Aboveground carbon sequestration in Norway Valley

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ABSTRACT

As anthropogenic climate changes continues to increase in intensity, a variety of potential mitigation solutions must be explored. Biotic carbon sequestration, especially by forests, represents a viable possibility for tempering the addition of greenhouse gases to the atmosphere. Saint Olaf College's Norway Valley natural area, a protected area of forest, may represent a contribution to this mitigation. In 2012, as part of the Ecological Research as Education Network's (EREN's) Permanent Forest Plot Project (PFPP), St. Olaf student Kirsten Maier estimated the aboveground biomass, carbon content, and carbon dioxide content of the mature trees of the area by measuring the diameter at breast height (DBH) of all mature trees in three 400-m^2 plots. Maier also investigated the species composition of small stems. This study expands on Maier's work by re-measuring the same trees in order to quantify changes in biomass and carbon content in the time that has elapsed since the previous study. Biomass, carbon content, and carbon dioxide content have all increased considerably since 2012, providing strong evidence that the area's potential for carbon sequestration is presently increasing. However, small-stem species composition was entirely dominated by *Acer saccharum*, causing concern for the future species richness of the area.

INTRODUCTION

In the years since the Industrial Revolution, human activity has exerted tremendous negative impacts upon the ecosystems of the world. Recently, human impacts surpassed natural disturbances as the primary force driving forested landscapes (Frelich & Lorimer 1990). Between 2000 and 2005, over one million square kilometers of global forest was destroyed by human activity (Hansen et al. 2010). Many ecological systems have been irreparably altered by anthropogenic activity and are not likely to ever be fully restored (Jackson & Hobbs 2009).

Carbon emissions are an enormous contribution to human destruction of the natural world. Greenhouse gases resulting from fossil fuel combustion, deforestation, and changes in land use can exert effects on ecosystems for up to a millenium (McKinley 2011, Runion 2003, Solomon 2009). Human carbon output has already begun to increase the temperatures of the world's oceans, and is expected to continue to do so (Doney 2010).

Changing temperatures have drastically changed the globe as a whole, altering ecosystems that provide habitats for all types of organisms. Heat waves and extreme precipitation are already occurring and are expected to further increase, with the majority of the globe experiencing novel climates by 2100 (Buckley & Kingsolver 2012). Climate change interacts with other human impacts such as deforestation, harvesting, and hunting, further contributing to losses in species richness (Costello 2013). Such changes are expected to have enormous impacts on the flora and fauna of the earth. Various estimates of the rate of species extinction worldwide range from 0.5% to 5% per year, which would result in the extinction of half of all Earth's species within 150 years (Costello 2013). The human-induced sixth mass extinction event in the history of life on Earth has been termed "anthropogenic climate change" (Dirzo 2014).

Offsetting the impacts of carbon emission will require proactive solutions from human communities; biotic carbon sequestration is a viable option that has recently begun to be studied in-depth. Biotic carbon sequestration is cost-effective, immediately available, and exhibits many ancillary benefits for both the forests' biomass and soil, whereas abiotic sequestration is expensive and in need of further development (Lal 2008). Furthering our knowledge of biotic carbon storage will enable us to address climate change more effectively. Understanding forests' ability to store carbon is becoming an increasingly important potential avenue for mitigating carbon release. The respiration cycle is highly temperature-dependent, so climate change is likely to decrease forests' ability to store carbon (Allen 2010).

From 1991 to 1997, the biosphere absorbed 3.4 out of 6.2 gigatons of CO_2 that would have otherwise been imposed on the atmosphere (Battle 2000). Those findings represent the entire globe; consequently, more research is needed in order to determine specific ecosystems' capabilities of carbon storage.

Therefore, through this study, I sought to quantify the extent to which Saint Olaf College's Norway Valley area is storing carbon. In 2012, St. Olaf student Kirsten Maier analyzed Norway Valley's carbon storage by calculating both the aboveground and soil biomass; she then converted the biomass values to determine total carbon and total CO_2 storage. Maier also sampled the small-stem density in the area in order to investigate species composition. I have expanded on her research by making the same measurements this year for aboveground biomass, in order to determine if the aboveground carbon storage capability of Norway Valley has increased.

Objectives

1. to quantify the aboveground biomass, carbon, and carbon dioxide storage of Norway Valley and compare them with the 2012 values
2. to determine whether diameter at breast height (DBH) differs between 2012 and 2014 for the three major species *Acer saccharum*, *Tilia americana*, and *Ostrya virginiana*
3. to discern whether small-stem species composition differs between 2012 and 2014

METHODS

Data were collected in Norway Valley, a restored forest fragment at Saint Olaf College, using the protocol developed by the Ecological Research as Education Network's (EREN) Permanent Forest Plot Project (PFPP) (Kuers et a. 2011). In 2012, Maier established three 20-by-20-meter plots, referred to as "path", "slope", and "obelisk" (named for landmarks in Norway Valley). I located these plots using Maier's flags from 2012; a compass allowed me to orient the entire plot as Maier did. In each plot, all mature tree individuals (DBH > 2.5 cm) were identified, and I measured the diameter at breast height. As I measured each tree, I mapped its location in the plot in order to aid potential future research. Each tree was tagged with a number from Maier in 2012, which facilitated organized and uniform data collection.

DBH measurements were converted to individual tree biomass via the equation below, from Jenkins et al. 2003 (for hard maple/oak/hickory/beech forests). The values for individual tree biomass were summed in order to obtain the total biomass for all measured trees in 2012 and 2014.

$$Biomass = \mathrm{Exp}(\beta_0 + \beta_1 * \ln \mathrm{DBH}), \text{ where } \beta_0 = -2.0127 \text{ and } \beta_1 = 2.4342$$

The biomass values were converted to carbon content using the equation from the Permanent Forest Plot Project (Kuers et al. 2011). Carbon content for each individual tree was summed to generate the carbon content of all measured trees in 2012 and 2014.

$$\mathrm{Carbon} = biomass * 0.45$$

In order to determine the CO_2 equivalent of the carbon content of each tree, I used the equation from Swarthmore 2011. The CO_2 equivalents for each tree were summed to provide the total CO_2 content estimation for all measured trees in 2012 and 2014.

$$CO_2 = carbon * 0.00367$$

In each of the three plots, a 5-by-5-meter plot was established in a random location, in accordance with PFPP protocol. All small stems (DBH < 2.5 cm, height > 0.5 m) were counted and identified by species.

R-commander and R statistical software (i386 3.1.1, 2014) were used for all statistical tests conducted. Analyses of variance (ANOVAs) were used to compare 2012 and 2014 for mean DBH, total biomass, total carbon content, and total CO_2 content. An ANOVA was also used to compare DBH among *Acer saccharum*, *Tilia americana*, and *Ostrya virginiana*.

RESULTS

The total aboveground biomass of Norway Valley was estimated to be 278,248.14 kilograms, in a 9,323 kilogram increase from 2012 (Table 1). The total aboveground carbon storage of Norway Valley was estimated to be 125,211.66 kilograms, in a 4,195.33 kilogram increase from 2012 (Table 1). The total carbon dioxide storage of Norway Valley was estimated to be 459.53 kilograms, in a 15.4 kilogram increase from Norway Valley (Table 1).

Acer saccharum heavily dominated the mature-tree composition all three plots surveyed. Of the 145 mature trees surveyed, 98 were *Acer saccharum*, 19 were *Tilia americana*, and 10 were *Ostrya virginia*; all other species comprised 18 trees. In total, *Acer saccharum* comprised 73.4% of the aboveground biomass of Norway Valley, *Tilia Americana* made up 26.0%, and *Ostrya virginiana* was 0.3%. All other species surveyed represented only 0.3% of the biomass (*Carya cordiformis*, *Celtis occidentalis*, *Cornus alternifolia*, *Frangula alnus*, *Fraxinus pennsylvanica*, and *Ulmus americana*) (Table 2.2, Figure 1).

The mean diameter at breast height (DBH) of all mature trees observed was 13.60 cm, an increase of 0.19 cm from 2012. Of the three most common trees observed in Norway Valley, *Tilia americana* had the largest DBH (27.87), followed by *Acer saccharum* (13.98); *Ostrya virginiana* had the smallest mean DBH of the three (5.47). All three of these species underwent increases in mean DBH since 2012 (Table 3).

The average biomass (kg) of each individual mature tree was not significantly different between 2012 and 2014, although it did increase (from 284.4 to 289.6, p = .95). Though statistically insignificant, all three of the most common species exhibited increases in average biomass between 2012 and 2014. Within *Acer saccharum*, mean mature tree biomass was not significantly different between 2012 and 2014 (287.9 and 295.12, p = .94). Within *Tilia americana*, mean mature tree biomass was not significantly different between 2012 and 2014 (763.18 and 783.81, p = .96). Within *Ostrya virginiana*, mean mature tree biomass was not significantly different between 2012 and 2014 (11.04 and 12.00, p = .88).

The small stem composition of the “obelisk” plot was completely dominated by *Acer saccharum* in 2012, with 20 *Acer saccharum* individuals observed and none of any other species. This continued in 2014, with observation of 22 *Acer saccharum* individuals and none of any other (Figure 2.1). In 2012, the “path” plot contained small-stem individuals of at least six different species, with *Acer saccharum* comprising 88% of them. In 2014, this plot's small-stem composition was all *Acer saccharum* (Figure 2.2). The "slope" plot had a sizeable presence of small-stem individuals of *Tilia americana* and *Prunus serotina* in 2012, but in 2014 the small-stem population was all *Acer saccharum* (Figure 2.3).

DISCUSSION

The considerable increase in the biomass of Norway Valley between 2012 and 2014 is indicative of positive trends in the carbon sequestration potential of the area. Increased biomass necessarily causes an increase in both the carbon and CO_2 content of the area, meaning that carbon sequestration has increased sizably in Norway Valley. Biotic carbon sequestration means that less carbon dioxide is released to the atmosphere, representing an important force for the mitigation of global warming (Battle 2000). Additionally, carbon sequestration is beneficial for forest soil, and other studies have noted its positive effects for biomass and forest growth (Lal 2008). Therefore, the observed increases in biomass are favorable from a forest management standpoint.

The increased biomass and the subsequent calculations for carbon and CO_2 content were all based on calculations for diameter at breast height (DBH). The average DBH of mature trees increased since 2012, indicating positive trends for forest growth. Accordingly, the average biomass of individual trees increased by 5.2 kilograms, demonstrating that forest dynamics as a whole are trending towards growth.

Forest managers of the Norway Valley area should be pleased to know that the trees of the area are growing. This is likely because the area has generally been protected from human impacts since being acquired by Saint Olaf College. Based on the trends observed between 2012 and 2014, it can be inferred that continued protection of this natural area will allow for additional forest growth (Tabarelli 2005). The bulk of global deforestation is driven by socioeconomic factors tending toward resource exploitation and economic growth (Ehrhardt-Martinez 1998). Since Saint Olaf College has no economic interest in changing the current land use model of protection, this is unlikely to change in the future. Therefore, we can expect that forest growth will continue in the future. Further studies could monitor whether growth is sustaining. Based on my findings, I recommend that Saint Olaf College continue protecting Norway Valley.

Despite this overall trend of growth, the results of small-stem surveys were concerning. In 2012, small-stem counts revealed a presence of at least six different tree species (Maier 2012). However, in 2014, in all three plots, *Acer saccharum* was completely dominant, with no counts of any other species. Previous research has shown that the life history traits of *Acer saccharum* allow it to quickly become dominant after disturbances (Bray 1956). In accordance with Bray's findings, this study found that *Acer saccharum* is effectively replacing several other species in the area. Since no non-*Acer saccharum* small trees were found in the plots surveyed, we should expect to see very few mature non-*Acer saccharum* individual trees in the future. A study in Missouri from 1968 to 1982 found that, over the long term, *Acer saccharum* became increasingly overriding as it replaced other species (Pallardy 1988). However, studies in similar forests have shown that seedling dominance is not necessarily correlated with adult dominance, so this may not be a concern for Norway Valley in the future (Bray 1956).

Therefore, there is a wealth of evidence to suggest that the increasing prevalence of *Acer saccharum* should be carefully monitored, as it is likely to have negative impacts on the species richness of the area. Ecological research generally indicates that species richness is a determinant of ecosystem health (Cam 2000, Maron 2012, Connell 1978). Consequently, future research in Norway Valley could aim to investigate the extent to which *Acer saccharum* is replacing other species, especially as this *Acer*-dominated seedling population grows older.

ACKNOWLEDGEMENTS

I would like to thank the Ecological Research as Education Network for facilitating this project. The organization and design of the study was made possible by EREN's precedents. I thank Kirsten Maier for conducting the first part of this study and for sharing her data with me.

Her work in 2012 made this project possible. Additionally, I thank Michael Mayer for assisting me with data collection - the process would have been extremely difficult to do alone. I thank Professor Kathy Shea for helping me locate Kirsten Maier's plots, for her expertise in Saint Olaf College's natural protected areas, and for her ongoing guidance and assistance throughout the duration of the project.

TABLES AND FIGURES

Table 1 - summary statistics comparing 2012 and 2014

	2012	**2014**	**Increase**
Total aboveground biomass (kg / ha)	291453.56	301557.52	10103.96
Total aboveground C (kg / ha)	131154.1	135700.88	4546.78
Total aboveground CO2 (kg / ha)	455.1	498	42.9
Total C of Norway Valley (kg)	1008575	1043539.8	34964.8
Total CO2 of Norway Valley (kg)	3499.8	3829.8	330
mean DBH of mature trees (cm)	13.41	13.60	0.19

Table 2.1 - biomass by species, 2012

	Biomass (kg)	**Percent of total**
Acer saccharum	25618.799	73.25010393
Ostrya virginiana	99.39	0.2841791229
Tilia americana	9158.18	26.18536633
Other species	98.051	0.2803506105
Total	34974.42	100

Table 2.2 - biomass by species, 2014

	Biomass (kg)	**Percent of total**
Acer saccharum	26560.8	73.38279524
Ostrya virginiana	108.03	0.2984677935
Tilia americana	9405.722	25.98634723
Other species	120.308	0.3323897371
Total	36194.86	100

Table 3 - changes in mean DBH by species between 2012 and 2014

	DBH (cm) 2012	**DBH (cm) 2014**	**Increase (cm)**
Acer saccharum	13.76	13.98	0.22
Tilia americana	26.18	27.87	1.69
Ostrya virginiana	5.24	5.47	0.23

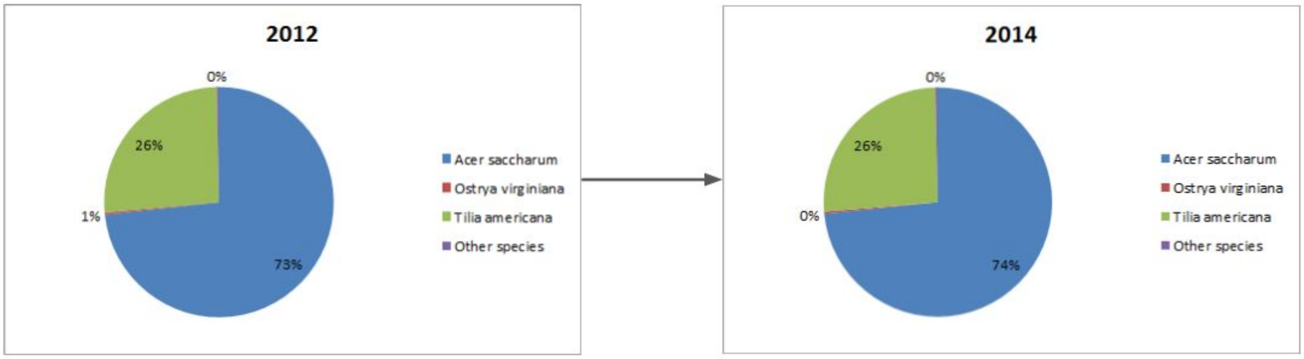

Figure 1. Biomass of Norway Valley by species

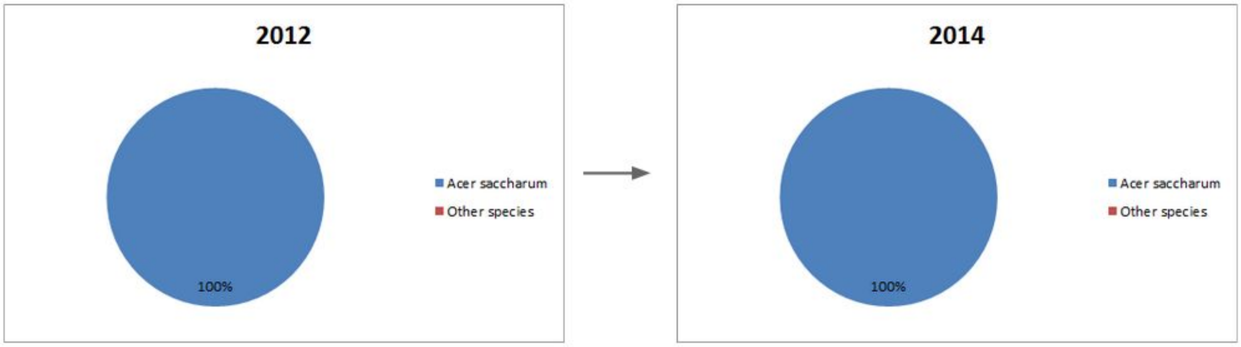

Figure 2.1. “Obelisk” plot small-stem species composition in 2012 and 2014

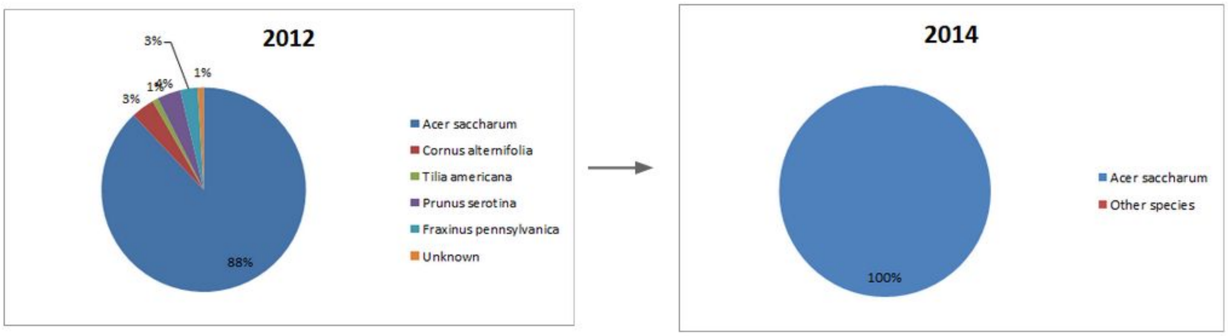

Figure 2.2. “Path” plot small-stem species composition in 2012 and 2014

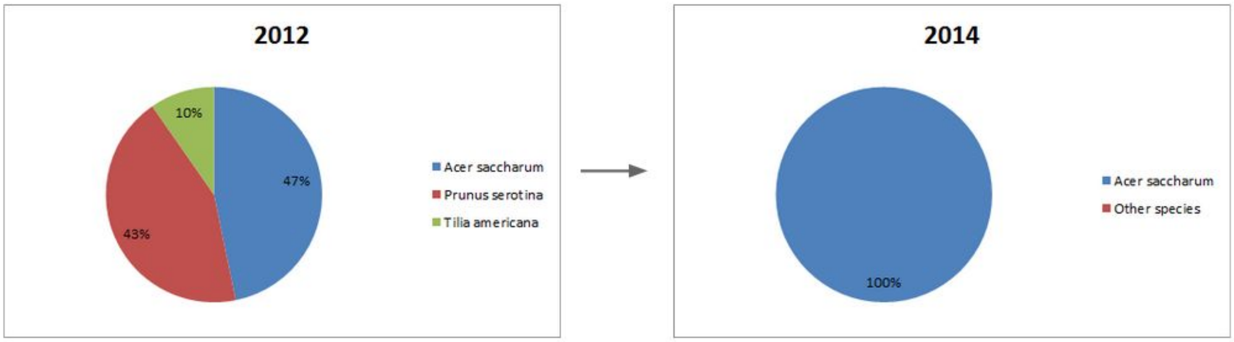

Figure 2.3. “Slope” small-stem species composition in 2012 and 2014

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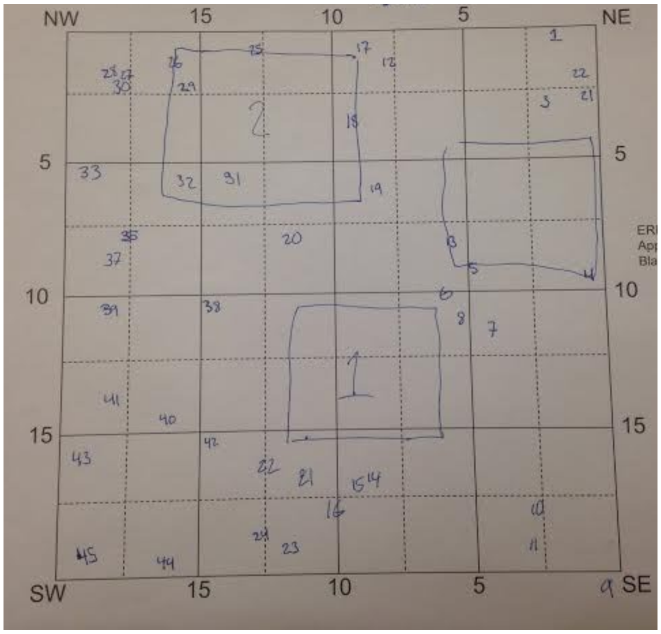
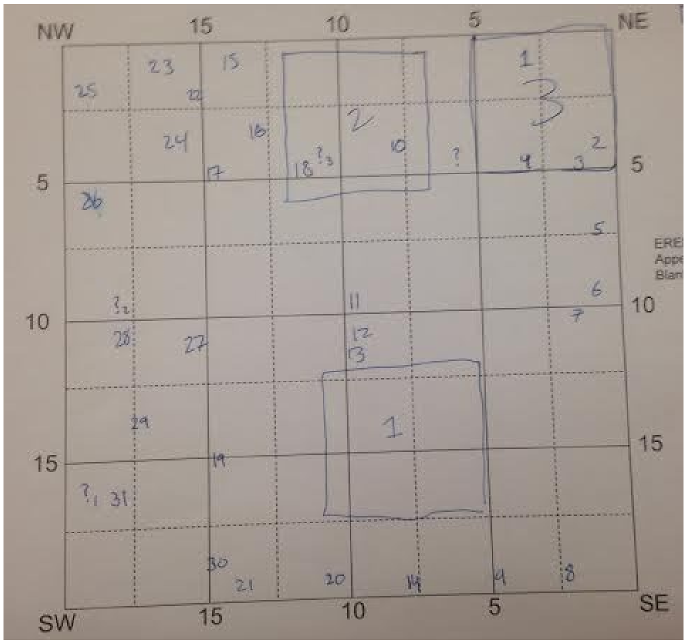
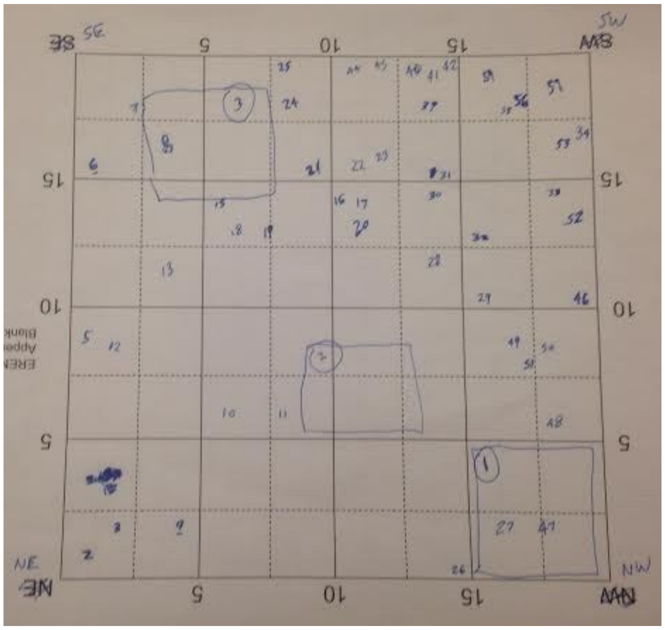
Appendix 1. Maps of individual tree locations in each of the three plots of Norway Valley. Each number corresponds to Maier's original tag from 2012. The squares represent the randomly chosen 5x5-meter subplots where small stems were sampled.



Obelisk plot



Path plot



Slope plot