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Quantifying Carbon Stocks within the Androscoggin Land Trust

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QUANTIFYING CARBON STOCKS WITHIN THE ANDROSCOGGIN LAND TRUST

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Completed in Partnership with Shelley Kruszewski, Executive Director of the Androscoggin Land Trust

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EXECUTIVE SUMMARY

Greenhouse gas (GHG) emissions from the burning of fossil fuels for transportation and electricity, land use and deforestation, agriculture, and industry are causing unprecedented rates of climate change. The climate emergency is intensifying as temperature extremes increase, snow and ice cover declines, and the oceans warm and acidify. The need to mitigate climate change is rapidly increasing and many mitigation efforts focus on the reduction of GHG outputs into the atmosphere, primarily the development of new renewable energy technologies in order to reduce the burning of fossil fuels. While a decreased reliance on fossil fuels is a key climate solution, a largely underappreciated method of mitigation is through enhancing the Earth's carbon stocks, the carbon sequestered and stored in the plant and soil biomass of forested landscapes. Implementing sustainable land management strategies to protect against land development and improve the land's sequestration potential provides an opportunity to increase the uptake of CO_2 and reduce the atmospheric carbon concentration. While land trusts might not immediately come to mind when thinking about climate change mitigation, their work to protect natural ecosystems, improve vegetation cover and prevent deforestation and development is important in carbon sequestration. The benefits of land trusts extends beyond protecting biodiversity, enhancing and protecting vulnerable ecosystems, and providing recreation opportunities for the community to also providing a natural climate solution.

This report is and exploration into the carbon sequestered and stored on land conserved by the Androscoggin Land Trust (ALT) in order to quantify ALT's mitigation benefits. ALT conserves 52 properties throughout the Androscoggin Watershed in Maine, working with local landowners and organizations to protect significant land that gives this region character. We quantified the carbon held in each of the four land types in which the properties can be characterized: mixedwood forest, mixedwood forest and wetland, mixedwood forest and agricultural land, and mixedwood forest and meadow/field.

We intend for the data, educational information about the carbon cycle and sequestration, and methodology that resulted from this project to be used to continue to quantify carbon held in more ALT properties, educate and inform the public about this benefit of ALT, and shared with other land trusts to allow them to complete similar projects. We provide ALT, and other Land Trusts, with the tools to increase the effectiveness of communicating their role in carbon sequestration and allow the value of land trusts in climate change mitigation to be fully appreciated and supported.

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INTRODUCTION

Since the 1750s the global atmospheric concentrations of greenhouse gases (GHGs), in particular carbon dioxide (CO_2), and methane (CH_4), have increased rapidly and now far exceed pre-industrial levels (IPCC Report 2007). In 2013 the daily level of CO_2 in the atmosphere exceeded 400 parts per million for the first time in human history (NASA). Levels have not been that high since the Pliocene era, three to five million years ago (NASA). Current climate change, as portrayed by the increase in temperature extremes and heavy precipitation events, shrinking of snow cover and glaciers, and warming and acidification of the oceans, is primarily due to human activities and associated with these anthropogenic (produced by humans) GHG emissions (Causes of Climate Change). Changes in the atmospheric abundance of GHGs alter the energy balance of the climate system by disrupting the carbon cycle and slowing or preventing heat from escaping the atmosphere by absorbing energy, essentially acting as a blanket over the Earth's surface (Miller, 2017, IPCC Report 2007). Changes in the atmospheric concentration of these GHGs through human activity increases the Earth's temperature more so than would otherwise occur at natural atmospheric concentrations. The urgency of climate change mitigation was exemplified by the Intergovernmental Panel on Climate Change (IPCC) special report released in 2018 on the impacts of global warming of 1.5 ˚C above pre-industrial levels. This was produced as part of the decision to adopt the Paris Agreement, and was an effort to bolster the global response to the threat of climate change and increase efforts in sustainable development, climate resilience and poverty eradication (IPCC Report 2018). The Madrid Climate Change Conference taking place in December, 2019 brings the world together as the climate emergency continues to intensify and its impacts are felt globally (COP 25).

Given the intense contributions of GHGs to climate change, the primary mode of mitigation is to reduce and stabilize the levels of heat-trapping GHGs in the atmosphere. According to the 2014 report on Climate Change by the IPCC, the goal of mitigation is to stabilize greenhouse gas levels to allow ecosystems to adapt naturally to climate change, ensure food production is not threatened and enable sustainable economic development (NASA). Mitigation includes either reducing the sources of GHG emissions, for example the burning of fossil fuels for electricity, heat or transportation, or enhancing the sinks that sequester and store carbon, including forests and soil. While renewable energy and decreased reliance on fossil fuels are key climate solutions, a largely under-represented avenue for climate mitigation is the carbon sequestration occurring globally in forested landscapes. Carbon sequestration is the absorption of atmospheric carbon within ecosystems and one-third of fossil fuel emissions are actually absorbed by landscapes such as forests, lakes and bogs, and thus preserving and increasing the size of these carbon sinks serves as an important mitigation method (Lunt et al, 2018). Given the urgency of reducing atmospheric concentrations of carbon dioxide, it is important to implement sustainable land management strategies to protect against deforestation and improve the land's sequestration potential (Lacher et al., 2019). While Land Trusts might not immediately come to mind when thinking about climate change mitigation, the work they do to protect against deforestation and preserve forested lands is important in preventing net loss of carbon from ecosystems and improving their sequestration potential. Although land trusts have historically focused their efforts on purchasing conservation easements and promoting local, state or federal easement programs, there is an increasing interest in exploring the carbon sequestration potential of the land they conserve (Merenlender, 2004).

In order to understand the role of Land Trusts in climate change mitigation, it is important to have a general understanding of the carbon cycle in association with land conservation (Figure 1). Carbon is the chief element of interest because it is essential to all life on earth and a major constituent of two of the most abundant greenhouse gases: carbon dioxide (CO_2) and methane (CH_4). CO_2 is by far the most common GHG emitted by human activities, and the burning of fossil fuels (sediment or rock derived carbon) for transportation, electricity and heat is the greatest contributor to climate change (IPCC Report 2007). By preserving the land, Land Trusts can promote the net uptake of carbon. The carbon balance of an ecosystem is the difference between its carbon gains and losses, and carbon cycles through two primary sources and/or sinks: plant biomass and soil. The plants in terrestrial ecosystems sequester CO_2 from the atmosphere through the process of photosynthesis and convert it to carbohydrates that the plant then uses as energy (Heimann et al., 2008). Carbon is therefore fixed, captured and stored in the leaves, twigs, roots and trunk of plant biomass. A portion of the sequestered CO_2 is released into the atmosphere primarily through plant and soil microbe respiration. Carbon is also stored in soil, divided between the living soil biota and the dead biotic material, or onsight dead biomass that makes up the soil. Organisms living in the soil include earthworms, nematodes, fungi, bacteria, and other microorganisms (Lal et al., 1997). The major source of soil carbon is detritus, dead organic material primarily from plant roots, twigs, leaves and other aboveground biomass. The soil microorganisms decompose this plant material and any carbon that is not released as CO_2 through microbial respiration remains in the soil and is stored as humus, the dark organic soil layer (Reiners, 1973) .

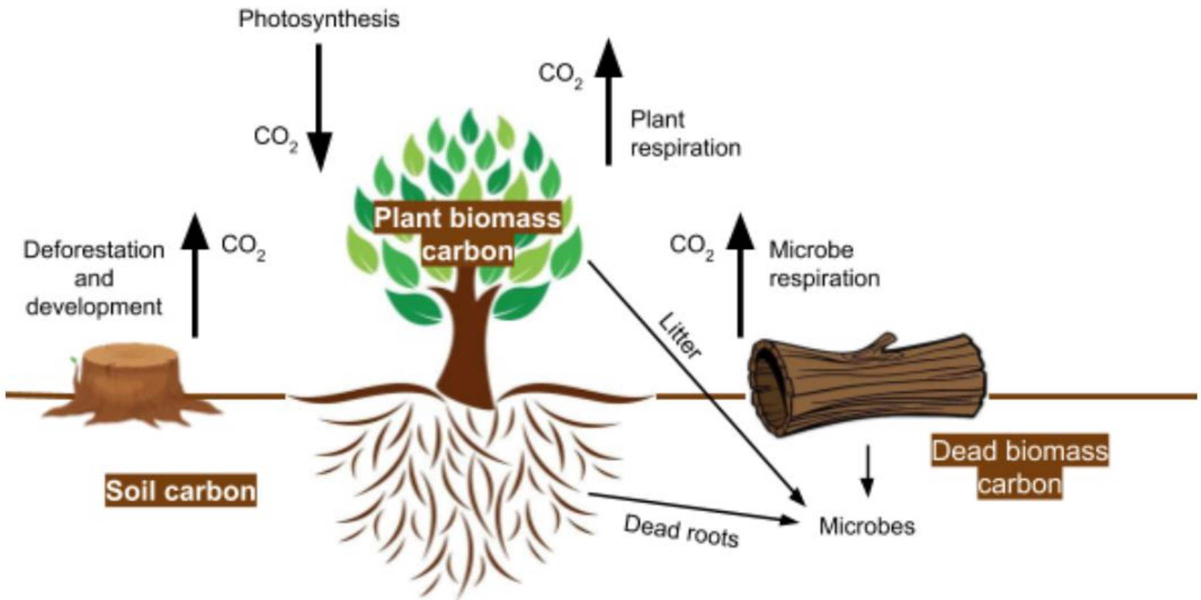


Figure 1. Carbon Cycle Diagram. Carbon sequestration, exchange and storage within forested landscapes. Main pools of carbon are plant biomass, dead biomass and soil.

Based on natural landscapes' role in the carbon cycle, ecosystems such as forested lands and bogs serve as carbon sinks through carbon sequestration and the net input of carbon: when more carbon is sequestered than released from the ecosystem. Forests experiencing growth in both size and number of trees function more efficiently as carbon sinks than forested lands in decline because new growth absorbs more carbon than is lost by decay, creating a carbon sink (Ravin, 2007). On the other hand, deforestation and land development both release carbon dioxide into the atmosphere by tree removal and soil disruption, and reduce the carbon pool and the land's carbon sequestration potential (Nowak, 2001). Carbon emissions from land-use and land-cover change accounted for approximately 12% of all anthropogenic carbon emissions from 1990 to 2013. (Popp et al., 2014). Since forests provide a sink for carbon by fixing CO_2 from the atmosphere to produce biomass, the work done by Land Trusts through their dedication to preserving these natural landscapes is important in reducing atmospheric CO_2 concentrations. The main mission of Land Trusts is to support the conservation of open space, farmland, woodland and other natural and historic areas while upholding the values representative of the community in which they work (Schauffer, 2019). Through conservation management, land use restrictions and the maintenance of natural landscapes, Land Trusts improve the carbon storage potential of acreage (Maine Land Trust, 2017). The forest management policies developed by Land Trusts, such as afforestation, reforestation and deforestation prevention, play an important role in climate change mitigation (Nowak, 2001).

The Androscoggin Land Trust (ALT), with 52 conserved properties throughout the Androscoggin Watershed in Maine is interested in quantifying the carbon stocks on their land to communicate this ecosystem service to the public. ALT was created in 1989 and works with local landowners and organizations to protect significant land that will give this region of Maine character for generations to come (ALT, 2019). The goals of ALT are summarized in three categories: land protection by conserving areas of ecological importance, stewardship through majority volunteer workers, and relationship and easement development with current landowners to ensure future protection of the area (ALT, 2019). As the climate rapidly warms and ecosystems shift, the director of ALT, Shelley Kruszewski, has put major thought into developing ways for ALT to communicate the importance of land trusts in mitigating climate change to the public. Although the Board of Directors at ALT is knowledgeable of the many ecosystem and community benefits of the land trust, there is a disconnect in many communities between land protection and the overarching issue of climate change, and this link is often difficult to communicate. Shelley has enlisted this group to provide ALT, and other Land Trusts, with the framework to increase the effectiveness with which they communicate their role in carbon sequestration and allow the value of land trusts in climate change mitigation to be fully appreciated and supported.

Research Aims and Objectives

Aim: Increase public understanding of carbon sequestration and provide the Androscoggin Land Trust with the tools to inform the public on how land trust land impacts climate change mitigation.

Objective 1: Develop the content, language and visual display of material that ALT can utilize to provide basic knowledge to the public about atmospheric carbon and carbon sequestration in relation to climate change and inform the public about ALT's role in climate change mitigation.

Objective 2: Quantify the amount of carbon sequestered by properties under ALT conservation management and communicate the methods used for replication in order to increase the capacity of other Land Trusts to quantify carbon stocks on their land.

Deliverables

Each of our objectives have been met through the development of our three main deliverables.

Deliverable 1 includes the following:

- Quantification of the amount of carbon stock contained in ALT land, which includes total kg of carbon held in trees and soil on all ALT properties as well as concentration of carbon in trees per unit area (m^2) and soil per unit of volume (m^3) and amount of carbon per unit area for each of the four properties sampled. The amount of carbon was extrapolated to each site type: mixed forest, forest and wetland, meadow and forest, and agricultural land and forest. This is included in the results and discussion.

Deliverable 2 includes the following:

- A lab manual with detailed field and laboratory methods to quantify the amount of carbon sequestered by different land types. ALT and other land trusts can use this lab manual to determine the amount of carbon stored in their land. The lab manual contains methods accessible to organizations or groups that do not have access to GIS or a GPS. This is included in the appendix.

Deliverable 3 includes the following:

- Carbon sequestration 101 website in the form of an ArcGIS Online storybook that will be accessible to the greater Androscoggin community, linked from the Androscoggin Land Trust website.
    - This includes introductory information about climate change and carbon sequestration in relation to the carbon cycle. It describes the link between land conservation and the carbon forested land sequesters and climate change mitigation. It provides a brief summary of the methods used to select the four ALT properties sampled and the field sampling methods. The webpage displays the data collected about ALT conserved land and the total amount of carbon stored on all ALT properties.
    - This website was created to reach as broad an audience as possible with the goal of educating the public about land trusts' role in climate change mitigation.
    - The website can be found at this link: https://androscoggin-alt.maps.arcgis.com/apps/Cascade/index.html?appid=8bc234470ab544b482fcacf46e8bfc80

METHODOLOGICAL APPROACH

To complete our research aim and objectives we collaborated with Shelley Kruszewski, Executive Director at the Androscoggin Land Trust, and followed the subsequent methodology. Due to the overlapping nature of our objectives, the development of the Carbon Sequestration 101 webpage and collection and analysis of carbon stock data occurred simultaneously, and data gathered to quantify carbon stocks held in ALT land informed web page development.

1. *Research:* We began by researching methods used by other organizations, including other Land Trusts, to quantify carbon held on their conserved properties. We identified two projects exploring carbon pools on managed forest land to research specifically: the work done in a collaboration between Kennebunk High School, University of New England, the Gulf of Maine Research Institute and Kennebunkport Conservation Trust, and a project completed by the Kennebec Land Trust. Although the work done by these land trusts informed the final presentation of our data and recommendations, we found it difficult to acquire their detailed methods and instead collected our data using the methods from the Bates Environmental Studies course ENVR 203 in their carbon sequestration lab.
2. *Stratified Sampling*
    a. *Land type Categorization:* In order to determine which sites we would sample we used a stratified design in which we categorized all of the ALT sites into four land type categories using the Forest Management Guides, property descriptions on the ALT website and information from Shelley. We did this to ensure we would sample from properties representative of all ALT land. The four land type designations are mixedwood forest, mixedwood forest and wetland, mixedwood

forest and agricultural land, and mixedwood forest and meadow/field. It is important to note that while there are 52 total properties, they are combined into 33 on the ALT website because the website does not split up the subsites within some of the properties. A map of the 33 properties and their land type designation is included in the appendix.

b. *Property selection:* In order to complete the project in one semester, we started by selecting a smaller sample size of ALT properties from the total of 52 properties to focus on. Shelley condensed the list of properties to 19 that she wanted us to focus on based on property size, accessibility and whether they had a Forest Management Plan. We then numbered those 19 properties within each land type category and used a random number generator to select one property within each land type. Based on some further consultation with Shelley about the accessibility of the properties and land ownership we decided on the four properties we would sample from: Hooper Pond (mixedwood forest and wetland), Spruce Mountain (mixedwood forest), Packard Littlefield Farm (mixedwood forest and agricultural land), and Sherwood Forest (mixedwood forest and meadow/field).

3. *Plot Selection and Sampling Technique:* We generated eight random points within the boundaries of each of the four properties using GIS. It is essential that these points are random in order to ensure all areas of the property have an equal chance of being chosen. This guarantees the sample location is representative of the property and was selected in an unbiased way. These random points will here-on be referred to as sampling plots at which we collected data. We generated eight points, but only four were actually used in the field due to time constraints and the ability to get to each of the points. Maps of the

plots sampled are located in the Appendix. The randomly generated sampling plot was the start of a 40 meter transect with the same data collected at 0 meters, 20 meters, and 40 meters (Figure 2). The direction of the 40 meter transect was decided using a random number generator to generate a number between 0 and 360.

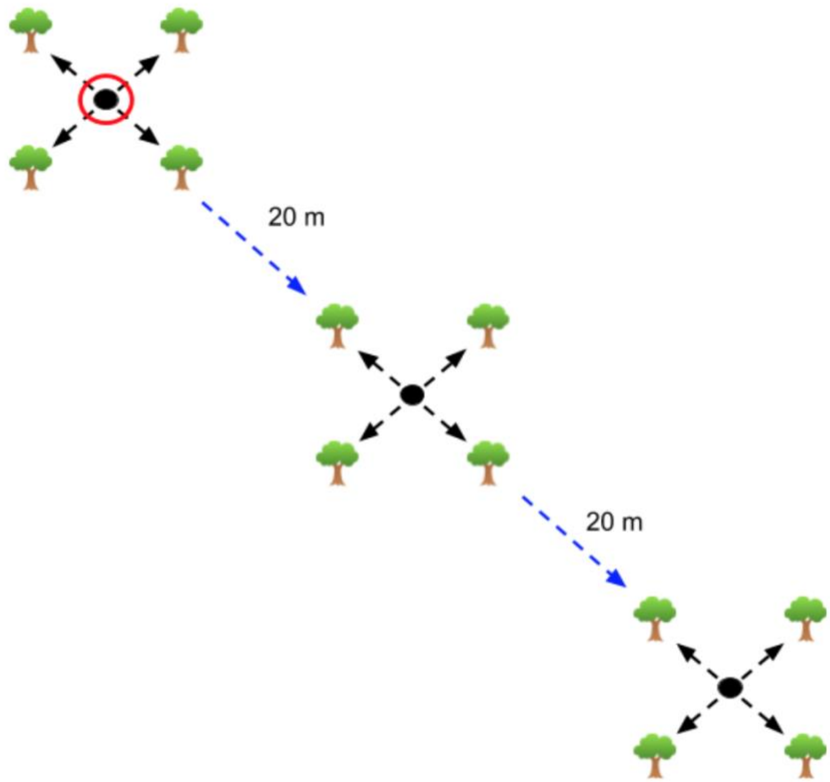


Figure 2. Sampling Technique. The point with the red circle around is the randomly generated sampling plot. The arrows between points depict the randomly generated direction and the 20 meter distance from the first plot to the subsequent two. The same data is collected at 0 m, 20 m and 40 m.

4. *Methods and Data Collection:* The field methods used to quantify the amount of carbon were heavily outlined by the field work done by the Bates Environmental Studies course, ENVR 203, in their quantifying carbon stock lab that takes place in Garcelon Bog in Lewiston, Maine (which is also a property owned by ALT). We will list the data collection for each of the four plots, but the same methods applies at the 20 m and 40 m marks. Data collection included the following:

a. Soil Sample directly at the randomly generated sampling plot and recorded depth of sample.

b. Measured distance to nearest mature tree in 4 directions:

    i. Tree species identified

    ii. Tree diameter at breast height (DBH) measured

    iii. 1 tree core taken per every 4 trees (1 for each plot)

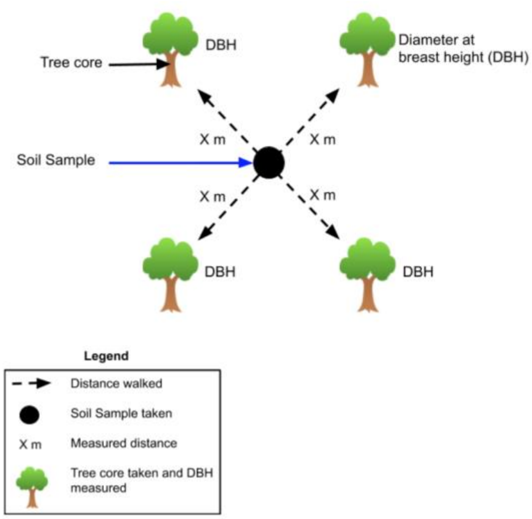


Figure 3. Data Gathering Method. The soil sample was taken at plot center and the dotted lines represent the distance to the closest mature tree in each of the four quadrants. At each tree DBH was recorded and 1 tree core taken per every 4 trees.

5. *Lab Work*: After collecting all of the field samples, lab work was needed to compute the amount of organic material, or material composed of dead/decaying plant or animal biomass, in our samples. To do this we measured and recorded the following:

    a. Tree Lab:

        i. Wet tree core sample weight

        ii. Dry tree core sample weight after at least 24 hours in 60 °C drying oven

        iii. Burnt tree core sample weight after spending 4 hours burned at 550 °C

    b. Soil Lab:

i. Soil sample volume measured in graduated cylinder

ii. Wet soil sample weight

iii. Dry soil sample weight after at least 24 hours in 60 °C drying oven

iv. Burnt soil sample weight after spending 4 hours burned at 550 °C

6. *Data Analysis and Calculations:* Using the lab data and field measurements and calculations provided by Carissa Aoki, professor of ENVR 203, we calculated the carbon stock contained in each of the four sampled properties. We calculated the carbon stock held in three different carbon pools: aboveground biomass (trees), belowground biomass (roots) and soil. With the calculations we generated two numbers for each property: average carbon concentration in tree biomass (kg C/m^2) and soil biomass (kg C/m^3). We then multiplied these concentrations by the property area (in m^2) for tree carbon and by the property area (in m^2) and organic soil depth for soil carbon and added them together (tree carbon and soil carbon) to get the total amount of carbon in kg for each of the four properties.

7. *Quantifying Carbon in all ALT Conserved Land:* Based on the stratified sampling design, we relied on the assumption that the carbon concentrations calculated for each property sampled was representative of all properties within that land type category. Based on this assumption we calculated the total amount of carbon in all of the 33 properties, based on land type, using the concentrations and area of each property. We then added up these totals to calculate the total amount of carbon in each land type and within all ALT conserved land.

RESULTS AND DISCUSSION

After sampling each of the four sites, completing the required lab work and computing property areas we were able to find the concentration of carbon stored in both trees (aboveground and belowground (roots)) and soil for our four sampled properties. We did not measure the amount of carbon stored in the shrubs because this process is the most time and labor incentive and produces the least accurate results. From these carbon concentrations we were able to calculate how much total carbon is sequestered and stored in each land cover classification by extrapolating from the acreage found on the ALT website. Finally, we were able to add up these numbers to present a rough estimate of the amount of carbon sequestered by all properties within ALT.

Sampled Site	Amount of Carbon in Trees (kg C/m_2)	Amount of Carbon in Soil (kgC/m_3)
Packard Little Farm	8.985306954	6.941737838
Sherwood Forest	23.28363137	504.0760517
Spruce Mountain	13.76983097	18.10782093
Hooper Pond	12.78966288	25.69913322

Table 1. Carbon Findings by Site. This table presents the concentration of carbon sequestered by each site that was sampled.

Presented here, Sherwood Forest (meadow and forest) has the greatest concentration of carbon in both the trees and the soils and Packard Little Farm (Agriculture and Forest) holds the least amount of carbon in both the trees and the soils. It is important to notice that across each property--except for Packard Little--soil holds a larger amount of carbon than the trees do. Soil is largely underappreciated in its capacity to store carbon, as we tend to think about trees and other plant biomass as carbon sinks, but as indicated by our data, soil is an important sink as well. It is also important to note that Packard Little is an active farm, which may play a role in the ability of the soil to sequester more carbon. It is largely known that agricultural soils are unable to hold as much carbon in them.

Land Cover Classification	Amount of Carbon (kg C)
Agricultural Land and Forest	102,675,960
Meadow and Forest	388,415,103.5
Mixed Forest	208,083,904
Wetland and Forest	218,373,601

Table 2. Carbon Findings by Land Cover Type. The table presents the amount of carbon sequestered by each land cover type in all properties conserved by ALT.

Presented here, the land cover that is sequestering the most carbon is the Meadow and Forest classification which is also the classification type the Sherwood Forest was representing. In addition to this, it is clear that the agricultural land and forest land classification hold the least amount of carbon.

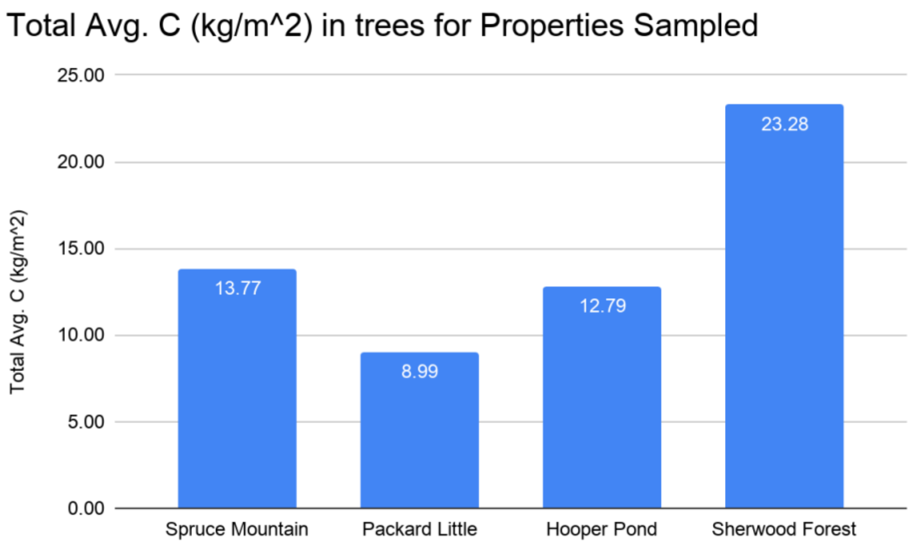


Figure 4. Average amount of carbon stored in trees per each property sampled. The x-axis presents the 4 sampling sites and the y-axis presents the total average amount of carbon sequestered in the trees in kg/m2.

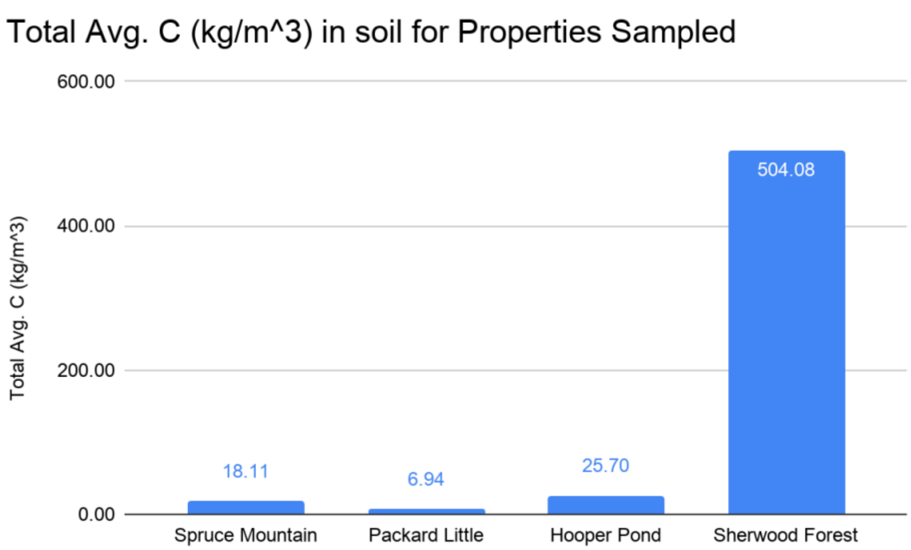
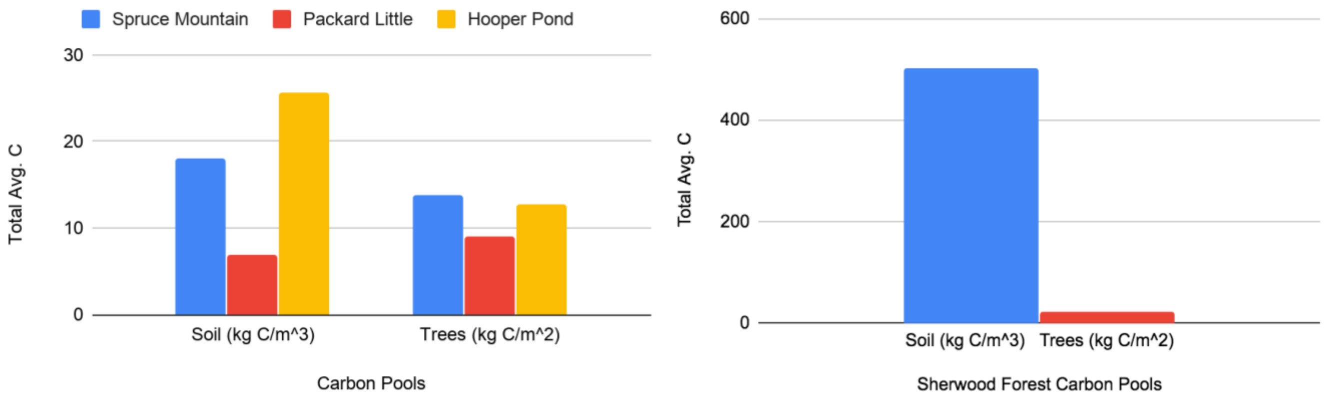
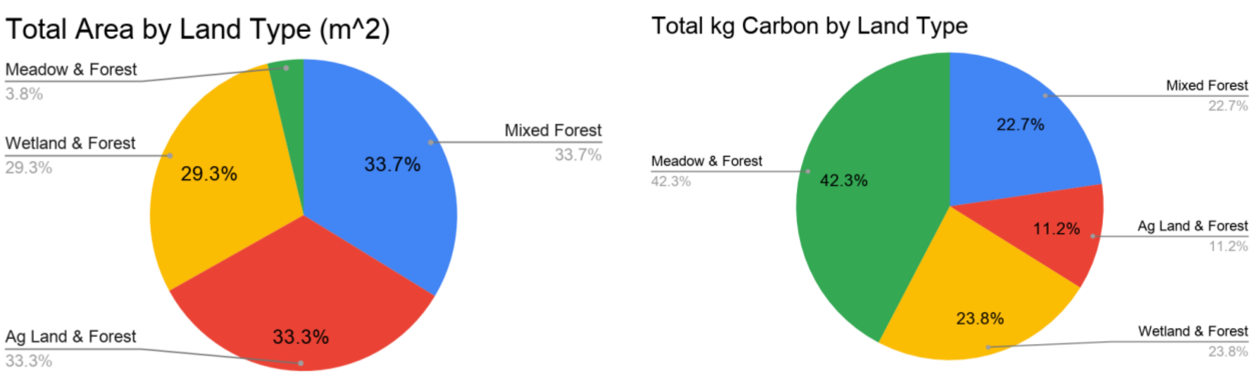


Figure 5. Total average amount of carbon in soil per each property sampled. The x-axis presents the 4 sampling sites and the y-axis presents the total average amount of carbon sequestered in the soil in kg/m2.



Figures 6 & 7. Comparison of the amount of carbon sequestered per site type and carbon pool. Sherwood Forest is presented on its own figure because the concentration of carbon is so much larger in its soil than the other properties sampled.



Figures 8 & 9. Percentage of Total Area by Land Type and Total kg of Carbon by Land Type. The figure on the left is presented to compare the amount of land cover type that is made up by all ALT properties while the figure on the right is presented to compare the amount of total carbon within the ALT properties and where it is sequestered.

Our data presents that Sherwood Forest and the rest of the meadow and forest properties sequester the largest amount of carbon. However, this property and the land type does not make up the largest acreage within ALT. In fact, Figure 8 shows that the meadow and forest land type category actually only makes up 3.8% of all ALT properties, the smallest of all four categories. While it may be true that meadow and forest does actually have a larger carbon stock than the other land types, it is possible that sampling error or lab error accounts for this large spike in carbon stock. It is also possible that because Sherwood Forest was the last site to be sampled in the fall, more organic matter within the sample could have been present, or its previous land use history, as it has not been logged in many years, may contribute to the high levels of soil carbon. In addition, we were only able to sample one property per land type and thus Sherwood Forest may be an outlier in the amount of carbon it sequesters.

The data we present is preliminary and a general estimate of the amount of carbon ALT holds in its lands and this must be considered in the ways that ALT uses the data. It is likely an underestimate of the amount of carbon because we did not measure shrubs and we used a depth of 42.5 cm for the organic layer of soil as that was the depth of sample we were accurately able to acquire, but the organic layer is likely deeper. Based on the CO_2 emissions from an average car, we calculated that our carbon estimations with the total of 917,548, 569 kg of carbon stored in ALT land would account for the land trust taking 151,410 cars off the road. This is valuable information for land trusts to have in terms of communicating how the work they do to conserve land mitigates climate change.

RECOMMENDATIONS

Based on our research about the work done by other land trusts, specifically the Kennebunkport Conservation Trust and the Kennebec Land Trust; our conversations with Shelley; the carbon data we collected and calculated; and the limits on the work we were able to complete we are providing three recommendations for the Androscoggin Land Trust.

1. Use the lab manual and the presented methodology to quantify carbon stocks on more ALT properties.
    a. ALT conserves a total of 52 properties and were were only able to collect carbon data for 4 of these. It is important that ALT increases the sample size for the carbon data since we only sampled one property per land type. Although the Forest Management Guides and property descriptions indicated that the selected properties were representative of the other properties within that land type, there is a possibility that based on previous land use and current management methods the carbon stored in the properties sampled is not actually an accurate representation.
    b. Based on sustainable management methods and land type the carbon sequestration of sites will likely change over time. It would be beneficial for ALT to collect temporal data on sites to quantify the changes in carbon stocks over time. Should the carbon stocks increase over time this would be further data that ALT could use to quantify the benefits of conserved land. This data could also indicate whether their are land management methods capable of improving carbon sequestration, such as sustainable harvesting.
2. Communicate this carbon data to the public and educate the community about ALT's role

in climate mitigation through carbon sequestration.

   a. One of our deliverables is the Carbon Sequestration 101 webpage and this should be a tool used by ALT to inform the public. This webpage should be linked from the ALT website and advertised to the public in newsletters and other communication platforms.
   b. Host presentations open to the public to explain the carbon cycle and the role land trusts play in carbon cycling.
   c. Partner with high schools in the Androscoggin area to develop course material; could include lab periods during which students collect and analyze carbon data. This would use the methods provided as one of our deliverables.

3. Use carbon data, based on the type of property, to predict how much carbon is stored by an area ALT is interested in acquiring, and/or use the methods detailed in the lab manual to actually quantify the carbon stocks.
   a. This data should then be communicated as reasoning to acquire the land and a quantifiable benefit of it becoming ALT property. This is information that could be shared with landowners interested in potentially incorporating their land into
   b. If there were to be a carbon market introduced in the future, this data could be used to indicate what it would mean to have an easement with specific management for carbon sequestration increase and this could be a future incentive to land owners, in which they could get money for their carbon storage.

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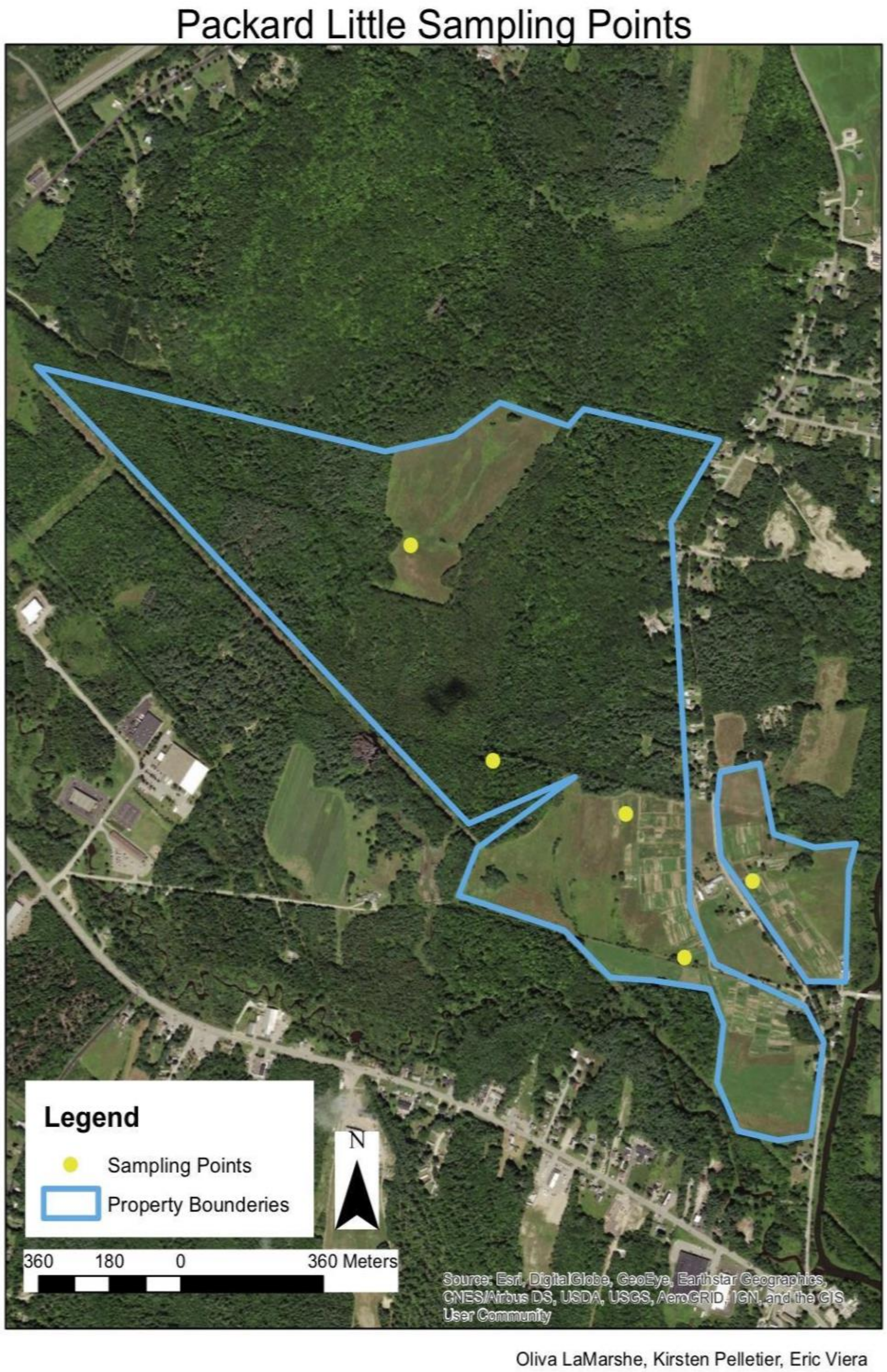
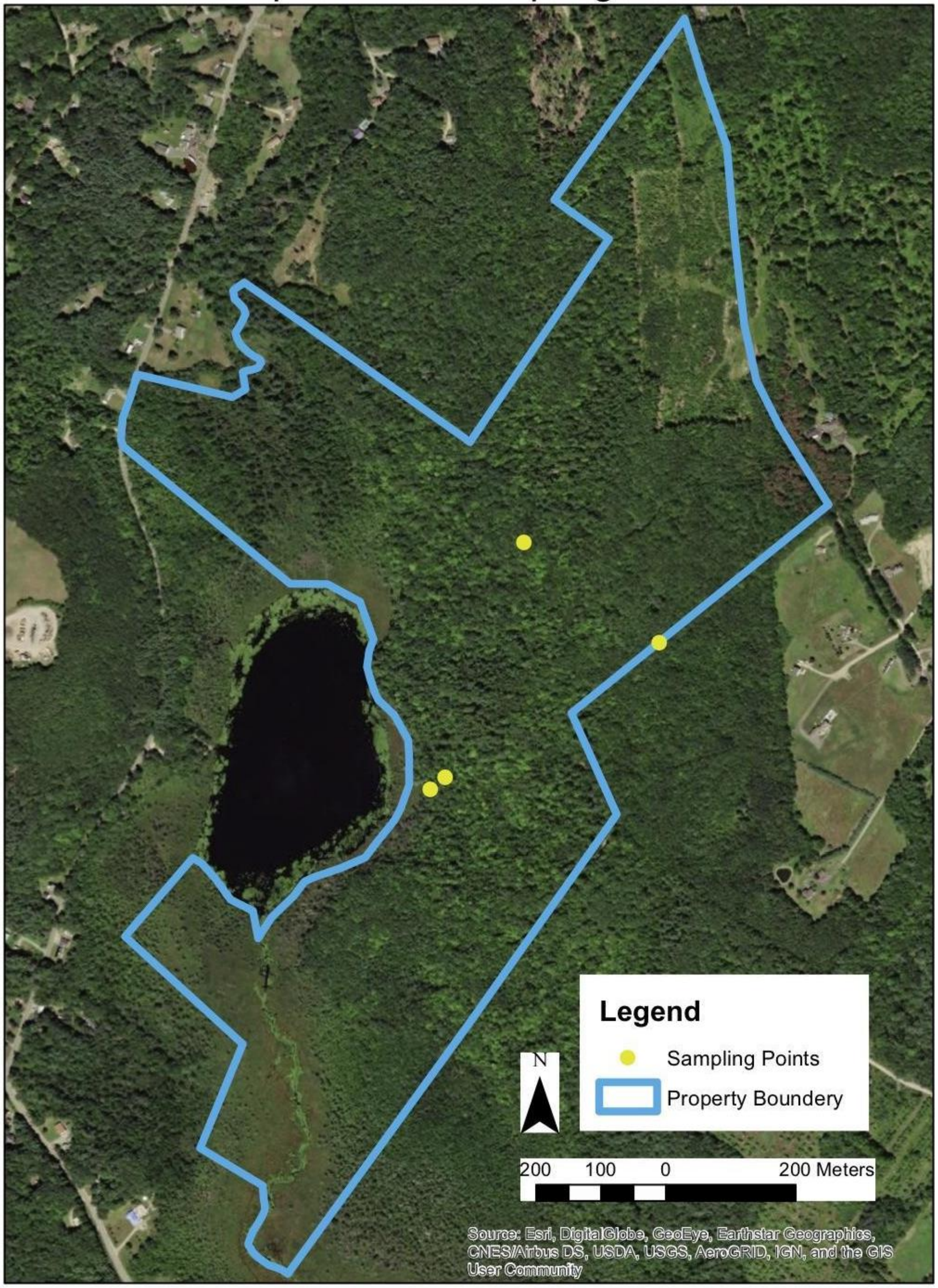
APPENDICES

APPENDIX A: Property maps of sample plots randomly generated using GIS.

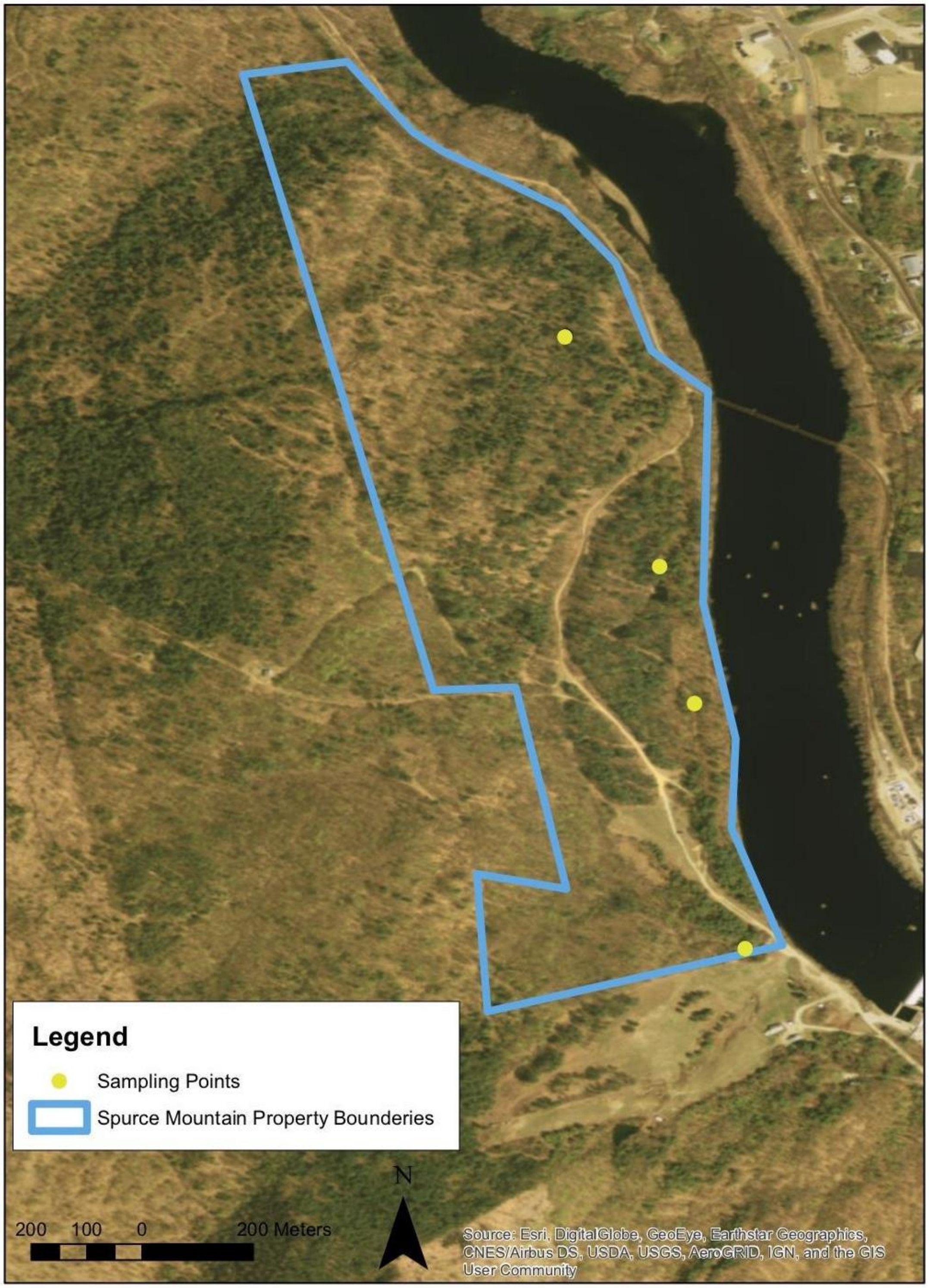


Hooper Pond Sampling Points



Olivia LaMarshe, Kirsten Pelletier, Eric Viera

Spruce Mountain Sampling Points

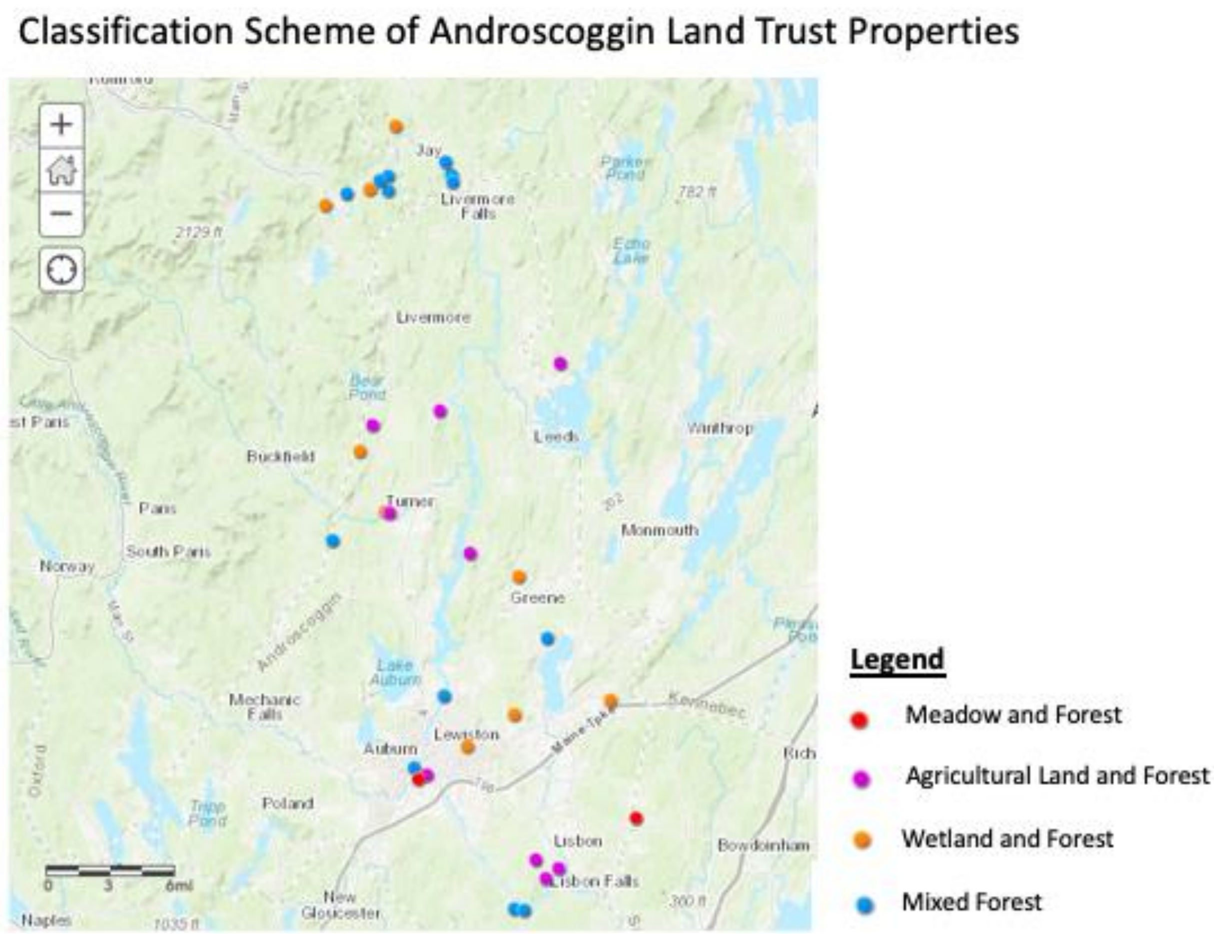


Kirsten Pelletier, Olivia LaMarche, Eric Viera

Sherwood Forest Sampling Points

Olivia LaMarshe, Kirsten Pelletier, Eric Viera

APPENDIX B: Map of all 33 properties listed on ALT website by land type: mixed wood forest, mixed wood forest and wetland, mixed wood forest and agricultural land, and mixed wood forest and meadow/field.



APPENDIX C: Full methods for field data collection and laboratory work/calculations.

These methods cover the sampling and calculations for trees (aboveground and belowground biomass) and soil, but do not include the methods for shrubs. Determining carbon in shrubs is the most time and labor intensive process and produces the least accurate result.

Materials

The following materials are needed in order to complete the field work for this project:

Fieldwork

1. Soil core sampler (at least 40 cm to extend into organic soil layer)
2. Tree corer (It is advisable to bring a screwdriver or similar tool with a point to clear out the end of the tree corer following sampling.)
3. Tape measure (at least 20 meters long)
4. Diameter at breast height (DBH) measuring tape
5. Tree identification guide
6. Bags for the soil and tree core samples and sharpie

Lab work

1. Graduated cylinder (and/or other container to measure soil volume)
2. Bench top scale (that can measure to a tenth of a gram)
3. Drying oven (must reach at least 65˚C)
4. Muffle furnace (must reach at least 550˚C)
5. Crucibles

Field Methods

Property Selection, Plot Selection, and Field Work Preparation

The Bates Capstone students working with the Androscoggin Land Trust used a stratified selection scheme to randomly select the sampled properties out of 52 total ALT properties. Randomizing the property selection was ensured so that the chosen properties were representative of all ALT properties as possible and that the selection process was not biased. The following is a description of the method used for property selection, but can be modified as needed.

1. Properties within the land trust should be divided into categories based on their land cover.
    a. ALT properties fell into four land type categories:
        i. Mixed wood forest
        ii. Agricultural Land and mixed wood forest
        iii. Bogs/wetland and mixed wood forest
        iv. Meadow and Mixed wood forest
2. From here, assign a numerical value to each site within each of the land-type categories. Use a random number generator to generate a number for each land type. The property in each land type that matches the generated number is the property where sampling will take place. In the case of the ALT project because of time constraints, this meant selecting four properties (one from each land type category) to sample. However, sampling more than one property within each land type is recommended to increase the sampling size. The same process of random number generation can be used multiple times in order to randomly select more than one property per land type.

3. Once properties have been chosen, use ArcGIS, or the proposed methodology (see Appendix D) in the case of no access to GIS, to map out the site and generate 6 random points. Only 4 points will end up being sampled, however generating 6 prior to being in the field ensures that at least 4 will be accessible.

Sampling Methods

1. Once the points are randomly selected (prior to heading out into the field) a GPS unit is used to find the exact longitude and latitude position of the point. Or if no access to GPS, use a tape measure to locate the plots based on the methods presented above.

Photo to the left shows the GPS Unit in the field locating each generated random sampling plot.

2. Once at the first plot, take a soil sample directly at that point. Collect a predetermined portion of the sample and label the bag in a schematic way. The length of this sample is not important, but it must be consistent in all sampling and it must reach below the humus layer and drive into the organic and subsoil levels. For reference, the ALT project collected 5cm in length of soil from the soil core sampler.

Photo to the left shows the sampled soil in the sampler being measured to the correct depth for volume purposes later on in the calculations. As mentioned above, 5 cm was measured here.

3. Next measure the distance from the point to the nearest fully grown/mature tree in each of the four directions to create 4 quadrants. Identify the type of tree, record the distance in meters and take the DBH of all 4 trees in centimeters (Figure 2.)

Photo to the left shows the DBH of a sampled tree being measured.

4. Take a tree core from one of the four trees. Attempt to take a tree core from all tree species that are identified in order to collect samples as representative of the property as possible. Ensure that the tree core is placed in a plastic bag that is correctly labeled.

An example of a tree corer, that was used to gather the tree core samples in ALT properties.

5. After all samples are taken at the first point, use a random number generator to select a number between 0 and 360. The number generated is the direction in which the transect will follow. Follow the randomly determined direction with a tape measure in as straight a line as possible and measure out 20 meters from the original plot. Complete all sampling methods (soil sample, tree core, etc.) at 20 meters and then repeat again at 40 meters (See Figure 3 for full diagram).

Photo shows a tape measure extended 20m in the direction of the randomly generation direction.

6. Repeat this sampling process for each of the four randomly generated plots, collecting 12 total data points, 3 sets of data at each plot.

Lab Work

Once all data is collected, bring the tree cores and soil samples to the lab where the samples will be weighed and burned. The goal of this lab work is to measure the organic content in all tree cores and samples through a loss-on-ignition process and relate the amount of organic matter to the amount of carbon stored.

Tree Core Samples:

1. Record the mass of the wet tree core samples.
    a. Make sure to record the mass of the container holding each sample and the mass of the soil and the container. This difference gives the actual mass of the sample.
2. Place each tree core samples in a drying at 65˚C for at least 24 hours. Once it has been over the 24 hours record the mass of the dried sample.
3. Take the tree core samples to the location of the furnace and transfer them into furnace safe crucibles. It will likely be required to subsample the dry samples so the crucibles are not overflowing. No material can be hanging over the edges of the crucible because when the samples are burned the residue must stay in your crucible and not fall out of it.
4. Weigh the crucible both alone and with the subsamples in it. Make sure to label the bottom of the crucibles using pencil with the sample ID (any other writing utensil other than pencil will burn off).
5. Place the crucibles in a rack and put them in the furnace at 550˚C for 4 hours.
6. Once samples are burned, record their weight and total organic matter content is the amount lost-on-ignition.

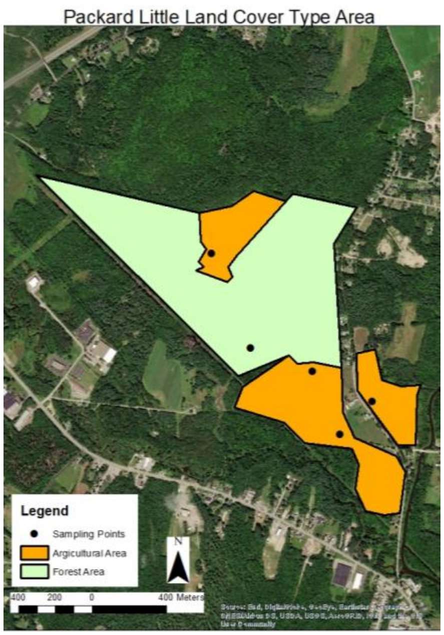
Soil Samples:

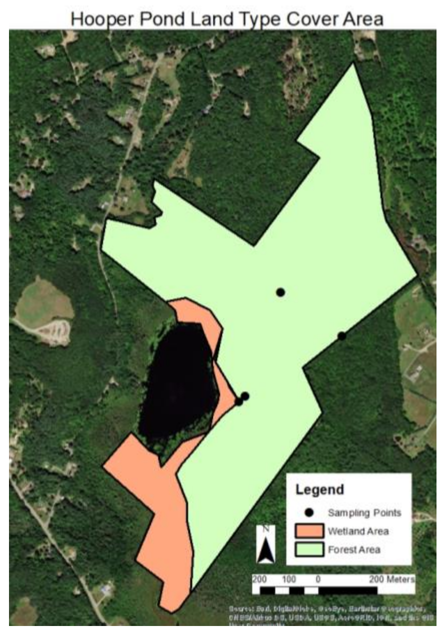
1. Place soil samples in a graduated cylinder to measure the wet sample volume.
2. Follow sets 1-6 present in the lab work of tree core samples above.

Calculations

Tree Calculations:

1. To begin the calculations, we first had to obtain the area of each land cover type. This was done on ArcGIS by estimating the lines of land types through satellite images. These are pictured below. Spruce Mountain did not need multiple polygons because it was all classified as the same land cover type. Spruce Mountain's area was found to be 567,216.7393 acres.





Figures 11 & 12. Maps showing the land cover type boundaries for Packard Little Farm and Hooper Pond. These areas were obtained by drawing out boundaries on ArcGIS Online. The areas for Packard Little were 841,329.4994 m^2 for agriculture and 28080815.6 m^2 for forest. Hooper Pond areas were 120,606.256 m^2 for wetland and 674,029.2077 m^2 for forest.

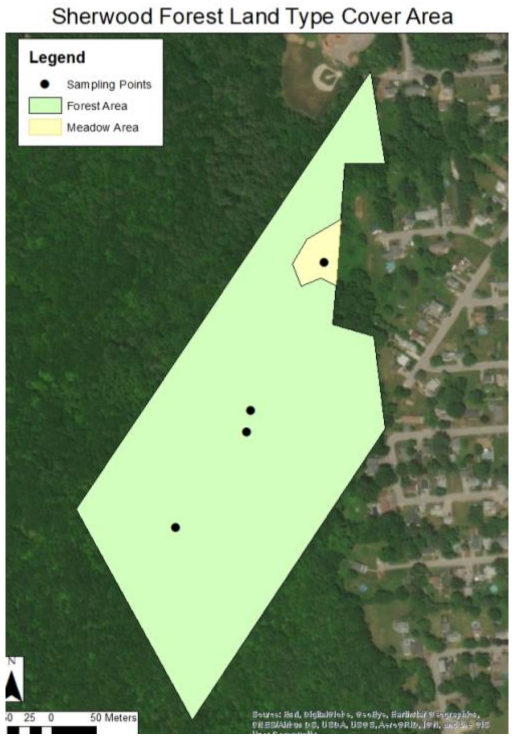


Figure 13. Map showing the land cover type boundaries for Sherwood Forest. Similar to figures 12 and 13, the area was calculated by drawing boundaries from a satellite image. The meadow portion of Sherwood Forest is 108663.1013 m^2 for forest and 2560.401701 m^2 for meadow.

Tree Calculations:

1. The number of tree species per hectare is calculated by multiplying the proportion of trees in one species out of the total number of trees in that polygon by the mean distance (m^2) to each tree in the given polygon.
    a. Number of tree species per hectare must be calculated for all species recorded at each property.
2. The following equation is used to calculate the concentration of carbon per tree species and these concentrations are added together to determine the total concentration of carbon within that polygon.

$$\text{TREES: } \overbrace{\frac{\text{number of species X}}{\text{total trees counted}}}^{\text{Proportion species X}} \cdot \overbrace{\frac{1}{(\text{mean distance (m)})^2} \cdot \frac{10^4 m^2}{ha}}^{\text{Total Trees / ha (density)}} \cdot \overbrace{\text{total biomass of species X (kg)}}^{\text{Biomass from lit}} \cdot \overbrace{\frac{g\ C}{g\ dry}}^{\text{Proportion C (from lit)}} \cdot \overbrace{\frac{1\ ha}{10^4 m^2}}^{\text{Unit Conversion}}$$

Figure 14: Carbon concentration in trees. Equation to calculate the concentration of carbon in trees in each polygon. The proportion of species X is based on the number of trees in the polygon. The literature value for the proportion of C (g C/g dry) is 0.52 for softwood trees and 0.49 for hardwood trees (Birdsey, 1992).

Tree Species X/ha	organic content (g OM/g dry tree)	Proportion C	Unit Conversion	Carbon Concentration (kg/m^2)	Area (m^2)	Total amount of C (kg)	tree species
103.2260129	0.9891039193	0.4846609205	0.0001	2.887506223	108663.1013	=AA2*AB2	White birch
154.8390194	0.9901230038	0.4851602719		3.856629576		419073.3303	Red Oak
103.2260129	0.9963163597	0.4881950163		2.90856161		316053.3249	White birch
25.80650323	0.9845442727	0.4824266936		0.1767804028		19209.50682	Ash
103.2260129	0.9955837704	0.4878360475		2.906422951		315820.9315	white birch
129.0325161	0.9894123875	0.4848120699		0.7911155671		85965.07101	American beech
412.9040516	0.9908536585	0.4855182927		10.31744944		1121126.053	Maple

Figure 15: Total Carbon content per species. Example excel spreadsheet of data used to calculate the total amount of carbon sequestered by each species within the polygon.

3. Once carbon concentration for each species is calculated, that value is multiplied by the total area (m2) of the polygon to provide the total amount of carbon sequestered in a property for that species. Sum the total carbon for each tree species to get the total amount sequestered by all trees. These calculations must be done for all polygons in the property and the totals added to calculate the total carbon stored in the entire property.

Soil Calculations:

1. Soil organic content is calculated by the difference between the pre and post burn mass (Dry sample (g) - burnt sample (g)). This is the loss-on-ignition.
2. Organic matter content in the soil is calculated as: Organic matter (OM) (g)/Dry Soil(g). This value must then be multiplied by the literature proportion of grams carbon per grams of organic matter. This value is 0.58 (g C/ g OM) (USDA).
3. Carbon concentration for each sampling plot was calculated by multiplying the following to result in a concentration in kg C/m^3;

$$\overbrace{\frac{g\ (\text{wet peat})}{cm^3}}^{\text{Field (wet) weight}} \cdot \overbrace{\frac{10^6 cm^3}{m^3}}^{\text{Unit Conversion}} \cdot \overbrace{\frac{g\ \text{dry}}{g\ \text{wet}}}^{\text{Proportion dry wt.}} \cdot \overbrace{\frac{g\ \text{OM}}{g\ \text{dry}}}^{\text{Proportion OM (loss)}} \cdot \overbrace{\frac{g\ \text{C}}{g\ \text{OM}}}^{\text{Proportion C (from lit)}} \cdot \overbrace{\frac{kg\ \text{C}}{g\ \text{C}\cdot 10^3}}^{\text{Unit Conversion}}$$

Figure 16. Carbon concentration in soil. Equation to calculate the concentration of carbon in soil in each polygon. The literature value for the proportion of C (g C/g dry) is 0.58 (g C/ g OM) (USDA).

4. From this calculation of soil carbon concentration, the total amount of sequestered carbon at each polygon can be calculated by multiplying the carbon concentration by the polygon area (m^2) and the depth at which the samples were taken. These values can then be summed to calculate the total amount of carbon contained in the soil.

APPENDIX D: Alternate Method for Random Plot Generation

In thinking of ways to make quantification of carbon an accessible process for all land trusts and other organizations, in Maine and the nation, it was necessary to create another method to generate random sampling plots. In doing this, we understand that not all organizations and people have access to ArcGIS to create random points for sampling. Below we have provided an alternative stratified sampling scheme that can be applied to any property around the world. The goal is to select non-biased points to begin each transect so that each sampling location is equally likely to be selected, and the selection of one spot doesn't influence the selection of the next, meaning the locations are independent of one another. To reduce bias, it is best to set the preset grids and/or lines on the map and select sampling points prior to heading out to the field.

Different Options:

1. Divide the area in half along the side that is the shortest and pick one side of the property to start on, along that shortest edge. The transect will be perpendicular to the shortest side (along the long side). Use random number generator to select a certain number of points (we can decide how many we want to sample) between 0 m and however many meters long the property is. Those will be the points that we stop as we move from the starting point. At each distance from the starting point we will select a random number between 1 and 360 and that will be the compass direction we go until we reach the edge of the property (sampling every 20 m). OR just turn a compass without looking to select the direction OR flip a coin to determine whether we go left or right at each distance and then sampling left/right until we get to the edge of the property.
2. Divide the area into thirds (or manageable sized sections - fourths, fifths, etc.) along the longest side of the property. Use random number generator to pick a random number

between 0 and the length (in meters) from one edge of the property to the next. The number of samples we want will determine how many random numbers we pick. Do this for each of the three transects. We will then walk that distance along the measuring tape and at the point flip a coin to determine whether we will sample left or right. Continue sampling until we reach the edge of the property or the location the next transect would be (sampling every 20 m).