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Campus Forest Carbon Sequestration: An Undergraduate Project Experience

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Abstract: Predicted changes in climate have generated interest in strategies to mitigate emissions of greenhouse gases and increase education on the topic. Our study involved an instructor-led team of 19 biology undergraduate students that aimed to quantify tree carbon sequestered on 67 hectares of a university campus forest near Utica, New York, and estimate its monetary value as a carbon offset. We identified individual hardwood and conifer trees and measured diameter at breast height (DBH) of 343 trees within fifteen 0.04-hectare sample plots during a 3-week period. We estimated total campus forest carbon to be 7,678 Mg and annual sequestration to be 82 Mg C/year. We also found additional educational value of this voluntary field research project beyond traditional ecology field exercises. Campus managers could choose to count sequestered carbon as an offset to annual CO_2 emissions from campus operations. Although our campus is not eligible to sell the accumulated carbon, we calculated a one-time offset to be worth $143,397 on the voluntary carbon trading market. Future studies could benefit from the efficient sampling methodology we used to quantify carbon contained in large forest areas and increased student learning from project-based field exercises.

Keywords: forest carbon, carbon inventory, campus carbon, tree, carbon sequestration, sustainability education, undergraduate students

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A predicted doubling of atmospheric carbon dioxide by the middle of the next century will likely lead to an increase in average global temperature of between 0.3 and 0.7 degrees C and an increase in extreme precipitation events (Stocker et al., 2013). These predicted changes in climate have generated interest in strategies to mitigate emissions of greenhouse gases and increase education on the topic. Among the Sustainable Development Goals of the 2030 Agenda for Sustainable Development include a climate change target intended to improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning (Rosa, 2017). Measuring forest carbon sequestration provides evidence of the forests' value as carbon sinks and is key to determining how much our forests can mitigate future additions of carbon dioxide to the atmosphere.

Forest ecosystems are capable of storing large quantities of carbon through biomass accumulation in trees (Goodale et al., 2002; Pan et al., 2011). The amount of carbon stored by a tree depends on its size, but roughly 25% of its wet weight is carbon (Lieth, 1963). The mass of carbon dioxide sequestered during growth is 3.67 times that of carbon alone. Thus, the amount of carbon dioxide consumed by a tree during growth is roughly 0.9 times its wet weight. Healthy, rapidly growing forests with middle-aged trees take up carbon at the highest rates. Very young trees grow rapidly, but account for little carbon uptake because their size is small. A mature tree's rate of growth slows and its potential for carbon sequestration diminishes. Mature forests also have more standing and fallen dead trees, so overall carbon uptake in mature forests is lowered by carbon release from decaying vegetation (Birdsey, 1992). Eventually, old forests reach a point where they achieve steady state and stop accumulating carbon.

Soils also contain large stocks of carbon, which can account for the majority of total carbon in temperate forest ecosystems (Heath et al., 2003). Presently, soils in temperate forests are accumulating carbon (Gaudinski et al., 2000). The rate of soil organic carbon sequestration depends on the complex interaction between climate, soil organisms, tree species, and the chemical composition of the litter, and requires further study (Lal, 2005).

The State University of New York Polytechnic Institute (SUNY Poly) campus, where this study was conducted, is part of the largest university system in the United States, with 64 campuses serving 1.4 million students annually [I]. There has been a recent emphasis by New York State to implement policies aimed at reducing the impact of greenhouse gas (GHG) emissions. The New York State Climate Leadership and Community Protection Act became law in 2019 [II]. It calls for reducing emissions by 40% of 1990 levels by 2030 and 85% by 2050. The remaining 15% of emissions would be offset to achieve carbon neutrality. Measuring both carbon dioxide sources and sinks is key to determining whether these ambitious new GHG reduction goals are met. Forest carbon sequestration may play an important role in achieving offsets.

Great opportunities exist to involve university students directly in determining rates of forest carbon sequestration on higher education campuses. Colgate University, in Hamilton, NY, conducted forest carbon inventories in 2013 and 2018 to verify carbon sequestration on their certified and managed forest properties (Colgate, 2018a). Campus forest carbon studies outside of New York State have been conducted for the purpose of calculating carbon offsets, using varied approaches. Several studies documented every tree on campus, involving much time and effort by the researchers (Cox, 2012; DeVilliers et al., 2014). Other studies estimated average canopy cover and spatial distribution of tree diameter (Rountree and Nowak, 1991; EIA, 1998).

Our study uses similar methodology as Colgate (2018a) to quantify the amount of carbon stored in trees on the SUNY Poly campus and to estimate the magnitude of the forest carbon sink. A voluntary GHG inventory of the SUNY Poly campus was initially conducted in 2011. It contained information on direct and indirect GHG emissions from sources that are controlled by the campus, but lacked information on carbon sequestration by the campus forest. We sought to conduct a campus forest inventory with a field-based research project embedded in an undergraduate ecology laboratory course.

Involving students in team-based research projects enhances their awareness of sustainability issues (Brunetti et al., 2013). A team-based project approach was applied in our study. It provided dual incentives to protect our campus forest as a carbon sink against campus emissions and to use the campus forest as a living laboratory for enhanced undergraduate learning.

The overall objectives of the study were to 1) determine how much carbon is stored in trees on the SUNY Polytechnic Institute campus; 2) estimate the annual carbon sequestration rate and calculate a GHG emissions offset from campus operations; 3) determine the dollar value of sequestered carbon to inform administrators; and 4) engage undergraduate students in collection of data, analytical methods, and authorship on a real campus sustainability research project.

Methods

Site Description

The SUNY Poly campus is located in the Mohawk river valley in central New York. It occupies over 162 hectares in a suburban area near Utica, NY, surrounded by residential neighborhoods, shopping centers, an industrial park, and farms among rolling wooded hills. The picturesque campus consists of eleven buildings spread out among parking lots, lawns, and 67 hectares of mostly unmanaged forest patches. In the past, only aesthetic and structural concerns have been used in decisions by facilities grounds crews and hired landscapers to trim or thin trees within these patches. Otherwise the majority of the campus forest has grown unmanaged since the campus was established in 1982.

The site's temperate climate is characterized by warm, wet summers and cold, wet winters with an average summer maximum temperature of 26.9◦C, and average winter minimum temperature of -0.1◦C [III]. The average annual precipitation is 1150 mm, which falls uniformly throughout the year [III]. Vegetation native to the region includes northern hardwood and conifer species.

Forest Carbon Inventory

The forest carbon inventory was conducted as a laboratory project in an undergraduate Ecology course during fall semester 2017. Three 170-minute sessions were used to complete the inventory. In the first session, sampling methods were demonstrated to the class of 19 students by establishing two practice plots. Students were informally quizzed, and later formally tested, on their acquisition of knowledge and sampling skills. In the subsequent two sessions, groups of four to six students, with instructor guidance, set out to establish 13 additional plots, identify tree species, and measure DBH of trees within plots. The following semester spring 2018, three students participated in an independent study project advised by the instructor. They analyzed data and authored sections of a report, some of which contributed to this manuscript.

Twelve forest units totaling 67 hectares of forest were included in the baseline measurements. We calculated the size of the SUNY Poly Utica, NY campus forest using a campus property lines map and a Google Earth area calculator tool by Daft Logic [IV]. To do this we located the borders of each forest unit on satellite imagery and digitally outlined them. Then the Daft Logic tool calculated the area of the polygons we drew. Forest unit boundaries were established based on natural features, like slope, aspect, streams, fields, and stand type, as well as presence of built infrastructure like roads, pathways, and buildings.

We used a spreadsheet tool to calculate the number of sample plots that would be appropriate to measure given the forest size [V]. We targeted a result within 10% of the true mean at the 95% confidence level, in accordance with recommendations by Pearson et al. (2007). Initial calculations called for a minimum of six 0.04-hectare sample plots. We desired all 12 forest units of varying size to be represented appropriately, which resulted in establishing 15 total sample plots (Figure 2).

We chose plot locations to ensure that the edge of each circular plot did not fall across any non-forested area, such as a unit border or stream bed. For ease of measurement we made sure that the plots were not on a very steep slope. Each plot was marked with a small stake in the ground and its location was recorded with a Garmin Etrex Touch 35 GPS unit.

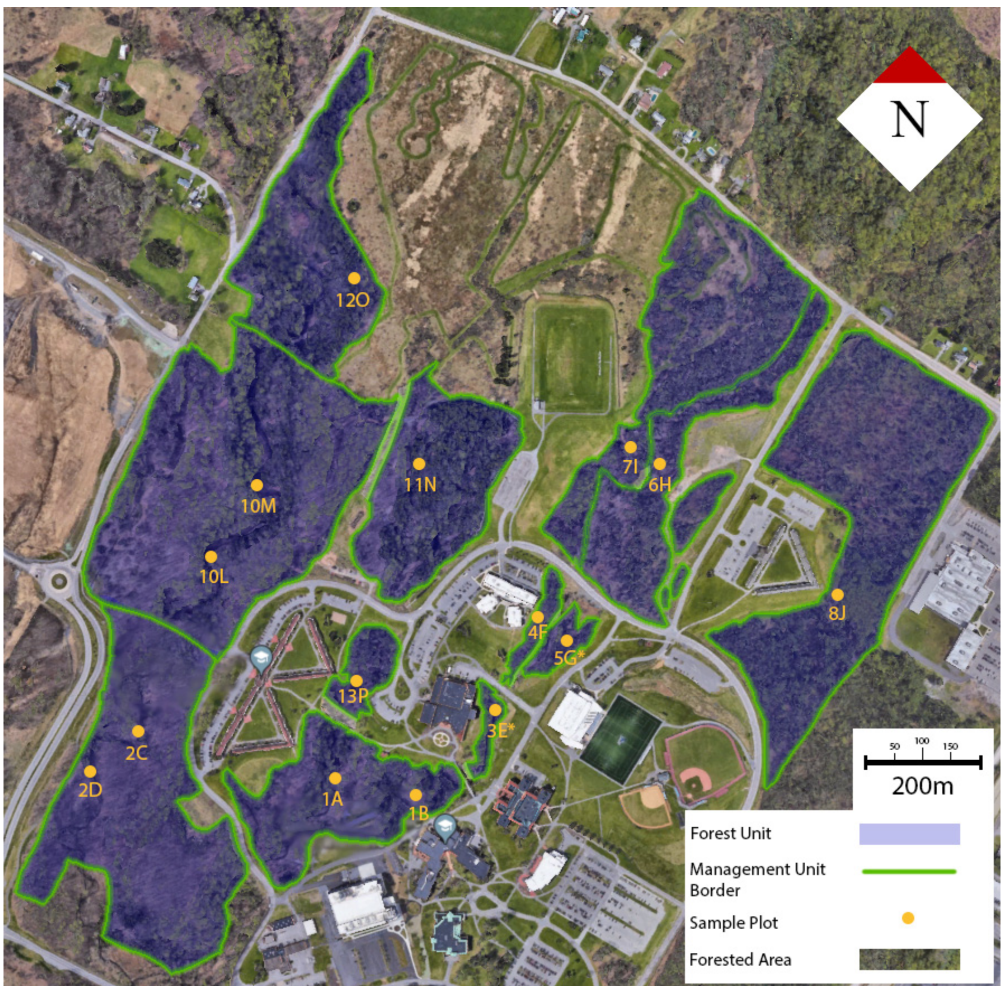

Figure 1. Campus map with plot locations within forest units. Individual landscape trees and forested area that lay outside of campus boundaries were excluded from the study. *Latitude and longitude of plots 3E and 5G were estimated using Google Earth due to GPS equipment error.

Circles with radius 11.3 m were used to establish 0.04-hectare plots (Figure 2). All live trees and shrubs with DBH > 7.6 cm and larger were identified and measured (Pearson et al., 2007).

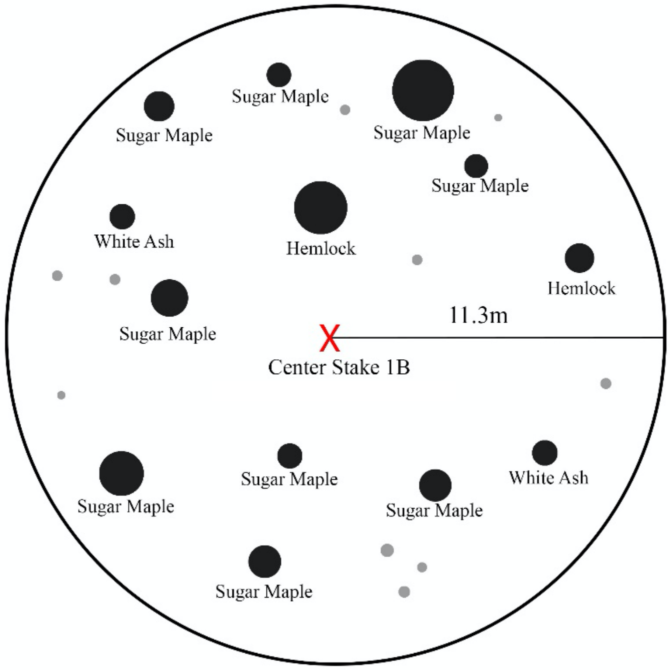

Figure 2. Each tree species was identified and its diameter at breast height (DBH) was measured. All trees greater than 7.6 cm DBH (dark circles) within 0.04-hectare sample plots with radius 11.3 m were sampled. Trees smaller than 7.6 cm DBH (light circles) were excluded from sampling. Trees shown are illustrative of actual data from plot 1B, but are not geolocated nor to scale.

A 1.8 m long PVC pole and panama angle gauge were used as aids in determining which trees were inside the border of each 0.04-hectare plot. This pole had a brightly colored marking tape 34.3 cm wide at breast height, centered at 1.4 m above ground level. When looking through a panama angle gauge, a diameter of 34.3 cm has a limiting distance of 11.3 m for a basal area factor of 10. This allowed students measuring trees to judge whether a tree was within the radius of the plot by looking back at the colored marking on the pole with an angle gauge (Figure 3). Trees near the plot borders were counted if a majority of the tree's diameter fell within the 11.3 m plot radius, and verified by a 15 m tape. DBH is typically measured with a D-tape, in units of pi times length (cm or inches). However, we measured tree circumferences with a 1 m tape and later converted to diameter in cm.

Figure 3a. Students used a panama angle gauge to locate the edge of each 0.04-hectare plot. 3b. Trees near the plot borders were counted if a majority of the tree's diameter fell within the 11.3 m plot radius, and verified by a 15 m tape. Used with permission of students.

Data collected by students was recorded on paper data sheets in the field and transcribed onto a consolidated spreadsheet (Colgate, 2018a). Student researchers entered tree species, circumference, and species group code for each stem DBH > 7.6 cm. We calculated above ground biomass according to the following equations established by Jenkins et al. (2003).

$$Soft\ Maple/Birch\ AGB = Exp(-1.9123 + ((2.3651 * Ln(DBH))))$$

$$Mixed\ Hardwood\ AGB = Exp\left(-2.48 + \left(\left(2.4835 * Ln(DBH)\right)\right)\right)$$

$$Hard\ Maple/Oak/Hickory\ AGB = Exp\left(-2.0127 + \left(\left(2.4342 * Ln(DBH)\right)\right)\right)$$

$$True\ Fir/Hemlock\ AGB = Exp\left(-2.5384 + \left(\left(2.4814 * Ln(DBH)\right)\right)\right)$$

We estimated below ground biomass using the following equation (Jenkins et al., 2003).

$$BGB = Exp(-1.6911 + (0.816/DBH)))$$

Finally, we summed above ground biomass and below ground biomass to calculate total tree carbon in our plots.

Carbon Sequestration Estimate

We summed the total tree carbon in our plots and divided by our sampling intensity ([# of plots x 0.04 hectares] ÷ forest size in hectares) to get an estimate of total carbon stored in the whole campus forest. Tree carbon was converted to CO2-equivalents (CO_2e) by multiplying by 3.67, the mass ratio of CO_2 to carbon.

We then estimated stand age by comparing our species-specific calculated carbon densities in each forest unit to published mean carbon densities in corresponding stand types (Smith et al. 2006). We estimated annual sequestration for each forest unit by annualizing the difference between two age classes. We summed these forest unit estimates to arrive at the sequestration estimate for the entire campus forest.

Carbon Offset Valuation

Values for carbon sequestration were determined by referencing average prices for two categories: overall carbon offsets and forested land offsets, according to Hamrick and Gallant (2017). We multiplied our calculated total Mg CO_2e times the published prices to get a range of potential monetary value for the campus forest offset.

Results

We delineated a total of 67 hectares of campus forest into 12 forest units (Fig. 1). We identified the species and measured the DBH of 343 trees within 15 sample plots (Table 1). The total tree carbon in plots sampled amounted to 70 Mg and the estimated total campus forest carbon equaled 7,678 Mg. On average, the campus forest stored 115 Mg carbon per hectare.

Table 1. Summary of data from forest units and sample plots including forest unit size (hectares), stand type, number of trees sampled in each plot, tree carbon in each plot (Mg), estimated total tree carbon (Mg), and estimated mean carbon density (Mg/hectare).

Forest Unit Number	Forest Unit Size (hectares)	Plot Identifier	Stand Type	Number of Trees in Plot	Total Tree Carbon in Plot (Mg)	Mean Carbon Density (Mg/hectare)
1	3.9	1A	hard maple-oak-hickory	25	4.9	136
		1B	hard maple-oak-hickory	13	6.0	
2	10.8	2C	mixed hardwood	29	4.9	118
		2D	mixed hardwood	33	4.6	
3	0.4	3E	mixed hardwood	16	6.0	151
4	0.6	4F	hard maple-oak-hickory	32	6.9	172
5	0.5	5G	mixed hardwood	25	3.1	77
6	4.8	6H	mixed hardwood	13	2.0	50
7	7.3	7I	soft maple-birch	6	2.5	64
8	11.3	8J	hard maple-oak-hickory	12	2.3	58
10	14.8	10L	hard maple-oak-hickory	29	6.1	140
		10M	true fir-hemlock	34	5.2	
11	5.8	11N	true fir-hemlock	30	4.4	110
12	5.6	12O	mixed hardwood	27	6.6	166
13	1.1	13P	mixed hardwood	19	4.2	105
Totals	67	-	-	343	70	-

We estimated the total annual sequestration of carbon by trees in the campus forest to be 82 Mg of carbon or 1.2 Mg of carbon per hectare. This amount of tree carbon is equal to 300 Mg of carbon dioxide equivalents per year or 4.5 Mg of carbon dioxide equivalents per year per hectare. Our carbon dioxide equivalent annual sequestration rate estimates are consistent with regional averages of 218 to 388 Mg (Birdsey, 1992).

Educational benefits were also realized. The instructor and team of undergraduate biology students engaged in a unique applied learning educational opportunity beyond traditional ecology field exercises. The entire class of 19 students learned field measurement techniques that are typically used by ecologists and foresters in a real forest setting. Students also learned about the environmental benefits of trees, including carbon emissions offsets, in the broader context of mitigating global climate change. A smaller team of three students analyzed the carbon inventory data, authored a report, and used it to inform campus administrators about carbon offset options for the campus forest. Additionally, the tree inventory served the entire campus community by initiating the creation of a campus tree care plan which subsequently led to Tree Campus USA designation [VI]. Student participation in data collection and analysis was recognized as a project of distinction by a panel of judges at a campus-wide undergraduate research poster presentation [VII].

We estimated the current value of the campus forest offset to be worth US $143,397 at US $5.1 per Mg based on the forest offset category referenced in Hamrick and Gallant (2017). Future prices for carbon offsets may vary and are subject to market forces and policy decisions.

Discussion

Three 170-minute Ecology lab sessions were needed for student teams to measure the 15 plots and only a relatively small number of trees (n=343). Basing sequestration rates on a small sample size could cause some uncertainty in the extrapolated results. However, we followed sampling recommendations by Pearson et al. (2007) in order to optimize standard error. This enabled us to obtain acceptable results with a lower sampling intensity than previous studies. Researchers wishing to conduct a forest carbon inventory on their campus could follow this method with relative ease. Those without access to a campus forest could develop a partnership with a local private land owner or public land management agency to conduct a similar study on nearby forested private or public land.

Since trees sequester carbon in a logarithmic pattern, middle-aged trees sequester carbon at a maximum level until old age, when they slow their carbon uptake (Unwin and Kriedemann, 2000). We did not account for planted landscape trees, future recruitment of small trees growing to enter the minimum size class, self-thinning process, nor mortality of large mature trees. Additional monitoring of the plots in subsequent years would allow us to account for these differences and assess their magnitude.

Future measurements of tree carbon in our plots would allow us to calculate annual carbon sequestration rates based on the differences measured. Compared to our estimate of 1.2 Mg carbon per hectare per year, the historical average for New York is about 1.4 Mg carbon (Birdsey, 1992). The sampling and calculation methods used here were used previously by staff at nearby Colgate University, in Hamilton, NY, to measure forest carbon on 437 hectares owned and managed by the university. They recently re-measured plots after five years and calculated annual carbon sequestration of 1.0 Mg carbon per hectare per year (Colgate, 2018a). If the SUNY Poly campus forest carbon plots were to be re-measured in 2022, we should expect annual carbon sequestration between 1.0 and 1.2 Mg carbon per hectare per year because our forests are similar in stand types and age to Colgate's, lie within the same climate region, and are relatively close to one another (56 km).

There are many potential benefits to universities giving attention to sustainability metrics. Campuses that reduce GHG emissions gain a better reputation among prospective students and staff who want to be a part of a green institution (Filho, 2011). Reporting GHG inventory and campus forest carbon sequestration improves an institution's score in the Sustainability Tracking, Assessment, and Rating System (Urbanski and Filho, 2015) and can earn higher rankings by independent publications, such as Sierra Club Cool Schools Ranking and Princeton Review Guide to Green Schools.

Engaging students in this course research project actually benefitted several campus groups, including the students themselves, the instructor, and administrators. Students not only gained practical experience in ecology and forestry field methods, data analysis, and research report writing, but also put field measurements into the greater context of quantifying carbon sequestration for the purpose offsetting GHG emissions to combat global climate change. The instructor advanced data collection and analysis with the help of free student labor.

Administrators received additional knowledge to inform management decisions and emissions reporting. The institution received the additional benefit of extra products created from teaching activities that were already taking place.

These benefits helped overcome some of the typical barriers encountered in university sustainability programming. One barrier is the voluntary nature of some reporting measures, including carbon accounting initiatives. When universities voluntarily make agreements to measure, track, and report sustainability metrics, they are under no legal obligation or mandate to do so. Embedding sustainability reports in course projects helps institutionalize data gathering and reporting (Savanick et al., 2017). Another barrier is the high cost of hiring dedicated staff to implement and manage sustainability goals. Student participation in research increases productivity without incurring major additional costs. Yet another barrier is nurturing a strong sense of place among students at universities. Nature-based stewardship projects can help increase students' sense of place, which plays a role in healthy mental development and can lead to pro-environmental behaviors (Krasny and Delia, 2015).

The forest carbon sequestration totals we calculated can be applied as an offset to emissions in the university's annual carbon accounting. To do this, the amount of carbon sequestered in campus forests each year is subtracted from measured greenhouse gas emissions in order to reduce the campus carbon footprint. Our results suggest that a relatively small proportion (2.4%) of the total emissions of 12,453 Mg CO2 eq per year (Bremer et al., 2011) will be sequestered in the SUNY Poly campus forest. DeVilliers et al. (2014) account for about 6% of KIWI University emissions, while Cox (2012) accounts for less than 1% of UC Northridge emissions. The SUNY Poly campus forest carbon inventory measured far fewer trees than previous studies, but extrapolated values can be used to account for a comparable amount of GHG offsets.

Because of the relation between forests and atmospheric carbon dioxide, forests can be managed in ways that would result in storage of additional carbon and thus reduce atmospheric carbon dioxide. Major forestry opportunities include maximizing the productivity of existing forest lands by careful management, protecting existing forest to reduce deforestation pressures, planting tree species that sequester the most carbon, and purchasing additional forest land (Birdsey, 1992; Kerchner and Keeton, 2014).

Campuses that have extensive tree plantings or universities that own forested parcels outside of the main campus have the potential to offset a larger percentage of total carbon emissions. Colgate University's offsite forest parcels are certified by the American Tree Farm System and managed for biomass harvesting. A biomass boiler feeds the central campus heating system. Carbon sequestered in Colgate University's forest lands account for up to 28% toward its carbon neutrality goal (Colgate, 2018b). Other carbon mitigation strategies besides forest sequestration, such as energy efficiency improvements and purchase of renewable energy certificates, are typically needed to further reduce campus net carbon emissions.

While the voluntary carbon market is still in its infancy, it is quickly developing the potential for a substantial profit (Hamrick and Gallant, 2017). It works by allowing voluntary buyers, usually from United Nations Framework Convention on Climate Change Annex I countries, to purchase carbon offsets which are used to compensate for carbon emissions produced by said buyer (Breidenich et al., 1998). The Paris Agreement in 2015 codified additional commitments for emissions reductions by signatory countries, bolstering the demand for carbon offsets.

The process of creating an offset typically consists of several steps, including validation, verification, intermediate sale, and final sale. The validation process is carried out by a third party on the parcel proposed for an offset. An auditor reviews the proposed sequestration plan and determines if it would be profitable to continue to the next step. Once the project is approved and under observation, another auditor will verify the operation by determining the impact of greenhouse gas mitigation produced by the offset. Once an end buyer is matched and the impact of the offset has been claimed, the offset is retired so that it cannot be resold to additional buyers (Hamrick and Gallant, 2017).

In recent years the carbon market has been quite volatile, with the value of carbon offsets depending on factors such as offset location, project type, and fluctuations in demand. In 2016, the average price for carbon offsets in North America was $2.9 per Mg CO2e, while the average price for forest and land use offsets was higher, at $5.1 per Mg CO2e (Hamrick and Gallant, 2017). Using these market prices as guideposts, the total carbon offset of the SUNY Poly campus forest is worth between $81,706 and $143,397. The additional carbon dioxide sequestered annually by the forest is worth between $868 and $1,528. Being a property of New York State, the campus is ineligible to sell its forest carbon offset. However, putting a monetary value on forest carbon sequestration increases the perceived importance of this ecosystem service and legitimizes preservation efforts.

Instructors seeking to conduct future campus inventories could improve on our methods. They could reduce the potential for plot selection bias by randomizing selections from a grid overlaid on a map the site, as in Colgate (2018a). Plot centers could be marked with larger, more brightly colored stakes to make them easier to find in subsequent years. Dedicated D-tapes are not necessary, but would make measuring DBH quicker. To better determine mean tree age within each stand, researchers could take tree core samples proportional to the diameter structure and evaluate by a weighted mean. Overall, our approach made an ideal applied learning project for an undergraduate science course on university campus containing some forested lands.

[I] https://www.suny.edu/about/fast-facts/
[II] https://www.nysenate.gov/legislation/bills/2019/s6599
[III] https://www.usclimatedata.com/climate/utica/new-york/united-states/usny1476
[IV] https://www.daftlogic.com/projects-google-maps-area-calculator-tool.htm

[V] https://www.winrock.org/document/winrock-sample-plot-calculator-spreadsheet-tool
[VI] https://www.arborday.org/programs/treecampususa/campuses.cfm
[VII] https://dspace.sunyconnect.suny.edu/handle/1951/70121
[VIII] https://stars.aashe.org/

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Author thumbnails


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