that he had been in touch with other cities about managing pests that were historically endemic to Charleston, and now were of concern in other cities.

Many interviews provided more perspective on how cities manage for diversity in practice. One interview subject explained, simply that "diversity is a safe goal." All interview respondents' cities had diversity goals, but expressed different primary concerns about finding suitable tree species. A number of cities are reaching their generalized city-wide goals, however the professionals expressed that a downscaled planning for diversity was needed. Some cities have blocks or neighborhoods where the same tree has been planted, and others had achieved all their diversity targets in parks but struggled to do so with street trees.

One of the great challenges of increasing diversity was the considerable limitations of purchasing tree stock from nurseries. Pittsburgh is planning to start a municipal nursery to have more in-house control over tree quality and species selection. Multiple respondents were able to start ordering different trees based on which trees had done well in recent droughts or storms, and based on the planting lists of other nearby cities further south. "I'm looking out to see what [tree species] there might be that, in the longer term, will survive," one of the interview subject explained. The respondent said that their department might purchase ten or so of these more southerly growing trees and plant them to see which ones thrive. Others had nursery contracts and saw greater barriers to changing the plants seeded by nurseries given the amount of time required for nurseries to produce a tree fit for urban planting.

All of the interview subjects also expressed that they aspired to plant a greater number of trees to increase the urban canopy but that resources were limited. Departments have limited funding and are tasked with responding to calls and concerns about trees that are sick, dying and damaged throughout the city and the emergency response needed after wind and rain events. Several interview subjects, when discussing the responsive forestry management with which their department is tasked, acknowledge that it is a more expensive way to care for an urban forest (as opposed to a proactive and adaptive approach), and a couple observed, anecdotally, that there are increasing number of calls about trees damaged from events than in the past.

Most interview subjects were committed to formal evaluation and review of urban forest health and progress on goals in forestry planning. More advanced assessment techniques like iTree and Ecosystem Assessments improved evaluation and a basis for implementation reviews. Generally the urban forest professionals we spoke to said that their city was evaluating plans regularly, though not as often as had been called for in their forestry plans.

This process of converting departments from reactive management to proactive planning is challenged by the time-intensive nature of urban forestry planning, which could take staff away from their work. However, many respondents felt that management or master plans were an important step in making urban forestry more proactive. The subjects that already had master plans indicated that they are updated or amended periodically. Master plans developed more recently within the study (in the past ten years) integrated evaluation into the planning process, while older plans or cities without plans relied on experienced staff members to gauge progress towards goals and offer advice on which strategies are possible, or feasible, for improving forest resiliency.

2.3.4 Innovative Strategies

Here we outline a number of specific innovative actions that have been implemented in different cities, in terms of planting or management.

<u>Planting Actions</u>
The following examples describe specific planting decisions and goals outlined by cities that are promoting resilient urban forests:

a) **Chicago** outlines planning to prepare for changes in the hardiness zones by working with the City nurseries, developers, and other stakeholders to amend landscape ordinances to accommodate plants that tolerate the changing climate and also to create a new plant-growing list with tree selections that can thrive in the expected warmer conditions. (Chicago Climate Action Plan, 43).

b) The **San Francisco** Urban Forest Plan cites this initiative in considering if test plantings of various tree species may also be appropriate for determining suitability (San Francisco Urban Forest Plan, 44).

c) **Toronto** is also piloting a seed diversity project in which locally adapted seeds of native species are propagated and young trees are used to increase genetic diversity of the urban forest. (Toronto's Strategic Forest Management Plan, 55).

d) **New York City** set the goal of planting one million trees between 2007 and 2017. However, in order to reach this goal, the New York City Department of Parks and Recreation (NYCDPR) needed a greater quantity of trees annually, direct control over the quality of trees, consistency in pruning and root ball size, and a method for filling gaps in the supply of specified tree species not being produced commercially. To meet these needs, the City created eight-year contracts with nurseries in Maryland, Buffalo and Long Island indicating that NYCDPR will purchase a minimum number of trees. The chosen nurseries were required to have experience growing and delivering trees to specified standards, a minimum number of diverse tree species already growing, and NYCDPR reviewed each individual nursery's business operation to ensure these stipulations. The contract also required NYCDPR personnel to tag trees while they are in the ground. Through these contracts, the city has been able to plant tree formerly restricted by low availability and consistent quality. (Stephens 2013)

e) **Palo Alto** emphasizes the selection of drought and recycled-water tolerant trees to adapt their canopy to future drought conditions and severe water conservation measures. The plan also outlines a strategy to coach their new plantings to actively encourage adaptability. This includes planting young trees or seeds, and providing mulch to help with water retention. (City of Palo Alto Urban Forest Master Plan, 95-97)

f) In **Seattle**, the Urban Forest Stewardship Plan outlines the need to preserve and maintain existing trees and plant new trees. It also emphasizes the need to plant trees "that maximize important functions and benefits, or replenish or enhance functions and benefits lost due to tree removal." (14) The Parks and Recreation Department also implements a two-for-one tree replacement program, but this initiative has proved difficult to implement fully due to lack of funds (44).

g) To support the **City of Austin**'s goal for a sustainable urban forest, the Urban Forest Plan outlines an implementations strategy to pursue "species, age, and geographic diversity." The plan also emphasizes the need to consider multiple factors in species selection including potential future changes in climate patterns. (Austin's Urban Forest Plan, 79-80)

<u>Management Actions</u>

The following examples outline how cities are managing their urban forest for climate adaptation:

a) In **New York City**, the Department of Parks and Recreation (DPR) will identify locations in which tree beds will be expanded to give roots more room to grow and reduce rate of mortality during storms. The DPR will first target 5% of all planting locations for this expansion in connection with the MillionTrees Initiative (A Stronger, More Resilient New York, 200)

b) In **New York City** the Department of Parks and Recreation's tree inspection and pruning efforts will be prioritized in areas that have been otherwise determined to be vulnerable to extreme weather events. (A Stronger More Resilient New York, 200).

c) **Toronto**'s plan references the Queensway Sustainable Sidewalk Study from 2009 which sought to apply innovative application for irrigation through filtered stormwater. Trees were planted within a continuous soil trench which used soil cells to maximize space. The design allowed for removal of smaller solids and contaminants before root uptake. (Toronto's Strategic Forest Management Plan, 54).

d) In **Palo Alto,** one of the primary concerns outlined by the Urban Forest Master Plan Draft was managing a water-efficient urban forest. Given increased drought conditions, as well as the drastic water conservation measures put forth by the city and State of California, this master plan outlines how urban forests will be managed with short- and long-term strategies to help existing and new trees adapt to a decrease in water use. This includes using recycled water and incorporating drought tolerant tree species to transition the composition of the city's urban canopy to a more adaptive system. (City of Palo Alto Urban Forest Master Plan Draft, 93-95)

e) To ensure the maintenance of their trees, the **City of San Diego**'s Draft Climate Action Plan and Draft Urban Forest Management Plan set the goal of hiring an urban forest manager. These plans are unique in comparison to other city documents because they specify the importance of having an urban forestry expert to achieve city goals. (City of San Diego Urban Forest Management Plan, 17)

<u>Community Engagement</u>

The following cities provide examples of ways public engagement can inform urban forestry management planning and implementation:

a) **The City of Palo Alto** conducted a survey of residents to gauge perceptions of the role that trees play in their community and in addressing climate change. The results of this survey were described and provide evidence to further support the City's efforts to increase their tree canopy and incorporate adaptation strategies to manage street trees. This is an excellent example of the city's ability to generate quantitative and qualitative information from their constituents to not only support, but inform urban forest management as well. (City of Palo Alto Urban Forest Master Plan Draft, 75-88)

b) Through their extensive public engagement process, the **City of Austin** determined that the top citizen goal for their urban forest was its sustainability, taking climate conditions into consideration (Austin's Urban Forest Plan, 12). The plan uses Austin's constituents to support the incorporation of climate change and adaptation strategies into urban forest management. These community engagement exercises included surveys, public meetings, and an education campaign (Austin's Urban Forest Plan, Appendix C). Austin used extensive feedback to develop performance measures based on the criteria prioritized most by citizens and will also serve to inform Austin's implementation priorities (Austin's Urban Forest Plan, 31-32).

2.3.5 Baltimore leads the pack

Baltimore was proven to be a leader in its consideration of not only how urban forests can address climate change, but how climate change impacts the urban forest. Baltimore began working with the Maryland Department of Natural Resources to identify existing canopy cover, with the goal of improving water quality in the Chesapeake Bay. It was through this study that the city's aggressive canopy cover goal of 46.3% was adopted. This study, in 2005, recommended that Baltimore develop a "comprehensive urban forest management plan" (APA, 36).

Baltimore does not currently have an urban forestry master plan or management plan similar to the other cities described in this study; however, the integrative DP3 serves as the blueprint that brings together multiple city agencies and partners to meet urban forestry goals. The section in which natural systems and urban forests are set as priorities may not reflect the detail provided by formal urban forestry planning documents, but the DP3 functions as the city document that directly states how urban forests can function as an adaptation tool and must be managed to be resilient. The DP3 discusses how natural systems have the "potential as a hazard mitigation and climate adaptation tool." (159)

While all of the cities acknowledge urban forestry's positive impact on air quality, Baltimore's DP3 makes the strongest link between worsened health risks and heat (85). Baltimore's DP3 specifically recognizes the potential for trees and other natural features to reduce risk (142) while also considering the climate's impact on urban forestry (147). This consideration of urban forests, not as a static entity, but as a dynamic system for addressing climate change places it among the urban forestry leaders identified in the study.

In terms of tree selection and management, the plan discusses that tree species with high adaptive capacity must be prioritized. This strategy ensures that the trees selected will tolerate and survive existing natural hazards and projected climate change. Baltimore recognizes that an adaptive urban forest is also necessary to reduce the amount of resources – both time and funding - that goes into managing city trees.

Unlike the majority of similar climate adaptation plans reviewed for this project, the DP3 outlines goals and implementation strategies that support greater city goals:

- NS-1- Utilize green corridors and parks to help protect surrounding communities from the impacts of hazard events. (214)
- NS-2- Increase and enhance the resilience and health of Baltimore's urban forest. (215)

Associated implementation strategies include creating a list of species that are "known to have a broad range of environmental tolerances." (215) The tree spatial tool developed for this project represents a product inspired by this particular strategy. Baltimore then calls for developing a tree inventory and adjusting planting strategies in response to changes in climate, pests, and city priorities. The DP3 also clearly outlines which city agency within the City of Baltimore organizational structure will be leading the charge in implementing these strategies, the stakeholders involved, a timeframe, and how it aligns with DP3 goals and existing city planning documents. (215)

2.4 Conclusion

In urban forestry plans, the use of urban forests to mitigate climate change is nearly universal. While urban forestry benefits like reducing surface heat and improving air quality are prevalent in all of the plans analyzed, few plans consider the role of urban forests in increasing the adaptive capacity of cities in a changing climate. Only cities selected as forestry leaders weighed an urban forest's vulnerability to projected climates. Even fewer adaptation and sustainability plans analyzed in the policy review contained this same consideration, but every adaptation-focused plan recommended increased canopy or tree planting as an adaptation measure. These findings demonstrate that while adaptation plans are setting canopy and tree planting targets to make cities more resilient to climate change, the urban forestry policies, practices and extra resources are not in place to make this an effective adaptation strategy.

2.5 Recommendations

In urban forestry plans, the use of urban forests to mitigate climate change is nearly universal. While urban forestry benefits like reducing surface heat and improving air quality are prevalent in all of the plans analyzed, few plans consider the role of urban forests in increasing the adaptive capacity of cities in a changing climate. Only cities selected as forestry leaders weighed an urban forest's vulnerability to projected climates. Even fewer adaptation and sustainability plans analyzed in the policy review contained this same consideration, but every adaptation-focused plan recommended increased canopy or tree planting as an adaptation measure. These findings demonstrate that while adaptation plans are setting canopy and tree planting targets to make cities more resilient to climate change, the urban forestry policies, practices and extra resources are not in place to make this an effective adaptation strategy.

References

American Forests. *10 Best Cities for Urban Forests.* 2013. http://www.americanforests.org/our-programs/urbanforests/10-best-cities-for-urban-forests/ (accessed April 14, 2015).

American Planning Association. *Planning the urban forest: Ecology, economy, and community development.* Chicago, IL: American Planning Association, 2009.

City of Alexandria Office of Environmental Quality. "Energy and Climate Change Action Plan." Alexandria, VA, 2011.

City of Atlanta, Georgia. "Downtown Tree Management Plan." Atlanta, GA, 2012.

City of Baltimore. "Disaster Preparedness and Planning Project (DP3)." Baltimore, MD. 2013

City of Chicago. "Urban Tree Planting List." Chicago, IL, 2010.

City of Gresham. "Urban Forestry Management Plan." Gresham, OR, 2011.

City of Palo Alto. "Draft Urban Forest Master Plan." Palo Alto, CA. 2015.

City of San Diego. "Draft Urban Forest Management Plan." San Diego, CA. 2015.

City of San Francisco. "Climate Action Strategy 2013 update." San Francisco, CA, 2013.

City of San Francisco. "San Francisco Urban Forest Plan." San Francisco, CA, 2014.

City Seattle. "Urban Forest Stewardship Plan." Seattle, WA. 2013

City of Syracuse. "Syracuse Sustainability Plan." Syracuse, NY, 2012.

City of Toronto. "Sustaining & Expanding the Urban Forest: Toronto's Strategic Forest Management Plan." Toronto, Ontario, 2012.

City of Vancouver. "Climate Change Adaptation Strategy." Vancouver, BC. 2014

Moll, Gary. *Shading our cities: A resource guide for urban and community forests.* Island Press, 1989.

Nowak, David J., et al. "Sustaining America's urban trees and forests: a Forests on the Edge report." (2010).

Seattle Office of Sustainability and Environment. "2013 Climate Action Plan." Seattle, WA, 2013.

Stephens, Matthew. "Tree Procurement Contracts: New York City's Quest for Amazing Trees."

The City of New York. "PlaNYC A Stronger, More Resilient New York." New York, NY, 2013.

Wood, Pamela, and Joe Burris. *Suburban counties gain population, Baltimore loses.* March 24, 2014. http://www.baltimoresun.com/news/maryland/baltimore-city/bs-md-census-gains-20140327-story.html (accessed April 12, 2015).

Chapter 3: Spatial Species Selection Tool for Urban Forestry

In this chapter:

3.1 Introduction & Goals

The goal of our multi-criteria spatial decision analysis tool is to help Baltimore's urban foresters and their many partners determine which tree species are most suited to a specific area of the city. Specifically, our goals are to help create and maintain an urban forest that is resilient to climate change, requires minimal management, and keeps Baltimore citizens safe. This tool is in direct response to Strategy NS-2 from Baltimore's *Disaster Preparedness and Planning Project* (2013) which is to "increase and enhance the resilience and health of Baltimore's urban forest." Based on a variety of site-specific characteristics as well as climate projections (as available), various risk analyses, and species-specific morphological characteristics, this model determines a suitability score for each tree species in a corresponding Vegetation Database, which was downloaded from the USDA PLANTS project, and ranks trees based on their overall suitability scores. Suitability scores are based on a total of nine criteria, which compare how a species' preferred climate and growing conditions match with on-the-ground characteristics in Baltimore as well as how the urban form of the area constrains tree choices. The tool also considers the ability of a tree species to withstand flooding (both fresh and seawater) and to provide shade in areas vulnerable to heat related injury. For each of the nine criteria in this model, a tree species can receive a maximum score of one. The magnitude of the tree suitability score for a criterion is based on studies of urban tree survival in the literature. Then, the nine criterion scores are combined in a weighted linear combination where criterion weights were garnered from a survey of experts currently working on urban greening efforts in Baltimore. This includes officials from the Baltimore Office of Sustainability, Department of Planning, Department of Recreation and Parks, Department of Public Works and Blue Water Baltimore. Using these final suitability scores, the model outputs a ranked list of area-specific suitable tree species for planting with suitability scores ranging from 0 (not suitable) and 1 (perfectly suitable). It is our hope that this tool will help Baltimore to increase the health and the resilience of Baltimore's future urban forest both now and in the future.

3.2 Tool Audience

Our intention was to build this tool in such a way that it would be accessible for a variety of users, including urban forestry professionals, city planners, stormwater managers, and even Baltimore citizens looking to plant a tree in their backyard. Given its straightforward user interface, the tool has succeeded in being user-friendly and accessible. However, given that the tool's results require interpretation, we recommend that the tool be used only by urban forestry professionals at this stage of development. Because we were unable to integrate utilities information and we made the conscious choice not to remove most invasive species from the vegetation database, the tool's output is just the first in a series of steps needed to determine the most suitable species for planting at a given site, and the average homeowner might not have the knowledge needed to consider these additional factors. In future iterations of this tool, perhaps, we can build these additional decision-making steps into the interface or create a different version of the tool for urban foresters and members of the general public, but this was outside the scope of our current project.

3.3 The Spatial Database

The Spatial Database contains 12 attributes representing location-specific characteristics of Baltimore. In all cases, the most up-to-date resources available were used to quantify site-specific characteristics. These attributes were manipulated in order to match the largely ordinal-scaled variables in the Vegetation Database so they could be compared to determine tree suitability (see Appendix E for the visualization of all spatial layers). A 10 x 10 meter square grid covering the City of Baltimore was created to capture spatial variations and make the data easily accessible by the model. The 12 layers were then resampled to 10-meter resolution using the Resample Tool with nearest neighbor assignment resampling technique, and converted to polygon shapefiles using the Raster to Polygon tool when necessary, and converted into string attributes in ArcGIS to avoid the automatically assigned zero values for areas with no data. The Spatial Join tool in ArcGIS was then used to associate the 12 attribute values to each grid cell, creating the Spatial Database. The Spatial Database, which contains over 2.5 million grid cells identified by a unique number, was exported as a dBASE table. The unique identification number can then be mined using Python to find the grid cell and the associated site-specific characteristics that correspond to the user's area of interest. In other words, all the user needs to know is the identification number of their selected cell in order to determine site-specific tree suitability. Metadata documenting the definitions of attribute values in the Spatial Database was also created to be used as reference in the future.

Details and processing procedures for each of the variables included in the spatial database are described as follows (see *References - GIS data* for detailed information on sources of spatial data):

> **Elevation:** Contours with 2-foot intervals, downloaded from OpenBaltimore, were used to create a digital elevation model (DEM) with 10-meter resolution using the Topo to Raster tool in ArcGIS.
>
> **Flood Zones:** Flood risk zones, downloaded from OpenBaltimore, were reclassified based on FEMA definition into minimal flood risk, 500-year flood (0.2% annual chance of flood event), and 100-year flood (1% annual chance of flood event) (FEMA, 2014).

Hardiness Zones: These are the current hardiness zones. Since Baltimore is expecting a two-zone shift, the corresponding minimum temperature shift was included in our model to account for climate change.

Heat Vulnerability: Heat vulnerability was quantified based on the IPCC Working Group 2 definition of vulnerability: exposure, sensitivity, and adaptive capacity.

a) *Exposure* was quantified using mean summer surface temperature at 100-meter resolution from ASTER GED emissivity data, downloaded from the Land Processes Distributed Active Archive Center (LP DAAC), and percent impervious surface cover, downloaded from the USGS Multi-Resolution Land Characteristics Consortium (MRLC) National Land Cover Database (NLCD). They were combined in a weighted average in which surface temperature was weighted 20% and impervious cover was weighted 80%. However, the two datasets were highly correlated (correlation coefficient = 0.74) making the exposure variable relatively insensitive to weighting schemes. These data were then aggregated up to the level of census tracts using mean exposure index values for consistency.

b) *Sensitivity* was based on six demographic indicators, as described to be important in *Reid et al., 2009*. All six indicators were extracted from the American Community Survey 5 year estimates (2007-2011). They include (1) percent of the population that is non-white (weighted 30%), (2) percent of population below the poverty line (weighted 25%), (3) percent of population living alone (17%), (4) percent of population living alone over 65 (13%), (5) percent of population over 65 (11%), and (6) educational attainment, quantified as the percent of the population receiving a high school diploma or less. As expected, the two "over 65" categories were highly correlated (correlation coefficient = 0.73), but both were included in this estimate of sensitivity, though at smaller weights than would have been used normally due to the fact that it was essentially double counted.

c) *Adaptive Capacity* was quantified using two factors: distance to cooling centers (weighted 70%) and distance to hospitals (30%). These distances are Euclidean distances, or "as the bird flies" estimates. Before combining these values, each factor was aggregated up to the census tract level by taking a mean of all values within a census tract.

Overall vulnerability was calculated using a weighted linear combination of exposure (20%), sensitivity (45%), and adaptive capacity (35%). Then Jenk's Natural Breaks were used to reclassify heat vulnerability into low, medium, and high vulnerability for use in our model. For more information on this analysis, please visit http://arcg.is/1FkWTEF.

Mean Summer Surface Temperature: The emissivity data (ASTER GED) from the Land Processes Distributed Active Archive Center (LP DAAC) was first converted from an .hdf5 file to a geoTiff using various packages in R. This dataset was derived from ASTER imagery taken between 2000-2010 in July, August, and September. During this conversion, the surface temperature variable was extracted from the variety of other information housed in the dataset, and it was translated from Kelvin to degrees Fahrenheit. Next, it was resampled from 100-meter resolution into 10-meter resolution.

Percent Impervious Surface: Percent impervious surface data of 2006 was downloaded from the USGS MRLC NLCD. The data were resampled from 30-meter resolution to 10-meter resolution.

Sea Level Rise Zones: Sea level rise zones data from 2007, downloaded from Maryland Department of Natural Resources, identifies areas vulnerable to inundation and flooding from sea level rise of 0-2 feet, 2-5 feet, and 5-10 feet.

Shade: First return signals from 2008 LiDAR data, downloaded from NOAA Office for Coastal Management, was used to determine building heights in Baltimore. The LiDAR data were joined with the building footprints data to create a digital elevation model (DEM), which was used as the input in the Area Solar Radiation Analysis tool in ArcGIS. This solar radiation tool used samples of sun positions in half hour increments for every day of the year and output solar duration maps for each month of the year. The month of April was used as a proxy for average hours of sunlight throughout the year based on a calculation of average hours of sunlight per day for each month's average when compared to the annual average. April's average hours of sunlight per day most resembled the annual average. The results were reclassified into low (0 to 3 hours of sunlight/day), medium (3 to 6 hours of sunlight/day) and high (more than 6 hours of sunlight/day) values in order to be comparable to the ordinal-scale shade tolerance values in the Vegetation Database.

Soil Texture: Soil texture groups, such as loam, sandy clay, silt loam etc., are defined by the percentage of sand, silt and clay in the soil. Spatial data on the taxonomic classification of the dominant soils in Baltimore from 2013 was downloaded from USDA Web Soil Survey. Since the spatial data contained only the classification code of different soil types, the composition percentages for each soil type were obtained from the soil report associated with the spatial data. Using formulae provided in the USDA Soil Texture Calculator (see Appendix F Table 1), these percentages were computed in R to determine the corresponding soil texture groups. These soil texture groups were then reclassified into fine, medium, and coarse soil, i.e., the same characteristic soil texture groups defined by USDA PLANTS Database (Appendix F Table 2) that are used in the Vegetation Database. Soil classified as urban soil does not contain any composition percentages; therefore, areas dominated by urban soil do not have data on soil texture.

Soil pH Max & Min: The pH range associated with each soil type was obtained from the soil report associated with the soil spatial data from 2013. Soil classified as urban soil does not contain any information on soil characteristics and properties; therefore, areas dominated by urban soil do not have data on soil pH.

Storm Surges: The storm surge data from 2015, downloaded from Maryland iMap, identifies potential flood areas from hurricane categories 1 to 5.

Street Buffer: The street buffer layer from 2014, downloaded from OpenBaltimore, contains polygons illustrating road borders in the City. A 10-meter buffer was then added to the layer to capture the street versus non-street planting environment.

Water: The water layer from 2014, downloaded from OpenBaltimore, indicates areas of surface water.

ID Number: Each 10 x 10 meter grid cell, created using the Create Fishnet tool in ArcGIS, is associated with a unique identification number. This unique identification number is associated with all 12 attributes and is used to identify the attributes associating with the selected grid cell.

In addition to the above attributes, the Spatial Database contains nine additional attributes that are not currently integrated into the algorithm for determining suitability scores:

Building Footprint: The building footprint layer, downloaded from OpenBaltimore, contains polygons illustrating the edges of buildings in the City.

Land Ownership: The land ownership data, provided by Victor Miranda (GIS Coordinator of Department of Recreation and Parks), was reclassified into publicly and privately owned land.

Land Use/Cover: Land use/cover data from 2010 was obtained from Maryland's Department of Planning.

Precipitation: Data on average annual precipitation, downloaded from WorldClim, was resampled from 1-kilometer resolution into 10-meter resolution. The data were then converted from millimeter to inches to match the units in the Vegetation Database. These data were not included in our algorithm because the degree of impervious surface cover in our study area decreases water percolation rates, meaning that average annual precipitation is not a good indicator of plant-available water (Sæbø et al., 2003).

Slope: The slope layer was generated from the DEM with inclination of slope calculated in degrees.

The Spatial Database can be easily updated when more up-to-date spatial data become available. A Python script was developed to (1) ensure that the ID number for each grid cell remains the same from each update so that the interactive map in the tool website does not need to be changed; (2) reduce the pre-processing procedures needed before creating an updated Spatial Database; and (3) standardize the geoprocessing procedures, field names, and output table to avoid breaking the suitability scoring algorithm Python script for the Tool. Refer to Appendix G for the procedures for updating the Spatial Database.

3.4 The Vegetation Database

The vegetation database was created using the USDA Plants database, found at http://plants.usda.gov/java/. The database is the result of a combined effort by the USDA NRCS National Plant Data Team (NPDT), the USDA NRCS Information Technology Center (ITC), the USDA National Information Technology Center (NICT) and many other partners. Its goal is to provide "standardized information about the vascular plants, mosses, liverworts, hornworts, and lichens of the U.S. and its territories (http://plants.usda.gov/about_plants.html)" The database is downloadable and completely customizable. Because our client has expressed an interest in finding and recommending trees resilient to climate change, we included trees currently found in Maryland, Virginia, North Carolina, South Carolina, and Georgia to account for the fact that tree species ranges will expand toward the poles as the climate warms (Parmesan et al., 2003). We confined our database to those trees that have full characteristics information in order to make our project easily replicable in other cities.

The database includes a variety of species-specific information, including distribution, taxonomy, ecology, morphology/physiology, and growth requirement characteristics. As previously mentioned, we constrained our model based on what was available within the PLANTS database itself, though we found that the majority of information we needed was represented within this framework. For a complete list of variables included in our database, see Appendix E.

One problematic feature of the database is that rather than distinguishing between native species and invasive species, it discriminates between native and *introduced* species, defining introduced species as any that were not present at the time of Columbus. While certain introduced species have become naturalized in the United States and do not pose any serious risks to biodiversity, others, such as *Ailanthus altissima*, are extremely invasive, and the Urban Forestry Division of the Baltimore City Department of Parks and Recreation recommends against planting them (City of Baltimore Street Tree Species List, 2013). We researched and removed these invasive species individually from our database. In addition, trees vulnerable to storm damage or pests, such as Emerald Ash Borer, were also removed from the Vegetation Database (see Appendix I for a complete list of removed species)).

While other tree selection studies have focused only on trees currently found within the city (Yang, 2009) or trees known to function well in urban settings (Roloff et al., 2009), this tool considers every tree included in the PLANTS database, meaning that "non-traditional" trees are considered alongside traditional urban trees. While it is difficult to predict the survivability of non-traditional trees and more study must be done of these individual species (Urban Forests & Trees, 269), this tool is a first attempt at quantitatively and rigorously evaluating these species for their suitability for urban planting, which has been deemed important in resiliency planning (Urban Forests & Trees, 269).

3.5 The Modules

This tool is split into nine distinct "modules," each of which quantifies a different aspect of tree survivability or manageability in the city. By comparing site-specific characteristics and tree preferences, each module outputs a single score between 0 and 1, as described below. These nine suitability scores are then combined using a weighted linear combination derived from expert opinion to output an overall tree suitability score. Thus, each tree in our vegetation database receives nine individual scores and one overall suitability score (see Figure 1 for a model schematic). Trees are sorted by their overall suitability score so that the output page of our model lists trees in order of suitability for the chosen site. See Table 1 for an overview of variables used and the descriptions below for more information about each individual module. To view the raw code used in this weighting algorithm, see Appendix J.

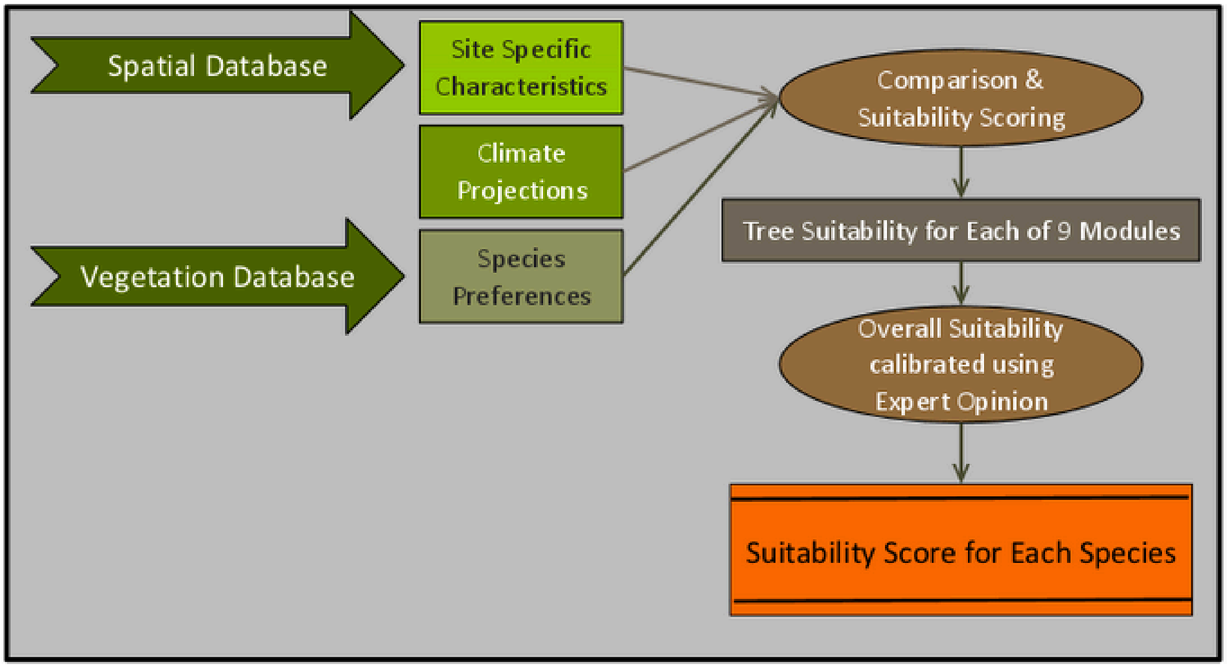


Figure 1. Model Schematic

Table 1. Overview of variables used in Tree Selection Module.

Module	Attributes from Spatial Database	Attributes from Vegetation Database	Climate Projection Attributes
Hardiness Zone Tolerance	Current Hardiness Zone	• Minimum Tolerable Temperature • Drought-Free Days Required	• Projected Hardiness Zone (2 zonal shift) • Projected Frost-Free Days
Heat Stress & Drought Tolerance	• Percent Impervious Cover • Average Summer Surface Temperature	• Drought Tolerance • Water Use	Implicitly considered because trees with low/no drought tolerance are given score of 0 for this module
Soil Indicators	• Minimum pH • Maximum pH • Soil Texture	• Minimum pH • Maximum pH • Soil Texture	n/a
Shade Tolerance	Hours of Daily Summer Sun	Shade Tolerance	n/a
Fresh Water Flood Tolerance	100- and 500-year Flood Zones	• Anaerobic Tolerance • Minimum Root Depth	Implicit
Sea Level Rise Inundation Tolerance	• Sea Level Rise Inundation Zones • Storm Surge Areas (category ≤ 3)	• Anaerobic Tolerance • Salinity Tolerance • Root Depth	Implicit
Proximity to Roads	Distance to Street	• Growth Form • Growth Shape • Maximum Height • Salinity Tolerance • Minimum Root Depth	n/a
Social Factors	Heat Vulnerability	• Maximum Height • Growth Form • Growth Shape • Toxicity	Implicit
Wind	Elevation	Minimum Root Depth	n/a

3.5.1 Module 1: Hardiness/Winter Survivability

Module Overview

This module tests whether a tree species falls within its respective hardiness zone, both now and according to future climate projections that indicate a two-zone shift, or an increase in minimum temperature by 10 degrees Celsius. Because the vegetation database does not actually contain hardiness zones, this model uses minimum tolerable temperature as a proxy, since hardiness zones are based on minimum winter temperatures. Two studies (Heinze and Shreiber, 1984, Roloff and Bärtels, 2006, as cited in Roloff et al., 2009) have shown that plants have an 80% probability of survival if growing in their allocated hardiness zone.

Additionally, this module compares current and projected number of frost-free days to a tree's minimum required number of annual frost-free days. The average current number of frost free days in Baltimore is 231 (Smith, 2004) and that number is expected to increase with climate change. While exact numbers for this increase are difficult to predict, the National Climate Assessment estimates an increase of approximately 16 days in the Baltimore region (Walsh et al., National Climate Assessment: Our Changing Climate, 2014).

Module Weighting

If trees can survive in both the current and projected hardiness zone and their required minimum number of frost free days is less than the current (and thus, projected) number of frost free days in Baltimore, they receive a perfect score for this module (one point). If trees can survive both hardiness zones but could only survive given an increase in frost free days, they get a lower score (0.5 points). If a tree's minimum frost-free requirement will not be met either now or in the future but they could still survive both hardiness zones, they receive a minimal score (0.2 points). If they could not survive in the current hardiness zone but could survive in the future, they get a minimal score (0.2 points). Otherwise, they get a score of 0.

3.5.2 Module 2: Heat Stress and Drought Tolerance

Module Overview

Cities are microcosms that create especially stressful conditions for trees, and heat stress and water stress self-perpetuate each other, yielding a positive feedback loop that can be devastating for trees. The urban heat island effect results in warmer temperatures in urban areas due to stored heat in various impervious surfaces, and can result in vast differences in temperature within a city and in nearby woodlands (Kim, 1992 and others). The same impervious surfaces that cause warmer conditions also lead to drier ones, because rainwater is unable to percolate through these surfaces. Instead, it runs off as storm water, meaning that very little water reaches the root system (Bartens et al., 2008). Trees require more water given the higher temperatures (due to the urban heat island), meaning that heat stress and water stress exist within a positive feedback loop (Sæbø et al., 2003). Roloff et al. (2006) use drought tolerance as one of two factors in a climate-species matrix model for predicting tree usability after the occurrence of climate change, illustrating this factor's importance in determining tree survivability. Because of their close relationship and the similarity of the site-specific characteristics that create both heat and water stress, these were grouped together in this module.

Water availability (average annual precipitation) was not considered in this module because there is growing consensus in the literature that average annual precipitation is not a good indicator of plant-available water in the urban environment due to the high amount of impervious surface cover that decreases water percolation rates. As explained in one study, "amounts of water available to trees at various locations are… often not correctly represented by annual or seasonal precipitation and the evapotranspiration ratio" (Sæbø et al., 2003).

Module Weighting

This module compares the site's percentage of impervious surface cover and average summer surface temperature with each tree species' drought tolerance and moisture use. While air temperature is most likely a better indicator of the urban heat island effect, this data was unavailable to us at an adequate resolution. However, surface temperature has been shown to be positively correlated with air temperature (Guan, 2011). Because the tree drought tolerance and moisture use levels are ordinal (high, medium, low), impervious surface and surface temperature were split into three ranges using ArcGIS's natural breaks (Jenks). Site-specific risk was assumed to be worst when both impervious cover and summer surface temperature were high and risk decreased gradually from there. Higher site-specific risk yielded stricter constraints on tree species fitness. For higher site specific risk, trees needed to have higher degrees of drought tolerance and lower degrees of moisture use in order to receive a perfect score for this module. Given that heat and water stress are expected in increase with climate change, trees with low or no drought tolerance were given a score of 0 for this module.

3.5.3 Module 3: Soil Indicators

Module Overview

To test soil suitability, a tree's desired soil pH and soil texture were compared to that of the site. While the survey of stakeholders in Baltimore indicated that soil suitability should account for 17% of overall tree suitability, there is evidence in the literature that soil type is more of a management concern than a constraint to tree suitability. As Sæbø et al. (2003) suggest,

> *Soil conditions [should] be considered more of a planning and a management problem, rather than factors to be considered in tree improvement programs. However, during a selection program, the range of soil conditions that the phenotypes in question can tolerate (pH, soil types, nutrient demand, water conditions) should be tested and described, in order to make it easier for the planners to choose the best trees and establish the best possible growing conditions (103).*

Module Weighting

Because pH was given in ranges for both the tree and the site, higher suitability scores were given for trees whose desired pH range fell completely within the range of the site, and smaller scores were given for those tree pH ranges which overlapped with site ranges but were not completely contained within. Next, soil texture at the site (coarse, medium, or fine) was evaluated based on tree preferences. If the site was designated as having "urban soils," soil suitability was assumed to be 0, given that these soils are often the least conducive to supporting vegetation. Overall, pH suitability was considered a better soil indicator than soil texture, accounting for 75% of the total tree score within this module while soil texture accounted for 25% of the score.

3.5.4 Module 4: Shade Tolerance

Module Overview

This module compares a tree's shade tolerance with the amount of daily summer sun at a given site. This module assumes no competition, meaning that shade-tolerant species are assumed perfectly suitable in higher sun conditions. This is because many scientists speculate that trees gained shade tolerance in order to occupy an unoccupied ecological niche, but that in fact, if they were not out-competed by trees with higher fitness/growth rates, they would vigorously grow in higher-sun conditions (Kocher, 2007).

Module Weighting

This module simply compares tree shade tolerance (tolerant, intermediate, or intolerant) to site-specific shade (high, medium, or low). If the given site is shady, only shade-tolerant trees will get a score of 1. If the site has medium shade, tolerant and intermediately shade tolerant trees get a score of 1. If the site has low shade (otherwise stated, it is sunny), all levels of shade tolerance in trees will get a score of 1. If any of the above conditions are not met, the tree gets a score of 0 for this module.

3.5.5 Module 5: Fresh Water Flood Tolerance

Module Overview

This module compares site-specific freshwater flood risk (characterized by the 100- or 500-year flood zones) and tree anaerobic tolerance and minimum root depth. It favors trees with high anaerobic tolerance because they would be better able to survive inundation and trees with deeper roots due to their enhanced ability to withstand high-velocity water flow. If trees are able to survive these inundations, there is evidence in the literature suggesting that they can help with storm water management (Fazio, 2010; Bartens, 2008) and, indeed, Baltimore's DP3 recommends the use of trees to reduce stormwater runoff (Strategy NS-3).

Module Weighting

Site-specific risk is dependent on the likelihood of a flood, and tree characteristic stipulations are stricter at higher-risk sites. Therefore, if the site is within the 100-year flood zone, trees must have high anaerobic tolerance and a minimum root depth greater than 20 inches in order to get a perfect score of 1. However, in a 500-year flood zone, trees with high or medium anaerobic tolerance will receive a perfect score. Overall, anaerobic tolerance accounts for 90% of the module score, while root depth accounts for 10%. If the site is not within a flood zone, all trees receive a maximum score of 1 and this is noted on the results page of our user interface.

3.5.6 Module 6: Sea Level Rise/Coastal Storm Tolerance

Module Overview

Resilience to sea inundation is based on two site specific characteristics: sea inundation zones and hurricane storm surge areas. According to the Maryland State Archives, Baltimore has never experienced a hurricane greater than category 2, and anything over category 3 would kill trees regardless of species (according to NOAA's Saffir-Simpson Hurricane Wind Scale). Therefore, only storm surge areas from storms with category 3 or less are included in this module. Similar to the Freshwater Flooding Module, site risk is quantified by assessing the probability of flooding event, meaning that if the site falls within lower category storm surge areas and lower sea level rise zones, trees must have higher resilience. In this module, tree resilience is based on anaerobic tolerance (ability to withstand inundation), salinity tolerance (ability to withstand inundation by salt water), and root depth (ability to withstand high-velocity water flow).

Module Weighting

Site-specific risk is dependent on the likelihood of flooding and tree characteristic stipulations are stricter at higher-risk sites. Therefore, if the site is within a 1-2 feet sea level rise zone and a category 1 storm surge zone, trees must have high anaerobic tolerance, high salinity tolerance, and relatively deep roots in order to receive a perfect score. However, if they are in a 5-10 feet sea level rise zone, they can have medium tolerance to either anaerobic conditions or salinity and still receive a perfect score. Anaerobic/salinity tolerance accounts for 90% of the score in this module, while root depth accounts for 10%. If site is not in any sea level rise or storm surge zones, the maximum score is assigned to all trees in our database and this is noted on the results page of our tool interface.

3.5.7 Module 7: Proximity to Roads

Module Overview

This module assesses tree shape, growth form, root depth, and salinity tolerance for sites within 10m of a road. The goal is to reduce maintenance needs in the form of pruning obstructive branches from roadways, thereby increasing tree health and decreasing maintenance costs for the city. Unaccounted for in this module is the presence of utilities such as power lines or underground infrastructure because that data is not publicly available for proprietary reasons.

Module Weighting

If it is a street tree, tall trees with a single stem or single crown are favored, based on the assumption that the right of way/median in which the tree will be planted will not allow for cloning or thicket-forming trees. Additionally, this module favors trees that are erect, conical, vase, or columnar in shape to minimize management needs in the form of pruning troublesome branches. This module also considers a tree's salinity tolerance given the use of road salt in Baltimore. Growth form is weighted 50%, growth shape is weighted 30%, tree height and salinity tolerance are weighted 10% each, and root depth is rated at negative 20%, meaning that if trees have shallow roots, 0.2 points are subtracted from their score.

3.5.8 Module 8: Social Considerations

<u>Module Overview</u>
This module considers measured heat vulnerability, based on a model of exposure, demographic indicators of sensitivity, and adaptive capacity (see "Heat Vulnerability" in section 3.3 above). If the user-selected location has a high or medium heat vulnerability value, then taller trees with round or oval crowns are favored because they will be better able to provide shade. Additionally, in this module, trees with high toxicity receive a negative suitability value, because trees with toxic fruits would not be recommended for an urban environment for safety reasons.

<u>Module Weighting</u>
In this module, if the site has high or medium heat vulnerability, trees with a single stem or single crown are favored based on their increased shading capacity. This is weighted 30% within the module. Trees with rounded, oval, or irregular shapes are favored because these are also more likely to provision shade. This was weighted 40% within the module. Tall trees (greater than 40m at mature height) were favored, accounting for 30% of the overall module score. If the site has low to no heat vulnerability, then overall suitability is assumed to be 1. Finally, if the tree has moderate to severe toxicity, it receives a negative score of 0.2 points, meaning that high toxicity reduces suitability within this module.

3.5.9 Module 9: Wind Risk Considerations

<u>Module Overview</u>
This module quantifies wind risk based on elevation - higher areas of the city (most notably, the northwestern area) are considered more at-risk for severe wind. This module does not consider existing infrastructure/canopy's ability to minimize wind impacts, as completing a wind-risk assessment was outside the scope of this project. Trees are ranked based on their minimum root depth, and trees with deeper roots are favored.

<u>Module Weighting</u>
If the site is in the top two elevation quantiles (as determined by Jenk's natural breaks and six classes), then it is assumed to have high wind risk. Therefore, trees with minimum root depths greater than 26 inches are given a perfect wind resistance score whereas trees with a minimum root depth less than 26 inches are given a score of 0. The use of 26 inches as the cutoff point was also based on Jenk's natural breaks, a statistical classification method based on the distribution of minimum root depth values in our tree database.

3.6 Determining Overall Suitability

In order to determine overall suitability, scores from the nine modules described above were combined into a weighted linear average. To determine weights for each module, the team completed a survey with six officials from the City of Baltimore Office of Sustainability, Department of Planning, Department of Recreation and Parks, Department of Public Works, and Blue Water Baltimore, employing Saaty's Analytical Hierarchy Process. The survey respondents were first briefed on the functioning of each module, and then asked to complete a matrix of pair-wise comparison of the relative importance of each of the nine modules (Appendix K). Team members remained in the room for this exercise in order to answer questions. Weights and consistency indices were calculated for each response using an online worksheet (Takahagi, 2005). The two responses that were inconsistent (consistency ratio less than 0.1) were excluded from our analysis under the assumption that the respondents did not fully understand the exercise. Across the four remaining survey responses, the soil indicators and hardiness/winter survivability modules generally received high weightings while social considerations and shade tolerance generally received low weightings. However, relative weights for the heat stress and drought tolerance and shade tolerance modules varied across the four survey responses (see Appendix L for individual survey results). Weights from the four survey responses were then averaged to generate the scores outlined in Table 2. The averaged weighting scores sums to 0.98 due to the rounding-off of original and averaged weights, which makes the maximum possible final suitability score for a given tree species 0.98.

Table 2. Module weights for determining final suitability.

Module	Weight
Hardiness/Winter Survivability	0.15
Heat Stress & Drought Tolerance	0.14
Soil Indicators	0.17
Shade Tolerance	0.07
Fresh Water Flood Tolerance	0.08
Sea Level Rise Tolerance	0.07
Proximity to Roads	0.11
Social Considerations	0.06
Wind Risk Considerations	0.13

3.7 The User Interface

The suitability scoring algorithm described in the preceding sections was built using the Python Programming language. Therefore, when it came time to build an online user-interface for our model, the Django framework for building websites that also uses Python was the clear choice, making our code easily translatable to this online interface. Alex Redkin, a web developer, was hired to build the basic website skeleton, which was then manipulated and customized by team members to increase aesthetic appeal and model transparency. The website has four pages, described below.

3.7.1 The Home Page

This page (Figure 2a) presents the name/goals of the tool as well as the interactive map and directions for its use. The interactive map was created in ArcGIS Online. A grid layer with the unique identification number for each 10 x 10 meter grid cell was uploaded and published as tiles in ArcGIS Online. The tile layer was added to a web map and set to be semi-transparent in order to show the underlying topographic map. Users have the option to use an aerial photo instead of the default topographic map as the base map. Users can zoom/pan to their location of interest in the interactive map or alternatively, put a specific address into the white box in the upper right corner of the map. Once they have found their site, they simply click where they would like to plant a tree and a box will pop up with a site ID. Then, they enter the site ID into the box below the map and click *Find Trees*. This will bring them to the results page, described below. The home page also has a link to the "about this tool" page at the bottom of the page.

3.7.2 About This Tool

This page (Figure 2b) gives some background information about how the tool works and describes each module in relatively simplistic terms. It also gives credit to the USDA PLANTS database for providing our vegetation database. This page is linked from both the homepage and the results page. However, on the results page, this page will open in a new tab so that model output values can be viewed at the same time. Thus, users can compare module definitions to module scores to gain a better insight into the model's output.

3.7.3 Results

This page (Figure 2c) presents the results of the model as well as some notes about the particular model-run that was just completed under the "Notes about Results" header. Tree species are listed in a table in the order of most to least suitable. This table includes common and scientific name, overall suitability, individual module scores, native status, and various qualitative information of individual species. The qualitative information section acts as a general repository for institutional knowledge about factors and concerns we were unable to build explicitly into our model, including management concerns and pest/disease issues. While these sections are relatively sparsely populated at this time, it is our intention that Baltimore experts will add to it, over time creating a rich database of both quantitative and qualitative details for individual tree species.

3.7.4 Admin

This page (Figure 2d) is password-protected and provides authorized users with access to the underlying databases (both spatial and vegetation), making them easily updateable. While updating the spatial database in this manner would be difficult as broad-scale changes in spatial data would yield the need to update hundreds of thousands of cells, this page is where qualitative tree characteristics can be updated using an intuitive, easily understood form. By giving login information to the various stakeholders in Baltimore, this tool can act as a central repository for institutional knowledge that is currently held individually by each organization.

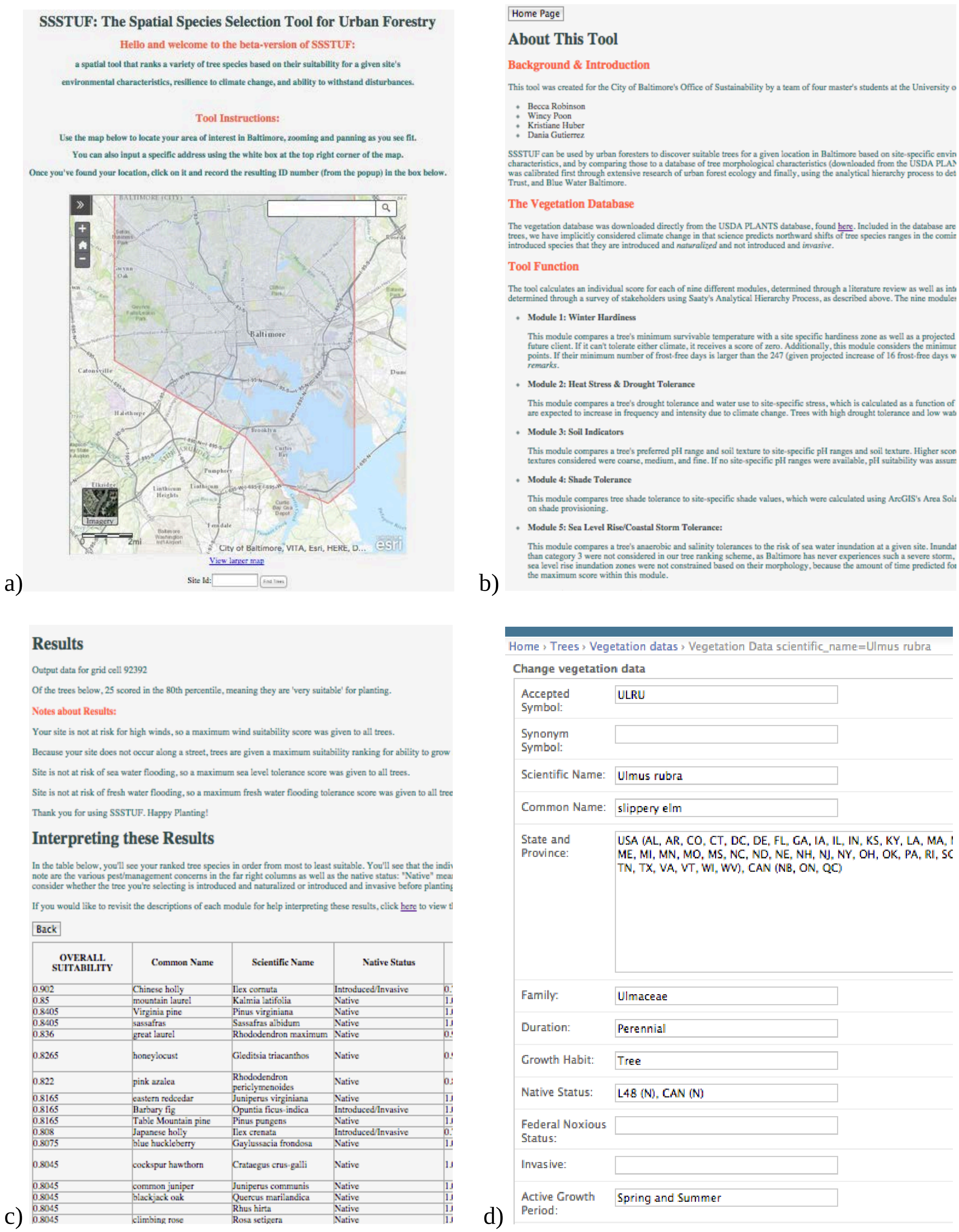


Figure 2. The online user interface of the model: a) Home page for selecting site of interest; b) About This Tool page for modules information; c) Results page for ranked list of species suitability scores; d) Administration page for updating the Vegetation and Spatial Databases.

3.8 Model Strengths

One of the greatest strengths of this model is that it takes the guesswork out of tree species selection. By incorporating the power of GIS, it allows the user to account for site-specific characteristics of their target planting area without needing to leave their desk or take any on-the-ground measurements, an ability that will hopefully help the survivability of newly planted trees. As far as we can tell from extensive research, this model is the first spatially explicit tree selection model.

Additionally, this model accounts for various social and management concerns, which could potentially decrease management costs for the city by taking a "right tree, right place" approach. Another strength of this model is that it accounts for climate change, which few urban foresters consistently consider in species selection, and is rarely addressed in current species selection tools. By considering all trees found in Maryland and several states further south, this model has the ability to choose "non-traditional" urban trees, which will increase biodiversity in cities and potentially, resilience to climate change, pest, and disease. Climate change is cited in the literature as an important consideration for the foreseeable future (Sæbø et al., 2005 in *Urban Forests and Trees*; Sukopp & Wurzel, 2003, Bisgrove & Hadley, 2002, Broadmeadow et al., 2005). Additionally, there is evidence to support the inclusion of non-traditional trees in urban areas to help species migrate northward, therefore helping species ranges to adapt to our changing climate (Woodall et al., 2010). This tool is one of the first tree selection tools to consider climate change, and is by far the most extensive in its considerations.

Finally, aside from the actual tree-selection algorithm, which we believe is the first of its kind, this tool serves as a central repository for the vast amount of institutional knowledge that is currently sequestered within individual organizations in Baltimore. Because there are so many stakeholders interested Baltimore's tree canopy, it is important that these organizations have an opportunity to share their knowledge with other organizations in order to create the best possible urban forest. Because this tool is publicly hosted and easily updateable, it allows Baltimore to avoid the "recurring nightmares" of environmental policy, outlined by Yaffee (1997) in which the fragmentation of knowledge or ideas yields inferior solutions, competition between organizations outweighs cooperation, short term interests win over long term concerns, and the fragmentation of authority yields "functional silos."

3.9 Model Weaknesses

While this model is novel in its aims and relatively comprehensive in its considerations, a few key elements are currently missing. The largest of these is that it does not consider pest or disease vectors. Our model was constrained by what information was available in the USDA Plants Database, so tree-specific pest data was unavailable to us. Additionally, it is difficult to predict with any certainty how pests/diseases will survive/spread given climate change, further preventing us from explicitly including this consideration in our model. However, qualitative pest and disease considerations can be added and updated in the online database, which addresses this issue.

Additionally, this model fails to consider tree cost or a species' commercial availability, which is often a limiting factor in urban planting campaigns. However, in our discussions with Baltimore stakeholders, the possibility/plausibility of using the tool to inform which trees Baltimore nurseries provide was discussed. This model also fails to consider various infrastructural hindrances, including the presence of utilities (power lines aboveground, pipelines belowground) and the amount of room a tree has to grow in a given location based on the built environment. We were unable to integrate utilities into our spatial tool due a lack of publicly available data, however, we anticipate that the qualitative reporting section of our online tool will address this issue, as foresters can recommend specific trees for planting under utility lines, for example. We were unable to account for site-specific room to grow as that information is subject to change and difficult to quantify spatially.

Lastly, the wind risk module is quite imprecise in its quantification of wind risk. Wind modeling is a difficult exercise that fell outside the scope of this project. Therefore, our model does not account for the effect of the built environment or the presence of existing trees in increasing/decreasing wind risk. We recommend that in the future, Baltimore complete a comprehensive wind risk analysis and integrate that new data into this model.

3.10 How to Interpret Model Results

We do not intend for this tool to be the definitive source for species selection in the future. While its considerations are broad and numerous, the tool cannot substitute for expert knowledge. We recommend that this tool's output be only a first step in the tree-selection process and that the results be thoughtfully considered in terms of tree native status, the qualitative data input by Baltimore stakeholders, and the site-specific variables we were unable to consider - specifically the presence of utilities. In its current state, this tool is probably best used by knowledgeable scientists who are able to thoughtfully interpret the model output. However, it is our goal that through model modifications and calibration, this tool will eventually be clear enough for use by the general public.

References

Literatures

Baja, Kristin, and Megan Griffith. *Disaster Preparedness and Planning Project.* Rep. Baltimore Office of Sustainability. October 2013. (accessed November 2014).

Baltimore City Recreation and Parks, Urban Forestry Division. "Baltimore City Street Tree Species List." July 8, 2013.

Bisgrove, Richard, and Paul Hadley. *Gardening in the Global Greenhouse: The Impacts of Climate Change on Gardens in the UK.* Technical Report, Oxford: UK Climate Impacts Programme, 2002, 139.

Broadmeadow, M.S.J., D. Ray, and C.J.A. Samuel. "Climate change and the future for broadleaved tree species in Britain." *Forestry* 78, no. 2 (2005): 145-161.

City of Baltimore. "Baltimore City Street Tree Species List". July 8, 2013. http://treebaltimore.org/wp-content/uploads/2014/03/StreetTreeSpeicesList_BaltimoreCity_Final_7-08-2013.pdf (accessed April 16, 2015)

City of Petaluma, CA. "List of Approved Street Trees." 2013. http://cityofpetaluma.net/cdd/pdf/approved-treelist.pdf (accessed April 21, 2015).

Fazio, Dr. James R. "How Trees Can Retain Stormwater Runoff." 2010. Tree City USA Bulletin 55. Arbor Day Foundation. Web. http://www.fs.fed.us/psw/programs/uesd/uep/products/11/800TreeCityUSABulletin_55.pdf (accessed April 21, 2015).

Federal Emergency Management Agency (FEMA). *Flood Zones.* FEMA. July 24, 2014. https://www.fema.gov/floodplain-management/flood-zones (accessed June 29, 2014).

Guan, Katharine K. "Surface and ambient air temperatures associated with different ground material: a case study at the University of California, Berkeley."*Environmental Sciences, University of California, Berkeley, ES196* (2011): 1-14.

Heinze, W., and D. Schreiber. "Eine neue Kartierung der Winterhärtezonen für Gehölze in Mitteleuropa." (Deutschen Dendrologischen Gesellschaft) 75 (1984): 11-56.

Kim, Hongsuk H. "Urban heat island." *International Journal of Remote Sensing* 13, no. 12 (1992): 2319-2336.

Kocher, Susan. *Forest Stewardship Series 5: Tree Growth and Competition*. Oakland: Regents of the U of California, 2007. Print.

New York City Department of Parks and Recreation. "Approved Species List." n.d. http://www.nycgovparks.org/trees/street-tree-planting/species-list (accessed December 11, 2014).

Nilsson, Kjell, Thomas B. Randrup, Jasper Schipperijn, and Cecil Konijnendijk. *Urban forests and trees.* Berlin: Springer-Verlag Berlin Heidelberg, 2005.

Parmesan, Camille, and Gary Yohe. "A globally coherent fingerprint of climate change impacts across natural systems." *Nature* 421, no. 6918 (2003): 37-42.

Program, U. (2014). 2014 National Climate Assessment Full Report. http://www.energyandclimatechange.org/view/article/537bc46d0cf226e0bdbfef38 (assessed April 21, 2015).

Roloff, and A. Roloff. "Bäume in der Stadt – was können sie fernab des Naturstandortes ertragen?" *Forst und Holz* 61 (2006): 350-355.

Roloff, Andreas, Sandra Kom, and Sten Gillner. "The Climate-Species-Matrix to select tree species for urban habitats considering climate change." *Urban Forestry & Urban Greening* 8, no. 4 (2009): 295-308.

Sæbø, Arne, Thorarinn Benedikz, and Thomas B. Randrup. "Selection of trees for urban forestry in the Nordic countries." *Urban Forestry & Urban Greening* 2, no. 2 (2003): 101-114.

Smith, Michael J., John B. Southard, Ruta Demery, and Daniel J. Bisaccio. *Earth's Dynamic Geosphere.* Armonk, NY: It's About Time, 2004.

Sukopp, Herbert, and Angelica Wurzel. "The Effects of Climate Change on the Vegetation of Central European Cities." *Urban Habitats* 1, no. 1 (February 2003): 66-86.

Takahagi, Eiichiro. *USAGE: Calculation (Software): Weights of AHP (Analytic Hierarchy Process).* 2005. http://www.isc.senshu-u.ac.jp/~thc0456/EAHP/AHPweb.html (accessed March 26, 2015).

University of California Statewide Integrated Pest Management Program. "Anthracnose." December 2009. http://www.ipm.ucdavis.edu/PDF/PESTNOTES/pnanthracnose.pdf (accessed December 11, 2014).

University of Georgia Center for Invasive Species and Ecosystem Health. *Status of Invasive Plants in Maryland.* 2014. http://www.eddmaps.org/tools/statereport.cfm?id=us_md (accessed December 11, 2014).

U.S. Department of Agriculture, Natural Resources Conservation Service. 2014. The PLANTS Database (http://plants.usda.gov, December2, 2014). National Plant Data Team, Greensboro, NC 27401-4901 USA.

Via, Sara, Richard Gomulkiewicz, Gerdien De Jong, Samuel M. Scheiner, Carl D. Schlichting, and Peter H. Van Tienderen. "Adaptive phenotypic plasticity: consensus and controversy." *Trends in Ecology & Evolution* 10, no. 5 (1995): 212-217.

Woodall, C.W., D.J. Nowak, G.C. Liknes, and J.A. Westfall. "Assessing the potential for urban trees to facilitate forest tree migration in the eastern United States." *Forest Ecology and Management* 259, no. 8 (2010): 1447-1454.

Yaffee, Steven L. "Why Environmental Policy Nightmares Recur." *Conservation Biology* 11, no. 2 (1997): 328-337.

Yang, Jun. "Assessing the impact of climate change on urban tree species selection: a case study in Philadelphia." *Journal of Forestry* 107, no. 7 (2009): 364-372.

References

GIS Data

City of Baltimore. *Open Baltimore – Building Footprint – Shape.* March 27, 2014. https://data.baltimorecity.gov/Geographic/Building-Footprint-Shape/deus-s85f (accessed September 17, 2014).

City of Baltimore. *Open Baltimore – Contour Interval 2ft – KMZ.* April 3, 2014. https://data.baltimorecity.gov/Geographic/Contour-Interval-2ft-KMZ/2uaw-yu39 (accessed September 17, 2014).

City of Baltimore. *Open Baltimore – Edgepave Street Poly*. April 3, 2014. https://data.baltimorecity.gov/Geographic/Edgepave-Street-Poly/gim5-45gr (accessed September 17, 2014).

City of Baltimore. *Open Baltimore – Floodplain*. July 21, 2014. https://data.baltimorecity.gov/Geographic/Floodplain/5q84-2ek5 (accessed September 17, 2014).

City of Baltimore. *Open Baltimore – Water*. April 3, 2014. https://data.baltimorecity.gov/Geographic/Water-Shape/fgsy-8jrm (accessed May 28, 2014).

Hijmans, J., Susan Cameron, and Juan Parra. *WorldClim – Global Climate Data*. 2005. http://www.worldclim.org/current (accessed October 22, 2014).

Maryland Department of Natural Resources. *Geospatial Data – Sea Level Rise Inundation Vulnerability.* October 1, 2007. http://dnrweb.dnr.state.md.us/gis/data/data.asp (accessed September 29, 2014).

Maryland Department of Planning. *Land Use Land Cover (2010) – Baltimore City*. 2010. http://planning.maryland.gov/OurProducts/downloadFiles.shtml (accessed November 17, 2014)

Maryland Geographic Information Office. *Maryland's Mapping & GIS Data Portal – Maryland Storm Surge.* 2015. https://www.arcgis.com/home/item.html?id=582ead72a28346f18a1f04b6fa039120 (accessed January 25, 2015).

Miranda, Victor. *Land Ownership*. 2015.

Morris, Bill. *GitHub – ophz-b (Hardiness zones).* August 9, 2013. https://github.com/wboykinm/ophz (accessed September 22, 2014).

National Oceanic and Atmospheric Administration (NOAA) Office for Coastal Management. *2008 City of Baltimore Lidar*. July 2012. http://coast.noaa.gov/dataviewer/webfiles/metadata/md2008_baltimorecity_template.html (accessed November 3, 2014)

U.S. Department of Agriculture, Natural Resources Conservation Service. *Web Soil Survey – Soil Survey Geographic database for City of Baltimore, Maryland.* December 13, 2013. http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx (accessed June 15, 2014).

U.S. Geological Survey, Land Processes Distributed Active Archive Center. *ASTER Global Emissivity Database North America Summer 1-kilometer V003*. 2014. https://lpdaac.usgs.gov/products/community_products_table/agns1km (accessed September 15, 2014).

U.S. Geological Survey, Multi-Resolution Land Characteristics Consortium. *NLCD 2006 (CONUS) Impervious Surface (2011 Edition).* 2011. http://www.mrlc.gov/viewerjs/ (accessed November 10, 2014).

Chapter 4: Tool Beta-Testing

In this chapter:

4.1 Purpose

The tree selection tool was developed to provide the City of Baltimore a platform through which tree planting decisions can be streamlined while supporting the city's Disaster Preparedness and Planning (DP3) urban forestry goals. In order to ensure the tool is user-friendly, and to increase its likelihood of ownership and use across Baltimore's urban forest stakeholders, beta-testing was identified as a critical phase of the tool's development and success. Beta-testing sessions were conducted with 17 Baltimore professionals who commented on the tool's interface, utility, and potential for improving the city's management of its urban forest. The tool was tested late in its development, and this was the first time the project client contact and stakeholders present had interacted with the program.

4.2 Methodology

4.2.1 Participants

A total of 17 Baltimore professionals participated in one beta-testing session. Each professional completed a worksheet and questionnaire. Convenience sampling was used to determine beta-testing participants: the project client determined which professionals to invite to the sessions based on the tool's intended audience. The Baltimore professionals that participated were self-selected based on their interest and availability. Because this was the initial testing of the tool with the client city, residents or business owners were not included at this stage. Additionally, the organizations or agencies represented may not reflect every stakeholder group that may use this tool in the future. The following reflects the organizations or agencies represented at the beta-testing sessions:

- City of Baltimore Office of Sustainability
- City of Baltimore Department of Planning
- City of Baltimore Department of Recreation and Parks
- City of Baltimore Department of Public Works
- TreeBaltimore
- Blue Water Baltimore
- Baltimore Tree Trust
- US Forest Service

4.2.2 Beta-testing design

Based on client and stakeholder availability, two consecutive days were selected to host two-hour beta-testing testing sessions - one on each of the two days. Each session was structured to give participants an opportunity to learn about the methods used to develop the tool, before they were given the opportunity to test it. Participants were asked to complete a worksheet and questionnaire that prompted them to provide quantitative and qualitative feedback regarding their impressions of the tool. The questionnaire contained Likert-response-scale (1-5), binomial (yes or no), and open-ended questions. Likert-scale variables measured satisfaction and agreement to multiple statements. Both sessions were intended to be structured similarly; however, due to technical difficulties prior to the second day of testing, the design was altered for the second session.

4.2.3 Session 1

Eleven professionals attended the first session. These professionals consisted primarily of staff from the Baltimore Office of Sustainability and Department of Planning, and a representative from Blue Water Baltimore. Team members gave a presentation introducing participants to the project, and the methodology behind the tool's development. The capabilities of the tool were then demonstrated. Participants were given the opportunity to ask clarifying questions prior to testing the tool. Each participant had access to a laptop on which to test the tool on their own. A worksheet was provided to participants with directions that guided them through using the tool, listed open-ended questions, and prompted participants to provide feedback as they used the tool. Once the worksheet was completed, participants were asked to complete a questionnaire with questions regarding the user experience and opportunities to provide suggestions for tool improvement. The structure of this first session lent itself to primarily receiving feedback regarding the utility and interface of the tool. Refer to Appendix M for the worksheet and questionnaire used during this session.

4.2.4 Session 2

Six professionals attended the second session. These professionals were primarily urban forestry professionals, with representatives from Baltimore Tree Trust, TreeBaltimore, the US Forest Service, and staff from the Baltimore Department of Recreation and Parks, and Department of Public Works. Team members gave the same introductory presentation from the previous day. Due to technical difficulties with online hosting, participants were not able to test the tool from their laptops. As a result, a more detailed demonstration of the tool was presented, in order to provide an extended experience with the tool, since participants were unable to actually use the tool themselves. A modified worksheet was given that prompted participants to provide detailed feedback of their initial impressions of the tool as it was presented. Once the demonstration of the tool and worksheet were completed, participants were asked to complete a modified questionnaire that measured overall impressions and provided an opportunity to give suggestions. Due to the modified structure of the second session, as well as the forestry-related expertise provided by participants, feedback not only pertained to the tool's utility and interface, but included questions and discussions regarding the tool's weighting and ranking process, which provided valuable insight for our recommendations for the future iterations of the tool. Refer to Appendix N for the modified worksheet and questionnaire used during this session.

4.2.5 Analysis

In order to combine data gathered from both beta-testing sessions, we tested for significant differences across tool testing experiences between Session 1 and Session 2. Due to a small sample size and lack of normality of the data, a Wilcoxon-Mann-Whitney test was conducted using R to test if the means of the Likert-scale variables (Q1, Q2, Q3, and Q7) varied between sessions. The p-values for each comparison were greater than 0.05, indicating that there was no significant difference between the experiences across beta-testing sessions. As such, further analysis used a merged dataset from both sessions. For quantitative variables, descriptive statistics (frequencies and means) were calculated. Open-ended questions were divided into suggestions or comments that related to changes that could be made to the tool by the project team, and comments related to changes that the City of Baltimore should consider in the future.

4.3 Results

4.3.1 Descriptive Statistics

On average, participants gave a rating of at least 4, on a scale of 1-5, of their overall impressions of the tool, the user interface, and their impressions of the interactive map (Table 3). Participants were divided on the labels provided on the tool's output table, and 92% of respondents selected "Yes" when asked if the final output was easy to interpret (Table 4).

Table 3. Beta-testing likert scale variable averages.

Question	Scale	Responses	Mean
How would you rate your overall experience with this tool?	"Very Dissatisfied" (1) to "Very Satisfied" (5)	15	4.1
To what extent was the user interface intuitive and easy to understand?	"Not at all" (1) to "To a great extent" (5)	16	4.1
Please select a response based on the following statement: The interactive map was easy to use and an appropriate visual for this tool.	"Strongly Disagree" (1) to "Strongly Agree" (5)	16	4.4
To what extent is the final output provided by the tool feasible for implementation?	"Not at all" (1) to "To a great extent" (5)	16	3.8

Table 4. Beta-testing binomial variable frequencies.

Question	Responses	Yes	No
Were any of the table headers/labels of the output difficult to understand?	16	50%	50%
Was the final output easy to read and interpret?	13	92%	8%

4.3.2 Feedback

The homepage generally received positive feedback in terms of its ease of use, but eight respondents emphasized the need to redesign the initial page. Additional comments were provided regarding the placement of links and text box. Four respondents recommended that the users should be able to click a site on the interactive map and be taken directly to tree output page. In regards to the output table, comments included reordering the columns to improve its interpretation; changing the way in which suitability is represented; and concerns regarding the output's accessibility to non-urban foresters. Comments and suggestions as they relate to actual recommendations for improving the tool are discussed further in Chapter 5: Recommendations. For the raw data from open-ended questions refer to Appendix O.

Chapter 5: Recommendations

In this chapter:

5.1 Discussion of Beta-testing Results

Overall, quantitative and qualitative results demonstrated that the tree selection tool was very well-received across all participants. Informally, the participants expressed their excitement about this new tool that will help them collectively meet the goals outlined by the Disaster Preparedness and Planning Project (DP3). The average ratings (at least 4 out of 5) regarding satisfaction with the overall tool, the user interface, and the interactive map indicate that the tool is clear and user-friendly. Qualitatively, participants described their appreciation of the simple interface of the tool, but emphasized that the tool website requires further design and branding. The lowest rating (3.8 out of 5) was associated with the feasibility of implementing the results generated by the tool. Comments regarding the tool output that likely explain this lower rating discussed the visual display of the output, the accessibility of information pertaining to the tool modules, and concerns about the output's use by non-forestry professionals. The results from both sessions demonstrate that this tree selection tool will be useful to Baltimore, but it is still in its development stages and must be revised prior to providing city-wide access.

During both sessions, it was clear that creating a tool platform that could be used by non-forestry, non-planning, or non-sustainability professionals was outside the scope of this project and under the purview of the City of Baltimore. The Baltimore project client and staff members that will serve as administrators of the tool in the future will be required to incorporate the majority of the suggestions made during the beta-testing sessions. As such, a discussion of the beta-testing results are divided into those that were and will be managed by the project team, and those that the City of Baltimore will manage to enhance the tool's accessibility to future users.

5.1.1 Project Team Tool Updates and Recommendations

The project team utilized beta-testing feedback to update the soil indicators module and make simple adjustments to the tool's interface. At both sessions, Baltimore stakeholders raised concerns about the soil indicators module because areas with urban soils were inputted as "no data" thus, suitability scores for tree species were not calculated in these areas. Beta-testers expressed the need to include this data, despite the lack of soils data for urban area. This update was made after the first beta-testing session in order to allow users to interpret the information from the remaining modules of sites designated to have urban soils. In the updated version of the model, soil suitability is assumed to be zero for any site with urban soils. Because participants in the first session expressed confusion over USDA-generated native species status labels, this attribute was updated prior to the second beta-testing session to reflect the terms used by stakeholders in the City of Baltimore to refer to native and introduced species.

During the beta-testers' use of the homepage and interactive map, it was apparent that users were distracted by the interactive map before reading the directions, resulting in confusion about the tool's functionality. Adjustments will be made to ensure that the directions for the tool will be clear and users will be able to see the directions and the map simultaneously. An additional suggestion for the homepage was to include information, either as a section on this webpage or as a new webpage, regarding the audience for which this tool is intended. The participants also recommended that the tool include a functionality that will allow users to save their outputs. For example, when users click "Find Trees" rather than going to the next page, a new window or tab could be opened so that outputs will not be lost as a user generates outputs for multiple sites. Another possible solution to this problem would be to have an export function associated with the output table so that the user can save the model's output for a given site to their computer hard drive.

Updates to the output page will be made to incorporate suggestions that improve the clarity of the information found in the output table. These updates include changing the placement of table headers in order of importance and locking the top headers as users scroll down the page. After participants expressed their confusion over USDA generated native species status labels, this attribute was updated to reflect the terms used by stakeholders in the City of Baltimore to refer to native and introduced species. Additional suggested changes include adding links to the corresponding USDA webpage for each tree species in the vegetation database, and a link on the results page to the "about this tool" page, which contains descriptions of each module.

The previously described updates to the tool's website reflect simple changes based on beta-testing results and these changes are within the project's original scope. At this stage, the tool is ready to be used by urban foresters, city planners and other professionals knowledgeable or associated with urban forestry. The tool, however, requires additional stages of development of increasing complexity in order to reflect its association with the City of Baltimore and the Disaster Preparedness and Planning Project (DP3), better meet stakeholder needs and expectations, and enhance the tool's accessibility to external stakeholders that may lack urban forestry expertise.

5.1.2 City of Baltimore Recommendations

It is recommended that the tool remains as an online resource, accessible to all potential users. If implemented in this manner, administrators must manage the website to serve as more than a platform for the tool. This requires making substantial revisions to the online platform's interface, updating the qualitative fields of the vegetation database to reflect local knowledge of urban forestry management, and adding resources that would inform implementation of the suggested trees from the tool's output. The City of Baltimore will also have to periodically update the modules and Spatial Database as new data becomes available.

Suggested improvements to the tool's interface included creating a homepage separate from the tool that would introduce the tool, an overview of Baltimore's urban forestry, the DP3, and associated partners. To maximize the tool's use and success, administrators must also develop branding for the tool that integrates it with existing city initiatives and strategies, including a new name. Beta-testers expressed their appreciation of the existing website's clarity and simple layout; as such, it is recommended that the revisions to the interface and branding reflect the simplicity of the original website, given its success during beta-testing.

Beta-testers also expressed concerns about the data and methods used to develop the wind risk module, and proximity-to-road module. A comprehensive model of wind risk was outside the scope of our project, and spatial data about utilities were unavailable to us, and this missing data limits the accuracy of these modules. However, the tool can be updated by City of Baltimore administrators when this data or a different method of reflecting these criteria becomes available. We anticipate that the qualitative reporting capabilities of our online interface will begin to address these issues in the meantime, as foresters can recommend certain trees for planting under power lines, as an example. The soil indicators module should also be updated when classification for urban soils data becomes available in the future. To provide clarity regarding all modules, the City of Baltimore should include both the condensed explanation of each module currently on the "About this tool" web page and a link to the user manual provided by the project team on the revised website.

The majority of beta-testing participants commented that non-forestry, non-planning, or non-sustainability professionals may have difficulty interpreting the output table. To improve the accessibility of the tool, it is recommended that the directions in the output page emphasize that the trees presented in the output table are suggestions. It is also critical that administrators provide information for how to plant suggested trees on the web page, make contact information for urban foresters available or develop additional resources that would support the users' tree selection and planting. One participant indicated their concern that the output table is not clear that in some cases, several trees are the most suitable for the chosen site. An additional functionality of the tool could group trees of similar suitability ratings as most suitable to the site, and directions should indicate that the user should conduct further research to determine which tree is best suited for their site. Moreover, the webpage should stress that users should do an assessment of the chosen site prior to making tree planting decisions based on the output table.

Additional recommendations made by beta-testers might rely on, or require, urban forestry stakeholders to change city policies and strategies. For example, several beta-testers expressed that the overall suitability scale of 0 to 1 is not a user-friendly way to interpret the tool output and compare suggested tree species. It was recommended that the scale should be represented by text or symbols that demonstrate grouping of species with high, medium, and low suitability. While this would enhance the user experience, it would require urban forestry stakeholders themselves to determine the thresholds that best fit the needs and strategies of urban forestry management. Doing so would support the idea expressed by several of the stakeholders in attendance at the beta-testing sessions to incorporate a suitability standard into tree planting requirements associated with city development. This idea is also associated with the suggestion to create a threshold under which trees will not be output in the results page. Administrators and stakeholders would have to determine whether it is appropriate to exclude what may be deemed "low suitability" trees. Given that this tool and the incorporation of adaptation into the management of urban forests are both novel initiatives, this particular suggestion may need to be incorporated in later versions of the tool.

Anecdotally, beta-testers discussed the possibility of including a functionality where users would be able to change the weight of each module themselves. This would allow a user to give the "social considerations" module a weight of 0, for instance if this was not a criteria of interest for their specific planting needs. Participants also mentioned that a likely situation would be needing to remove soil as a criteria for selecting a tree species to be planted in a planter or with topsoil brought to a site, (particularly in areas with where soil is classified as "urban" and might be a very limiting criteria). While this may give local users the ability to apply their own knowledge of a site and/or trees, it is recommended that Baltimore discuss this particular change with internal and external stakeholders to determine how this approach would work in practice.

The beta-testers also discussed the fact that many of the suggested trees in the tool output cannot be found at local nurseries and how the tool could be used to inform nursery stock in the future. Testers discussed running the tool for the entire City of Baltimore to discover the most frequently-recommended species, and using that output to communicate with the nurseries with which they work to help them provision the species necessary to utilize the tool's recommendations.

As the tool is revised and updated, it is highly recommended that the City of Baltimore coordinates usability- and beta-testing sessions with internal and external stakeholders. This will ensure that the future tool continues to meet the needs of the City of Baltimore, reflects strategy outlined in the DP3, and remains accessible to all intended users. For future beta-testing sessions, participants should represent as many potential users as possible, including residents and business representatives.

Once the tool is revised and ready to be introduced to all associated Baltimore urban forest partners, businesses, and residents, administrators should conduct workshops or informational sessions to inform futures users of the tool. It is suggested that administrators maximize their reach into the community by conducting workshops or informational sessions with TreeBaltimore partners or prominent urban forestry organizations and building a network of informed users that could then reach out to their respective constituents. Outreach to current stakeholders and potential users of the tool is essential to ensure the tool's use and appropriate implementation. This type of outreach could also serve as a way to bring community members together to take ownership of this tool as they provide insight and information for tree planting best practices that could be incorporated into the qualitative aspects of the tool. An outreach plan associated with the tool's implementation is necessary to encourage users to consider current and future natural hazards when making tree planting decisions in order to support the city's goal of a healthy urban forest.

Appendix A: List of City Governments reviewed in Policy Analysis

City	Size Classification	Leader	Southeast	Forestry Plan?	Adaptation Plan?
Alexandria, VA	100k-500k			□	-
Ann Arbor	100k-500k	□	□	□	□
Asheville, NC	100k or fewer				
Atlanta, GA	100k-500k	□		□	□
Austin, TX	100k or fewer	□	□	□	□
Charleston, SC	100k or fewer				
Charlottesville, VA	100k or fewer				
Chicago, IL	1 million or greater	□	□	□	□
Edmonton, AL	500k-1 million	□	□	□	□
Evanston, IL	100k or fewer	□	□	□	□
Grand Rapids, **MI**	100k-500k	□	□	□	□
Gresham, OR	100k-500k	□	□	□	□
Melbourne, VIC	1 million or greater	□	□	□	□
Minneapolis, MI	100k-500k	□	□	□	□
New York, **NY**	1 million or greater	□	□	□	□
Norfolk, VA	100k-500k				
Palo Alto, **CA**	100k or fewer	□	□	□	□
Philadelphia, PA	1 million or greater	□	□	□	□
Pittsburgh, PA	100k-500k	□	□	□	□
Portland, OR	500k-1 million	□	□	□	□
Raleigh, NC	100k-500k				-
San Diego, CA	1 million or greater	□	□	□	□
San Francisco, CA	500k-1 million	□	□	□	□
Santa Monica, **CA**	100k or fewer	□	□	□	□
Seattle, WA	500k-1 million	□	□	□	□
Syracuse, NY	100k-500k	□	□	□	-
Tampa, FL	100k-500k			□	-
Toronto, ON	1 million or greater	□	□	□	□
Vancouver, BC	500k-1 million	□	□	□	□

•	Yes
	No
-	Used a Sustainability Plan for the purpose of Analysis (In Lieu of Adaptation Plan Only)

Appendix B: City Plans Used in Policy Analysis

City	Urban Forestry Document	Climate Adaptation Document
Alexandria, VA	Alexandria Urban Forestry Management Plan	City of Alexandria Energy and Climate Change Action Plan (2012)
Ann Arbor	Urban and Community Forest Management Plan	City of Ann Arbor Climate Action Plan
Asheville, NC	None	None
Atlanta, GA	Downtown Tree Management Plan	Our Path to Sustainability: Sustainability Report for Atlanta (2008)
Austin, TX	Austin's Urban Forest Plan: A Master Plan for Public Property (2013)	Austin's Community Climate Plan Draft (2014)
Charleston, SC	None	None
Charlottesville, VA	City of Charlottesville, VA Urban Forest Management Plan (2009)	None
Chicago, IL	Chicago's Urban Forestry Agenda (2009)	Chicago Climate Action Plan, Strategy 5: Adaptation (2008)
Edmonton, AL	Urban Forest Management Plan (2012)	The Way We Green (2011)
Evanston, IL	Evanston Urban Forest Management Plan (2003)	Evanston Climate Action Plan (2008)
Grand Rapids, MI	Urban Forest Management Plan (2009)	Grand Rapids Climate Resiliency Report (2013)
Gresham, OR	Urban Forestry Management Plan (2011)	Gresham Climate Futures Report (2010)
Melbourne, VIC	Urban Forest Strategy Making a Great City Greener (2012)	City of Melbourne Climate Change Adaptation Strategy (2009)
Minneapolis, MI	City of Minneapolis Urban Forestry Policy (2004)	Minneapolis Climate Action Plan (2013)
New York, NY	Guidelines to Urban Forest Restoration	A Stronger, More Resilient New York (2013)
Norfolk, VA	None	None
Palo Alto, CA	Draft Urban Forest Master Plan (2015)	Palo Alto Climate Protection Plan (2007)
Philadelphia, PA	Parkland Forest Management Framework (2013)	Local Action Plan for Climate Change (2007)
Pittsburgh, PA	Pittsburgh Urban Forest Master Plan	Pittsburgh Climate Action Plan (2012)
Portland, OR	Urban Forest Action Plan (2007)	City of Portland and Multnomah County Climate Action Plan (2009)
Raleigh, NC	None	Sustainability Initiatives (2009)

San Diego, CA	Draft Urban Forest Management Plan (2015)	Climate Action Plan Draft (2015)
San Francisco, CA	San Francisco Urban Forest Plan (2014)	Climate Action Strategy 2013 Update
Santa Monica, CA	Santa Monica Urban Forest Master Plan (2011)	15 X 15 Climate Action Plan (2013)
Seattle, WA	Urban Forest Stewardship Plan (2013)	Seattle Climate Action Plan (2013)
Syracuse, NY	Syracuse Urban Forest Master Plan (2001)	Syracuse Sustainability Plan (2012)
Tampa, FL	Urban Forest Management Plan (2013)	Tampa Comprehensive Plan (2008)
Toronto, ON	Sustaining & Expanding the Urban Forest: Toronto's Strategic Forest Management Plan (2012)	Change is in the Air: Climate Change, Clean Air and Sustainable Energy Action Plan (2007)
Vancouver, BC	Urban Forestry Management Plan (2007)	Climate Change Adaptation Strategy (2012)
Washington, DC	Assessment of Urban Forest Resources and Strategy (2010)	Climate of Opportunity- A Climate Action Plan for the District of Columbia (2010)

Appendix C: Cities Interviewed in Policy Analysis

Interview Subjects interviewed via phone from February 1 – March 31, 2015

One urban forestry professional was interviewed from each of the following cities. Interview subjects worked in and with city governments in varying departments including Parks Departments, Parks and Recreation, Forestry Divisions, Departments of Public Works and members of Forestry Commissions.

Charleston, South Carolina
Charlottesville, Virginia
Evanston, Illinois
Grand Rapids, Michigan
Palo Alto, California
Portland, Oregon
Santa Monica, California
Syracuse, New York

The IRB exemption process prohibits this report from identifying by name or specific position any of our interview subjects.

Appendix D: Interview Questions and Procedures in Policy Analysis

Purpose

The City of Baltimore, as part of their climate adaptation strategy, has pledged to double their tree canopy over the next 20 years in order to mitigate for a variety of climatic hazards that are projected to worsen in the future, including length and magnitude of heat and precipitation events, sea-level rise, and increased prevalence of extreme weather events such as tornados. To help the City of Baltimore successfully and sustainably expand their urban forest, we will be identifying urban forestry best practices and analyzing the incorporation of climate change and resilience into said practices. To obtain this information, we propose a qualitative analysis of semi-structured interviews of professionals, either employed or partnered with city governments. The interviews will consist of questions that will allow respondents to openly discuss their experience with and knowledge of urban forestry in the context of climate change and resilience.

Structure of interview

Semi-structured interviews will be conducted via phone.

Length of Interview

The interviews will be approximately 30 minutes in length.

Respondents

Respondents will consist of professionals associated with urban forestry (i.e. city foresters, city planners, non-profit partners, etc.). Potential respondents have been identified through searching city urban forestry or sustainability web pages and/or sustainability or urban forestry management plans.

Pre-Interview Procedure

- Describe purpose of study and interview to respondent. Explain structure of interview to respondent.
- Describe population, sampling frame, sampling method and sample size.
- Explain that there is no potential of risks to respondent. No personal information will be obtained or revealed that would connect respondent to the information in this study. Information relating to the practices of their employer will be used if permission has been granted by the respondent to connect information they have provided during the interview directly to their employer.
- Explain to respondent that they may decline to answer a question or discontinue the interview at any time.
- Request verbal permission to connect information provided in regards to "best practices" to their respective city. Explain to respondents that we will contact them before disseminating information for their review and approval, if their information is connected to their place of employment.

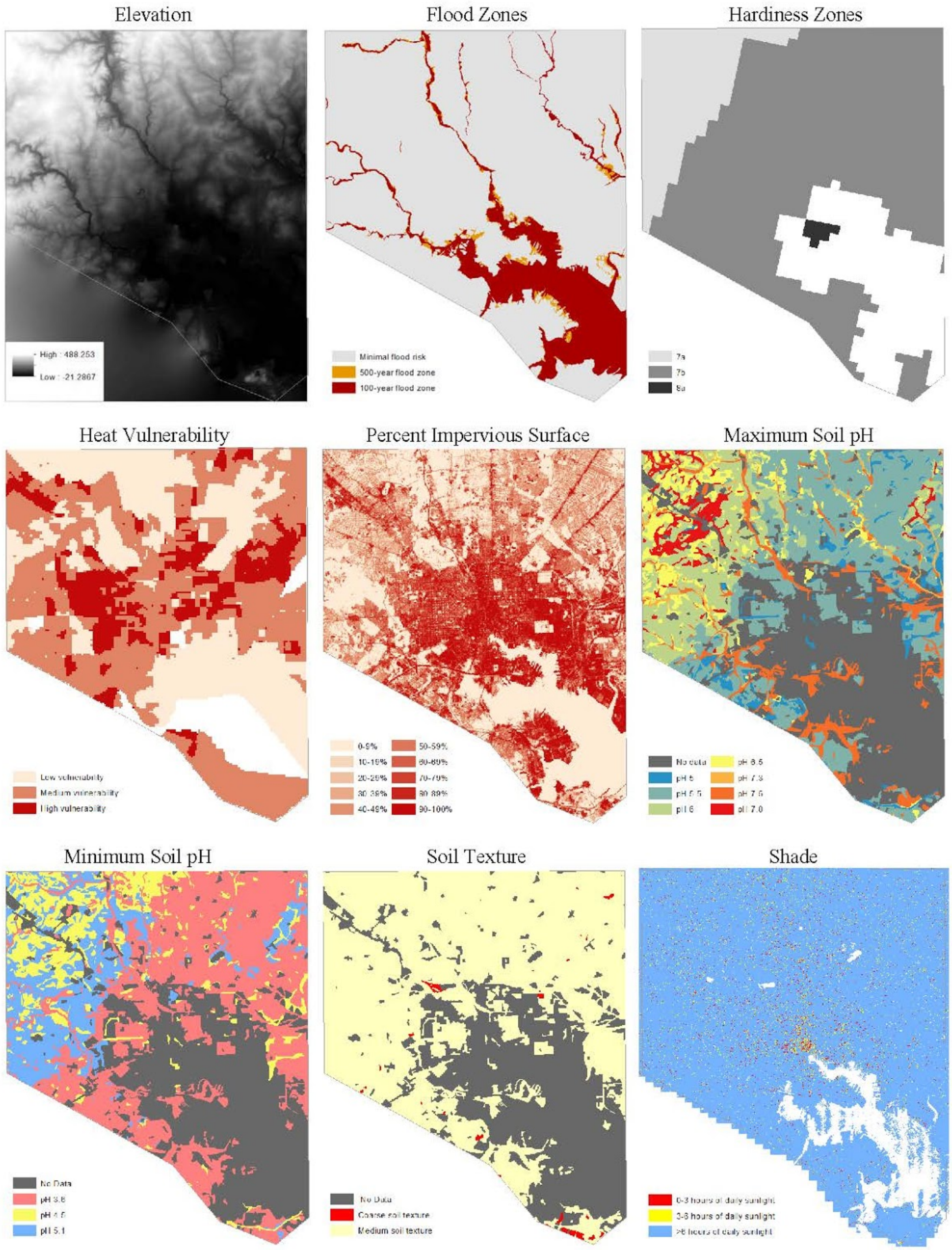
  - The respondent may request time to make this decision in order to receive internal consent from employer. In this case, inform the respondent that you will contact them via email one week after the interview for their employer's decision. If the respondent prefers to wait for their employer's, reschedule the interview for a later date.
- Request verbal permission to record interview. Explain to respondent that recordings will be used strictly for a qualitative study and will not be published.
- Obtain verbal consent from respondent to participate in the interview.

Interview Questions

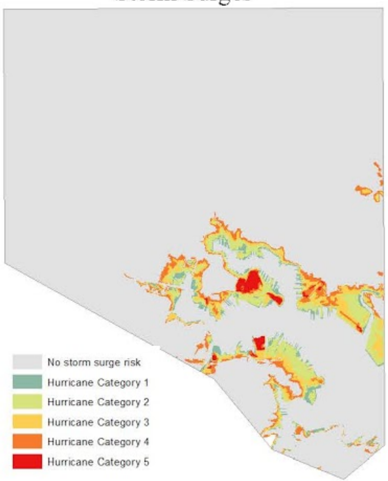
- Do you foresee specific challenges related to climate change in forestry management in your city? (or)
- Has your city experienced challenges to urban forest health? What are these challenges?
- [If has adaptation plan/specific forestry recommendations] How does the adaptation plan relate to urban forestry management in practice? (Did you have a role in developing it, do its recommendations line up with the existing urban forestry programs)
- What strategies are going into urban forest management plans in your city that incorporate projected climate impacts and the uncertainty of climate change (or uncertainty in general if climate planning is not being integrated)
- How do these concepts and strategies translate in practice? If this process is challenging, please tell us how.
- What partners were involved in the development of the plan or strategy, and which partners are involved in implementation?
- How will your city's urban forestry plans be monitored and evaluated?

[Describe the project's decision support tool and tree selection criteria] Can you please describe how you would use this tool? What limitations can you foresee?

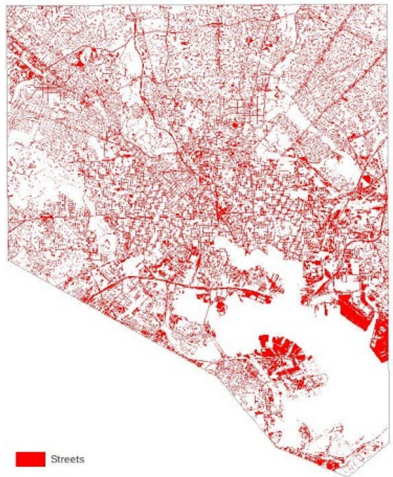
Appendix E: Visualization of Spatial Data in the Spatial Database



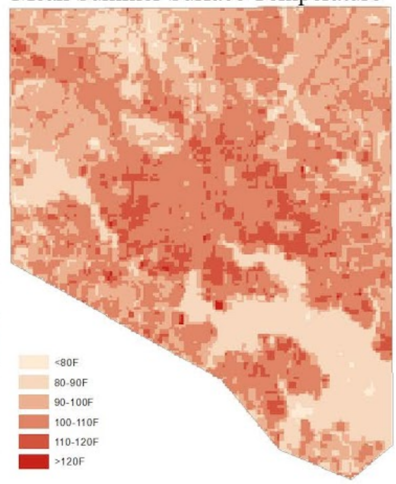
Storm Surges



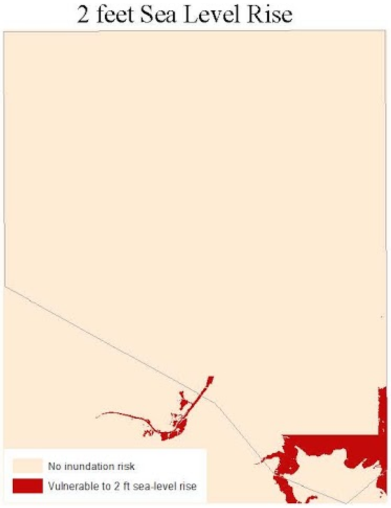
Street Buffer



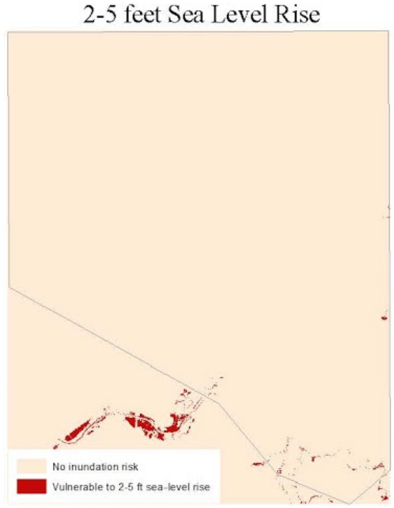
Mean Summer Surface Temperature



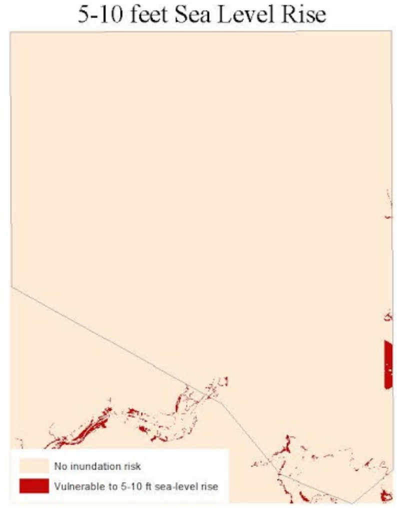
2 feet Sea Level Rise



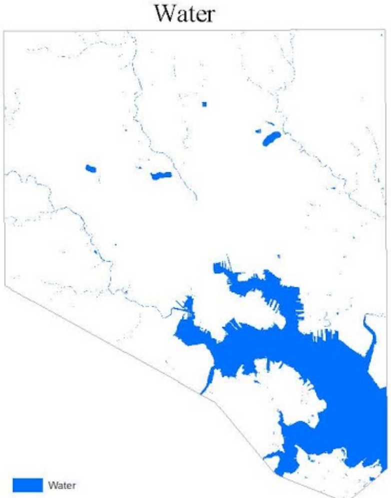
2-5 feet Sea Level Rise



5-10 feet Sea Level Rise



Water



Appendix F: Reclassification of Soil Data for the Spatial Database

Table 1: Formulae provided by the USDA Soil Texture Calculator were used for classifying different soil types into soil texture categories. "silt", "clay", and "sand" represent the percent of silt, clay, and sand that the specific soil type contains.

Soil Texture	**Formula**
Sand	((silt + 1.5*clay) < 15)
Loamy Sand	((silt + 1.5*clay 15) and (silt + 2*clay < 30))
Sandy Loam	((clay 7 and clay < 20) and (sand > 52) and ((silt + 2*clay) 30) or (clay < 7 and silt < 50 and (silt + 2*clay)30))
Loamy Sand	((clay 7 and clay < 27) and (silt 28 and silt < 50) and (sand 52))
Silt Loam	((silt 50 and (clay 12 and clay < 27)) or ((silt 50 and silt < 80) and clay < 12))
Silt	(silt 80 and clay < 12)
Sandy Clay Loam	((clay 20 and clay < 35) and (silt < 28) and (sand > 45))
Clay Loam	((clay 27 and clay < 40) and (sand > 20 and sand 45))
Silty Clay Loam	((clay 27 and clay < 40) and (sand 20))
Sandy Clay Loam	(clay 35 and sand > 45)
Silty Clay	(clay 40 and silt 40)
Clay Loam	(clay 40 and sand 45 and silt < 40)

Table 2: Categorizing soil texture classes into the characteristics soil texture groups identified by USDA PLANTS Database.

Characteristics soil texture group	**Soil texture classes**		
Coarse	• Loamy coarse sand • Very fine sand • Loamy very fine sand	• Coarse sand • Loamy fine sand • Loamy sand	• Fine sand • Sand
Medium	• Silty clay loam • Fine sandy loam • Coarse sandy loam • Very fine sandy loam	• Sandy clay loam • Sandy loam • Clay loam	• Loam • Silt • Silt loam
Fine	• Sandy clay	• Clay	• Silty clay

Appendix G: Procedures for Updating the Spatial Database

Non-categorical attributes, including soil pH, percent impervious surface, mean summer temperature, precipitation, elevation, and slope, should be converted into string format to avoid an automatically assigned zero value for areas with no data. Before running the code, users have to update the inventory CSV file with the updated file path. The new spatial data can contain additional attributes; users only need to update the field names that represent the data in the inventory file to indicate the attribute values to be added to the Spatial Database. The "Description" and "Standardized Field Name" columns, as well as the column titles in the inventory file should not be modified so that the Python code can extract the correct information. When running the code, users need to specify the directory path of the original grid layer, inventory file, and where the outputs will be saved. Since the Spatial Database contains over 2.5 million grid cells, it may take several hours to update one single attribute. Currently, the Python script is developed in a way that all data will be updated, i.e. users cannot choose to update only one or a selected list of attributes. Future improvements may be made such that users can select the specific attribute to be updated, which would speed up the updating process.

Appendix H: Search Parameters used to Generate the Vegetation Database – USDA PLANTS Database

Below are the search criteria in the "advanced search" functionality of USDA PLANTS at http://plants.usda.gov/adv_search.html. The search result was downloaded. A database from the search result was created using the *text to columns* tool in Excel, and was saved as a csv file.

Categories	**Attributes**	**Categories included**
Distribution	State and Province	GA, MD, NC, SC, VA
Taxonomy	Scientific Name	All (Accepted Names and Synonyms)
	Common Name	All
	Family	All
	Kingdom	Plantae
Ecology	Duration	All
	Growth Habit	Shrub, Subshrub, Tree
	Native Status	All
Legal Status	Federal Noxious Status	All
	Invasive	All
Morphology/ Physiology	Active Growth Period	All
	C:N Ratio	All
	Fall Conspicuous	All
	Flower Conspicuous	All
	Foliage Color	All
	Foliage Texture	All
	Growth Form	All
	Growth Rate	All
	Height at Base Age, Maximum (feet)	All
	Height, Mature (feet)	All
	Leaf Retention	All
	Lifespan	All
	Nitrogen Fixation	All
	Resprout Ability	All
	Shape and Orientation	All
	Toxicity	All
Growth Requirements	Adapted to Coarse Textured Soils	All
	Adapted to Medium Textured Soils	All
	Adapted to Fine Textured Soils	All
	Anaerobic Tolerance	All
	Cold Stratification Required	All
	Drought Tolerance	All
	Frost Free Days, Minimum	All
	Moisture Use	All
	pH (Minimum)	All
	pH (Maximum)	All
	Precipitation (Minimum)	All
	Precipitation (Maximum)	All
	Root Depth, Minimum (inches)	All
	Salinity Tolerance	All
	Shade Tolerance	All
	Temperature, Minimum (°F)	All

Appendix I: Tree Species removed from the Vegetation Database

The following tree species are removed from the Vegetation Database based on the recommendations in the Street Tree Species List created by the City of Baltimore in 2013.

Common Name	**Scientific Name**	**Reasons**
Box Elder	*Acer negundo*	Storm damage/structural problems
Silver Maple	*Acer saccharinum*	Storm damage/structural problems
Norway Maple – all varieties	*Acer platanoides*	Invasive
Silk Tree/ Mimosa	*Albizia julibrissin*	Invasive
Tree of Heaven	*Ailanthus altissima*	Invasive
Japanese Angelica Tree	*Aralia elata*	Invasive
Paper Mulberry	*Broussonetia papyrifera*	Invasive
Autumn Olive/Russian Olivee	*Elaeagnus umbellata*	Invasive
White Ash – all varieties	*Fraxinus americana*	Blighted by Emerald Ash Borer
Green Ash – all varieties	*Fraxinus pennsylvanica*	Blighted by Emerald Ash Borer
Ash – all varieties	*Fraxinus spp.*	Blighted by Emerald Ash Borer
Ginkgo	*Ginkgo biloba*	Fruit has bad order
Black Walnut	*Juglans nigra*	Dangerous when nut drop
Tuliptree	*Liriodendron tulipifera*	Storm damage/structural problems
White Mulberry	*Morus alba*	Invasive
Paulownia/Princess Tree	*Paulownia tomentosa*	Invasive
Amur Cork	*Phellodendron amurense*	Invasive
Poplars	*Populus (all species)*	Storm damage/structural problems
Wild Cherry	*Prunus serotina*	Storm damage/structural problems
Calery Pear – all cultivars	*Pyrus calleryana*	Invasive
Sawthooth Oak	*Quercus acutissima*	Invasive
Black Locust	*Robinia pseudoacacia*	Storm damage/structural problems
All Willows	*Salix spp.*	Storm damage/structural problems
Scholar Tree	*Sophora japonica*	Invasive
Chinese Elm – all cultivars	*Ulmus parvifolia*	Invasive
Siberian Elm	*Ulmus pumila*	Invasive

Appendix J: Raw Algorithm Code for Calculating Suitability Score

```
import operator

from django.shortcuts import render

from forms import SiteIdForm
from models import SiteData, VegetationData


def home_page(request):
  return render(request, 'home.html', {'form': SiteIdForm()})

def about_page(request):
  return render(request, 'about.html')


def get_tree(request):
  sitenum = request.POST['site_id']
  site = SiteData.objects.get(sid=sitenum)

  header = ["OVERALL SUITABILITY",
         "Common Name",
         "Scientific Name",
         "Native Status",
         "Heat & Drought Suitability",
         "Shade Suitability",
         "Soil Suitability",
         "Street Suitability",
         "Social Suitability",
         "Fresh Water Flooding Suitability",
         "Sea Water Flooding Suitability",
         "Winter Suitability",
         "Wind Suitability",
         "Potential Pests",
         "Management Concerns",
         "Other Issues",
         "Additional Remarks"]

  scored_trees = []
  matched_trees = 0
  suitable_trees = 0
  noresults = []
  notes = []
  messages = []
##    if site.pHmax == 0 and site.pHmin == 0:
##        messages.append("no site-specific soil pH data available for your chosen site, so pH suitability
score assumed to be zero.")
  notes.append("Output data for grid cell %s" % sitenum)

 # assumes shift of 2 hardiness zones
```

```
    if site.hardiness == "7a":
        min_temp = 0
        proj_min_temp = 10
    elif site.hardiness == "7b":
        min_temp = 5
        proj_min_temp = 15
    elif site.hardiness == "8a":
        min_temp = 10
        proj_min_temp = 20
    else:
        min_temp = 0
        proj_min_temp = 10

##
##    if site.street == 0:
##        messages.append("Because your site does not occur along a street, trees are given a maximum suitability ranking for ability to grow along roads.")
##    if site.slr2 == 0 and site.slr2_5 == 0 and site.slr5_10 == 0 and site.stormsurge == 0:
##        messages.append("Site is not at risk of sea water flooding, so a maximum sea level tolerance score was given to all trees.")
##    if site.flood != 3 and site.flood != 2:
##        messages.append("Site is not at risk of fresh water flooding, so a maximum fresh water flooding tolerance score was given to all trees.")
##

    for tree in VegetationData.objects.all():
        winter_score = 0
        heat_score = 0
        soil_score = 0
        shade_score = 0
        street_score = 0
        social_score = 0
        fresh_score = 0
        sea_score = 0
        wind_score = 0

        native_str = str(tree.native_status)
#        messages.append(native_str)

        if native_str.find("L48 (N)") != -1:
            native_status = "Native"

        elif native_str.find("L48 (I)") != -1:
            native_status = "Introduced/Invasive"

        final_suitability = 0
        tree_tuple = ()
        if site.water == 1:
            noresults.append("You have chosen an area that is either water or does not have sufficient data for suitability scoring. Please click 'back' and start again.")
            break
```

```
    else:
        if tree.growth_form not in ["Climbing", "Prostrate", "Rhizomatous", "Stoloniferous",
"Colonizing"]:

            #winter score

            if tree.temperature_min <= min_temp:
                if tree.temperature_min <= proj_min_temp:
                    if tree.frost_free_days_min < 231:
                        winter_score += 1
                    if 231 <= tree.frost_free_days_min <= 247:
                        winter_score += .5
                    if tree.frost_free_days_min > 247:
                        winter_score += .2
                elif tree.temperature_min > proj_min_temp:
                    winter_score += .2
            else:
                winter_score = 0

            #drought tol score
            if tree.drought_tolerance == "Medium" or tree.drought_tolerance == "High":
                if site.impervious >= 64:
                    if site.tmean >= 103:
                        if tree.drought_tolerance == "High" and tree.moisture_use == "Low":
                            heat_score += 1.00000000
                        elif tree.drought_tolerance == "High" and tree.moisture_use == "Medium":
                            heat_score += .800000000
                        elif tree.drought_tolerance == "High" and tree.moisture_use == "High":
                            heat_score += .300000000
                        elif tree.drought_tolerance == "Medium"and tree.moisture_use == "Low":
                            heat_score += .700000000
                        elif tree.drought_tolerance == "Medium" and tree.moisture_use == "Medium":
                            heat_score += .600000000
                        elif tree.drought_tolerance == "Medium" and tree.moisture_use == "High":
                            heat_score += .200000000
                    elif 92 <= site.tmean < 103:
                        if tree.drought_tolerance == "High" and tree.moisture_use == "Low":
                            heat_score += 1.00000000
                        elif tree.drought_tolerance == "High" and tree.moisture_use == "Medium":
                            heat_score += 1.00000000
                        elif tree.drought_tolerance == "High" and tree.moisture_use == "High":
                            heat_score += .400000000
                        elif tree.drought_tolerance == "Medium"and tree.moisture_use == "Low":
                            heat_score += .900000000
                        elif tree.drought_tolerance == "Medium" and tree.moisture_use == "Medium":
                            heat_score += .700000000
                        elif tree.drought_tolerance == "Medium" and tree.moisture_use == "High":
                            heat_score += .300000000
                    elif site.tmean < 92:
                        if tree.drought_tolerance == "High" and tree.moisture_use == "Low":
                            heat_score += 1.00000000
```

```
            elif tree.drought_tolerance == "High" and tree.moisture_use == "Medium":
                heat_score += 1.00000000
            elif tree.drought_tolerance == "High" and tree.moisture_use == "High":
                heat_score += .500000000
            elif tree.drought_tolerance == "Medium"and tree.moisture_use == "Low":
                heat_score += .900000000
            elif tree.drought_tolerance == "Medium" and tree.moisture_use == "Medium":
                heat_score += .900000000
            elif tree.drought_tolerance == "Medium" and tree.moisture_use == "High":
                heat_score += .300000000
    elif 25 <= site.impervious < 64:
        if site.tmean >= 103:
            if tree.drought_tolerance == "High" and tree.moisture_use == "Low":
                heat_score += 1.00000000
            elif tree.drought_tolerance == "High" and tree.moisture_use == "Medium":
                heat_score += .900000000
            elif tree.drought_tolerance == "High" and tree.moisture_use == "High":
                heat_score += .400000000
            elif tree.drought_tolerance == "Medium"and tree.moisture_use == "Low":
                heat_score += .800000000
            elif tree.drought_tolerance == "Medium" and tree.moisture_use == "Medium":
                heat_score += .700000000
            elif tree.drought_tolerance == "Medium" and tree.moisture_use == "High":
                heat_score += .300000000
        elif 92 <= site.tmean < 103:
            if tree.drought_tolerance == "High" and tree.moisture_use == "Low":
                heat_score += 1.00000000
            elif tree.drought_tolerance == "High" and tree.moisture_use == "Medium":
                heat_score += 1.00000000
            elif tree.drought_tolerance == "High" and tree.moisture_use == "High":
                heat_score += .500000000
            elif tree.drought_tolerance == "Medium"and tree.moisture_use == "Low":
                heat_score += 1.00000000
            elif tree.drought_tolerance == "Medium" and tree.moisture_use == "Medium":
                heat_score += .800000000
            elif tree.drought_tolerance == "Medium" and tree.moisture_use == "High":
                heat_score += .400000000
        elif site.tmean < 92:
            if tree.drought_tolerance == "High" and tree.moisture_use == "Low":
                heat_score += 1.00000000
            elif tree.drought_tolerance == "High" and tree.moisture_use == "Medium":
                heat_score += 1.00000000
            elif tree.drought_tolerance == "High" and tree.moisture_use == "High":
                heat_score += .600000000
            elif tree.drought_tolerance == "Medium"and tree.moisture_use == "Low":
                heat_score += 1.00000000
            elif tree.drought_tolerance == "Medium" and tree.moisture_use == "Medium":
                heat_score += 1.00000000
            elif tree.drought_tolerance == "Medium" and tree.moisture_use == "High":
                heat_score += .400000000
    elif site.impervious <= 64:
```

```
    if site.tmean >= 103:
        if tree.drought_tolerance == "High" and tree.moisture_use == "Low":
            heat_score += 1.00000000
        elif tree.drought_tolerance == "High" and tree.moisture_use == "Medium":
            heat_score += .900000000
        elif tree.drought_tolerance == "High" and tree.moisture_use == "High":
            heat_score += .400000000
        elif tree.drought_tolerance == "Medium"and tree.moisture_use == "Low":
            heat_score += .800000000
        elif tree.drought_tolerance == "Medium" and tree.moisture_use == "Medium":
            heat_score += .700000000
        elif tree.drought_tolerance == "Medium" and tree.moisture_use == "High":
            heat_score += .300000000
    elif 92 <= site.tmean < 103:
        if tree.drought_tolerance == "High" and tree.moisture_use == "Low":
            heat_score += 1.00000000
        elif tree.drought_tolerance == "High" and tree.moisture_use == "Medium":
            heat_score += 1.00000000
        elif tree.drought_tolerance == "High" and tree.moisture_use == "High":
            heat_score += .500000000
        elif tree.drought_tolerance == "Medium"and tree.moisture_use == "Low":
            heat_score += 1.00000000
        elif tree.drought_tolerance == "Medium" and tree.moisture_use == "Medium":
            heat_score += .800000000
        elif tree.drought_tolerance == "Medium" and tree.moisture_use == "High":
            heat_score += .400000000
    elif site.tmean < 92:
        if tree.drought_tolerance == "High" and tree.moisture_use == "Low":
            heat_score += 1.00000000
        elif tree.drought_tolerance == "High" and tree.moisture_use == "Medium":
            heat_score += 1.00000000
        elif tree.drought_tolerance == "High" and tree.moisture_use == "High":
            heat_score += .600000000
        elif tree.drought_tolerance == "Medium"and tree.moisture_use == "Low":
            heat_score += 1.00000000
        elif tree.drought_tolerance == "Medium" and tree.moisture_use == "Medium":
            heat_score += 1.00000000
        elif tree.drought_tolerance == "Medium" and tree.moisture_use == "High":
            heat_score += .400000000

#soil score
if site.pHmax == 0 and site.pHmin == 0:
    soil_score += 0.00000000
elif tree.ph_min >= site.pHmin and tree.ph_max <= site.pHmax:
    soil_score += .7500000000
elif (tree.ph_min >= site.pHmin and tree.ph_min < site.pHmin) or \
     (tree.ph_max <= site.pHmax and tree.ph_max > site.pHmax):
    soil_score += .500000000
else:
    soil_score += 0.00000000
```

```
if site.soil_text == "coarse":
    if tree.adapted_cts == "Yes":
        soil_score += .2500000000
elif site.soil_text == "medium":
    if tree.adapted_mts == "Yes":
        soil_score += .2500000000
elif site.soil_text == "fine":
    if tree.adapted_fts == "Yes":
        soil_score += .25
else:
    soil_score += 0

#shade score
if site.shade == 1:
    if tree.shade_tolerance == "Tolerant":
        shade_score += 1.00000000
    else:
        shade_score += 0.00000000
elif site.shade == 2:
    if tree.shade_tolerance == "Intermediate" or tree.shade_tolerance == "Tolerant":
        shade_score += 1.00000000
    else:
        shade_score += 0.00000000
elif site.shade == 3:
    if tree.shade_tolerance == "Intolerant" or tree.shade_tolerance == "Intermediate":
        shade_score += 1.00000000
    else:
        shade_score += 0.00000000

# sea score
if site.slr2 == 1 and site.stormsurge <= 3:
    if tree.anaerobic_tolerance == "High" and tree.salinity_tolerance == "High":
        sea_score += 1
        if tree.root_depth_min <= 20:
            sea_score -= .1
   if tree.anaerobic_tolerance == "High" and tree.salinity_tolerance == "Medium":
        sea_score += .7
        if tree.root_depth_min <= 20:
            sea_score -= .1
    if tree.anaerobic_tolerance == "Medium" and tree.salinity_tolerance == "Medium":
        sea_score += .5
        if tree.root_depth_min <= 20:
            sea_score -= .1

    else:
        sea_score = 0

if site.slr2_5 == 1 and site.stormsurge <= 3:
    if tree.anaerobic_tolerance == "High" and tree.salinity_tolerance == "High":
        sea_score += 1
        if tree.root_depth_min <= 20:
```

```
            sea_score -= .1
        if tree.anaerobic_tolerance == "High" and tree.salinity_tolerance == "Medium":
            sea_score += .8
            if tree.root_depth_min <= 20:
                sea_score -= .1
        if tree.anaerobic_tolerance == "Medium" and tree.salinity_tolerance == "Medium":
            sea_score += .6
            if tree.root_depth_min <= 20:
                sea_score -= .1
        else:
            sea_score = 0
    if site.slr5_10 == 1 and site.stormsurge <= 3:
        if tree.anaerobic_tolerance == "High" and tree.salinity_tolerance == "High":
            sea_score += 1
            if tree.root_depth_min <= 20:
                sea_score -= .1
        if tree.anaerobic_tolerance == "High" and tree.salinity_tolerance == "Medium":
            sea_score += 1
            if tree.root_depth_min <= 20:
                sea_score -= .1
        if tree.anaerobic_tolerance == "Medium" and tree.salinity_tolerance == "Medium":
            sea_score += .8
            if tree.root_depth_min <= 20:
                sea_score -= .1
        else:
            sea_score = 0
    if site.slr2 == 0 and site.slr2_5 == 0 and site.slr5_10 == 0 and site.stormsurge == 0:
        sea_score = 1
    # fresh water flooding score

    if site.flood == 3: #100 year flood
        if tree.anaerobic_tolerance == "High":
           fresh_score += .9
            if tree.root_depth_min >= 20:
                sea_score += .1
        if tree.anaerobic_tolerance == "Medium":
            fresh_score += .6
            if tree.root_depth_min >= 20:
                sea_score += .1
        else:
            if tree.root_depth_min >= 20:
                sea_score += .1
    elif site.flood == 2: #500 year flood
        if tree.anaerobic_tolerance == "High" or tree.anaerobic_tolerance == "Medium":
            fresh_score += 1
    else:
        fresh_score = 1
    #street score
    if site.street == 0:
        street_score += 1.00000000
    elif int(site.street) == 1:
```

```
            if tree.growth_form == "Single Stem" or tree.growth_form == "Single Crown":
                street_score += .500000000

            if tree.shape_orientation == "Vase":
                street_score += .300000000
            elif tree.shape_orientation == "Erect" or tree.shape_orientation == "Conical" or
tree.shape_orientation == "Columnar":
                street_score += .200000000
            elif tree.shape_orientation == "Oval":
                street_score += .100000000

            if tree.height_mature > 40:
                street_score += .100000000

            if tree.salinity_tolerance == "High" or tree.salinity_tolerance == "Medium":
                street_score += .100000000

            if tree.root_depth_min < 20:
                street_score -+ .2

        # social score
        if site.heat == 2 or site.heat == 3:
            if tree.growth_form == "Single Stem" or tree.growth_form == "Single Crown":
                social_score += .300000000
            if tree.shape_orientation == "Rounded" or tree.shape_orientation == "Oval" or
tree.shape_orientation == "Irregular":
                social_score += .400000000
            if tree.height_mature >= 40:
                social_score += .300000000
        elif site.heat == 1 or site.heat == 0:
            social_score += 1

        if tree.toxicity == "Moderate" .or tree.toxicity == "Severe":
            if social_score >= .2:
                social_score -= .200000000
            else:
                social_score = 0

        # wind score
        if site.elevation >= 284:
            if tree.root_depth_min > 26:
                wind_score += 1
        if 203 <= site.elevation < 284:
            if tree.root_depth_min > 26:
                wind_score += 1

        if site.elevation < 203:
            wind_score += 1

        final_suitability = (heat_score * .140000000) + \
                    (shade_score * .070000000) + \
```

```
                        (soil_score * .1700000000) + \
                        (street_score * .11000000000) + \
                        (social_score * .06000000) + \
                        (winter_score * .15000000) + \
                        (fresh_score * .080000000) + \
                        (sea_score * .07000000) +\
                        (wind_score * .13000000)

            tree_tuple = (final_suitability,
                    tree.common_name,
                    tree.scientific_name,
                    native_status,
                    heat_score,
                    shade_score,
                    soil_score,
                    street_score,
                    social_score,
                    fresh_score,
                    sea_score,
                    winter_score,
                    wind_score,
                    tree.potential_pests_diseases,
                    tree.maintenance_management,
                    tree.potential_problems,
                    tree.additional_remarks)
            scored_trees.append(tree_tuple)
            matched_trees += 1
            if final_suitability >= .80:
                suitable_trees += 1

  data = sorted(scored_trees, key=operator.itemgetter(0), reverse=True)

  if site.water == 0:
      if site.elevation < 203:
          messages.append("Your site is not at risk for high winds, so a maximum wind suitability score was
given to all trees.")
      if site.slr2 == 1 and site.stormsurge <= 3:
          messages.append("Your site is at risk of inundation given a 2 ft rise in sea level as well as flooding
due to category 1, 2, or 3 hurricanes.")
      if site.slr2_5 == 1 and site.stormsurge <= 3:
          messages.append("Your site is at risk of inundation given a 2-5 ft rise in sea level as well as
flooding due to category 1, 2, or 3 hurricanes.")
      if site.slr5_10 == 1 and site.stormsurge <= 3:
          messages.append("Your site is at risk of inundation given a 5-10 ft rise in sea level as well as
flooding due to category 1, 2, or 3 hurricanes.")
      if site.street == 0:
          messages.append("Because your site does not occur along a street, trees are given a maximum
suitability ranking for ability to grow along roads.")
##        if site.street > 0:
##            messages.append("Site along street")
      if not site.soil_text:
```

```
            messages.append("According to the Web Soil Survey, your site has 'urban soils', meaning it could not be evaluated for soil texture or soil pH. Therefore, soil suitability is assumed to be 0.")
        if site.slr2 == 0 and site.slr2_5 == 0 and site.slr5_10 == 0 and site.stormsurge == 0:
            messages.append("Site is not at risk of sea water flooding, so a maximum sea level tolerance score was given to all trees.")
        if site.flood != 3 and site.flood != 2:
            messages.append("Site is not at risk of fresh water flooding, so a maximum fresh water flooding tolerance score was given to all trees.")
        if site.elevation >= 284:
            messages.append("This site has a high wind risk. Trees with deeper roots have been favored, but please consider other management concerns when planting here.")
        notes.append("Of the trees below, %d scored in the 80th percentile, meaning they are 'very suitable' for planting." % suitable_trees)
        messages.append("Thank you for using SSSTUF. Happy Planting!")
        if site.pHmax == 0 and site.pHmin == 0:
                messages.append("no site-specific soil pH data available for your chosen site, so pH suitability score assumed to be zero.")

    # import pdb;pdb.set_trace()
    return render(request, 'tree.html', {'header': header, 'data': data, 'messages': messages, 'notes': notes, 'noresults': noresults})
```

Appendix K: Survey for Criteria Weighting

Worksheet used for the survey for criteria weighting using Saaty's Analytical Hierarchy Process.

Baltimore Resilient Urban Forest Tree Selection Tool
Modules Weighting Worksheet

*Input Value Range: 1/9 – 9

	Hardiness Zone/Winter Durability	Heat Stress & Drought Tolerance	Soil Indicators	Shade Tolerance	Fresh Water Flooding Tolerance	Sea Level Rise/Coastal Storm Tolerance	Planting Site (Streets vs Non-Street)	Social Factors	Wind Risk
Hardiness Zone/Winter Durability									
Heat Stress & Drought Tolerance									
Soil Type									
Shade Tolerance									
Fresh Water Flooding Tolerance									
Sea Level Rise/Coastal Storm Tolerance									
Planting Site (Streets vs Non-Street)									
Social Factors									
Wind Risk									

1/9 – 1/2: Less important 1: Equally important 2 – 9: More important 1

Appendix L: Survey Responses for Criteria Weighting

The following table shows the four survey responses that are consistent in the weighting.

Criteria	Response 1	Response 2	Response 3	Response 4
Hardiness Zone/Winter Durability	0.11	0.09	0.23	0.17
Heat Stress & Drought Tolerance	0.06	0.06	0.13	0.33
Soil Type	0.34	0.08	0.18	0.09
Shade Tolerance	0.10	0.05	0.05	0.10
Fresh Water Flooding Tolerance	0.05	0.09	0.12	0.07
Sea Level Rise/Coastal Storm Tolerance	0.05	0.08	0.10	0.07
Planting Site (Streets vs Non-Street)	0.18	0.09	0.07	0.09
Social Factors	0.04	0.14	0.05	0.03
Wind Risk	0.07	0.32	0.07	0.05

Appendix M: Beta-testing Questionnaire Session 1

Baltimore Tree Selection Tool Worksheet

Beta-Testing Workshop - Baltimore, MD

Thank you for agreeing to participate in our beta-testing procedure. We really appreciate your time and feedback. Below, please find directions for use, as well as questions about your experience with the tool.

Directions for Use:

1. **Visit http://52.11.217.110/ to access the tool via your web browser.**
2. **Use the map on the homepage to locate your hypothetical planting site, noting that you can zoom in and out, pan around the map, and input a specific address if you so desire.**

What are your first impressions of the tool's homepage?

Were the directions you found at the top and bottom of the page clear and helpful?

Circle: Yes or No

Is there something you would like to change about the interface/appearance of the homepage? If so, please explain below.

Please describe your impressions of the interactive map. Is there anything you would change about it?

3. **Click "Find Trees." This will bring you to a new page on which you can view your generated species list.**
4. **Along the top of the page, notice that the model prints out general information, including the cell. This section will also contain important information about the model ranked tree species. For instance, there were some areas for which we were unable to get soil pH data. If you chose one of those areas, you'll get an alert here that says "no site-specific soil pH data available, so pH suitability score assumed to be zero." In this top section you will also find the number of trees for which scores were generated.**

Baltimore Tree Selection Tool Worksheet

Beta-Testing Workshop - Baltimore, MD

Was the information at the top of the page clear and helpful? Why or why not?
Is there additional information you would like to know about your specific model inquiry that was not provided in this section?

5. **Below these alerts, you'll see a table of tree species, ranked by their suitability indices. Included in the table are the common and scientific names, as well as any pest or management concerns associated with that tree species.**

What are your first impressions of the output table?

Was the list of ranked trees easy to read and understand? Why or why not?

6. **Should you want to re-try the tool for a different area, click "back" and repeat the process for a new location.**
7. **Now that you have been familiarized with the tool, please take a minute to read the "About this Tool" page, which you can navigate to by clicking the link at the bottom of the home page.**

Is there additional information you would like to see on this page that would be useful to your understanding and use of the tool?

Baltimore Resilient Urban Forest Tree Selection Tool
Beta-Testing Questionnaire

Now that you have tested the tree selection tool, please take 10-15 minutes to complete the following survey about your experience with this tool. Answer these questions to the best of your ability based on your experience as you used the tool, interpreted labels and features, and analyzed the tool's outputs. Your responses will remain anonymous and will strictly be used for the purposes of improving this tool.

How would you rate your overall experience with this tool?

Very Dissatisfied	Dissatisfied	Neutral	Satisfied	Very Satisfied

To what extent was the user interface intuitive and easy to understand?

1	2	3	4	5
Not at all		Neutral		To a great extent

Please select a response based on the following statement: The interactive map was easy to use and an appropriate visual for this tool.

Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

Were any of the table headers/labels of the output difficult to understand?

Circle: Yes or No

If so, please describe which aspects of the output were difficult to understand.

Was the final output easy to read and interpret?

Circle: Yes or No

To what extent is the final output provided by the tool feasible for implementation?

1	2	3	4	5
Not at all		Neutral		To a great extent

Baltimore Resilient Urban Forest Tree Selection Tool
Beta-Testing Questionnaire

Please explain your answer to the previous question.

Is there any feature of the tool that you would like to know more about, or did the corresponding information pages answer all your questions? (Refer to Section 7 in worksheet)

Did you come across any issues during your experience? If so, please describe.

Is there an additional functionality you wish this tool could have? If your answer is yes, please describe.

Please provide any additional comments or suggestions regarding the tool's interface, usability and functionality.

Thank you for completing this survey!

Appendix N: Beta-testing Questionnaire Session 2

Baltimore Tree Selection Tool Worksheet

Beta-Testing Workshop - Baltimore, MD

Thank you so much for agreeing to participate in our beta-testing procedure. We really appreciate your time and feedback. Please complete this worksheet as we walk you through the tool.

Please take a few minutes to answer the following questions as the tool's homepage is introduced.

What are your first impressions of the tool's homepage?

Is there something you would like to change about the interface/appearance of the homepage? If so, please explain below.

Please describe your impressions of the interactive map. Is there anything you would change about it?

Please take a few minutes to answer the following questions about the initial information presented in the output page.

Was the information at the top of the page clear and helpful? Why or why not?
Is there additional information you would like to know about your specific model inquiry that was not provided in this section?

Please take a few minutes to answer the following questions about the tree species output table.

What are your first impressions of the output table?

Was the list of ranked trees easy to read and understand? Why or why not?

Is there additional information about the tree species listed that would be useful? Please describe below.

Beta-Testing Questionnaire

Now that you have been introduced to the tree selection tool, please take 10-15 minutes to complete the following survey about your experience with this tool. Answer these questions to the best of your ability based on your impressions of the interface, interpretation of labels and features, and analysis of the tool's outputs. Your responses will remain anonymous and will strictly be used for the purposes of improving this tool.

How would you rate your overall impression of the tool? Consider interface, utility, and information generated, in your response.

Very Dissatisfied	Dissatisfied	Neutral	Satisfied	Very Satisfied

To what extent was the user interface intuitive and easy to understand?

1	2	3	4	5
Not at all		Neutral		To a great extent

Please select a response based on the following statement: The base map used for the interactive map is an appropriate interface for this tool.

Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

Were any of the table headers/labels of the output difficult to understand?
Circle: Yes or No

If so, please describe which aspects of the output were difficult to understand.

Was the final output easy to read and interpret?
Circle: Yes or No

Beta-Testing Questionnaire

To what extent is the final output provided by the tool feasible for implementation?

1	2	3	4	5
Not at all		Neutral		To a great extent

Please explain your answer to the previous question.

Is there an additional functionality you wish this tool could have? If your answer is yes, please describe.

Is there additional instructions or necessary background information that you think should be provided on the homepage, output page, or "About this Tool" page that would help users of this tool?

Do you have any comments about the methodology explained during the presentation or concerns about limitations of the tool?

Please provide any additional comments or suggestions regarding the tool's interface, usability and functionality.

Thank you for your feedback!

Appendix O: Beta-testing Open-ended Responses

What are your first impressions of the tool's homepage?

- Easy, straightforward, could use some design help, color, images etc.
- Very basic appearance
- It's very sparse but good that it's not cluttered. Prominent map makes it easy to view.
- Informative. Possibly break up the text into grid pattern
- I like it! I think you should keep the name.
- Good maybe move the "About this Tool" higher above the map
- New name needed. Data is missing in a lot of areas. User-friendly. Easy to follow. Search toolbar is great
- Very nice layout. Clean and simple is good
- Looks user-friendly. Easy to use
- Simple, easy to read
- Has good information, clear, easy to read. If a web designer got involved it could be "flashier" but for what this is it is great.
- Very reminiscent of other map tool sites
- Needs work
- Not bad, but not as exciting as Tree Harmony
- Too busy
- Liked seeing the map of Baltimore -good way to start
- Very plain. Once branding is selected, then this should be improved. Also, for the city using the tool, they will link other resource.

Was the information at the top of the page clear and helpful? Why or why not?

- Yes
- Yes although I don't think you should get the message on the next page if cell is invalid. Going back to map you have to start over
- Yes. Not overly detailed, just enough.
- Separate text into grid pattern. Easier to read than paragraph style.
- Yes, very clear in explaining when some characteristics were n/a
- Yes
- Results general statement is helpful. Notes about results not accurate -issue if it's a street and not says it's not
- Yes. I like the notes about the site. Otherwise I might not know if the area is in the floodplain or not (for example)
- Yes
- Yes
- Information was clear. There was no data for area I chose. Which doesn't make sense because it is one of our urban heat island targets where we are planting a ton of trees
- Yes, making sure people read it first is important
- Bullets instead of a paragraph at the top would be easier to read
- Yes but like I've said, I went right to map! Had to go back to see it. Text kinda tiny.
- The results for the suitability should be organized. Consider blank scores

Is there something you would like to change about the interface/appearance of the homepage? If so, please explain below.

- On my computer I couldn't see the whole map and the box below without scrolling down. Should see them all at once. Also should have color, photos, etc. Also would be cool if map was on side and results on the other so you can see both at once.
- Remove space above title. Bring ID# box above map
- "Can it be tweaked to load fester, ex: boxes don't populate until you're zoomed way in?
- Can the site ID box automatically populate when you click on a box?
- Maybe an ""about"" link to explain who would use this and why?"
- Move the Site ID search on the side of the embedded map so there is no need to scroll
- It would be nice to be able to go right to the "find trees" after clicking on a square instead of copy/pasting the site ID
- Add City of Baltimore symbol and Baltimore OoS symbol. Use Baltimore OoS color concept for text
- When you click the back button have to go back to the previous screen -not the homepage
- Maybe make it "splashier"
- No
- Simple, I like it. User-friendly will be mentioned, I believe because you see the map and most will skip the text, which is very relevant to use.
- Less white. Maybe some sidebars with links to more info or reasons why you might want to use this tool
- Send to web page designer!
- More graphics, less tiny text

Please describe your impressions of the interactive map. Is there anything you would change about it?

- Maybe it would be good if existing canopy was in the base layer
- Color invalid cells so we don't select them
- Takes a long time to load, doesn't always load correctly.
- Larger on page if possible. In pop-up link directly to the results page and host on separate webpage or window on same page next to map. Add a zoom tool to zoom to specific area (as opposed to standard scaled zoom)
- Expand to Baltimore County (They are very flexible on planting southern species)
- "Retain location after searching database or open new window or tab -this would be helpful to compare different conditions
- Have feature where if you hover over water or cells with no data it says data not available"
- Like the map a lot. Good to zoom in and out. Nice to have different interface options
- Mentioned above. Show cells that do not have data (so you can't click on it)
- Easy to use
- Had issue with toggling or something on page. The map was following the cursor -couldn't fix it with the home button- maybe give a warning. I like that it gives two ID options if it is confused
- Click to table rather than type in location

- Thought this worked well, but when a cell is selected, it needs to automatically populate input
- Map looks good
- Seems user-friendly
- No really like the map
- Allow direct fill for the site ID look up

Is there additional information you would like to know about your specific model inquiry that was not provided in this section?

- Yes, what are the suitability values for your site and for the species?
- "Bird friendliness of various tree species
- If there is no value for soils, include the list of trees anyway
- Could probably exclude toxicity
- Maybe exclude trees that won't survive in future? Provide an option for this?"
- Would be great to filter out "introduced" species. I am fine with southern species but we generally try to avoid planting non-native
- "It would be cool if you could sort or query the results to narrow down choices based on things like form, height or other characteristics
- It would be helpful to know which are native to MD or mid-Atlantic
- It would be cool if you could hover over the column headers and get a description of that factor"
- "Going over the species type (with a cursor) could a picture of the tree come up?
- Going over each category (with a cursor) could more detailed info box pop up that includes detailed info"
- The option to view more detailed data
- Wording tied to species selection based off data.
- If I wanted to do a large afforestation project on parkland, how would you recommend that I use the tool? Click on each cell individually?
- I'd like to learn more about the criteria (decisions) for a number of the modules
- Better soil data

What are your first impressions of the output table?

- Overall suitability should come out as a whole #. The 0-1 scale is too stats-speaky. Also needs photos for the non-tree experts
- Basic. Hard to tell that many trees share "1st place"
- Pretty good and clear. Maybe take out all but L48 native info. Exclude shrubs? Some sites that are along streets are coming up as not occurring along a street.
- Very detailed, but not too overwhelming
- Lots of shrubs, maybe even perennials? Would be nice to filter by minimum maximum height (15' or greater) not a ton I recognize at the top, probably because of climate resilience factor. Time to start learning.
- Data is missing for a lot of areas -especially around water bodies. Soil issues -urban soil hard to get data for areas
- Looks good
- How are the suitability values calculated? Can we add/subtract variables?

- Easy to read
- I love it. Tree/data people should love it. Difficult for common folk.
- Consumer report typology
- Too much blank space, large numbers centered in the cells
- Excellent! Good level of detail
- Species were not appropriate, not readily available from wholesale nurseries in the mid-Atlantic
- Needs some graphic formatting. Initially I didn't know which column/value to look at first

Was the list of ranked trees easy to read and understand? Why or why not?

- Yes. Native status is a bit confusing
- Numerical values don't mean anything to public. What they want to know is "good match", "med match", "bad match" for that variable
- Yes. Would be nice if it were a little more narrow so you didn't have to keep scrolling left to right to see all the data for a tree. Would also be nice if the table at the top (scientific name, common name, native status, etc.) followed you as you scrolled down the page, for ease of viewing interpreting
- Yes
- Yes I wish the column headings could be frozen at top. Would be good to be able to link each result to the database page about it especially with pictures that would be amazing if it were possible.
- Yes, other than when no trees come up
- Good to have by most suitable (like that at the top). Yes -easy to read table/chart. Nice to have native areas/states
- Yes. Good explanation of how the variables are scored, so it's useful information
- Yes
- Yes
- Yes. Again making notes so random citizen will realize when there may be an issue
- Overall ranking should appear first
- I like the suggestion to reorder the columns common name, scientific name, suitability score…
- Yes! But place columns in order of importance
- Yes
- Yes

Is there additional information you would like to see on this page that would be useful to your understanding and use of the tool?

- Background needs text editing. Not just for urban foresters. Also, need to mention City of Baltimore and OoS. Connection to DP3. Module info is great -need more to review it, but like it for now.
- Want more data on how this was determined
- More info available option would be great if people wanted more details on the methodology as the table came up
- I would make the use for all interest not just urban forester
- Logical and easy to follow. Would like to see more data on how suitability values were obtained
- Greater detail on the methodology process maybe another page explaining it
- Maybe make this a bigger button. Easy to read and understand

If so, please describe which aspects of the output were difficult to understand.

- The scores don't mean anything to the user. Things user wants to know? What are the ratings for my cell? How well does this species fit those factors?
- Just the native status one, as it included obscure acronyms
- Maybe a tooltip to appear (when hovering over name and clickable) that shows description of header
- I couldn't remember which factors had gone into certain modules -a link or outline page to that info would be super
- Format of native species
- Why data was missing in key areas
- When a site would have no trees selections because of no soils data, but it should be a good site.
- More information on the scoring may be useful to some
- Change order of heading. In some cases output requires referencing text that appears previously. Use consumer report typology.
- Larger font, what do the numbers mean? Scale from 0 to 1? Text at top saying "top 3 were in 80th percentile" is too small and easily missed
- Have a website designer make it legible/user-friendly
- Set the table headers as frozen so when you scroll down so header remain. Allow pop up to provide definition if user clicks on header

Is there additional information about the tree species listed that would be useful? Please describe below.

- Eventually, photos, species info, maintenance needed. Tied to individual trees.
- Maybe if you click on a species in the output, get a text box saying why that tree was picked for that site
- Yes, apart from the modules, columns for: height, spread, evergreen, deciduous

Please explain your answer to the previous question. (To what extent is the final output provided by the tool feasible for implementation?)

- Numbers should be converted to whole numbers photos should accompany each species
- Preference lists are great. The visual presentation of this needs work. Ranking isn't obvious that the first several trees are actually ranked the same.
- Right now many important areas of the city for planting are not included. The tool is also slow to load/doesn't load consistently. Would be great to link to more data about each tree.
- Easy to share and understand the results
- We would still have further filtering to do (shrubs, perennials) but overall this is great.
- Will assist in areas where there is data. Would like to figure out why data is missing in so many place
- A list of trees and why they are suitable is very useful. It's especially nice that users can add notes
- It would be beneficial to make more data available. If tree data isn't available it would be helpful to say why, try and give a best estimate, and/or say what data is locking. Great for giving easy, quick results
- Need to have urban soil included otherwise it doesn't help us for a huge portion of city where we are prioritizing tree plantings in our heat islands
- Great to use as part of tree selection
- When cell is selected, needs to populate input selection. Graphics need to be improved. How are reports generated
- Missing some expert opinion about what works for street tree sites
- They'll know which trees to kick out automatically. Lay people will not -not without additional info in comments section
- Sample site inputted resulted in tree species that would not be appropriate for site
- It's a single step to help in decision making

Is there additional instructions or necessary background information that you think should be provided on the homepage, output page, or "About this Tool" page that would help users of this tool?

- Refresher on modules and criteria
- The powerpoint was more informative maybe include more of that info
- More depth about modules, weighing and considerations
- A way to analyze disease/pests and costs would be useful. How often data layers updated?
- Only if citizen cooking for one tree/private property
- We went through it too fast to assess. A manual will be important
- I'd have to spend more time looking at it
- Depends on audience. Jazzier for more novice.
- Emphasis for the purpose with respect to resiliency

Did you come across any issues during your experience? If so, please describe.

- Yes. No urban soil data means I can't see recommended street trees.
- Areas with no data, actually should show a result
- Map a little buggy (zooming randomly -might have been connectivity issue)
- Missing info along shorelines and urban soil areas
- Soil data issues. Data missing in lots of areas
- When going back to the map, it would be nice if it zoomed to where you were
- No data. Zoom feature was overly sensitive. Slow loading.
- Got a lot of "no data" because of urban soil. Cursor and map issues

Is there an additional functionality you wish this tool could have? If your answer is yes, please describe.

- It would be great if the users could manually toggle on and off different variables
- Separate zoom tool. Link to results in pop-up. Show results on same page -half map, half results
- If user could check their preferences as described earlier to filter out certain categories, that would be cool
- Yes: query results based on different characteristics; link to USDA database for photos of trees; open new window or tab with results
- Pictures of trees; biodiversity consideration; power line and utility info; areas over water can/should say on homepage -"not plantable area"; distinguishing between roadway flow vs floodplain; ability to remove factors that are skewing data (no soil info); wind in areas with no cover or protection; species that should be planted near each other -variety benefits; turning modules on and off or changing weighting of modules manually
- Print/export list with map of site
- A data output for every cell. A way to automatically update layers. Average cost of tree
- Maybe picture of trees. Is there any value for any planting "guidelines" that could come up?
- Pictures of trees? Or leaf? That would be interesting. Especially if community groups use this
- Export feature
- Ability to exclude trees not suitable for street trees
- Click directly from cell to output
- Height/width selections, evergreen vs deciduous
- Could for more user friendly use icons for shape of trees for example. Depends on user
- Ability to export data. Compatibility of cross-planting

Do you have any comments about the methodology explained during the presentation or concerns about limitations of the tool?

- No
- No
- Conflict between wanting tall street trees (for sidewalk clearance) and low street trees (for power line clearance)
- Wind risk and proximity to roads modules: double check soundness of what is good vs not as good
- Methodology explained very well. Well thought out. Novices seem to want absolutes and plant selection is very complex
- We gave a lot of recommendations for complementary resources and next versions, but I think you accomplished goal/intent of tool

Please provide any additional comments or suggestions regarding the tool's interface, usability and functionality.

- This is great and I can see using it with a few tweaks. Getting there! Thank you for your hard work!
- Very good start. Really helpful.
- The ability to turn the variable layers on and off might be useful
- Need to add urban soil
- Wording to explain numbers in the output table
- Larger fonts and better graphic design if possible
- Very usable for professionals. More info needed for homeowners to use
- Great learning tool for people