Effect of major and minor disturbances

on the carbon stored in successional forests

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ABSTRACT

Carbon storage in post-disturbance forests differ depending on whether the disturbance was major or minor. In this study in Trelease Woods and Philips Tract, we examined whether number of trees per area, species composition and/or average size of trees in a forest recovering from clear cut (major disturbance) and species composition in a forest recovering from disease (minor disturbance) explained changes in carbon storage due to the respective disturbances. If species composition (and associated wood densities) explains the difference in carbon storage after disturbance, then species composition will differ between pre-disturbance and post-disturbance forests. If number of trees per area and average size of trees explain the difference in carbon storage between an old-growth forest and a forest recovering from major disturbance, then the old-growth forest will have more trees per area and greater mean tree DBH than the young, recovering forest. The main assumption is that today’s post-disease old-growth forest is representative of the old-growth forest that was clear-cut 56 years ago. Number of trees per species and the DBH of each tree in 4 m2 quadrats were measured. Carbon storage recovered in the post-disease forest was found to be 167.8% of that in the pre-disease forest and in the young, recovering forest it was 65.8% of that in the old-growth forest. Species composition differed in both post-disturbance forests. The number of trees per area was less in the young, recovering forest than in the old-growth forest. However, the mean tree DBH of the old-growth forest was less than the mean tree DBH of the young forest. Carbon storage recovered after a minor disturbance was more complete than that after a major disturbance and so a major disturbance will have a greater effect on climate change than a minor disturbance.

INTRODUCTION

Carbon storage in a forest is determined by the amount of carbon sequestered from the atmosphere and the amount of carbon released into the atmosphere. All living organisms in a forest are carbon sources that release carbon into the atmosphere via the process of respiration (Heimann and Reichstein 2008). Trees undergoing photosynthesis are the principal carbon sinks that sequester carbon in a forest. The carbon sequestered that is not immediately released through respiration of the trees goes into building the biomass, especially the wood, of each tree (Luyssaert et al. 2008). The greater the mean tree wood density in a forest the greater the carbon storage (Nogueira et al. 2007). After each tree undergoes mortality, the carbon stored in the wood of the tree is released back into the atmosphere by decomposers acting on the wood and respiring (Naeem et al. 2000). Determining the carbon stored in forests is important because it allows us to predict how carbon concentration in the atmosphere is likely to change and thereby lead to climate change (Coulston et al. 2015).

Carbon storage in a forest is affected by factors both at the individual tree-level and at the whole forest-level. Carbon compounds make up about half of the biomass in all species of trees (McKendry 2002). The factors that affect carbon storage include the size and longevity of the individual trees, the species composition, and the number of trees per area of forest (Veno 1976). The greater the number of trees per area of forest the greater the amount of carbon stored. Large, old trees sequester larger amounts of carbon compared to smaller young trees (Stephenson et al. 2014). The rate at which each tree species can sequester carbon and the amount of carbon that can be sequestered by all the individuals of each species (i.e. the species composition) also affect the carbon stored in the forest (Kirby & Potvin 2007).

An ecological disturbance reduces the carbon stored in a forest and leads to succession, thereby slowly restoring the forest’s carbon storage. Disturbances lead to sudden spikes in tree mortality. Decomposers act on the car-bon compounds that make up the dead trees and, through the process of respiration, return the stored carbon to the atmosphere (Goward et al. 2008). Forests undergoing succession usually experience changes in the average size of its component trees, the number of trees per area and the species composition (Veno 1976). As the forests mature, trees grow in size and accumulate more and more carbon (Stephenson et al. 2014). Young forests retain a similar forest structure as they mature but the species composition changes considerably and so the forest’s wood density ‘profile’ changes (Pena-Claros 2003).

The carbon storage recovered by forests after a disturbance is different depending on whether the disturbance was major or minor. Forests undergoing succession after a major disturbance event, like crop abandonment, experience changes in the number of trees per area, the species composition and the average size of the trees thereby leading to a change in the carbon storage (Goward et al. 2008). Forests recovering from a disease, a minor disturbance, are most directly affected by the changing species composition as the disease greatly reduces the abundance of one species and allows other species to grow and thrive in its place (Castello et al. 1995). This study aims to determine how the carbon storage differs in a forest recovering from major vs minor disturbance. Information about the effects of major and minor disturbances can help policymakers to make more sustainable policy decisions (Coulston et al. 2015).

This study’s objective was to determine whether the size of individual trees, species composition, number of trees per area or a different combination of each factor may explain the changes in forest carbon storage due to major vs minor disturbances. If species composition (and associated wood densities) explains the difference in carbon storage after disturbance, then species composition will differ between pre-disturbance and post-disturbance forests. If number of trees per unit area explains the difference in carbon storage between an old-growth forest and a forest recovering from a major disturbance, then the old-growth forest will have more trees per area than the old-growth forest. If the size of individual trees explains the difference in carbon storage between an old-growth forest and a young, recovering forest, then the old-growth forest will have a greater mean DBH than the young forest. It was assumed that higher wood density meant greater carbon storage and that today’s post-disease old-growth forest is representative of the old-growth forest that was clear-cut 56 years ago.

METHODS

*Study sites*

This study was conducted in the old-growth forest of Trelease woods and the young, recovering forest in the Philips Tract. Trelease woods, a 26.8-hectare fragment, is located 5 km northeast of Urbana in Champaign County, Illinois, USA (40°13’, 88°14’W). It contains high-quality upland mesic forest and is flat with elevation differences less than 5 m. In 1922, this forest had 37 woody species, 6 liana species, and 134 herb species.  American elm and sugar maple used to dominate. Between 1925 and the 1970s, there was a sharp increase in the number of sugar maple trees and a corresponding decrease in elms.  This was due to the widespread deaths of the elms around the 1950s from phloem necrosis and Dutch elm disease (a fungal disease that is spread by bark beetles). The elms were almost eliminated and the sugar maple thrived. In 2005, unpublished data collected by J. Edginton showed that the forest had become very dominated by sugar maple while the Ohio buckeye, basswood, and hackberry were also very prominent.

The Philips Tract, a 52.6 hectare abandoned farm (purchased by the U of I in 1968), is located on the west of the Trelease woods. Corn was planted in a 38mX210m strip at the NE corner of the Philips Tract in 1968 and then abandoned in 1969. The strip is now a successional strip that has almost no slope and silt-loam soil.  There are 14 species of trees in the strips that have started to grow as a result of dispersal by wind, birds, and mammals. The strip also has 6 species of shrubs and 4 species of woody vines.  Its understory under a closed canopy of trees/shrubs is sparse with few herbs.  In open and light canopy areas, dense grasses and goldenrod are the dominants. (Augspurger 2016)

*Experimental design*

Measurements of tree DBH and number of trees of each species were made in the pre- and post-disease Trelease woods and the successional plots in the Philips Tract. Tree species, DBH and number were determined in 25 2mX2m quadrats in post-disease Trelease woods and 25 2mX2m quadrats in the NE successional plot of the Philips Tract (I assume previous data for pre-disease Trelease forest already exists?). The 50 quadrats were located in two 50mX2m strips that were marked off in the young forest and old forest sampling grids. The quadrat width was determined by spreading the arms from end-to-end and all the trees that fell within the two arms’ lengths in the 50m stretches were determined for species and DBH. The shrubs and other trees that did not reach breast height were not measured. The average of the individual DBH was converted into biomass using allometric equations.

*Statistical tests*

The species composition of pre-disease vs post-disease old forest and young forest vs old forest were tested by two X^2 tests for independence. The average size of old vs young forest and the number of trees of old vs young forest were tested by two t tests.

RESULTS

Carbon storage was greater in post-disease Trelease Woods than in pre-disease Trelease Woods. The amount of carbon stored in the pre-disease forest was 89006 kg/ha while the amount stored in the post-disease forest was 149370 kg/ha. Thus, the carbon storage recovered after the minor disturbance was about 167.8% (Table 1).

Species composition was different in the pre- and post-disease old growth forest (Fig 1). There were large increases in the numbers of sugar maples and Ohio buckeyes in the forest recovering from disease. Basswood was also present in greater quantities. Sugary elms, on the other hand, were almost completely wiped out. The distribution of number per species was, however, independent of whether the forest had gone through disease or not (X2-test P>0.05).

Carbon storage was lower in the young recovering forest than in the adjacent old-growth forest. The carbon stored in the young forest was 98308 kg/ha while the carbon stored in the old-growth forest was 149370 kg/ha. Based on these values, the carbon storage recovered by the young forest that had suffered a major disturbance 56 years prior was 65.8% (Table 1).

Species composition of the young, recovering forest was significantly different from the old-growth forest (X2-test P<0.05) (Fig 2). The young forest’s species composition was mostly split between Black Cherry, Mulberry, Hawthorn and Honey Locust while the old-growth forest had an almost completely different species composition with most of it split between Sugar Maple, Ohio Buckeye and Basswood.

Mean DBH of individual trees was significantly larger in the young, recovering forest than it was in the old-growth forest (X2-test P<0.05) (Fig 3).

However, the average number of trees per area was significantly greater in the old-growth forest compared to the young forest (X2-test P<0.05) (Fig 4).

DISCUSSION

The percentage carbon recovered after a minor disturbance was 167.8 % while that after a major disturbance was 65.8 %. Based on these results, the post-disease forest had recovered more carbon storage than was stored in the pre-disease forest while the forest recovering from clear cut had recovered less carbon storage than it had before the disturbance. It is most likely that the factor that had the greatest effect on carbon storage in the post-disease forest was the changing species composition. This is because a disease usually only affects one species and the reduction of this species allows other unaffected species to take over (Castello et al. 1995). In contrast, a major disturbance usually leads to drastic changes in all quantitative aspects of a forest, including the species composition, the number of trees per area, and the size of individual trees (Veno 1976). Therefore, the carbon storage in the forest recovering from clear-cut was heavily reduced while the carbon storage recovered in the post-disease forest was more complete (dependent primarily on the species composition).

This study’s result that the carbon storage recovered in a forest recovering from a minor disturbance is more complete than that in a forest recovering from a major disturbance is consistent with prior studies in a mixed deciduous forest in Michigan, USA (Gough et al. 2007) and in temperate forests in Midwestern United States (Flower et al. 2013). In the mixed deciduous forest in Michigan (Gough et al. 2007), study plots that had experienced an additional clear cut stored on average 26% less carbon than a reference stand. On the other hand, the temperate forests that were impacted by the Emerald Ash Borer (EAB) disease in Midwestern United States (Flower et al. 2013) had similar amounts of carbon storage as the forests in the study that were not impacted by EAB.

The results support the hypothesis that a change in species composition explains the difference in carbon storage between a pre- and a post-disease forest however the species composition was independent of whether or not the forest had undergone disease. The post-disease forest had a different species composition compared to the pre-disease forest, with large numbers of sugar maples and Ohio buckeyes replacing slippery elms in the post-disease forest. Sugar maples were the dominant species that replaced the elms in the post-disease forest and they had a higher wood density (0.63 vs 0.50 specific gravity) than the elms. Thus, the post-disease forest was able to sequester more carbon than the pre-disease forest and the % carbon recovered was around 168%.

This study’s finding that species composition differed between pre- and post-disease forest were consistent with prior studies that examined changes in species composition due to Beech bark disease (Forrester et al. 2003) and the Emerald Ash Borer (Flower et al. 2013). The effect of Beech bark disease on species composition was examined in a northern hardwood forest (Forrester et al. 2003) and it was found that there was a small variation in the biomass (and thereby carbon storage) in the forest which depended on the species that had been replaced and the replacement species. The temperate forests that were impacted by the Emerald Ash Borer (EAB) disease in Midwestern United States (Flower et al. 2013) showed small changes in carbon storage, which could be explained as due to the enhanced growth of non-Ash trees in these forests compared to the forests in the study that were not impacted by EAB.

As predicted there was a greater number of trees per area in the old-growth forest than the forest recovering from clear-cut. There was also support for the hypothesis that a difference in species composition explained the change in carbon storage between the old-growth forest and the young, recovering forest. The dominant species in the young forest (Hawthorn, Mulberry and Ash) all had lower wood densities than the sugar maples, which largely dominated in the old-growth forest. The average size of trees however was larger in the young, recovering forest and thus the results did not support the prediction that the mean size of trees would be greater in the old-growth forest. This might be due to the large amount of carbon that was released into the atmosphere by decomposers acting on dead trees after the forest had experienced the clear cut (Gough et al. 2007). Trees in the young forest were thus able to sequester larger amounts of carbon and grow very large rapidly. Number of trees per area, size of trees and the species composition all differed significantly between the old-growth forest and the young, recovering forest, and are thus all factors that determine how much carbon is stored in a forest recovering from clear cut.

Prior studies in a lowland dipterocarp forest in Malaysia (Okuda et al. 2003) and four rainforest plots in India (Pomeroy et al. 2003) did not support this study’s finding that mean tree size in an old-growth forest is greater than that of a forest recovering from a major disturbance. Both studies agreed that mean tree size tended to decline after a major disturbance. In the dipterocarp forest (Okuda et al. 2003) the decline in mean tree size was more due to the change in height of the trees rather than the mean DBH of the forest. The result that old-growth forest and a forest recovering from a major disturbance differ in species composition was supported by several prior studies (Okuda et al. 2003; Pena-Claros 2003; Pomeroy et al. 2003). These studies were carried out in different types of forests in Malaysia, India and Bolivia and they all showed significant changes in species composition after major disturbances. The study in the four rainforest plots in India (Pomeroy et al. 2003) also showed that the number of trees declined for forests recovering from major disturbances and this agrees with our result that number of trees per area in the old-growth forest was greater than that in the young, recovering forest. In a study in mixed deciduous forest in Michigan, USA (Gough et al. 2007), study plots that had experienced an additional clear cut stored on average 26% less carbon than a reference stand and this provides support for this study’s finding that carbon storage was reduced after a major disturbance.

One major limitation of the study was that it was carried out in only one forest that underwent a minor disturbance and one forest that underwent a major disturbance. Our calculations for the mean size of trees in the old-growth forest and the young, recovering forest contrasted with previous studies (Okuda et al. 2003; Pomeroy et al. 2003) that showed that trees in the undisturbed forests had larger on average than in the forests recovering from major disturbances. This might be because our study did not account for differences in height and/or the representative old-growth forest for which mean DBH was measured was actually dissimilar to the forest that was clear cut 56 years ago. Another limitation was the small number of quadrats used in measuring the species composition of the post-disease forest and the forest recovering from clear cut. A future study would include a larger number of forests that are recovering from major and minor disturbances. The measurement would be carried out in a greater number of quadrats which are randomly spaced. Wood density and average height of each tree species would also be measured. Lastly, the pre-disturbance values of the forests undergoing major disturbance would be used instead of the values in a representative old-growth forest.

Forests that have been affected by disturbance experience changes in carbon storage. This study clearly showed that the carbon storage in a forest recovering from a major disturbance is greatly reduced and that the number of trees per area, species composition and average size of trees affect the change in carbon storage. The study also showed that the change in carbon storage in a forest after a minor disturbance can be explained by differences in species composition, however the change in species composition was independent of whether the forest had experienced minor disturbance or not. The carbon storage recovered after a minor disturbance was more complete than that after a major disturbance. This shows that a major disturbance may have a greater impact on the climate than a minor disturbance.

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|  | Table 1 | | | |  |
|  | % Carbon storage recovered by forests after a minor vs major disturbance | | | |  |
| Type of  Disturbance | Reference | | Sample | | % Recovery |
| Minor | 1950s Old Forest (pre-disease) | | 2016 Old Forest (post-disease) | | 167.8 |
| Total Carbon Storage (kg/ha) | 89006 | Total Carbon Storage (kg/ha) | 149370 |
| Major | 2016 Old Forest | | 2016 Young Forest | | 65.8 |
| Total Carbon Storage (kg/ha) | 149370 | Total Carbon Storage (kg/ha) | 98308 |

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| Figure 1. Number of individual trees per area (400 m2) vs the species of trees in pre- and post- disease Trelease woods | | |
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| Fig 2. Number of trees per area(400 m2) vs the species of trees in old-growth forest and in young, recovering forest | | | | | | |
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| Fig 3. Average DBH of trees in old-growth forest vs young, recovering forest | | | | | |
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| Fig 4. Mean number of trees per area(400 m2) in old-growth forest vs young, recovering forest | | | |
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