Identifying Opportunities and Pathways to Increase Carbon Sequestration through Reforestation on the Vassar Ecological Preserve

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Land Acknowledgement

I would like to acknowledge that this research and thesis project was conducted on the homelands of the Munsee Lenape, Indigenous peoples who have an enduring connection to this space and land despite being forcibly removed from the land by European colonization. Today the Munsee Lenape continue as the Stockbridge-Munsee Community in Wisconsin, the Delaware Tribe and the Delaware Nation in Oklahoma, and the Munsee Delaware Nation in Ontario. Every member of the Vassar community since the College's conception in 1861 has benefited from the removal of these native peoples. Our work on this land is aimless without efforts to counteract the structures that have allowed us to benefit from and continuously perpetuate injustice against Indigenous Americans. To that end, it is on this land that I was able to conduct research and ecological analyses for my senior thesis.

If you are interested in the history of the land you are on and the indigenous peoples who have cared and stewarded for that land, you can learn more about their histories and present stories here: https://native-land.ca/

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Table of Contents

Key Terminology:

Aboveground biomass: The aboveground, standing dry mass of live or dead matter from tree or shrub life forms including stem, stump, branches, and bark.

Carbon sequestration: The process of capturing and storing CO_2 from the atmosphere.

Carbon offsets: The attempt by a business or institution to cancel out some of its carbon emissions by investing in a project that sequesters carbon from the atmosphere.

Diameter at breast height (DBH): A measurement often taken in forest sampling, DBH is the diameter of the tree measured at 1.3 meters or 4.3 feet above the ground at the tree's base.

Greenhouse gasses (GHG): The gasses that trap heat in the atmosphere and therefore are responsible for warming the Earth's surface. The primary GHG produced from human activities is carbon dioxide.

Metric Tons of CO_2 Equivalent ($mtCO_2e$): The unit of measurement for carbon offsets and carbon reducing practices. CO_2 equivalent represents the amount of a GHG whose atmospheric impact has been standardized to that of one unit mass of CO_2 (US EPA, 2014).

Chapter 1: Introduction

Carbon sequestration is the process through which natural mechanisms remove carbon dioxide from the atmosphere and counteract carbon emissions by storing carbon dioxide in the ocean, terrestrial environments, and geologic formations (Sundquist et al. 2008). Terrestrial carbon sequestration occurs when CO_2 is absorbed from the atmosphere through the process of photosynthesis and then is stored in biomass and soil, and is a critical component to combating climate change. The main actors in terrestrial sequestration are forests, and as forests age, forest managers can take actions that minimize the negative effects of climate change and take advantage of the positive benefits forests have in mitigating the climate. This thesis provides guidance on forest management at Vassar Farm and Ecological Preserve to help mitigate climate change caused in part by carbon release and contribute to lowering Vassar College's carbon footprint.

Roughly 450 million years ago terrestrial plants began to disperse across Earth's surface, rapidly increasing global carbon sequestration and drastically cooling Earth's climate. (Servais et al. 2009). In the context of today's changing climate, terrestrial sequestration is imperative to mitigating stressors from anthropogenic greenhouse gas emissions. In 2018 alone, the 691 million acres of United States forestland sequestered 564.5 million tons of CO_2 (Canham, 2021), which is enough CO_2 to offset the greenhouse gas emissions from roughly 110 million passenger cars driven for a year (US EPA, n.d.). Net sequestration across all categories of forestland (full forestland, urban trees, afforestation, harvested wood products, and deforestation) offsets 11% of total United States greenhouse gas emissions annually (Canham, 2021).

With the prior metric in mind, the distribution of sequestering regions is uneven across the United States. The eastern forests of the United States are a carbon sink with 85% of total

U.S. forestland sequestration occurring in this region (Canham, 2021). This is partly due to the eastern corridor of the U.S. being the most heavily forested portion of the country, and many forests in the east are regrowing from land clearing several hundred years ago. In contrast, Rocky Mountain states are net sources of carbon to the atmosphere due to the ongoing damage of insects and fire to the region's forests, causing more carbon to be released than is being sequestered by the forestland (Canham, 2021). The Pacific Coast, is at the moment, a carbon sink due to high biomass stocks and sequestration rates, but is in danger of becoming a carbon source due to the increased intensity and frequency of fires (Canham, 2021). Variation in carbon sequestration can be seen within country regions as well as across the country. For example, within New York State, Hudson Valley forests and forests of eastern New York store about five times as much carbon per acre compared to upstate forests (C. Canham, 2021, personal communication) because of regional soil and climate conditions that result in higher productivity. In the Hudson Valley there is also a higher proportion of smaller, more protected forest patches, like the Vassar Ecological Preserve, which is distinct from the logging that occurs in the northern region of the state (C. Canham, 2021, personal communication).

As beneficial as carbon sequestration is, it cannot be the only way in which greenhouse gas emissions are counteracted. Vassar College has implemented a framework for carbon neutrality that outlines reductions in carbon emissions and ways to counteract specific sector emissions, such as emissions coming from energy usage, transport, or agriculture, that may be impossible to completely reduce (Vassar Sustainability, 2020). In order to amend this impossibility of reaching zero emissions, many institutions and large companies have invested in carbon offsets as a means of outsourcing carbon sequestration and offsetting their own carbon footprint. Carbon offsets often are achieved through one of two different projects, those intending to reduce or avoid carbon emissions from an alternative project (i.e. installing a solar field rather than a coal plant) or those acting as an additive form of carbon sequestration (i.e. planting trees that will sequester carbon as they grow through photosynthesis). Companies are able to purchase and account for these offsets entirely remotely; with the click of a button carbon offsets can be purchased and then implemented completely separate from the business. Unfortunately, with the purchase of carbon offsets often comes the idea that offsets are best and more easily achieved on land separate from that which we interact with daily.

Higher education institutions comparable to Vassar have already purchased offsets as a means of reaching carbon neutrality. Connecticut College has been outsourcing its carbon offsets since the 1990s, one of which planted trees for the Klinki tree project in Costa Rica (Connecticut College, n.d.). Colgate University invests in a different offset project every one to two years, with one of the most recent investments being the Rimba Raya Biodiversity Reserve in Borneo (Colgate University, n.d.). These investments may make sense to Colgate and Connecticut College given they are most likely economically feasible projects, but if the goal of investing in offsets is to create meaningful, long-term changes to greenhouse gas emissions, then tropical projects should not be the main focus. Tropical forests are known to have a much shorter lifespan than forests in other parts of the world, including often living half as long as trees in temperate forests (Kimbrough, 2020). If the goal is to enact long-term meaningful change, it is not as beneficial to plant trees that will release carbon back into the atmosphere much more quickly upon their death. In the sense of Vassar's own carbon footprint, purchasing tropical offsets similar to Connecticut and Colgate makes less environmental sense given that Vassar already has a large preserve where carbon offset projects can be implemented.

The previously mentioned projects are examples where institutions have outsourced their offsets, and from the surface they seem like outstanding investment opportunities. Offsets pose many issues, one of which being that many of these reforestation efforts are not targeting areas in need of help. These areas are often already natural and protected, and there is nearly no added benefit by instituting sequestration and accounting for natural processes that are already occurring (Elgin, 2020). Furthermore, reforestation and restoration efforts must be strategic, and the responsiveness of offset programs to plant native or ecologically diverse trees is difficult to guarantee (Einhorn, 2022). Many times carbon offsets are used to excuse other carbon emitting functions of the institution, rather than implementing lower emitting processes (Al Ghussain, 2020). Tree plantings and offsets cannot be the only way that a company or institution intends to reduce its carbon footprint, but it can be an additive method that works concurrently with other emission-reducing measures. There is no need to outsource this offsetting at Vassar College, with the proximity of Vassar Farm and Ecological Preserve that could be managed more efficiently with carbon sequestration in mind.

This thesis proposes additive methods of carbon sequestration that Vassar College can employ that will also increase the resiliency and diversity of plant communities on the Vassar Ecological Preserve. I am encouraging Vassar College to implement carbon offset projects and work on their own land as a means to aid in Vassar's goal of carbon neutrality and also to manage the Vassar Preserve with ecological resilience and carbon sequestration in mind.

Vassar's terrestrial carbon sequestration can be improved by targeting low-sequestering and/or invasive-dominated areas with invasive removal and reforestation with native, high-sequestering species. Invasive removal and native planting can also help combat invasive species establishment which often result in biodiversity loss, canopy gaps, and reduced ecosystem services of the Preserve. I am urging Vassar College to utilize the benefits of having a 416 acre preserve as a part of our campus, and the carbon sequestration and storage potential that this land provides.

Chapter 2: Vassar College and Other Academic Institutions: Achieving Carbon Neutrality

There are other institutions that have made it their goal to achieve carbon neutrality. Out of the institutions taking on this challenge, those chosen as a comparison to Vassar have a similar size, location, endowment, and goals. The information included throughout this chapter have been sourced from institutional plans- such as Vassar's Climate Action Plan- as well as institutional information reported to certification programs. One certification program is the Association for the Advancement of Sustainability in Higher Education Sustainability, Tracking, Assessment, and Rating System (AASHE STARS). AASHE STARS is a global medium through which colleges and universities can engage in transparent and self-reporting practices to measure their sustainability performance (AASHE, n.d.). Institutions are granted either "Platinum", "Gold", "Silver", "Bronze", or "Reporter" status based on their reported sustainability information, with Platinum having the most intense sustainability measures and Reporter status signifying institutions that do not have strong sustainability measures. The following sections explore Vassar College, Colgate University, Middlebury College, and State University of New York School of the Environment and Forestry. Each heading or subsection is the title or subheading of a document produced from the institution that is relevant to carbon management and carbon neutrality at the institution. The goal of this section is to compare Vassar's own steps towards carbon neutrality and land management with other institutions.

Vassar College

Vassar College is a private, co-educational liberal arts college located in Poughkeepsie, New York. Vassar resides on a 932 acre campus that is home to 2400 undergraduate students (Vassar College, n.d.). Vassar's endowment sits around $1.17 billion (Siderhurst, 2020). In addition to the main campus, Vassar's lands also include the Vassar Farm and Ecological Preserve, which tends to be treated as land separate from the central or main campus. This sentiment is reflected in document creation such as the Vassar Climate Action Plan, and also the AASHE STARS Report, which sideline the VFEP in the inclusion of these documents.

Climate Action Plan

The 2020 Vassar Climate Action Plan outlines the College's efforts to address the climate crisis and reach carbon neutrality by 2030. The 2020 Climate Action Plan builds on Vassar's 2016 Climate Action Plan, and continues to document progress that the school has made towards carbon neutrality. To build upon the 2016 plan, the 2020 Plan includes two additional commitments: becoming a signatory of the Second Nature Presidents' Climate Commitment and building the next five years of climate action at Vassar around the United Nations Sustainable Development Goals. These two goals provide Vassar with a globally recognized framework for sustainability efforts and a newly framed climate plan pledging to share its annual progress towards carbon neutrality as well as developing efforts to increase the community's resilience to climate change impacts (Vassar Sustainability, 2020).

The Climate Action Plan provides information to its stakeholders (ie: Vassar community, investors, trustees, administration, and students) on how Vassar plans to achieve carbon neutrality and, in the longer term, climate positivity by sequestering more carbon than the

College emits (Vassar Sustainability, 2020). The Plan identifies various goals for the following five years, two of which involve the Vassar Farm and Ecological Preserve (Restorative Land Management Guidelines and Carbon Reduction and Reinvestment), highlighted below (Vassar Sustainability, 2020).

Restorative Land Management Guidelines

The aim of these guidelines is to provide an overarching framework for how campus grounds and the Vassar Ecological Preserve are managed (Vassar Sustainability, 2020). This framework includes:

- Involving preservation and management of the Vassar Farm and Ecological Preserve as a part of the College's decarbonization strategy.
- Selecting native plants and plants with resilience to climate change impacts as often as possible, where suitable for a location's aesthetic needs.
- Acknowledging that carbon sequestration from trees and shrubs maintained on campus can reduce Vassar's total carbon footprint.

While these guidelines will not be completed for a few more years, the goal is not to produce incredibly strict parameters. The goal of these guidelines is to treat as many spaces as possible on campus as a living land acknowledgment, and tell the story of what the land used to be, through the land, while still acknowledging that we exist in a changing climate. At the moment there is no implementation plan for how these parameters will be integrated into practice on campus grounds (C. Kenfield, 2022, personal communication).

Carbon Reduction & Reinvestment

Vassar College has acknowledged the role that the Vassar Farm and Ecological plays in the College's goal of carbon neutrality through this goal of carbon reduction and reinvestment. The Preserve has been identified as a carbon sink, and according to the 2018 i-Tree Ecosystem Analysis, the Vassar Farm and Ecological Preserve stores just over 7,700 mtCO_2e, and sequesters an additional 240 metric tons of CO_2 annually (Finley, 2018). The 2020 Climate Action Plan states that the Office of Sustainability in conjunction with the VFEP will pursue third party verification of on-campus carbon sequestration. This plan has since fallen through and Vassar views third party verification as too costly. Rather than third party verification of our own land accounting for the carbon that land sequesters, the College is looking into purchasing offsets that would sequester and store an equal amount of carbon as the VFEP in a remote carbon offset.

Additionally, the 2020 Climate Action Plan states that the way in which Vassar has engaged in carbon accounting has reflected how investments in energy efficiency and the electrification of campus facilities have decreased the amount of GHG emitted into the atmosphere. In contrast, as the Climate Action Plan points out, the considerable resources being invested into ongoing maintenance and conservation of the VFEP are not similarly reflected in the impact on Vassar's carbon management, meaning that there is not as much of a return in monetary value (Vassar Sustainability, 2020). The Climate Action Plan suggests that purchasing carbon offsets to plant trees across the country or world would have more of a direct impact on Vassar's reported carbon footprint than growing the same number of trees on campus, insinuating an investment in remote rather than on-campus offsets. (Vassar Sustainability, 2020).

Vassar Ecological Preserve

The Vassar Ecological Preserve's 416 acres of land are available as a space for educational resources and ecological restoration. The mission of Vassar's Preserve is to "protect and preserve the ecological integrity of the land and ensure that educational value is preserved" (Vassar Farm and Ecological Preserve, n.d.). The Preserve hosts a variety of student volunteer and work opportunities both independently and through the Vassar Undergraduate Research Summer Institute. Continuing, many classes engage with the Preserve for laboratory or research purposes and students are able to utilize the land on the Preserve for thesis and independent projects (Vassar Farm and Ecological Preserve, n.d.). Further uses of the Preserve include hiking trails for the general Poughkeepsie and Hudson Valley community as well as athletic fields and trails for the Vassar rugby and cross country teams, respectively.

Vassar Ecological Preserve Conservation Action Plan

The Conservation Action Plan, created by Lindsay Charlop, Keri VanCamp, Margaret Ronsheim, Dylan Finley, and Lydia Kiewra, provides a framework for protecting ecological diversity of the land and prioritizing conservation efforts on the Vassar Ecological Preserve. The Conservation Action Plan aims to guide the Preserve through five major action areas, one of these being Ecological Management and Restoration (Charlop et al., 2019). Ultimately, the Conservation Action Plan calls for identification of focus areas on the Preserve, posing three guiding questions: What do we want to conserve? What are the barriers to conservation? How can we overcome these barriers? (Charlop et al., 2019)

The Conservation Action Plan identifies areas on the Preserve that should be prioritized for restoration and management efforts based on threats such as invasive species and habitat fragmentation (Charlop et al., 2019). Broadly, these target areas are the Eastern Forest Corridor and the Open Central Corridor on the Vassar Ecological Preserve (see Map 1 in Appendix). The Conservation Action Plan also identifies forest community types that are priorities for restoration, both within and outside of the central and eastern corridors. These communities are: Red Maple Hardwood Successional Swamp, Floodplain Forest, Beech Maple Mesic Forest, and Appalachian Oak-Hickory Forest (Charlop et al., 2019). The Eastern Forest Corridor has suffered from invasive species growth which has in turn resulted in forest canopy gaps and consequent habitat fragmentation. Through practices that prevent invasive species spread, reduce disturbance and fragmentation of habitats, and emphasize restoration, the Conservation Action Plan maintains and strengthens natural areas on the Preserve (Charlop et al., 2019).

i-Tree Ecosystem Analysis

In 2016, Dylan Finley, an employee of the Preserve at the time, conducted an assessment of the vegetation structure, function, and value of the V using the Carbon i-Tree v6 urban forest software. This assessment, published in 2018, was derived from data collected from 25 field plots located through the Vassar Farm and Ecological Preserve (Finley, 2018).

In the assessment, the following metrics were calculated (Finley, 2018):

- Number of trees: 75,390
- Tree cover: 85.2%
- Most common tree species: *Acer rubrum* (red maple, 10.8%), *Malus sieboldii* (Toringo crabapple, 10.1%), *Fraxinus americana* (white ash, 10.0%)
- Percentage of trees less than 6” (15.2cm) in diameter: 57.0%
- Carbon storage: 8.544 thousand tons ($1.11 million equivalent)
- Carbon sequestration: 265.3 tons/ year ($34.4 thousand/ year)

- Oxygen production: 580.7 tons/ year
- Avoided runoff: 577.2 thousand cubic feet/ year ($38.6 thousand/ year)
- Structural values: $52.6 million

Carbon Storage and Sequestration

In estimating the annual gross sequestration of all tree species, *Acer rubrum* had the highest estimate, followed by *Quercus rubra*. In terms of estimated carbon storage, the same was found with *A. rubrum* and *Q. rubra* being the best at storage. Of all species sampled, *A. rubrum* also stores and sequesters the most carbon of the Preserve cumulatively, with approximately 20.3% of total carbon stored and 18.4% of all annually sequestered carbon (Finley, 2018).

Vassar AASHE Profile

Vassar was certified Gold Status by the AASHE STARS program in 2021, and scored 69.13 out of 100 possible points with certification status valid through May 2024 (Vassar College Office of Sustainability, 2021). The following sections of this portion are pieces of the report sent to the program that relate to Vassar's land management and carbon sequestration, and the accompanying scores are what Vassar scored on that portion of the report.

Landscape Management (1.87/2.00)

Landscape management under the AASHE program for Vassar ultimately focuses on lands directly on campus, which seems to exclude the Vassar Ecological Preserve. With that in mind, the Vassar campus encompasses a total of 932 acres (including the Preserve), with 89.27% of those grounds being managed organically (Vassar College Office of Sustainability, 2021). The organic landscape management approach has been a “mow and grow” approach that results in the mowing of grass areas once a week during the growing season. For “on-campus” plant stewardship protocols, major landscape plantings are recommended by the landscape architecture consultant Michael Van Valkenberg Associates (MVVA), who also developed the landscape master plan for Vassar. A key component of this master plan is the use of native plants, and MVVA has made specific recommendations that follow these guidelines. Furthermore, there has been the development of plans for invasive vine removal and the establishment of naturalized areas on campus (Vassar College Office of Sustainability, 2021).

Greenhouse Gas Emissions (4.67/ 8.00)

Vassar’s baseline greenhouse gas emissions upon first reporting to the AASHE STARS program was 25,409.11 metric tons of CO_2 equivalent, and in 2021 the college reported 14,134.22 mtCO_2e (Vassar College Office of Sustainability, 2021).

The AASHE report offers an opportunity for institutions to identify any carbon sinks present on the land that they occupy. For Vassar, this section of the report was left empty as Vassar has yet to identify or verify any land (such as the Vassar Ecological Preserve) as viable carbon sinks. There is also no information on any reduction initiatives set forth by the College to lower its emissions.

Summary

Vassar College is striving towards carbon neutrality, and has already employed a variety of methods and changes in the functioning of the school in order to reach this goal by 2030. The College has identified the integral role that the VEP can and has played in reaching carbon neutrality, but has steered away from investing into the Preserve due to more economically plausible investments in energy and other forms of offsets. Vassar has employed structural methods to investigate and assess their carbon footprint, but has yet to fully account for the role and impact that the Preserve can play on carbon mitigation at the College. Investing in offset projects is a beneficial strategy through which Vassar can invest in the Preserve and reduction of its carbon footprint.

Colgate University

Colgate University is a private, co-educational liberal arts university located in Hamilton, New York. Colgate's 575 acre campus supports 2900 students every year (Colgate University, n.d.), and the University's endowment sits at $1.3 billion (Swaminathan, 2021). In addition to its campus, the University has 1,057.5 acres of forested land, 339 of which are located directly on the University's campus. In April of 2019, Colgate achieved carbon neutrality as its net carbon emissions reached zero, and in doing so became the first college or university in New York State to reach carbon neutrality (Colgate University, n.d.). In their process of reaching carbon neutrality, Colgate enacted many different measures. Those that relate to carbon forest management, offsets, and sequestration, are discussed in the following sections. The documents referenced are the 2017 Colgate Bicentennial Plan for a Sustainable Carbon Neutral Campus, the 2018 Colgate Forest Carbon Inventory and Projections, and Colgate's AASHE Profile.

2017 Bicentennial Plan For a Sustainable and Carbon Neutral Campus

General Information

Colgate University committed to sustainability in 2009 when the Second Nature's Carbon Commitment, and hired the University's first sustainability director. The Colgate Bicentennial Plan is a living document which outlines Colgate's commitment to carbon reduction and discusses the current and past emissions by the University and the framework in place to reach carbon neutrality (Colgate University Sustainability, 2017). Much of the document specifies commitments of the University and what administrative office/ faculty member is responsible for monitoring the progress to that commitment. Part of this commitment required Colgate to achieve carbon neutrality by offsetting remaining emissions which began in 2013. Another portion of this plan called for a resampling of forest plots on Colgate's forest properties, which was completed in 2018 and led to the creation of the 2018 Forest Carbon Inventory & Projections report (Colgate University Sustainability, 2017). Colgate recognizes that carbon storage and annual sequestration is an important function of their forested land, and by determining the annual sequestration of forested lands they can gain a better understanding of the role that Colgate's forests can play in reducing carbon (Colgate University Sustainability, 2017).

Carbon Offsets

This document calls for Colgate to develop a plan to implement and finance carbon offsets that would contribute to the University reaching carbon neutrality. The University acknowledges that while on-campus projects that reduce carbon emissions should be the top priority for reaching carbon neutrality, there needs to be outside investment in order to reach carbon neutrality, which is what led the University to invest in offsets (Colgate University Sustainability, 2017).

In 2012, Colgate began working with Patagonia Sur, a sustainable investment company that works on implementing offset projects with investments from outside entities. Colgate purchased 5,000 tons of forestry-based offsets per year for a 15 year period from Patagonia Sur, supporting a reforestation project in the Palena province of southern Chile. The plan aims to plant 225,000 native trees over the course of 15 years on 428 acres of land that has been allotted to the Colgate University Forest (Colgate University Sustainability, 2017).

At the time that this plan was written, Colgate University was planning to spend an estimated $144,628 annually for investments in carbon offset projects. These investments would result in an estimated 13,152 mtCO_2e mitigated per year across three different sectors: the Patagonia Sur Reforestation Project (5,000 mtCO_2e), offsets in a voluntary market (6,152

$mtCO_2e$), and renewable energy certificates (2,000 $mtCO_2e$) (Colgate University Sustainability, 2017). This outline of costs and estimated carbon offsets inspired the University to make the commitment of forming a Carbon Offset Working Group in order to evaluate and recommend offset options for Colgate to further offset their carbon footprint (Colgate University Sustainability, 2017).

2018 Colgate Forest Carbon Inventory & Projections

The 2018 Colgate Forest Carbon Inventory & Projections publication documents the methodology Colgate uses to analyze carbon sequestration in tree biomass on Colgate's forested properties (Colgate University, 2018).

Plot Establishment

The Winrock Sampling Calculator (Winrock International, n.d.) was used to determine the number of sample points required to confidently calculate the amount of carbon sequestered terrestrially in Colgate's forest properties. The study used data from the United States Forest Service Forest Inventory Analysis data in order to accurately make calculations. These calculations resulted in 173 plots systematically spaced across Colgate's property. Each plot was 1/10 acre in size and marked for revisiting purposes, and all live trees and shrubs 3.0 inches in DBH or larger were measured to the tenth of an inch. These 173 plots will be revisited and used in making estimates of a changing forest carbon stock at five year intervals beginning in 2013 and most recently in 2018 (Colgate University, 2018).

Calculation of Total Tree Carbon

In order to calculate the carbon sequestered for all of Colgate's forest land, the Jenkins et al. (2003) parameters and equation for estimating aboveground biomass were used including the species group stratifications (Colgate University, 2018).

Results

The baseline estimate of total tree carbon in Colgate University's Forest properties is 52,794 metric tonnes, which equates to 193,755 tonnes of carbon sequestered (Colgate University, 2018).

Annual Sequestration Estimates

Comparing the sequestration of the sampled plots in 2013 with data from 2018's resampling allows for the trends of carbon sequestration in Colgate's forests to be seen. Using statistical analysis, the University was able to estimate the amount of carbon sequestered annually, 3,776.4 tonnes a year (Colgate University, 2018).

Colgate AASHE Profile

Colgate was a reporting member to the AASHE STARS Program, but allowed their Gold Status to expire in February of 2021 (Colgate University, 2017). With that in mind, this information is slightly dated but relevant to Colgate's approach for carbon mitigation and management.

Greenhouse Gas Emissions (8.56/ 10.00)

Colgate University purchased carbon offsets valued at 6,578 Metric Tons of CO_2 Equivalent in the reporting period. A large portion of these offsets (5,000 mtCO_2e) has been sourced from Patagonia Sur where, since 2012, Colgate has planned on purchasing 5,000 mtCO_2e per year for 15 years (Colgate University, 2017). The project being funded by Colgate is a reforestation project in the Patagonia Sur Nature Reserve in the Palena province of southern Chile. The agreement between Colgate and Patagonia Sur is that 225,000 native trees will be planted on roughly 428 acres of land over the course of 15 years, and this land will become Colgate University Forest following the project completion (Colgate University, 2017). This ownership of the land will allow students and faculty to conduct research in the Patagonia Sur Nature Reserve.

In New York, Colgate's local forest has been certified by the American Tree Farm System for long-term sustainable management. The trees in the forest have been inventoried and sequester 1,578.0 mtCO^2e annually, and the University's forest is actively managed for carbon sequestration (Colgate University, 2017).

Summary

Colgate University has used both foreign and local offsetting in order to reach its carbon neutrality goals. In reaching carbon neutrality in 2019, Colgate accounted for terrestrial forest carbon stock in their forest properties and calculated their stock with a statistically significant analysis of forest properties belonging to the University. Colgate has been able to account for 28% of their gross emissions being sequestered by their forest properties, and while there is no intent to specifically increase the carbon sequestration on their forested lands, there is monitoring and reevaluation occurring to keep track of terrestrial forest carbon stock.

Middlebury College

Middlebury College is a private, coeducational liberal arts college located in Middlebury, Vermont. Middlebury is home to a student body of 2,500 undergraduates on a 350 acre campus, with an additional 2,400 acres of land owned off the main campus (Middlebury College, n.d.). Middlebury's endowment as of October 2021 sits at $1.5 billion (Middlebury College, n.d.). Middlebury was at the forefront of colleges/ universities in the United States to become carbon neutral, achieving the status in 2016 (Middlebury College Sustainability, n.d.). In the process of striving for carbon neutrality, Middlebury underwent many changes in functioning, such as constructing a biomass gasification plant in late 2008 which burns locally sourced wood chips to heat and cool campus buildings, cogenerating 15-20% of campus electricity (Middlebury College Sustainability, n.d.). As a part of their carbon-neutrality process, Middlebury also strived to include their forested property. The following sections and documents discuss Middlebury's move towards carbon neutrality and how they integrated their forest property into that goal.

Middlebury Lands

Middlebury College owns several thousand acres of land in the Champlain Valley and Green Mountains, and is therefore committed to land stewardship on these lands (Middlebury College, n.d.). The stewardship of this land adheres to the following guiding principles; recognizing the importance of environmental sustainability and stewardship; fiscally responsible decision making; acknowledging that lands are parts of broader ecosystems working to improve the biological integrity of those ecosystems; recognizing the value of the traditional Vermont landscape; recognizing that the appropriate use of lands can help reach broader sustainability goals; recognizing the value of land as an educational resource; and embracing the idea thea land stewardship is interdisciplinary (Middlebury College, n.d.).

The lands owned are the Bread Loaf Campus, Battell Research Forest, Otter Creek, and Jackson Lands. The College owns 2,000 acres of land at and around the Bread Loaf campus, which is a satellite campus of Middlebury's main campus and was conserved with the Vermont Land Trust in 2015 (Middlebury College, n.d.). Blue Source, a carbon accounting company assessed the land and quantified carbon credits based on the amount of carbon dioxide sequestered by Bread Loaf forests. Portions of these carbon credits have been used to offset remaining pieces of Middlebury's carbon footprint (Middlebury College, n.d.).

The Battell Research Forest is a 104 acre old-growth northern hardwood-hemlock forest and National Natural Landmark that was donated to the College in 1911. This forest property is home to pines and hemlocks that are over 300 years old, many of which established themselves following fires in the 1700s and 1800s (Middlebury College Biology Department, n.d.). The forest is an important site for classes, faculty, and student research projects, especially surrounding forest ecology.

Otter Creek is an area that the College stewards which is home to a diverse wetland system with red maple-northern white cedar swamps and a variety of other ecological communities (Middlebury College, n.d.).

Jackson Lands makes up 377 acres of land and was gifted to the College in 2012. The woods, fields, and ponds provide various educational, conservation, agricultural, and recreational uses (Middlebury College, n.d.).

Carbon Neutrality at Middlebury College: A Compilation of Potential Objectives and Strategies to Minimize Campus Climate Impact, 2003

This proposal is the initial document prepared for the carbon reduction initiative at Middlebury College, which first began in 2003 due to pressure from students and staff. This document was created as a part of a seminar at Middlebury in the spring of 2003 titled "The Scientific and Institutional Challenges of Becoming Carbon Neutral" (Acher et al., 2003). The faculty and students involved in the course recognized that emissions occurred and strategized methods through which the College could reduce carbon emissions. Regardless of the carbon reduction strategies employed by Middlebury, though, CO_2 will still be produced by the College and there will still be residual emissions that could be reduced. In order to address these lingering emissions, on-campus and off-campus carbon sequestration were both identified as methods of carbon reduction.

When it comes to sequestration, Middlebury College identifies improving terrestrial carbon sinks as a temporary solution to an ongoing problem. The development of these sinks allows more time to achieve further reductions in other sectors of the College's functioning (Acher et al., 2003). To improve these sinks, the proposal suggests investing in off-campus carbon offset companies, such as Future Forests (UK Based), American Forests, and Pacific Forests. In profiling the companies, the proposal weighs local magnitudes such as preservation and reforestation of area (Acher et al., 2003).

On-campus opportunities for carbon offsets were also investigated, and of those opportunities, reforestation and agricultural sequestration were noted. Reforestation within Middlebury's own timber harvesting procedures, and the implementation of no-till agricultural practices both have the potential to maximize CO_2 sequestered and stored and make these processes more sustainable (Acher et al., 2003).

Carbon Sequestration and its Relationship to Forest Management and Biomass Harvesting in Vermont (2010)

This document was produced by the Winter 2010 Environmental Studies Senior seminar course. The purpose of this report is to summarize ways in which carbon can be measured and managed in Vermont forests (Crosby et al., 2010). In 2010 when the report was written, it was unknown if any landowners in Vermont were managing their land with carbon sequestration in mind.

Measuring Carbon

The document provides methods for measuring carbon sequestration. The first is ecological quantification, which involves measuring living aboveground and belowground biomass, dead organic matter, and soil carbon (Crosby et al., 2010). This quantification is done using biomass equations for multi-species groups from Jenkins et al. (2004) to measure biomass of Middlebury College Lands. Another method for measuring carbon sequestration is by using computer models and simulations, specifically the Carbon Density Model supplied by Heath et al. (2003).

Carbon Storage on Middlebury College Lands

Carbon storage was calculated using the Carbon Density Model from Heath et al. (2003), and in 2010 it was estimated that between 322,932 and 354,129 tons of carbon were being stored on Middlebury College forest land (Crosby et al., 2010).

Managing Carbon on Middlebury College Lands

The forest community that sequesters the most carbon in and around Middlebury, Vermont, is maple-beech-birch forest. This was determined by comparing the total forest carbon in the four main types of northern hardwood forests: maple-beech-birch, northern hardwood talus woodland, hemlock forest, and floodplain forest (Crosby et al., 2010). This result was reached in 1997 using calculations in eastern United States forests. With this in mind, forest communities of mixed species composition as well as mixed age ranges are believed to be best overall for carbon sequestration due to younger trees having higher carbon sequestration rates, while older trees have greater carbon storage (Crosby et al., 2010).

Middlebury AASHE Profile

Middlebury College was a reporting member to the AASHE STARS Program, but allowed their Gold Status to expire in December of 2020 (Middlebury College, 2017). With that in mind, this information is dated but relevant to Middlebury's approach for carbon mitigation and management.

Greenhouse Gas Emissions (9.50/ 10.00)

In the reporting year 2017, Middlebury reported 22,954 metric tons of CO_2 equivalent sequestered on the Middlebury Bread Loaf Campus, which the College manages specifically for carbon sequestration (Middlebury College, 2017). In addition to on-campus offset verification, Middlebury also purchased carbon offsets worth 634 metric tons of CO_2 equivalent (Middlebury College, 2017). The offsets are purchased from Native Energy, a Vermont-based offset business, and the offsets are purchased in order to balance out the emissions from Middlebury's Snow Bowl ski area.

Landscape Management (1.50/2.00)

Middlebury College is recognized by the Arbor Day Foundation's Tree Campus USA Program, which provides a framework for colleges and universities to grow their community forests, and in turn recognizes universities and colleges that have worked in cultivating sustainable forests and tree communities on their campuses (Middlebury College, 2017).

Furthermore, the Middlebury campus Master Plan states that native plants should be used in campus plantings, and when possible those plants should be obtained from Middlebury's own forested lands (Middlebury College, 2017).

Summary

Middlebury College has employed a variety of methods and land management techniques in reaching their goal of carbon neutrality. When it comes to carbon sequestration on its own land, most of the information for action comes from Middlebury's 2003 carbon neutrality proposal. The main use of carbon sequestration in Middlebury's journey to carbon neutrality was when the College's Bread Loaf Campus was conserved in the Vermont Land Trust and Blue Source quantified the land for carbon credits, which Middlebury used to offset its remaining carbon emissions. Middlebury as an institution received flack for the use of offset credits to reach carbon neutrality (in part due to the amount of carbon credits used in the process), but declared carbon neutrality nonetheless.

State University of New York College of Environmental Science and Forestry

State University of New York's College of Environmental Science and Forestry (SUNY ESF) is a specialized university in Syracuse, New York that is a part of the State University of New York System. SUNY ESF is home to 1800 undergraduate students and 400 graduate students (SUNY ESF, n.d.). ESF's endowment is about 38.8 million (SUNY ESF, n.d.), and the College owns multiple campuses that equal about 25,000 acres of land and college forest properties. This land is integral to the College's functioning and it serves as a teaching and research laboratory for faculty and students.

SUNY ESF is one of the most environmentally driven and conscious colleges or universities across the globe and has been a college of forestry for over 100 years. The goal of the College is to move past carbon neutrality and strive towards becoming carbon negative. SUNY ESF has accrued a large amount of environmental accolades and awards, one of which being one of the ten universities worldwide to be rated platinum by the AASHE.

Carbon Management

SUNY ESF has been tracking their carbon footprint since signing the American Colleges and Universities Presidents Climate Agreement (now known as Second Nature) in 2007 (SUNY ESF Sustainability, n.d.). Second Nature holds colleges and universities accountable for reducing their carbon emissions to the maximum extent possible, and then offsetting the remaining emissions to reach net zero greenhouse gas emissions.

In 2009, ESF inventoried their greenhouse gas emissions and completed a Climate Action Plan to save energy, reduce fossil fuel use, and reduce emissions as much as possible (SUNY

ESF Sustainability, n.d.). The Climate Action Plan emphasized the construction and implementation of clean energy systems as well as energy efficiency and conservation.

Carbon Forest Management

ESF calculates carbon sequestration on 25,000 acres of College forest properties. Forest growth on College properties is monitored across continuous forest inventory plots every year. ESF has over 700 forest inventory plots through their five forest properties statewide. The plots primarily include northern hardwood species such as: sugar maple, red maple, yellow birch, beech, white ash, red oak, white pine, hemlock, red spruce, and pine/softwood plantations of various species (SUNY ESF Sustainability, n.d.).

ESF is interested in pursuing ways to further mitigate the College's carbon emissions, including quantifying and including additional greenhouse gas sinks, sources, and fluxes in the ESF carbon budget such as belowground biomass. Additionally, the College is interested in engaging in research on remote sensing of continuous forest inventory plots, visualizing forest regeneration and carbon sequestration over time, forest carbon policy and management strategies, as well as Second Nature Carbon Offset Network projects such as community tree plantings (SUNY ESF Sustainability, n.d.).

SUNY ESF AASHE Profile

SUNY ESF has earned Platinum Status by the AASHE STARS program for their sustainability initiatives occurring on campus. ESF earned an overall score of 85.66 points out of a possible 100 (SUNY ESF, 2021).

Landscape Management (1.44/ 2.00)

ESF has adopted a Native Plant Policy, which declares that only plant species native or naturalized to New York State and/ or the northeast United States will be planted in the future at the College (SUNY ESF, 2021).

Research (17.33/ 18.00)

Sustainability related research occurs in every department of the College, and 59.02% of all employees that conduct research at SUNY ESF are engaged in sustainability research. SUNY ESF has active research that is funded by the New York State Department of Environmental Conservation that contributes to analyses of carbon stocks on ESF forest properties, which works in conjunction with studies of forest carbon stock and fluxes at the statewide landscape scale (SUNY ESF, 2021).

Greenhouse Gas Emissions (8.00/ 8.00)

Identifying Carbon Sinks:

ESF faculty and staff members have identified two forest properties for official designation as sequestration initiatives. These two properties, including 2,181 acres of the Pack Demonstration Forest in Warrensburg, NY, and 1,486 acres of Heiberg Memorial Forest in Tully, NY, have been managed to maintain that growth in carbon stocks exceeds harvest. As a part of the 2009 Climate Action Plan, the annual combined sequestration rate for these forest properties was calculated to be 7,000 $mtCO_2e$ per year (SUNY ESF, 2021).

In addition to the Pack Forest and Heiberg Forest, ESF has forest properties in a total of eight locations throughout central New York and the Adirondack region. In total, ESF's forest properties sequester around 24,000 $mtCO_2e$ annually, nearly double the College's baseline carbon footprint of 12,145 $mtCO_2e$ calculated in 2007. Under AASHE STARS reporting guidelines, the 7,000 $mtCO_2e$ per year sequestered Pack and Heiberg Forests count as "Institution-catalyzed carbon offsets generated", which is considered an internally designated, verified, and managed sequestration initiative that contributes to lowering the College's carbon footprint (SUNY ESF, 2021).

Identifying Emission Reduction Initiatives:

ESF is committed to quantifying and tracking as many GHG flows as possible and relevant in monitoring and mitigating the College's carbon footprint. This commitment involves the participation of students, faculty, and staff in using the campus as a living lab for forest carbon research, policy, initiatives, and discourse. ESF has begun to evaluate ways to further improve monitoring and mitigation of the school's carbon footprint by looking at instituting permanent, additional, and verifiable changes. These methods include the active participation in Second Nature's Offset Networking group for peer-verified offset projects, and continued research and implementation of offset projects (SUNY ESF, 2021).

Summary

SUNY ESF is at the forefront of higher education sustainability worldwide. The College has ingrained sustainability into the way that the school functions and integrates sustainability into all campus processes. ESF is responsible for managing over 25,000 acres of land distributed through various satellite campuses in the Adirondacks and Northern New York. When it comes to forest carbon sequestration, ESF has ample amounts of funding and resources being put forward to further the College's commitment to emissions reduction. The College is involved in working groups such as the Second Nature working group on GHG Accounting for Bioenergy and Forest Sequestration, and ESF has also outlined a variety of forest-related carbon research initiatives that the school plans to pursue. With this in mind, ESF has acknowledged and embraced the importance of carbon sequestration institutionally and has made it a priority in their research and practice.

Chapter 3: Vassar Farm and Ecological Preserve

Vassar's carbon sequestration options on-campus are mainly found on the Preserve, and in order to see how sequestration management might look on the Preserve it is first necessary to understand the history and aims of the Preserve. Since Vassar's inception in 1865, the school has always had land designated for farm use. This gardening land was originally located west of Raymond Avenue adjacent to today's Vassar Lake (Ronsheim et al., 2006). The farm relocated to its current location, south of Vassar's Main Campus, in the early 1900s and continued functioning as a dairy farm on nearly 300 acres of deeded land to the college (later leading to 416 acres through additional property acquisitions). In this location, the farm grew and provided food for the college as well as work opportunities for students, who at the time donned the name "Farmerettes" (Ronsheim et al., 2006). The farmerettes found themselves working on the farm during WWI and WWII and kept up with the demand for agricultural needs and filled holes left in the workforce. In 1957 the farm was deemed not financially viable to continue supplying food for the growing college by the trustees (Ronsheim et al., 2006). Following this, dairy cows and other livestock were auctioned off and cultivation of the fields ceased for the time being.

In 1968, various Vassar professors began envisioning another role that the residual space on the farm could occupy. Margaret Wright led a group of Vassar biologists in 1973 to propose a center for ecological study on the Vassar Farm (Ronsheim et al., 2006). This plan came to fruition in 1978, when the president of the college at the time, Virginia Smith, granted money for the creation of a field station and trail system on the land. The establishment of the Vassar Ecological Preserve continued to develop over years with the assistance of more monetary donations and specifically the Swain Endowment, which funds operations to maintain the

Preserve as a field station and educational resource (Ronsheim et al., 2006). In 1995 a permanent field station was built on the Preserve thanks to the Collins Gift.

The Vassar Ecological Preserve today is vastly different from the farm that occupied the land. The Preserve now contains 416 acres of land maintained as an educational and ecological resource, and is also the largest greenspace in the city of Poughkeepsie. The mission of Vassar's Preserve is to "protect and preserve the ecological integrity of the land and ensure that educational value is preserved" (Vassar Farm and Ecological Preserve, n.d.). To this end, the Preserve is home to a variety of research and recreational uses. The Preserve hosts Community Engaged Learning students, work-study positions, and summer internship opportunities both independently and through the Vassar Undergraduate Research Summer Institute. Many classes also engage with the Preserve whether that be for experiential learning (i.e. Thoreau's cabin and the labyrinth), as well as for research purposes and students are able to utilize the land on the Preserve for thesis and independent research projects (Vassar Farm and Ecological Preserve, n.d.). Further uses of the Preserve include hiking trails for the general public as well as athletic fields for the Vassar rugby teams and trails for the Vassar cross country teams.

Another important area on the Preserve is the EcoRestore site, which has a history of dumping and a presence of silt piles on the land. Initially, Poughkeepsie used the area as an organic waste management/ composting site and in the mid 1990s Greenway Environmental, an environmental services company, conducted large scale compost on 3 acres of the site which later grew to 7.4 acres in 2005 (K. VanCamp, 2022, personal communication). Ultimately, Vassar and Greenway could not come to terms on a contract due to fundamentally different visions for the site which led to the acceptance of unauthorized materials being dumped into the site (K. VanCamp, 2022, personal communication). Following this, the site was abandoned and left with piles of organic debris. Due to the degraded state of the site, it was used as a staging area during construction of Vassar's Bridge for Laboratory Sciences building which opened in January of 2016 (K. VanCamp, 2022, personal communication). The use of the site for dumping was well known in the community and illegal dumping of garbage, construction debris, and woodchips continued to be a regular occurence. In 2019 the site was finally regraded and the area has now become a priority for ecological restoration on the Preserve (K. VanCamp, 2022, personal communication).

The Vassar Ecological Preserve has created the Conservation Action Plan, which was created to develop a framework for protecting ecological diversity of the land as well as prioritizing conservation efforts (Charlop et al., 2019). The Conservation Action Plan aims to guide the Preserve through five major action areas, one of these being Ecological Management and Restoration. This process plays into the mission statement of the Preserve and focuses on the maintenance of natural areas on the land. The Conservation Action Plan calls for identification of focus areas on the Preserve, one of the main focuses being maintaining intact forest corridors both in the center (containing the EcoRestore site) and on the eastern side of the Preserve, with the goal of merging them to provide benefits for animal migration (see Figure 2 in the Appendix) (Charlop et al., 2019). The land on the Preserve is composed of varying ecological communities and is separated amongst old growth and new growth forests. Old growth forests are found on the eastern corridor of the Preserve, where land was not used for farming due to a slope present in the terrain (Charlop et al., 2019). Through supporting and implementing practices that prevent invasive species spread, reduce disturbance and fragmentation of habitats, and emphasize restoration, the Conservation Action Plan intends on maintaining and strengthening the natural areas on the Preserve.

Vassar College has created a Climate Action Plan which outlines the methods through which the college intends to achieve its 2030 goal of carbon neutrality. This Climate Action Plan connects to the Conservation Action Plan through the identification of Vassar's Ecological Preserve as a carbon sink, meaning that it acts as a storage and sequestration space for carbon from the atmosphere (Vassar Sustainability, 2020). The premise of the Climate Action Plan is to provide guidance for the College and its stakeholders on how Vassar plans to be carbon neutral, and in the longer term, climate positive by sequestering more carbon than the College emits (Vassar Sustainability, 2020). The Plan proposes developing Restorative Land Management Guidelines that work on the basis of ensuring sustainable management and maintaining of natural areas on Vassar's campus. While these guidelines won't be completed for a few more years, the idea behind them is to examine how space is currently used on campus. The goal is to treat as many spaces as possible as a living land acknowledgment, and tell the story of what the land used to be, through the land, while still acknowledging that we exist in a changing climate (C. Kenfield, 2021, personal communication).

When addressing carbon reduction and reinvestment within the realm of Vassar, the Climate Action Plan suggests that purchasing carbon offsets on the other side of the country- or world- would be more beneficial in reducing Vassar's carbon footprint than planting the same amount of trees already planted on the Vassar Ecological Preserve (Vassar Sustainability, 2020).

The Vassar Ecological Preserve sequesters 265.3 metric tons of carbon per year and stores an additional 8,545 tons (Finley, 2018). The forests on the Preserve sequester and store these amounts while also being home to large areas of shrubland, canopy gaps, and invasive species. The shrubland area is home to a large portion of invasive species (*Malus sp*., *Lonicera maackii, Lonicera morrowii*, and *Rosa multiflora*), and the western and eastern corridors experience a large amount of canopy gaps. There are many ways in which sequestration and storage on the Preserve can be increased; whether this be through reforestation efforts in the shrubland and canopy gaps, further reforesting and supporting of the EcoRestore site, and the general combatting of invasive species to permit tree and high-sequestering species growth.

Chapter 4: Calculating Carbon Sequestration

This section outlines the various mechanisms and results drawn from identifying low-sequestering areas of Vassar's Preserve, as well as identifying the low-sequestering forest community types and tree species present on Vassar's Ecological Preserve.

Vassar Ecological Preserve, URSI 2021

During the summer of 2021, I took part in the Undergraduate Research Summer Institute working on the sampling of 51 1/10 acre forest community plots on Vassar's Ecological Preserve. As a part of this field-work, diameter at breast height (DBH) data, which is measured at about 4.5 feet or 1.37 meters was collected for each tree at each plot. This data was recorded and analyzed, leading to the compilation of the dbh of 961 sampled trees. This dbh data was used to calculate the amount of carbon sequestered in each tree, and that data was then transformed to determine the average sequestration of different tree species and different ecological communities on the Preserve. The ecological communities present in sampling are shown in Table 1 in the Appendix.

Methodology

This section outlines the methodology and procedures that were used to first establish the forest plots and obtain DBH data, and then to calculate the amount of carbon being stored in each tree after sampling each plot.

Forest Plot Protocol

Plots were established according to the United States Forest Service Forest Inventory Analysis Program (Reams, 2021). Upon arriving at the Southwest corner of each plot, a rebar was placed (if establishing a new plot, just relocated if resampling a plot) within the community at the Southwest corner. Using a meter tape, 20m was measured in the North and East directions from the rebar with flags being placed at 5, 10, and 20m in each direction. From one of the 20m flags, another 20m tape was used to identify the Northeastern corner of the plot, and GPS coordinates were recorded for each corner of the plot.

At the rebar, a plot photo was taken facing Northeast into the center of the plot. Aspect and slope were recorded from the center of the plot, and a canopy photo was also taken from the center of the plot using a fisheye lens. The rebar and any large objects (i.e. trees) were flagged with flagging tape labeled with the plot code for easier identification when being resampled. Environmental conditions (soil type, vegetation cover, slope, aspect, etc.) were recorded into the PLOTS Access Database.

Subplots

Herb Subplot (5x5m)

Within the first set of 5m flags, every herbaceous species present was identified, and the percentage of the 5x5m plot that every species made up was determined.

Shrub and Vine Subplot (10x10m)

Within the second set of flags (10m flags), each shrub and vine species was identified. Shrubs, generally any shrub, seedling, or tree (woody plant) that is not yet of tree height (5 m) were placed into two categories: S1, those that were 2-5m in height, and S2, any shrub that was under 2m tall. For each species of vine and shrub, the percentage of the 10x10m plot that each species occupied was estimated as well as within each strata and the total coverage for each strata.

Tree Subplot (20x20m)

Tree species were split into three categories:

- T3 trees: located in the subcanopy, these trees are 5m or taller, but still at least 5m below the rest of the canopy.
- T2 trees: located in the canopy, this height is variable based on the forest but these trees comprise the majority of the canopy.
- T1 trees: emergent in the canopy, these trees are crown trees notably higher than the rest of the main canopy.

At each canopy level, tree species were identified and the overall percentage of the canopy that each tree species covered was determined.

Obtaining DBH Measurements (20x20m)

In the 20x20m plot, the diameter at breast height (1.37m, 4.5 feet) was measured of each tree that was tall enough to be in T3 (at least 5m tall) and was greater than 4cm in DBH. The DBH was recorded along with the tree species and the canopy category of the tree (ie T1, T2, or T3). If trees have stems that split below DBH height, each stem is recorded.

Other Information

The invasive species index was determined for the entire 20x20m plot for the presence of invasive herbs, vines, shrubs, and trees. The index follows these guidelines:

- 0: no invasive species present
- 1: a majority of invasive species
- 2: slightly more invasive species than native species
- 3: mostly native species
- 4: dominant native species

Calculating Aboveground Biomass

The biomass of trees sampled at each plot was calculated using the widely accepted and applicable equation provided by Jenkins et al. (2004), also used by Colgate University and SUNY ESF in calculating their own carbon sequestration. Jenkins et al. provide a comprehensive database for diameter-based regressions for North American tree species, and with that a general equation for calculating biomass.

The equation is as follows:

$$bm = Exp(\beta_0 + \beta_1 ln(dbh))$$

where:

bm= total aboveground biomass (kg) for trees greater than 2.5cm in DBH

dbh= diameter at breast height (cm)

Exp= exponential function

ln= natural log base "e" (2.718282)

β_0 and β_1 are parameters based on tree species group and values can be seen in Table 1 in the Appendix.

In order to assign each tree species to a species group as shown in Table 2 in the Appendix, Jenkins et. al (2004) provided a table for assigning species to each group. This information along with species assignments to each group are shown in Table 3 in the Appendix.

Estimating Carbon Storage from Biomass

The average carbon content of a tree is generally estimated to be 50% of the tree's dry weight total volume, or aboveground biomass as measured in this research. With this in mind, to determine the weight of carbon in each tree, the biomass was multiplied by 0.5 to calculate units of carbon in each tree.

The atomic weight of carbon is 12 units, and the atomic weight of oxygen is 16 units. In order to determine the amount of carbon stored in each tree, I used the ratio of carbon dioxide (44 units) to carbon (12 units), which results in 3.67. To calculate the weight of carbon dioxide stored in each tree in kilograms, the weight of carbon in the tree was multiplied by 3.67 (University of New Mexico, n.d.).

Findings: Forest Carbon Storage on the Vassar Preserve

Through the series of plots sampled and the calculation of tree carbon storage, patterns can be seen across community types and tree species in which store and sequester the most carbon dioxide (Figure 5). This section presents the findings from 2021 forest plot sampling on the Vassar Ecological Preserve.

The plots which stored the most carbon on the Preserve were plots located in Southern Successional Hardwood Quercus communities, composed mainly of *Quercus sp.* as well as *Acer sp,* where the average carbon being stored across the community was 1270.43kg/ plot. Of the plots sampled over the summer, five were located in SSHQ community types. There were 80 trees measured across those five plots, and of those trees, about 33.8% of those were of the genus *Quercus*, and another 18.8% were of the genus *Acer*.

The lowest storing plots on the Preserve were located in SS and SSHM communities, which were dominated by Malus sp. Of the 206 trees measured in these communities, 84.2% were *Malus sp.*, with the remaining 15.8% including *Prunus serotina*, *Ulmus americana*, and *Fraxinus americana*.

Figure 1 in the Appendix shows the average amount of CO_2 sequestered by each tree species present in sampling on the Preserve. *Quercus sp.*, or oak trees sequestered the most carbon, and *Malus sp.*, or apple trees, sequestered some of the less along with *Carpinus caroliniana*, *Cornus florida*, and other shrub-like species.The more densely a plant's cells are packed together, the more carbon it can store, and *Quercus sp.* produce some of the densest wood in North American trees. Oaks are native hardwood trees with 12 different species native to New York State. *Quercus sp.* trees are notoriously good at storing carbon both in literature and in my own work at Vassar's Preserve, with *Q. bicolor*, *Q. rubra*, and *Q. alba* having the most stored carbon on the Preserve. Furthermore, the root systems of oak trees are extensive and are built from carbon, therefore oak trees extend their storage capabilities into soil carbon storage.

Discussion

The data highlights areas of the Preserve where sequestration potential could be improved. The southern section of the Preserve is characterized by dense shrubland and Southern Successional Hardwood *Malus* communities which are dominated by species with low carbon sequestration potential, most notably apples (*Malus sp.*). This southern shrubland area of the Preserve has been a lower priority for restoration efforts and is home to a strong presence of invasive shrubs, such as the apples.

Underplanting portions of the southern shrubland area with tree species that have a higher potential for sequestration, such as *Quercus sp.*, could substantially increase the amount of CO_2 sequestered on the Preserve and increase its carbon sequestration rate in the long-term. SSHM is also a heavily invaded community with invasive shrubs such as *Lonicera morrowii* and *L. maackii*. Invasive removal and management is essential in this area of the Preserve, and coupling this with the underplanting of native hardwoods to increase sequestration can meet goals of both the Conservation Action Plan and Climate Action Plan.

With this in mind, not all of the shrubland should be converted to forested areas with tree plantings. In order to maintain the ecological diversity of the Preserve in line with the Conservation Action Plan, a proportion of shrubland must remain. These areas, though, can still be targets for invasive species removal and plantings with native and high sequestering shrubs.

Much of the management work on the Preserve this year has been targeting the clearing of canopy gaps in the Preserve's eastern corridor with the goal of planting native trees in these gaps in the future. The Preserve suffers from canopy gaps on various areas of the land; some gaps are natural and many due to the onslaught of invasive vines and shrubs. Underplanting in canopy gaps where invasive shrubs and vines have been removed allows the establishment of native and, ideally, high sequestering trees which would strengthen the forest and contribute to Vassar reaching carbon neutrality. Undertaking this path towards forest management and carbon sequestration also contributes to both the Conservation and Climate Action Plans, by strengthening the eastern forest corridor and supporting increased carbon sequestration.

Despite this opportunity, there is still no inclusion of planting for carbon sequestration in the Climate Action Plan. Thinking specifically about the shrubland area first, an area of land that has 200 *Malus sp.* (based on the average CO2 sequestration of *Malus sp*. sampled) would sequester 19,667.98 kg, or 19.67 metric tons of carbon annually. If that land were instead 200 *Quercus bicolor*, the same amount of land and number of trees could sequester 528,827.11 kg, or 528.83 metric tons of CO2 in terrestrial biomass alone. With those numbers, 200 *Q. bicolor* sequester 26.89 times as much carbon annually compared to 200 *Malus sp*. This number of trees, if *Q. bicolor*, would also provide more nutrients for bird species and insect species on the Preserve.

Furthermore, the size of the plots sampled over the summer were 20x20m, or 0.1 acres. The invasive species removal team on the Preserve has been working on clearing canopy gaps of invasives this semester. The gaps they have been working on are located in the eastern corridor of the Preserve and are much larger than the size of a plot. Using the ArcGIS Collector app, I was able to map the area of the canopy gaps being worked on this semester. The three main gaps are all larger than the size of a plot, as shown in Figure 3, with areas of 656, 302, and 621 square meters. The average carbon sequestration across plots in the Red Maple Hardwood Swamp community, where these gaps are located, was 862.43kg. If these canopy gaps, larger than the plot size, were to be filled with high-sequestering, native trees, carbon sequestration in these areas could increase from essentially 0 kg to on average 862.43 kg. There are more than just two or three canopy gaps, as well. Surveys of the Preserve identified a wide sprawl of canopy gaps on the western and eastern side of the Preserve, which are shown in Figure 3. Knowing that these areas have potential for reforestation that can greatly impact the school's carbon footprint can allow the prioritization of which gaps to focus on.

There are two kinds of canopy gaps on Vassar's Preserve; those that form naturally from tree fall from weather or natural causes, and those that are victim to invasive vines and shrubs that pull down an existing canopy and fill a gap with invasive species. When it comes to determining which canopy gaps to prioritize, it is more important to prioritize those that have formed from natural causes rather than invasive species. The naturally occurring gaps are more important due to the ability of plantings to help prevent invasive species from taking over the area, and also plantings will help speed up natural regeneration of the gap. However, it is still important to work in areas that have already been taken over by invasive species and work towards clearing those areas and then eventually reforesting them with native plantings.

Chapter 5: Recommendations

The research conducted for this thesis elicits a variety of recommendations for both sustainable carbon management at the Vassar Ecological Preserve, as well as organizational recommendations for Vassar College to better support carbon storage and neutrality as an institution. This section provides suggestions for methods of increasing carbon sequestration for Vassar College, as well as incentives to conduct said work.

Native Plantings

An essential component of increasing Vassar's carbon sequestration is the continuation of native plantings on Vassar's Ecological Preserve. Specifically, high-sequestering native species are integral to projects on the Preserve. The Preserve suffers from various canopy gap areas that are victims of invasive vine and shrub dominance, and upon the removal of these nonnative species, tree plantings to occupy and restore the areas are of the utmost importance.

The selection of trees used in plantings and reforesting initiatives are important to think about the forest that is wanted in the future, as many trees take more than a decade to mature. Table 4 provides tree species that would be beneficial to plant on the Preserve for carbon sequestration, and to strengthen native plant communities. When it comes to choosing which trees to plant, it is also important to think about whether to plant quick sequestering trees or longer sequestering trees. In the short-term, it may be helpful to plant fast growing trees that can remove carbon from the atmosphere quickly. However, with a goal of removing enough CO_2 from the atmosphere to meaningfully reduce greenhouse gas emissions from Vassar College, the length of time that carbon is stored is imperative to planning what species to plant. With this in mind, the ideal tree species are large, long-lived, dense trees, such as oaks.

Oak trees, genus *Quercus*, are native hardwood trees with 91 different species native to North America, and 12 different species native to New York State. Oak trees are notoriously good at storing carbon. Out of trees sampled this summer on the Vassar Preserve, Q. bicolor, Q. rubra, and Q. alba have the most stored carbon (Figure 1). The more densely a plant's cells are packed together, the more carbon it can store, and oak trees produce some of the densest wood in North America (Tallamy, 2021, p. 122). Furthermore, the root systems of oak trees are extensive and are built from carbon, therefore oak trees extend their storage capabilities into soil carbon storage. Oaks have mutualistic relationships with mycorrhizal fungi, which make large amounts of carbon-rich glomalin, which is a protein that provides soil much of its structure. Furthermore, oak mycorrhizae deposit glomalin into the soil surrounding oak roots throughout the life of the tree, and every pound of glomalin produced by oak mycorrhizae is a pound of carbon no longer warming the atmosphere, and this glomalin remains in the soil for hundreds to thousands of years (Tallamy, 2021, p. 123).

To add to the resumé of oaks, they have been a dominant species in the Northeastern United States since prior to Native American occupation. Oak trees are fire resistant, and with semi-frequent, low intensity fires, oak trees historically dominated the Northeastern landscape as maples were kept in check with these fires (Canham, 2020, p. 57). To this extent, oaks are hardy trees that are climate resilient, and are also able to provide a variety of ecosystem services. Oak trees are the top life-support trees in 84% of counties in North America, largely because of their importance for insect and bird populations, as well as the necessity of their leaf litter for decomposers and fungi (Tallamy, 2021, p. 39). Oak species support over 500 caterpillar species, which in turn support bird species who require insects as food. Birds and oak trees have a mutualistic relationship, specifically with blue jays (*Cyanocitta cristata*) who have been known to preferentially disperse wide amounts of healthy, disease resistant acorns (Tallamy, 2021). The acorns of oak trees are also an essential form of nutrition for mammals during the winter months (Tallamy, 2021).

In terms of planting oak trees, the most cost effective way to do this is by collecting acorns dispersed by oak trees on the Preserve. White oak (*Q. alba*) acorns germinate in the fall just days after dropping, whereas red oak (*Q. rubra*) acorns germinate the following spring after dropping (Tallamy, 2021). White oak acorns should be planted soon after collecting, about ½ inch deep in potted soil, and they won't appear aboveground until spring (Tallamy, 2021). In order to prevent interference with sapling growth by deer and invasive vines, it is recommended to protect the saplings with some sort of enclosure, either fence or wire to prevent animals from snacking on the newly sprouting tree.

Other alternative methods of obtaining oak trees/ saplings are purchasing the trees, though this process comes with the risk of producing rootbound trees. Purchasing potted trees requires the trees to spend ample time and energy towards untangling their roots from being potted, and large transplanted trees have a 50% chance of surviving once moved (Tallamy, 2021). Another alternative purchase method is to seek out bare-root whips, which are saplings that come free from a container with soil (Arbor Day Foundation, 2022). Bare-root trees should be planted in early spring so that they can break dormancy in sync with seasonal changes, and bare-root trees will typically surpass the size of larger containerized trees within a few years (Tallamy, 2021).

Incentives

Regenerate New York Forestry Cost Share Grant Program (Regenerate NY)

The Regenerate NY program is a grant program aimed to support forest regeneration in order to allow forests to continue providing essential ecosystem services such as climate change mitigation (Birnbaum & NYS Department of Environmental Conservation, n.d.). The program recognizes the threats that white-tailed deer and invasive species pose to forest health, and intends to fund active management of land (Birnbaum & NYS Department of Environmental Conservation, n.d.). Through the grant program, landowners can apply for financial assistance that support the establishment and renewal of healthy forests. Regenerate NY is a cost share reimbursement program, meaning that all costs are incurred by the landowner before they can be reimbursed by the program (Birnbaum & NYS Department of Environmental Conservation, n.d.).

Those who are eligible for the grant are any individual, partnerships, for-profit entity, or not-for-profit entity that owns between 10 and 1,000 acres of land that is forested or can become forested through planting (Birnbaum & NYS Department of Environmental Conservation, n.d.). Applicants must also work with a DEC cooperating forester, and projects must be completed within three years. Projects must also include aspects of at least one of the following: afforestation/ reforestation, forest stand regeneration, competing vegetation control, or deer exclosures. The amount of awards range from $3,000 to $50,000, with a total of $450,000 available in the last grant round (Birnbaum & NYS Department of Environmental Conservation, n.d.). There is a match requirement for the grant program of 25%, meaning that a $25,000 program could receive funding of $20,000, with $5,000 of the project costs covered by the applicant. Applications are due in the fall and the deadline for the last application cycle was October 8th, 2021.

In relation to the management of forested areas on the Preserve, the money from the Regenerate NY grant program could be used to target canopy gap areas. The funding from this program can go towards purchasing bare-root whips or other native seedlings to plant in cleared canopy gaps in order to reforest and repair the gaps.

Regional Greenhouse Gas Initiative (RGGI)

RGGI is the first market-based regulatory program in the United States aimed at reducing greenhouse gas emissions. Created in 2003, the program is a cooperative effort between the states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont to cap and reduce CO_2 emissions from the power sector (NYSERDA, n.d.). RGGI recognizes reforestation/ afforestation, improved forest management, and avoided conversion of forested lands as eligible project types (RGGI, n.d.). RGGI's guidelines require projects to satisfy a performance test and be independently verified, and offset projects would be credited for 25 years following the commencement of a project. The lifespan of projects is 100 years and project owners are responsible for monitoring, verifying, and reporting data for the 100 years after allowances have been awarded (NYSERDA, n.d.).

The idea behind these projects is that upon completion, an estimate of the carbon impact of the project will be assessed and verified, therefore accounting for carbon on the land and in the state of which the project takes place. There is a forest project protocol that provides the requirements for forest projects that create CO_2 offset allowances under the requirements of RGGI states (RGGI, 2013). The forest protocol also provides eligibility rules, methods to quantify GHG reductions, instructions on project monitoring, and procedures for reporting Offset Project Data reports (RGGI, 2013).

This program provides incentives and funding for projects that contribute to New York State's carbon budget and projects that intend to lower the state's carbon emissions (NYSERDA, n.d.). Vassar can seek out funding and verified offsets by implementing a project on Vassar's campus.

Hudson Estuary Trees for Tributaries

Trees for Tribs offers free native trees and shrubs for qualifying planting projects located in the Hudson River estuary watershed (NYS Department of Environmental Conservation, n.d.). Eligible applicants are those who own or manage property near a stream in the Hudson estuary watershed. The program is statewide but with a focus in the Hudson estuary watershed and has a goal of reforesting New York state's tributaries to create a forested riparian buffer that helps decrease erosion, flood damage, and as well as improve wildlife and stream habitat. Trees for Tribs is a program stemming from the Colonel William F. Fox Memorial Saratoga Tree Nursery in Saratoga Springs (NYS Department of Environmental Conservation, n.d.). The nursery produces more than 1.5 million seedlings annually and more than 6 million seedlings representing over 50 species are currently growing at the nursery. The nursery is the provider of the seeds and saplings for Trees for Tribs and offers the benefit of native, climate-adapted plants (NYS Department of Environmental Conservation, n.d.).

The application deadlines are March 1 for a planting in the spring, and August 1 for a planting in the fall. It is recommended to apply before the deadline if you have a large site or want to request specific plant species. In addition to providing the shrubs and trees, Trees for

Tribs also provides guides for planting said plants, and there is also a separate but adjacent Buffer in a Bag program (NYS Department of Environmental Conservation, n.d.).

Buffer in a Bag provides organizations and private landowners with free tree and shrub seedlings to help establish or improve a stream buffer on their property. Anyone who owns or manages land in New York State with at least 50 feet along a stream or waterbody is eligible to receive a free bag of seedlings (NYS Department of Environmental Conservation, n.d.). The kits are sent to selected applicants starting in late April to early May, and each bag includes 35 bare-root, native tree and shrub seedlings that are one to two feet tall. The species included in this year's bag were wetland rose (Rosa palustris), pussy willow (Salix discolor), ninebark (Physocarpus sp.), winterberry (*Ilex. verticillata*), and red oak (*Q. rubra*) (NYS Department of Environmental Conservation, n.d.).

Vassar has consistently applied for and received seedlings from Trees for Tributaries that have allowed plantings to occur both on the Preserve and on the main campus. The Casperkill creek runs through the eastern portion of the Preserve, and therefore encourages many opportunities for planting alongside the stream. With this in mind, there are opportunities for planting trees along the Casperkill both on the main campus and on the Preserve. This area is part of the Preserve is dominated by nonnative shrubs and trees and would benefit from underplantings of native trees to establish a stronger buffer, as the most effective buffers are composed of native forest (Wenger and Fowler, 2000).

Feasibility and Target Areas

Depending on the type of planting, tree plantings can range in cost and procedure. At the Preserve, one of the most cost-effective and natural ways of planting trees is collecting acorns and supporting their propagation. Acorn collection and propagation is cost effective and very feasible given the amount of acorns that naturally drop from oak trees on the Preserve. Furthermore, with funding from external sources such as the Regenerate NY program, Trees for Tributaries, the RGGI, and already existing Vassar funds (the Swain Endowment), purchasing and securing native trees for planting is a fairly doable task. The Vassar Preserve has purchased native trees and shrubs in the past, though the prices for these trees are higher, and it may be more economically feasible to focus on acorn collection/ propagation, as well as trees from Trees for Tributaries and funding for trees from Regenerate NY.

Target areas for reforestation and planting on the Preserve should be the canopy gaps on the western corridor as well as those on the eastern corridor, as shown in Figure 3 in the Appendix. There is also the southern shrubland area (see Figure 2 and Figure 4 in Appendix), which is a low sequestering and invasive-dominated area.

Third Party Verification

One way to grow and maintain the amount of carbon stored on Vassar's Ecological Preserve is to commit to the management of the Preserve's carbon storage through third party verification. Third party verification is the process through which a landowner can get their property verified by an accredited institution to estimate the amount of carbon stored and sequestered by their forested land. Verification is often used to be able to accurately account for the amount of carbon stored and sequestered by land and so that the carbon can be quantified in reaching carbon neutrality or counting towards offsets.

SCS Global Services

SCS is a company providing global leadership in third-party environmental and sustainability certification, auditing, and standards development since 1984. SCS works across various industries with project developers, landowners, manufacturers, and private or municipal operators (SCS Global Services, n.d.). The verification team at SCS has a long history of experience in Agriculture, Forestry, and Other Land-Use (AFOLU) which includes forest inventory and sampling, remote sensing, GIS, forest biometrics and modeling, soil carbon, and combined Verified Carbon Standard- Climate Community Biodiversity audits, and combined Forest Stewardship Council and forest carbon audits (SCS Global Services, n.d.).

Carbon offset projects are developed to provide real reductions in GHG emissions by reducing, absorbing, or avoiding the release of carbon dioxide. SCS works with landowners to provide third-party verification, which is crucial to selling or trading carbon credits in global carbon markets (SCS Global Services, n.d.). SCS has verified over 295 million tons of carbon emissions reductions to date (Second Nature, n.d.).

Organizational Recommendations

In addition to managing Vassar's Ecological Preserve for carbon sequestration and investigating third-party verification, there are also changes that Vassar can undertake with organizations that the school is already a part of. This section proposes extra steps that Vassar can take in different organizations that the school is already a member.

Second Nature Offset Network

Vassar is a signatory of the Second Nature Presidents' Climate Commitment, which commits the College to sharing its annual progress towards carbon neutrality as well as developing efforts to increase the campus's and community's resilience to climate change impacts.

Second Nature offers a variety of opportunities for higher education institutions to communicate and network with one another regarding carbon neutrality commitments and pathways to reaching carbon neutrality. One of these opportunities is the Offset Network, which is a collaboration through Second Nature of higher education institutions with a goal to catalyze and support offset projects that would provide educational and research opportunities for students, faculty, and staff (Second Nature, n.d.). The Offset Network provides a variety of resources to encourage and support offset projects such as: case studies and examples of previous carbon offset projects; guidance documents for project development; peer connections amongst schools and institutions, and peer verification from other institutions regarding project implementation review, feedback, and ultimately verification (Second Nature, n.d.).

Joining the Second Nature Offset Network would provide various gateways to networking carbon reduction projects amongst other higher education institutions. In addition to the workshopping benefits, there is also the benefit of the Offset Network's Peer Verification Program (Second Nature, n.d.), which is a more affordable method of external authentication of carbon offsets. This program would allow Vassar to establish offset projects that directly benefit the campus and nearby communities by investing in the Ecological Preserve and implementing carbon offset projects on the Preserve.

Arbor Day Foundation's Tree Campus USA Program

The Tree Campus USA Program through the Arbor Day Foundation provides a simple framework for colleges and universities to grow their community forests, achieve national recognition, and create a campus their students and staff are proud of (Arbor Day Foundation, n.d.). Vassar College is already a member of the Tree Campus USA Program, and in order to be recognized as a Tree Campus, they must adhere to standards set forth by the Arbor Day Foundation. These standards are: the establishment of a campus tree advisory committee, evidence of a campus tree care plan and verification of the plan's dedicated annual expenditures, the school must observe Arbor Day, and there must be the creation of a service-learning project aimed at engaging the student body (Arbor Day Foundation, n.d.).

As a student at Vassar College, I was unaware that the campus was a member of the Tree Campus USA Program, or that Vassar had a campus tree advisory committee, or that there were service-learning projects aimed at engaging the student body. If Vassar increased or publicized the relationship with the Tree Campus USA Program more, it could spur more student involvement in tree care and presence on campus. While the Preserve is 416 acres, the rest of Vassar's 932 acre campus is home to academic and residential buildings, administrative offices, athletic facilities, and large natural areas surrounding Sunset Lake and Graduation Hill. This connection with the Tree Campus USA Program can inspire Vassar to plant more trees on campus and reincorporate naturalized areas.

AASHE STARS Program

As mentioned previously in this paper, Vassar College is certified Gold Status by the AASHE STARS program, and scores 69.13 out of 100 possible points following evaluation by the program. Under the “Greenhouse Gas Emissions” section of the report, Vassar scored 4.67 out of a possible 8 points (Vassar College Office of Sustainability, 2021). Vassar has reported a decrease in annual emissions of 11,274.89 mtCO_2e since the College’s baseline reporting year in 2005 (Vassar College Office of Sustainability, 2021). Despite this, there are still opportunities for improvement amongst the data and information that Vassar chooses to report. A portion of the Greenhouse Gas Emissions section of the report is dedicated to any net carbon sinks that the college or university may engage with or utilize.

Vassar’s Ecological Preserve has gone long undervalued in the eyes of the College, and identifying and verifying the land as a carbon sink is one step that the school can take to better invest in and recognize the unique position that the school is in by having a Preserve as a part of the campus. Vassar can begin the process of identifying and verifying the lands of the College as a carbon sink by interacting with SCS Global Services or the Second Nature Offset Network.

Chapter 6: Conclusion

This research had two main goals: identify current patterns of carbon sequestration on the Vassar Ecological Preserve to see how these patterns are a reflection of species composition and land use history, and determine the potential for restoration and reforestation with carbon sequestration in mind. Using forest plot data, I found the current distribution of carbon sequestration across the Preserve. With this, I was able to attribute lower sequestering areas to two primary causes: canopy gaps and invasive vegetation presence. In sampling and collecting data on forest communities, *Quercus sp.* were the highest sequestering species and Successional Southern Hardwood Quercus was the highest sequestering community type.

The Conservation Action Plan identifies the central and eastern corridors of the Preserve as conservation priorities. With my research, I argue that the southern shrubland and the western corridor should be prioritized in restoration efforts with native high-sequestering species such as *Quercus sp.* The western corridor experiences a high density of canopy gaps, and both the western corridor and southern shrubland are victims of intense invasive vegetation presence. Canopy gaps and invasive species act as limiting factors in regards to carbon sequestration, and sequestration could be maximized and invasives could be deterred by reforesting these areas with native, high-sequestering tree species. Integrating these efforts with the Conservation Action Plan provides an opportunity to support native forest communities and enhance connectivity on the Preserve.

Invasive species removal and native reforestation are one piece of this thesis, but there is also the opportunity for Vassar to utilize the carbon stored and sequestered by land on the Preserve. The Preserve offers the space and potential for the College to implement carbon offset projects on its own land, benefitting both the land and Vassar and combating inherently colonialist foreign offset programs. Reforestation with native, high-squestering species can drastically shift the patterns of sequestration across the Preserve and help Vassar reach its goal of carbon neutrality. Investing in the Preserve is more than that; it is an investment into the climate, the community, the Preserve, and Vassar itself as a model for other institutions to follow.

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Appendix

Table 1. Shows the ecological communities and respective tree compositions present on the Vassar Ecological Preserve during forest plot sampling that consisted of trees large enough to measure DBH (≥4cm).

Community Type	**Community Description**
Southern Successional Hardwood (SSHQ)	Dominated by *Quercus rubra* and other species including *Acer sp.*, *Ulmus americana*, *Fraxinus americana, Juniperus virginiana,* and *Prunus virginiana* (Edinger et al., 2014).
Red Maple Hardwood Swamp (RMHS)	*A. rubrum* is dominant with either *Fraxinus sp.* or *Ulmus sp*. Other trees include *Carya cordiformis, Carpinus caroliniana, Q. bicolor*, and *Pinus strobu*s (Edinger et al., 2014).
Beech Maple Mesic Forest (BMMF)	*A. saccharum* and *Fagus grandifolia* are codominant with presence of *F. americana, Ostrya virginiana,* and *A. rubrum* (Edinger et al., 2014).
Appalachian Oak Hickory (AOH)	Dominated by *Q. rubra, Q. alba, and Q. velutina*. Subcanopy of *Cornus florida* and *C. racemosa, Prunus virginiana,* and *Carya sp*. (Edinger et al., 2014).
Vernal Pool (VP)	Trees include *A. rubrum, U. americana, Fraxinus sp.*, and *Q. bicolor* (Edinger et al., 2014).
Beech Maple Mesic Forest Variant (BMMV)	Variant community of BMMF, dominated by *O. virginiana, A. platanoides, A. saccharum,* and *A. rubrum* (Edinger et al., 2014).
Floodplain Forest (FF)	Characterized by *A. saccharinum, A. rubrum, A. saccharum, F. americana, Populus deltoides, U. americana, C. cordiformis and C. ovata, Juglans nigra, Q. bicolor,* and *Q. palustris* (Edinger et al., 2014).
Successional Northern Hardwoods/ Successional Southern Hardwoods (SNHSSH)	Occurs on sites that have been cleared or disturbed. Characterized by *P. deltoides, A. rubrum, Prunus serotina, F. americana,* and *U. americana* (Edinger et al., 2014).
Successional Red Cedar Woodland (SRCW)	Dominated by *J. virginiana* and otherwise characterized by a smaller number of isolated tree species. Commonly occurs on abandoned agricultural fields (Edinger et al., 2014).
Successional Shrubland/ Successional Southern Hardwoods Malus (SS/ SSHM)	Characterized by over 50% shrub cover, home to many shrubs and small trees, dominantly *Malus sp*. with other isolated tree species (Edinger et al., 2014).
Successional Southern Hardwoods Malus (SSHM)	Variant of SSH, canopy is dominated by *Malus sp*. with the occasional presence of *P. serotina* and other isolated tree species (Edinger et al., 2014).

Table 2. Provides the parameters for the biomass equation based on wood density supplied by Jenkins et al. (2004). *Table adapted from Jenkins et al., 2004.*

Table 1.—Parameters and equations[a] for estimating total aboveground biomass for all hardwood and softwood species in the United States (from Jenkins et al. 2003)

	Species group[b]	Parameter β_0	β_1	Data points[c]	Max d.b.h.[d]	RMSE[e]	R^2
					cm	*log units*	
Hardwood	Aspen/alder/ cottonwood/ willow	-2.2094	2.3867	230	70	0.507441	0.953
	Soft maple/birch	-1.9123	2.3651	316	66	0.491685	0.958
	Mixed hardwood	-2.4800	2.4835	289	56	0.360458	0.980
	Hard maple/oak/ hickory/ beech	-2.0127	2.4342	485	73	0.236483	0.988
Softwood	Cedar/larch	-2.0336	2.2592	196	250	0.294574	0.981
	Douglas-fir	-2.2304	2.4435	165	210	0.218712	0.992
	True fir/hemlock	-2.5384	2.4814	395	230	0.182329	0.992
	Pine	-2.5356	2.4349	331	180	0.253781	0.987
	Spruce	-2.0773	2.3323	212	250	0.250424	0.988
Woodland[f]	Juniper/oak/ mesquite	-0.7152	1.7029	61	78	0.384331	0.938

Table 3. The species present in sampling on the Preserve that were used in calculating biomass, and then ultimately carbon storage, and their species group as assigned by Jenkins et al (2004).

FIA ID	**Common Name**	**Family**	**Genus**	**Species**	**Species Group**
68	eastern red cedar	*Cupressaceae*	*Juniperus*	*virginiana*	cedar/ larch
129	eastern white pine	*Pinaceae*	*Pinus*	*strobus*	pine
261	eastern hemlock	*Pinaceae*	*Tsuga*	*canadensis*	true fir
316	red maple	*Aceraceae*	*Acer*	*rubrum*	soft maple/ birch
317	silver maple	*Aceraceae*	*Acer*	*saccharinum*	soft maple/ birch
318	sugar maple	*Aceraceae*	*Acer*	*saccharum*	hard maple/ oak/ hickory
402	bitternut hickory	*Juglandaceae*	*Carya*	*cordiformis*	hard maple/ oak/ hickory
403	pignut hickory	*Juglandaceae*	*Carya*	*glabra*	hard maple/ oak/ hickory
407	shagbark hickory	*Juglandaceae*	*Carya*	*ovata*	hard maple/ oak/ hickory
409	mockernut hickory	*Juglandaceae*	*Carya*	*tomentosa*	hard maple/ oak/ hickory
452	northern catalpa	*Bignoniaceae*	*Catalpa*	*speciosa*	mixed hardwood
531	american beech	*Fagaceae*	*Fagus*	*grandifolia*	hard maple/ oak/ hickory
541	white ash	*Oleaceae*	*Fraxinus*	*americana*	mixed hardwood
602	black walnut	*Juglandaceae*	*Juglans*	*nigra*	mixed hardwood
660	apple species	*Rosaceae*	*Malus*	*sp.*	mixed hardwood
701	eastern hophornbeam	*Betulaceae*	*Ostrya*	*virginiana*	mixed hardwood
742	eastern cottonwood	*Salicaceae*	*Populus*	*deltoides*	aspen/ alder/ cottonwood/ willow
743	bigtooth aspen	*Salicaceae*	*Populus*	*grandidenta*	aspen/ alder/ cottonwood/ willow
762	black cherry	*Rosaceae*	*Prunus*	*serotina*	mixed hardwood
802	white oak	*Fagaceae*	*Quercus*	*alba*	hard maple/ oak/ hickory
804	swamp white oak	*Fagaceae*	*Quercus*	*bicolor*	hard maple/ oak/ hickory
830	pin oak	*Fagaceae*	*Quercus*	*palustris*	hard maple/ oak/ hickory
833	northern red oak	*Fagaceae*	*Quercus*	*rubra*	hard maple/ oak/ hickory
837	black oak	*Fagaceae*	*Quercus*	*velutina*	hard maple/ oak/ hickory
901	black locust	*Leguminosae*	*Robinia*	*pseudoacacia*	mixed hardwood
951	American basswood	*Tiliaceae*	*Tilia*	*americana*	mixed hardwood
972	American elm	*Ulmaceae*	*Ulmus*	*americana*	mixed hardwood

Table 4. Tree species recommended for planting on the Vassar Ecological Preserve due to high carbon sequestration, ecosystem services, and ability to combat invasive species.

Tree Species	**Common Name**	**Average CO_2 Stored (kg)**
Quercus rubra	red oak	2461.52
Quercus bicolor	swamp white oak	2644.136
Quercus alba	white oak	2440.39
Juglans nigra	black walnut	2387.713
Quercus palustris	pin oak	1631.547
Quercus velutina	black oak	1463.000
Acer rubrum	red maple	811.683
Prunus serotina	black cherry	544.446
Pinus strobus	white pine	804.175
Robinia pseudoacacia	black locust	891.156

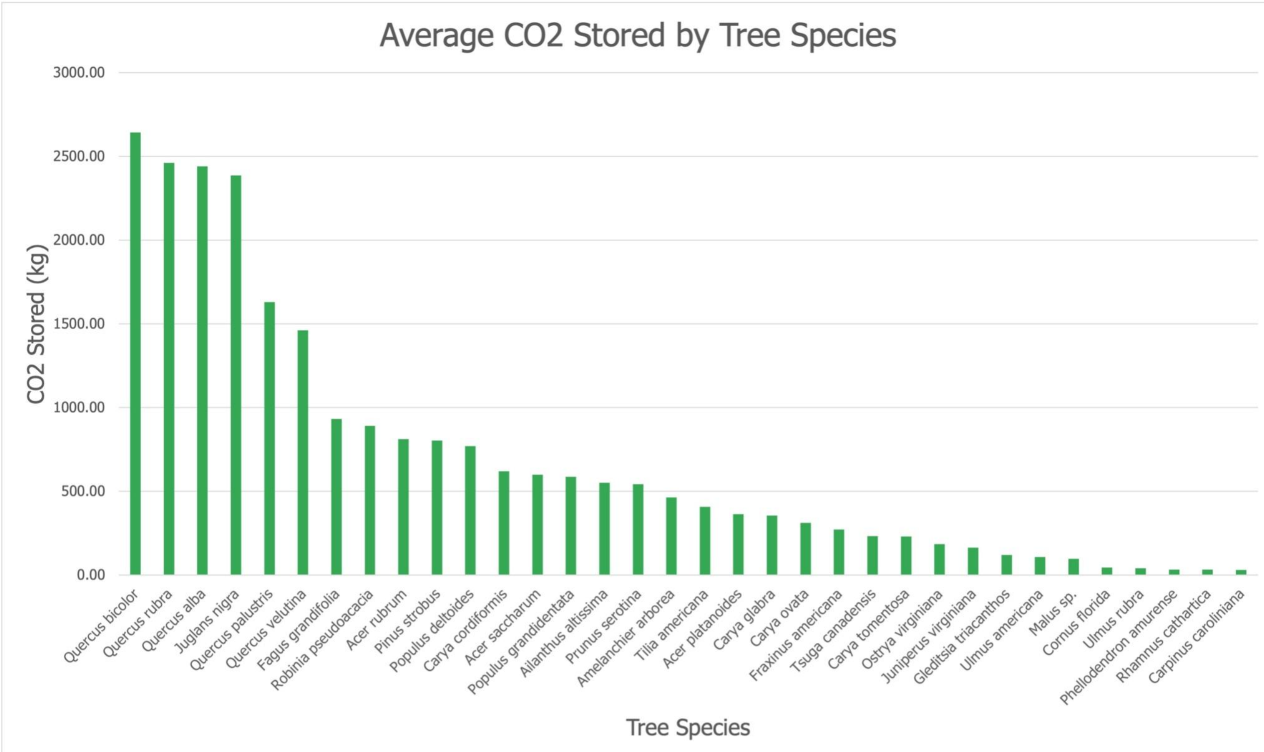

Figure 1. Shows the average amount of CO_2 sequestered (kg) by each tree species. Taller trees, notably *Quercus sp.*, sequester more; smaller tree species and non-natives, such as *Malus sp.* typically sequester less.

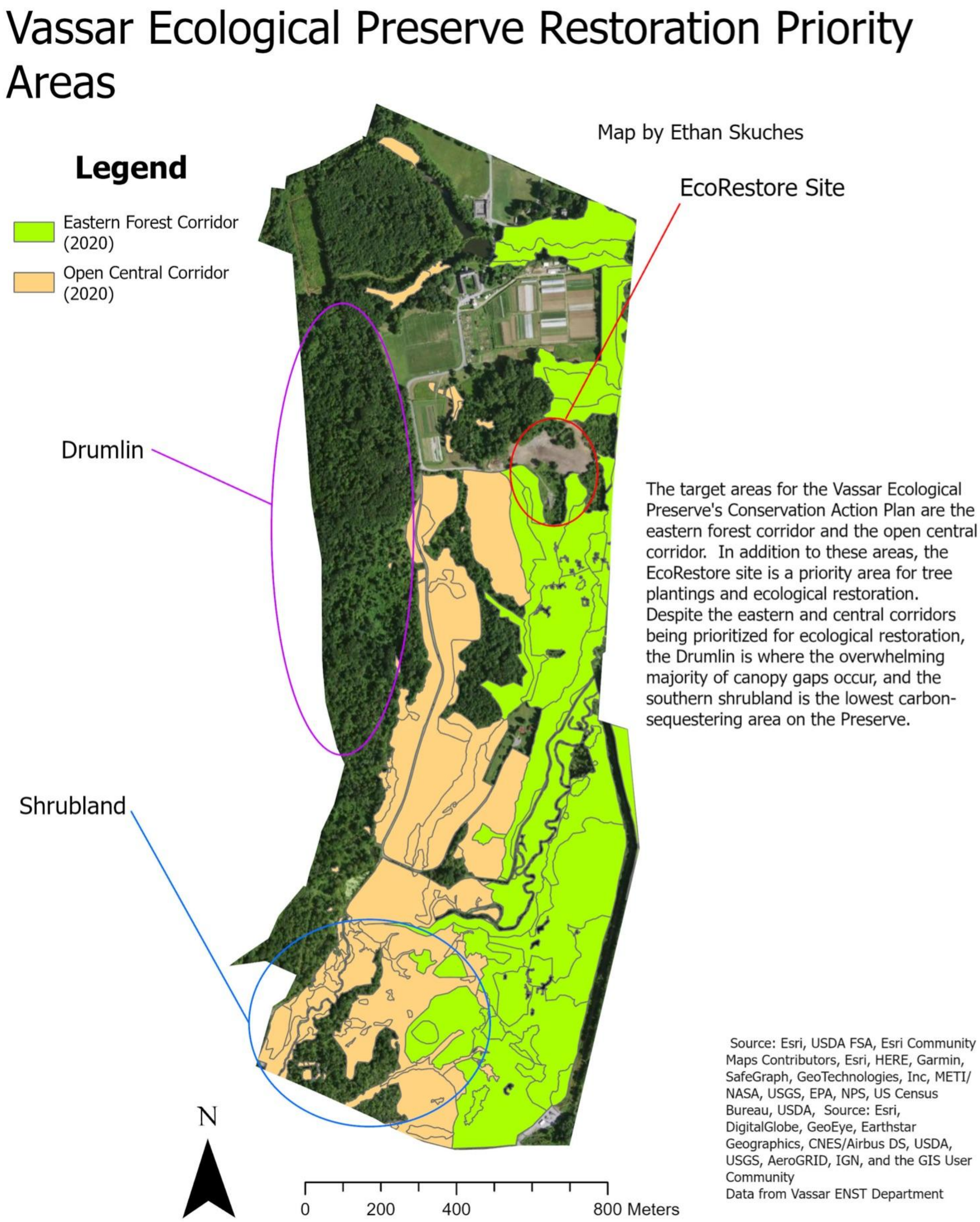

Figure 2. The eastern and central corridors, along with the EcoRestore site are conservation priority areas according to the Conservation Action Plan (Charlop et al., 2019).

Figure 3. The western corridor of the Preserve experiences many canopy gaps due to invasive vine and shrub pressure. These canopy gaps are also experienced on the eastern corridor, but in a lower density.

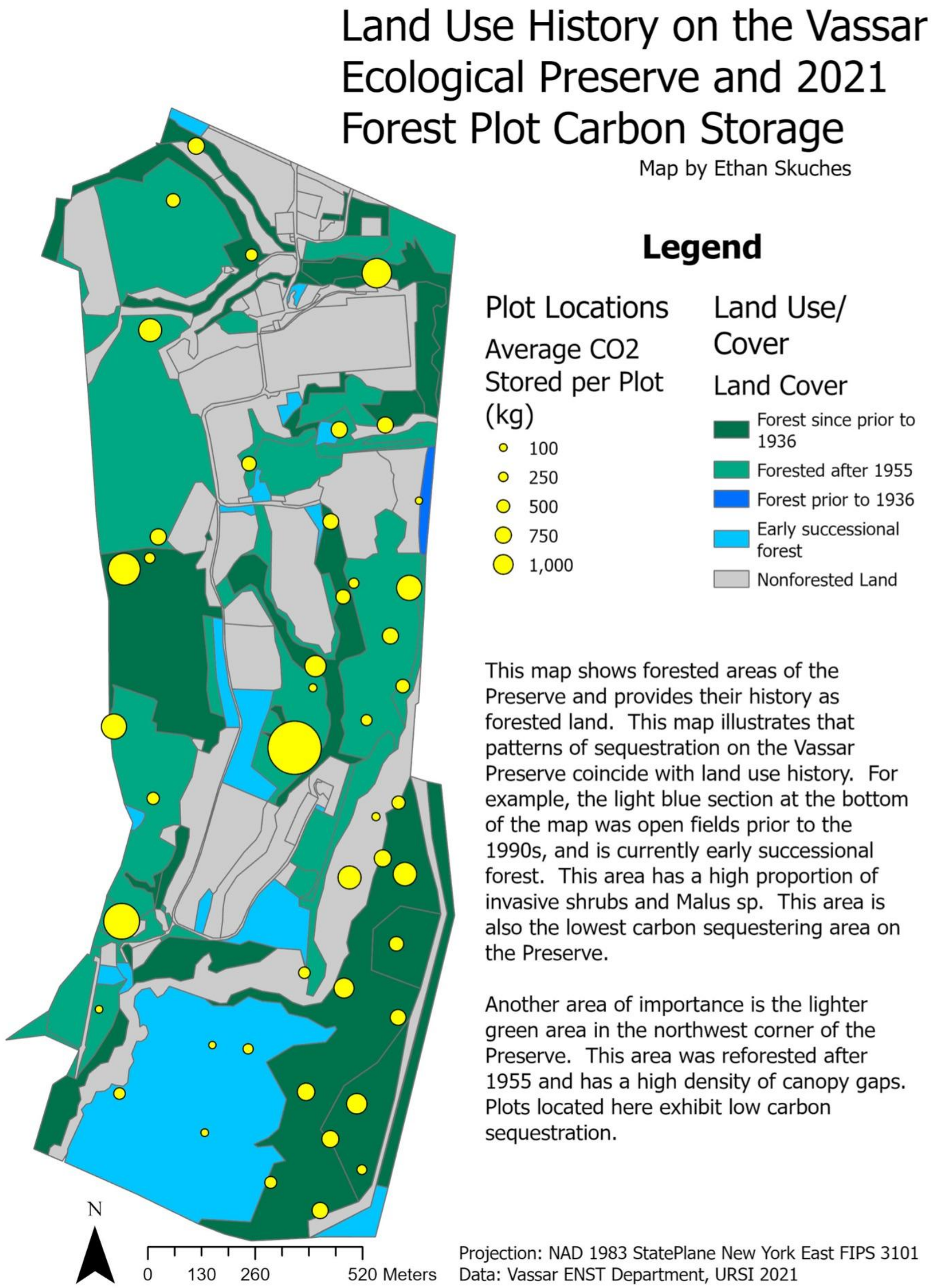

Figure 4. Carbon sequestration patterns on the Preserve are reflective of land use history. Early successional forest areas are dominated by invasive species and are therefore low sequestering.

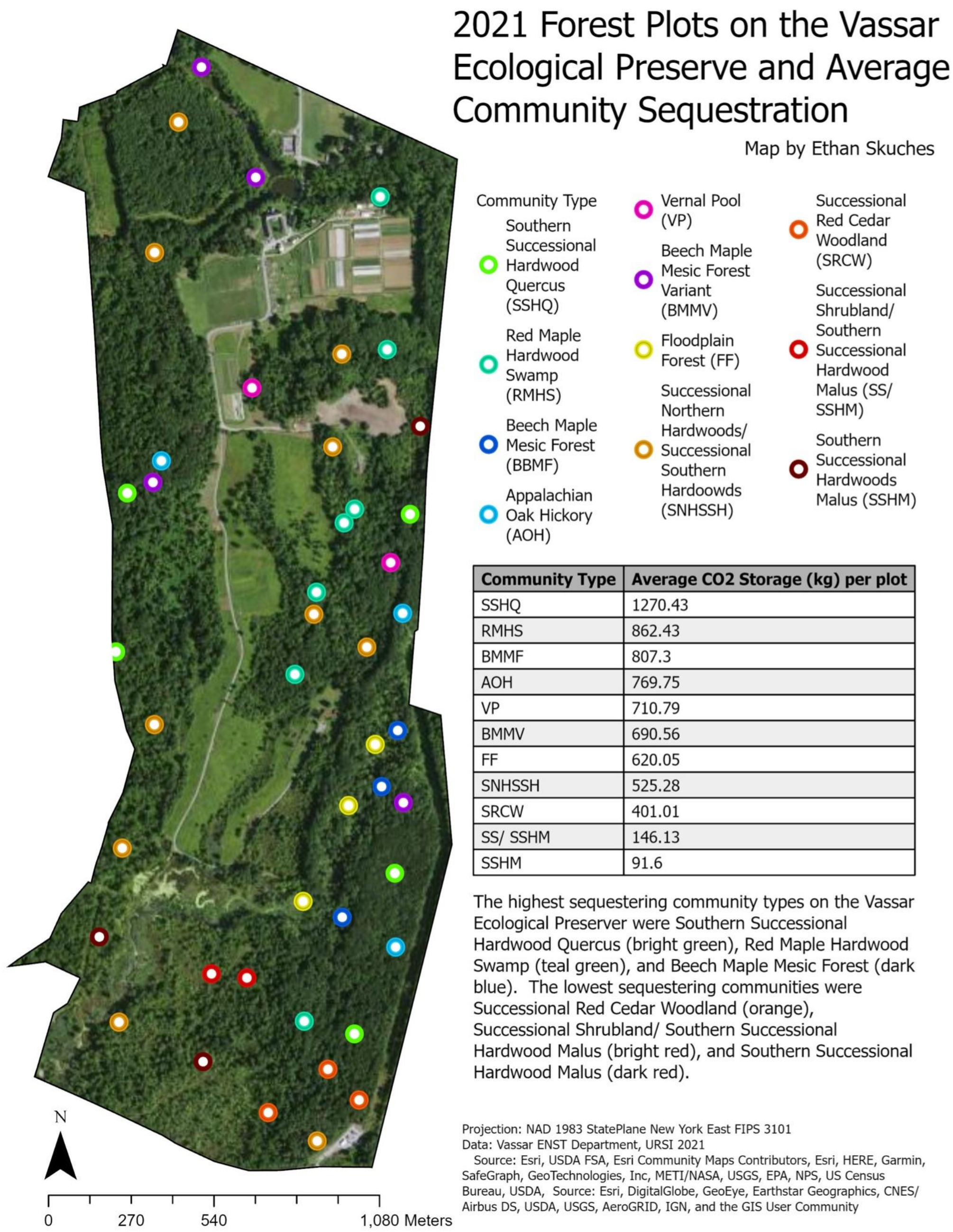

Figure 5. Forest plot locations and the forest community type they are located within. Also included is the amount that each forest community sequestered by plot on average. The community that had the highest average sequestration was SSHQ, and the community with the lowest was SSHM.