EVALUATING AND PRIORITIZING DUKE'S NATURAL LANDSCAPES

by
Marshall Upshaw
Siying Li

Dr. Clark, Adviser
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Advisor Signature: _____
Charlotte Clark

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Executive Summary

Institutions of higher education across the country are increasingly looking to better understand the natural landscapes on their campuses. Institutions are conducting full tree inventories, biodiversity surveys of specific areas of their campuses, targeting particular habitats to preserve, and more. But, none of the institutions examined during this study have developed a way of comparing the value of individual spaces on their respective campuses. To help Duke University better understand its natural landscapes, we created a framework that will allow decision makers on campus to compare the relative values of individual, undeveloped spaces on campus. This framework can be used in campus planning and landscape management discussions.

The developed framework consists of five major criteria: ecological value, programmatic/use value, cultural value, pedagogical value, and aesthetic value. Each of the five criteria is then broken down into various indicators, which are each given a score of high, medium, or low. The framework itself provides the users with explanations for what specific characteristics warrant a high, medium, or low for each indicator. Then, after all of the indicators are assigned a score, the framework produces an overall rating of that space. This rating is a number ranging from zero to one hundred, which is translated into a final high, medium, or low score for the space.

The framework was developed with input and oversight from the Duke Campus Sustainability Committee (CSC) and the Natural Resources Subcommittee (NRS). Members of the CSC and NRS, with a variety of both ecological and administrative backgrounds, provided feedback on criteria and indicator choices, as well as the characteristics identified for the high, medium, and low ratings. Selected members of the NRS filled out a series of comparison tables we provided them, following Analytic Hierarchy Process methods, in order to allow us to develop a weighting system for the five criteria and the indicators within those criteria.

In order to test our tool, we applied the framework to a test site on Duke's campus, Cameron Woods, a roughly 2.5 acre section of woods on Duke's West campus. The final result indicate that the test site study, Cameron Woods, is an area of medium value, based on the evaluation conducted using the framework. By applying the framework, we were

also able to make a few significant improvements to its functionality and usability, as shown in our full report.

The tool developed in this study is a user-friendly framework in an Excel document format that will allow a dedicated committee of campus experts to ascertain the relative values of one natural landscape on campus to another. These relative values will help Duke identify areas of campus that are particularly worthy of preserving and will help inform management decisions related to any evaluated site. The final scores given to sites using this framework can be incorporated into the many pieces of information used in campus management and planning such as the campus master plan.

This study makes several important recommendations:

- The framework presented in this report should be utilized by an officially formed committee in order to ensure that all evaluations of all natural landscapes on Duke's campus, using the framework, are consistent.

- Duke University should develop a system allowing faculty to register formal research plots on campus.

Duke University should use the framework presented in this report not only as a way of determining the relative values of natural landscapes on campus, but as a way of identifying natural landscapes that warrant more active management.

1. Introduction

Duke University is committed to making "decisions with the goal of improving the long-term quality and regenerative capacity of the environmental, social, and economic systems that support the University's activities and needs." (Duke University, 2005) To that end, University president, Richard Brodhead, appoints twelve administrators, twelve faculty members, and eight students to the Campus Sustainability Committee (CSC), annually (Duke University, 2014a). They represent a large group of stakeholders, including schools, various University departments, and campus student groups.

In 2014, Duke University further created the Natural Resource Subcommittee (NRS) of CSC to make recommendations on broad goals for natural resources planning and campus open spaces' evaluation. The Natural Resource Subcommittee has been tasked with developing a framework to gauge the relative health and importance of undeveloped campus spaces (Duke University, 2014b). For the purposes of this paper the terms "natural spaces" and "undeveloped" will be used interchangeably to refer to areas that are either unaltered by humans or are maintained to preserve their natural ecosystem "These are predominately the remnant woodlands across campus that have an identifiable boundary, a continuous tree canopy and no occupied buildings. They typically will have little or no active management or maintenance, but any ecologically rich landscape that contributes to the natural environment may fit into this category – even if maintained" (2014 11 27 interview with Mark Hough).

The NRS was formed and tasked with the development of this framework because Duke did not have a formal system to evaluate and prioritize undeveloped spaces on campus. Mark Hough (Campus Landscape Architect) and Bryan Hooks (Director Grounds Management) are chair and co-chair, respectively, of the NRS. NRS has members from the

Grounds Management Department, the Duke Forest, the Nicholas School of the Environment, the Sara P. Duke Gardens, and the Facilities Management Department—including our client, Sustainable Duke. See Table 1 for a complete list of members.

Table 1 Natural Resources Subcommittee Members

Name		Position
Mark	Hough	Campus Landscape Architect
Bryan	Hooks	Director, Grounds Management
Katie Rose	Levin	Ground Management
Ryan	Lavinder	Facilities Management
Sara	Childs	Director, Duke Forest
Bobby	Mottern	Duke Gardens
Curt	Richardson	Professor of Resource Ecology; Director, Duke University Wetland Center
Nicki	Cagle	NSOE Professor
Mark	Goodacre	Religion, Trinity
Ryke	Longest	Law, Duke Environmental Law and Policy Clinic
Scott	Winton	GPSC representative
Danielle	Su	EA representative
Siying	Li	NSOE graduate student
Marshall	Upshaw	NSOE graduate student

Our client for this work is Sustainable Duke—the official office of sustainability at Duke University. Sustainable Duke works to further efforts related to environmental sustainability on campus. As part of those efforts, Sustainable Duke holds seats on both the CSC and the NRS. Tavey Capps, Environmental Sustainability Director for Sustainable Duke and member of both the CSC and NRS, championed the use of this research to aid the NRS in their work for the 2014-2015 school year. This study, undertaken at the behest of the NRS, seeks to develop a framework that would allow Duke managers and planners to identify undeveloped areas of campus of particular ecological value and health. Furthermore, the framework will inform decisions about both the preservation of these spaces and the level of management they require.

This study has three main objectives:

- Define vocabulary relevant to undeveloped areas at Duke

- Benchmark processes at other institutions of higher education to determine best practices
- Develop a framework for evaluating relative value and health of undeveloped spaces and conduct a case study to test the framework as a tool for resource management

The framework concept, as suggested by the NRS, is a matrix of selected criteria used to evaluate natural spaces on campus. This matrix also contains sub-criteria and definitions, and explanations of items requiring clarity, and culminates in yes/no; high, medium, low; and numeric sections for the evaluator to complete. The resulting rating of the space enables campus decision makers to evaluate relative value and health of various undeveloped spaces.

2. Background

Duke University's master plan (Duke University, Office of the University Architect; Weinstein Copeland Architects; Hewitt Architects, 2000a) includes many layers of data, including transit, academic needs, and commercial development. However, a natural resource layer is missing among the existing components. The closest things to natural resources in the current planning process are the recognition that Duke should preserve the "University in the forest" feel and that the campus should be aesthetically pleasing (Duke University, Office of the University Architect; Weinstein Copeland Architects; Hewitt Architects, 2010b). The recognition that Duke should become more proactive about preserving and managing campus natural spaces had a direct impact on the formation of the NRS and in the formation of this research team.

2.1. Natural Spaces and Human Well-being

The monetary benefits of nature are well known. Our biosphere is estimated to provide roughly 94 trillion dollars of direct benefits to humans, when 2015 inflation values are

considered (Costanza et al. 1987). Within that set of benefits, the proportion allocated to general human well-being is much harder to quantify.

Studies have shown that exposure to natural or "green" spaces helps students concentrate on their schoolwork (Kuo & Taylor, 2004, p. [Page 371]). Exposure to green spaces has been linked to lower levels of stress (Thompson, 2012, p. [Page 221]). Furthermore, in order for benefits like those listed above to occur, the person must be fully immersed in the green space—a picture or video of a green space is not sufficient (Kort, 2006, p. 309). Such benefits provide strong reasons for preserving natural landscapes, particularly at institutions of higher learning.

2.2. Framework

In the context of our work, a framework is a matrix containing cells for the results (high, medium, low) of indicators, which contribute to larger criteria categories. It is intended to be used by project managers or other decision makers on campus who are trying to evaluate a specific tract of land, and is the final product intended for use by our client. Please see Appendix B for the final framework created in this study.

Frameworks are a common tool used in the fields of sustainability, ecology, and conservation. They provide a consistent and structured way for the reader and/or the user to evaluate a specific thing or place.

The U.S. Green Building Council uses a framework in its Leadership in Energy & Environmental Design (LEED) program (U.S. Green Building Council, n.d.). LEED is a means by which to evaluate the sustainability strategies and practices employed in new construction, building renovation, neighborhood development, and operations and maintenance (U.S. Green Building Council, n.d.). The result of this framework is a rating of bronze, silver, gold, or platinum.

A second relevant example of a framework is the Sustainable Sites Initiative (SITES), a program that registers "ecologically resilient" outdoor spaces and provides them with a rating of one to five stars (Sustainable Sites Initiative, 2015). This rating system may be used in concert with LEED, and allows the user to place an ecological value on their outdoor spaces.

3. Methods

The process of this study developed a vocabulary to define natural landscapes, examined other institutions' processes, and finally developed a framework for evaluating relative value of spaces in conjunction with a case study of one a small patch of woods located on Duke's west campus – Cameron Woods. The methods are divided into four sections: vocabulary, benchmarking, building the framework, and conducting the case study. The vocabulary and benchmark sections describe the process. The framework section addresses the benchmarking works, the methods found in the literature, and participatory approaches (interviews, etc.) in the design and development of the framework. The last section describes the methods of designing, data collection, and applying the framework in case study. Appendix E displays the dates and main themes from interviews we conducted and meetings we participated. At each interview or meeting, one team member was responsible for taking notes and sharing the notes to the other team member through a joint Dropbox folder.

3.1. Vocabulary Developing

To design the framework, we started by developing a vocabulary to define natural areas. First, through interviews and meetings, we developed and revised the definitions of land categories for Duke's campus and clarified the potential areas where our framework might be applied (2014 09 12 and 2015 01 06 interviews with Mark Hough & Tavey Capps;

2014 11 06 NRS meeting) (appendix E). Then, we reviewed the documents of existing practices on campus (the Campus Tree Program, the Storm Water Master Plan, the 2000 Master Plan, etc.) according to our client and NRS recommendations. We identified criteria that contribute to the culture and aesthetic values of Duke's campus from Duke University Landscape Design Guidelines and the 2000 Campus Master Plan (Duke University, 2014).

Furthermore, we conducted a comprehensive literature review on relevant papers and documents to identify criteria for the framework through online searches in academic journal databases. Since the framework aimed at evaluating the relative natural resource value of open spaces, we focused on reviewing academic papers and reports about ecosystem services evaluation, biodiversity, compensating mitigation framework, and campus sustainability assessment. We also browsed the publications focused on best practices for conserving ecosystem health, such as the key biodiversity components matrix in Business and Biodiversity Offsets Program (BBOP) developed by the Forest Trends (Business and Biodiversity Offsets Programme (BBOP), 2009), and high conservation values in FSC Principles and Criteria for Forest Stewardship (FSC, 2006). This review process produced useful insights and provided a large amount of information for our study, particularly regarding choosing proper criteria and indicators for the framework.

Prior to our study, Duke hired a consulting company, Andropogon Associates Ltd., to evaluate ecological use values for Chapel Woods during the 2014-2015 school year. We arranged an interview with the Andropogon consulting team on Nov 13 through our client. This interview lasts 2 hours, and focuses on their evaluation method (the High Priority Open Space/ Ecosystem Service Areas Criteria). After the interview, we made observations with them on the site (Chapel Woods) for approximately one hour to understand their methods of

on-site inventory survey. The Andropogon team provided a valuable perspective during the development of our framework.

3.2. Benchmarks with the Peer Universities

Before implementing a framework for Duke, our client wanted to learn how other similar colleges and universities address campus natural resource evaluations. We therefore began the process of looking for best practices, or benchmarking.

First, we identified a set of universities our client considered to be peer institutions. Our client suggested we start by looking at Ivy+ Sustainability Consortium member schools and expand our search after exhausting those sources. The Ivy+ Sustainability Consortium[1] is a collective of institutions of higher education committed to reducing greenhouse gas emissions from campuses and sharing innovations and research practices related to campus sustainability. The Ivy+ group of universities shares similar goals in both academic and sustainability initiatives. Our client also suggested that we look at Dalhousie University's Natural Environment Plan, based on a suggestion from a colleague of hers at the University of North Carolina. They suggested Dalhousie's plan was closely like what the CSC and Sustainable Duke were looking for. We added Dalhousie University's Natural Environment Plan as another comparison school.

To obtain information, we collected material culture and conducted interviews. For each of the Higher Education Institutions, we searched the respective institutions sustainability and master plan websites. We particularly focused on finding content related to inventory systems that identify features and values of campus spaces. We further interviewed

[1] The Ivy + group is a subset of the Consortium on financing Higher Education, including Brown University, Columbia University, Cornell University, Dartmouth College, Georgetown University, Harvard University, Johns Hopkins University, Massachusetts Institute of Technology, Princeton University, Stanford University, University of Chicago, University of Pennsylvania and Yale University. Retrieved from http://sustainability.yale.edu/people-partners/strategic-external-partnerships/ivy-plus.

institution sustainability and natural resource departments via email. We prepared the interview questions and email content, and Tavey Capps sent the email to all the Ivy+ Schools and to other universities with which she has regular contact. Other schools that Tavey reached out to were major universities in the same part of the country as Duke—The University of Chapel Hill is an example of one such school. The interview guide contained the following questions:

- Do you have a campus-wide document used in the evaluation of outdoor spaces?
- Do you have any kind of natural resource inventory of your campus? This could be anything from a list of types of habitats found in various parts of your campus, to a GIS map with different features in different layers.
- If you do have either of the items listed above, how does your campus use them in the decision-making processes of campus planning?

We found relevant web-based data on Cornell and Dalhousie University websites, and obtained email responses from Stanford University, University of North Carolina, the University of Kentucky, and Cornell University. We combined results from the material culture research and from the email interviews.

We considered sending out a follow up email, but the University of Kentucky sent out a similar email query the shortly before our email went out, with no more responses than we got. They sent out the email on December 18th (ours was sent out on the 19th) to help inform their campus Landscape Guidelines document. Because the University of Kentucky did not get any responses that we had not already gotten ourselves, we decided that the schools that were likely to respond had responded.

The following table shows the various ways we collected data from schools. Schools that responded to the email as well as schools with web resources that were deemed relevant are included. The material culture we gathered during this process was carefully reviewed for relevant information about how the school does the following: gathers information about campus natural resources, analyzes information about campus natural resources, makes decisions based on natural resources on campus, and shares the information they have related to natural resources on campus with the campus community.

Table 2 School Data Collection

University	Web Resources	Email Response	Natural Resource Plan
Cornell University	✓		✓
Dalhousie University	✓		✓
University of Kentucky		✓	
University of North Carolina		✓	
Stanford University		✓	✓

3.3. Framework

After the literature review and benchmarking works, we began the building process for the evaluation framework.

Much of our data and information were gathered through periodic planning meetings. We participated in five monthly NRS meetings (Nov 6, Jan 9, Feb 3, Mar 2, and April 6) and three CSC meetings (Dec 2, Jan 23, and April 14), and presented our progress to date for discussion and input prior to each meeting. CSC members made recommendations to guide the direction of the framework, worked with Sustainable Duke staff, and facilitated

communication of our group's work and results to the stakeholders they represent (Duke University, 2014b; 2014 12 02 & 2015 02 23 CSC meeting). The Natural Resources Subcommittee reviews and makes recommendations based on goals for the evaluation (Duke University, 2014b; 2014 11 6, 2015 02 09, 02 03 & 03 02 NRS meetings). The Subcommittee provided information and suggestions for the framework criteria for evaluating and prioritizing campus landscapes, and for identifying values that are important to inform decisions for the stewardship of Duke's natural spaces and ecosystems.

In some ways, the data we gathered during meetings was observational in nature and in others we asked direct questions for feedback, making these meetings more like script-guided interviews. As needed, at least one of the team members took notes at each meeting and shared them with the absent research partner on Dropbox. We also met individually with the Subcommittee members listed in Table 3. All members were invited to contribute ideas for indicators that they felt were important for Duke's campus. They brought valuable experience and knowledge to the study. The team members met before each meeting and interview (appendix D) to prepare materials, and also to control the overall process and direction of the project. The length of team meetings depended on the context and time availability.

Table 3 In Person Meetings with Subcommittee Members

Name		Title	Date
Sara	Childs	Director, Duke Forest	11/10/14
Katie Rose	Levin	Grounds Management	12/08/14
Dr. Nicolette	Cagle	Nicholas School of the Environment professor and naturalist	1/23/15
Scott	Winton	Duke Graduate and Professional Student Council representative	2/06/15

We gathered information from NRS members in these interviews—both from their proposed suggestions and from their answers to specific questions we prepared before interviews. They provided recommendations, which helped us to identify key criteria for designing the framework, and suggested sources to collect documents and existing data files (GIS, etc.) for the determinants of the evaluation.

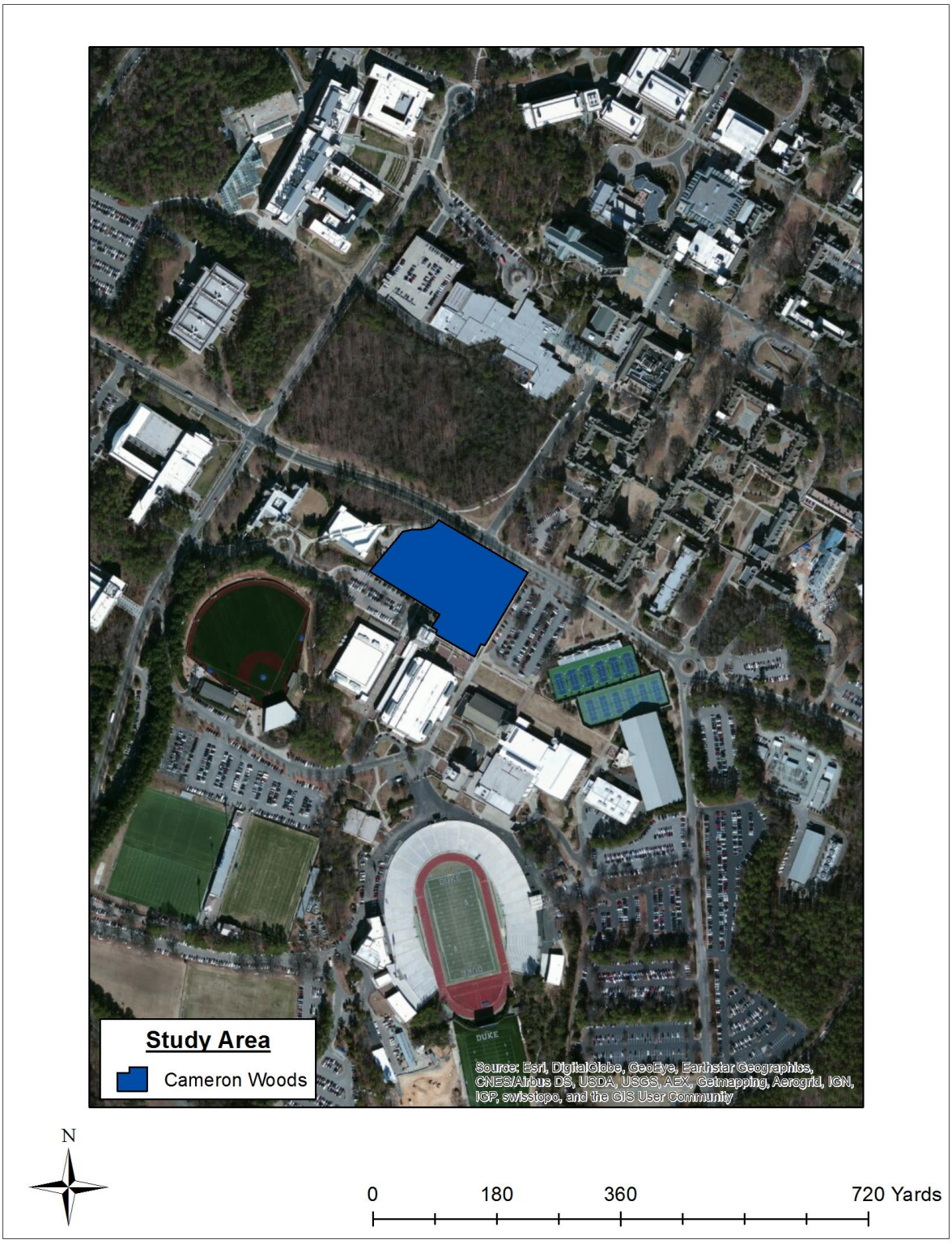
We completed our first framework draft in Dec 2014. It contained three groups of criteria: land use, land characteristics, and features contributing to Duke's Identity. After the NRS meeting (2015 01 09), the criteria were revised into five groups: ecological value, programmatic/use value, cultural value, pedagogical value, and aesthetic value. These criteria were identified through a series of university stakeholder interviews (NRS and CSC meetings), consultations with grounds management staff, and campus master plans. We utilized the input from our client, CSC, and the NRS to help identify management priority perspectives, community needs, and historical meanings for these criteria. Comments were solicited from our client, advisor, and subcommittee members at the initial development and at the revision stages of each draft of the framework via e-mail and meetings. These

comments were then incorporated into the final version of the framework (shown in part 4 results).

3.4. Case Study

We began to use the initial draft of the framework to conduct a case study as a pilot test of the framework's feasibility in January 2015. Our client suggested we select an area for the case study similar in size and habitat to Chapel Woods. The selected case study area is Cameron Woods on Towerview Rd., on Duke's west campus. Cameron Woods and Chapel Woods are roughly the same size, 2.4 and 3 acres, respectively. Both areas act contain pedestrian traffic, appear to have relatively the same level of ecosystem health, and are a mix of old growth and new growth forest. The location is shown in Figure 1.

Figure 1 Cameron Woods



We also considered the woods behind Fuqua Business School, "Gazebo Grove" (a large field area on Duke's East Campus), and the woods at the corner of Towerview Road and Erwin Drive. These areas all warrant further review with our framework. But, all of the areas were less similar to Chapel Woods than Cameron Woods is. The following table shows the similarities and differences between Chapel Woods and test sites that were considered.

Table 4 Similarity of Considered Test Study Sites to Chapel Woods

Site	Size	Use and/or Traffic	Primary Habitat Type
Cameron Woods	✓	✓	✓
"Fuqua Woods"			✓
Central Campus Hollows			
Northeastern corner of East Campus		✓	

We used multiple methods to collect data for the indicators. These methods can be found in the case study framework itself. The framework allows, for some indicators, more than one way of collecting data. The following table shows how we collected data for those indicators, as well as indicators that do not yet have a mechanism in place (i.e. items that require a committee evaluation).

Table 5 Methods in Case Study

Indicator	Determinant
Biodiversity level	North Carolina State University biodiversity map (McKerrow, Williams, & Collazo, 2006) This index allows for quick assessment of an area's biodiversity levels, at a 30 meter resolution.
Current level of use	Estimated based on conversations with Tavey Capps and Mark Hough, and by our own observations in the area.
Formal plotted research	No official research registration system exists on campus yet. This was determined by observation (no obvious plots in the area) and conversations with the faculty representatives on the NRS.
Unique educational value **Visual quality** **Perceived health of landscape**	The committee to determine these qualifications does not yet exist. These were estimated to the best of our own ability and were confirmed by the NRS.

The case study was designed to show whether the indicators and criteria are appropriate for evaluating the natural resources of an area, and for prioritizing the areas. It also helped

answer what resources (data, experts, etc.) are required to apply the framework to the whole campus.

3.5. Weighting Approach

After we obtained the preliminary results of the framework, we evaluated what weighting approach would effectively prioritize the criteria and indicators in the framework. We chose the Analytic Hierarchy Process (AHP). AHP is a multi-criteria decision making method, originally developed by mathematician Thomas L. Saaty, and is a tool with numerous applications in areas of planning and management (Saaty T. L., 1980). It has been used for evaluations of different problems in urban landscape management (Li, 2005; Srdjevic, Lakicevic, & Srdjevic, 2013; Kim & Sato, 2000). AHP uses a pairwise comparison method to generate weightings (ratio scales) for criteria, instead of simply listing and ranking the levels of importance. Pairwise comparisons could result in the relative importance of each criterion. Appendix F and Excel Appendix A ("AHP Example") provide an illustrative example for the AHP approach.

First, we needed an expert panel to collect criterion values. Our client chose several members of the NRS to build an expert panel for us to conduct the expert survey. This panel consisted of four experts (including the client): Tavey Capps (Environmental Sustainability Coordinator), Mark Hough (Campus Landscape Architect), Nicolette Cagle (Nicholas School of Environment Professor), and Katie Rose Levin (Grounds Management).

Second, we provided the panel with matrices containing the criteria (Table 5). The experts filled in the orange cells by comparing the importance of criteria in the blue column to the criteria in the green row (i.e. is the item in the blue cell more important, less important, or equal to the item in the green cell). Only the orange cells need to be filled. The white cells

are the reciprocal values of the associated orange cells. The gray cells are all blank because, for example, “Ecological Value” cannot be more or less important than itself.

Table 6 Pairwise Comparison Matrix: Criteria

Criteria	Ecological Value	Programmatic /Use Value	Cultural Value	Pedagogical Value	Aesthetic Value
Ecological Value	1	**A**			
Programmatic /Use Value		1			
Cultural Value			1		
Pedagogical Value				1	
Aesthetic Value					1

Each expert filled out 6 comparison matrices. The templates of these pairwise comparison matrices are in Excel Appendix B - AHP NRS. In this step, members had to express their opinions on the relative importance of one criterion in the pairwise comparison matrix to another one at a time. The values used in the pairwise comparisons by experts are the scales introduced by Saaty (Saaty T. L., 1990) (Saaty T. L., 1980) (in Table 6). According to this scale table, the available scaless for the pairwise comparisons are members of the following scales: 9, 8, 7, 6, 5, 4, 3, 2, 1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9. For example, in the cell marked “A” (in Table 5 above), the respondent would need to decide if “Ecological Value” is more important, as important, or less important than comfort. So, if they think convenience is slightly more important than “Programmatic Value”. Then, they would put a number like 3 or

4 in the cell. However, if they think that "Ecological Value" is slightly less important than "Programmatic Value" they would put in numbers like 1/3 or 1/4.

Table 7 The Fundamental Scale for Pairwise Comparisons

Note: Element *a* and *b* are any two of the criteria.

Intensity of Importance	Definition	Explanation
1	Equal importance	Element ***a*** and ***b*** contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment slightly favor element ***a*** over ***b***
5	Essential importance	Experience and judgment strongly favor element ***a*** over ***b***
7	Demonstrated importance	Element ***a*** is favored very strongly over ***b***; its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring element over ***a*** over ***b*** is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed. For example, 4 can be used for the intermediate value between 3 and 5
Reciprocals of above nonzero	If ***a*** has one of the above numbers assigned to it when compared with ***b***. Then ***b*** has the reciprocal value when compared with ***a***. (i.e. if ***a*** is 9, ***b*** is 1/9)	

The next step was to estimate the weightings from the pairwise matrix (Saaty T. L., 1990) (Saaty T. L., 1980) (Triantaphyllou & Mann, 1995). First, we used the geometric mean calculation to combine the four individual pairwise comparison matrices collected from the four experts. That is, the elements in each row in each individual matrix were multiplied by those in other three matrices, and the result was product matrix. Then we take the n-th root of

the product matrix of row elements (where n is the number of criteria). Next, by dividing them with the column sum of them, the numbers are normalized. Then, through further calculation, we will obtain a vector of priorities from the pairwise comparison matrix. The vector is in ratio scales and is just the weightings for criteria.

Furthermore, the AHP approach has a consistency test. We consider th pairwise comparisons matrices being adequately consistent "if the corresponding consistency ratio (CR) is less than 10%" (Saaty T. L., 1980). First, we estimated the consistency index (CI). We added the columns in the pairwise comparison matrix and multiplied the resulting vector by the vector of priorities (the weightings). This calculation gave a result, an approximation of the maximum eigenvalue, denoted by λ_{max}. Then, the CI value was obtained by the formula: CI = (λ_{max} - n)/(n - 1)[2]. Finally, we got the consistency ratio CR, by dividing the CI value from last calculation by the Random Consistency Index (RI) in Table 7. (Triantaphyllou & Mann, 1995)

The last step was to give the final evaluation results by multiplying the weightings to the findings (High/Medium/Low). High is a score of 1; Medium is a score of 0.5; Low is a score of 0. The final evaluation score has a range from 0 to 100. For the overall evaluation of the area, 0-33 is Low; 34-66 is Medium; 67-100 is high.

[2] "n" is the number of criteria in the matrix.

Table 8 Random Consistency Index Refer Table

Number of Criteria	RI
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51

4. Results

4.1. Vocabulary

In order to facilitate the understanding of this work—for both Duke University in their use of the framework and readers of this report—we have developed a glossary of terms. That glossary is available at the end of this report, in Appendix D.

4.2. Benchmarks

Duke is striving to be a leader in leadership and environmental sustainability, but Duke is not the first school to evaluate natural resources on a college campus. In creating the framework proposed in this study, we consulted some of the exemplary works done by other institutions.

Very few schools have natural resource plans displayed on university websites and very few schools that responded to our email requests had any documents resembling what we were creating with this stud. The following three evaluations, conducted by other institutions of higher learning, best fit what the CSC, the NRS, and our client wanted out of

our study. The universities are presented in order from most similar to our work, to least similar.

Dalhousie University

Dalhousie University's Natural Environment Plan most closely resembled the outcome that the CSC and Duke were looking for. Their plan includes a matrix (Appendix A) to aid in decisions regarding new construction, grounds management, and climate change mitigation and adaption opportunities (Dalhousie University, 2012). They list specific criteria (with descriptions), the values of those criteria, indicators that will be used in assessment of the criteria, as well as baselines and targets.

The Dalhousie plan identifies criteria that are important to the university, why they matters, and how to reach their goals, but cannot be directly applied to individual sections of their campus, because those criteria and the metrics used are designed to show total campus numbers, not numbers that can be compared from one site to another. Our proposed framework for Duke's natural resource evaluation differs from the Dalhousie approach in that it will be used to identify and evaluate specific tracts of land.

Our framework takes the same specific criteria by criteria approach, while offering campus planners and administrators a way to assess either the entire campus at once, or a unique site. One of the logical next steps to this project would be to establish baselines and to set goals for the broader elements (habitat, species, etc.) of the framework and to create goals/targets—like Dalhousie has done.

Stanford University

Stanford's Habitat Conservation Plan (Stanford University, 2013) specifically identifies habitats for the endangered species found on campus land. The plan is interesting

and unique, because it was developed in partnership with the federal government and is pursuant to the Endangered Species Act (Stanford University, 2013).

Section 10 of the Endangered Species Act mandates that a land owner may be allowed to destroy known habitat for a protected species, during the course of an otherwise lawful activity, if the landowner provides a plan to further protect the species in another capacity (U.S. Congress, 1973). Stanford identified ideal habitat areas for several endangered species that they agreed to preserve and study in order to receive permission from the federal government to further develop other habitats containing those same species.

The compulsory nature of this plan and of Stanford's partnership with a government agency make it quite different from what Duke seeks to do. However, the identification of exemplary habitat spaces for conservation and protection purposes are very similar to goals of our study. For example, their site descriptions cover information like canopy density, general habitat makeup, and animal populations present at the site.

Cornell University

Cornell University's Master Plan (Cornell University, 2013) directly incorporates natural resource evaluation and a climate action plan. This plan is unique among the universities we studied in that rather than informing the master plan, the natural resource evaluation is *part* of the plan. Also unique to Cornell's Master plan is that, rather than seeking to identify lands that are most deserving of protection, they identify built areas on campus that will be converted back into natural spaces. In fact, Cornell plans to reduce their total number of developed acres from 585 to 535 by 2050 (Cornell University, 2013).

The second, and final explicit consideration given to natural spaces in Cornell's plan is to protect outdoor teaching a research space. According to the Plan, "the working countryside of Cornell's campus is essential to the academic mission. (Cornell University,

2013). This echoes the similar concerns for registered teaching sites on Duke's campus, as proposed by the NRS.

Duke University shows no signs of reducing the campus-building footprint any time soon. Therefore, given that the overall goal of Cornell's plan is to reclaim spaces, while Duke's is to identify areas to protect, the two approaches are quite different.

4.3. Framework[3]

Sustainable Duke is invested in adding natural resource evaluation and framework planning to the Sustainability Strategic Plan in FY 2015, as an extension of the Climate Action Plan (Duke University, 2014c). Based on the data we collected and analyzed and informed by the client's needs, we created a framework and developed criteria for evaluating relative values of select campus landscapes, prioritizing landscapes, and informing future master planning to ensure we maintain our "campus in the forest." The area for evaluation on campus is first categorized into one of two land categories (Natural Landscapes or Designated Landscapes) (definitions in 4.3.2). If the area belongs to "Natural Landscapes", Duke University could use the framework of this project to evaluate and prioritize it. The below Table 8 display the final framework.

[3] The following sub-sections explain the framework layout and show selected portions of the framework as examples. The complete framework can be found in appendix B.

Table 9 Framework for evaluating and prioritizing duke's natural landscapes

CRITERIA	INDICATOR	DETERMINANT
OVERRIDING FACTORS	ENDANGERED OR PROTECTED SPECIES	Are there species in the area protected by state or federal law?
	LEGAL BUFFER/EASEMENT	Is Duke legally required to maintain a buffer in this area?
	VOLUNTARY BUFFER/EASEMENT	Does Duke maintain a voluntary buffer in this area for any reason?

Table 9 Framework for evaluating and prioritizing duke's natural landscapes (continued)

CRITERIA	INDICATOR			FINDINGS	DETERMINANT	SOURCES
ECOLOGICAL VALUE	SPECIES	Invasive Species		Low	No invasive species;	Documents & On-site inventory
				Medium	Invasive species; not disrupt the natural ecosystem in a large way;	
				High	Invasive species; disrupt in a large way.	
		Unique native species		Low	No unique native species;	Documents & On-site inventory
				Medium	1 or 2 unique native species;	
				High	3 or more.	
		Population size and vulnerability		Low	State and Federal designations	Durham County List
				Medium		
				High		
		Importance of role in ecosystem	Keystone Species	Low	No keystone species in the area;	Interview & On-site inventory
				Medium	1 or 2 keystone species;	
				High	3 or more.	
			Not a keystone species, but important to ecosystem operation	Low	No such species in the area;	
				Medium	1 or 2 such species in the area;	
				High	3 or more such species.	
	HABITAT	Condition		Low	To be determined by Campus Assessment Committee and contracted experts as needed.	Documents & Interviews
				Medium		
				High		
		Vulnerability		Low	To be determined by Campus Assessment Committee and contracted experts as needed.	Documents & Interviews
				Medium		
				High		
		Riparian system		Low	The area doesn't drain into a riparian system;	Interview & On-site inventory
				Medium	The area drains into a riparian system;	
				High	There is a riparian system in the area.	
		Forest age		Low	This is determined by the Campus Assessment Committee. No trees older than 100 years old;	On-site inventory
				Medium	Some trees older than 100 years old in the area;	
				High	Many trees older than 100 years old in the area.	
		Percentage of area cover		Low	Less than 30% is covered with trees, shrubs;	On-site inventory
				Medium	30-60% of the area is covered with trees, shrubs;	
				High	More than 60%.	
		Level of Biodiversity		Low	To be determined by campus (or contracted) experts. Or by NC State Biodiversity map (page 52). Low (0-60); Medium (61-131); High (132 and above)	NC State map
				Medium		
				High		
		Presence of specimen trees		Low	As defined by trees with notable size, quality, health, form and age relative to species	On-site inventory
				Medium		
				High		

Table 9 Framework for evaluating and prioritizing duke's natural landscapes (continued)

CRITERIA	INDICATOR		FINDINGS	DETERMINANT	SOURCES
ECOLOGICAL VALUE	SOIL ATTRIBUTES	Soil compactness	Low	To be determined using a penetrometer. Low: below 200 PSI;	On-site inventory
			Medium	Medium: 200-299 PSI;	
			High	High: 300 and above PSI	
		Soil series rarity level	Low	The USDA soil survey mapping tool is used to identify the soil type for a plot of land. Then compare the Durham county soil survey to determine rarity of the soil series.	Map tool; Durham soil survey
			Medium		
			High		
	REGULATING SERVICES	Air quality regulation	Low	As calculated using iTree. Both values represent absorption rates.	On-site inventory & iTree calculation
			Medium		
			High		
		Carbon Sequestration	Low		
			Medium		
			High		
	HABITAT FRAGMENTATION	Interior spaces	Low	Interior spaces are areas further than 100 m from a forest edge. Low: no interior space;	On-site inventory
			Medium	Medium: fewer than 5 acres of interior space;	
			High	High: more than 5 acres.	
		Connectivity to other habitats	Low	No connectivity to other habitats;	On-site inventory
			Medium	This area is not directly adjacent to other habitats, but is close enough to other habitats that it may act as a corridor;	
			High	This area is directly adjacent to other habitats.	

Table 9 Framework for evaluating and prioritizing duke's natural landscapes (continued)

CRITERIA	INDICATOR		FINDINGS	DETERMINANT	SOURCES
PROGRAMMATIC /USE VALUE	CURRENT LEVEL OF USE	Level of use	Low	Determined by Campus Assessment Committee based on site studies and interviews with the Duke community	Interview & On-site inventory
			Medium		
			High		
	ACCESSIBILITY	Pedestrian ways	Low	The area does not contain pedestrian ways;	On-site inventory
			Medium	Part of the area contains pedestrian ways;	
			High	Pedestrian ways throughout the entire area.	
		Nearby public transportation	Low	No public transportation access within 100 meters;	
			Medium	Public transportation access within 100;	
			High	Public transportation access on/adjacent to.	
		ADA accessibility	Low	It is not accessible to handicapped persons;	
			Medium	It is partially accessible to handicapped persons;	
			High	Handicapped access throughout the area.	
	UTILITY/NON-BUILDING INFRASTRUCTURE	Existing of utility/non-building infrastructure	Low	No such infrastructure in the area;	Documents & On-site inventory
			Medium	Minor infrastructure of this nature in the area;	
			High	An abundance of such infrastructure in the area.	
	MASTER PLAN DESIGNATION	Designated building site	Low	No master plan designation;	Documents & Interviews
			Medium	It has been identified as a potential build site;	
			High	This area is designated as a specific building site.	

Table 9 Framework for evaluating and prioritizing duke's natural landscapes (continued)

CRITERIA	INDICATOR	FINDINGS	DETERMINANT	SOURCES
CULTURAL VALUE	HISTORIC SIGNIFICANCE	Low	Determined by Campus Assessment Committee using University resources, including Duke Archives.	Documents & Interviews
		Medium		
		High		
	CEREMONIAL SIGNIFICANCE	Low	Determined by Campus Assessment Committee using University resources, including Duke Archives, Office of Student Affairs and University Development.	Documents & Interviews
		Medium		
		High		
	NAMING OR OTHER RECOGNITION	Low	This area has no name;	Documents & Interviews
		Medium	This area has a commonly used name that is not based on a board of trustees designation;	
		High	This area has an official board of trustees name designation.	
PEDAGOGICAL VALUE	FORMAL PLOTTED RESEARCH	Low	No plotted research in the area; (based on future registration system)	Documents & Interviews
		Medium	1 or 2 registered research sites in the area;	
		High	3 or more registered research sites in the area.	
	TEACHING	Low	No teaching in the area;	Documents & Interviews
		Medium	1 or 2 classes that use the area for teaching;	
		High	3 or more classes use the area for teaching.	
	UNIQUE EDUCATIONAL VALUE	Low	Determined by Campus Assessment Committee using Faculty interviews and precedent from other schools	Documents & Interviews
		Medium		
		High		
AESTHETIC VALUE	VISUAL QUALITY	Low	Determined by Campus Assessment Committee using site studies, view shed analyses, interviews/surveys of Duke community, and other means	Documents & Interviews
		Medium		
		High		
	PERCEIVED HEALTH OF LANDSCAPE	Low	Determined by Campus Assessment Committee using site studies and other means	Documents & Interviews
		Medium		
		High		

4.3.1. Structure

As shown in Table 8, the first framework consideration is the three overriding factors: endangered or protected species, legal buffer/easement, and voluntary buffer/easement. First, if there are endangered species in this area, the developers need to submit Habitat Conservation Plans for the application of an incidental take permit under Endangered Species Act Sec. 10. Protected species also need certain conservation plans. Second, developers need to review legal regulation and legislation to identify whether Duke University is required to maintain a buffer in this area. Third, developers would review existing voluntary buffer/easement, such as the one Duke maintains along most of the Erwin road edge of campus as a courtesy to the city of Durham (2014 09 12 meeting with Mark Hough and Tavey Capps). Duke University also registered 1220 acres for voluntary protection with the North Carolina Natural Heritage Program (Orange County NC, 2008).

The second framework consideration is the five criteria values: Ecological, Programmatic/Use, Cultural, Pedagogical, and Aesthetic Value. Each criterion has associated indicators, findings, determinant, and sources. Table 9 below shows the simplified structure of the framework. Each criteria value is further broken down in to indicators (1to 3 layers). These indicators are variables measuring the status or conditions of each value. When using this framework, we will check all the indicators for the certain studied area, as in case study. These indicators require a High/Medium/Low designation (e.g. level of soil compactness). These decisions and designations are finally put in the "findings" column. In the excel vision of this framework, the finding column has a dropdown list for each indicators. The user could easily click one of the three choices (High/Medium/Low) to fill in the findings column. Finally, the Determinant column further specifies and explain how to determinant high,

medium, or low. The Sources column provides information and references about data resources, as necessary.

Table 10 Framework Structure

CRITERIA	INDICATOR		FINDINGS	DETERMINANT	SOURCES
Ecological Value Programmatic/Use Value Cultural Value Pedagogical Value Aesthetic Value	1	1.1		LOW	
				MEDIUM	
				HIGH	
		1.2		LOW	
				MEDIUM	
				HIGH	
	2			LOW	
				MEDIUM	
				HIGH	
	3			LOW	
				MEDIUM	
				HIGH	

4.3.2. Land categories Definitions

This study breaks the whole campus area down into two land categories: natural and designated landscapes.

- Natural landscapes are the remnant woodlands that have an identifiable boundary, a continuous canopy and no occupied buildings, across campus. They typically will have little or no active management or maintenance (Chapel woods, Central campus hollows, Cameron Woods), but any ecologically rich landscape that contributes to the natural environment may fit into this category-even if maintained (Duke Pond, SWAMP, Lemur Center).
- Designated landscapes are all campus landscapes that are not in the “Natural” category. These are spaces and landscapes designed and built to serve a programmatic purpose for the Duke community. These can be specific plazas, courtyards, quads, or

areas of concentrated development with little or no natural area remaining (Krzyzewskiville, West Quad, East campus, Engineering Quad, Campus Drive). Roadways, parking lots and the interstitial spaces between projects also belong to this category.

These definitions focus on main typical features only for classifying the campus areas in Duke University. The map below displays the location of natural landscapes directly and clearly. The green areas on this map are the existing natural landscapes on campus.

Figure 2 Natural Landscapes in Duke University[4]

4.3.3. Criteria and Indicators

This framework focuses on values that our client wants to preserve through sustainable management of the natural environment. Each criterion has a group of indicators

[4] Hough, Mark. "Map of Forested Areas on Campus- Including non-Grounds managed sites." Feb. 2015. E-mail.

with 1-3 layers. The first two layers are most important to understand the context of the values.

- Ecological Value: Species, Habitat, Soils Attributes, Regulating Services, Habitat Fragmentation
- Programmatic/Use Value: Accessibility, Utility/Non-building Infrastructure, Current Level of Use, Master Plan Designation
- Cultural Value: Historic significance, Ceremonial significance, Naming or other recognition
- Pedagogical Value: Formal Plotted research, Teaching, Unique Educational Value
- Aesthetic Value: Visual quality, Perceived health/quality of landscape.

Then, in column of findings, we make decisions and designations for each indicator (High/Medium/Low). The Determinant column further specifies the questions for each indicator. The Sources column provides information and references about data resources.

4.4. Weighting

Appendix G displays the final pairwise comparison results (geometric means) from NSR members. Table 10 below shows the weighting results after calculation of the AHP approach. All pairwise comparison matrices passed the consistency test. Excel Appendix C - AHP Calculation displays the calculation process in details.

Table 11 Weighting for Criteria and Indicators

CRITERIA	Weighting	INDICATOR	Weighting
ECOLOGICAL VALUE	54%	SPECIES	28%
		HABITAT	42%
		SOIL ATTRIBUTES	12%
		FRAGMENTATION	19%
PROGRAMMATIC/USE VALUE	9%	ACCESSIBILITY	25%
		UTILITY/NON-BUILDING INFRASTRUCTURE	15%
		MASTER PLAN DESIGNATION	36%
		CURRENT LEVEL OF USE	25%
CULTURAL VALUE	8%	HISTORIC SIGNIFICANCE	54%
		CEREMONIAL SIGNIFICANCE	20%
		NAMING OR OTHER RECOGNITION	26%
PEDAGOGICAL VALUE	17%	FORMAL PLOTTED RESEARCH	50%
		TEACHING	20%
		UNIQUE EDUCATIONAL VALUE	30%
AESTHETIC VALUE	11%	VISUAL QUALITY	71%
		PERCEIVED HEALTH OF LANDSACPE	29%

4.5. Case Study

By testing the framework on our case study site, we learned several valuable things about the framework itself and were able to make several improvements to the framework. These improvements ranged from data accessibility issues to simple aesthetic changes that improved the ease of use.

The first lesson of note is that collecting the data for our framework required help and input from many members of the campus community. In order to ensure that future use of the framework is as easy as possible, we compiled a list of contacts for various topics around campus. This list can be seen in appendix C.

Evaluating the test site also revealed a lack of data for certain criteria in the framework. In some cases, the data were available in various documents or web tools. In

other cases, such as the level of biodiversity in an area, we suggested sources of data that could be used as proxies—to only be used if there were not resources or time to collect more detailed data. In order to address these issues, we added a column to the framework with links to documents that could be of use to the evaluator(s).

Finally, we removed one of the indicators for regulating services after completing the case study. The regulating services section previously had a section for water filtration properties of the site. But, we discovered that calculating these filtration properties in iTree—the ecosystem services calculation software that is available to Duke students, faculty, and staff—is much more time and data intensive that we previously thought. In order to calculate water filtration, one must have the species name, age, diameter breast height, crown diameter, crown height, trunk height, and root range of each tree. After consulting our client, we determined that Duke University would never spend the time or money to conduct that sort of evaluation of the entire campus. The client then agreed that we should remove the indicator.

Overall, the case study using Cameron Woods proved to be a valuable endeavor. It led to direct changes in the framework. It created new conversations within the NRS. And, it provided useful data to our client, the CSC, and Duke University.

The findings from our case study can be found in the following table:

Table 12 Case Study Findings

CRITERIA	INDICATOR	FINDINGS
OVERRIDING FACTORS	ENDANGERED OR PROTECTED SPECIES	NO
	LEGAL BUFFER/EASEMENT	NO
	VOLUNTARY BUFFER/EASEMENT	NO

Table 12 Case Study Findings (continued)

CRITERIA	INDICATOR			FINDINGS	NOTES
ECOLOGICAL VALUE	SPECIES	Invasive Species		Medium	Albizia julibrissin, Elaeagnus umbellata, Magnolia grandiflora, Microstegium vimineum, Euonymous fortunei
		Unique native species		Medium	Halesia tetraptera
		Population size and vulnerability		Low	No species observed were classified as threatened or worse, at the State or Federal level. However, several bird species exist in the area that meet these classifications and may use Cameron Woods for food, shelter, or migration.
		Importance of role in ecosystem	Keystone Species	Low	
			Not a keystone species, but important to ecosystem operation	Low	Sphyrapicus varius (not observed directly, but evidence of sap wells), they create important feeding sources for other birds.
	HABITAT	Condition		Medium	
		Vulnerability		Medium	
		Riparian system		Low	
		Forest age		Medium	This area contains a mixture of older and newer trees.
		Percentage of area cover		High	Varies depending on season. 1% accounts for non-cover over path areas during certain times of the year.
		Level of Biodiversity		Medium	Used NC State map because estimating biodiversity would require a multi-seasonal study.
		Presence of specimen trees		Medium	Several large white oak in the area (30+ in dhb).

Table 12 Case Study Findings (continued)

CRITERIA	INDICATOR		FINDINGS	NOTES
ECOLOGICAL VALUE	SOIL ATTRIBUTES	Soil compactness	Low	Average reading of 139.
		Soil series rarity level	Low	White Store-Urban land complex 0-10 percent slopes, 3.4 percent of all topsoils in Durham County, or, 6,358 acres out of 188,928.
	REGULATING SERVICES	Air quality regulation	30.6 lbs. Pm/Yr. (10 microns or larger)	This indicator does not actually impact the final score (high, medium, low) of the site. The client just wants to make sure this information is available.
		Carbon Sequestration	7.4 Tons/Yr.	This indicator does not actually impact the final score (high, medium, low) of the site. The client just wants to make sure this information is available.
	HABITAT FRAGMENTATION	Interior spaces	Low	Paths through the space create edges.
		Connectivity to other habitats	Medium	No direct connectivity but is close enough to other habitats that it may act as a corridor.

Table 12 Case Study Findings (continued)

CRITERIA	INDICATOR		FINDINGS	NOTES
PROGRAMMATIC /USE VALUE	CURRENT LEVEL OF USE	Level of use	Low	
	ACCESSIBILITY	Pedestrian ways	Medium	Paths exist in the space and connect users to and from Cameron Indoor Stadium and other locations.
		Nearby public transportation	Medium	Bus stops can be found within 100 meters of the north portion of the space.
		ADA accessibility	Medium	Two of the three pathways are paved and gently sloped.
	UTILITY/NON-BUILDING INFRASTRUCTURE	Existing of utility/non-building infrastructure	Medium	Some electrical lines exist for powering the path lights.
	MASTER PLAN DESIGNATION	Designated building site	Low	

Table 12 Case Study Findings (continued)

CRITERIA	INDICATOR	FINDINGS	NOTES
CULTURAL VALUE	HISTORIC SIGNIFICANCE	Low	
	CEREMONIAL SIGNIFICANCE	Low	
	NAMING OR OTHER RECOGNITION	Medium	
PEDAGOGICAL VALUE	FORMAL PLOTTED RESEARCH	Low	
	TEACHING	Medium	
	UNIQUE EDUCATIONAL VALUE	Medium	Estimated by research team and client, in lieu of the not yet formed "Campus Assessment Committee".
AESTHETIC VALUE	VISUAL QUALITY	Medium	Estimated by research team and client, in lieu of the not yet formed "Campus Assessment Committee".
	PERCEIVED HEALTH OF LANDSCAPE	Medium	Estimated by research team and client, in lieu of the not yet formed "Campus Assessment Committee".

Overall, Cameron Woods receives a relative rating of 34 out of 100. This score means that the site is of "medium" value and importance. And, as we can see, the site was only two points away from dropping to a "low". However, it is important to note that a score of 100 would be virtually impossible—there is no way for a space to have all of the characteristics found in the framework. Because this is intended to show the relative value of a space, a score of 34 may prove to be a fairly average score for campus lands. Applying this framework to the other natural spaces on campus will provide much more insight on that topic.

5. Conclusion

This comprehensive evaluation tool will equip Duke University to understand, manage, and preserve natural spaces on campus. However, several topics covered in the framework warrant additional attention.

5.1. Areas for Further Research

Duke Forest maintains an up-to-date list of all research being done on Forest property; Duke University's campus would benefit greatly from duplicating that system. Second, any and all biodiversity research on campus could potentially contribute to a database that would serve as data for the biodiversity component of the framework (as well as individual species sections of the framework). Finally—and, most importantly—Duke University should establish a committee tasked with applying the framework to campus areas. The framework contains some objective criteria (e.g.: aesthetic value), and having the same group of experts evaluate areas of campus will help maintain consistency.

5.2. Limitations of the Study

This framework, though it is the most complex and inclusive of its kind—to the knowledge of its creators—is not without its weaknesses. The following paragraphs identify the weaknesses we see within the framework and our study.

The framework contains a certain amount of subjectivity. Criteria like "aesthetic value" and "historical significance" are inherently subjective terms. Other assessments, such as whether an area has enough old growth to go from "medium" to "high" in that category are also up for interpretation. However, it is our hope that the University will designate a qualified list of individuals to use the framework we have created. If the same group evaluates every area on campus, the results may still contain subjectivity, but the goal of creating a tool with which to evaluate natural areas on campus relative to one another is still very much possible.

Like anything in life, you get out of this framework what you put into it. Certain indicators for criteria we have selected require quite a bit of funding and/or person hours. Calculating the exact level of biodiversity for an area, for example, could be a multi-year project. In cases like these, we tried to provide two options for those responsible for filling out the framework in the future: a quick option (like the North Carolina State University biodiversity map) and a thorough option (like having an expert determine the true level of biodiversity in an area). These options will allow the University to decide how much time and money to put into these evaluations.

Finally, this framework is only a way of starting the conversation about natural spaces at Duke. Our project team is under no illusions that areas receiving an over "High" value from this framework will be deemed sacred and will be forever protected. The University has

to balance advancing its academic mission, the needs of providing lifesaving space for the hospital system, and a myriad of other things. It is simply our hope that adding this piece of the puzzle will make it easier to include the naturally beautiful places on our campus in conversations about development and management.

5.3. Final Thoughts

Duke University strives to be a leader in any and all ways possible. To that end, the framework developed in this study provides Duke with a one of a kind assessment system for campus natural landscapes. The framework incorporates ecological and human use components to strike a balance between the two. It creates a common language with which to compare natural landscapes. It allows the University to incorporate natural resources directly into planning process. And, most importantly, it creates a non-prescriptive way of identifying landscapes on campus that deserve more attention.

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Appendix A – Dalhousie University Matrix (pages 6-8)

2.3.1 Ecological values, objectives, indicators, and targets

Table 2: Ecological values. Natural Environment Planning Framework for Dalhousie University

	Values	Objectives	Indicators	Targets	
				Baseline	Target
Shade	Summer shade/ UV control	Increase the amount done by campus vegetation	Percentage of campus zones that are adequately shaded	Establish baseline by 2015	Increase campus shading by 2025
Shelter	Shelter from weather	Increase the amount done by campus trees	Percentage of pedestrian walkways that are adequately sheltered	Establish baseline by 2015	Increase the number of trees planted and increase the planting density of trees along major walkways and sidewalks
Carbon removal	Carbon removal	Maximize carbon removal by campus vegetation	Net annual carbon sequestration and total carbon storage	Complete itree by 2015	Target based on i-tree analysis not yet completed
Air quality	Particulate control	Increase the amount done by campus vegetation	Monetary equivalent of particulate control service	Complete itree by 2015	Target based on i-tree analysis not yet completed
	Chemical control	Increase the amount done by campus vegetation	Monetary equivalent of chemical control service	Complete itree by 2015	Target based on i-tree analysis not yet completed
Biodiversity	Ecosystem diversity	Increase area of naturalized ecosystems (landscapes left to grow and change naturally e.g. Sherrif Hall oak stand, Ocean Pond)	Percentage of campus that is naturalized	Baseline measured in 2013. AC campus 10% naturalized; Halifax campuses less than 1% naturalized	Identify naturalization opportunities by 2015. Target: 15% (AC) and 5% (Halifax) of campus area that is naturalized
	Species diversity	Even out age-class diversity of campus trees to improve resilience of urban forest	Percent of trees planted in the last 10 years	Baseline measured in 2010: 25% (Halifax); AC baseline by 2015	Stagger tree planting each year
		Raise native tree representation in the campus urban forest	Percent of campus vegetation that is native or indigenous	Baseline measured in 2010: 44% (Halifax campuses); AC baseline by 2015	Increase campus vegetation that is native or indigenous.
			Genera that comprise more than 10% of all campus trees	Baseline measured in 2010: 30% of species are *Acer* spp., 12% *Quercus* spp. (Halifax); AC baseline by 2015	No genus comprises more than 10% of all campus trees
			Acadian old-growth species that represent at least 5% of all campus trees	Baseline measured in 2010: red oak makes up 12% of all campus trees (Halifax); AC baseline by 2015	Increase the number of Acadian old-growth tree species.

2.3.1 Ecological values, objectives, indicators, and targets

Table 2: Ecological values. Natural Environment Planning Framework for Dalhousie University

	Values	Objectives	Indicators	Targets	
				Baseline	Target
	Genetic diversity	Expand gene pools of native species improve resilience of urban forest	Range of cultivars of species	Establish baseline by 2015	Increase number of cultivars per species planted, proportional to the number of trees planted
Ecosystem condition	Ecosystem condition	Increase canopy cover	Percent canopy cover	Baseline established in 2010: approx. 15% (Halifax); AC baseline by 2015	20% canopy cover (Halifax campuses)
	Tree condition	Improve tree health	More research needed	Establish baseline by 2015	More research needed
Water	Stormwater control	Increase the amount done by campus trees	Monetary equivalent of stormwater control service	itree baseline by 2015	Target based on i-tree analysis not yet completed
	Water purification	Increase the amount done by campus trees	More research needed	Establish baseline by 2015	More research needed
Noise buffer	Amelioration of excess campus noise	Increase the amount done by campus trees	More research needed	Establish baseline by 2015	More research needed
Microclimate	Amelioration of adverse winds	Increase the amount done by campus trees	More research needed	Establish baseline by 2015	More research needed
Air temperature reduction	Reduce heat island effect	Increase the amount done by campus vegetation	Campus canopy cover	Establish baseline by 2015	Increase shading of rooftops and paved surfaces (e.g., greenroof, tree cover)
Wildlife (birds)	Bird habitat	Increase amount of bird-at-risk habitat	Range of plant species that attract birds-at-risk	List of plant species included on page 42	Increase number of species that attract birds-at-risk
Erosion control	Soil stabilization	Increase the amount done by campus vegetation	Percent of slopes that are vegetated	Establish baseline by 2015	Slopes <30 degrees, 100% vegetated

2.3.2 SOCIAL VALUES, OBJECTIVES, INDICATORS, AND TARGETS

Table 3: Social values. Natural Environment Planning Framework for Dalhousie University

	Values	Objectives	Indicators	Targets	
				Baseline	Target
Aesthetics	Urban vegetation triggers the senses	To maintain and improve upon a positive aesthetic appeal	Degree of campus satisfaction	Establish baseline by 2015	Increase survey respondent satisfaction
Human health	Sense of psychological well-being	Increase sense of well-being	Degree of campus satisfaction	Establish baseline by 2015	Increase survey respondent satisfaction
	Physical health	Increase opportunity for active and passive recreation	Inventory of campus greenspace and sports infrastructure	Establish baseline by 2015	Increase survey respondent satisfaction with recreation opportunities on campus
Marketing	Vegetation as a University marketing tool	Maintain a vegetated landscape for marketing and promotion	Degree of influence	Baseline established in 2012: 10% of survey respondents chose Dalhousie partially because of campus aesthetics	Continue and improve campus aesthetics for campus marketing purposes.
Engagement	Campus engagement	Increase quality and quantity of opportunities for campus population to engage in urban tree management	Degree of satisfaction with engagement opportunities	Establish baseline by 2015	Increase survey respondent satisfaction
Education	Campus awareness	Increase campus awareness	Degree of campus awareness and urban vegetation values	Establish baseline by 2015	Increase the number of values articulated by survey respondents
	Working knowledge	Increase working knowledge	Investment in campus monitoring, research, and employee education programs	Establish baseline by 2015	Designate portion of grounds and planning budget for education
	Scientific knowledge	Increase scientific knowledge	Number of campus landscapes that provide learning opportunity, campus as a 'living laboratory'	Establish baseline by 2015	Designate landscapes and define plant material suitable for education programs

2.3.3 Economic values, objectives, indicators, and targets

Table 4: Economic values. Natural Environment Planning Framework for Dalhousie University

	Values	Objectives	Indicators	Targets	
				Baseline	Target
Energy savings	Institutional energy savings	Increase the amount done by campus trees	More research needed	itree baseline by 2015	Target based on i-tree analysis not yet completed
Materials	Food	Increase the amount of edibles available from campus trees	More research needed	Establish baseline by 2015	More research needed
	Wood	Increase the amount of woody materials available from campus tree removal	More research needed	Establish baseline by 2015	More research needed

Appendix B – Duke University's Natural Resource Framework

LAND CATEGORY	CRITERIA	INDICATOR			EVIDENCE	DETERMINANT	SOURCES
NATURAL AREA (PARCEL OF LAND COMPRISED OF X+OF ACRES OF WOODLAND, BODY OF WATER OR OTHER NATURAL FEATURE WITHOUT OCCUPIED BUILDINGS) EXAMPLES: CHAPEL WOODS, CENTRAL CAMPUS HOLLOWS, DUKE POND	Overriding factors		Endangered or protected species			Are there species in the area protected by state or federal law?	
			Legal buffer/easement			Is Duke legally required to maintain a buffer in this area?	
			Voluntary buffer/easement			Does Duke maintain a voluntary buffer in this area for any reason?	
	ECOLOGICAL VALUE	SPECIES	Invasive Species			"Low" indicates there are no invasive species in the area, "Medium" indicates that there are invasive species in the area that don't disrupt the natural ecosystem in a large way, "High" indicates there are invasive species in the area that disrupt the natural ecosystem in a large way.	
			Unique native species			"Low" indicates there are no unique native species in the area, "Medium" indicates 1 or 2 unique native species in the area, "High" indicates 3 or more unique native species in the area.	
			Population size and vulnerability			State and Federal designations	Durham County List
			Importance of role in ecosystem	Keystone Species		"Low" indicates there are no keystone species in the area, "Medium" indicates 1 or 2 keystone species in the area, "High" indicates 3 or more keystone species in the area.	
				Not a keystone species, but important to ecosystem operation		"Low" indicates there are no such species in the area, "Medium" indicates 1 or 2 such species in the area, "High" indicates 3 or more such species in the area.	
		HABITAT	Condition			To be determined by Campus Assessment Committee and contracted experts as needed	
			Vulnerability			To be determined by Campus Assessment Committee and contracted experts as needed	
			Riparian system			"Low indicates that the area doesn't drain into a riparian system, "medium" indicates that the area drains into a riparian system, "high" indicates that there is a riparian system in the area.	
			Tree age			"Low" indicates that there are no trees older than 100 years old in the area. "Medium" indicates that there are some trees older than 100 years old in the area. "High" indicates that there are many trees older than 100 years old in the area. This will be determined by the Campus Assessment Committee.	
			Percentage of area cover			"Low" indicates that less than 30% of the area is covered with trees and/or shrubs, "medium" indicates that 30-60% of the area is covered with trees and/or shrubs, "high" indicates that more than 60% of the area is covered with trees and/or shrubs.	
			Level of Biodiversity			To be determined by campus (or contracted) experts, or by NC State Biodiversity map (page 20). Missing the NC State Biodiversity map, 0-30 indicates "low", 31-131 indicates "medium", and 132 and above indicates "high".	NC State map
			Presence of specimen trees			As defined by trees with notable size, quality, health, form and age relative to species. "Low" indicates the area has no specimen trees, "medium" indicates the area contains several specimen trees, "high" indicates the area contains many specimen trees. These levels are to be determined by the grounds department or by the Campus Assessment Committee.	
		SOIL ATTRIBUTES	Soil compactness			To be determined using a penetrometer. "High" is 300 and above, "Medium" is 200-300, and "Low" is below 200.	
			Soil series rarity level			The USDA soil survey mapping tool can be used to identify the soil type for a plot of land. The identified soil type(s) can then be compared to the Durham county soil survey to determine rarity of the soil series.	Map tool Durham soil survey
		REGULATING SERVICES	Air quality regulation			As calculated using iTree. Both values represent absorption rates.	
			Carbon Sequestration				
		HABITAT FRAGMENTATION	Interior space			Interior spaces are areas farther than 100 meters from a forest edge. "Low" indicates that this area has no interior space, "medium" indicates that this area has fewer than 2 acres of interior space, "high" indicates that this area has more than 2 acres of interior space.	
			Connectivity to other habitats			"Low" indicates that this area has no connectivity to other habitats. "Medium" indicates that this area is not directly adjacent to other habitats, but is close enough to other habitats that it may act as a corridor. "High" indicates that this area is directly adjacent to other habitats.	
	PROGRAMMATIC USE VALUE	CURRENT LEVEL OF USE				Determined by Campus Assessment Committee based on site studies and interviews with the Duke community	
		ACCESSIBILITY	Pedestrian ways			"Low" indicates that the area does not contain pedestrian ways, "medium" indicates that part of the area contains pedestrian ways, "high" indicates that there are pedestrian ways throughout the entire area.	
			Nearby public transportation			"Low" indicates that there is no public transportation access within 100 meters of the area, "medium" indicates that there is public transportation access within 100 meters of the area, "high" indicates that there is public transportation access on or adjacent to the area.	
			ADA accessibility			"Low" indicates that the area is not accessible to handicapped persons, "medium" indicates that the area is partially accessible to handicapped persons, "high" indicates that there is handicapped access throughout the area.	
		UTILITY NON-BUILDING INFRASTRUCTURE				"Low" indicates there is no such infrastructure in the area, "medium" indicates that there is minor infrastructure of this nature in the area, "high" indicates there is an abundance of such infrastructure in the area.	
		MASTER PLAN DESIGNATION				"Low" indicates the area has no master plan designation, "medium" indicates that the area has been identified as a potential build site, "high" indicates that the area is designated as a specific building site in the campus master plan.	
	CULTURAL VALUE	HISTORIC SIGNIFICANCE				Determined by Campus Assessment Committee using University resources, including Duke Archives	
		CEREMONIAL SIGNIFICANCE				Determined by Campus Assessment Committee using University resources, including Duke Archives, Office of Student Affairs and University Development	
		NAMING OR OTHER RECOGNITION				"Low" indicates that the area has no name, "medium" indicates that this area has a commonly used name that is not based on a board of trustees designation, "high" means that this area has an official board of trustees name designation.	
	PEDAGOGICAL VALUE	FORMAL PLOT FOR RESEARCH				"Low" indicates there is no plotted research in the area, "medium" indicates that there are 1 or 2 registered research sites in the area, "high" indicates 3 or more registered research sites in the area. (based on future registration system)	
		TEACHING				"Low" indicates there is no passive teaching in the area, "medium" indicates that there are 1 or 2 classes that use the area for passive teaching, "high" indicates 3 or more classes use the area for passive teaching.	
		UNIQUE EDUCATIONAL VALUE				Determined by Campus Assessment Committee using Faculty interviews and precedent from other schools	
	AESTHETIC VALUE	VISUAL QUALITY				Determined by Campus Assessment Committee using site studies, viewshed analyses, interviews/surveys of Duke community, and other means	
		PERCEIVED HEALTH OF LANDSCAPE				Determined by Campus Assessment Committee using site studies and other means	

Appendix C – Campus Experts

Topic	Expert	Contact Information
Flora	Katie Rose Levin	katierose.levin@duke.edu
Fauna	Dr. Nicolette Cagle	nicolette.cagle@duke.edu
Soil	Dr. Dan Richter or Dr. Norm Christensen	drichter@duke.edu normc@duke.edu
Formal Research Location Registration	Sara Childs	sara.childs@duke.edu
Regulating Services/ Ecosystem Services	Dr. Lynn Maguire	lmaguire@duke.edu
Easements and Buffers	Adem Gusa	Adem.Gusa@duke.edu
Campus History/Culture		
Campus Aesthetics	Mark Hough	Mark.Hough@duke.edu
Pedagogical Value	Dr. Nicolette Cagle	
Campus Master Plan	Mark Hough	Mark.Hough@duke.edu
Campus Sustainability	Tavey Capps	tavey.mcdaniel@duke.edu

Appendix D – Glossary

- **Designed landscapes:** These are all campus landscapes that are not in the "Natural" category. These are spaces and landscapes designed and built to serve a programmatic purpose for the Duke community. These can be specific plazas, courtyards, quads, or areas of concentrated development with little or no natural area remaining (Krzyzewskiville, West Quad, East campus, Engineering Quad, Campus Drive). Roadways, parking lots and the interstitial spaces between projects also belong to this category.
- **Framework:** In the context of our work, a framework is a matrix containing cells for the results (high, medium, low) of indicators, which contribute to larger criteria categories. It is intended to be used by project managers or other decision makers on campus who are trying to evaluate a specific tract of land. See Appendix C for the final framework created in this study.
- **Natural landscapes:** These are often remnant woodlands that have an identifiable boundary, a continuous canopy and no occupied buildings, across campus. They typically will have little or no active management or maintenance (Chapel woods, Central campus hollows, Cameron Woods), but any ecologically rich landscape that contributes to the natural environment may fit into this category-even if maintained (Duke Pond, SWAMP, Lemur Center).

Appendix E – Meeting Dates

- Campus Sustainability Committee Meetings
    - 2/23/2015
        - Mark presented our framework concept
        - Comments from committee members
            - Consider looking for best practices from tourist sites like Central Park and National monuments
        - The rest of the meeting focused on unrelated topics
- Subcommittee Meetings
    - 11/06/2014
        - It was emphasized that this is NOT to be a prescriptive framework
        - Discussed differences between open and natural spaces
        - Discussed importance of making various stakeholder voices heard
    - 1/09/2015
        - Told not to use points in the framework, stick to things like "high, medium, low"
        - Revise biodiversity to be relative to expected levels
        - Rework soil components (led to later meeting with Dr. Cagle)
        - Additional minor comments/suggestions for framework
    - 2/03/2015
        - Told to add soil compactedness to soil section of framework
        - Consider splitting easements into both legal and voluntary
        - Additional minor comments/suggestions
- Meetings with Tavey Capps and Mark Hough
    - 9/12/2014
        - Learned about Chapel Woods assessment being conducted by consulting group, Andropogon
        - Discussed issues related to the inconsistent terminology used to define campus natural spaces
    - 1/30/2015
        - Feedback on draft of Framework
            - Particular interest in making the species sections more clear
    - 2/09/2015
        - Feedback on draft of Framework
    - 1/06/2015
- Andropogon Meetings
    - 11/13/2014
        - Reviewed their recent work in Chapel Woods
        - Toured the site
        - Asked them for advice on framework setup

- Individual Interviews
    - Dr. Nicolette Cagle
        - Dr. Cagle provided information and resources about soil for Durham
        - Dr. Cagle suggested we use i-Tree to calculate ecosystem services of the area
        - Dr. Cagle offered to provide us with data from various species inventories of Cameron Woods
    - Dr. Charlotte Clark
        - 12/10/2015 (this meeting also included Tavey Capps)
            - Set timeline for the remainder of the semester
            - Charlotte and Tavey provided suggestions for experts to speak with on campus
            - Discussed how to approach this project
        - 1/23/2015
            - Set up timeline and expectations for final report
        - 3/30/2015
            - Discussed final presentation and paper edits
    - Tavey Capps
        - 9/08/2014
            - Brief overview of what the Facilities department (which houses Sustainable Duke) is looking for
            - Informed that some definitions exist, but that we need to create more and help chose from some existing definitions as well
            - Orientation on key people on campus that may be interested in/use this work
    - Katie Rose
        - 12/08/2014
            - Discussed the importance of making this tool useful beyond the Facilities Department
            - Katie Rose suggested we look at Cornell, Sewannee, and Ivy+ member schools for benchmarking
    - Sara Childs
        - 11/10/2014
            - Discussed Duke Forest management practices
            - Discussed buffer trees/aesthetic management zones
    - Scott Winton
        - 2/06/2015
            - Discussed biodiversity
                - Difficulties in counting species
                - Year round study needed
            - Went birding at Cameron Woods site

Appendix F – An illustrative example of Analytic Hierarchy Process

Suppose there are five criteria for a citizen to choose the ways of transportation (private cars, buses, or subways):

- Convenience: Are the transportation tools easy to access? (Is the parking lot near the apartments? Is bus station near the destination? Etc.)
- Comfort: Do people feel comfortable when they in the transportation tools?
- Expense: Do people spend much money on transportation (tickets, fuels, etc.)?
- Time: Do the transportation tools waste/save time (low speed, traffic jam, etc)?
- Environmental effects: Do the transportation tools have any negative environmental effects?

Then the pairwise comparisons are used to reveal people's preferences on these five criteria when they choose the ways of transportation. An empty temple of the matrix is in Table F1. People need to compare these criteria from blue cells to green cells. (i.e. is the item in the blue cell more important, less important, or equal to the item in the green cell). Only the orange cells need to be filled. The write cells would be the reciprocal values of the associated orange cells. Please refer to the Excel Appendix A ("AHP Example") to see the formula in cells.

Table F1 The Pairwise Comparison Matrix Template

Criteria	Convenience	Comfort	Expense	Time	Environmental effects
Convenience	1				
Comfort		1			
Expense			1		
Time				1	
Environmental effects					1

Table F2 is a pairwise comparison matrix that has been filled. For instance, when criterion **convenience** is compared to **comfort**, I determined that is **convenience** between to be classified as "Moderate more important and "Essential more important " than criterion **comfort**. Thus the corresponding comparison assumes the value of 4. A similar interpretation is true for the rest of the entries.

Table F2 the Sample Pairwise Comparison Matrix

Criteria	Convenience	Comfort	Expense	Time	Environmental Effects
Convenience	1	4	1/4	1/2	1/3
Comfort	1/4	1	4	3	3
Expense	4	1/4	1	2	3
Time	2	1/3	1/2	1	3
Environmental Effects	3	1/3	1/3	1/3	1

In this study, there are two experts completed the pairwise comparison matrices. After calculation in excel, this approach came to the results of weighting. The calculation process and final results are in Excel Appendix A ("AHP Example").

Appendix G – Pairwise comparison results from NSR members

- **Coding**

LAND CATEGORY	CRITERIA	CRITERIA	INDICATOR	INDICATOR
NATURAL LANDSCAPES	ECOLOGICAL VALUE	A1	SPECIES	B11
			HABITAT	B12
			SOIL ATTRIBUTES	B13
			REGULATING SERVICES	B14
			FRAGMENTATION	B15
	PROGRAMMATIC/USE VALUE	A2	ACCESSIBILITY	B21
			UTILITY/NON-BUILDING INFRASTRUCTURE	B22
			MASTER PLAN DESIGNATION	B23
			CURRENT LEVEL OF USE	B24
	CULTURAL VALUE	A3	HISTORIC SIGNIFICANCE	B31
			CEREMONIAL SIGNIFICANCE	B32
			NAMING OR OTHER RECOGNITION	B33
	PEDAGOGICAL VALUE	A4	FORMAL PLOTTED RESEARCH	B41
			TEACHING	B42
			UNIQUE EDUCATIONAL VALUE	B43
	AESTHETIC VALUE	A5	VISUAL QUALITY	B51
			PERCEIVED HEALTH OF LANDSACPE	B52

- **Results**

Criteria	A1	A2	A3	A4	A5
A1	1	5.79	4.53	4.43	5.24
A2	0.17	1	1.47	0.52	0.59
A3	0.22	0.68	1	0.53	0.64
A4	0.23	1.93	1.88	1	2.25
A5	0.19	1.68	1.57	0.44	1

A1	B11	B12	B13	B15
B11	1	0.71	2.24	1.63
B12	1.41	1	3.34	2.55
B13	0.45	0.30	1	0.52
B15	0.61	0.39	1.93	1

A2	B21	B22	B23	B24
B21	1	2.30	0.39	1.19
B22	0.43	1	0.54	0.61
B23	2.55	1.85	1	1.14
B24	0.84	1.63	0.88	1

A3	B31	B32	B33
B31	1	2.11	2.66
B32	0.47	1	0.59
B33	0.38	1.68	1

A4	B41	B42	B43
B41	1	2.65	1.63
B42	0.38	1	0.67
B43	0.61	1.50	1

A5	B51	B52
B51	1	2.45
B52	0.41	1