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Potential gains in C storage on productive forestlands in the northeastern United States through stocking management

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Abstract. One method of increasing forest carbon stocks that is often discussed is increasing stocking levels on existing forested lands. However, estimates of the potential increases in forest carbon sequestration as a result of increased stocking levels are not readily available. Using the USDA Forest Service's Forest Inventory and Analysis data coupled with the Forest Vegetation Simulator, we estimate that, for a seven-state region in the northeastern United States, timberland contains about 1768 Tg of carbon in aboveground live biomass across all stocking classes. If all medium and understocked stands had the carbon density of fully stocked stands, an additional 453 Tg of carbon would be stored. While the carbon gains per unit area are greatest for understocked stands, generally fewer than 10% of stands are in this condition. The increase in carbon storage per unit area is smaller for stands in the medium stocked class, but the large proportion of stands in this condition offers considerable opportunities. Our analysis indicates that, when seeking to increase forest carbon storage, managing stocking levels is an option with considerable potential, especially since no changes in land use are required.

Key words: forest carbon management; forest carbon sequestration; Forest Inventory and Analysis; Forest Vegetation Simulator; northeastern United States forests.

Introduction

Emerging carbon markets and the continuing development of state and regional climate action plans and agreements have focused attention on carbon sequestration as an ecosystem service and as an additional value of forests. Land-based carbon mitigation options such as afforestation of marginal agricultural lands and establishment of riparian buffers are frequently evaluated during the drafting of such plans due to the relatively low costs, the large increase in carbon stored per unit area, and the opportunity to accrue important co-benefits such as improved water quality and increased wildlife habitat.

An option relatively overlooked by research studies, possibly due to the long history of operational stocking control in forestry, is to increase stocking of understocked forests. Managing the distribution, number, and kinds of trees on a site is the main way foresters affect forest growth. Stocking can be conveyed directly using stand density measures such as basal area or number of trees per hectare, or as a comparison of current stand status to an "ideal" or reference stand of similar age and productivity potential. For this study, we chose a comparative measure of stocking. A fully stocked forest stand is one in which the growing space can be fully utilized by the trees; stands in the fully stocked category are considered to be at the optimal density for maximum growth (Gingrich 1967). Stocking management of existing forests has often been considered in applications such as state climate action plans to increase the density of carbon stored in existing forests (for examples, see Maine Department of Environmental Protection [2004], Minnesota Climate Change Advisory Group [2008], Michigan Climate Action Council [2009]). The Maine Climate Action Plan lists specific targets and timelines for increasing stocking in poorly stocked stands (Maine Department of Environmental Protection 2004).

Few published research studies report on the potential gains in forest carbon from increased stocking of understocked forests. Birdsey et al. (2000) review a number of forest sector-related options to reduce carbon emissions and increase sinks. Increasing the density of trees on non-stocked and poorly stocked forestland is specifically discussed as an option, though estimates of potential carbon gain from increased stocking are not given. Using forest statistics bulletins published by the USDA Forest Service Forest Inventory and Analysis (FIA) program, Vasievich and Alig (1996) estimate that opportunities to increase growth exist on roughly 81.7 million hectares of timberland outside the national forest system; the majority of these consist of restocking poorly stocked or currently nonstocked timberland. Huang et al. (2004) conducted an analysis of the economic feasibility of several types of forest carbon sequestration projects in the United States and report that ~56% of loblolly/shortleaf pine stands in the South are understocked. Planting these understocked forests

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represents an important opportunity to increase carbon storage, especially on lands with higher site productivity. Birdsey (1992) estimates carbon storage resulting from increased productivity of poorly stocked timberland by forest type and broad geographic region, using average values derived from FIA data combined with some basic assumptions. He reports that the greatest gains were likely when regenerating poorly stocked stands in a deficient state, such as those with competing vegetation or trees in very poor condition.

The purpose of this study is to investigate the potential for additional carbon storage in aboveground live biomass on understocked productive forestland in the northeastern United States. Productive forestland, also called timberland, is defined by the FIA Program (USDA Forest Service; *available online*),[2] as forested land capable of producing a minimum of 1.4 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ of timber, accessible, and not reserved from harvest. While storing carbon on all forestland, defined as land with 10% cover (or equivalent stocking) in live trees, offers additional opportunities, only timberland is considered in this study. Non-timberland forest is minor in the northeast and economic management opportunities will likely be low. The main research questions are: (1) What is the mean carbon density in northeastern U.S. forests for each stocking class? and (2) What is the potential increase in the amount of carbon stored in aboveground live biomass if poorly stocked and medium stocked timberland was fully stocked? Increasing stocking of less than fully stocked stands is a commonly mentioned management option: What is the potential, hypothetically, to increase carbon storage in existing forests?

Methods

The study area includes Maine, Vermont, New Hampshire, Massachusetts, Connecticut, New York, and Pennsylvania. This area is well forested; the amount of land area classified as forestland ranges from 58% in Connecticut and Pennsylvania to 89% in Maine (see Table 1 for land area data). These northeastern forests are in the temperate humid ecoclimatic zone with strong seasonal changes. The dominant forest-type group in the region is maple–beech–birch, with substantial amounts of the oak–hickory type present in Connecticut, Massachusetts, and Pennsylvania; Maine forests have a large spruce–fir component. The majority of forested lands in the study area are in private ownership (Butler 2009). Financial assistance and technical expertise for forest management including stocking considerations are available to private forest landowners from the USDA Forest Service (*available online*)[3] through States and other partners.

Ground plot inventory data from the FIA program (see footnote 2) were used to assess the potential gains in carbon storage if poorly and medium stocked stands carried the carbon density found in fully stocked stands. Forest inventory protocols began changing from a periodic survey to an annualized system in 1999; generally, a sampling "panel" of one-fifth of the plots in these states is inventoried in a given year. In Maine and Pennsylvania all established plots had been inventoried at the time we accessed the data, while other states generally had two or three panels of plots available. Rhode Island was not included because the number of plots inventoried was too small to calculate realistic mean carbon densities for each stocking class. The extensive nature of the FIA design provides information for strategic decisions: each forested phase-2 FIA plot represents 2429 ha of forestland (Bechtold and Patterson 2005).

Table 1. Land area by state (as of 2007) for the seven-state study region in the northeastern United States.

State	Land area (10^6 ha)		
	Forest land	Other land	Total land area
Maine, ME	7152	841	7993
Vermont, VT	1869	527	2396
New Hampshire, NH	1963	360	2323
Massachusetts, MA	1283	747	2031
Connecticut, CT	726	529	1255
New York, NY	7555	4673	12228
Pennsylvania, PA	6708	4899	11608
Total	27256	12576	39834

Notes: The data source is Smith et al. (2009). Data may not sum to totals due to rounding.

All available annual data for timberland in the study area were downloaded by us in 2007 from the FIA database using the Mapmaker 2.1 interface from the FIA website, which created files ready for use with the Forest Vegetation Simulator (FVS; *available online*).[4] Since the time the data were accessed, FIA has made numerous changes to the structure of the FIA database; a new interface is being developed to create files formatted for use in FVS. FVS is the nationally supported set of regionally specific growth and yield models maintained by the USDA Forest Service. The ability to calculate carbon stocks has been incorporated into the Fire and Fuels Extension (FFE) of FVS (Hoover and Rebain 2008, Reinhardt et al. 2009). Since the data were collected in different years, FVS was used to grow each FIA plot forward to a common year of 2005, and the carbon estimation functions in the FFE were used to generate the estimates of carbon in aboveground live biomass for each individual plot, using the generalized biomass equations of Jenkins et al. (2003). The mean and standard error of the plot carbon densities were then calculated for each forest-type group and stocking-class combination. Mean carbon densities were not calculated for each age-class combination due

[2] ⟨http://fia.fs.fed.us/⟩
[3] ⟨http://www.fs.fed.us/spf/⟩
[4] ⟨http://www.fs.fed.us/fmsc/fvs/⟩

TABLE 2. Stocking-class boundaries used in this study.

Stocking class	Class boundaries (%)
Nonstocked	0–9.99
Poorly stocked	10–34.99
Medium stocked	35–59.99
Fully stocked	60–99.99
Overstocked	>100

Note: The data source is Arner et al. (2001).

to the low numbers of plots available in the younger age classes; stand age is a rough approximation, especially in heterogeneous stands. Mapmaker was also used to retrieve the area by stocking class for each forest-type group in each state; nonstocked timberland area was excluded because the focus of the analysis was on differences in carbon density between stocking classes.

The assignment of stocking classes to each FIA plot nationwide is an automated procedure using species-specific functions of diameter developed from normal yield tables and stocking charts. Stocking functions were adopted that relate the area occupied by an individual tree to the area occupied by a tree of the same size growing in a fully stocked stand of like trees; details of the approach are given in Arner et al. (2001). The stocking values of all live trees on the plot were calculated and the class was assigned as listed in Table 2. Note that these stocking algorithms were not designed to categorize forest stocking in terms of carbon, that is, fully stocked does not mean potential carbon is reached. An algorithm customized to emphasize carbon would provide more precise results.

Statewide estimates of current carbon storage on timberland are the product of mean carbon storage for a particular stocking level/forest-type group combination and the area in that category. Estimates of additional carbon storage potential by county were generated by assigning the mean carbon density of fully stocked plots in that county to poorly stocked, or poorly and medium-stocked plots in that county, then calculating the additional carbon that could be stored above the current level. Counties with <10% of land area in timberland were excluded, as were counties where all designated timberland was in the nonstocked condition.

RESULTS

Across the study area, the proportion of timberland area in the poorly stocked class averaged ~10%, with slightly higher values in New York and Pennsylvania (Fig. 1). Generally the proportion of overstocked timberland was minor, at <5% by area. The highest value was 10% by area in Maine, which has a sizeable amount of densely stocked young stands. In the seven-state region of the northeastern United States about 49% of the timberland area, roughly 12 million hectares, was less than fully stocked.

Mean carbon density in aboveground live tree biomass (AGB) for timberland only is shown by county in Fig. 2. The inventory plots encompass a variety of stocking classes and forest types. Mean carbon densities on timberland varied widely: most counties in Pennsylvania fell in the 68–82 Mg C/ha category, while many counties in Massachusetts and Connecticut averaged >83 Mg C/ha.

On fully stocked plots, mean carbon density in AGB ranged from about 74 to 106 Mg C/ha, with most states averaging in the 90s (Table 3). Mean carbon density on poorly stocked plots fell between 25 and 36 Mg C/ha, while medium stocked plots showed a broader range, with values averaging 53–72 Mg C/ha. The difference in average carbon density of AGB was greatest between the poorly and fully stocked categories for all states, ranging between 42 and 81 Mg C/ha, with most values ~60 Mg C/ha. Carbon density was higher by 30–35 Mg C/ha in fully stocked stands than stands in the medium stocking class for all states studied (with higher and lower mean values in Vermont and Maine, respectively). Differences in carbon density between the poor and medium stocking classes were more variable, with values of 19–47 Mg C/ha, with most in the 20s (Table 3).

We applied the differences in average carbon density between poorly stocked and fully stocked forests by county, to arrive at the potential hypothetical increase in carbon storage on timberland if poorly stocked lands carried the current carbon density of fully stocked lands (Fig. 3a). Results varied widely by state and were largely a function of stocking class, although age-class distribution was a contributing factor. The potential increase in carbon density on timberland if both poorly and medium stocked stands carried the current carbon density of fully stocked plots is shown in Fig. 3b. Many counties throughout the study area could offer opportunities to increase carbon in existing stands, with potential gains of 12 Mg C/ha or greater. Current (2005) standing stocks of carbon in AGB on timberland for each state are given in Table 4, along with the statewide

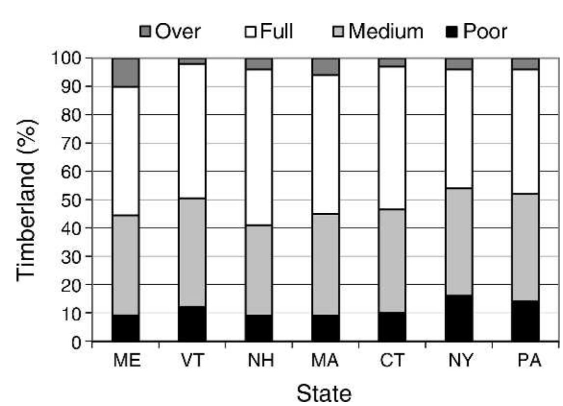

FIG. 1. Distribution of timberland in the northeastern United States, by stocking class (overstocked, fully stocked, medium stocked, and poorly stocked). The seven states are: ME, Maine; VT, Vermont; NH, New Hampshire; MA, Massachusetts, CT, Connecticut; NY, New York; and PA, Pennsylvania.

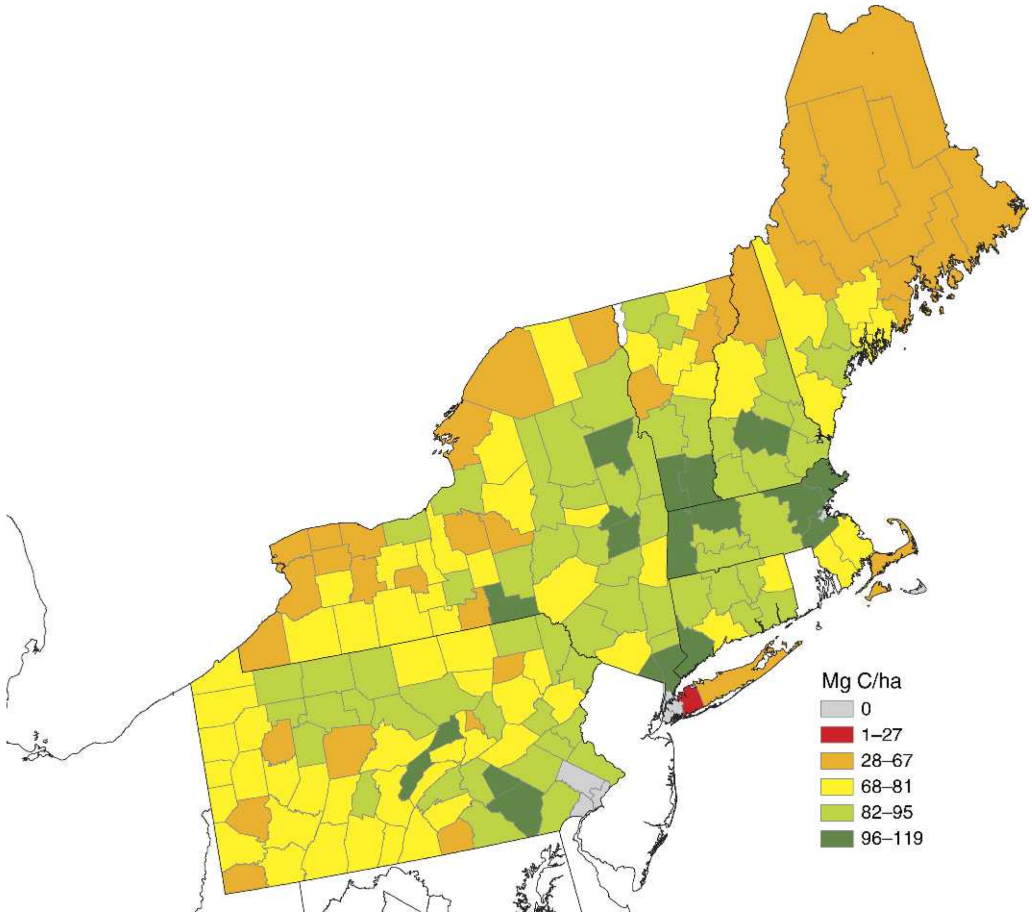

FIG. 2. Mean carbon density on timberland (aboveground live tree biomass) by county. Counties in gray contained few or no timberland plots.

estimates of the potential gains above current levels that would result if the area in poor and medium stocking classes carried the same carbon density as the fully stocked timberland. If the mean carbon density on all timberland acres was equivalent to those of fully stocked areas of the same age, the additional carbon that could potentially be stored represents 19–31% of current standing stocks in the states across the study area. The highest absolute potential is for New York; Maine, Vermont, and Massachusetts average ~19%, with the remaining states between 26–30%. In absolute terms, larger states or states with poor stocking will exhibit the highest theoretical potential. The highest potential for additional carbon storage is in Pennsylvania and New York, where an additional 273 Tg C could be stored if all timberland carried the carbon density of fully stocked stands.

We estimate that timberland in these forests currently contains 1768 Tg C in AGB, which is 453.8 Tg C, or 25% lower, than they would be if all stands were fully stocked. If it took 40 years for all stands to reach full stocking, the increase in carbon over this time period is about 11 Tg C/yr. This is a substantial increase, as the forests in these states are currently estimated to sequester a net 9.8 Tg C/yr in all non-soil carbon pools on all forestland (Smith and Heath 2008).

Discussion

Vasievich and Alig (1996) calculated that regenerating understocked forests on private timberland of the United States could result in sequestering ~76.1 Tg C/yr on 81.7 million hectares, which is about 57% of the total private timberland. This is ~0.93 $Mg\ C \cdot ha^{-1} \cdot yr^{-1}$ although there is no discussion about the time period over which this rate could be expected to occur. Our results indicate 453.8 Tg C more could exist in northeastern U.S. timberland if all forests were fully stocked, which would be about 0.94 Mg C/ha/yr if it took 40 years to reach a fully stocked state (but not explicitly including carbon changes due to age changes). Our estimate that ~49% of the northeastern timberland area was less than fully stocked is similar to the estimate by Huang et al. (2004) that 56% of loblolly/shortleaf stands in the southern United States are understocked. These comparisons highlight that understocking is an issue in many forests, and that fully stocked forests

TABLE 3. Carbon density of aboveground live tree biomass on timberland, by state and stocking class, including land area occupied and number of plots.

State and stocking class	C density (Mg C/ha)		Land area (10^3 ha)	No. plots
	Mean	SE		
Maine				
Overstocked	55.1	2.16	760.9	466
Fully stocked	73.9	0.79	3117.5	1600
Medium stocked	53.2	0.58	2409	409
Poorly stocked	32.1	1.16	604.5	155
Mean	63.1			
Vermont				
Overstocked	90.2	15.7	44.6	22
Fully stocked	94.1	1.95	849.5	228
Medium stocked	55.5	1.8	685.6	95
Poorly stocked	36.3	4.59	215.3	23
Mean	80.3			
New Hampshire				
Overstocked	116	8.73	78.7	50
Fully stocked	91.7	1.87	1023.7	293
Medium stocked	60.7	4.56	611.8	134
Poorly stocked	34.2	2.83	170.2	27
Mean	82.9			
Massachusetts				
Overstocked	144	11.3	70.2	23
Fully stocked	103	2.73	589.2	139
Medium stocked	69.4	2.24	427.6	81
Poorly stocked	32.7	5.39	104.9	14
Mean	92.3			
Connecticut				
Overstocked	104	28.3	19.6	10
Fully stocked	106	3.38	350.3	75
Medium stocked	71.9	2.32	251.5	50
Poorly stocked	24.9	2.26	72.8	9
Mean	89.1			
New York				
Overstocked	116	6.69	225.7	106
Fully stocked	92.8	1.31	2515.4	699
Medium stocked	59.4	1.04	2379.4	405
Poorly stocked	30.7	1.74	1051.1	127
Mean	78.8			
Pennsylvania				
Overstocked	98.7	5.53	239.5	188
Fully stocked	95.9	0.87	2842.9	1542
Medium stocked	62.7	0.72	2419.7	1027
Poorly stocked	34.8	1.17	877.3	268
Mean	79.4			

Note: The number of forest survey panels completed varies by state.

feature substantially more carbon than understocked forests.

Planting trees on lands that are currently not forested obviously provides large and easily quantifiable carbon gains. However, there are a limited number of hectares where tree planting is feasible in the northeast due to economic, policy, and other considerations. While many state climate plans and various assessments of forest-related climate mitigation options mention adjustments in stocking levels as a strategy, few estimates of the potential carbon gains from changes in stand stocking have been calculated. Our analysis shows that stocking levels can have a large influence on the amount of carbon stored on timberland, and that managing stand stocking may provide opportunities to sequester additional carbon; this is most easily achieved during the early stages of stand development. However, we agree with Birdsey (1992) who suggests that regenerating poorly stocked stands of low productivity, and essentially starting over with a new stand, can achieve substantial carbon gains.

In each of the seven states studied there were considerable differences in the carbon density between stocking classes. For almost every state, the difference between poorly stocked and fully stocked plots was ~60 Mg C/ha. Although the proportion of timberland area

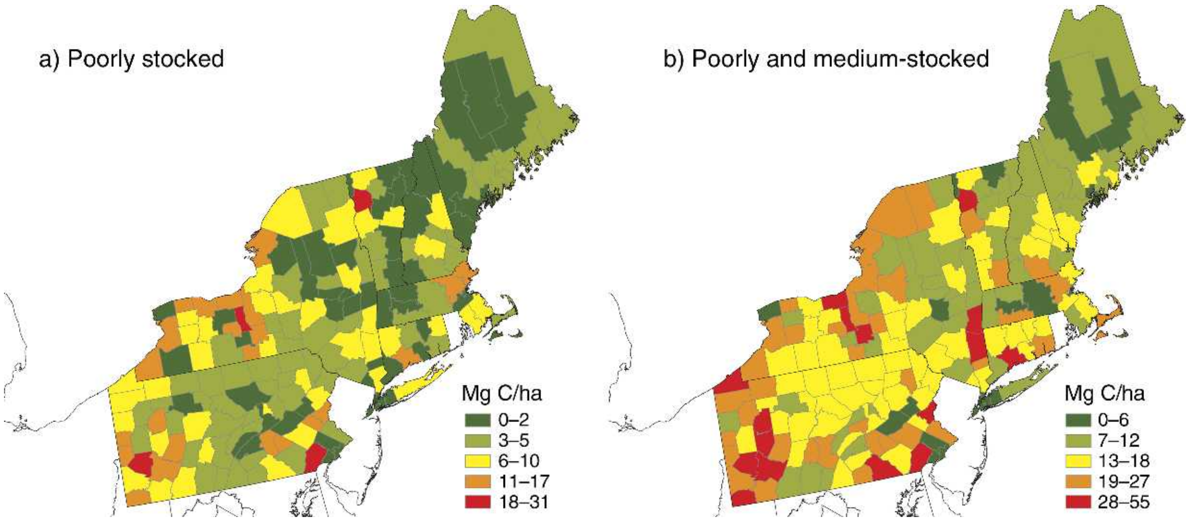

FIG. 3. Potential increase in carbon density on timberland (aboveground live tree biomass) by county (a) if poorly stocked acres were fully stocked and (b) if poorly and medium stocked acres were fully stocked. Note that the two panels have different carbon density scales.

in the poorly stocked condition is generally only around 10% in each state studied, the potential increase in carbon storage that could be achieved if poorly stocked stands were increased to full stocking represents 6–14% of current timberland carbon stocks. The highest potentials are in New York and Pennsylvania (14% and 11%, respectively), the states with the highest proportion of poorly stocked lands. Potential increases are lowest in Maine (6%). Of the states studied, current timberland carbon density is lowest in Maine; this is mainly a result of harvesting activity and other disturbances. One-quarter of the sample plots in Maine are 40 years old or less, and these younger stands, even when fully stocked, have a lower carbon density due to the smaller diameters of the young trees. About 65% of the overstocked plots in Maine were 40 years old or less; the average carbon density for overstocked stands was lower than that of fully stocked stands for this reason (by comparison, just 4% of overstocked stands in Massachusetts were 40 years old or less).

While the proportion of poorly stocked stands by area is small, the magnitude of the difference between poorly and fully stocked stands is quite large in all states, and even the difference between poorly and medium stocked stands is considerable (representing 3–6% of the current standing carbon stocks on timberland). However, a much larger proportion of timberland area is of medium stocking (see Appendix for estimates of timberland area by stocking class at the county level). The difference between medium and fully stocked stands is also substantial, ~30 Mg C/ha (Table 3). When this response is combined with the large land area in this stocking class, the result is large potential gains in carbon storage across the forested landscape. In some cases, land may be in the medium stocked condition due to planned density management treatments to achieve management objectives associated with medium stocking. However, lower stocking levels are commonly the result of missed opportunities during the early stages of stand development. Many additional megagrams of carbon could be stored in existing forests if timberland that is in the

TABLE 4. Estimated stock of carbon in aboveground live tree biomass on timberland in 2005, and potential carbon storage gains from changes in stocking levels.

State	Carbon stock (Tg)	Potential carbon gain (Tg)		
		Poor to medium stocked	Poor to fully stocked	Medium to fully stocked
ME	414.1	13.4	26.6	50.9
VT	130.8	4.2	12.5	26.0
NH	146.1	4.2	9.4	19.1
MA	105.2	3.8	7.4	13.6
CT	57.0	3.2	5.4	9.3
NY	463.3	28.9	62.8	76.8
PA	478.5	24.8	54.0	80.1
Total	1768.0	82.6	178.1	275.8

Note: For state abbreviation code see Table 1.

medium stocked class for reasons other than silvicultural treatments was fully stocked (Table 4). While some treatments to increase stocking levels, such as interplanting, are often not economically feasible, ensuring prompt and successful regeneration of stands following harvest or other stand-replacing disturbance is a practicable means of creating fully stocked stands over the long term.

Further opportunities to increase carbon density are also possible by restocking stands that are currently nonstocked; however, only stocked stands were included in this analysis. While data for overstocked stands are presented here and treatment of overstocked stands may influence carbon dynamics, we did not consider the effects of applying stocking control in these stands. Increasing stocking levels in understocked stands is not a strategy that will produce immediate results but is an option that can be considered, especially in areas where there is limited land area available for afforestation. Our results also serve as a reminder that when stands are regenerated, stocking levels should be carefully monitored when carbon sequestration is a major management objective. Ensuring prompt and successful regeneration is a low-cost way to achieve a fully stocked condition, and any necessary interventions are most easily applied during the early stages of stand development. We recognize that there are economic and policy considerations related to implementing increases in stocking levels, and that increased stocking may not be an appropriate strategy in all geographic regions and forest types. In particular, areas that are fire prone or susceptible to repeated droughts or pest outbreaks may be most appropriately maintained at lower stocking levels to meet forest health objectives. However, the purpose of this study is not to examine the suitability of increased stocking as a management strategy across the landscape, but rather to assess the theoretical potential for increased carbon storage in existing forests based on the current carbon density and stocking levels of timberland in the northeastern United States.

The potential effects of climate change could alter the growth rates of northeastern forests and affect their ability to sequester carbon, as well as changing the usefulness of increased stocking levels as a means of increasing forest carbon storage. Hayhoe et al. (2007) projected potential changes in climate for the northeastern United States under various emissions scenarios using multiple models. They found that for the period 2035–2064, under a low-emissions scenario, average annual temperature was projected to increase 2.1°C while annual precipitation was projected to increase by 5%. The majority of the increased precipitation was predicted to occur in the winter months; the frequency of short-term droughts was also projected to increase under all scenarios. Research is needed to consider how climate change may affect the amount of stocking required for a stand to be considered fully stocked under future conditions, as well as the ability of forests to continue to act as a carbon sink.

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APPENDIX

A table showing timberland area (as of 2005) in the seven states in the northeastern United States by county and by stocking class (*Ecological Archives* A021-051-A1).

Ecological Archives A021-051-A1

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Appendix A (TABLE A1). A table showing timberland area (as of 2005) in the seven states in the northeastern United States by county and by stocking class. Numbers in parentheses indicate percentage of timberland represented by the stocking class. Counties with less than 10% of land area in timberland, or with all timberland currently in a nonstocked condition have been omitted.

State	County	Timberland area (ha)		
		Fully stocked	**Medium stocked**	**Poorly stocked**
CT	Fairfield	23,040 (41%)	32,667 (59%)	- (0%)
CT	Hartford	58,888 (62%)	18,780 (20%)	12,073 (13%)
CT	Litchfield	101,796 (60%)	36,791 (22%)	21,762 (13%)
CT	Middlesex	26,514 (46%)	29,536 (51%)	- (0%)
CT	New Haven	20,284 (34%)	34,164 (58%)	4,471 (8%)
CT	New London	44,766 (46%)	33,478 (35%)	17,237 (18%)
CT	Tolland	26,552 (41%)	38,944 (59%)	- (0%)
CT	Windham	48,420 (50%)	27,103 (28%)	17,293 (18%)
		350,262	**251,464**	**72,835**
MA	Barnstable	11,217 (42%)	4,631 (17%)	10,805 (41%)
MA	Berkshire	95,938 (56%)	50,598 (29%)	7,660 (4%)
MA	Bristol	33,307 (41%)	33,354 (41%)	11,501 (14%)
MA	Dukes	- (0%)	4,616 (44%)	5,866 (56%)
MA	Essex	26,215 (65%)	6,245 (16%)	2,026 (5%)
MA	Franklin	70,376 (50%)	40,280 (29%)	8,528 (6%)
MA	Hampden	68,357 (58%)	45,086 (38%)	4,958 (4%)
MA	Hampshire	57,572 (52%)	41,446 (37%)	5,922 (5%)
MA	Middlesex	38,153 (50%)	26,372 (34%)	7,448 (10%)
MA	Norfolk	14,453 (31%)	28,015 (59%)	- (0%)
MA	Plymouth	27,272 (32%)	48,261 (57%)	7,125 (8%)
MA	Worcester	146,355 (52%)	98,662 (35%)	33,098 (12%)
		589,215	**427,565**	**104,937**
ME	Androscoggin	35,076 (45%)	28,223 (36%)	7,825 (10%)
ME	Aroostook	633,011 (42%)	533,285 (35%)	144,701 (10%)
ME	Cumberland	72,586 (49%)	57,300 (39%)	10,722 (7%)
ME	Franklin	180,775 (46%)	133,125 (34%)	37,667 (10%)
ME	Hancock	169,220 (49%)	107,616 (31%)	30,805 (9%)
ME	Kennebec	63,807 (41%)	65,458 (42%)	12,526 (8%)
ME	Knox	22,870 (36%)	25,743 (40%)	11,293 (18%)

ME	Lincoln	46,571 (54%)	22,827 (26%)	15,607 (18%)
ME	Oxford	272,137 (55%)	150,896 (31%)	48,585 (10%)
ME	Penobscot	351,837 (45%)	270,444 (35%)	68,126 (9%)
ME	Piscataquis	396,261 (44%)	288,854 (32%)	78,537 (9%)
ME	Sagadahoc	24,018 (49%)	17,098 (35%)	3,038 (6%)
ME	Somerset	438,204 (46%)	329,989 (35%)	66,304 (7%)
ME	Waldo	78,888 (51%)	52,102 (34%)	9,864 (6%)
ME	Washington	254,445 (43%)	237,774 (40%)	40,257 (7%)
ME	York	77,796 (39%)	88,320 (44%)	18,727 (9%)
		3,117,502	**2,409,053**	**604,584**
NH	Belknap	34,944 (47%)	29,825 (41%)	6,584 (9%)
NH	Carroll	106,365 (53%)	63,626 (32%)	19,900 (10%)
NH	Cheshire	92,081 (58%)	45,805 (29%)	11,897 (8%)
NH	Coos	204,547 (49%)	179,849 (43%)	28,711 (7%)
NH	Grafton	247,599 (66%)	103,429 (27%)	21,512 (6%)
NH	Hillsborough	68,943 (42%)	70,654 (43%)	14,990 (9%)
NH	Merrimack	119,434 (61%)	37,096 (19%)	23,548 (12%)
NH	Rockingham	57,534 (47%)	38,873 (32%)	13,657 (11%)
NH	Strafford	17,863 (32%)	23,575 (43%)	8,683 (16%)
NH	Sullivan	74,396 (63%)	19,077 (16%)	20,716 (18%)
		1,023,705	**611,808**	**170,197**
NY	Albany	24,016 (34%)	34,814 (50%)	11,492 (16%)
NY	Allegany	61,760 (42%)	59,673 (41%)	21,429 (15%)
NY	Broome	59,695 (56%)	31,906 (30%)	13,241 (12%)
NY	Cattaraugus	102,253 (43%)	78,661 (33%)	47,521 (20%)
NY	Cayuga	20,995 (41%)	21,535 (42%)	7,009 (14%)
NY	Chautauqua	35,867 (30%)	47,798 (39%)	37,720 (31%)
NY	Chemung	31,737 (50%)	19,467 (31%)	6,407 (10%)
NY	Chenango	74,016 (53%)	43,135 (31%)	9,652 (7%)
NY	Clinton	53,959 (31%)	75,670 (43%)	41,489 (24%)
NY	Columbia	36,828 (39%)	35,838 (38%)	21,275 (23%)
NY	Cortland	24,412 (32%)	30,459 (40%)	21,238 (28%)
NY	Delaware	112,779 (45%)	93,554 (37%)	41,883 (17%)
NY	Dutchess	43,733 (34%)	53,137 (42%)	27,238 (21%)
NY	Erie	31,927 (38%)	30,800 (36%)	20,678 (25%)
NY	Essex	116,718 (49%)	90,066 (38%)	21,467 (9%)
NY	Franklin	98,461 (39%)	105,603 (42%)	34,485 (14%)
NY	Fulton	33,620 (52%)	23,510 (36%)	7,530 (12%)
NY	Genesee	7,998 (23%)	10,152 (29%)	17,094 (49%)
NY	Greene	42,085 (42%)	43,837 (44%)	8,385 (8%)

NY	Hamilton	41,795 (36%)	67,618 (58%)	3,492 (3%)
NY	Herkimer	74,724 (48%)	57,639 (37%)	21,291 (14%)
NY	Jefferson	30,188 (19%)	84,904 (54%)	36,435 (23%)
NY	Lewis	87,034 (39%)	105,997 (48%)	22,686 (10%)
NY	Livingston	25,569 (53%)	11,694 (24%)	8,487 (18%)
NY	Madison	31,372 (34%)	25,278 (27%)	33,970 (37%)
NY	Monroe	26,752 (69%)	4,378 (11%)	7,795 (20%)
NY	Montgomery	18,442 (59%)	6,428 (21%)	3,005 (10%)
NY	Nassau	1,142 (20%)	- (0%)	4,568 (80%)
NY	Niagara	22,513 (66%)	- (0%)	6,399 (19%)
NY	Oneida	54,079 (32%)	66,736 (39%)	44,994 (27%)
NY	Onondaga	41,288 (44%)	26,343 (28%)	21,365 (23%)
NY	Ontario	19,961 (27%)	34,038 (46%)	15,982 (22%)
NY	Orange	28,622 (33%)	39,868 (47%)	15,121 (18%)
NY	Orleans	5,973 (24%)	7,072 (29%)	11,377 (47%)
NY	Oswego	94,142 (64%)	33,032 (23%)	13,731 (9%)
NY	Otsego	35,501 (22%)	74,039 (46%)	36,892 (23%)
NY	Putnam	13,312 (35%)	19,282 (50%)	- (0%)
NY	Rensselaer	33,469 (39%)	46,336 (54%)	2,802 (3%)
NY	Rockland	- (0%)	5,635 (65%)	2,984 (35%)
NY	St. Lawrence	137,793 (30%)	207,745 (46%)	101,547 (22%)
NY	Saratoga	72,410 (52%)	37,391 (27%)	27,700 (20%)
NY	Schenectady	12,044 (37%)	13,121 (40%)	4,522 (14%)
NY	Schoharie	65,147 (55%)	42,707 (36%)	4,301 (4%)
NY	Schuyler	23,560 (55%)	12,565 (29%)	4,922 (12%)
NY	Seneca	3,944 (16%)	7,852 (32%)	6,300 (26%)
NY	Steuben	82,961 (40%)	81,809 (40%)	30,301 (15%)
NY	Suffolk	12,639 (26%)	12,558 (26%)	19,294 (40%)
NY	Sullivan	84,250 (45%)	75,571 (40%)	24,768 (13%)
NY	Tioga	28,299 (47%)	19,089 (32%)	11,580 (19%)
NY	Tompkins	21,869 (35%)	21,170 (34%)	14,915 (24%)
NY	Ulster	86,205 (56%)	44,997 (29%)	22,954 (15%)
NY	Warren	83,009 (66%)	31,932 (25%)	3,221 (3%)
NY	Washington	46,617 (40%)	48,003 (41%)	11,498 (10%)
NY	Wayne	13,983 (31%)	16,494 (37%)	10,318 (23%)
NY	Westchester	23,516 (50%)	16,686 (35%)	5,969 (13%)
NY	Wyoming	13,448 (25%)	32,880 (61%)	7,470 (14%)
NY	Yates	4,977 (15%)	10,951 (33%)	8,960 (27%)
		2,515,406	**2,379,451**	**1,051,146**
PA	Adams	16,975 (39%)	16,222 (38%)	9,469 (22%)
PA	Allegheny	13,470 (21%)	27,477 (42%)	23,367 (36%)
PA	Armstrong	17,189 (18%)	54,833 (58%)	21,696 (23%)

PA	Beaver	9,176 (23%)	14,245 (35%)	16,792 (42%)
PA	Bedford	74,534 (48%)	60,741 (39%)	9,965 (6%)
PA	Berks	30,319 (42%)	25,754 (36%)	10,945 (15%)
PA	Blair	35,171 (43%)	28,455 (35%)	17,923 (22%)
PA	Bradford	67,825 (42%)	62,229 (38%)	27,410 (17%)
PA	Bucks	15,385 (41%)	11,406 (31%)	7,962 (21%)
PA	Butler	21,722 (25%)	39,042 (45%)	20,788 (24%)
PA	Cambria	39,369 (37%)	54,722 (51%)	9,066 (9%)
PA	Cameron	48,085 (54%)	22,511 (25%)	5,468 (6%)
PA	Carbon	36,181 (57%)	15,656 (25%)	5,191 (8%)
PA	Centre	121,132 (59%)	54,949 (27%)	21,855 (11%)
PA	Chester	13,696 (36%)	12,605 (33%)	11,580 (31%)
PA	Clarion	32,075 (32%)	35,437 (36%)	25,825 (26%)
PA	Clearfield	75,178 (36%)	93,275 (45%)	34,487 (16%)
PA	Clinton	106,977 (60%)	54,875 (31%)	12,190 (7%)
PA	Columbia	26,994 (45%)	29,959 (50%)	2,126 (4%)
PA	Crawford	47,347 (36%)	53,454 (41%)	27,849 (21%)
PA	Cumberland	26,432 (54%)	18,905 (38%)	1,040 (2%)
PA	Dauphin	31,678 (50%)	18,072 (29%)	9,248 (15%)
PA	Elk	91,407 (49%)	83,000 (45%)	6,395 (3%)
PA	Erie	34,116 (36%)	34,342 (36%)	21,087 (22%)
PA	Fayette	37,178 (32%)	58,556 (51%)	12,647 (11%)
PA	Forest	51,947 (51%)	31,002 (30%)	6,189 (6%)
PA	Franklin	36,277 (43%)	33,558 (40%)	12,998 (16%)
PA	Fulton	31,120 (44%)	26,299 (37%)	7,224 (10%)
PA	Greene	18,233 (19%)	58,948 (61%)	18,764 (20%)
PA	Huntingdon	64,395 (39%)	78,605 (48%)	13,208 (8%)
PA	Indiana	43,081 (36%)	38,892 (33%)	34,302 (29%)
PA	Jefferson	55,744 (57%)	29,366 (30%)	7,119 (7%)
PA	Juniata	25,677 (43%)	22,843 (38%)	7,233 (12%)
PA	Lackawanna	34,287 (45%)	31,946 (42%)	10,309 (13%)
PA	Lancaster	17,808 (50%)	14,047 (40%)	3,162 (9%)
PA	Lawrence	15,896 (43%)	8,983 (25%)	11,057 (30%)
PA	Lebanon	13,493 (55%)	6,342 (26%)	3,865 (16%)
PA	Lehigh	14,323 (60%)	4,902 (21%)	4,062 (17%)
PA	Luzerne	72,940 (51%)	47,894 (34%)	14,417 (10%)
PA	Lycoming	126,001 (55%)	78,962 (35%)	19,358 (9%)
PA	McKean	101,008 (46%)	71,987 (33%)	39,054 (18%)
PA	Mercer	22,290 (37%)	28,674 (47%)	9,738 (16%)
PA	Mifflin	25,795 (53%)	15,835 (33%)	5,399 (11%)
PA	Monroe	44,259 (43%)	43,874 (42%)	10,417 (10%)
PA	Montour	5,255 (61%)	2,035 (23%)	1,369 (16%)
PA	Northampton	7,548 (30%)	13,466 (54%)	3,132 (12%)
PA	Northumberland	30,405 (56%)	17,496 (32%)	4,699 (9%)

	Perry	45,836 (55%)	26,456 (32%)	7,723 (9%)
PA	Pike	64,748 (57%)	40,128 (36%)	7,980 (7%)
PA	Potter	142,964 (64%)	46,424 (21%)	29,245 (13%)
PA	Schuylkill	77,700 (62%)	31,559 (25%)	1,902 (2%)
PA	Snyder	20,240 (44%)	22,160 (48%)	3,036 (7%)
PA	Somerset	77,933 (49%)	51,519 (33%)	24,325 (15%)
PA	Sullivan	22,773 (24%)	55,747 (58%)	14,427 (15%)
PA	Susquehanna	46,105 (40%)	52,736 (46%)	9,875 (9%)
PA	Tioga	90,735 (47%)	77,707 (40%)	20,424 (10%)
PA	Union	32,921 (74%)	7,002 (16%)	2,095 (5%)
PA	Venango	35,558 (29%)	66,301 (54%)	16,371 (13%)
PA	Warren	78,085 (44%)	69,718 (39%)	25,759 (14%)
PA	Washington	18,038 (18%)	51,693 (50%)	31,572 (31%)
PA	Wayne	72,157 (54%)	37,630 (28%)	18,164 (13%)
PA	Westmoreland	49,081 (42%)	43,226 (37%)	24,361 (21%)
PA	Wyoming	26,308 (41%)	31,869 (50%)	5,456 (9%)
PA	York	11,456 (28%)	18,634 (45%)	8,516 (21%)
		2,842,868	**2,419,686**	**877,263**
VT	Addison	31,326 (35%)	23,918 (26%)	27,964 (31%)
VT	Bennington	66,894 (52%)	30,760 (24%)	20,688 (16%)
VT	Caledonia	55,292 (39%)	58,819 (42%)	26,702 (19%)
VT	Chittenden	27,034 (31%)	23,100 (27%)	35,884 (42%)
VT	Essex	68,633 (42%)	73,368 (45%)	12,034 (7%)
VT	Franklin	36,157 (33%)	57,817 (53%)	11,652 (11%)
VT	Lamoille	55,626 (55%)	41,467 (41%)	4,070 (4%)
VT	Orange	73,536 (48%)	61,351 (40%)	18,676 (12%)
VT	Orleans	70,986 (56%)	46,204 (37%)	6,140 (5%)
VT	Rutland	83,308 (45%)	91,123 (49%)	11,770 (6%)
VT	Washington	68,322 (48%)	58,397 (41%)	13,019 (9%)
VT	Windham	108,312 (63%)	48,607 (28%)	11,926 (7%)
VT	Windsor	104,085 (52%)	70,724 (35%)	14,762 (7%)
		849,510	**685,655**	**215,287**

Notes: Percentages do not sum to 100% because overstocked hectares are not included in the table. Area data source is FIA Evalidator (available from the FIA website), data accessed 11/24/2009. Area data are very similar but not an exact match to those used to conduct the analysis; the Mapmaker interface is no longer available and the FIA database was updated and reformatted in May 2009.