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Effect of Silvicultural Treatments on Carbon Storage of Northern Hardwood Forests

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Abstract : This study is designed to provide forest managers and landowners with tools to estimate the effect of forest management on carbon storage, investigating living tree biomass, detritus, and harvested wood products as variables. Thinning, selection cutting, and uncutting were applied to the three different forest types in New York, USA. Carbon storage of the original stands was 90, 56, and 101 Mg ha^{-1} at the Allegheny hardwood forest, Northern hardwood forest, and Oak - black cherry forest, respectively. Among treatments, uncutting generally stored the greatest amount carbon. However, the rate of carbon storage was the smallest at the uncut treatment in all the sites. The 50% thinning, 50% selection, and 50% thinning treatments were the highest rate of carbon storage at the Allegheny hardwood forest, Northern hardwood forest, and Oak - cherry forest, respectively. In this study, only short term was applied to simulate carbon sequestration after silvicultural treatment. So, more research is needed to determine whether any silvicultural treatment can store significantly more carbon than no treatment over the long term.

Keyw ords : *Allegheny hardwood forest, carbon sequestration, Northern hardwood forest, oak - cherry forest, selection cutting, SILVAH, thinning*

Introduction

Combustion of fossil fuels and other human activities are the primary reasons for the increased concentration of atmospheric carbon dioxide, which is likely to accelerate the rate of climate change. The role of forests in carbon sequestration is of great political as well as ecological importance as natural sinks of carbon. The Kyoto Protocol calls for each Annex I country under UNFCCC that ratifies the agreement to reduce greenhouse gas emissions by specified targets below a 1990 baseline level during the first commitment period, 2008 to 2012.

The role of forests in carbon sequestration is to transform atmospheric carbon dioxide into organic matter. Many researchers have examined ways to sequester more carbon in forests or to offset losses from these systems (Cooper, 1983; Dewar, 1990; Nabuura and Mohren, 1995). These include establishing new stands, reducing forest burning and deforestation, and storing wood in durable products. However, the effect of silvicultural activity on carbon storage has rarely been studied.

In New York State, forests cover 62% of the total land area, with 85% of forests in private ownership (Alerich and Drake, 1995; Canham and King, 1998). Half of the forested area is economically mature and the majority is not protected from timber harvesting. But few have written management plans for carbon storage so far.

The offset credits associated with forest growth could change the economics of land use and forest management in the region. Forest managers and landowners need to be aware of the effects of alternate treatments on carbon storage as well as economic products.

The objectives of this study were to calculate carbon storage in aboveground biomass of a northern hardwood forest using a forest inventory simulator, and to predict which silvicultural treatments are effective for carbon storage by simulating biomass increment, pools of detritus, and the fate of harvested carbon and to make recommendations for future research efforts as well as silvicultural decision-making in support of carbon sequestration.

Materials and Methods

1. Data Source and Silvicultural Treatments

Stand tables were used for Allegheny northern hardwood forest stand data cruised by USFS experimental

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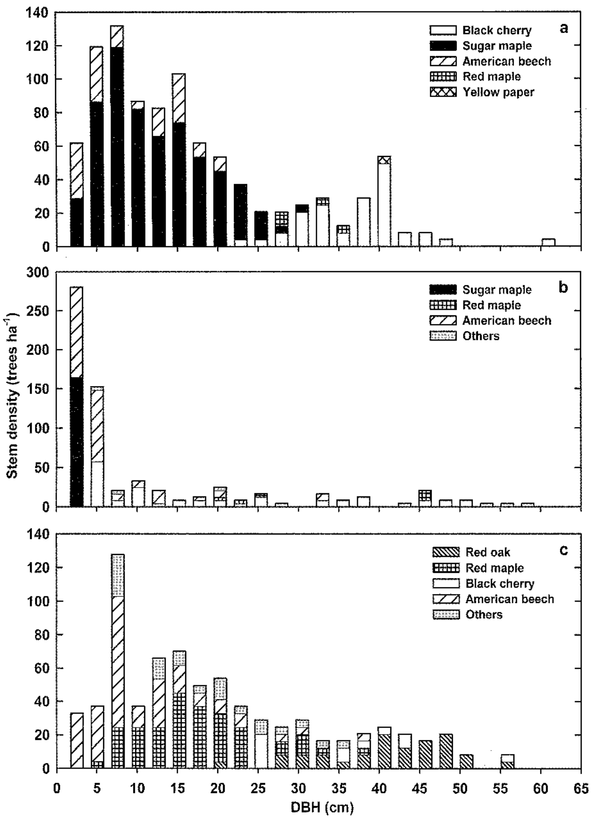

Figure 1. Tree density by DBH classes at the study sites: (a) Allegheny hardwood forest, (b) Northern hardwood forest, and (c) the Oak - black cherry forest.

Table 1. Cutting amount (%) for each treatment by diameter at breast height (DBH) class.

Treatment	DBH (cm)	Allegheny hardwood	Northern hardwood	Oak - black cherry
			%	
30% thinning	15-30	23	15	100
	31-45	11	5	42
	46-60	26	1	18
50% thinning	15-30	47	81	100
	31-45	41	40	60
	46-60	100	16	41
30% selection cut	15-30	32	0	0
	31-45	0	0	47
	46-60	0	10	22
50% selection cut	15-30	65	11	100
	31-45	27	7	69
	46-60	0	46	53

station in Burlington. Three different forest types in northern hardwood forests were investigated (Figure 1). Black cherry and red maple were dominant species at the Allegheny hardwood forest and at the Northern hardwood forest sugar maple and American beech were dominant species.

Importance of silvicultural treatment should be based on how widely they are used in New York State. In this study, thinning, selection cutting, and uncutting were considered. The 30% and 50% thinning and 30% and 50% selection cutting were applied for the silvicultural treatment (Table 1).

2. Trees

The living parts of trees are a sink for CO_2 while the forest is growing after silvicultural treatment. The model ignores the ecophysiological processes that regulate forest growth (Dewar, 1991). The main purpose of the model is to highlight the role played by harvesting practices.

Foliage and fine roots are ignored here in the description of the carbon pool in living trees because of their relatively small contribution (Cooper, 1983).

SILVAH version 5, a stand analysis, prescription, and management simulator program for eastern hardwoods (Marquis and Ernst, 1988), was used to simulate standing crops of large trees (> 5 cm in DBH). Field inventory data including tree species, diameter, and condition on northern hardwood stands are available for SILVAH. The data were converted to carbon amount using equations researched by USFS (Marquis, 1977). This process was repeated for each treatment and was compared with the results.

3. Detritus

Decomposition rates were based on published rate loss constants derived from measurements of a fraction or fractions of substrate lost per unit of time reported for materials in northern hardwood forests (Pastor and Post 1986). If such values were not available, the decomposition rates of temperate deciduous forests were used. k values sorted stem, branches, foliage, barks, stumps and roots. In order to use these k values to estimate decomposition, an equation incorporation rate loss constants (Richards, 1967) were rearranged to derive the following equation:

$$y = e^{(-tk)}$$

where t is the number of years since the onset of decomposition of a given material, and y is the fraction of original material remaining t years since the onset of decomposition.

4. Wood product

The wood products represent carbon stored in various wood products after harvesting that not yet decayed back to carbon dioxide. The harvested wood was allocated to one of four products group based on diameter of the stem. The average residence time of carbon in wood used to produce energy, paper, particleboard, and sawn timber were estimated by the carbon retention curves. Retention time was 4, 13, 30, and 65 years for pole, small saw, medium saw, and large saw timber, respectively.

The model Weibull carbon retention curves were applied for this study. Thompson and Matthews (1989) constructed model Weibull carbon retention curves for various timber products recognized by the market, based on estimates of the time to maximum rate of carbon loss and of the time to 95% carbon loss from each product.

In this study, carbon storage was estimated as the sum of three major forest ecosystem components: live trees, detritus, and harvested wood. The estimated volume of live trees, detritus, and harvested wood was added and converted to the amount of carbon stored. The decomposition rate constants applied to the mass of detritus and wood product pools, so the results were not sensitive to assumptions about the density of these materials. Although soil carbon storage is extremely large, it was ignored, assuming that silvicultural treatments don't significantly affect carbon change (Metting *et al.*, 2001).

Results and Discussion

The three forest types differed in carbon storage. Carbon storage of the original stands was 90, 56, and 101 Mg ha^{-1} at the Allegheny hardwood forest, Northern hardwood forest, and Oak - black cherry forest, respectively. The carbon storage at the Northern hardwood forest is about half of other sites because the size of trees is small even though it has huge number of stems (Figure 1).

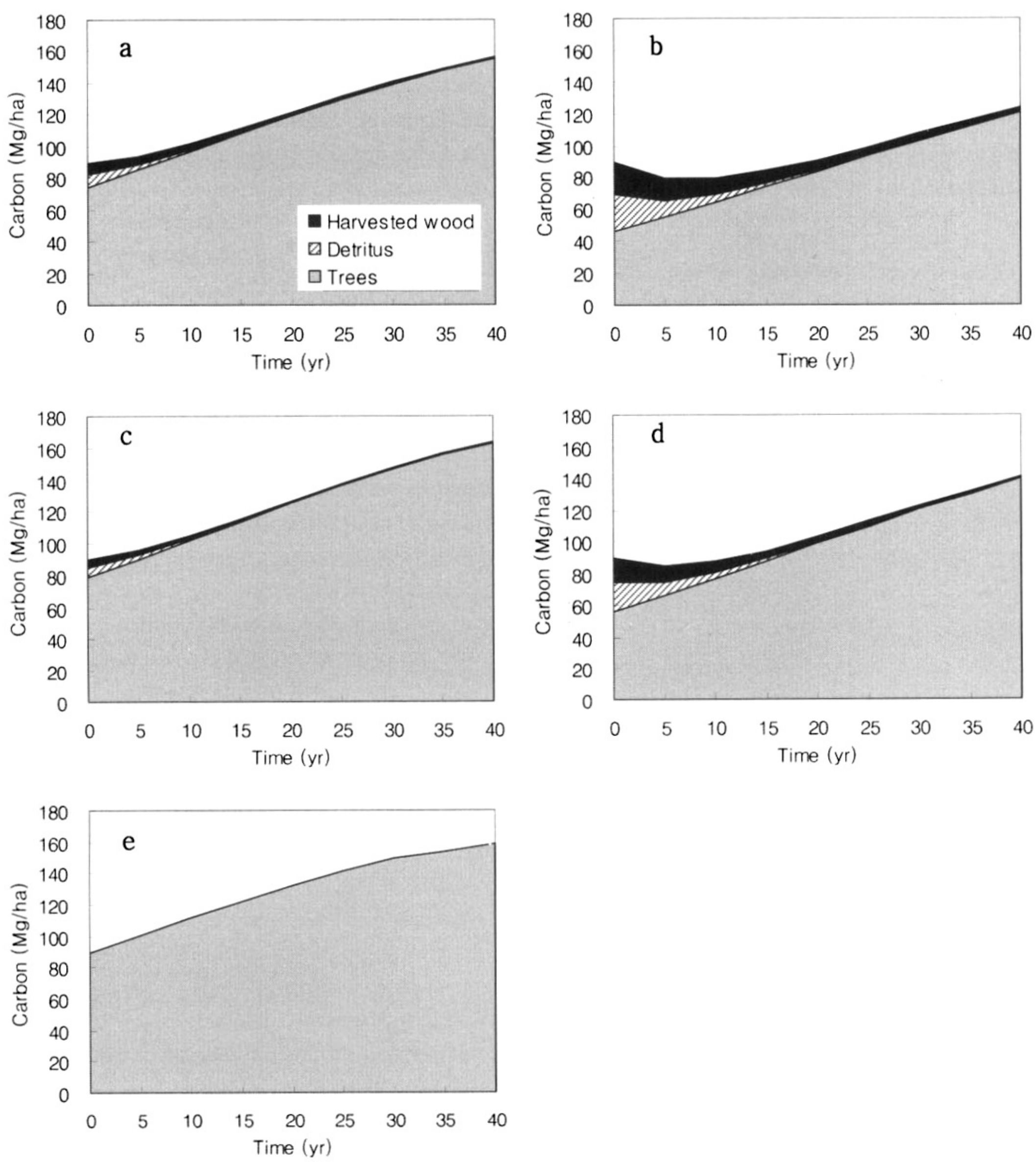

Figure 2. Carbon sequestration was simulated for 40 years at each application of (a) 30% and (b) 50% thinning, (c) 30% and (d) 50% selection cutting, and (e) uncutting at the Allegheny hardwood forest.

Sugar maple and American beech < 5 cm in diameter were composed of this forest more than 90%. Carbon storage of this study was comparable to the Northeastern American deciduous forests (Cutis *et al.*, 2002).

The order of carbon sequestration by the living trees at the uncut sites was changed by the silvicultural treatment: Allegheny hardwood (158 Mg ha^{-1}) > Oak - cherry forest (142 Mg ha^{-1}) > Northern hardwood forest (91 Mg ha^{-1}) at the last year in the simulation. Even though carbon storage was the smallest at the Northern hardwood forest, the percentage increase of carbon storage was the highest.

Total carbon sequestration was reduced in the beginning of the simulation by the silvicultural treatment and then increased after 5 years in the 50% thinning and 50% selection cutting treatment at all the sites. Results of the simulations suggested that tree cutting reduced total carbon storage compared to uncutting except 30% selection cutting at the Allegheny hardwood forest (Figure 2, 3, and 4), because the growth of residual trees was less rapid than the decomposition of the detritus and harvested wood products. The techniques to increase the durability of harvested woods should be developed to store carbon longer in the woods (Edlund and Nilsson, 1998).

Changes in carbon storage in each forest types were primarily determined by the growth of live trees. The rate of accumulation of carbon in live trees was greatest in the Allegheny Hardwood forest, where black cherry and sugar maple typically had the fastest volume growth,

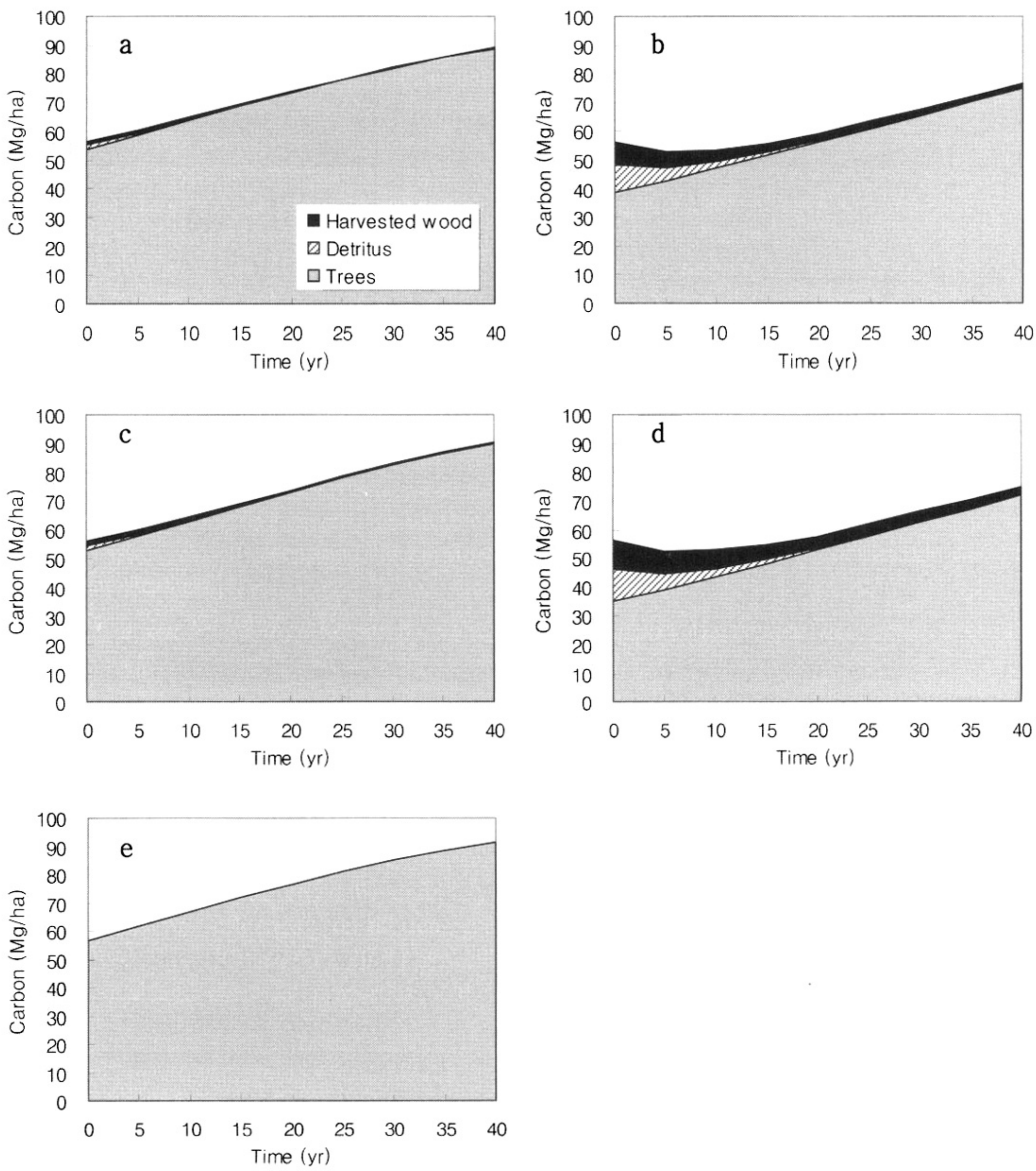

Figure 3. Carbon sequestration was simulated for 40 years at each application of (a) 30% and (b) 50% thinning, (c) 30% and (d) 50% selection cutting, and (e) uncutting at the Northern hardwood forest.

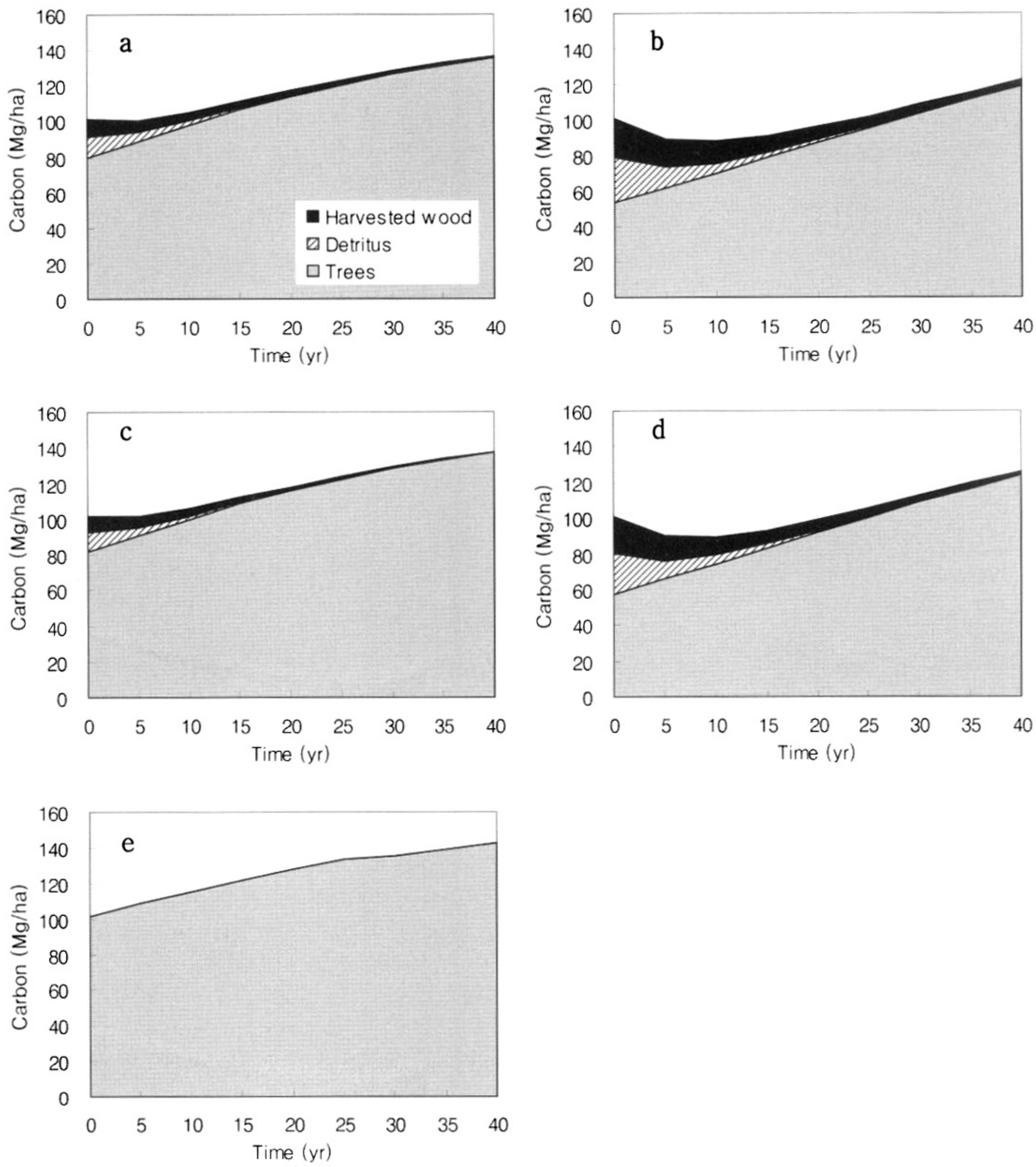

Figure 4. Carbon sequestration was simulated for 40 years at each application of (a) 30% and (b) 50% thinning, (c) 30% and (d) 50% selection cutting, and (e) uncutting at the Oak - black cherry forest.

showing 1.8-2.6 times more carbon storage of the end of simulation than that of the beginning.

Among treatments, uncutting generally stored the greatest amount carbon. However, the rate of carbon storage was different by silvicultural treatment. The 30% selection cutting treatment increased carbon storage (163 Mg ha^{-1}) slightly more than that of uncutting (158 Mg ha^{-1}) in the Allegheny hardwoods. The rate of carbon storage in living trees was the smallest at the uncut treatment in all the sites (Figure 2, 3, and 4). The 50% thinning, 50% selection, and 50% thinning treatment were the highest rate of carbon storage at the Allegheny hardwood forest, Northern hardwood forest, and Oak - cherry forest, respectively.

The SILVAH, which was developed for the Allegheny hardwood and Northern hardwood forest, cannot be applied in other regions without modification because the basic assumptions and parameters were specific for the local area. One of disadvantage of this simulation is not to include the change of species composition during simulation period even though silvicultural treatment changed species composition and site quality (Sendak *et al.*, 2003).

In this study, only short term was applied to simulate carbon sequestration after silvicultural treatment. During 40 years simulation, the growth rate of living trees in the 50% thinning and 50% selection cutting treatment linearly increased, but the curve of growth rate was sigmoid at the other treatments. The carbon sequestration would be diverse by site quality, species composition, and stand age, but sampling data of this study were simple and site quality is relatively uniform. More research is needed to determine whether any silvicultural treatment can store significantly more carbon than no treatment over the long term in diverse forest ecosystems.

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