RIT Environmental Science Capstone: Campus Carbon 2017

Final report – December 18, 2017

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Abstract

As climate conditions continue to change due to a rise in anthropogenic greenhouse gas emissions, the quantification of carbon storage capacity for all land covers is only going to become more important. Rochester Institute of Technology (RIT) seeks to achieve carbon neutrality by 2030 by terminating all campus emissions that contribute to climate change. Our prime objective to achieve this goal is to identify the current carbon storage and sequestration potential for each land cover type on campus. To do so, stratified random samples were collected for two prominent land covers: the carbon storage potential was analyzed for each soil type on campus, and vegetation carbon storage potential was measured for turf and forested land covers. A universal tool to measure the amounts of above- and below-ground carbon for the entirety of campus, regardless of soil type and land cover, was created using the geographic information systems (GIS) platform ArcGIS Online, an online tool accessible from any web browser. Our secondary objective was to collect baseline carbon flux data on campus. To accomplish this we designed an experiment to compare whether unmowed or consistently mowed grass plots store less carbon. Our results suggest mowed plots store more carbon, but there are significant caveats. Lastly, we sought to adapt carbon storage measurement methods for multiple audiences and complete at least two outreach events. We wrote and tested methods to measure carbon storage for soils, trees, and grass covers before adapting them for others to use, such as RIT soil science students and girl scouts. We taught both groups about carbon sequestration, the significance of our project, and how they can help.

Introduction

Carbon is a key element to life on earth. Carbon cycles throughout all living things via two key processes: photosynthesis and respiration. Plants remove carbon from the atmosphere (in the form of carbon dioxide), using photosynthesis to turn the carbon into organic compounds that plants and animals can use. Organisms including humans use this organic carbon to respire, gaining energy to do work while returning carbon dioxide to the atmosphere, thus completing the carbon cycle. Before the Industrial Era, carbon cycled throughout the environment at a natural rate. However, in the last few centuries, humans have knocked the carbon cycle out of balance. To accommodate the rapidly increasing energy needs of a growing world population and economy, humans are emitting 49 Gigatons of CO_2 per year as of 2010, contributing significantly to rising surface temperatures on Earth (IPCC, 2014). Ongoing rapid development of wild lands is destroying photosynthetic plants that would remove (sequester) the extra carbon we emit. Conversions of land into agricultural fields, residential neighborhoods, and commercial developments has created positive feedback loops exacerbating carbon emissions throughout all terrestrial, atmospheric, and oceanic ecosystems (Cox et al., 2000). In short, human activity has led to more carbon being added to the atmosphere, warming the planet's climate through the greenhouse effect.

There are numerous disastrous effects of a rapidly warming climate, such as rising sea levels, ocean acidification, habitat loss, decreased food security, human health risks, extreme weather, and loss of biodiversity (Solomon et al., 2009; Doney et al., 2009; Lobell & Field, 2007; McMichael et al., 2006; Frich et al., 2002; Deutsch et al., 2008). To prevent a global catastrophe, carbon emissions must be measured and then prevented or offset. Reducing carbon emissions is possible in any ecosystem, not just extremely productive carbon sinks like tropical rainforests. A study in Baltimore found that urban environments can have a significant effect on carbon budgets (Pickett et al., 2008). Although carbon is inevitably lost when land is developed, the study found that carbon storage in urban environments can be increased in through both soil and vegetation. Additionally, the study concluded that animal and plant life in urban environments can be surprisingly diverse; even small green spaces in urban environments provide paired benefits such as carbon sequestration and useful habitat (Blair, 2004).

One study sought to evaluate the effect of carbon dioxide mitigation strategies by using computer simulations to systematically change factors such as land cover type, temperature, and levels of afforestation to estimate low, middle, and high carbon storage values (Krause et al., 2017). Researchers used this information to model a variety of scenarios and their projected carbon storage values for every change in these influencing factors. Overall, it is imperative that preventative measures be taken to combat rising carbon dioxide levels if we wish to minimize the extent of climate change. This method of estimating high and low values would benefit future decision-making on RIT campus because the modelled projections would clearly accentuate which areas require strict preservation and which areas could be suitable for further development.

Project Background

As a signatory of the American College and University Presidents' Climate Commitment, Rochester Institute of Technology (RIT) is working to minimize its carbon footprint and achieve carbon neutrality by 2030 (Rochester Institute of Technology, 2017). See Appendix B for details on RIT's Climate Action Plan. The objective of this project is to provide our client Enid Cardinal, the senior sustainability advisor to RIT president Dr. Bill Destler, with the necessary tools to tackle the difficult task of offsetting the RIT's scope 3 carbon emissions. Scope 3 emissions are indirect emissions, including emissions from air travel, commuting, and materials sent to the landfill. Scope 1 and 2 emissions include carbon directly emitted by RIT facilities and emissions indirectly emitted by providers from which RIT purchases power (Greenhouse Gas Protocol). RIT's scope 3 emissions, which we are helping to offset, were 23,871 metric tons of carbon dioxide in 2012.

This ongoing project has been worked on by undergraduates in the Environmental Science program, with data contributed by other undergraduates in courses such as Soil Science and Ecology. Although soil and tree carbon data has been collected on most of campus, much of the data is missing or too old to be relevant. A regression analysis was never actually run by previous Environmental Science capstone students. Generating a regression equation will allow Ms. Cardinal to calculate the amount of carbon stored at any location on campus based the soil type and land cover that are present. This equation will be used to estimate how much carbon has the potential to be emitted when a land cover is changed, like when a new building displaces a grassy knoll. It can be also be used to improve land management practices by identifying the locations that store the most carbon on campus.

Objectives for the Spring and Fall 2017 semesters

By the end of 2017 we aimed to complete the following three key objectives:

1. **Estimate how much carbon is stored in every area of campus.** Our approach is to sample soil and aboveground carbon across campus in order to create and test a regression equation. The equation will be used to estimate carbon storage at any location based on area, land cover, and soil type. We will deliver condensed GIS data using ArcGIS Online, which can be accessed from any computer with a web browser.
2. **Collect baseline carbon flux data on campus.** We set up long-term study plots on campus where future environmental science students can resample to determine how carbon storage changes over time on campus.
3. **Adapt our methods and complete two outreach events**. After finalizing our own methods to be used by future RIT students, we adapted our methods into a suitable form for young future scientists and their teachers, who may not have the same access to equipment that we do.

Detailed procedures for meeting these objectives are in the next section, identified by their objective number (1-3).

Methodology

1A - Estimate soil carbon storage:

Generate stratified random sample locations based on soil type; the average carbon content of each soil type on campus, as projected by the Natural Resources Conservation Service, is shown in Figure 2. At each sample site take three bulk density samples before doing loss on ignition tests to determine the average carbon content of each location. A summary of our methods is below, and Figure 1 in Appendix A is a map of our study sites. Our methods are based on methods used by Dr. Korfmacher's soil science classes who have gathered much of the existing soil data. A detailed procedure is available in the supplemental document titled "Soil carbon method", referenced in Appendix C.

I. Decide how many total samples can be taken in the time allotted. Divide those samples up proportionally based on the percentage of the total area covered by each soil type. Use the "create random points" function in ArcGIS to randomly place sampling locations within each soil type.
II. At a sampling site, clear debris from the soil and pound the bulk density chamber into the soil until its top is flush with the soil surface.
III. Remove the chamber from the ground with a trowel, making sure no soil escapes the bottom of the chamber, and place the sample in a plastic bag and label with the date, team name, site number, and replicate number.
IV. Repeat steps 2-3 twice more at the same sample site to later calculate average values for bulk density and carbon content for each site.
V. Dry 100 g of each sample at 105 °C for a minimum 24 hours before weighing to determine the fraction of mass remaining. Use that fraction to calculate bulk density
    Bulk Density = (total dry weight) / (volume of chamber)
VI. Incinerate the dried samples in a muffle furnace at 360 °C for two hours, then calculate the mass lost on ignition (organic matter) and carbon content:
    LOI = (mass before incineration - mass after incineration) / (mass before incineration)
    Carbon content = LOI*0.5*total dry weight*100 (g/cm^2)
    Average bulk density and carbon content at each sampling site.
VII. Convert carbon content into carbon area density (kg/m^2) = bulk density * carbon content * depth. We used a depth of eight inches in our calculation as recommended by Dr. Korfmacher.

1B - Estimate tree carbon storage:

Generate stratified random sample locations based on the type of forest cover, as shown in Figure 3, and then measure the height and diameter of every tree that has a diameter greater than 5 cm within each sample plot. Calculate the carbon stored in each tree using equations generated by other researchers, then add all the carbon values together to determine the carbon stored per unit area. A summary of our planned procedure follows. A complete detailed procedure is available in the document “Tree carbon method”, referenced in Appendix C.

I. Decide how many total samples can be taken in the time allotted. Divide those samples up proportionally based on the percentage of the total area that is covered by the three distinct forest types: deciduous, woody wetland, and mixed. In ArcGIS, use the “create random points” function to randomly place sampling locations within each of these forest types.
II. At each sample site, measure X meters (we did 3 meters) from the GPS point in at least eight directions and plant flags at each point to create a circular plot.

Record the area of the plot, πr^2, where *r* is the length from center of the plot to the outside edge.

III. Identify the tree species present in the plot using a field guide or this online resource: http://forestry.about.com/cs/treeid/a/hard_tree_id.htm
IV. For each tree in the plot record the following:
    A. Species
    B. DBH: Diameter at Breast Height (4-5 ft off the ground) using tree calipers
    C. Height of the tree. Use the Nikon Forestry Pro to measure this.
V. Calculate biomass for each tree in the plot using an equation specific to the tree species, as given in Appendix A of the 1982 Tritton and Hornbeck paper.
VI. Find percent carbon for the tree species using the chart titled “Carbon and hydrogen contents of hardwood and softwood North American species” in the paper by Lamlom and Savidge (2003).
VII. Determine the carbon density of each plot. Add up all the tree carbon masses in a plot and divide the total by the area of the plot to get areal density (kg/m^2).

1C - Estimate aboveground carbon storage in other non-forest environments:

During the spring semester, David conducted a literature review (referenced in Appendix C) to determine the best way to measure carbon storage in land covers that qualify as wetlands and grasslands as defined by the National Land Cover Dataset (NLCD). During the fall semester methods for measuring soil carbon, grassland carbon, and tree carbon were adapted for RIT campus and trialed in the field. Methodology for wetland carbon storage was written but not tested; methods for root carbon storage were not adapted and therefore not measured. This provides future capstone students with a place to start in their research.

1D - Manually digitize land cover polygons on campus to improve on NLCD 2011

I. Use ArcGIS Pro software to insert a new basemap. Choose the satellite imagery option, as demonstrated below in Figure 4.
II. Under “databases” in the “Catalog” pane, click “new” - “feature classes” to create a new layer to store digitized polygon data. Provide with an appropriate label to reflect the land cover being digitized, such as “Wetlands.”
III. Create polygons via the “features” option under the “edit” tab; click create and choose the “polygon feature template.”
IV. Add values to these new features, such as area, using the “add field” option in the

attribute table.

V. To avoid data gaps along the borders of differing land cover classes, set the snapping extent by going to “edit” tab and the “snapping” group. Set parameters as desired, but typically XY tolerance is set as 10 pixels and “snap to sketch” is enabled. These were the snapping extent parameters we used for our analysis.
VI. Repeat steps 2-5 to create 6 additional feature classes for the remaining land covers.
VII. Designate different colors to each class by right-clicking on its layer under “catalog” as a way to differentiate land covers.
VIII. The final product of this digitization can be found below in Figure 6.

1E - Create a regression equation for estimating soil carbon content at a location on campus:

I. Convert carbon percentage values for each point into mass of carbon per unit area using bulk density measurements and a depth of 8 inches (suggested by Dr. Korfmacher).
II. Do exploratory linear regression analyses in R to determine what variables significantly affect carbon storage and on RIT’s campus.
III. Choose best regression equation based on adjusted R^2 values and sensibility.

1F - Create tool in ArcGIS online that the client can use to calculate carbon storage:

I. Into an ArcGIS online map, import shapefiles for the National Land Cover Database (Figure 5), a land cover database manually digitized by Ashley (Figure 6), and soil type on RIT’s campus (Figure 2).
II. Separately intersect land cover databases with the soil type layer.
III. Create spreadsheet with soil carbon regression equations derived in R so a user can plug in areas of each soil type, land cover, and soil type x land cover to calculate belowground carbon storage.
IV. Create tabs in that spreadsheet for calculating aboveground storage based on carbon storage per area values calculated from our research or found in literature.
V. Write instructions for drawing a custom polygon in ArcGIS online with “Map Notes”, intersecting that polygon with the appropriate layers, and finding the values to plug into the spreadsheet.

1G - David’s project for IMGS-431, Environmental Applications of Remote Sensing

The complete methods and results of this subproject are explained in a separate paper referenced in Appendix C.

I. Download WorldView-2 multispectral (8 band) imagery covering RIT’s campus.
II. Use ENVI 5.4 to generate unsupervised land cover classifications of campus.
III. Use ENVI 5.4 to manually select training sites for all significant land covers then generate and refine supervised land cover classifications.
IV. Manually pinpoint locations on campus where the land cover is known. Use these ground truth points to test the accuracy of each classification using a confusion matrix.

1H - Ashley's project for IMGS-431, Environmental Applications of Remote Sensing

I. Download WorldView-2 multispectral (8 band) imagery covering the extent of RIT campus in June
II. Use ENVI 5.4 to create a Normalized Difference Vegetation Index (NDVI)
III. Use ENVI 5.4 to run a Principal Components analysis
IV. Create Regions Of Interest (ROIs) for our mow comparison sites and tree sampling sites.
V. Extract the pixel values for each ROI, and use as ground truth points.
VI. Use Microsoft Excel to calculate aboveground biomass as a function of: band contribution, NDVI values, and Principle Component values.
VII. Run a stepwise regression with an alpha level of 0.05 to model aboveground biomass for the entirety of campus.

2A - Establish long-term plots to compare carbon storage in mowed and unmowed turf and collect rough flux data

I. Use pre-approved long-term study sites or obtain approval from FMS to study a new grassland/turf location.
II. At each sampling point, measure a ½ meter by ½ meter square and mark the corners with flags. Flag another quadrat of the same size ½ meter away from the first quadrat.
III. Fence off a ½ meter buffer zone around the quadrat(s) to to prevent human interference. The fence should not stop sunlight, water, or small organisms from entering the sampling site.
IV. Clip all biomass within the fence (sample site and buffer zone) to 3 inches above the ground.
V. Leave the control quadrats to grow until the end of the experiment.
VI. To simulate regular mowing of the treatment quadrats, clip all biomass above 3 inches every two weeks. Collect all the clipped biomass and store it in plastic bags for analysis.
VII. Near peak biomass, complete a final clipping and collection of all biomass in both control and treatment quadrat to 3 inches above the ground. Separately, clip the remaining stubble biomass (the part that survives the winter) down to ground level in a 6 cm by 6 cm subsection of the quadrat and store in a separate bag.
VIII. Weigh the fresh biomass in each bag then dry it in the oven for 2 hours at 70 °C and weigh it again.
IX. Estimate that 50% of the dry biomass is carbon.
X. Extrapolate the carbon measured in the stubble subsection to the whole quadrat:

    total stubble carbon = (quadrat area / stubble subsection area) * stubble carbon

XI. Calculate the net primary production (NPP) of each quadrat over your study period by adding up all the carbon collected over the study period plus 50% of the stubble carbon collected at the end:

$$NPP = (C_{\text{week 2}} + C_{\text{week 4}} + \ldots + 0.5 \cdot \text{total stubble C}) / \text{quadrat area} / \text{time period}$$

XII. If your study included the whole growing season, your time period can be 1 year.
XIII. Calculate the maximum carbon storage of a quadrat by adding up all the carbon collected at peak biomass, in both the original clippings and the stubble clippings:

total carbon storage = (peak clipping carbon + stubble carbon) / quadrat area

3A - Lesson plan development

I. Draw partially labelled carbon cycle and photosynthesis diagrams so students can fill in parts on their own.
II. Create a short quiz including the two diagrams to test students on big picture concepts related to carbon sequestration, like the greenhouse effect, fossil fuels, and climate change.
III. Make a big poster with completely unlabeled versions of carbon cycle and photosynthesis diagrams to fill in during the lesson.
IV. Write a list of topics to talk about in order to address issues covered by the quiz.

Timeline

Week of	**Tasks completed**
Feb 1, 2017	➢ Met with our interim client Dr. Korfmacher to discuss previous work done on the project ➢ Read through and summarized the methods described in the final papers of Environmental Science students who last worked on this project ➢ Consolidated all files provided by previous students ➢ Sorted through and annotated the non-GIS data (powerpoints, word docs, images, etc) provided by previous students ➢ Repaired Rebecca and Jason’s ArcMap project and imported all provided GIS data
Feb 7, 2017	➢ Compared previous capstone data with Dr. Korfmacher’s data to create the most up-to-date carbon map that eliminated any duplicate information ➢ Emailed Dr. Tyler asking if she taught Concepts 2008, and if she did whether she has any notes or GIS data we could use ➢ Emailed Dr. Hane asking if she still has field notes or GIS data from Conservation Biology 2009/2010 and Ecology 2013
Feb 14, 2017	➢ Finished merging cleaning up all available soil sample data from previous capstones and classes ➢ Created thematic maps to show the current state of the project ➢ Outlined our proposed next steps for the project ➢ Made slides to explain the project to our classmates and Ms. Cardinal
Feb 21, 2017	➢ Updated our maps/presentation for Ms. Cardinal based on feedback from teachers and classmates ➢ Read the Norris paper on carbon dynamics that Dr. Korfmacher suggested ➢ Refined our methods for keeping our project organized (started using Trello)
March 1, 2017	➢ Emailed Jan van Aardt about integrating capstone work into remote sensing next semester

	➢ Drafted methods for measuring soil and tree carbon, which we and hopefully other classes will use ➢ Researched clinometer options ➢ Started processing the tree data Dr. Tyler gave us
March 8, 2017	➢ Drafted a proposal outlining the work we will potentially do over the summer for Dr. Korfmacher ➢ Began writing our mid-semester report ➢ Finalized soil and tree carbon methods ➢ Ashley learned about our legal system at jury duty
March 22, 2017	➢ Wrote and turned in a draft of our mid-semester report for our client ➢ Suggested edits to the FEAD grant proposal ➢ Created a spreadsheet for generating stratified random samples based on soil and tree type
March 29, 2017	➢ Updated project proposal for Ms. Cardinal ➢ Updated FEAD and P2I grants for Dr. Korfmacher ➢ Created a presentation about our project proposal for our mid-semester client meeting
April 5, 2017	➢ Mapped out 25 soil sample locations ➢ Obtained gear required for gathering soil samples ➢ Took 4 soil samples (3 replicates in each location)
April 12, 2017	➢ Took 6 more soil samples ➢ Finalized our project proposal for Ms. Cardinal
April 19, 2017	➢ Collected the remaining 45 soil samples (3 replicates from each of 15 sites) ➢ Created a new map showing all completed soil points ➢ Adapted our capstone proposal into a draft of our final report
April 26, 2017	➢ Dried 75 soil samples and and calculated bulk density for each ➢ Prepared 150 samples (2 replicates from each of the 75 samples) for loss-on-ignition analysis ➢ David wrote his paper reviewing carbon measurement methods for grasslands, wetlands, and root systems
May 3, 2017	➢ Measured trees at 25 sites (DBH, height, species) ➢ Created and printed a poster to present at Imagine RIT
May 10, 2017	➢ Completed loss-on-ignition analysis for 150 soil samples ➢ First pass at tree carbon calculations using general equations ➢ Work on regression analysis ➢ Presented our poster at Imagine RIT ➢ Updated final report with latest results ➢ Generated final maps of our sampling locations ➢ Created slides for final client meeting ➢ Final client meeting for the spring semester
July 1, 2017 to	➢ Collected and processed soil samples from 100 more sites

August 28, 2017	➢ Tidied up tree and soil data ➢ Established 4 long term mowed-comparison plots ➢ Created slides to update client on summer progress
September 13, 2017	➢ Measured the grass in our 4 plots and realized the grass hadn’t grown enough in a week to mow ➢ Expanded our presentation for Enid to cover all the land covers we’ve studied so far ➢ Met with Dr. Whitney to discuss soil stats and how to present them to our client
September 20, 2017	➢ Wrote 3 outreach proposals ➢ Formalized semester todo list in Trello after our client meeting ➢ Started making a worksheet to evaluate outreach effectiveness ➢ Contacted Dr. Tyler about potential outreach with her girl scout troop
September 27, 2017	➢ Reached out to Jan van Aardt to discuss our final project for Remote Sensing ➢ Reached out to Dr. Hane to discuss potentially adding more tree variables ➢ Met with Karl’s TA Liam to discuss the Soils Lab we will teach ➢ Added to our outreach assessment
October 4, 2017	➢ Tweaked outreach assessment ➢ Created carbon cycle fill-in-the-blank exercise ➢ Created photosynthesis fill-in-the-blank exercise ➢ Found elevation data for RIT to add to soil and tree analysis ➢ Updated ArcGIS online map with latest data
October 12, 2017	➢ Started digitizing land cover database for campus ➢ Created slides to update client on the 19th
October 18, 2017	➢ Finalized a date for our outreach with Dr. Tyler’s girl scout troop ➢ Refined our outreach quiz ➢ Sketched out a lesson plan for outreach ➢ Updated our project proposal document to match objectives discussed with Enid last month ➢ Continued digitizing campus land covers
October 25, 2017	➢ Made answer key for girl scout quiz ➢ Sent lesson plan, quiz, and answer key to Dr. Tyler for feedback ➢ Drafted lesson plan for our one-hour lesson in soil science ➢ Collected soil samples near future Alumni house
November 1, 2017	➢ Redid soil stats with Ashley’s land cover database ➢ Finalized slides and spiel for our soil science lesson ➢ Talked to Dr. Karl Korfmacher’s soil class for an hour ➢ Worked on mid-semester report ➢ Met with Dr. Jan van Aardt to discuss remote sensing final projects ➢ Made our outreach quiz easier and sent it to Dr. Tyler for feedback
November 8, 2017	➢ Processed soil samples taken near Alumni House construction ➢ Redid soil stats with those two new samples and generated lots of charts ➢ Wrote mid-semester report

November 14, 2017	➢ Emailed everyone the updated version of our mid-semester report ➢ Created carbon cycle poster for outreach ➢ Met with Dr. Tyler to go over outreach materials ➢ Identified trees at outreach sites ➢ Meet with the girl scouts for outreach
November 29, 2017	➢ Finished collecting samples from grass plots ➢ Trimmed subsections of grass plots down to ground ➢ Delineated remaining tasks in Trello
December 6, 2017	➢ Dried and processed ~100 grass samples ➢ Calculated and graphed average carbon storage at the four grass sites ➢ Set up spreadsheet for calculating soil carbon in an area based on our regression equation ➢ Created layers in ArcGIS online for measuring areas to plug into that soil carbon spreadsheet ➢ Found literature values for carbon mass per area to plug into aboveground carbon calculator
December 13, 2017	➢ Final client meeting ➢ Finished final report and deliverables

Deliverables

Completed as of December 18, 2017

- ✓ Methods for measuring carbon storage in soil, trees, grass, and wetlands for other RIT students to use.
- ✓ Literature review paper looking at different methods for measuring carbon storage and sequestration in roots, wetlands, and grasslands.
- ✓ Poster for Imagine RIT 2017.
- ✓ Report summarizing our methods and results from our work from January to December 2017 (you're reading this).
- ✓ Regression equations for determining carbon storage in locations at RIT based on soil type and land cover.
- ✓ Established long term grass study sites on RIT's campus and carried out an initial experiment there. Future students can continue sampling in these locations to study carbon fluxes over time.
- ✓ Published updated GIS data viewable on any computer via ArcGIS online. View it here (log in with your RIT account).
- ✓ Created an outreach lesson plan for kids (~5th grade) on the importance of carbon sequestration and how they can measure it.
- ✓ Created a short quiz and answer key to test the results of our outreach.
- ✓ Completed outreach with Dr. Christy Tyler's girl scout troop.
- ✓ Met with Dr. Korfmacher's Soil Science class to discuss the importance of our project and recruit his students to contribute to our dataset.

- ✓ Collected soil samples from where the new Alumni House will be built.
- ✓ Used interpolation to create static soil carbon map of campus.
- ✓ Used ArcGIS online to create a tool Ms. Cardinal and Facilities Management Services can use to make land use decisions. The tool allows users to determine how much carbon is stored within a polygon they draw in the ArcGIS online interface.
- ✓ Updated this paper to contain the results of our whole year-long project.
- ✓ Generated and tested supervised and unsupervised classifications of campus
- ✓ Aboveground biomass model created using remote sensing applications

Results and discussion

Field Work

We gathered an additional 125 soil samples that were randomly placed within certain soil types to make the total dataset closer to a truly stratified random sample of soil type. We collected three soil core replicates from each location and calculated bulk density, carbon content, and soil carbon areal density (kg/m^2) following method 1A; this data was extrapolated across campus. The distribution of all 275 sites overlayed with this dataset can be found in Figure 1 below. Due to the time-consuming nature of these analyses (each location requires 3 replicate samples for bulk density analysis and 2 replicates from each sample for carbon content analysis) we chose to do the bulk of soil work during the summer which was funded by Dr. Karl Korfmacher's FEAD grant from RIT. Out of our 125 total new samples, 25 samples were gathered and analyzed during the spring semester, and 100 were analyzed over the summer.

We collected tree data in 21 of the 25 locations generated in our stratified random sample based on forest type (Figure 3). The remaining locations were left unsampled because there were no forests or trees present there. Tree carbon areal density (kg/m^2) was calculated utilizing method 1B. This data collection process took longer than anticipated because so much of RIT's forest were actually wetlands; simply reaching our sampling points was an ordeal. Overall, we spent 12+ hours locating and measuring just those 21 forest sites.

One challenge we faced in the early springtime was the inability to correctly identify trees before the leaves were fully developed. Initially we took photos to try and identify these trees, but this was very time consuming. To resolve this issue we instead went back to our 21 sites once there were leaves. It would be most efficient for future project workers to conduct tree identification during the summer. The Nikon Forestry Pro device we used to measure tree height was effective but not perfect. It requires the person to stand 25+ feet away from the tree that is being measuring (which can be difficult in denser forests) and needs a relatively clear line of sight. Due to time constraints we only took one height measurement for each tree. Ideally one should average a few measurements of the same tree from multiple angles since it can be difficult to actually identify the very top of a tree in a forest.

Soil Analysis

Many of the soil points gathered by groups besides us and Andy Wegman had incomplete data; for example, the points sampled by previous soil science classes were missing bulk density measurements, which are required to calculate carbon density. So we fit the 234 soil points measured by the two of us and Andy Wegman with a general linear model to determine which of the two variables we're investigating explain the variability of soil carbon on campus. The three variables included in our linear regression are soil type, team (who collected the data), and land use (NLCD or Ashley's land cover classification). We found that all three impact soil carbon storage, but to varying degrees.

We found that soil type alone accounts for 20.5% of the variation in soil carbon on campus. Land cover alone (according to the NLCD) accounts for 16.4% of the variation, but 20% is accounted for if we used Ashley's land cover database instead. Team alone accounts for 7% of soil carbon variability on campus. These results show that Ashley's land cover database is approximately 3.6% more useful for explaining soil carbon across campus than the NLCD database. Ashley manually classified campus in a vector format using high-resolution satellite imagery. As expected, this was more accurate than the NLCD, which covers the entire country at a coarse 30 meter resolution.

If we combine those factors in linear regressions, we can explain a significant portion of the variation of soil carbon on campus. Together, soil type, NLCD, and an interaction term between those variables explains 36% of carbon variation:

*Carbon = soil_type + NLCD + (soil_type * NLCD)*
Adjusted $R^2 = 0.3610$

If we substitute Ashley's land cover classification (AshleyLC) for the NLCD, the resulting regression improves slightly, explaining 38% of the variation:

*Carbon = soil_type + AshleyLC+ (soil_type * AshleyLC)*
Adjusted $R^2 = 0.3800$

Including team as a variable in those last two equations increases the R^2 value by a few percent in both cases, confirming that who is gathering the data does impact the data itself. This suggests that the methods employed by each team have been inconsistent. One of our deliverables is standardized methods for gathering carbon data in soil and multiple land covers; if future contributors follow these methods, team should explain less carbon variation in future statistical analyses.

*Carbon = soil_type + NLCD+ (soil_type * NLCD) + team*
Adjusted $R^2 = 0.4620$

*Carbon = soil_type + AshleyLC+ (soil_type*AshleyLC) + team*
Adjusted $R^2 = 0.4203$

Considering all 234 samples, Figure 13 clearly shows that our soil carbon data is heavily skewed to the right. In other words, the vast majority of samples were between 1% and 5% carbon. On the other hand, the bulk density of those same samples seems normally distributed with most samples having bulk density between 1 and 1.5 g/cm^3, as seen in Figure 14.

Figure 15 shows the distribution of soil carbon within each soil type on campus. There were many significant differences in carbon stored based on soil type. The most prominent soil types on campus are Ca (Canandaigua - covering 23.5% of the area), Ng (Niagara - 18.5% coverage), OdA (Odessa silt loam with 0 to 3 percent slopes - 8.8% coverage), and CkB (Claverack loamy fine sand with 2 to 6 percent slopes - 6.5% coverage). Of those soil types, Canandaigua soils have the greatest variation in carbon storage capability and stores the most carbon on average, followed by Niagara, Odessa, and Claverack. Soil types ArB (Arkport very fine sandy loam, 0 to 6 percent slopes), CeA (Cayuga silt loam, 0 to 2 percent slopes), ChB (Churchville silt loam, 2 to 6 percent slopes), ClB (Collamer silt loam, 2 to 6 percent slopes), CoC (Colonie loamy fine sand, 6 to 12 percent slopes), Ee (Eel silt loam), HfA (Hilton fine sandy loam, 0 to 3 percent slopes), HlA (Hilton loam, 0 to 3 percent slopes), OnF (Ontario loam, 25 to 60 percent slopes), SeA (Schoharie silt loam, 0 to 3 percent slopes), SeB (Schoharie silt loam, 2 to 6 percent slopes), and W (Water) all have lines instead of full box-and-whisker plots, showing that there is not enough points to characterize the carbon content variation within those soil types.

Figure 16 shows the distribution of bulk density within each soil type on campus. Of the four most prominent soil types on campus (Ca, Ng, OdA, and CkB), Canandaigua soils were the healthiest on average (lowest bulk density) followed by Niagara, Odessa, and then Claverack. Our average bulk density values for these soil type were: 0.9, 1.2, 1.3, 1.3 g/cm^3, respectively. This is in comparison to the NRCS soil survey values, 1.1, 1.4, 1.4, and 1.3 g/cm^3, respectively. Our data shows slightly lower bulk density values for each of these four soil types, except the Claverack soil which was on par with the expected, NRCS bulk density value. These results suggest RIT's soils are have a greater compaction than average soils of the same type.

The distribution of soil carbon for each land cover on campus, as indicated in the 2011 National Land Cover Database, can be found in Figure 17. Land covers with significant differences in their ability to store carbon were: barren land with developed high intensity, emergent wetlands, and grasslands; developed high intensity with cultivated crops, developed medium intensity, emergent wetlands, grasslands, open water, pasture, and shrub. However land covers including barren land, developed high intensity, and grassland are represented as lines instead of boxes indicates there is not enough data to account for the carbon content variation within those land covers. Therefore there is not enough evidence to support any claims using these relationships.

Bulk density values for the NLCD land covers are shown in Figure 18. Wetlands with their soft soil laden with organic matter expectedly have low density, while developed areas and barren land have higher density due to compaction. The spread of bulk density values is greatest in deciduous forests and woody wetlands, which are the most prominent natural land covers on campus. The bulk density spread in agricultural land covers is smaller, likely because all that land is consistently treated similarly (plowing, compaction by tractors).

The y-axis in Figure 19 represents the percentage of carbon stored per land cover as designated by Ashley's land cover classification, shown on the x-axis. As expected, it shows that wetlands and forest store more carbon in their soils than other land covers, while built environments and impervious surfaces store the least amount of carbon. Soil carbon storage in wetlands and forests is highly variable compared to the remaining land covers, suggesting that some wetlands and forests are more effective at storing carbon than others. Preservation of these high-storage sites should have the utmost priority

Figure 20 shows bulk density values on the y-axis with Ashley's land cover classifications on the x-axis. This confirmed forest and wetlands have the most variable bulk density values, and further data needs to be collected to determine actual values from superfluous values.

The measured carbon content of all 234 soil samples were interpolated using ArcGIS online to create a new map for estimating soil carbon storage in any location on campus. This map, shown in Figure 6, is an alternative to the soil map in Figure 2, which is based on soil data from the Natural Resources Conservation Service.

Tree Analysis

Figure 21 shows the results of our aboveground tree carbon analysis for our 21 sample sites, where tree carbon was estimated using method 1B. In terms of carbon per area, we found that deciduous forest has the highest carbon storage on average, followed by mixed forest containing deciduous and evergreen trees, and woody wetlands with the lowest average carbon storage. This is likely because the deciduous areas we walked through have the highest density on campus; woody wetlands tended to have more dead trees, which we didn't include in our analysis. The "mixed forest" sites we sampled were not actually mixed forest, confirming the faultiness of the National Land Cover Database, they were predominantly deciduous forests.

Turf Grass Analysis

The carbon storage of control and treatment grass plots are shown in Figure 22, and the locations of the sites themselves are shown in Figure 10. We hypothesized that unmowed grass plots would sequester more carbon than mowed grass plots because they would be able to grow naturally, longer. Over our study period of August through November 2017, the unmowed plots sequestered more carbon at sites A and B. At site C, treatment and control plots sequestered nearly the same amount of carbon, and the mowed plots at site D sequestered more carbon than the unmowed plots. A t-test was conducted, and refuted our hypothesis that unmowed plots would store more carbon; no statistically significant differences between the carbon stored in control versus treatment plots (p=0.81).

These results took into account the stubble biomass (the part below 3-inches in height) which we think was a mistake. The stubble biomass was collected in 6cm by 6cm subplots within each 50cm by 50cm plot, then extrapolated to estimate the amount of stubble carbon in the whole plot. In retrospect, we don't think a single subplot that is 69 times smaller than the main plot is a good way to measure stubble biomass. Extrapolating a measurement from such a small area leaves too much room for error. We repeated the statistical analysis excluding the stubble biomass and found a significant difference between control and treatment plots at a 90% level of significance (p=0.098). The mowed plots stored more carbon over the study period than the unmowed plots, refuting our hypothesis, as shown in Figure 23. One big caveat with this result is that our study only covered the second half of the year. Future capstone students should repeat this study but over a time period covering the whole growing season.

Table 1: Total grass carbon (g) clipped from August to November 2017. These values exclude carbon stored in stubble biomass.

	A	**B**	**C**	**D**
Control	7.026	4.6	2.736	10.176
Treatment	9.318	12.552	5.653	11.324
Control standard deviation	0.635	0.052	0.784	0.35
Treatment standard deviation	3.324	1.895	1.172	1.494

Synthesis

We applied the average carbon values for each land cover to their matching polygons in NLCD 2011 (Figure 5) and Ashley's land cover database (Figure 6). An overview of where these carbon values came from can be found in Figure 24; they are either from our data or were literature based. The resulting aboveground carbon density maps are shown in Figure 8 for NLCD, and Figure 9 for Ashley's land cover database. We added the interpolated soil carbon map (Figure 7) to each of these aboveground carbon maps, creating a single map for each land cover database for estimating total carbon storage above and belowground, seen in Figures 11 and 12. These maps were integrated into an interactive ArcGIS Online tool for estimating total carbon stored within a polygon, as described in method 1F.

Outreach

Our initial outreach activity was the presentation of our poster, referenced in Appendix C, at Imagine RIT on May 6, 2017. This poster highlighted the what and why our capstone group has been focused on, as well as the benefits of doing this research. Future students who work on this project should improve the exhibit by making it interactive and thus more engaging for children.

We met with RIT professor Dr. Christy Tyler's girl scout troop on November 17 as our primary outreach activity for the fall semester. We planned to allocate a 10 minute interactive lecture that briefly covered topics such as: photosynthesis, the carbon cycle, the greenhouse effect, and climate change, before taking the children outside to demonstrate how to measure carbon content that is stored in trees. To determine what the children already knew and measure the effectiveness of our lesson, we gave them a short assessment, as seen in Appendix C, before and after the activity. This tested the children's prior knowledge which helped us decide where to begin; we were able to determine which topics required more focus than others. After measuring trees (diameter, height, and species), we reconvened inside to talk about what it actually meant in terms of carbon storage potential and whether that location was effective at storing carbon. One complication that we were not expecting was the high level of energy contained within these six 10 year-olds. To accommodate their short attention spans, and keep them engaged, we improvised to include a short coloring activity where the girls were asked to draw a picture of the environment and include one fact they learned from our presentation. Overall the girls were very attentive and seemed to enjoy themselves, especially when we stopped talking at them and went outside where they were able to fully participate in data collection.

A secondary outreach activity for this fall was meeting with Dr. Karl Korfmacher's soil science class to explain the importance of our project and how his students can help out as young undergraduates. This outreach was not required therefore we did not create an extensive lesson plan like we did for the girl scouts. For this activity we created a powerpoint presentation that features the purpose, methods, and results of our capstone project. This was presented as a short lecture before we took the students outside to one of our mow-comparison sites. We chose to discuss our methodologies at this site so we could give the students an idea of what they may do one day, and so they were not bored by us reading our methods slides at them. At this site we also demonstrated how the clinometer works, and gave the students the opportunity to try their hand at measuring trees. Korfmacher's teaching assistant Liam Megraw was in charge of guiding the students through their remaining fieldwork section of their lab.

Remote Sensing Analysis

Using computer software ENVI 5.4 to classify the entirety of RIT campus, we will create highly detailed land cover classifications, and an aboveground biomass model. The results of these subprojects are referenced in Appendix C.

Ideas and suggestions for future work

- We completed our model and ArcGIS online tool for calculating carbon above and belowground at the very end of our project, so it has not been tested. Future students should collect carbon density measurements at random locations that weren't used to generate the model. This truth data could be used to quantify the accuracy of our model.
- Update the ArcGIS online tool and spreadsheet to include options for estimating carbon based on David's supervised and unsupervised land cover databases.
- Sample carbon in open water, wetlands, and other land covers we didn't have time to study; include dead trees in tree carbon measurements. The tool for estimating aboveground carbon should be more accurate with custom carbon storage per area values from RIT's campus instead of literature values.
- Dr. Tyler provided us with tree carbon data from ecology classes she taught at RIT in 2008. Future groups working on this project should re-sample trees Dr. Tyler's classes tested in 2008 to determine how much carbon they've sequestered in the last 10 years.
- Continue grass experiments over the course of a full growing season. We only got them set up in August, so we missed the productive months when the grass would grow quickly and sequester the most carbon.
- Use light/dark box methodology to assess carbon fluxes in grasslands or other land covers. These methods measuring gas exchange require more time and expensive equipment but will give more precise measurements of carbon sequestration over time.
- Write and test methods to measure carbon in roots and in saplings–two things we ignored in our analysis this year.
- Test if other variables like soil type, land cover, and elevation have a significant effect on

aboveground carbon storage.

- One major flaw in our overall schedule was the decision to measure soil and tree carbon during different weeks, which was costly in terms of time because that meant trekking the entirety of campus on multiple occasions. One challenge associated with this sampling, is only having two people to carry the required equipment for measuring above and belowground carbon storage. Future students should map all sample sites before completing any sampling to plan optimal, time-conserving routes.
- Create and test a detailed protocol to allow other teams to easily submit data to this dataset. Right now there is no clean pipeline for this.

Conclusion

Analysis of our soil samples revealed soil type and land cover are the driving factors for soil carbon storage, but together they only account for less than 40% of soil carbon variation, according to our model. Further work must be conducted to determine what variables can explain the remaining variation in soil carbon storage.

A comparison of mowed and unmowed grass plots revealed no significant difference in carbon storage between the two groups when stubble biomass was included (p=0.81). However, when we ignored the stubble biomass due to the imprecise methods used to measure it, we found that mowed plots stored significantly more carbon than the unmowed plots from August through November 2017 (p=0.098). One major caveat regarding these conclusions is that data was only collected over half of a growing season. It is crucial for future groups to collect data for the entirety of the growing season to accurately measure how much carbon is sequestered under the different test conditions.

When compared to the other forest types, deciduous forests were capable of storing more carbon; this is likely attributable to the high density of trees in deciduous forests on campus versus the relatively low density in woody wetlands and mixed forests. If carbon storage data had been collected and measured for dead trees, we may have found more carbon storage in woody wetlands..

The results our field work, data analysis, and literature reviews culminated in two major deliverables our client can use. First, the total above- and below-ground static carbon density maps displayed in Figures 11 and 12 clearly highlight the areas on campus with the highest carbon storage capabilities. Ms. Cardinal can use these maps to defend these carbon-dense areas from development as she seeks to meet RIT's carbon neutrality target. Second, we delivered an interactive ArcGIS Online map that can be used in combination with a provided excel spreadsheet to estimate total carbon storage in a user-selected area on campus. Land management decision makers can use this to compare the carbon impacts of developing different areas of campus. Together, these tools will allow Ms. Cardinal and other RIT officials to make well informed, strategic land alteration decisions to meet the carbon neutrality goal set forth in the Climate Action Plan.

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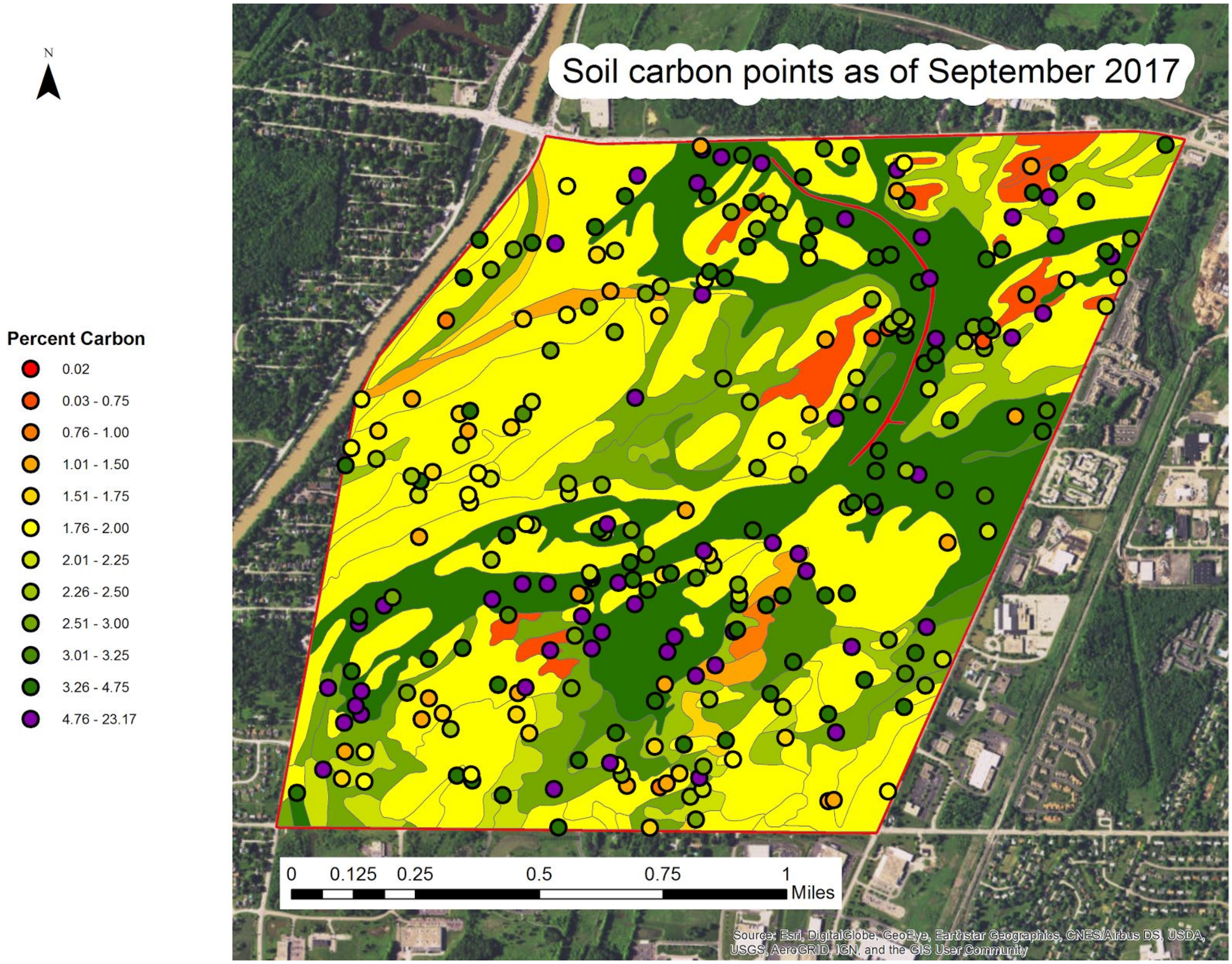
Appendix A: Maps



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 1: A map of RIT’s soils, where soils with little expected carbon content are red, and soils with high expected carbon content are darker green. The 275 soil samples in our dataset are shown as circles, colored just like the soils: samples with low measured carbon content are red and samples with high measured carbon content are green. Locations with the highest carbon content are highlighted in purple.

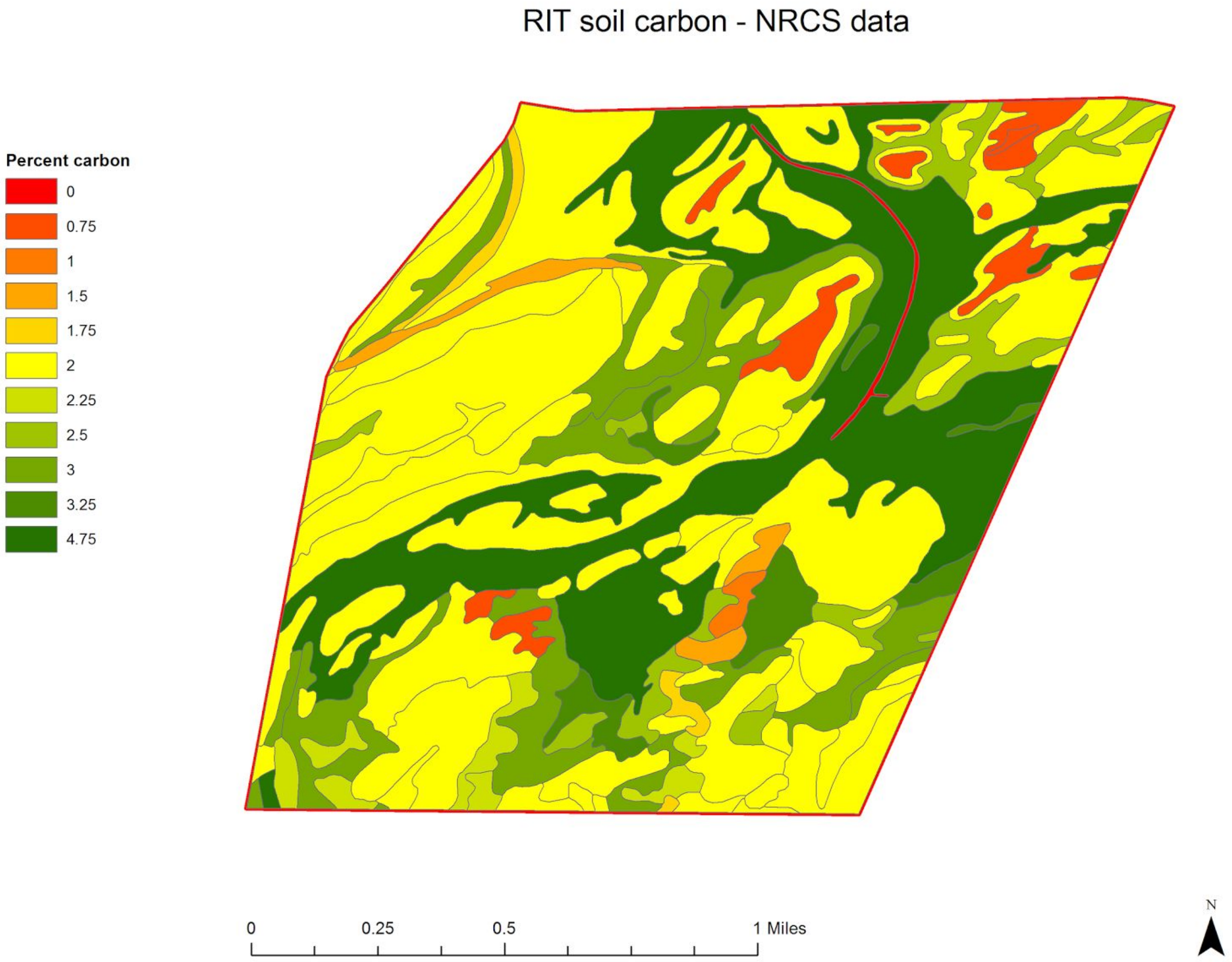
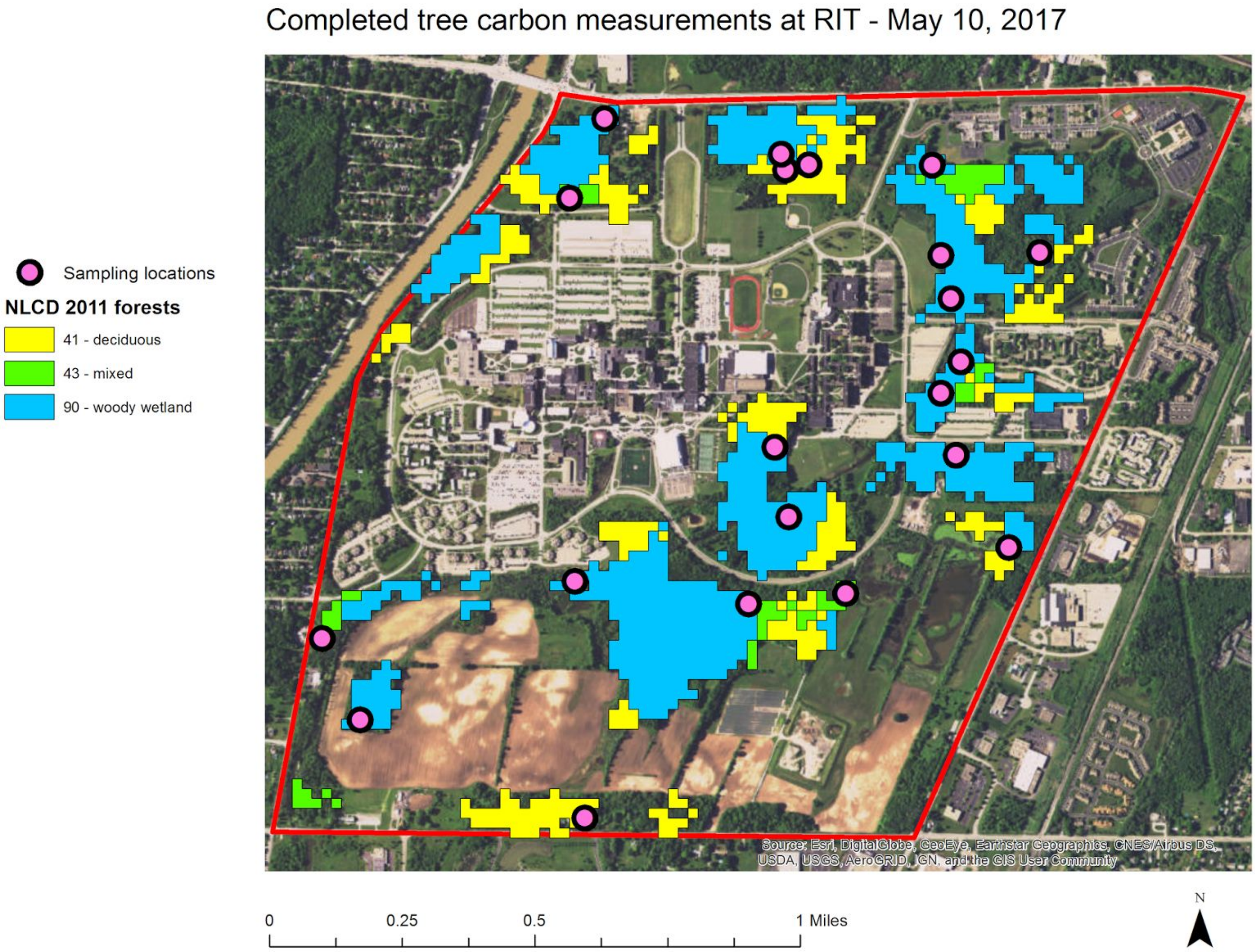
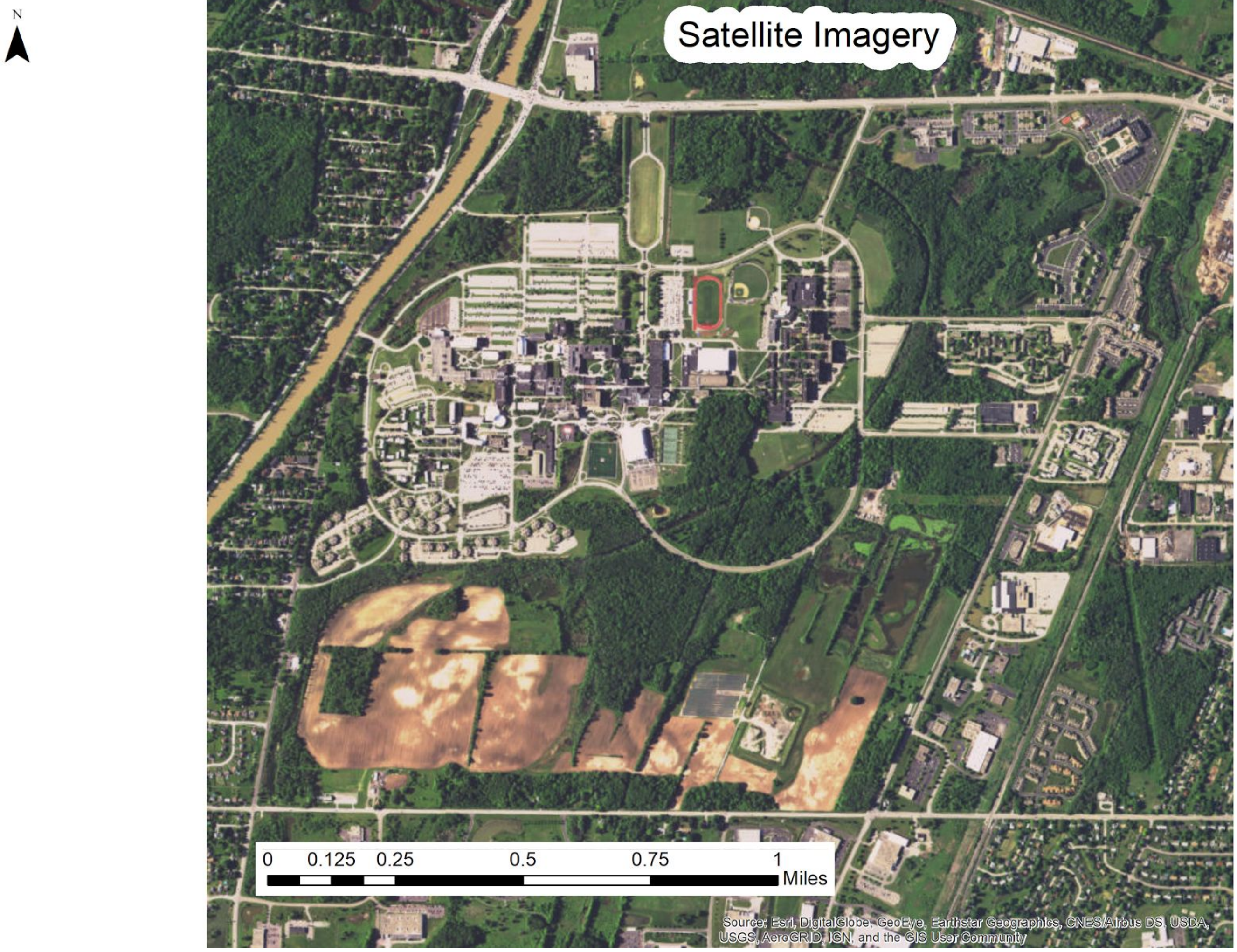


Figure 2: Soil on RIT’s property color coded by expected carbon content based on Natural Resources Conservation Service data. Redder polygons have low expected carbon content and greener polygons have higher expected carbon content.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 3: A map of RIT's forested areas supplied by the 2011 National Land Cover Database. Each of the pink dots represents 1 of the 21 locations where tree carbon was measured in the spring 2017 semester.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 4: This unaltered satellite image of RIT campus was used as the basemap for Ashley's digitization of the various land covers on campus, and included as a reference map.

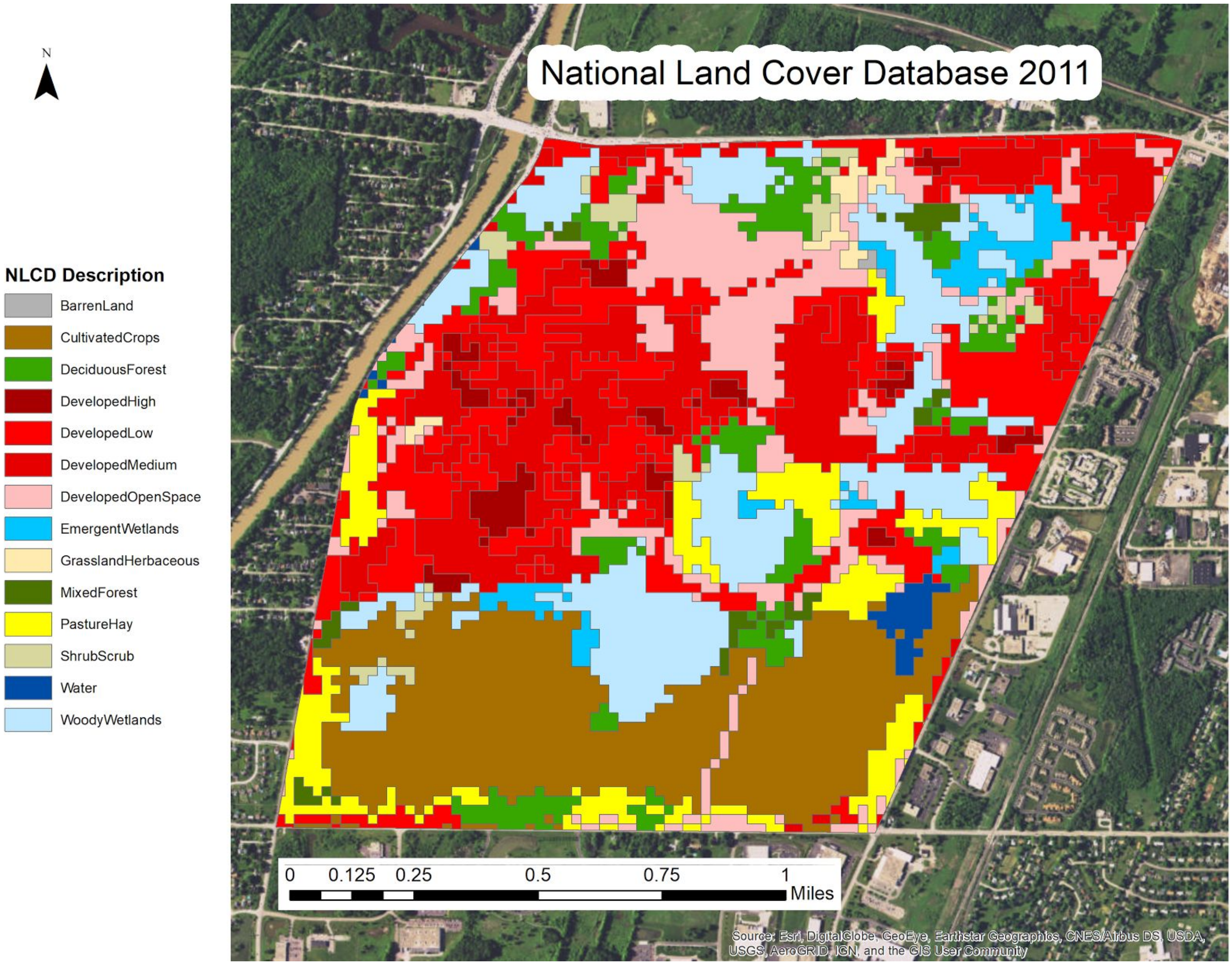
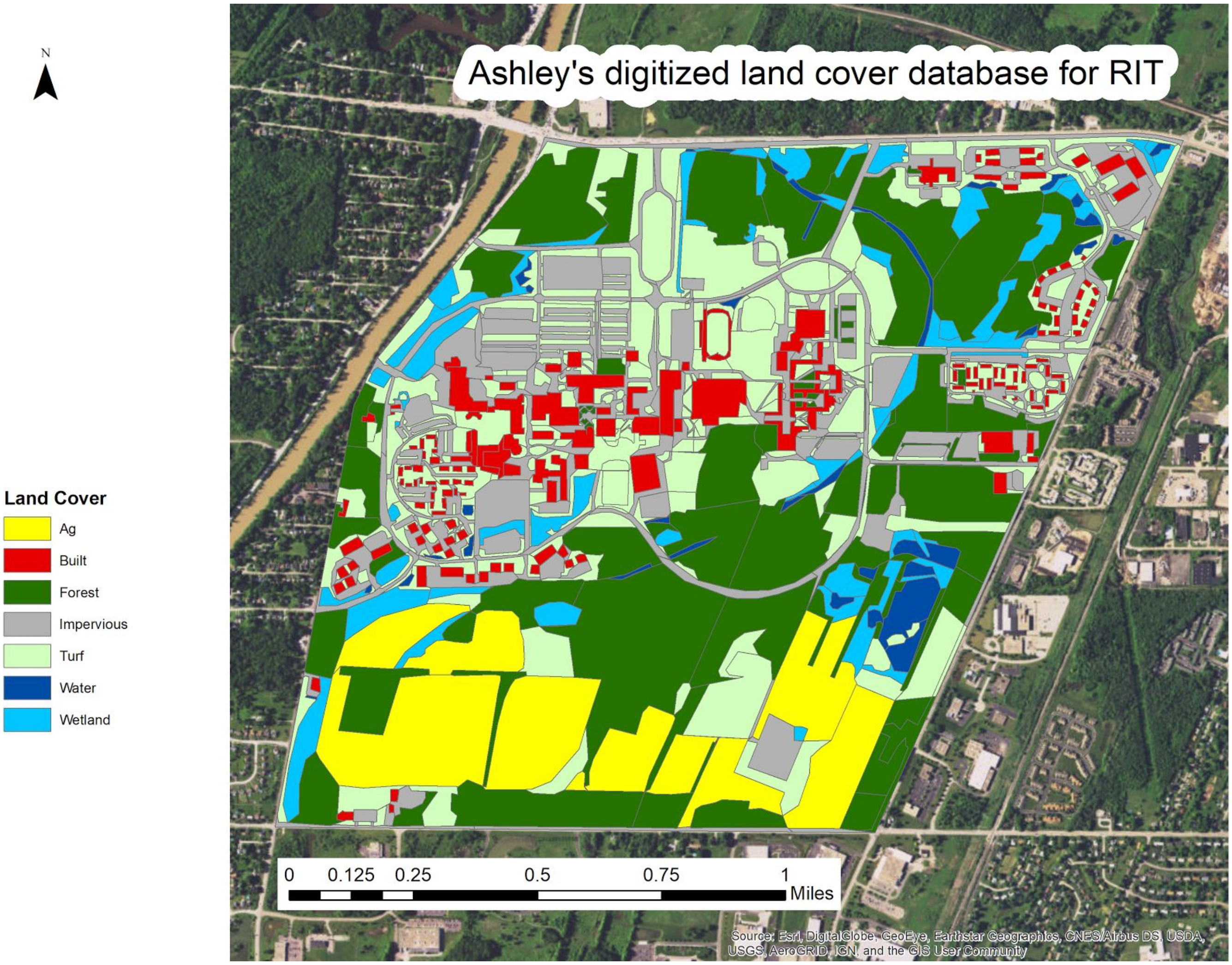


Figure 5: Land covers on the RIT campus according to the 2011 National Land Cover Database. This is the classification scheme we used in our original analyses before utilizing Ashley's land cover map. It is possible to see the land cover discrepancies between the recent, unaltered satellite imagery in Figure 4 and this 2011 NLCD map, hence why we switched to Ashley's slightly more accurate map.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 6: Ashley's land cover classification of the RIT campus based on the satellite imagery from Figure 4. Yellow represents agricultural land use; dark green represents forested areas; and light green represents turf areas that are maintained through mowing. The dark blue indicates the location of water compared to the lighter blue that shows wetland areas. Red is representative of the built environment such as buildings whereas gray is for impervious surfaces such as roads and parking lots.

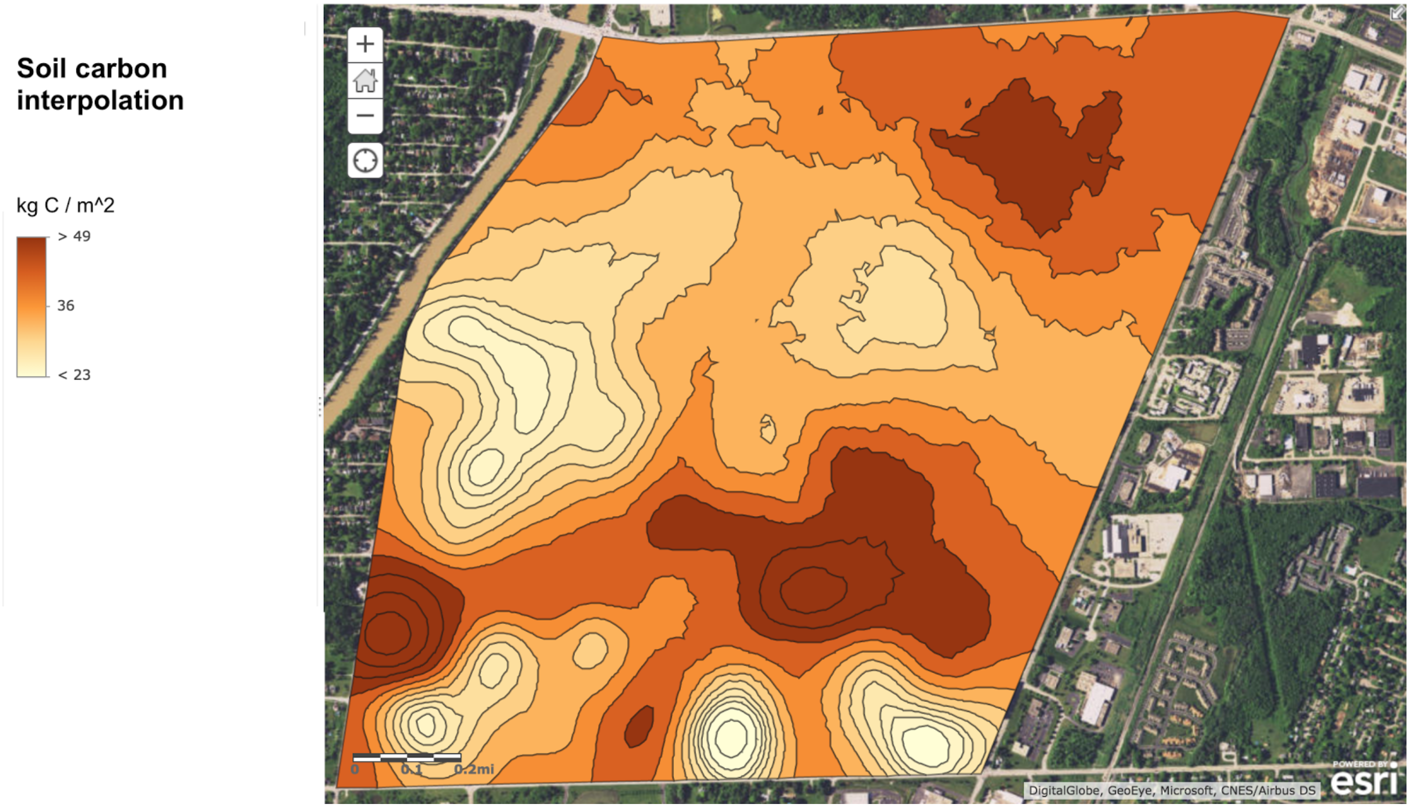


Figure 7: A map of soil carbon content on campus interpolated from all the soil data gathered by Ashley and David, and Andy Wegman. Darker areas are expected to have more carbon in their soils.

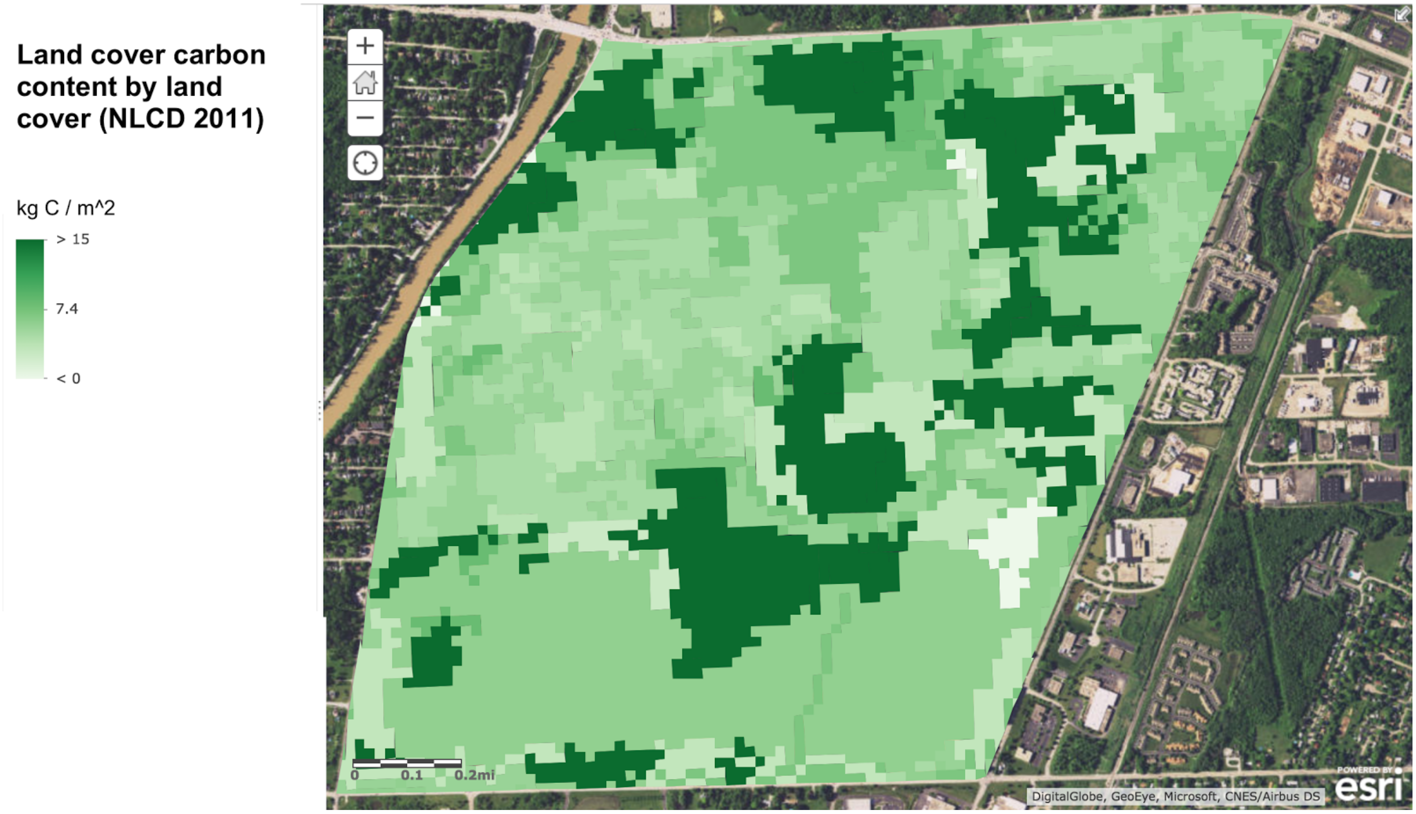


Figure 8: Aboveground carbon content matched to land covers as classified in the 2011 National Land Cover Database (Figure 5). The values for carbon content came from a combination of our own research and literature.

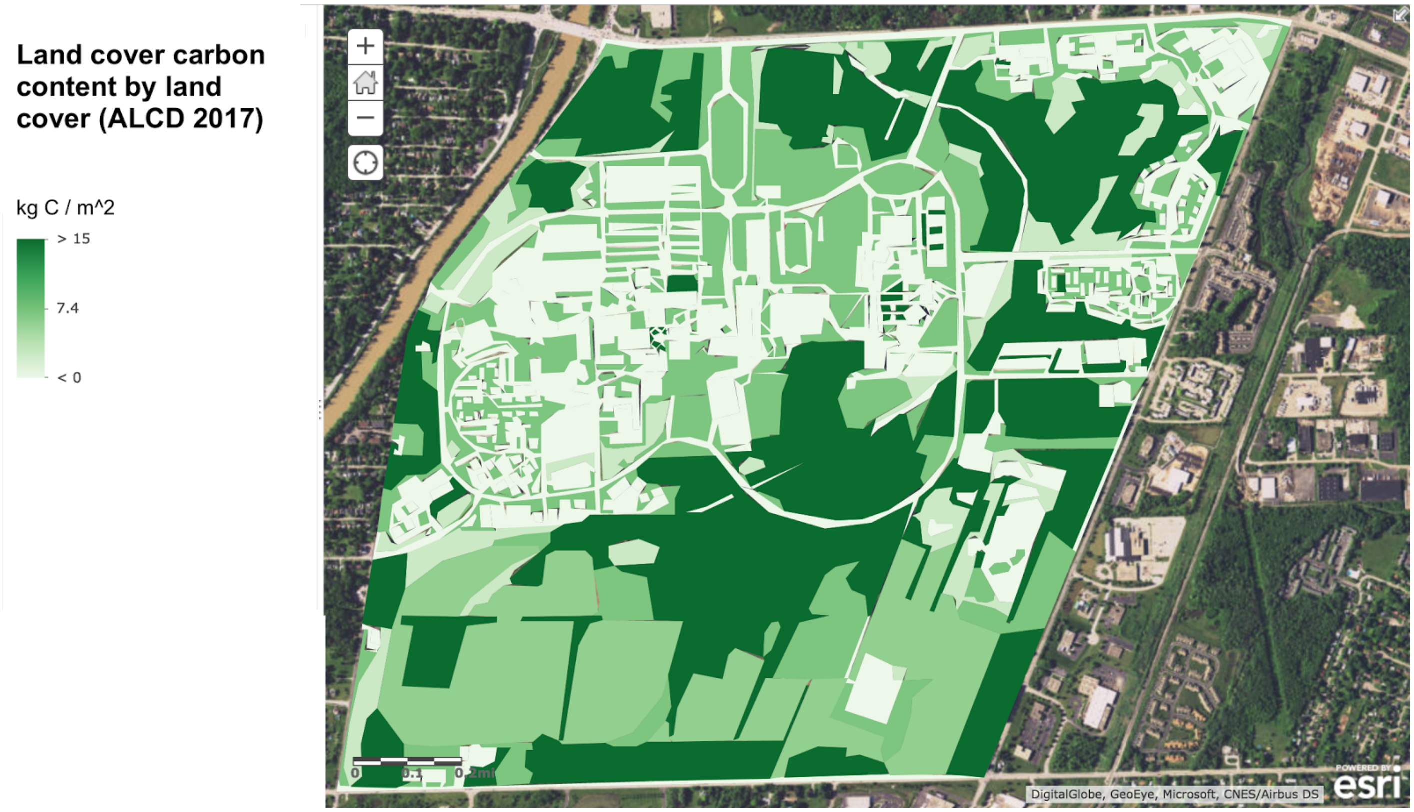


Figure 9: Aboveground carbon content was matched to land covers as digitized by Ashley (Figure 6). The values for carbon content we did not measure came from assorted literature (Figure

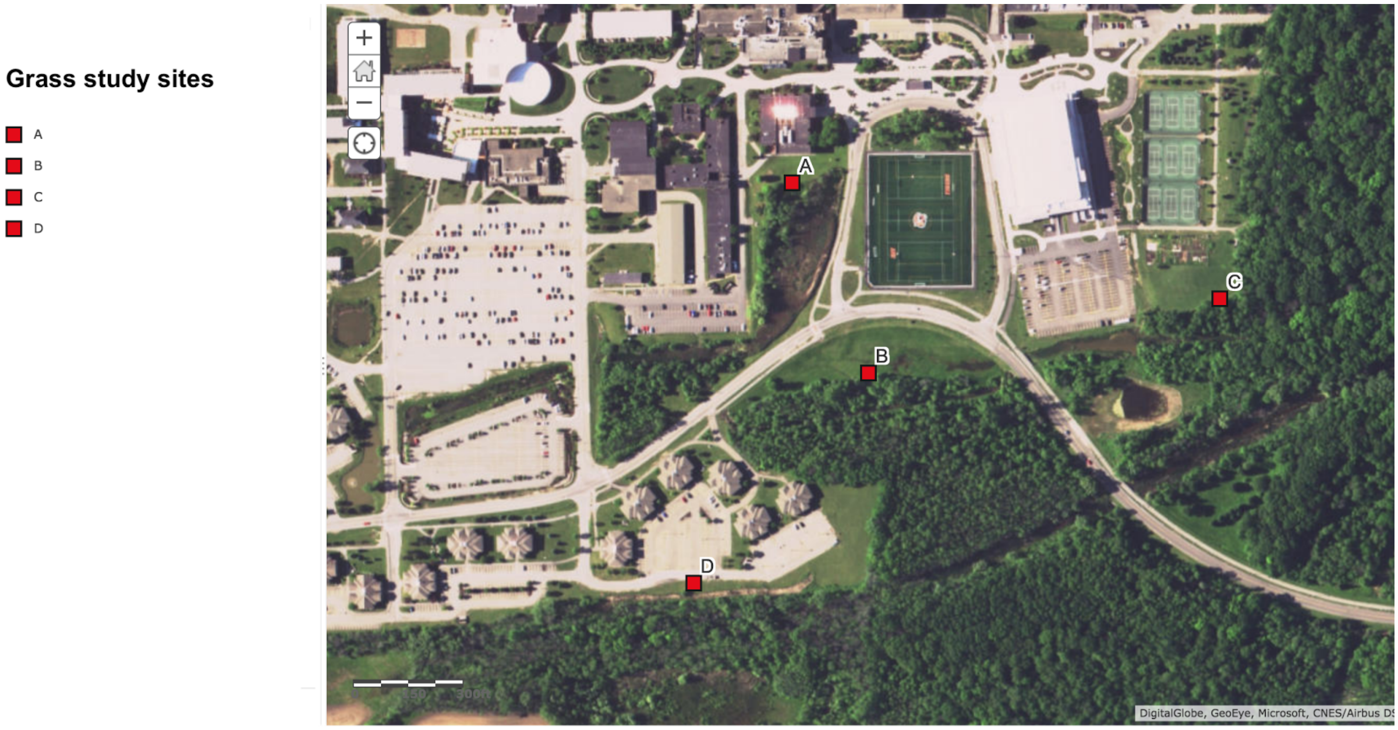


Figure 10: This shows the location of our four grass study sites. Site A is in a consistently mowed lawn behind the College of Business, right next to a wetland, on top of Odessa silt loam soil. Site B is in a sunny, infrequently mowed field next to a forested wetland. Site C is consistently mowed, between the community garden and a deciduous forest that provides heavy shading at the site. Much of the ground cover at B is a moss, and the soil is gravelly. Both B and C are located in Niagara silt loam. Site D is in a consistently mowed strip of grass between a parking lot and a wetland on Canandaigua soil.

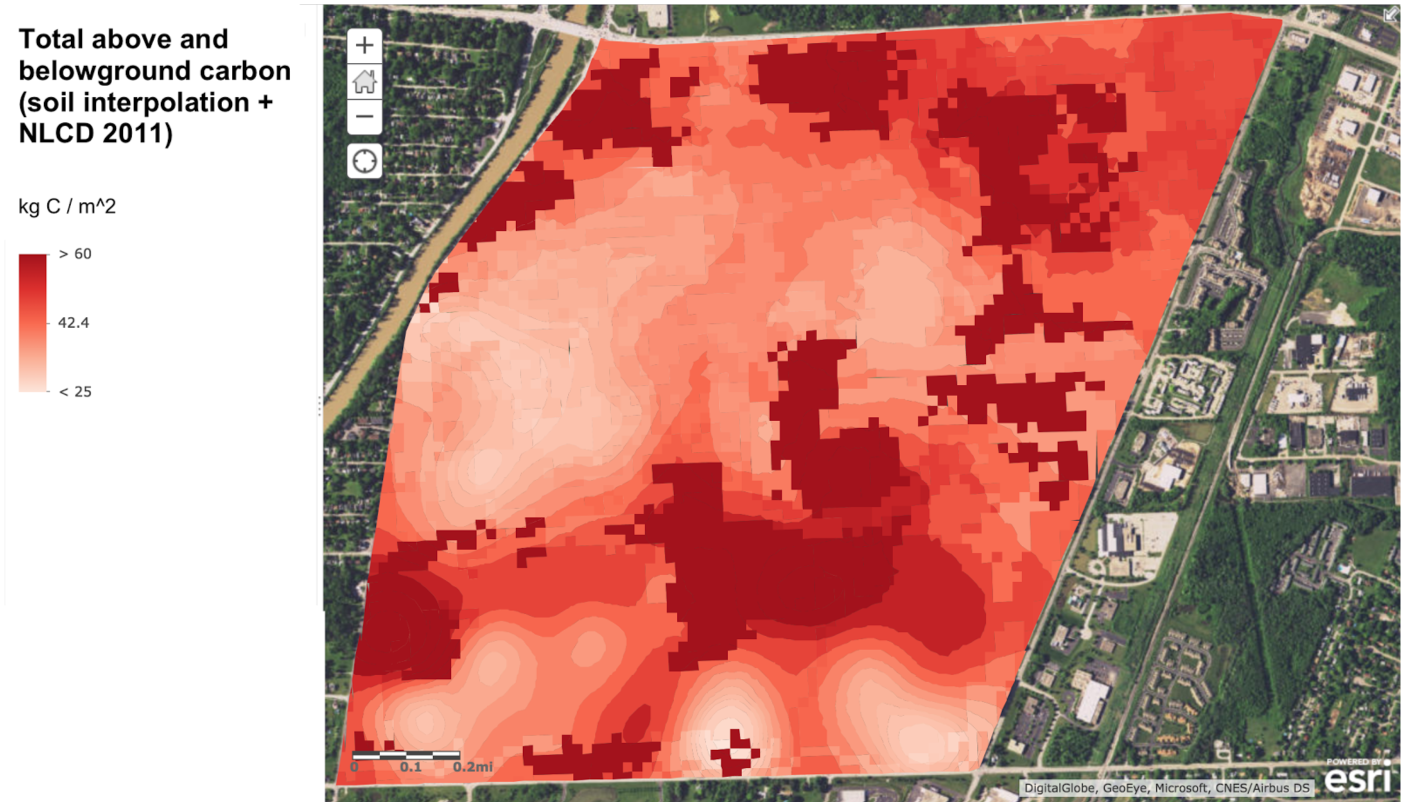


Figure 11: Total above and belowground carbon in kg/m^2. This is a combination of our interpolated soil map (Figure 7) and the NLCD 2011 aboveground carbon map (Figure 8).

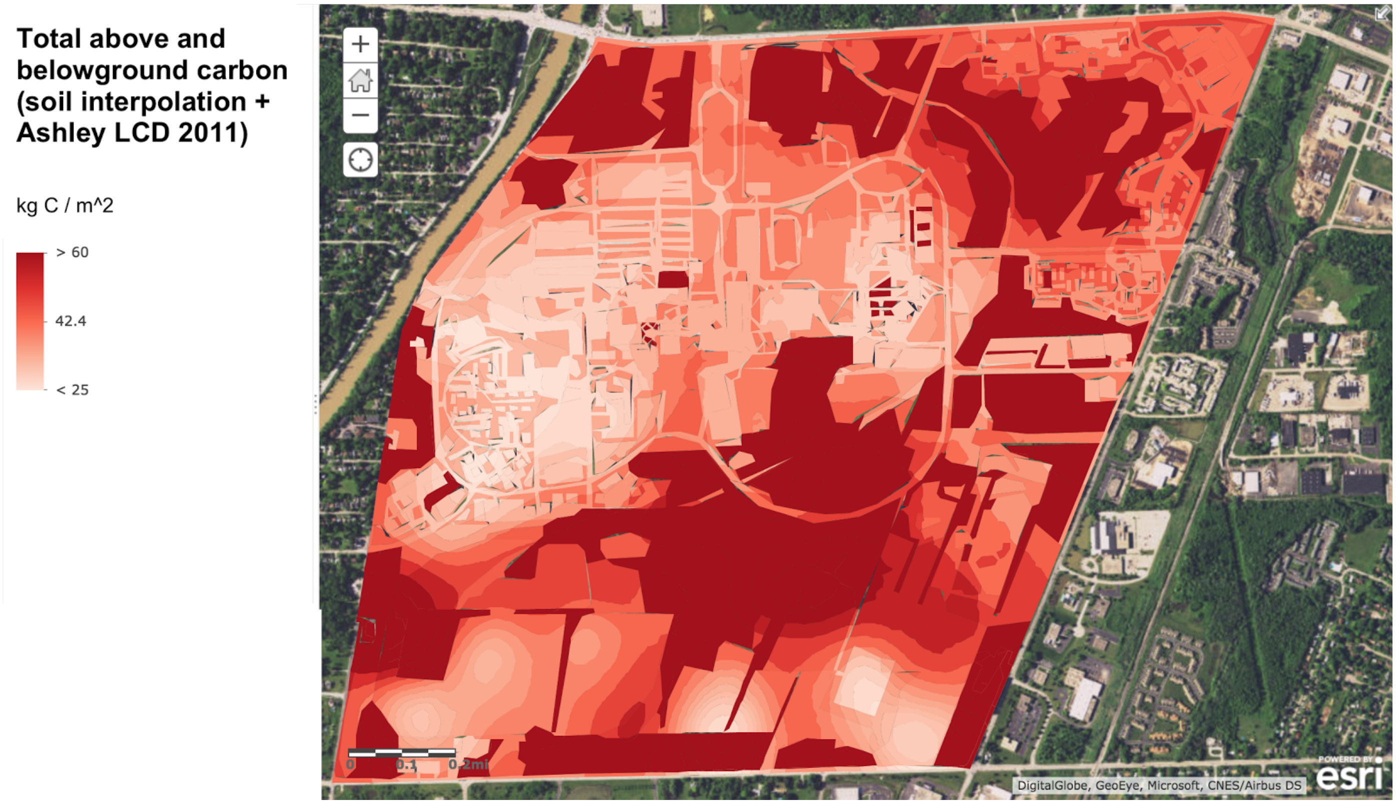
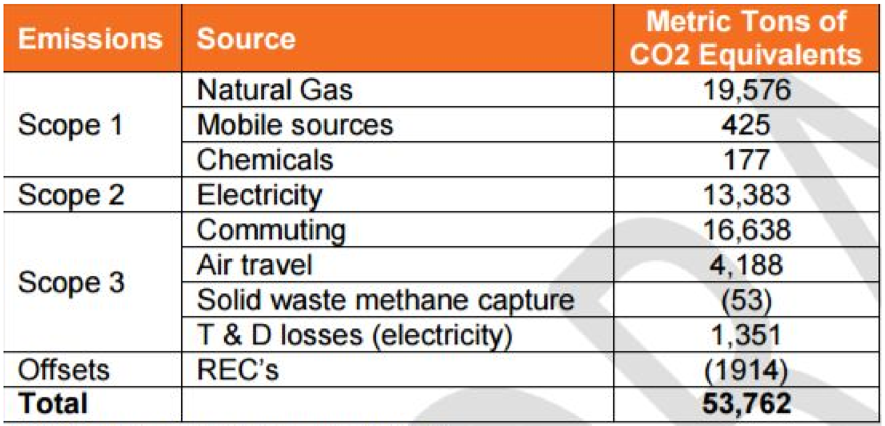


Figure 12: Total above and belowground carbon in kg/m^2. This is a combination of our interpolated soil map (Figure 7) and aboveground carbon map according to Ashley's land cover classification (Figure 9).

Appendix B: RIT’s Draft Climate Action Plan

This year the RIT sustainability office has revised the goals of its climate action plan; these new commitments are: “RIT will be carbon neutral for Scopes 1 and 2 emissions and will reduce Scope 3 emissions by at least 50% by 2030. In order to realize the Scope 3 reductions, offsets will likely be required” (RIT Advisory Committee et al., 2017). Read the full draft report here.



Emissions	Source	Metric Tons of CO2 Equivalents
Scope 1	Natural Gas	19,576
	Mobile sources	425
	Chemicals	177
Scope 2	Electricity	13,383
Scope 3	Commuting	16,638
	Air travel	4,188
	Solid waste methane capture	(53)
	T & D losses (electricity)	1,351
Offsets	REC’s	(1914)
Total		**53,762**

Table 2: RIT’s 2016 GHG Emissions by source

Appendix C: Supplemental materials

Tree_carbon_method_ABDC.pdf
Soil_carbon_method_ABDC.pdf
Wetland_carbon_method_ABDC.pdf
Grass_carbon_method_ABDC.pdf
Literature_review_DC.pdf
Imagine_poster_2017_ABDC.pptx
Outreach_quiz_ABDC.pdf
Outreach_quiz_answers_ABDC.pdf
Soil_Science_presentation_ABDC.pdf
Carbon_calculator_ABDC_2017_readme.pdf
Carbon_calculator_ABDC_2017.xlsx
Online interactive map: https://arcg.is/1uSD9v
RIT_land_cover_classification_DC_2017.pdf
C_Storage_Lit_Values_AB.pdf
Ashley_remote_sensing_paper.pdf

Appendix D: Charts

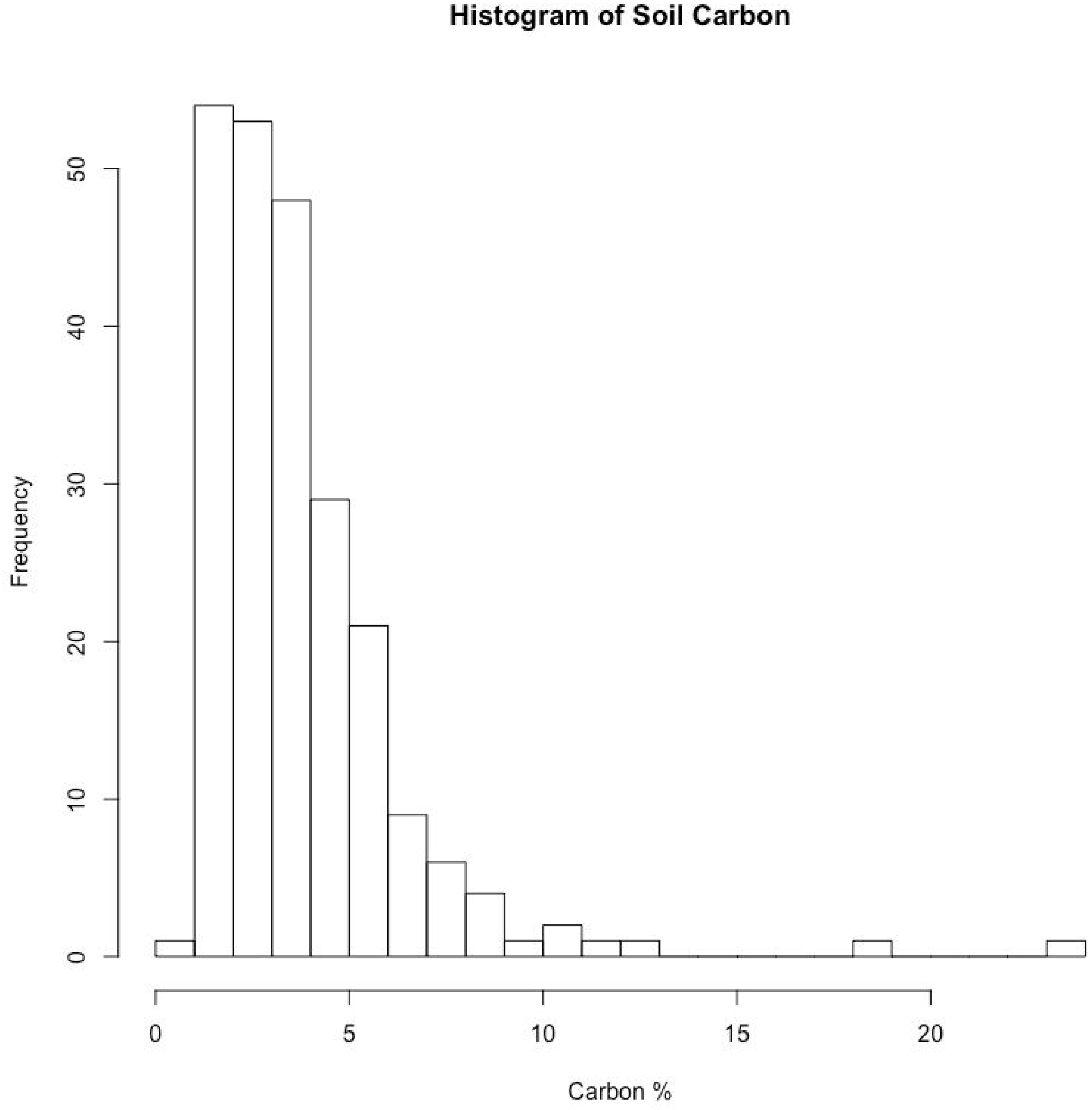


Figure 13: Histogram showing the frequency of carbon content percentages in 234 soil samples collected by Ashley, David, and Andy Wegman. The distribution is heavily skewed to the right where the vast majority of samples were between 1% and 5% carbon.

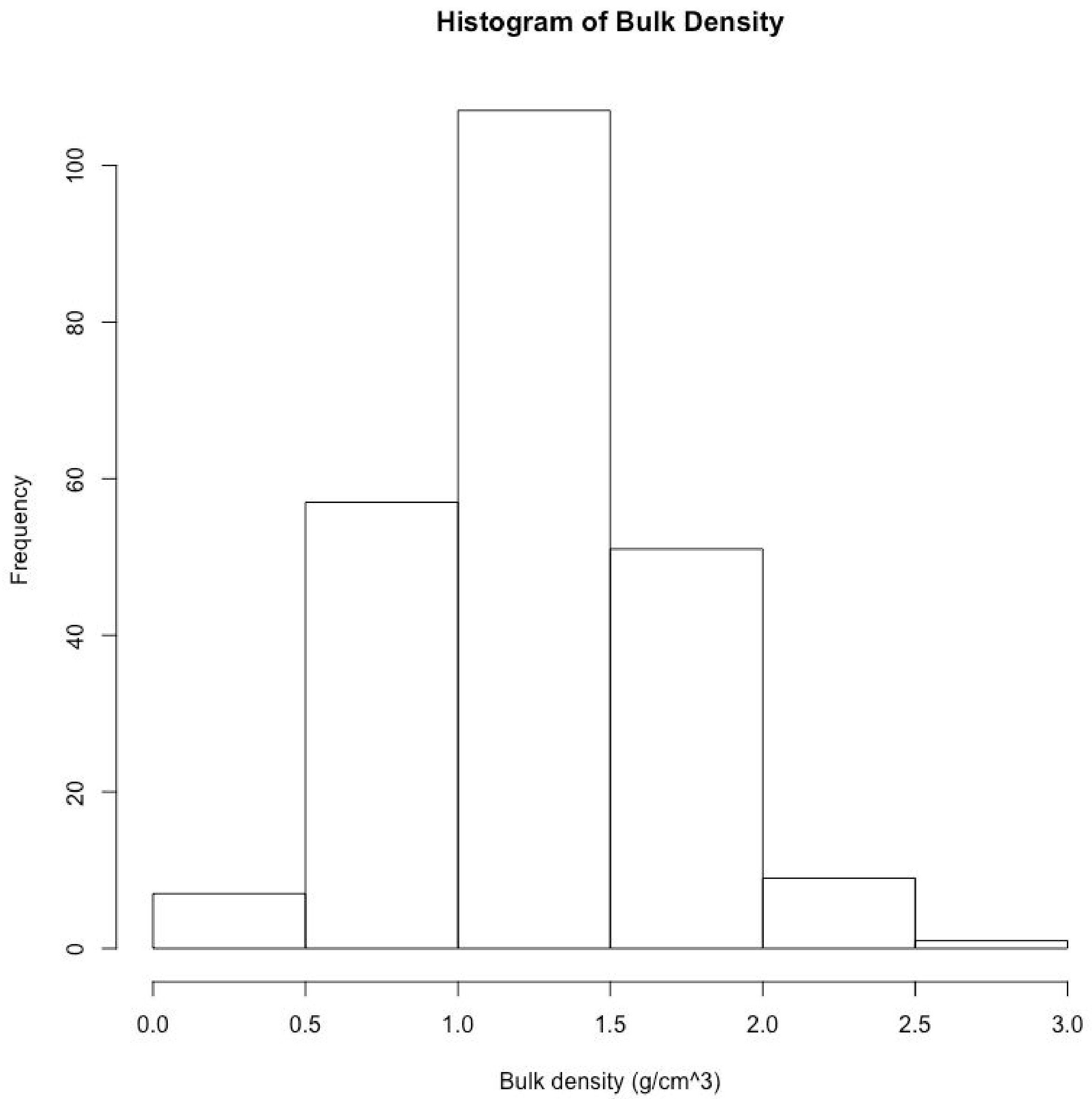


Figure 14: Histogram showing the frequency of bulk density values in the 234 soil samples collected by Ashley, David, and Andy Wegman. The majority of samples had a bulk density between 1.0 and 1.5 g/cm^3, and this implies that the majority of samples were healthy because their bulk density less than 1.5 g/cm^3.

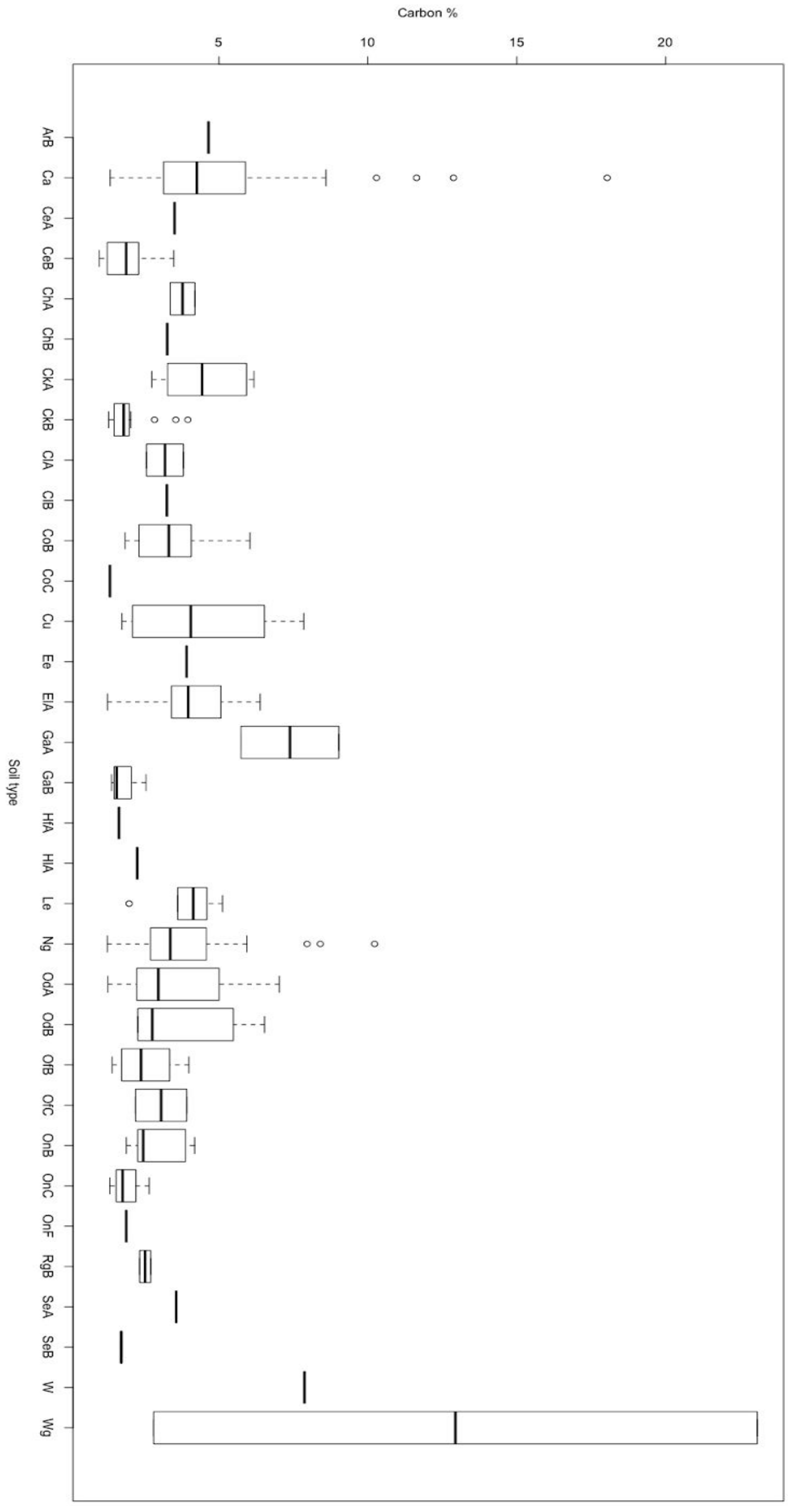


Figure 15: Carbon content of 234 samples for all soil types on RIT campus. Of the four most common soil types on campus (Ca, Ng, OdA, and CkB), Canandaigua soils have the greatest variation in carbon storage capability and stores the most carbon on average, followed by Niagara, Odessa, and Claverack.

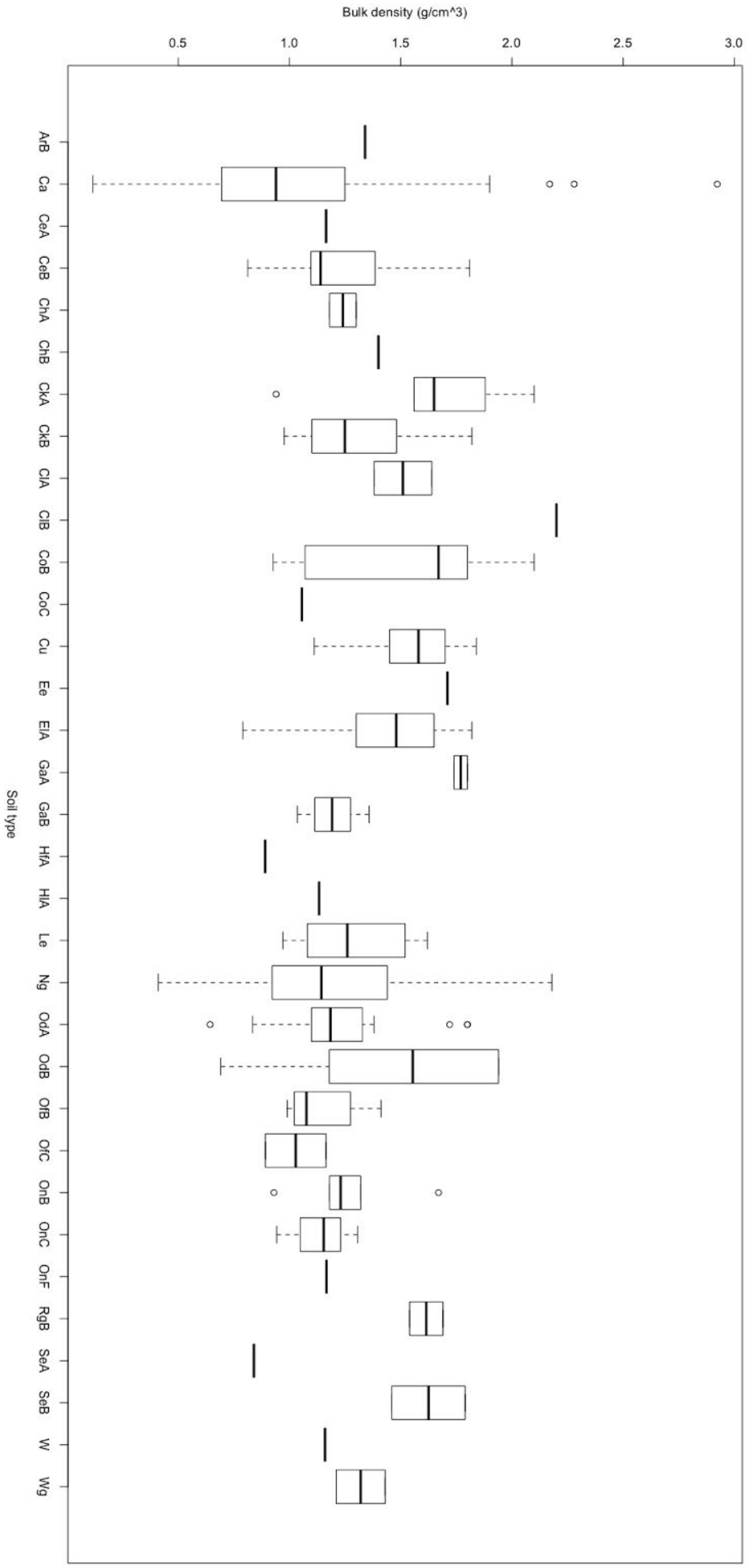


Figure 16: Bulk density of 234 samples by soil type, where the lower the bulk density value is the healthier the soil type. Of the four most prominent soil types on campus (Ca, Ng, OdA, and CkB), Canandaigua soils were the healthiest on average followed by Niagara, Odessa, and then Claverack.

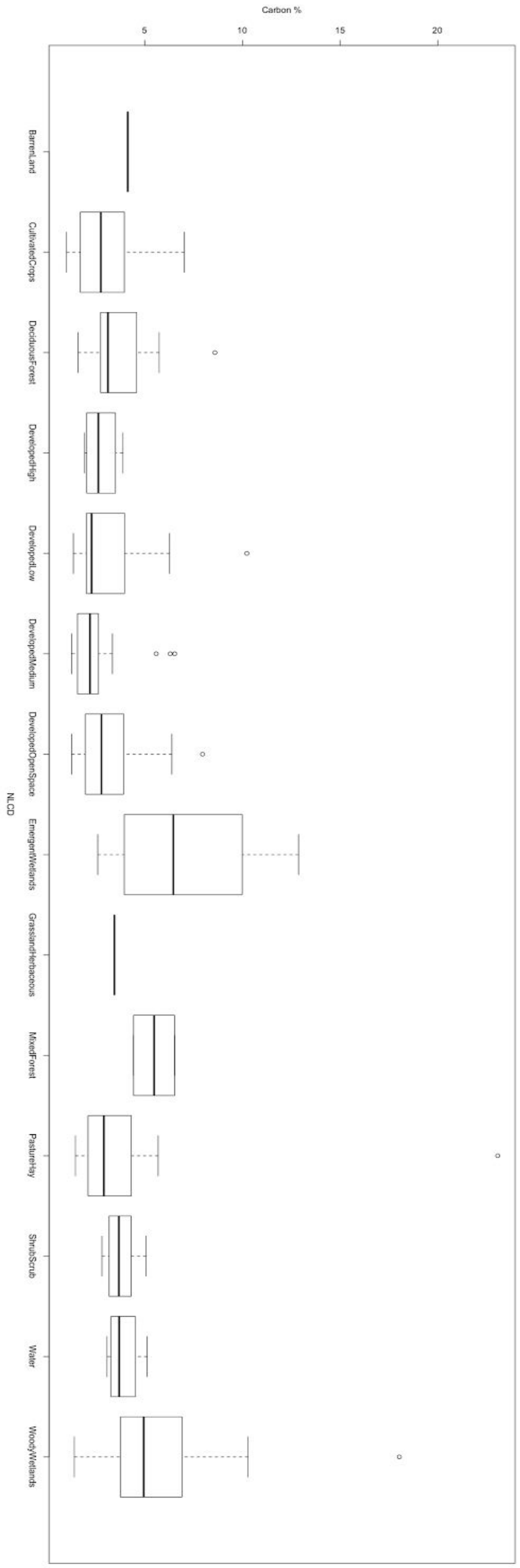


Figure 17: Carbon content of 234 soil samples by NLCD land cover description. Both types of wetlands have the highest carbon storage capability whereas the developed areas have the lowest. There is not enough data for barren land and grasslands to draw any conclusions.

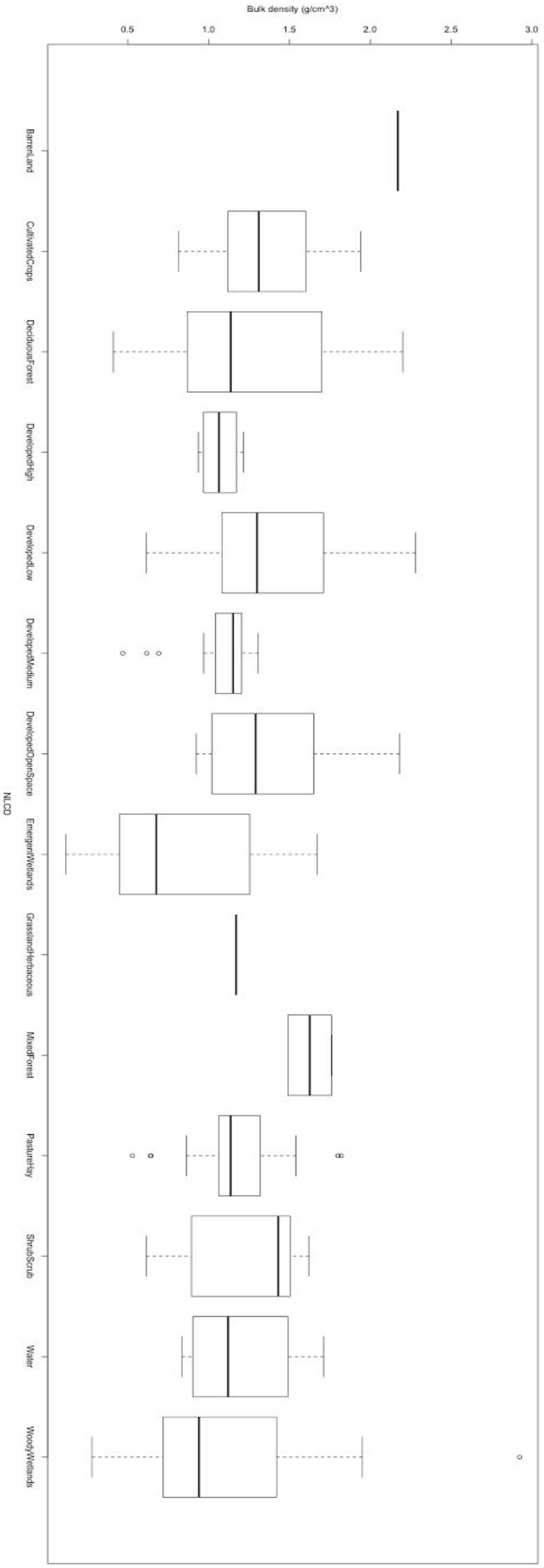


Figure 18: Bulk density of 234 soil samples by NLCD land cover description. Most land covers have fairly variable bulk density in their soils except for the developed land covers. Wetlands have the lowest bulk density.

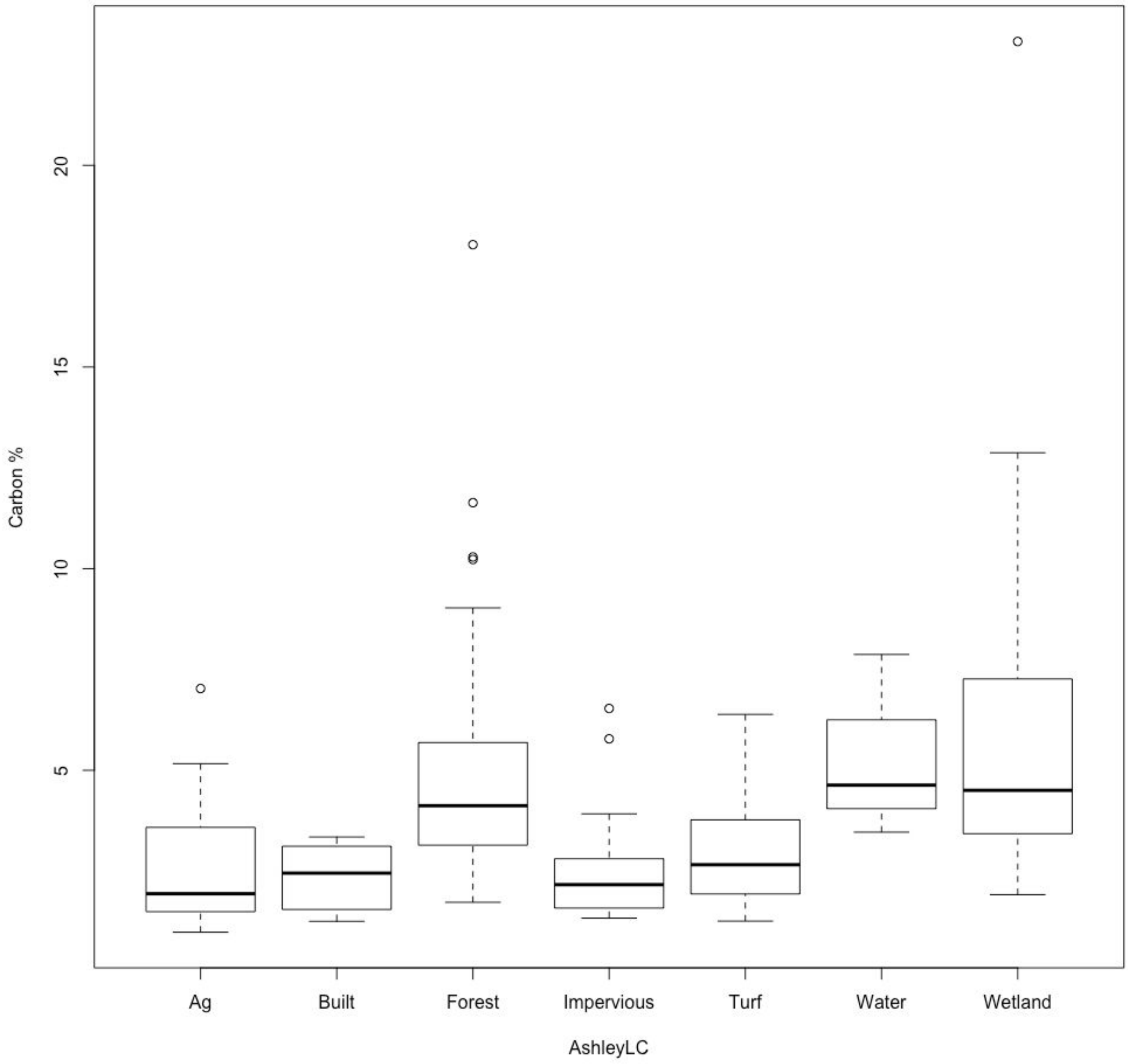


Figure 19: Carbon content of 234 soil samples by land cover as classified by Ashley. This shows that wetland soils, again, have the highest carbon storage capacity, followed by forests. Unsurprisingly, impervious and build land covers had the lowest carbon storage potential.

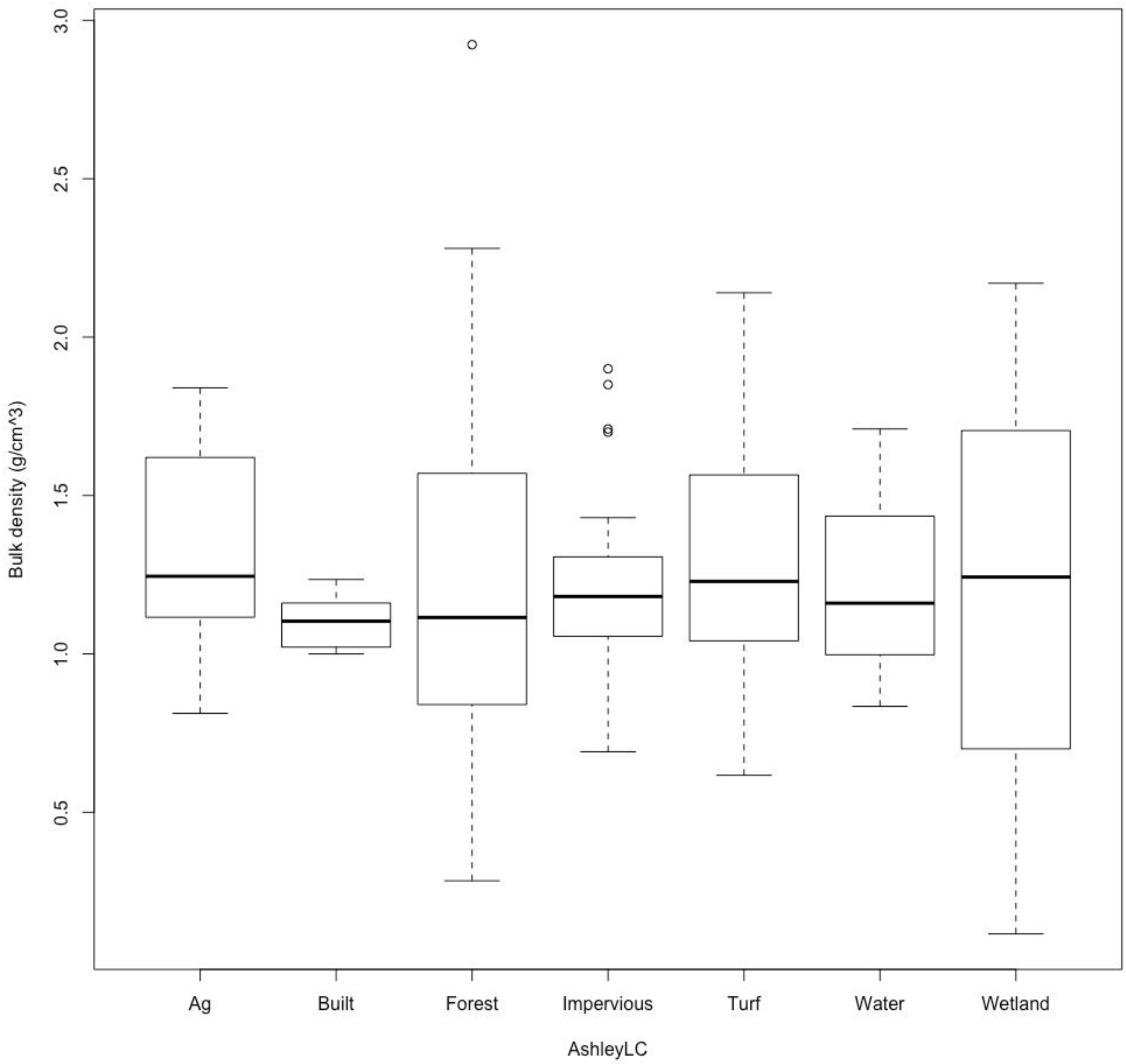


Figure 20: Bulk density of 234 soil samples by land cover as classified by Ashley. Natural land covers like forests and wetlands again show highly variable bulk density.

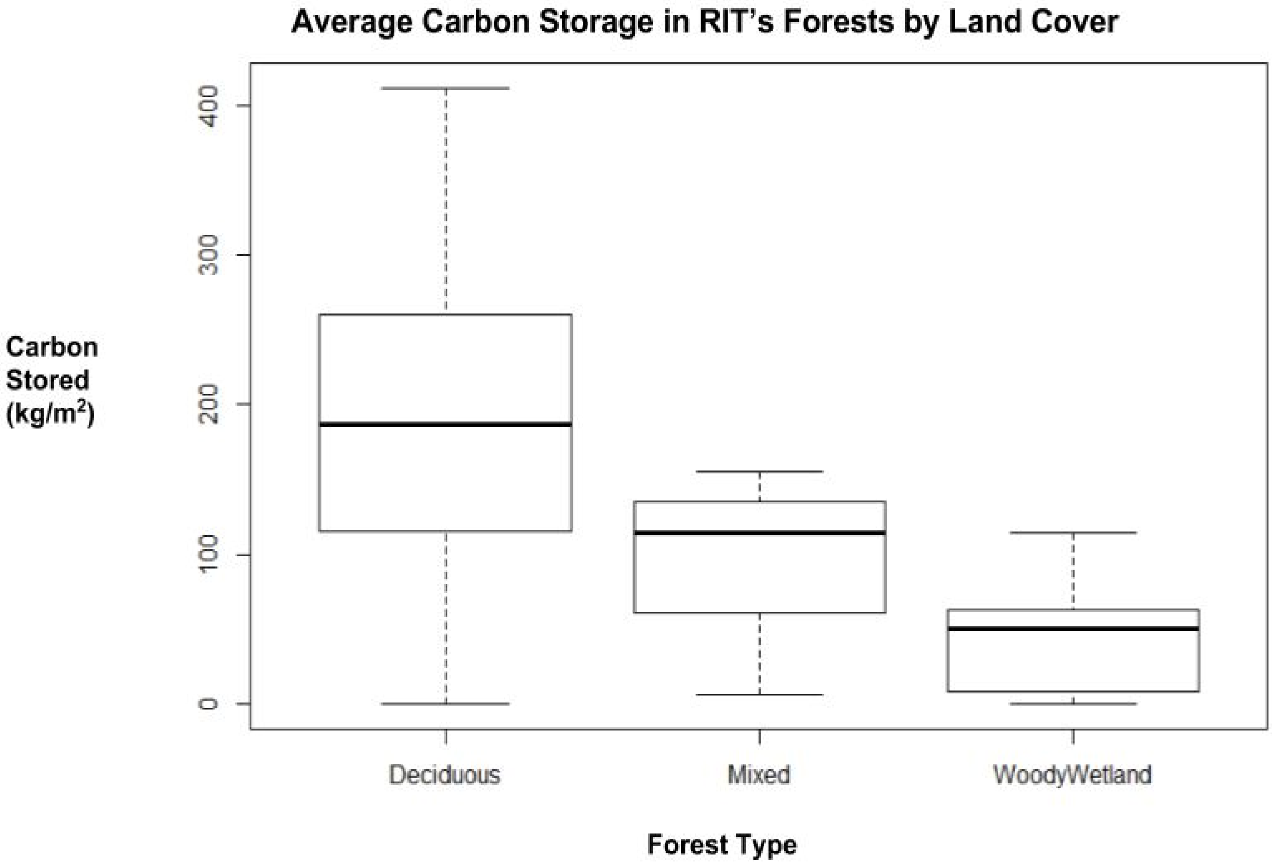


Figure 21: The estimated aboveground carbon storage for the different forest types of RIT campus based on 21 samples. Deciduous forests store the largest amount carbon, probably because these forests are the most prevalent on campus.

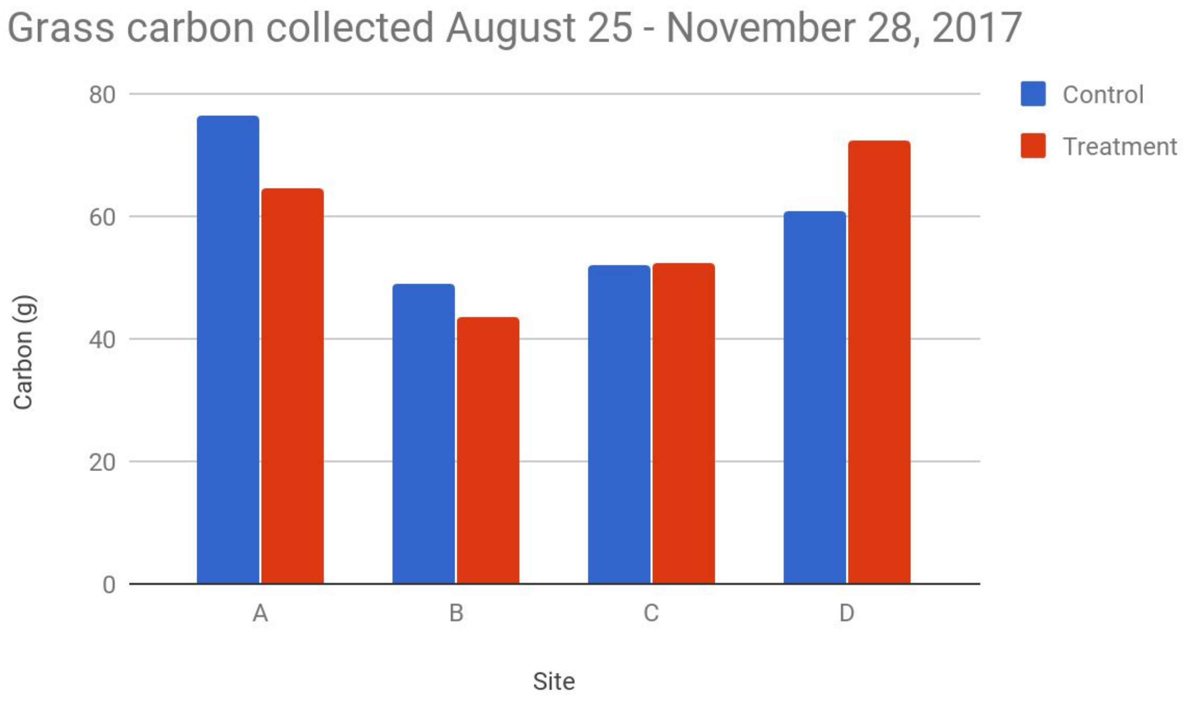


Figure 22: This chart shows the total amount of carbon (grams) stored in the biomass of the control and test plots for each of the mowed comparison sites. A T-test reveals there is no significant difference between the control and treatment sites (p=0.81). These are four individual sites where each site has different soil characteristics, different vegetation, and is under slightly different land management regimes. See Figure 10 for detailed descriptions of each site.

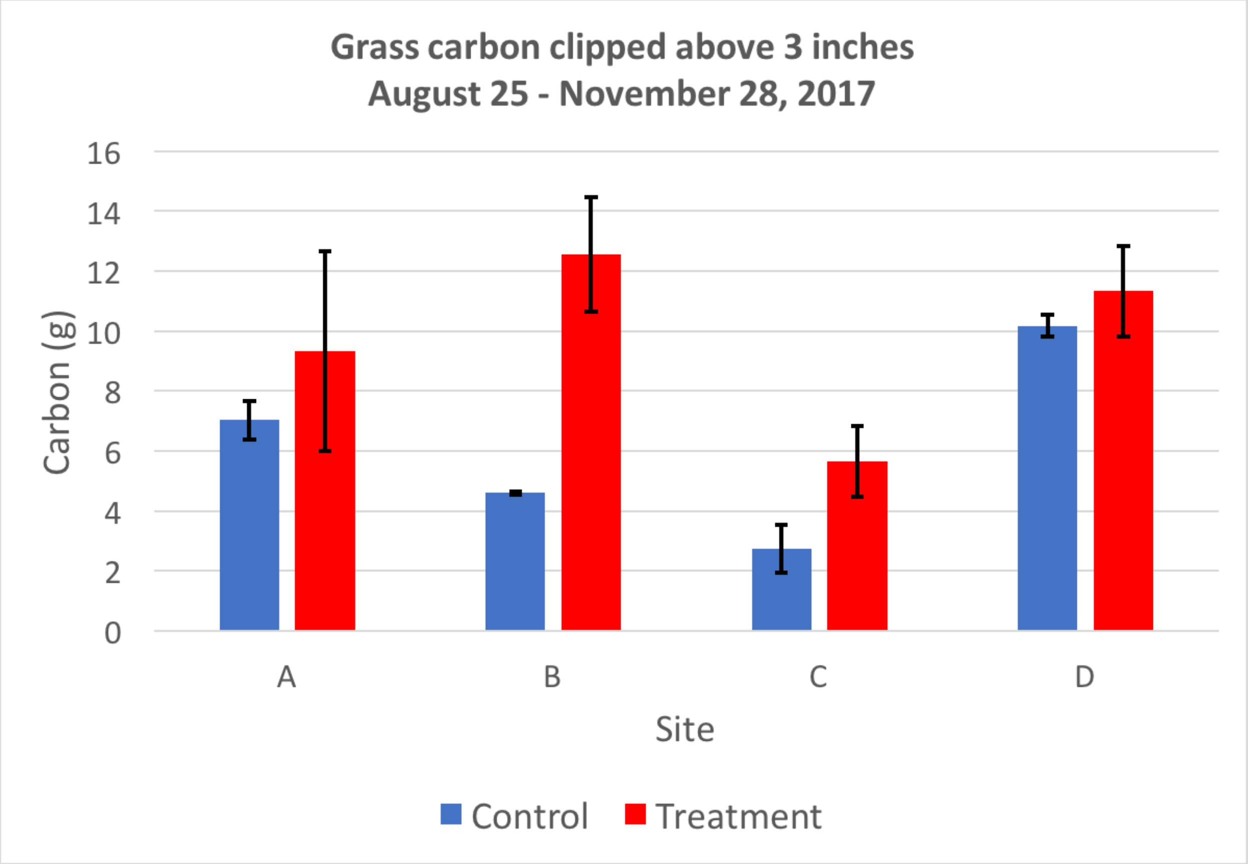
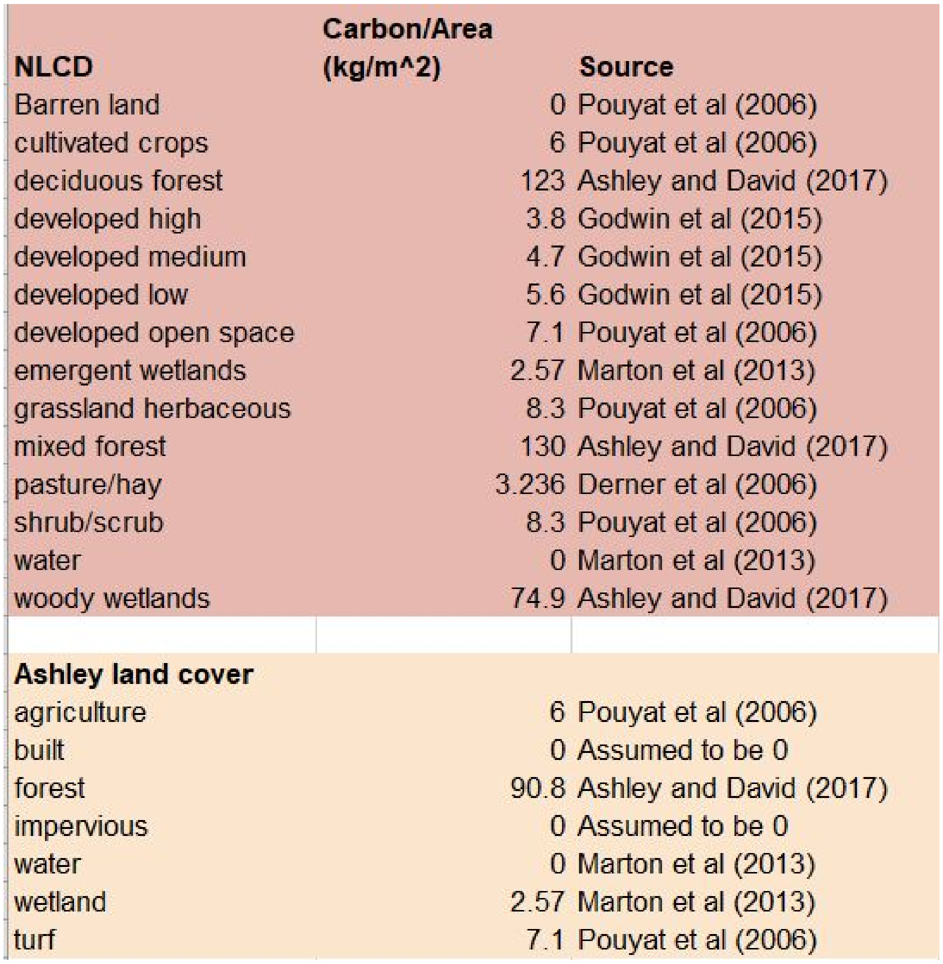


Figure 23: The amount of carbon (g) clipped aboved three inches over the course of the study period. Three inches is the typical mowing height used by RIT groundskeeping. Error bars represent one standard deviation. A T-test reveals there is significant difference between the control and treatment sites at the 90% level of significance (p=0.098). These four sites are not four replicates; each site has different soil characteristics, different vegetation, and is under slightly different land management regimes. See Figure 10 for detailed descriptions of each site.



NLCD	**Carbon/Area (kg/m^2)**	**Source**
Barren land	0	Pouyat et al (2006)
cultivated crops	6	Pouyat et al (2006)
deciduous forest	123	Ashley and David (2017)
developed high	3.8	Godwin et al (2015)
developed medium	4.7	Godwin et al (2015)
developed low	5.6	Godwin et al (2015)
developed open space	7.1	Pouyat et al (2006)
emergent wetlands	2.57	Marton et al (2013)
grassland herbaceous	8.3	Pouyat et al (2006)
mixed forest	130	Ashley and David (2017)
pasture/hay	3.236	Derner et al (2006)
shrub/scrub	8.3	Pouyat et al (2006)
water	0	Marton et al (2013)
woody wetlands	74.9	Ashley and David (2017)
Ashley land cover		
agriculture	6	Pouyat et al (2006)
built	0	Assumed to be 0
forest	90.8	Ashley and David (2017)
impervious	0	Assumed to be 0
water	0	Marton et al (2013)
wetland	2.57	Marton et al (2013)
turf	7.1	Pouyat et al (2006)

Figure 24: A summary of carbon storage literature values used for interpolation. This was done to accurately account for carbon storage in land covers whose data we could not collect. These sources can be found in the supplemental materials section.