Innovating the Nantucket Tree Inventory

An Interactive Qualifying Project submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfilment of the requirements for the
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ABSTRACT

The goal of this project was to help the Nantucket Land Council enhance urban tree appreciation and maintenance records in downtown Nantucket. To do this, we established a tree inventory system that utilized GIS location-tracking technology and data collection procedures and created a mobile website prototype designed for public education on downtown trees. The inventory system led to several project deliverables, including a spreadsheet of tree data, a map displaying the GIS locations of each tree, and instruction manuals describing the inventory process. The mobile website prototype, "ACKnowledge the Trees," had both a tree scavenger hunt and an interactive tree tour mode. Recommendations were made for both the inventory system and mobile website for future project improvements.

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EXECUTIVE SUMMARY

Introduction

Trees are often overlooked in today's society. Trees provide numerous benefits, including shade, oxygen, and mental support, and as such they should be maintained properly and appreciated through educational materials. On Nantucket, the downtown trees add natural beauty and historical importance to the island.

Both the Nantucket Land Council (NLC) and Department of Public Works (DPW) promote tree maintenance and education on the island. In the 1980's, the DPW collected tree attributes such as tree species and height for all the downtown trees, and in 2016, that data was placed into a tree inventory spreadsheet. The NLC used this data to promote tree education by creating a brochure of the downtown trees and hosting public tree tours.

Mission, Objectives, and Methods

The goal of this project was to enhance urban tree appreciation and maintenance records in downtown Nantucket. To do this, a new tree inventory system containing reorganized data from the old DPW tree inventory and newly-collected data was created. The inventory is designed for multiple purposes, including marking each tree's location on a map of the island, historical and current data comparisons, and prototyping an engaging mobile website for tree education. The project was broken down into the following objectives:

1. <u>Improve the Nantucket tree inventory system</u> by identifying attributes to record in the new inventory, creating a data dictionary to collect the data, and organizing the tree data into an easily-accessible spreadsheet.
2. <u>Collect data on town trees in the downtown area</u> by collecting GIS locations and tree attributes for each tree, processing and entering the data into the inventory, and mapping the trees' GIS locations.
3. <u>Develop methods to promote tree education through interactive experiences</u> by developing a mobile website prototype that teaches users about the trees on Nantucket.

Results and Outcomes

The new tree inventory system was made up of components such as a list of important tree attributes, a data dictionary for recording the attributes, and a spreadsheet containing the collected data (**Figure 1)**. The inventory system can be used to create a map displaying tree locations, compare present and historical data, create instruction manuals for using the inventory system, and promote tree education via a mobile website.

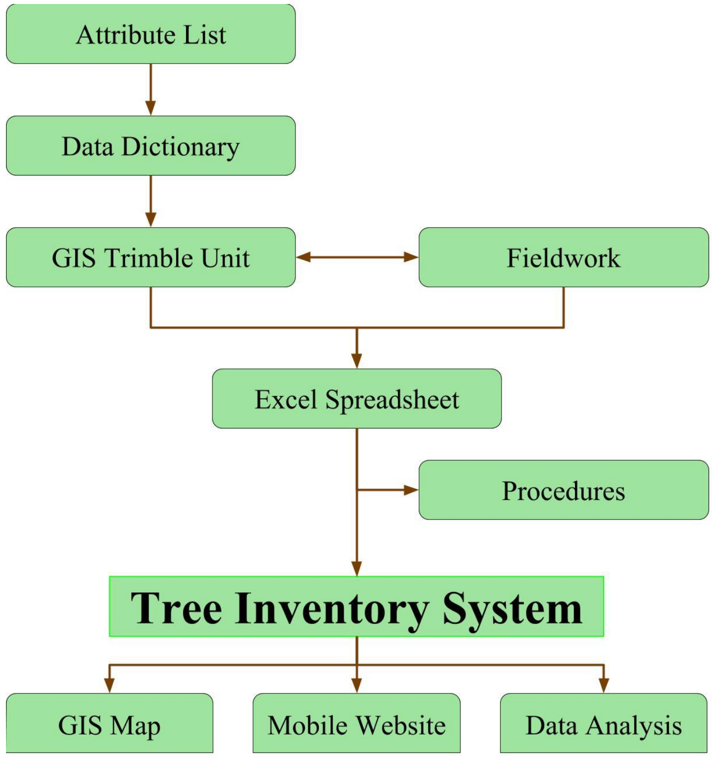

Figure 1: The components and products of the tree inventory system.

System Overview

The finalized attribute list, containing the most important data to record from each tree, is converted into an electronic format known as a data dictionary. The data dictionary is then installed on a GIS Trimble unit (**Figure 2)**, allowing the user to record attributes as the GIS coordinates of each tree are being recorded.

Figure 2: A GIS Trimble unit using the data dictionary for data collection in the field (Project Team Photo).

After collecting data, the data is exported into an Excel spreadsheet that serves as the tree inventory. A revised spreadsheet exists for easier interpretation and integration with applications such as the mobile website that can be edited at any time, allowing the NLC and DPW to easily modify the information.

The ACK Tree Inventory System Manual accompanies the tree inventory system and contains procedures that describe modification of the data dictionary, operation of the GIS Trimble unit, tree data collection, processing the collected data into a spreadsheet, and marking the GIS tree locations on a map, as well as supplementary materials such as a list of equipment needed and a tree identification chart.

Using the System

Once this inventory system was established, it could be used for many different purposes, including:

- Downtown Trees data layer - the GIS location of each tree can be marked on a map of the island (**Figure 3**)**.** The map can then be sent to the Nantucket GIS specialist for the creation of a data layer showing each tree's location as a point on a map on the Nantucket town website.

Figure 3: A GIS map that shows the locations of each tree surveyed. Each dot represents a tree, and the blue dots represent American elms.

- Data analysis - with the updated data in the spreadsheet, the NLC and DPW can observe trends in the downtown tree population using data from previous years, such as the historical tree data from 1986. An analysis example is shown in **Figure 4**.

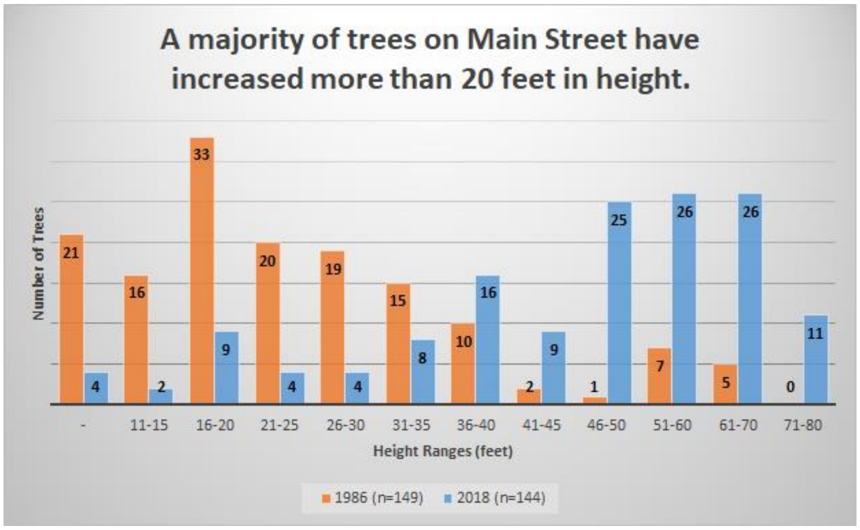

Figure 4: A bar chart comparing heights of Main Street trees in the 1980s and 2018.

- <u>Mobile website</u> - "ACKnowledge the Trees," the prototype for an interactive and educational mobile website about the downtown trees **(Figure 5)**, has both an interactive scavenger hunt ("Nantucket Tree Adventure") and a general tree tour mode. In the scavenger hunt, users follow clues to find specific trees and access that tree's information from the tree inventory. In the tree tour mode, users can tap on any tree in the area to access data from the inventory such as species, height, or when the tree was planted.

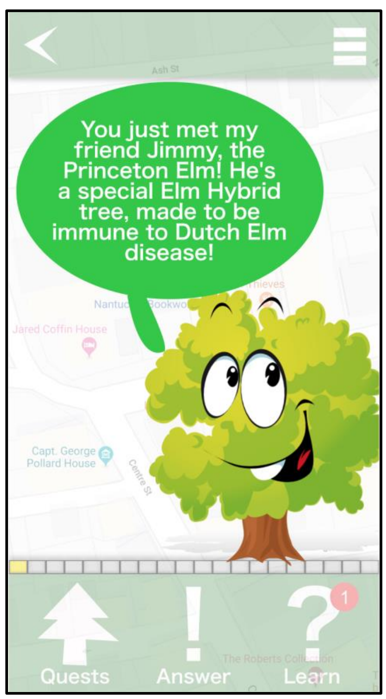

Figure 5: The tree guide "Oakley" who guides the user in the scavenger hunt of the mobile website.

Recommendations

The following recommendations are for the NLC and DPW to consider when continuing work on the tree inventory:

- Create new identification numbers for the trees - identify each tree with the street name and a unique number and make new medallions with this naming convention.
- Collect data in both summer and winter - identify the trees by their leaves in the summer and observe damage and maintenance issues more easily in the winter.
- Use the data analysis for maintenance plans - based on trends in tree growth, create maintenance protocols for specific tree species and individual trees.
- Proceed with mobile website development - add more functionality to the website, such as adding more quests for the scavenger hunt, making the tree identification flowchart interactive, connecting the website to an online version of the data spreadsheet, etc.
- Increase the advertisement of the mobile website - advertise the mobile website in the NLC's downtown tree brochure and in the Nantucket visitor's center, add a prize for completing the scavenger hunt, etc.

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1.0 INTRODUCTION

Trees are often overlooked in today's technology-driven society. We are so focused on enhancing our own lives that we often forget about the visual and environmental benefits nature provides. For instance, trees provide shade during hot summer days and supply materials to make paper and build houses. They also produce oxygen that we need to survive; urban forests generate enough oxygen for two-thirds of the U.S. population each year (Nowak, 2007).

On the island of Nantucket, trees can be found along many streets in the downtown district, as shown in **Figure 1**. These trees add natural beauty and historical importance to the island by becoming landmarks, increasing shade, and adding visual interest to streets. Due to the benefits they provide to residents, businesses, and the town, trees deserve to be recognized through educational material available to the public. To prevent the educational material from becoming outdated, attributes such as condition and height should be recorded bi-annually for each tree and placed in an inventory system. As each tree adapts to the changing environment, the inventory should be updated regularly, thereby providing correct and relevant data to be used in educational programs.

Figure 1: A cobblestoned Main Street featuring many different trees in downtown Nantucket (Project Team Photo).

The practice of creating a tree inventory for the benefit of arborists and public education has been implemented in many areas around the world. For example, in Worcester, Massachusetts, a team of WPI students catalogued native tree species into an interactive map in response to Asian long-horned beetles destroying the hardwood tree population. The catalog could then be used to determine if any trees were at risk of infection from Asian longhorned beetles and where new trees could be planted (Costello, 2010).

On Nantucket, the Department of Public Works (DPW) and the Nantucket Land Council (NLC) created a tree inventory containing attributes of trees in the downtown area, including species, height, and overall health **(Appendix A)**. Using the information from the 2017 inventory, along with their own knowledge about the trees, the NLC provided guided tree tours along many of the roads, as seen in **Figure 2**. On these tours, the history of the island trees and how they are preserved is explained to the participants (Nantucket Land Council, 2018f).

Figure 2: The NLC offering a downtown tree tour to the public (Nantucket Land Council, 2018f).

To enhance the tree tours, the NLC created a brochure describing the diverse tree population in downtown Nantucket, as seen in **Figure 3**. This brochure describes a self-guided walking tour as well as historical records and examples of common species in the downtown district (Nantucket Land Council, 2016). The NLC also hosts educational programs involving the school system and public classes to keep younger kids informed on the value of the island trees (Nantucket Land Council, 2018b).

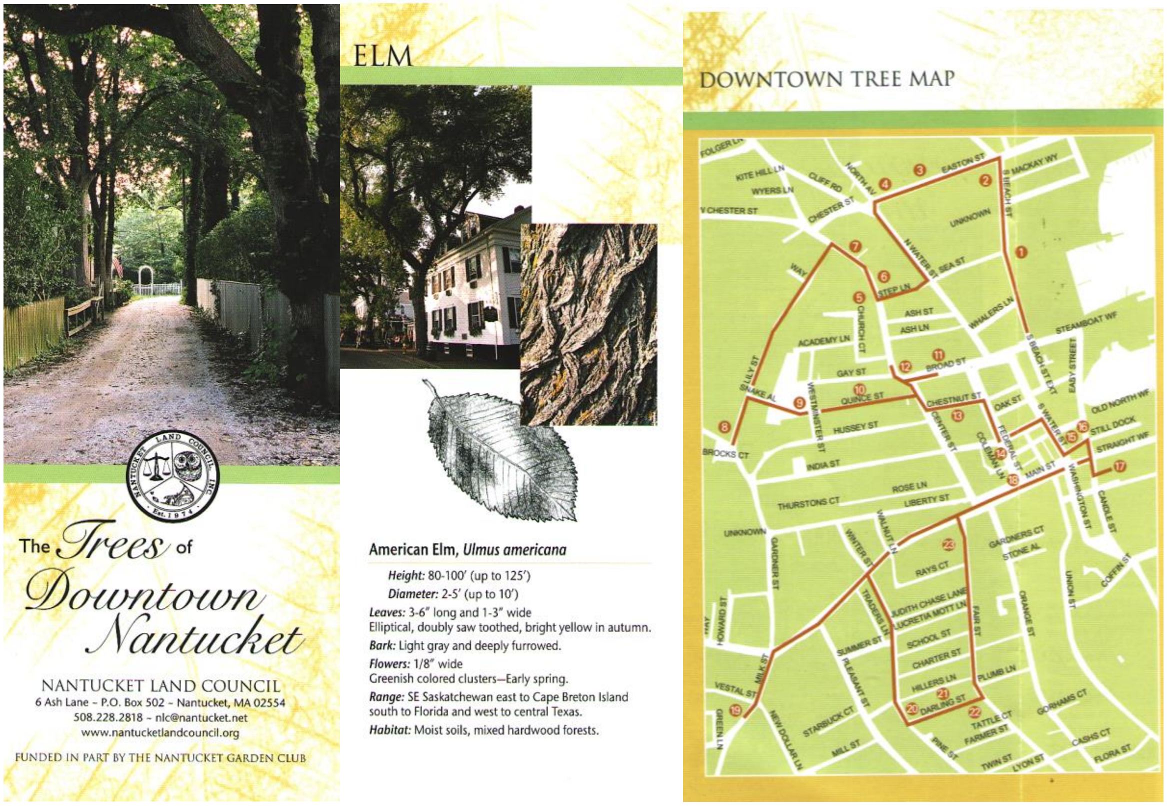

Figure 3: Excerpts from the "Trees of Downtown Nantucket" brochure, created by the Nantucket Land Council (Nantucket Land Council, 2016).

Despite the multiple downtown tree educational programs hosted by the NLC each year, there is still room for improvement regarding the tree inventory and educational programs. For example, the current Nantucket tree inventory is stored in many different forms and places within the NLC and DPW. In 2017, the collected data was transferred by the DPW to a spreadsheet, sampled in **Appendix A**, to make the tree data more accessible to the public. Updating the data presented in the spreadsheet and adding additional attributes would allow for missing data to be recovered and new data to be catalogued (365 Data Science, 2018).

The goal of this project was to increase awareness and maintenance of the trees in downtown Nantucket. The three main objectives identified by the team were to improve the Nantucket tree inventory system, collect data on town trees in the downtown area, and develop methods to further the education about trees through interactive experiences.

We worked with the NLC, our project sponsor, to fulfill these objectives. The NLC asked us to reorganize their current tree inventory by creating a new electronic version. The improved tree inventory blended GPS coordinates, data attributes, and pictures into a single system where data could be viewed and edited. Once we determined the attributes to record and how to record them, we traveled around the downtown area, recording tree data for the inventory. Since there were hundreds of trees to chart and the time allowed to complete the project was limited, we developed concise and precise procedures designed to be easily followed by future interns who would continue our work.

Although the new electronic inventory enhanced tree maintenance for the DPW and organized important tree data for the NLC, we still needed to work on increasing public education regarding trees. Therefore, we developed a prototype for an interactive mobile website that residents and tourists of all ages would enjoy. The website was proposed and developed to help people learn more about the trees on the island and encourage them to appreciate the benefits that trees provide (Molden, 2018).

2.0 BACKGROUND

The island of Nantucket has a comforting feel as you walk through the historic district, in part because of the trees that surround you. As a result, the trees and their health issues are of interest to residents, and thus tools to aid with management and education are important. In this chapter, research topics relevant to tree management and public education are presented.

2.1 A Brief History of Nantucket's Trees

Nantucket boasts a variety of tree species, many of which are scarce or absent elsewhere in New England. This section describes what trees grew on Nantucket in the past, how the tree population has since changed over time, and how certain trees have become important to the island in the present day.

2.1.1 Early History of Nantucket Trees

About 11,000 years ago, spruce and jack pine trees were dominant in Nantucket and common to the greater New England area. Nantucket was still part of the continent, meaning Nantucket trees were, at the time, all North American trees. 2,000 years later, when the post-glacial climate warmed up, spruce and jack pines were replaced by pitch pine, white pine, birch, and oak trees. Other tree species that sprung up during this time period included bayberry, beech, tupelo, maple, and hickory. These species are still found in protected areas of Nantucket today (Dunwiddie, 1989).

About 5,000 years ago, rising sea levels formed Nantucket Sound, turning Nantucket into an island. The rising sea levels and high shoreline erosion rates led to rapid island shrinkage. High winds and salt spray increased, causing the variety of trees in Nantucket forests to become restricted by saline-misted winds (Dunwiddie, 1989).

During European settlement, the pitch pine species was scarce on the island. However, the pitch pine population surged in 1847 when the pine species was reintroduced by Josiah Sturgis, and as time progressed into the 20th century, pines were planted all over the island (Dunwiddie, 1989). However, the spread of pitch pines introduced the Nantucket pine moth, which causes considerable foliar damage and sometimes even death to pitch pines. At first, the moth was confined to the island, but it soon spread to the mainland where it is still a major problem today.

Another disease that affected the island trees was Dutch elm disease (DED), which first appeared in northern Europe in 1918, and was first detected in North America in 1931. The disease could be easily transferred between trees, and many streets on Nantucket and Northeastern America were lined with elm trees at the time, so many American elms died from the disease. By the 1980s, some 77 million American elms had been lost to DED in North America, including Nantucket (Campanella, 2011). Fortunately, since Nantucket is separated from the mainland, fewer American elm trees died on the island than on the mainland, and many older elms can still be observed in the downtown district today (Dunwiddie, 1989).

2.1.2 Historically Important Nantucket Town Trees

In the downtown district, many historically important trees have been officially recognized by the town of Nantucket as “Town Trees”. Before the tree can become an official Town Tree, the Nantucket Tree Committee (NTC) must confirm that each tree meets at least one of the following five requirements:

- The tree was purchased, or its planting was paid for, by the Town;
- The tree stands on or has its trunk partially on Town-owned property;
- The tree was donated or otherwise conveyed to the Town;
- The tree has been maintained more than once by use of Town funds, equipment or personnel during the last 20 years, with the visits separated by more than one year; or
- The tree is marked with a Town tree medallion (Town tree designation, 1998).

Due to the large number of Town trees, the town has set aside money for tree planning and maintenance of Town trees since the 1900s. Assisted by the DPW, there are two full-time employees that are responsible for all the downtown trees.

To help the DPW inform the public about the Town trees, the Nantucket Land Council created a brochure shown in **Figure 3** that includes a walking guide showcasing some of the more notable Town Trees (Nantucket Land Council, 2016). One of the highlighted downtown species in this brochure is the American elm (Nantucket Land Council, 2016). At maturity, it arches skyward in a graceful vase shape, as seen in **Figure 4**. The American elm tree is the preferred sidewalk tree in the northeastern United States, as it is America’s “greatest shade tree” due to its wide-spreading branches, “arching growth, fountains of cascading leaves and light-dappled shade” (Leske, 2007).

Figure 4: An American elm tree (Msact, 2012).

After the Great Fire of 1846 burned down almost two-thirds of downtown Nantucket, American elm trees were planted on almost every street corner and remained there until Dutch elm disease (DED) attacked in the 1900s. Fortunately, since Nantucket is an island, it was possible to utilize disease prevention and pruning strategies to prevent the loss of all the island's American elms due to DED. American elms that were affected by the disease were replaced by elm hybrids; one such hybrid was the Buisman elm, an elm species cultivated from DED resistant trees in the Netherlands. However, these trees did not provide shade as well as the American elm trees did, both due to their shape being narrower and branches less arching, as seen in **Figure 5** (Nantucket Land Council, 2016). As of August 2007, about 300 elm trees remain in downtown Nantucket, both recently planted and centenarians (Leske, 2007).

Figure 5: A Buisman elm tree (Brinkerink, 2013).

2.2 Arborist Crash Course

An arborist is an individual that takes care of and can identify individual trees. This practice is valued in towns, universities, parks, and other establishments. As a major portion of this project revolves around the tree and its reputation on Nantucket, the building blocks of trees will be briefly explained. To further explain details about identifying and analyzing trees, a brief course on tree identification is presented below.

2.2.1 Basics of Tree Anatomy

“Tree” is a common word among nature enthusiasts, explorers, or anyone who has looked outside. However, each user has his or her own definition of a tree. A tree can be described as a large woody plant with leaves, bark, and branches. While this definition will produce the correct image, a more precise description of a tree states “a plant having a permanently woody main stem or trunk, ordinarily growing to a considerable height, and usually developing branches at some distance from the ground" (Tree, 2018). This definition dives into more detail yet still leaves some anatomy undefined.

Starting with the basics, the trunk of a tree is composed of multiple layers as seen in **Figure 6**. The outermost layer is the bark, which protects and stabilizes the tree. Working inward, the next layer is cambium. This is the part of the tree that produces new bark each year. The third layer is the sapwood, which carries water to the leaves. Further inward is the heartwood; these dead cells provide the main structure and support for the tree. Each layer of the trunk is vital to the survival and growth of the tree (United States Department of Agriculture, 2018).

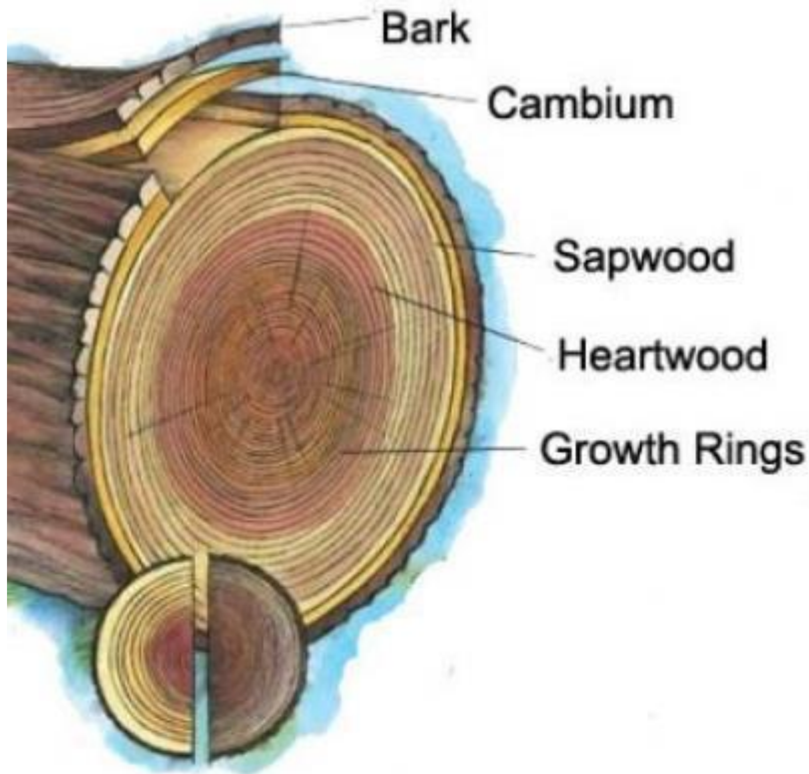

Figure 6: Diagram of the layers of a tree trunk
(United States Department of Agriculture, 2018).

Looking upward at the canopy of a tree, the focus falls on the leaves. While visually intriguing, these chlorophyll-filled leaflets also perform vital functions to keep the tree alive and healthy. Leaves use a process called photosynthesis to create glucose from light energy. This is essential because glucose is the main building block for growth processes and reproduction efforts within foliage. In addition, pathways that carry glucose, water, and other nutrients reside in the leaves (UC Davis, 2018). In combination with the pathways located in leaves, roots connect to those pathways after collecting nutrients from the surrounding soil (Westonbirt, 2018). Once absorbed, water and nutrients are carried through the pathways to the leaves to be used in photosynthesis (UC Davis, 2018). Roots also act as an anchor to the earth while stabilizing the trunk.

2.2.2 Tree Identification Techniques

The identification of a tree requires close observation of individual trees and their many parts. One way of distinguishing between tree species begins with separating the plant kingdom into smaller, more distinct groups based on shared physical characteristics. The correct order of classification for plants begins at phylum, which divides into class, order, family, genus, and species.

Once a major feature has been identified, it becomes a matching game; e.g., if the tree has vertically peeling bark, it must then be matched to the type of leaf that typically grow on trees with vertically peeling bark. Then, whether using traditional or technology-based identification methods, the corresponding leaf type, bark type, and crown shape can confirm the tree species. For example, as shown in **Figure 7**, the American beech has a light brown prickly fruit. Based on this observation, matching the leaf shape becomes less cumbersome, since the American chestnut and American beech have similarly shaped fruit. Trees with similar fruit are the American chestnut and American beech. However, they have different leaf shapes which makes them discernable from one another.

Figure 7: American beech tree leaves (left) and fruit (right)
(Ohio Department of Natural Resources, 2018).

Two major methods for tree identification exist: the traditional method of using a book and pictures to identify characteristics on each tree, and the newer method of using technological programs and imaging. The traditional method of tree species identification involves looking at the leaves, fruit, bark, and other attributes of the tree and finding them in a reference book. On the other hand, technology-driven tree identification typically works by taking a picture of a leaf from the tree. This image can then be compared to other leaves in a database in order to give the user options that match or are close to the tree species. The user may have to use manual identification to choose the correct species of the tree from the options the program presents.

While both methods are effective, amateur arborists may still experience difficulties when using either of the two methods. For example, when using the newer method, the technology may fail to recognize the picture taken and give the user indefinite or incorrect results. Likewise, limitations of using the traditional method include struggling to distinguish between two species that look very similar, and working with the altering appearance of fruit, seeds, and leaves of trees during seasonal changes; these seasonal changes may not be represented in the reference book that is being used and make it difficult to identify the species. Despite the method of identification, it takes practice to correctly and confidently discern a single species among a forest of trees.

2.3 Environmental Factors Affecting Nantucket's Trees

The variety of tree species on Nantucket can be attributed to several environmental factors that shape the landscape and flora. This chapter describes the conditions that Nantucket trees constantly endure, and the potential health issues they face. This information will help identify some of the key details that were included in the nature education part of our project.

2.3.1 The Impact of the Environment on Nantucket Tree Populations

Residents and tourists considering the downtown trees may question the distribution of species around the island. The distribution can be based on the environmental factors affecting flora, including trees. Major environmental conditions that trees must be resilient to include salt spray, poor soil conditions, and increased carbon dioxide.

Regardless of species or location, every tree on the island must constantly adapt to the changing climate. As the concentration of carbon dioxide in the earth's atmosphere increases, trees absorb more carbon dioxide and continue to grow. Certain trees are inherently better at taking in increased amounts of carbon dioxide, including the London plane, yellow poplar, and silver maple, three prominent tree species on Nantucket. These species will likely continue to thrive on the island as the concentration of carbon dioxide in the atmosphere continues to rise (American Arborists, 2018).

Another environmental factor is the Atlantic Ocean. Saline particles are droplets containing water and abnormally high concentrations of sodium chloride. They can be carried off the ocean surface by strong bursts of wind and deposited onto the coast, where they are absorbed into the soil (Williams, 1901). The particles can also be introduced onto the island soil via ocean spray or salt spray when strong water currents cause waves of salt water to crash onto the island, depositing saline particles along the coast and increasing their concentration (Appleton, 2015). Constant exposure to saline particles can drastically alter the way the trees grow. For example, saline particles can cause unnatural reproduction cycles for trees that are exposed to them, and the severity of the impact depends on a multitude of factors, including the frequency and duration of exposure to the particles, tree species, size, the amount of light available, temperature, and humidity (McCune, 1991).

Fortunately, several species of trees on Nantucket are resistant to the effects of saline particles. Horse chestnut, white ash, American holly, black walnut, sweetgum, and English oak can all grow in soil with increased saline particle concentrations (Appleton, 2015). All these species can be found in the downtown district, although sweetgum and English oak are more common to downtown area than the other species mentioned. These species are also commonly found in the hardwood forests surrounded by salt marshes and ponds in the northeastern section of the island (Nantucket Conservation Foundation, 2018).

2.3.2 Tree Health Issues

The Nantucket trees are not only affected by environmental conditions, but also by parasites and diseases. As shown in **Figure 8**, the Nantucket pine tip moth (NPTM) is a pest that affects many varieties of pine trees, including loblolly, pitch, Virginia, and ponderosa, especially if the trees are less than 25 feet tall (US Forest Service, 2011a; Dixon, 2017). Of all the different types of pine tip moths, the NPTM has the 2nd largest distribution in the United States. The NPTM mostly causes growth loss and stem deformity in pines, due to the larvae feeding inside growing shoots, buds, and conelets (Dixon, 2017). As shown in **Figure 9**, the damage is unsightly, but it seldom leads to tree mortality (US Forest Service, 2011a).

Figure 8: A pupa (left) and adult (right) Nantucket Pine Tip Moth (Rhyacionia frustrana life cycle, 2010).

Figure 9: A side by side comparison of a healthy pine (left) and an infested pine (right) (Anderson 2003).

Signs and symptoms of the NPTM include foliage discoloration (needles turning from green to reddish brown), dead or dying branch tips that are often curved or tipped, fine silk webbing on branch tips, and the presence of larvae or pupae. To manage the Nantucket pine tip moth, both preventive strategies, such as promoting early crown closure, and corrective strategies, like hand-pruning infested shoots and conelets, are effective (Dixon, 2017).

Another disease that affects Nantucket trees is Dutch elm disease (DED). It is a vascular wilting disease that is the leading cause of death for elms (Brazee 2017, Dutch Elm 2011). The disease can spread in two ways: through the native elm bark beetle or from diseased trees to nearby healthy trees through interconnected root grafts (Brazee 2017). The signs and symptoms differ between the two transmission methods. When transmitted via beetle, the leaves on one branch begin yellowing and wilting in a process known as flagging, as shown in **Figure 10**. Adjacent branches then begin flagging as the disease spreads, and the tree continues to lose health for a year or more until it dies (Dutch Elm 2011, Brazee 2017). In contrast, when the disease is spread through root grafts, the leaves wilt and turn brown, rapidly killing the tree. The tree is often killed during the same season it was infected (Dutch Elm 2011). Despite the differences, the characteristic symptom of DED is the presence of longitudinal brown bands or streaks in the outer rings of sapwood, as seen in **Figure 11** (Brazee 2017). Lab tests are needed to confirm the presence of DED, since the signs of the pathogen are microscopic (Dutch Elm 2011).

Figure 10: A healthy elm tree (left) compared to an DED infected elm tree (right) (University of Minnesota, 2018).

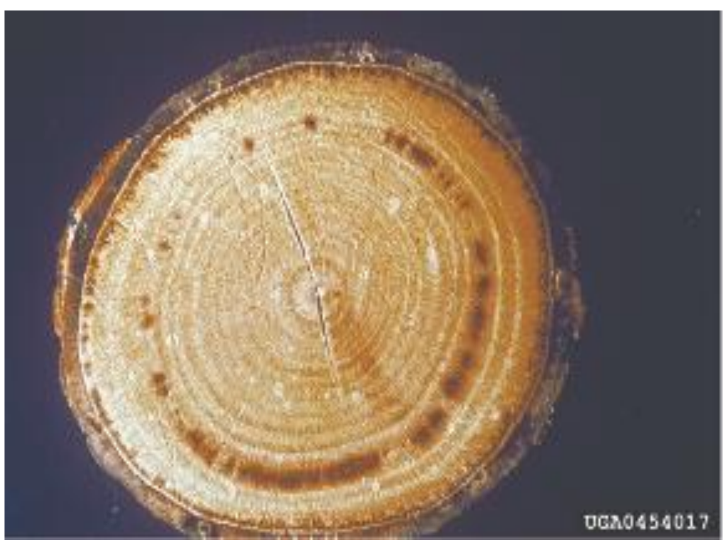

Figure 11: The characteristic brown ring of a tree infected with DED (DASNR, 2017).

Several strategies prevent DED from spreading between trees. Regular scouting for flagging prevents advanced disease growth. If flagging occurs, tree branches are pruned and bark is checked for brown bands. In order to prevent burrowing or fungi growth, quickly removing infected trees and eliminating all debris must be done. Annual or biennial preventative fungicide and mulch rings also protect young trees from DED. Breaking root grafts, although expensive, will prevent transmission via roots (Brazee 2017, Dutch Elm 2011).

2.4 Nantucket Land Council: Project Sponsor

Our project sponsor, the Nantucket Land Council (NLC), has played a major role in communicating the importance of tree preservation on Nantucket to residents and visitors. The NLC has completed many different projects since its inception, and its collaborations with other related groups have improved the recognition of tree species on the island.

2.4.1 The NLC and its Contributions

The Nantucket Land Council (NLC) is a non-profit organization dedicated to preserving Nantucket's natural surroundings and maintaining proper ownership of land on the island. In 1974, a group of Nantucket residents concluded that the island's environment was suffering due to the mistreatment of the land. Together, the island residents formed the Nantucket Land Council and have since preserved more than 1,400 acres of land across Nantucket, Muskeget Island, and Tuckernuck Island, which are shown in **Figure 12** (Nantucket Land Council, 2018c).

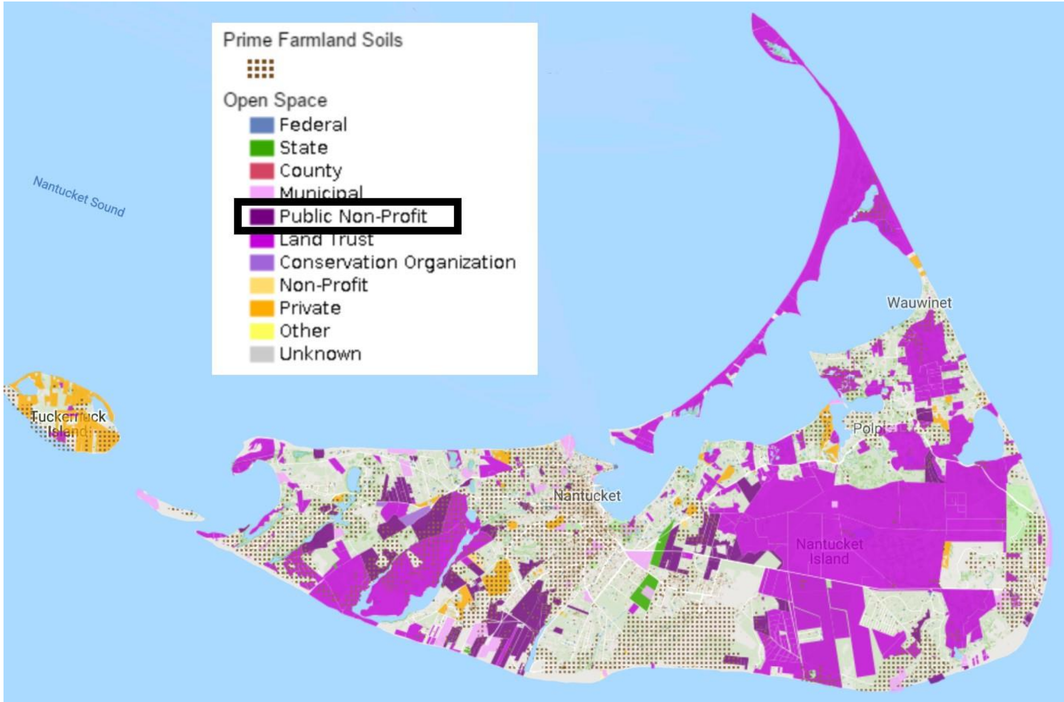

Figure 12: A map of conserved land on Nantucket Island (Town of Nantucket, 2018).

The NLC's overarching motto is "Planning, Protecting, Preserving." The organization **plans** educational events to spread awareness of Nantucket's natural surroundings. It **protects** land ownership rights by preventing larger institutions from acquiring and altering the landscape without legal permission. Finally, the NLC seeks to **preserve** the natural beauty of the island by researching land conservation methods (Nantucket Land Council, 2018a).

The NLC believes in the importance of education in conservation. The organization hosts many events to teach the Nantucket public about the natural beauty that spans the entire island. Some of these events include tree tours in the downtown district and oyster farm harbor tours located along Nantucket Harbor. In addition, the NLC offers academic scholarships and conducts school field trips for local Nantucket schools to teach students about conserving nature on the island (Nantucket Land Council, 2018b).

To preserve Nantucket's natural landscape, the NLC has researched environmental issues affecting life on the island. Specifically, the NLC has focused on Nantucket's water resources, including the Atlantic Ocean, Nantucket Harbor, and the local ponds, wetlands, and salt marshes. Over time, it became increasingly important for the NLC to observe the chemical composition of water on Nantucket. Many other research topics have been pursued by the NLC, such as the analysis of the green crab population in Nantucket Harbor, the restoration of eelgrass populations, and the improvement of the island's stormwater infrastructure. Most of these areas of study have required collaboration with other organizations, some local to Nantucket and others located in different parts of New England (Nantucket Land Council, 2018d).

2.4.2 Partnership with the DPW

One of the groups that the NLC has partnered with is the Department of Public Works (DPW). Since 2017, the NLC has been working with the DPW on improving Nantucket's stormwater system by closely studying the chemical composition of the rainwater to ensure that no dangerous chemicals have been emptying into Nantucket Harbor. The NLC has also suggested several solutions for preventing water blockage in the stormwater infrastructure, including forming dedicated rain gardens to use up surplus water or setting aside man-made wetlands to dump the water (Nantucket Land Council, 2018e).

The NLC also used the DPW's previous tree inventory projects as inspirations for new tree data collection in the summer of 2017. In 1986, the DPW identified trees using "data cards" containing information about each tree and medallions with unique ID numbers for each tree. The map the DPW created for the trees in 1986 is shown in **Figure 13**. In 2016, the DPW completed an official tree inventory, an excerpt of which is shown in **Appendix A**. Medallions with new ID numbers were placed on the many elm trees in the downtown area, and the data from 1986 was updated to accurately reflect the trees' current states. These projects helped guide the NLC's own data collection process for the trees in the downtown district. Although the data was lost when the equipment malfunctioned, the data collection experience helped the NLC understand the importance of recording maintenance-related tree issues as well as educational information (McNeil, 2018).

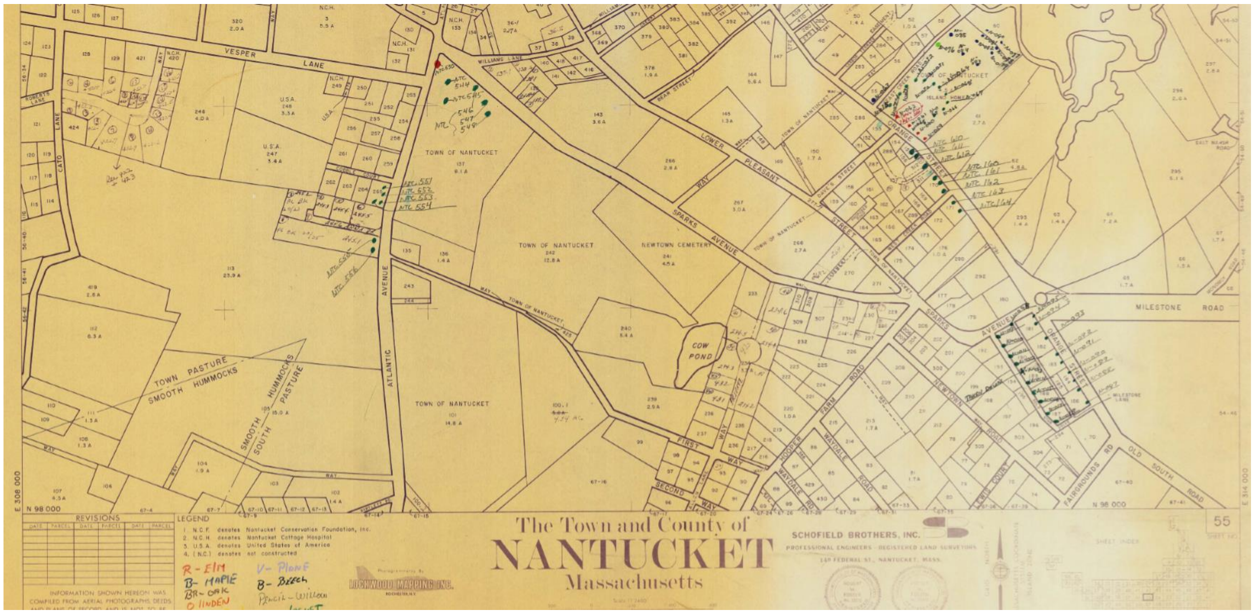

Figure 13: Map of Nantucket town tree locations (Town and County of Nantucket Mass, 1986).

2.5 Tree Inventory

One way to keep track of disease spread, prevention efforts, and management methods is to compile a tree inventory. A tree inventory is a database of information pertaining to the location, health, and species of trees in a specified area. Besides being a place to store data, a tree inventory also enhances maintenance and education regarding urban tree populations. Especially important in towns with large urban tree populations, inventories make it easier for personnel to update and review data on each tree. After an inventory is complete, it can be used for a variety of purposes including risk assessments, the study of storm-damaged trees, and the identification of town species composition (Nielsen, 2014). Enhancing the maintenance capabilities of the town and having a current and informative tree inventory leads to more informative educational programs and a better appreciation of the trees in downtown Nantucket.

2.5.1 Uses of Tree Inventories

The preservation of urban tree populations and education of local citizens are common goals of nature-focused organizations, and is done using brochures, tours, and the sponsorship of local events focused on environmental issues. Residents can learn how trees add value, produce oxygen, provide shade, and create visual interest for the town through local education events, and tree inventories can aid educators by providing data about the tree population and its health. Learning about the benefits that each tree species provides, as seen in **Figure 14**, will help residents appreciate what urban trees offer the community. A tree inventory is also helpful to town officials and groundskeepers for maintenance purposes. An increase in tree maintenance can positively affect the health and living conditions of island residents by increasing tree health and sidewalk conditions. For example, having detailed and organized information can support the scheduling of tree pruning and removal.

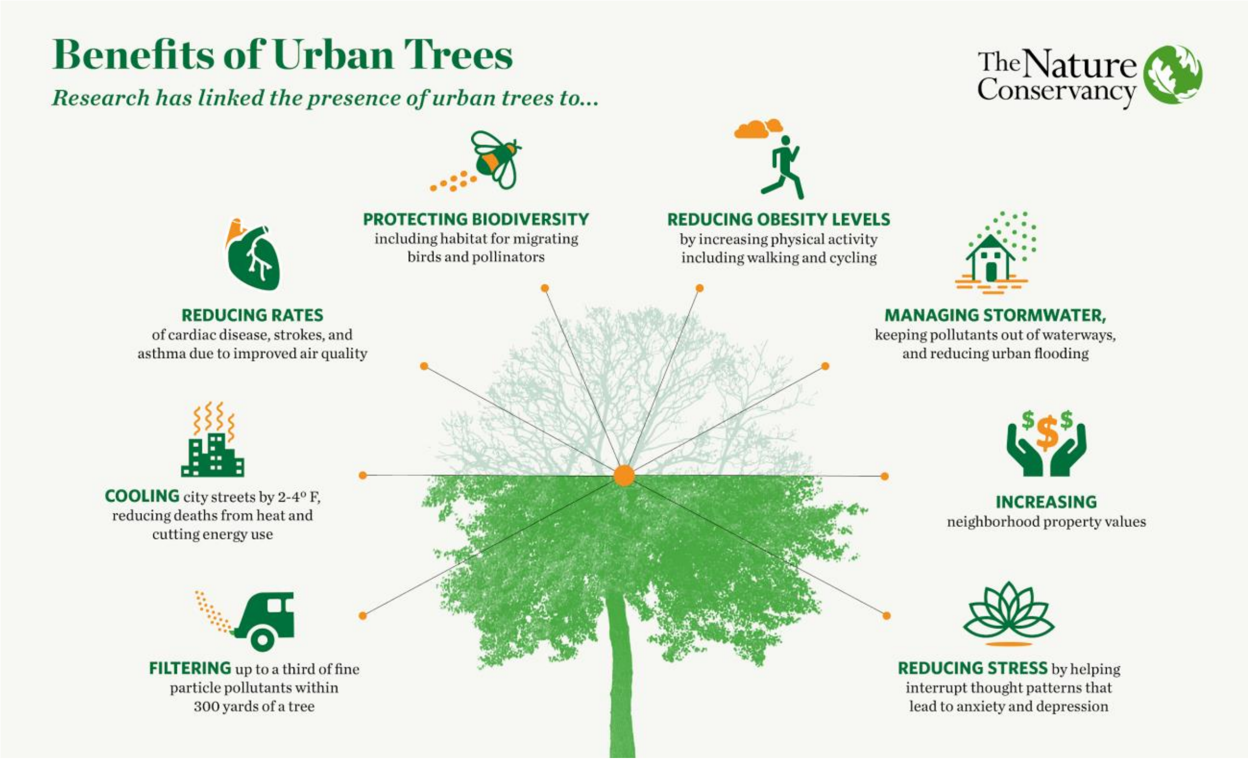

Figure 14: Benefits of Urban Trees diagram (The Nature Conservancy, 2018).

Along with the benefits of tree maintenance, information stored in tree inventories can be used to maintain town structures. As shown in **Figure 15**, maintenance items can include sidewalks, roads, power lines or buildings which reside close to the trees. Keeping track of the size and health of nearby foliage can prevent damage to structures and residents in the future.

Figure 15: Image of tree roots cracking adjacent sidewalk; coffee for scale (Project team photo).

2.6 Past Projects

Several previous projects looked at have implemented tree inventories, GIS software, and mobile websites. Some were completed by off-campus organizations, while others were examples of previous projects completed by WPI students. All the projects described below have served as inspirations for our mission to help enhance Nantucket's downtown urban tree community.

2.6.1 WPI Tree Inventory

The best model for our inventory design came from the WPI tree inventory. The inventory was completed by the Bartlett Tree Company for WPI facilities use. The WPI tree inventory utilized Arbor Scape, a GIS software package, and extensive field work to collect tree data. Since its completion, the inventory has provided WPI facilities with knowledge of maintenance needs that help them properly care for the trees (Carlsen, 2018). In addition, the inventory will be used to create a phone application for campus visitors. The comprehensive information of the trees would give the users a sense of importance that is currently lacking on campus.

A sample of the WPI inventory is shown in **Table 1**. Many of the attributes listed, including tree identification number (Tree ID), common name, and diameter at breast height (DBH), were important to record in our own inventory of the downtown Nantucket trees. In addition, the table below highlights the advantages of having both qualitative and quantitative data: numbers provide exact measurements for data analysis, while descriptive words are easy to interpret. The idea of having both qualitative and quantitative data played a key role in the downtown Nantucket tree inventory created (Carlsen, 2018).

Tree ID	Common Name	DBH (in.)	Risk Rating	Target	Priority	Assess ment	Pruning	Cable	Defect(s) or Observation(s)
659	Oak - Scarlet	52	Moderate	Side walk	1	-	Remove	-	• Co-dominant leaders • Poor branch structure • Overextended branch • Cavity - branch • Cavity - stem • Fungi/conks
664	Oak - Scarlet	34	Moderate	Sitting Area	1	-	Clean, Reduce	-	• Co-dominant leaders • Overextended branch • Wound - root flare • Wound - stem • Decay - branch • Decay - stem

Table 1: Section of tree inventory created by Bartlett Trees for the WPI facilities of the WPI campus (Carlsen, 2018).

2.6.2 Urban Tree Planning

In 2010, WPI students Anna Costello, Brandon Grace, William Seibold, and Matthew Wzorek completed an IQP project that established a tree database for Worcester, Massachusetts in response to an increase in Asian long-horned beetles. Asian long-horned beetles are known to feed on a variety of hardwood trees, including maple, birch, elm, and other species common to Worcester County. The group created the database to allow organizations such as the City of Worcester Forestry Department to monitor damage caused by the beetles and to protect trees endangered by them (Costello, 2010).

The WPI students populated the database with data about each tree gifted to Worcester residents in the affected area and recorded each tree's GIS location. They then displayed those locations on an interactive map with a software package called ArcMap. As shown in **Figure 16**, ArcMap enabled the students to couple the location of the tree with its attributes such as species, height, and damage or disease that may have been caused by the Asian long-horned beetles. This user-friendly map made it easy to see where in Worcester each of the gifted trees were precisely located and gave the town an updated sense of the tree population after the beetle infestation.

Figure 16: A small portion of the Urban Tree Planning group's interactive map. The dots represent the general locations of the trees (Costello, 2010).

Like the Urban Tree Planning project, we utilized GIS software to determine the location of each tree in downtown Nantucket. Although we did not create a map ourselves, we did optimize the collected data in ArcMap and sent it to the town GIS specialist so he could create the map.

2.6.3 Worcester Art Museum

In the spring of 2018, WPI students Peter Emidy, Sean Gillis, Spencer Herrington, and Ty Moquin created a mobile website to increase visitor interest in the Worcester Art Museum. They first brainstormed different website possibilities by sketching paper prototypes for their website. These early website design ideas were then converted to digital mockups using a software package called Figma, which allowed the students to stylize their prototypes and create the final design for each page (Emidy, 2018).

To create the final website, the group took the HTML and CSS code generated by the Figma designs and added interactivity between each page using JavaScript code. Some of the interactivity included switching between pages, playing an audio tour, and selecting tabs for different floors of the museum. **Figure 17** shows part of the final design of the website (Emidy, 2018).

Figure 17: Multiple pages, including Exhibits, Audio Tours, and Interactive Map pages created for the Worcester Art Museum website (Emidy, 2018).

This IQP served as a major inspiration for the mobile website prototype created for our project. Many of the core ideas behind the websites were the same, such as having multiple different pages and utilizing interactive maps. We used the HTML, CSS, and JavaScript code from the WAM project as a foundation for our own website structure. We built upon that foundation with our own user interface designs and additional functionality, most of which relied upon many benefits of GIS technology.

2.7 GIS Technology

A key area for this project was working with Geographic Information Systems (GIS) Software. GIS can gather, manage, and analyze location data. The data is analyzed and organized from layers and spatial location into 3D images and maps of the data locations (Esri, 2018). GIS software is the backbone of all GPS software used today and is implemented in almost every device around the globe, which is why we used it for our prototype mobile website to track a user's location and tell them about nearby downtown Nantucket trees. In this section, examples of GIS integration with phone applications and tree inventories will be discussed to explain potential utilization of GIS technology for our own project.

2.7.1 GIS Phone Applications

The most popular example of a GIS application (app) outside of GPS navigation software is Pokémon Go. This mobile app has been downloaded more than 800 million times between Android and iOS users. In this game, users travel the real world searching for virtual monsters to capture and train. Players then compete for domination of certain areas around the world, and the GIS software tracks information like player density and names of specific locations, changing the density of virtual monsters dynamically (Nintendo, 2016).

The clear attraction of Pokémon Go, outside of the popularity of the Pokémon brand, is the blend of the real world with the virtual world to create an immersive experience. Since we used GIS software to update the information of the trees, it is possible that GIS software could be used in an interactive experience and transformed into a game. Pokémon Go shows that people are more willing to be active and to participate in new experiences when interactivity is involved.

2.7.2 GIS Tree Inventory

One example of a GIS application for tree inventories is ArborPro. Founded in 2003, ArborPro provides a GIS tree inventory application meant for consumer use. ArborPro has millions of trees in their database, and they serve over 250 universities, parks, and recreational areas. ArborPro utilizes the latest in GIS technology to provide the user with an immediate visual representation of any tree in the urban forest (ArborProUSA, 2018). In **Figure 18**, examples of the ArborPro interface are shown, including the mobile unit used to collect data (left), an example of the map that may be created through the software (bottom right), and the screen that appears when data is being collected on a single tree (top right).

ArborPro attempts to be an intuitive GIS tree inventory program, trying to give clients a simple way to view and edit any information they take in on their tree inventory, on several different platforms and devices.

Figure 18: ArborPro Enterprise Edition (ArborProUSA, 2018).

2.8 Background Summary

Trees are without a doubt an important part of modern society. On Nantucket, trees such as the American elm have been officially recognized as Town trees and have become an integral part of island culture (Nantucket Land Council, 2016). These Town trees have changed over time due to changes in climate and the introduction of diseases like Dutch elm disease, resulting in a wider variety of species.

This diversity has inspired many island residents to maintain and protect the trees. Groups like the Nantucket Land Council have educated the public on the island trees and protected tree-populated land (Nantucket Land Council, 2018b). Other organizations such as the Department of Public Works have monitored the trees using an outdated tree inventory, allowing them to analyze tree damage and species composition (Nielsen, 2014).

However, more can be done to further promote tree management and appreciation. Using existing GIS models such as ArborPro, the location of each island tree can be recorded and placed into the inventory (ArborProUSA, 2018). Taking inspiration from previous Worcester Polytechnic Institute projects such as the WPI tree inventory and the Urban Tree Mapping Interactive Qualifying Project, tree data can be stored in a more comprehensive and efficient inventory.

3.0 METHODOLOGY

Mission Statement and Objectives

The goal of this project was to enhance urban tree appreciation and maintenance records in downtown Nantucket by establishing a new tree inventory system and developing an engaging and educational mobile website about trees. The project was broken down into the following objectives:

1. Improve the Nantucket tree inventory system.
    a. Research examples of successful electronic tree inventories.
    b. Identify the most important attributes to record in the tree inventory.
    c. Assess the current state of the Nantucket tree inventory, using the attributes as a guide.
    d. Use the assessment to design a data dictionary to collect the specified tree attributes.
    e. Organize the updated and new data into an easily-accessible spreadsheet.
2. Collect data on town trees in the downtown area.
    a. Identify the trial and final data collection areas.
    b. Identify GIS locations and collect tree attributes for each town tree in the trial area.
    c. Process the collected trial data and enter into the new tree inventory database.
    d. Develop a protocol for future data collection.
    e. Create instructional materials to aid future data collectors.
    f. Transfer the tree inventory data to the town GIS specialist for data layer creation.
3. Develop methods to promote tree education through interactive experiences.
    a. Research mobile website development techniques and ideas.
    b. Develop a mobile website prototype that not only teaches users about the trees on Nantucket but also engages the users in an enjoyable experience.

The order of these objectives is presented in **Figure 19**.

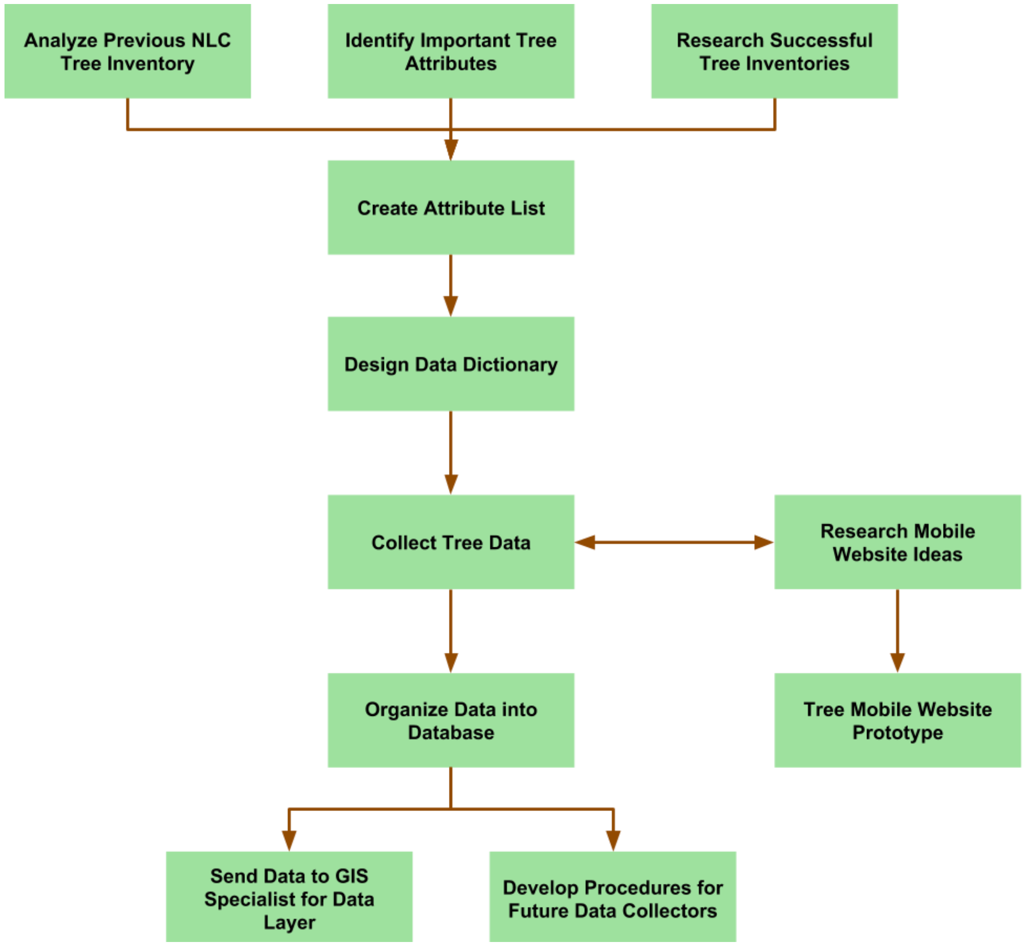

Figure 19: Project Methodology Outline.

The tree inventory was envisioned to be a tool for maintenance and educational use. Certain attributes about each tree were stored in the inventory, and each tree corresponded to a GIS data point on a data layer created by the town's GIS specialist. Giving residents access to all this information would be overwhelming and unnecessary, so to pass this information to the general public, educational material based on the tree inventory data was created.

3.1 Improve the Nantucket Tree Inventory System

Before updating the Nantucket tree inventory system, research was completed on other tree inventories that had accomplished similar tasks. Attributes recorded for each tree were evaluated and considered for inclusion when creating the final attribute list for the Nantucket tree inventory. In addition to research, the Nantucket Land Council (NLC) provided a preliminary list of attributes, shown in **Appendix B**, that they wanted to include in the final attribute list.

To complete the finalized attribute list, advice from local tree experts, attributes from the WPI inventory, attributes from the previous Nantucket inventory, and the list from the NLC were combined into what was called our attribute list. Once finalized, a specialized online format of the attribute list called a data dictionary was created. The data dictionary contained all our chosen attributes and organized the data so that each attribute was assigned a specific type of input method such as a text box for writing comments, a number box, or a drop-down list containing multiple predetermined options.

The data dictionary was then transferred to a GIS data collection unit provided by the NLC called the Trimble unit **(Figure 20)**. Once data was collected using the data dictionary on the Trimble unit, the data was exported from the Trimble unit and imported into the GPS Pathfinder software for processing. GPS Pathfinder could correct the GIS locations captured by the Trimble unit by reducing satellite interference and export the data as various file types, including an Excel spreadsheet. However, the exported spreadsheet had no column headings and some unnecessary data. Therefore, we modified that spreadsheet to streamline the data and make it easier for the NLC and DPW to download, access, and modify the database.

Figure 20: The GIS Trimble unit with the data dictionary for recording tree attributes (Project Team Photo).

3.2 Collect Data on Town Trees

The data collection area was determined by the Nantucket Land Council based on tree value, size, historical importance, and previous NLC data collection experience. This area was then reduced to a trial collection area by taking into consideration traffic, historical importance, and downtown location. The initial proposed data collection area is outlined in **Appendix C**, while the trial collection area was defined as Main Street.

Prior to data collection, the NLC and two DPW tree experts helped identify the species of trees in the trial area. This data was written down and later referenced when collecting GIS locations and attributes of the trees. Information regarding tree maintenance needs were also solicited from the DPW tree experts on an ask and receive basis. Due to the time-consuming nature of collecting the GIS location of each tree, information passed on from tree experts was entered into the database later.

The data collected from each tree in the trial area was then processed using the GPS Pathfinder software. Data was then exported as a spreadsheet to display the tree attributes and an ArcMap file to display the GIS tree locations. In the ArcMap file, after the coordinate system was finalized for all the tree locations, the file was then sent to the Nantucket GIS specialist. The GIS specialist then used the ArcMap file to create a data layer for the Town of Nantucket website. The data layer displayed the locations of each tree recorded with the GIS unit, as a dot on a map of the island. The data layer can be accessed by the public through the town website.

After collecting and processing the trial area data, multiple step-by-step procedures were developed that explained how to operate the Trimble unit, how to identify downtown trees, how to collect tree data with the Trimble unit, how to process the collected data in GPS Pathfinder, and how to prepare the collected data in ArcMap for input into the town GIS layer. Once we felt the procedures were understandable, they were given to a fellow WPI student to test. The student completed the procedures and gave feedback on the clarity of the directions. After each procedure was deemed repeatable and easy to follow, procedures were combined into a booklet so future interns could continue collecting data on the rest of the downtown trees with ease.

3.3 Develop Methods to Promote Tree Education

The final deliverable for this project was a prototype of a mobile website meant to educate the residents and tourists of Nantucket about the trees in the downtown area. We first researched mobile website development to determine what our design approach would be (i.e. if the mobile website would simply identify trees or provide a more interactive experience).

Through brainstorming sessions, we combined the research with our own website ideas to determine what we wanted the mobile website to accomplish. We sketched our ideas on paper and used an online program called Invision to create user interface (UI) mockups to show what the mobile website would potentially look like. Then, taking inspiration from the Worcester Art Museum IQP project's mobile website code, we created a semi-functional version of our UI mockup. Using HTML and JavaScript code, we implemented our core ideas about how the mobile website would operate, and we developed the website as far as we could during our time on the island.

Unfortunately, the seven-week time constraint meant the website could not be fully developed while we were on the island. Therefore, we also created a framework for how the website could be created with additional UI mockups and flowcharts for future design and creation. The framework included aspects of the mobile website that we wanted to include but could not due to time constraints, and some ideas for our sponsors moving forward if they wanted to hire professional website developers for the mobile website.

4.0 THE NEW ACK TREE INVENTORY SYSTEM

The creation of an inventory system begins with establishing a system framework. The system framework contains multiple components, each of which contributes a necessary function to the entire system. The inventory system contains all collected tree data and allows users to access the data in an Excel spreadsheet. This data can be used to create many different educational and maintenance-related tools. This chapter describes each component and some possible uses of the inventory system, as well as providing some recommendations for improving the system. The outline for this chapter is presented in **Figure 21** below.

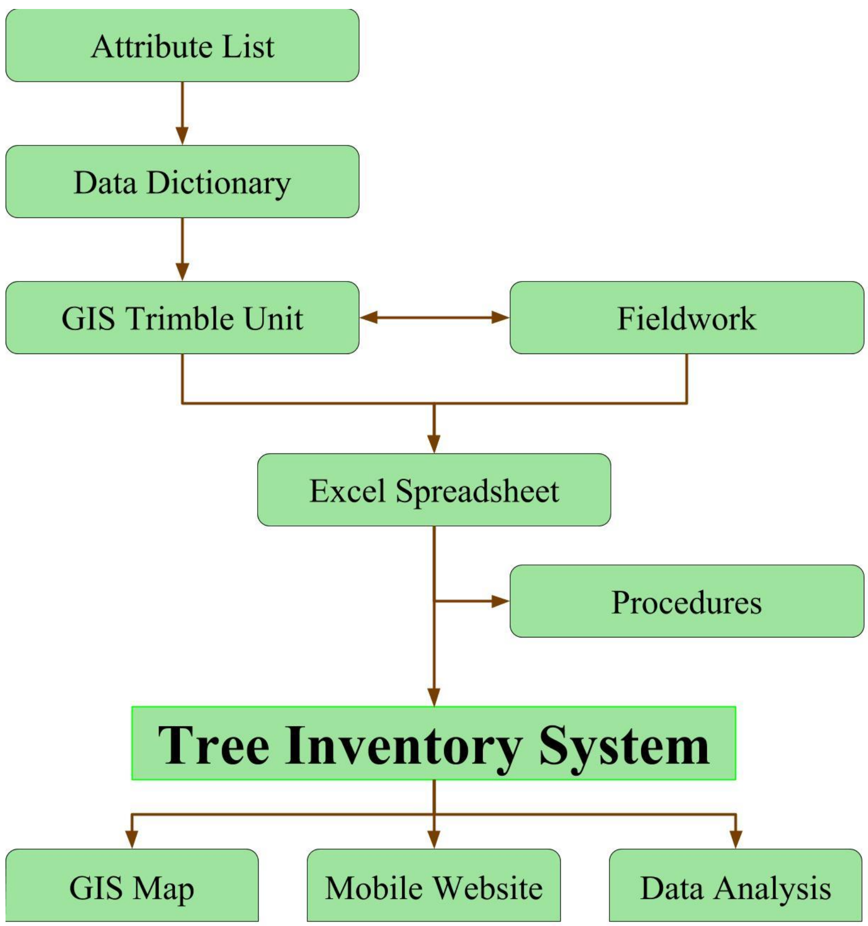

Figure 21: The tree inventory system structure.

4.1 Attribute List and Data Dictionary

The attribute list (**Appendix D**) is the first component of the ACK Tree Inventory System. It is organized into primary and secondary attributes. Primary attributes are prioritized by the NLC and DPW for data collection, whereas secondary attributes are less of a priority and could be entered by NLC or DPW staff later.

The primary attributes are:

- Felled? (if the tree has been cut down)
- New ID Number
- Existing ID Numbers (if available)
- Common Name, Genus, and Species
- Location
- Height (in feet)
- Diameter at Breast Height (DBH) (in inches)
- Tree Condition
- Tree Damage
- Maintenance Notes
- Other Comments

The secondary attributes are:

- Tree Type
- Sidewalk Condition (and photo if needed)
- Date Planted
- Last Sprayed, Fertilized, and Trimmed
- Diseases
- History
- If the tree is felled, can a new tree be planted here?

A digital form of the attribute list known as a data dictionary is created using a software package called GPS Pathfinder. In the data dictionary, each attribute has an input type. For instance, “species” has a drop-down menu with predetermined options, whereas “maintenance notes” has a comment box where a brief description can be entered. The data dictionary can then be transferred to the GIS Trimble unit, where it makes data collection easy and efficient. **Appendix E** shows the general concept of the data dictionary.

The data dictionary can hide certain attributes based on previously-collected attributes. For example, if a tree is felled, the data dictionary does not ask for the height or diameter of that tree. This functionality makes the data collection process faster than if every attribute had to be recorded for each tree. The data dictionary can be saved and manually edited in the GPS PathFinder software.

It is recommended to finalize the data dictionary before starting data collection. If the data dictionary is modified after data has been collected, such as if new attributes are added, that data will not be compatible with the new dictionary and will have to be updated manually, which is a time-consuming process.

4.2 GIS Trimble Unit and Fieldwork

The GIS Trimble unit is used for data collection in the field. It works in coordination with the GPS PathFinder software. In addition to using the data dictionary for fieldwork, the Trimble unit collects the GIS locations of data points by using satellites to pinpoint the exact location of the unit as it is collecting data. The location of each tree is recorded alongside the attributes specified in the data dictionary. This data is stored on an SD card within the device so the data can be accessed after data collection. **Figure 22** shows the GIS Trimble unit in action.

Figure 22: The GIS Trimble unit can record tree attributes and GIS coordinates of each tree (Project Team Photo).

Since future collectors may not be familiar with tree identification, there is a guide that serves as a "cheat sheet" for the genus, species, and tree type for each variety of tree in downtown Nantucket **(Appendix F)**. Since tree identification relies heavily on leaf structure, it is recommended that the tree inventory data be collected during the summer, when the leaves are on the trees. However, since large amounts of leaves can obscure damage and maintenance issues, the data should be revisited in the winter so these maintenance issues can be easily identified.

Also, each tree is identified using a numbering system. The previous systems use three-digit numbers to identify each tree, but there is no apparent order to any of the assigned numbers (**Figure 23**). Therefore, it is recommended that a new identification system with corresponding tree tags using the street name and a unique number be created. For each street, the ID number should begin with 1 and continue numerically until the last tree on the street is recorded. As an example, a tree on Main Street could be identified as “Main-37”. This identification system allows for a better visualization when looking at the data without the map and simplifies the process of locating each tree when conducting fieldwork.

Figure 23: The previous tree numbering system: some historical trees have the left medallion and some elms have the right medallion (Project Team Photos).

4.3 Excel Spreadsheet

Once collected data is transferred from the Trimble unit to the GPS Pathfinder software and corrected for any satellite errors, the data can be exported as multiple different file types for different programs, including Excel, Google Earth, and ArcMap. All file types make it easy to view the data depending on the type of information being sought. For a tree inventory, the best way to view and edit the data is in an Excel spreadsheet, as it is a useful tool for editing and organizing the data, creating charts for data analysis, and viewing the entire inventory at once.

The Excel spreadsheet contains all the trial area data and will contain all the data that will be collected in the future. There is another version of the spreadsheet, shown in **Figure 24**, that has been modified for easier readability and integration with other applications such as the mobile website. This spreadsheet can be edited at any time, making it easy for the NLC and DPW to update old information and add their own data. Other included Excel files contain the attribute list and an inventory log that keeps track of the data collector, date of collection, number of hours worked, ID numbers assigned, and streets recorded.

New ID Number	Historical ID Number	Elm ID Number	Common Name	Genus	Species	Location	Height (feet)	DBH (inches)	Condition	Is there damage to the tree?	Does the tree need maintenance?
Main-53	111	886	American Elm	Ulmus	americana	Private Land	61-70	28.7	Good	None	None
Main-54	112	876	American Elm	Ulmus	americana	Private Land	61-70	30.3	Good	None	Minor
Main-55	-	-	Black Walnut	Juglans	nigra	Sidewalk	36-40	6.8	Good	None	None
Main-56	-	874	American Elm	Ulmus	americana	Sidewalk/Roadside	61-70	25.8	Good	Minor	None
Main-57	-	-	Buisman Elm	Ulmus	minor 'Christine Buisman'	Sidewalk	36-40	14	Fair	None	None
Main-58	-	870	American Elm	Ulmus	americana	Sidewalk/Roadside	71-80	35.9	Good	Minor	Minor
Main-59	-	875	American Elm	Ulmus	Americana	Sidewalk/Roadside	71-80	28.9	Good	None	Minor

Table 2: A sample of the revised spreadsheet that contains all the collected trial data.

In addition to these files, the following recommendations may prove to be useful:

- A photo inventory of the downtown trees should be created and updated every year. This will help the NLC and DPW observe how each tree and its surroundings affect each other.
- The data should be updated at least every 2 years to monitor sidewalk and road damages that could be affecting tree health.
- A new Excel sheet should be created for each year of data collection. While the older data may be less important to aspects of the inventory system such as the mobile website, this data will be useful for future data comparisons.

4.4 GIS ArcMap

By exporting shapefiles from GPS Pathfinder and establishing the GIS coordinate system in the ArcMap software, a map displaying each tree's location can be created. This map, a portion of which is shown in **Figure 24**, will be integrated by the Nantucket GIS specialist with the town website for public viewing.

Figure 24: The ArcMap GIS map. Each icon represents an urban tree, and the blue dots represent American elms.

4.5 ACK Tree Inventory System Manual

To aid future data collectors, an organized booklet serves as a manual that accompanies the tree inventory system. The booklet contains supplementary materials, such as a list of equipment needed for each procedure, a tree identification chart, and procedures that describe modification of the data dictionary, operation of the GIS Trimble unit, tree data collection, processing the collected data into a spreadsheet, and marking the GIS tree locations on a map. **Figure 25** illustrates the general format of each procedure.

For data dictionary modification:

1) In PathFinder, to open the data dictionary:
- Select “Data Dictionary Editor” **(Figure 8)**.
- Select “File” at the top left and select “Open.”
- Select the data dictionary file (**.ddf**) to open.

2) Once the data dictionary is opened, all the attributes will be displayed in a list **(Figure 9).**
- To add a new attribute or modify/delete an existing attribute, select the correct button below the list of attributes **(Figure 10)**.

3) Add the new dictionary to the GIS unit:
- Insert the SD card into the computer.
- Select “Data Transfer” **(Figure 2)**.
- Select “Send.”
- Select “Add,” then choose “Data Dictionary.”
- Select the **.ddf** file to transfer.
- Select “Transfer All.”

4) The dictionary will now be accessible from the GIS unit during data collection.

Figure 8: The “Data Dictionary Editor” button is located on the leftmost taskbar, seventh button down.

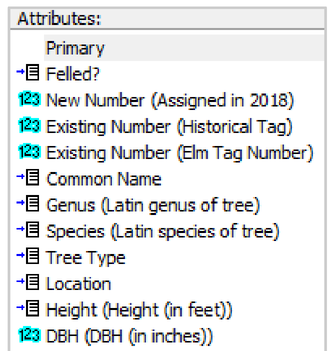

Figure 9: The attributes in the data dictionary will be shown in the right-hand column in the data dictionary editor.

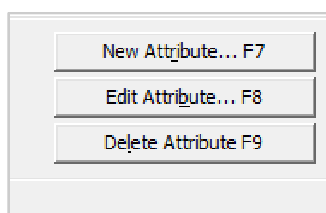

Figure 10: The buttons for adding new attributes or editing/deleting existing attributes are located at the bottom of the data dictionary editor window.

Figure 25: The procedure for data dictionary modification.
Each procedure was formatted in this style.

In addition to the manual[1], each individual procedure was printed on stock paper and laminated. The booklet serves as an “office copy” that will stay at the NLC office, whereas the individual laminated procedures will be used during fieldwork. It is recommended that a smaller “field copy” of the procedures be printed on cardstock, laminated, and bound together on a metal ring for easier use in the field.

[1] The ACK Tree Inventory System Manual is available at the NLC Office for viewing

4.6 Data Analysis

Data that has been collected and placed in the spreadsheet can be analyzed using Microsoft Excel. Comparing 2018 tree data to data collected by the DPW in 1986 can provide insight into the concerns, difficulties, and positives of downtown tree growth over the years.

One example of data analysis that may be of interest to the NLC is the composition of tree species of Main Street. The graph below (**Figure 26**) represents tree species composition on Main Street in 2018. This graph shows that while Main Street houses a variety of tree species, the main species are elm varieties.

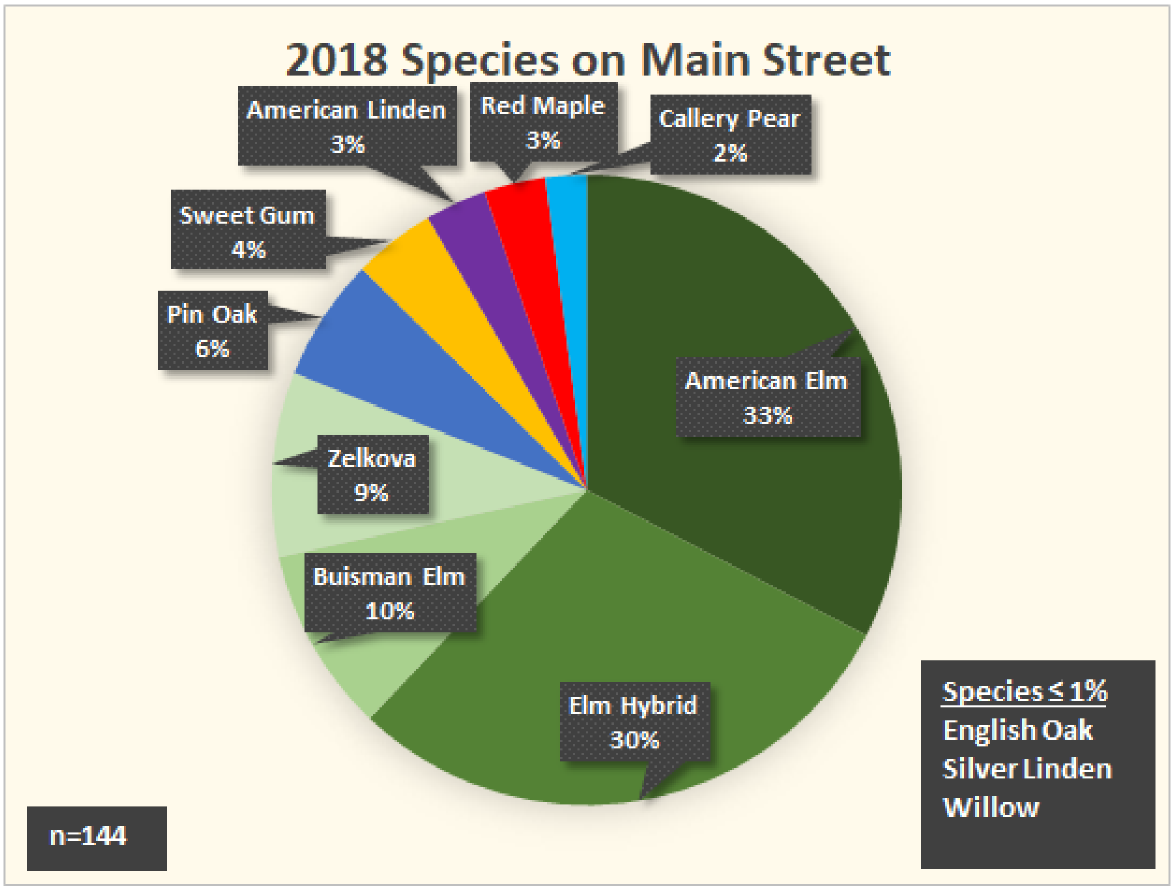

Figure 26: A graph comparing tree species composition of Main Street.
Green slices represent variants of elm tree species.

In addition to comparing the 2018 species on Main Street, the tree data from 1986 can be compared to the current data. A graph comparing the elm varieties from both data sets can be seen in **Figure 27** below. Each encircled species is a variety of elm. Over time, the American elms have been replaced with Dutch elm disease-resistant varieties to offset the amount of elms dying from the disease.

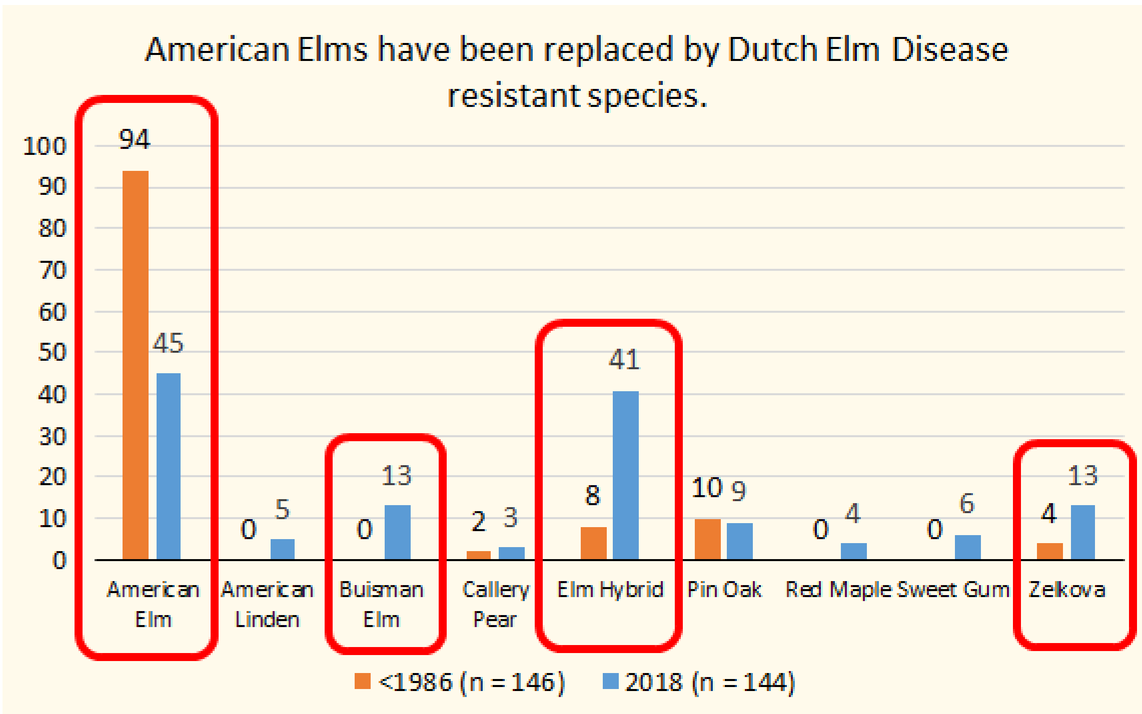

Figure 27: A graph comparing species composition of Main Street before 1986 and in 2018, with red outlining the variety of elms.

The new data also allows comparison between the average heights and DBH measurements of trees on Main Street from 1986 and 2018 (**Figure 28** and **Figure 29).** Both diameter and height are increasing to the point where they require special attention. While it is great that the trees are healthy enough to double in size and height, the data raises concerns about the maintenance needed to keep the trees healthy. Larger diameters and heights indicate that the tree is older and has the possibility of becoming less healthy, which can lead to increased susceptibility to disease.

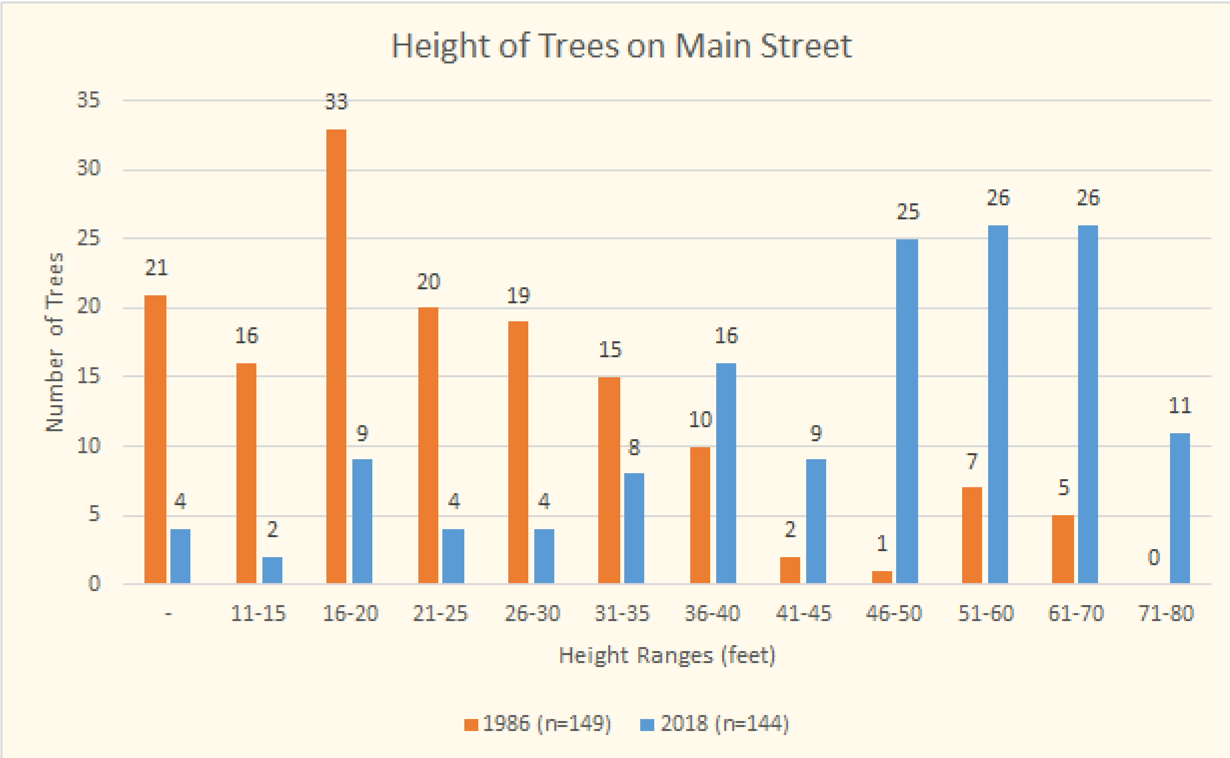

Figure 28: A graph that shows the average height distribution of trees on Main Street in the 1986 data set and the 2018 data set.

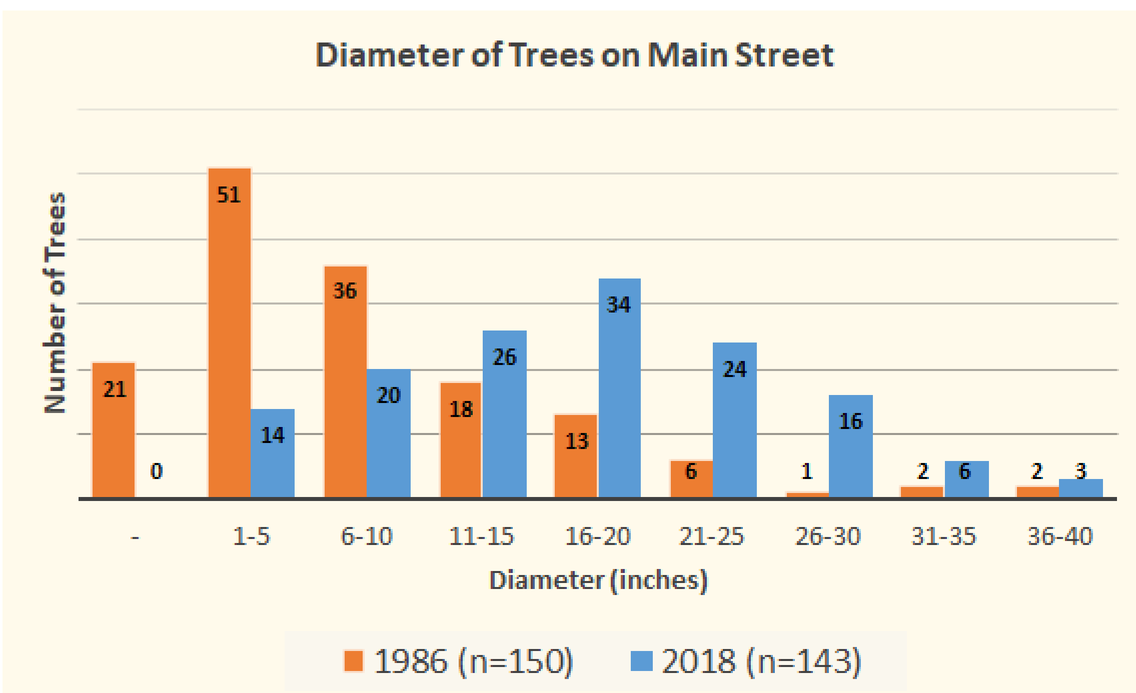

Figure 29: A graph that shows the average DBH distribution of trees on Main Street in the 1986 data set and the 2018 data set.

A similar historical comparison can be made between the same trees over a time period. In the graph below **(Figure 30)**, 10 trees that were documented over the past 30 years have increased in diameter at a steady rate. This is noteworthy because of the size increase for each tree that survived during this period.

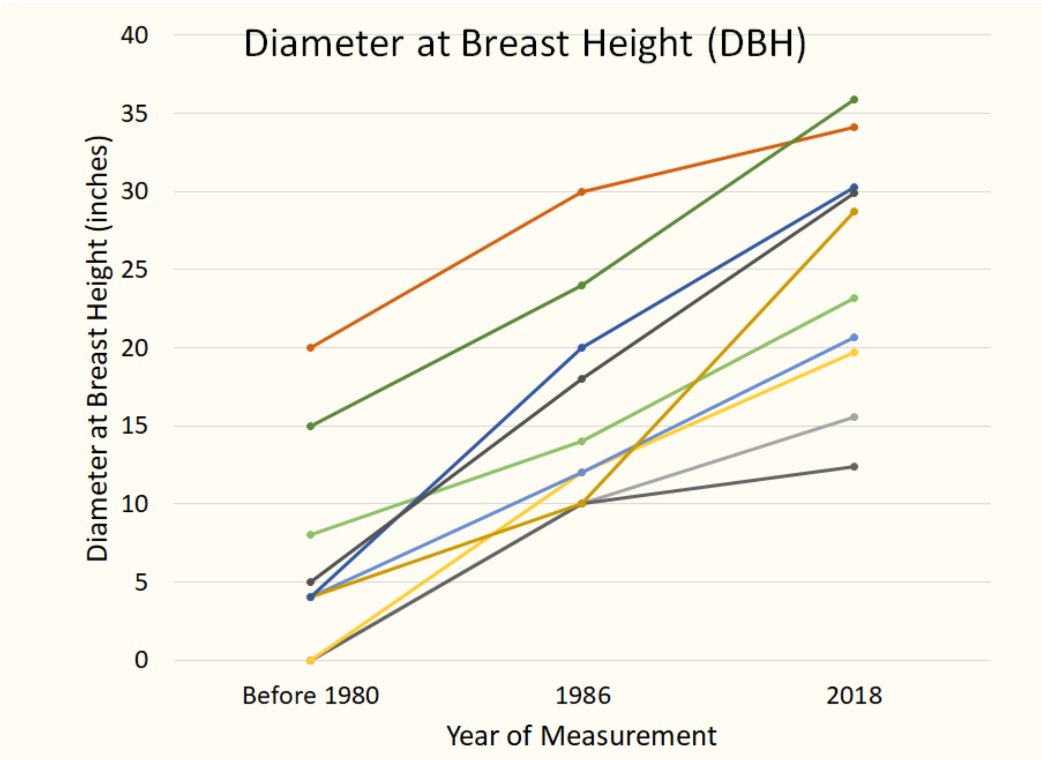

Figure 30: A graph that tracks the DBH of specific trees over time from the 1986 data set to the 2018 data set.

These are just a few examples of data analysis that the NLC and DPW can use to compare historical tree data to current tree data. It is <u>recommended</u> that both the NLC and DPW create maintenance programs based on these comparisons. For instance, the DPW could decide to monitor certain tree species or individual trees based on tree diameter and height change. The NLC could also use this information to highlight noteworthy trees on their tree tours and brochure.

5.0 “ACKNOWLEDGE THE TREES”

The mobile website prototype, “ACKnowledge the Trees,” serves as an educational tool for teaching island residents and tourists about the trees in the downtown district. This chapter describes the concept of the mobile website and the enhancements that can be made to fully develop it.

5.1 Mobile Website Overview

The mobile website has two main modes: a scavenger hunt mode called “The Nantucket Tree Adventure”, and a mobile tree tour mode. In the scavenger hunt mode, the user is given quests in which they need to find a specific tree and input the correct identification number for that tree. If the correct number is entered, the user gains a point and learns some fun facts about that tree. All this information is given to the user via a friendly cartoon tree guide “Oakley.” **Figure 31** shows a potential design for the scavenger hunt mode.

Figure 31: A potential layout for the scavenger hunt mode of the mobile website.

The other main mode of the mobile website is the tree tour mode. In the tree tour mode, the user can freely explore the downtown area using GIS location-based software. When the user taps on a tree on the map, a window explaining details about the selected tree, such as tree species and fun facts, is displayed. **Figure 32** below shows a potential design for the tree tour mode.

Figure 32: A potential layout for the tree tour mode of the mobile website.

GIS technology is integrated into both modes of the mobile website, tracking the user's location as they walk around the downtown area. Tracking user location is necessary for the mobile website, since the users should have to explore to find nearby trees.

A tree identification flowchart in which users can manually identify tree species can also be accessed from the mobile website via a submenu. The flowchart contains several questions for the user to follow, such as whether the leaves of the tree are serrated or whether the buds on the tree are round or pointed. Depending on the answers to these questions, the user will end up at a certain tree species.

The "Nantucket Tree Adventure" is tailored for younger audiences, while the Mobile Tree Tour mode is mainly for those who want to learn about the trees on their own. Either way, by using this mobile website, people can learn about the trees in downtown Nantucket. The user interface mockups created can be found here, and the actual prototype of the mobile website can be found here. (*Note:* the mobile website prototype was not designed with computer access in mind, so for use an actual mobile device for the best experience possible.)

5.2 Mobile Website Recommendations

5.2.1 Proceed with Mobile Website Development

The mobile website could not be fully realized because of the seven-week time constraint on the island. Therefore, there are many additions that can be made to further the functionality and create an even better educational tool for the public to use. Some of these possible additions include the following:

- Adding more quests to the "Nantucket Tree Adventure"
- Making the included tree identification flowchart interactive, such as being able to traverse the flowchart easily by entering responses for each question in a text box
- Connecting the website to an online version of the inventory without relying on fixed data in the code of the website

There are many other ideas besides those listed above that could be implemented into the mobile website by hired professionals. This project laid the groundwork for the mobile website, utilizing the core ideas of GIS location-tracking software and tree identification. Others could easily build upon this foundation with some of the ideas mentioned, allowing the mobile website to eventually become a major instrument in tree education on Nantucket.

5.2.2 Increase the Advertisement of the Mobile Website

"ACKnowledge the Trees" may become a popular educational resource for tourists and island residents. For people to discover the mobile website, it should be advertised to the greatest extent possible.

Flyers can be implemented almost anywhere, and these flyers could contain QR codes that lead users who scan them directly to the mobile website. These could be implemented in coffee shops, on boards throughout the downtown area, and feasibly anywhere flyers can be posted. The Visitor's Center could also be a great place to advertise the mobile website, as the website is a great example of family entertainment.

The Nantucket Land Council could even advertise the mobile website themselves by having winners of the "Nantucket Tree Adventure" come to the NLC office and receive a prize. This prize could be a sticker of a tree, a tree plush toy, or any other prize that would be fun to own. The scavenger hunt winners could then recommend the "ACKnowledge the Trees" website to their friends and family, increasing the entire user base for the website.

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APPENDIX A: Sample from Existing Nantucket Tree Inventory

This table contains a small portion of the previous Nantucket tree inventory that the DPW and the NLC shared with us.

LOCATION	NUMBER	SPECIES	DBH (in.)	HEIGHT (feet)	CONDITION	SPRAYED	FERTILIZED	DATE	COMMENTS
2 GOLDSTAR DR	N-011	HONEY LOCUST-NORTH	9 ¾	17	GOOD VIGOR	-	-	11/24/81	RAISED TREE AND GAVE HARD PRUNING 11/24/81
2 GOLDSTAR DR	N-012	HONEY LOCUST-SOUTH	8	25	GOOD VIGOR	-	-	11/25/81	RAISED BRANCHES AND GAVE HARD TRIM 11/25/81
GALEN AVE-LESEKE	NHT 81-875	LOCUST	3	15-20	GOOD	-	FALL 81'	-	PLANTED FALL OF 1981
GARDENER CORNER OF HOWARD AND GARDENER	NO 287	ELM	16 CAL	30 TALL	GOOD	3 TIMES 1956	-	9/6/56	REMOVED DIED 1982

APPENDIX B: Tree Inventory Data Collection Field

The following list of information was sent to us by the Nantucket Land Council. It explains the minimum amount of data we needed to collect from each tree, including ID number, species, location, and condition (Molden, 2018).

GPS location collected by TerraSync - 30 - 60 - or 90 count?

1) **Number**
   a) Existing tag number
      i) OTHER - comment box
   b) New number
      i) OTHER - comment box

2) **Species**
   a) American beech
   b) American elm
   c) American holly
   d) American Linden
   e) American sycamore
   f) Amur Cork
   g) Black walnut
   h) Callery pear (2-3 SSP)
   i) Crabapple
   j) Dawn redwood
   k) Elm hybrid
   l) English holly
   m) English oak
   n) FELLED
   o) Gingko
   p) Honeylocust
   q) Horse chestnut
   r) Katsura
   s) London plane
   t) Norway maple
   u) Silver maple
   v) Sweet gums
   w) Thundercloud Cherry
   x) Weeping beech
   y) White ash
   z) White willow
   aa) Yellow poplar
   bb) Yellowwood
   cc) OTHER - comment box

3) **Location**
   a) Sidewalk
   b) Sidewalk roadside

c) Sidewalk/private land
d) Private land
e) Road
f) Parking lot
g) Recreation area
h) OTHER - comment box

4) **Damage / disease**
a) N/A
b) Lower bark damage
c) Car damage
d) Broken limbs
e) Disease
f) Rot
g) Wires - trimmed
h) OTHER - comment box

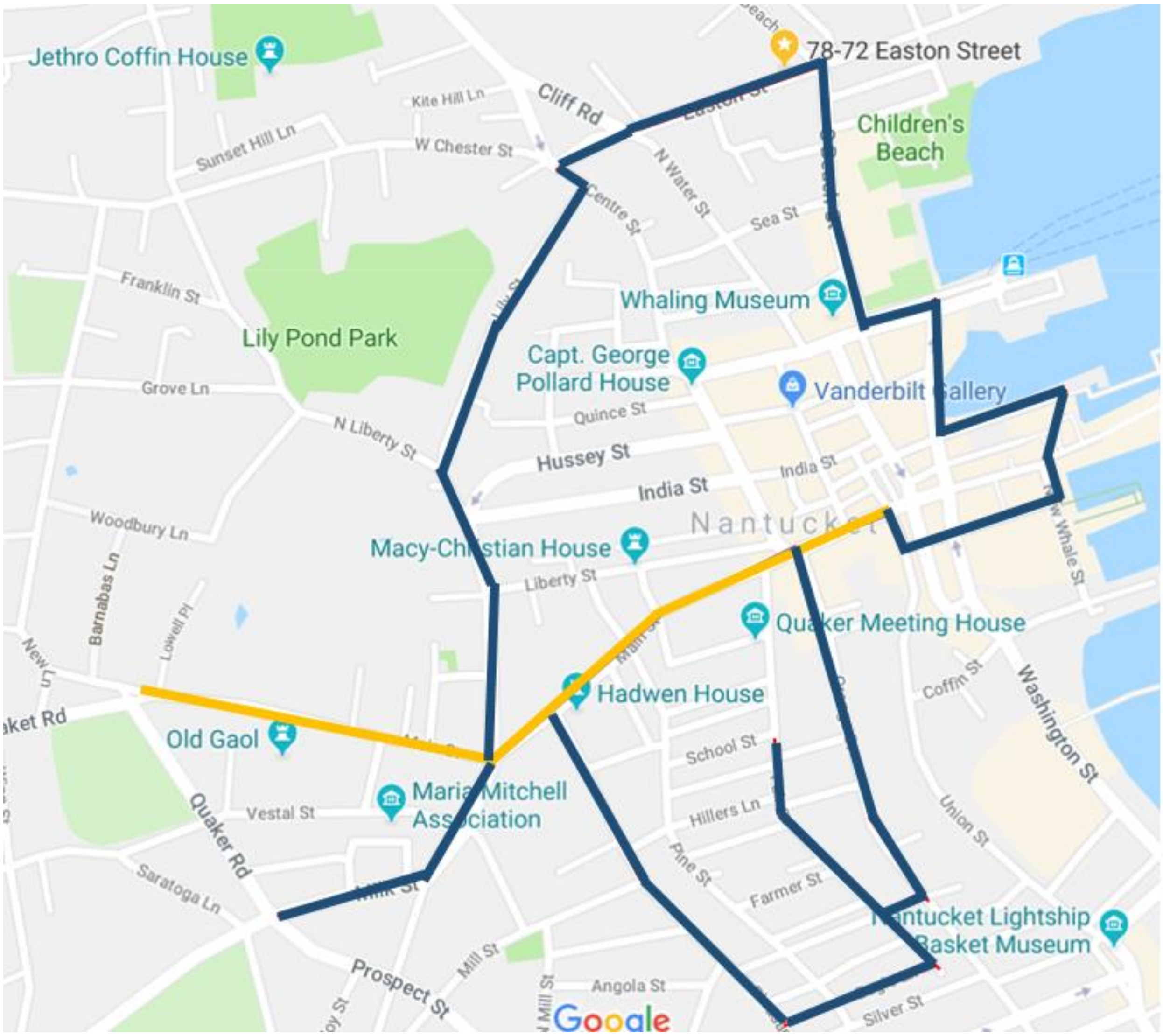
5) **DBH (Diameter at Breast Height)**
a) Number box

6) **Height**
a) Number box
OR
b) Range <5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-35, 35-40, 40-45, 45-50, >50, >60, >70

7) **Other notes**
a) Comment box

APPENDIX C: Downtown Nantucket Map

This map shows the boundaries of the downtown region (blue outline) in which trees could be surveyed, specified by the Nantucket Land Council. The highlighted orange street is the trial area of Main Street (Molden, 2018).



APPENDIX D: Tree Attribute List

This table displays the final attributes recorded. One asterisk (*) signifies primary attributes, two asterisks (**) signifies secondary attributes, and a plus sign ($^{+}$) signifies information that would be confirmed or collected from the Town Arborists or other sources.

Attribute	Description
Felled?*	Has the tree been cut down?
New ID Number (Assigned in 2018)*	Assigned ID number; part of the new numbering system
Existing ID Number (Historical Tag)*	ID number on the dull grey tag nailed onto the tree, with "N.T.C" carved in it
Existing ID Number (Elm Tag)*	ID number on the smaller, silver tags nailed onto the tree
Common Name*$^{+}$	e.g. American Elm, Zelkova, Sweet Gum
Genus*$^{+}$	Latin genus, e.g. Ulmus, Zelkova, Liquidambar
Species*$^{+}$	Latin species e.g. americana, serrata, styraciflua
Tree Type**	e.g. Shade, Ornamental, Evergreen
Location*	Where is the tree?
Height (in feet)*	How tall is the tree?
DBH (in inches)*	Diameter at Breast Height - the diameter of the tree trunk
Tree Condition*	Good = (mostly) healthy Fair = somewhat healthy; some damage/disease, may require some maintenance Poor = unhealthy; needs maintenance
Is there damage to the tree?* (Damage?)	Major = large frost crack/vehicle damage Minor = small amount of damage/damage that is partially/mostly healed None = No damage to the tree
Describe the damage**	e.g. broken limbs, vehicular damage, storm damage, frost crack
Is maintenance needed?*	Major = too much ivy, lots of low branches Minor = few low branches, little ivy, None = No maintenance needed

Maintenance Notes*	e.g. low branches need trimming, need guy lines, ivy needs trimming
Sidewalk Condition**	Good = a few loose bricks, otherwise fine Fair = raised sidewalk, missing/displaced bricks Poor = major curb/brick displacement, sidewalk obstruction
Describe Sidewalk Condition**	e.g. raised sidewalk, displaced curb
Sidewalk Photo**	A clear photo of the sidewalk
Date Planted+	When was the tree planted?
Other Comments*	Comments that don’t fit anywhere else
Last Sprayed**+	When was the tree last sprayed?
Last Fertilized**+	When was the tree last fertilized?
Last Trimmed**+	When was the tree last trimmed?
Diseases**	e.g. rot, DED
History+	Anecdotes, fun facts, history, etc.
New Tree?**	Could a new tree be planted in this spot?

APPENDIX E: Data Dictionary Table

This table represents how the data dictionary was structured. The default visibility option for each attribute is listed. On some of the attributes, when a condition is met - when a different attribute has a value equal to (==) or not equal to (=/=) an input - the visibility option is changed.

Attribute	Type of input	Possible inputs	Default Option	Condition Test	Conditional Option
Felled?	Menu (Radio Buttons)	Yes No	Required	-	-
New Number (Assigned in 2018)	Number Box	0-10,000	Required	-	-
Existing Number (Historical Tag)	Number Box	0-10,000	Normal	-	-
Existing Number (Elm Tag)	Number Box	0-10,000	Normal	-	-
Common Name	Menu (Picklist)	Names of common trees	Required	If "Felled?" == Yes	Normal
Genus	Menu (Picklist)	Genera of trees	Normal	-	-
Species	Menu (Picklist)	Species of trees	Normal	-	-
Tree Type	Menu (Picklist)	Types of trees	Normal	-	-
Location	Menu (Picklist)	Sidewalk Sidewalk roadside Sidewalk/private land Private land Road Parking lot Recreation area	Required	-	-
Height (in feet)	Menu (Picklist)	<5 41-45 6-10 46-50 11-15 51-60 16-20 61-70 21-25 71-80 26-30 81-90 31-35 91-100 36-40 >101	Required	If "Felled?" == Yes	Not Permitted
DBH (in inches)	Number Box	0-10,000	Required	If "Felled?" == Yes	Not Permitted
Tree Condition	Menu (Picklist)	Good Fair Poor	Normal	If "Felled?" == Yes	Not Visible
Is there Damage to the tree? (Damage?)	Menu (Picklist)	Major Minor None	Normal	If "Felled?" == Yes	Not Visible
Describe the damage	Comment Box	Text (up to 100 characters)	Not Visible	If "Damage?" =/= None	Normal

Is maintenance needed?	Menu (Picklist)	Major Minor None	Normal	If "Felled?" == Yes	Not Visible
Maintenance Notes	Comment Box	Text (up to 100 characters)	Not Visible	If "Damage?" =/= None	Normal
Sidewalk Condition	Menu (Picklist)	Good Fair Poor	Normal	-	-
Describe Sidewalk Condition	Comment Box	Text (up to 100 characters)	Not Visible	If "Sidewalk Condition" =/= Good	Normal
Sidewalk Photo	Photo Submission	Photograph	Not Visible	If "Sidewalk Condition" =/= Good	Normal
Date Planted	Date	mm/dd/yyyy	Normal	-	-
Other Comments	Comment Box	Text (up to 100 characters)	Normal	-	-
Last Sprayed	Date	mm/dd/yyyy	Normal	If "Felled?" == Yes	Not Visible
Last Fertilized	Date	mm/dd/yyyy	Normal	If "Felled?" == Yes	Not Visible
Last Trimmed	Date	mm/dd/yyyy	Normal	If "Felled?" == Yes	Not Visible
Diseases	Comment Box	Text (up to 100 characters)	Normal	If "Felled?" == Yes	Not Visible
History	Comment Box	Text (up to 100 characters)	Normal	-	-
New Tree?	Menu (Radio Buttons)	Yes No	Not Visible	If "Felled?" == Yes	Required

APPENDIX F: Tree Identification Cheat Sheet

This chart was included with the procedures as a guide to help users quickly identify the common name, genus, species, and tree type for each tree surveyed.

Common Name	Genus	Species	Tree Type
Ash	Fraxinus	americana (white)	Shade Ornamental
Beech	Fagus	grandfolia (american)	Shade
Callery Pear	Pyrus	calleryana	Flowering Ornamental
Catalpa	Catalpa	bignonioides (southern)	Shade Ornamental Flowering
American Chestnut	Castanea	dentata (american)	Shade
Cork	Phellodendron	amurense (amur)	Flowering
Crabapple	Malus	coronaria	Flowering Ornamental
Elm	Ulmus	americana (american)	Shade
		parvifolia (chinese)	Shade Ornamental
		buisman (minor 'Christine Buisman')	Ornamental
		minor 'Atinia' (english)	Shade
Elm	Zelkova	serrata	Shade Ornamental
Elm Hybrid	Ulmus	americana 'new harmony' (New Harmony)	Shade
		americana 'princeton' (princeton)	Shade
		davidiana var. japonica 'Prospector' (prospector)	Shade
Ginkgo	Ginkgo	biboba	Shade Ornamental
Holly	Ilex	opaca (american)	Evergreen Ornamental
		aquifolium (english)	Evergreen
Honeylocust	Gleditsia	triacanthos	Shade
Horse Chestnut	Aesculus	hippocastanum	Shade Ornamental
Linden	Tilia	americana (american)	Shade

		europaea (european)	Shade
		cordata (litteleaf)	Shade Flowering Ornamental
		tomentosa (silver)	Shade Ornamental
Maple	Acer	platanoides (norway)	Shade
		rubrum (red)	Ornamental
		saccharum (sugar)	Shade Ornamental
		saccharinum (silver)	Shade
Oak	Quercus	robur (english)	Shade
		acutissima (sawtooth)	Shade
		stellata (post)	Shade
		palustris (pin)	Shade
		rubra (red)	Shade
Pine	Pinus	clausa (scrub)	Evergreen
Poplar	Liriodendron	tulipifera (yellow)	Shade Ornamental
Redwood	Metasequoia	glyptostroboides (dawn)	Shade
Sweet Gum	Liquidambar	styraciflua	Shade
Sycamore	Platanus	occidentalis (american)	Shade
		acerifolia (london plane)	Shade
Walnut	Juglans	nigra (black)	Nut-producing tree Shade
Willow	Salix	alba (white)	Shade
Yellowwood	Cladrastis	kentukea	Shade Flowering