Caroline Crain

Major: *Biology*

Minor: Environmental Education

Mitigating Carbon Emissions: Four Strategies for Sequestering Atmospheric CO2 in Trees

ABSTRACT

Human-induced climate change is scientifically accepted, and the planting of trees is suggested as a means to reduce atmospheric CO2. This seems an efficient way to reduce CO2 and maximize ecological and aesthetic benefits, but the reality is more complicated. This study will calculate the carbon budgets of four CO2-reducing strategies: 1) urban forestry projects, 2) afforestation (plantings of trees in non-urban areas), 3) natural regrowth, and 4) preserving mature forests. Strategies 1-3 will assess the break-even point, the number of years trees need to reduce carbon in excess of the carbon cost to plant them. Strategy 4 will calculate the carbon sequestered in mature forests, estimating how long trees planted in strategies 1-3 would take to reach an equal level of removal. In addition, forests of different ages and compositions will be analyzed for carbon sequestration rates. Conclusions made will inform the public of the most effective tree-based CO2 reducing alternative.

PERSONAL STATEMENT

I was five years old. The forest in my backyard, known to most as the Great Smoky Mountains National Park, invited me into a place of creation, in which the flora and fauna of my imagination dwelled. I was ten years old. The passion of discovering creatures had not been extinguished, but had morphed, as I now searched for salamanders, ant colonies, and tall pines. I was fifteen years old. I laid out guides of local trees and arthropods that thrive among the banks of rivers as I prepared for elementary school students to come to the Little River Watershed Association's annual Stream School event that I helped facilitate. I am almost twenty years old. The forest has once again become my innovation ground. The same imagination that discovered new species of flora fifteen years prior now focuses on imagining techniques to understand the undiscovered. I stand examining ecological interactions, hypothesizing how the flora can teach me, can teach humans, the power withheld in a single tree.

The experiences of my childhood perfectly prepared me for undergraduate research. When taking a biodiversity course at Elon, I began to understand that not only are the mechanisms of growth, storage, maintenance, and reproduction complex within a single tree, but the interactions among differing arboreal species, nonvascular plants, fungi, bacteria, and so on, altogether create a complex system that provide unique ecosystem services. While conducting labs in biodiversity and population biology courses, walks through the Elon University Forest began to open my eyes to the ecosystem service of carbon sequestration. To expand my undergraduate education experience beyond my passion for ecological systems, I studied abroad in Europe this past winter term, where I focused on urban planning and architecture, subjects seemingly unrelated to my field. In both Madrid and Sevilla, Spain, I was exposed to sustainable urban planning, where trees were used to sequester carbon and reduce carbon emissions in the city. Connections between ecosystem services provided in natural forest settings and within urban environments fostered a curiosity in me of the mechanisms behind trees serving as carbon sinks.

I believe that science is an active pursuit, not just a sink of historical information, and I wish to be a participant rather than a spectator. My goal in learning has never been to hold biological knowledge to myself, but to foster a curiosity and working knowledge in others. Moving forward in my educational career, I plan to pursue a graduate program where I am able to learn and contribute to the field. The potential to work for the US Fish and Wildlife Service, become a professor at a research institution, or work for an environmental education organization facilitating multigenerational learning of ecological principles greatly excites me. Because the nature of sustainability and natural science fields are evolving rapidly, it is important for me to conduct high quality research that could influence public knowledge and policy. Receiving the Lumen Prize would allow me to influence my peers and contribute to scholarship and public policies regarding research in the most impactful strategy to utilizing trees for carbon sequestration.

PROJECT DESCRIPTION

Focus:

Human activities have resulted in modern levels of atmospheric carbon dioxide (CO2) higher than any known in over 3 million years ("National" 2020). These activities, which include industrialization, urbanization, habitat destruction, and fossil fuel combustion, have caused elevated levels of several greenhouse gases, of which CO2 is increasingly important because it is most abundant. Increased atmospheric CO2 concentration is globally linked with accelerated climate change by the Intergovernmental Panel on Climate Change (IPCC) and numerous scientists around the world (Ripple et al. 2020). The combustion of fossil fuels for transportation, industry, and electricity is the most significant contributor to the measurable rise in atmospheric CO2 over the past 150 years (Nowak and Crane 2002). The current daily average reading of global atmospheric CO2 is over 413 ppm, an increase of more than 75 ppm (>22%) in only forty years (Lindsey 2020). The effects of climate change on humans and natural systems are already apparent and are increasing in frequency and intensity (Edenhofer et al. 2015). These effects will likely exacerbate existing social conflicts and socioeconomic disparities, as many of the poorest people in the United States and around the world live in places where negative effects will be most severe. In addition to its social consequences, climate change is predicted to affect ecological forest structure by changing disturbance regimes, shifting species compositions, and altering species growth rates and overall forest productivity. These changes could have negative long-term ecological and economic consequences (Johnson et. al. 2013).

One antidote to increasing atmospheric CO2 is carbon sequestration, the process whereby CO2 is removed from the atmosphere. Trees do this wonderfully well, keeping carbon in their tissues for centuries and adding to the carbon in soils each year. Utilizing the natural process of carbon sequestration in trees could serve as a mitigation strategy as scientists around the world strive to minimize the effects of carbon emissions and climate change (McKinley et al. 2011). Efforts to mitigate the rise of atmospheric CO_2, including new tree plantings, have both market (monetary) and non-market (to human well-being) benefits. Market benefits, especially in urban areas, include the beautification that increases home values. Non-market benefits, in addition to sequestration, include valuable ecosystem services provided by forests such as cooling the surface of Earth and purifying water and air. Restoration of trees in properly planted regions has great potential to reduce atmospheric CO_2. It is estimated that Earth could support 4.4 billion hectares (ha) of canopy cover, an increase in excess of 50% over the 2.8 billion ha of canopy cover currently existing (Bastin et al. 2019). In his most recent State of The Union address, President Trump even committed the United States to joining the worldwide community in planting trees, though he did not say that the purpose was to reduce atmospheric CO_2. Mitigation efforts must include international cooperation and will necessitate discussions of ethical considerations involving the sharing of effort and benefits.

Recent studies have examined both the carbon sequestration rates and ecological benefits of urban forestry, of afforestation (the intentional planting of trees for agricultural, ecological, or aesthetic use), and of natural reforestation that could sequester carbon from the atmosphere (Nowak and Crane 2002; Gutrich 2007; Song 2018). Indeed, it is estimated that restoration of trees on their native landscapes could result in more than 7 $GtCO_2$ in cumulative removals by 2050, which is more than any other proposed mitigation pathway (Mulligan et al. 2020). Amidst all of the suggestions about different methods for growing trees, we are not aware of any study that directly compares the sequestration and ecological benefits of urban forests, planted forests, naturally reforested areas, and old growth forests as carbon sinks. In order to evaluate the most effective way to remove carbon from the atmosphere, numerous factors including the how (what method is used to grow trees), the where (will trees be planted in appropriate areas), and the what (are the appropriate tree species being planted) must all be examined concurrently. In this study we will examine the 'how' question directly and peripherally address the where and the what.

This study will develop carbon budgets for four distinct scenarios to analyze the effectiveness of using trees to sequester CO_2: 1) Urban forests, plantings of trees alongside streets and within neighborhoods, 2) Plantings of trees in jurisdictionally defined non-urban areas (called afforestation), including trees utilized in the agricultural sector of the economy, 3) Reforestation of open areas through the natural process of secondary succession, and 4) Old-growth forests left undisturbed. Only through direct comparison of carbon sequestration in different forest types can we begin to determine the most effective method of sequestering carbon from the atmosphere to alleviate the effects of climate change in our world today.

Scholarly Process:

This project will begin with a systematic literature review from peer-reviewed scientific papers and accredited economic databases of case studies, extended research experiments, and analyses of urban, planted, reforested, and old-growth forests as they pertain to economic and ecological costs and benefits. Literature will be examined in an effort to observe current guidelines for field techniques of measuring carbon sequestration, examine previous datasets, and guide focus on which scenarios outlined above are studied less often.

In addition to the literature review that gives us global perspective on each of the four tree growing scenarios, we will use data that we collect from local sources to compare carbon sequestration trends in the southeast to those reported globally.

Data collection for the development of our carbon budgets will take place in the North Carolina Piedmont region for several reasons: 1) There is a long history of forest ecology studies and an abundance of literature available on forests in this region due to the diversity and abundance of forests, and 2) The Piedmont region of North Carolina has forests that are easily accessible for data collection from Elon, North Carolina, 3) Dr. Vandermast has contacts with the Duke Carbon Offset Initiative, which is a leader in urban forest plantings for carbon offsets, 4) Dr. Vandermast has contacts with managers of other local natural areas that offer us opportunities to collect high-quality data. Among the areas available to use for data collection are Elon University Forest (EU Forest), high-quality natural areas managed by the North Carolina Botanical Garden, and local parks. A portion of the data collection of afforestation and natural growth plots will occur in Panama through a winter-term course co-lead by Dr. Vandermast, which allows for comparison of sequestration between the Southeastern United States to other regions. To develop our carbon budgets, we will be collecting data from forests of different ages stages, including some old-growth forests. Plantings in Durham and Greensboro will be used for urban forest data. For trees of all species, and of all sizes, we will use well-established peer-reviewed protocols to estimate the current amount of carbon sequestered in their tissues and how much can be sequestered over any time period we choose.

Once we have developed the carbon budgets for each scenario, we will ask the following questions: 1) What is the break-even point for plantings, meaning the number of years these trees need to grow to accumulate carbon in excess of the carbon cost utilized in planting them? 2) How many years does it take trees planted in scenarios 1-3 to reach the level of sequestration we find in old-growth forests? 3) How much carbon is lost when a mature forest is lost and how long does it take a planted forest to recoup that amount? 4) What is the carbon cost from planting the wrong trees in the wrong place, as often seen in urban forests? 5) How much does planting the wrong trees in the wrong place delay the break-even point? 6) How does both carbon sequestration and tree growth differ in trees when they are young versus after they have reached their peak sequestration rate?

Proposed Products:

Several primary outcomes from my research are relevant to both my personal academic growth and the recognition of Elon as a leader in sustainability initiatives. Publishing a paper in a scholarly journal is one of the most effective means to relay research to the scientific community, and that is the first proposed product. Additionally, I will present my research at regional and national conferences including, but not limited to, the Association of Southeastern Biologists annual conference, the National Conferences on Undergraduate Research, and the Ecological Society of America annual conference. Publishing a paper and presenting my research at conferences both regionally and nationally will allow me to gain experience in scientific communication skills that I will build upon in post-graduate programs and opportunities.

Beyond my personal academic growth, the education of my peers on the topic of carbon sequestration is one of my top priorities in planning the outcomes of this study. I plan to work alongside Dr. Vandermast and Dr. Merricks in the biology department to develop curriculum relevant to my findings that may be implemented into non-major biology courses at Elon University. Additionally, we will work to facilitate a spring interdisciplinary seminar open to students and faculty across majors to examine carbon sequestration directly in Alamance county.

FEASIBILITY

Several questions regarding access to data and field site locations may arise, however through much research and discussion, I am confident that the project is feasible. Through localized research projects conducted by students in the past several years under the mentorship of Dr. Vandermast, data related to carbon offset in an urban context is readily available. In addition to the past urban data collections in Durham and Greensboro, I have access to local forests in the piedmont region ranging from pine stands to mixed hardwood stands that will allow me to collect the information as outlined in my methodology. Dr. Vandermast and Dr. Hamel co-teach a course in Panama over winter-term which has allowed Dr. Vandermast to have access to plots of forests that will serve as the primary source for data collection of the afforestation carbon sequestration scenario. Data collection in Panama will occur throughout the Winter-term course.

Funding from the Lumen Prize will additionally allow me to purchase newer and more accurate equipment, as outlined in the budget, that will provide more precise data. In regards to the physical calculations of carbon measurements required for a study such as this, I have access to peer-reviewed mathematical formulas that can examine both rate of sequestration and current carbon held in a system.

Dr. Vandermast has significant experience in mentoring undergraduate research at Elon. He is in his 16th year at the University and has mentored (including this project) 38 projects with 37 students. Dr. Vandermast is a plant ecologist with a focus on forest communities. This project is derived from recent work with the Duke Carbon Offset Initiative (DCOI), for which he acted as a peer validator for two urban forestry carbon offset projects in Durham, NC. This work was conducted with another Elon student, Kylie Roehrle (‘19), who was recognized as a Provost’s Scholar because of this project. Dr. Vandermast is also currently a Sustainability Scholar, and is focusing his work in this area on adding a climate change module to the teaching he does for non-majors biology. He is specifically interested in adding a module that will look at various carbon sequestration strategies, including the ones examined in this project. The data collection for this project uses a standard protocol for identifying and measuring trees.

BUDGET

General Field Equipment:
-$80: Diameter tape (2)
-$150: Dial Caliper

Travel to Field Sites:
-$500: Travel

Conference Travel Expenses:
-$175 - NCUR (Pensacola, Florida)
    -$100: Registration/accommodations (with Elon NCUR Travel Grant)
    -$75: Food
-$1300 - ASB (Little Rock, Arkansas)
    -$200: Registration Fees
    -$350: Air Travel
    -$600: Accommodations
    -$150: Food
-$2500 - ESA (Long Beach, California)
    -$300: Registration Fees
    -$500: Air Travel
    -$1500: Accommodations
    -$200: Food
-$200 - Poster Printings

Academic Expenses:
-$6,000: Panama Winter-term study abroad program
-$6,000: Graduate school applications and visits, Winter-term study abroad program

PROPOSED EXPERIENCES and PRODUCTS

	Experiences	Products
Summer 2020	-Begin analysis of Elon University Forest Data -Ecological Internship or REU at other university	-Excel file of analyzed data -Annotated bibliography
Fall 2020	-Register for 2 credit hours of 499 -Produce SURE application -Collecting and analyzing data of urban forests and Elon University Forests	-Submit SURE application for Summer of 2021
Winter 2021	-Study abroad in Panama, Panama forestry data collection	-Excel file of analyzed Panama forestry data

Spring 2021	-Register for 2 credit hours of 499 -Continue collecting and analyzing data in Piedmont Region -Travel to Association of Southeastern Biologists conference	-Produce poster of preliminary results for ASB conference
Summer 2021	-SURE at Elon -Finalize data collection	-Draft of research paper -Continuation of data analysis spreadsheets
Fall 2021	-Register for 2 credit hours of 499 -Meet with Dr. Jessica Merricks to discuss adding carbon sequestration module to non-major's biology curriculum -Travel to Ecological Society of America conference	-Draft of curriculum for non-major's biology courses at Elon -Produce poster/paper for ESA conference
Winter 2022	-Study abroad through Elon program to fulfill Elon Core Requirements	-Outline of papers for conferences
Spring 2022	-Register for 2 credit hours of 499 -Travel to National Conference of Undergraduate Research -Travel to Association of Southeastern Biologists conference -Travel to prospective graduate schools Present at Elon SURF	-Produce posters/papers for conferences -Produce peer-reviewed journal paper submission

BIBLIOGRAPHY

Bastin J-F, Finegold Y, Garcia C, Mollicone D, Rezende M, Routh D, Zohner CM, Crowther TW. 2019. The Global Tree Restoration Potential. Science. 365(6448):76–79. doi:10.1126/science.aax0848.

Edenhofer O, Pichs-Madruga R, Sokona Y, Minx JC, Farahani E, Kadner S, Seyboth K, Adler A, Baum I, Brunner S, et al., editors. 2015. Climate Change 2014: Mitigation of Climate Change; Summary for Policymakers Technical Summary; Part of the Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: Intergovernmental Panel on Climate Change.

Gutrich J, Howarth RB. 2007. Carbon Sequestration and the Optimal Management of New Hampshire Timber Stands. Ecological Economics. 62(3):441–450. doi:10.1016/j.ecolecon.2006.07.005.

Johnsen K, Keyser T, Butnor J, Gonzalez-Benecke C, Kaczmarek D, Maier C, McCarthy H, Sun G. 2013. Productivity and Carbon Sequestration of Forests in the Southern United States. In: Climate Change

Adaptation and Mitigation Management Options. CRC Press. p. 193–248. [accessed 2020 Mar 8]. http://www.crcnetbase.com/doi/abs/10.1201/b15613-9.

Lindsey R. 2020. Climate Change: Atmospheric Carbon Dioxide. NOAA Climate.gov Press Release. [accessed 2020 Mar 8]. https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide

McKinley DC, Ryan MG, Birdsey RA, Giardina CP, Harmon ME, Heath LS, Houghton RA, Jackson RB, Morrison JF, Murray BC, et al. 2011. A Synthesis of Current Knowledge on Forests and Carbon Storage in the United States. Ecological Applications. 21(6):1902–1924. doi:10.1890/10-0697.1.

Mulligan, J.; et al. (2020): CarbonShot: Federal Policy Options for Carbon Removal in the United States - Climate Engineering - Kiel Earth Institute. [accessed 2020a Mar 8]. https://www.climate-engineering.eu/single/mulligan-j-et-al-2020-carbonshot-federal-policy-options-for-carbon-removal-in-the-united-states-13816.html.

National Climate Report - January 2020 | State of the Climate | National Centers for Environmental Information (NCEI). [accessed 2020 Mar 8]. https://www.ncdc.noaa.gov/sotc/national/202001.

Nowak DJ, Crane DE. 2002. Carbon Storage and Sequestration by Urban Trees in the USA. Environmental Pollution. 116(3):381–389. doi:10.1016/S0269-7491(01)00214-7.

Ripple WJ, Wolf C, Newsome TM, Barnard P, Moomaw WR, et al. 2020. World Scientists' Warning of a Climate Emergency. BioScience. 70:8-12. doi.org/10.1093/biosci/biz088.

Song XP, Tan PY, Edwards P, Richards D. 2018. The Economic Benefits and Costs of Trees in Urban Forest Stewardship: A Systematic Review. Urban Forestry & Urban Greening. 29:162–170. doi:10.1016/j.ufug.2017.11.017.