The Intersection of Land Use History and Exurban Development:

Implications for Carbon Storage in the Northeast

Kemen Austin

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ABSTRACT

This study focuses on carbon loss due to residential development in two towns in central New Hampshire currently undergoing rapid exurban development. Carbon is important to examine in the context of land use change within rural New England because the region's forests are currently net carbon sinks. Therefore a reduction in carbon uptake will increase net greenhouse gas emissions. Forest regrowth on abandoned farmland has lead to increasing carbon stocks in soils and forest biomass, while exurban and suburban sprawl is a countervailing force. This study examines whether there are different levels of soil carbon loss depending on the land-use history of a house site, (e.g. field, pasture, or woodlot). This study examines soil carbon at 16 house sites, 5 of which were examined more intensively through the use of quantitative soil pits. We found that past land use history has a significant influence on soil carbon loss associated with house development. In central New Hampshire construction of a house results in an average loss of 40 Mg C/ha, while houses constructed on former plowed fields lose 35 Mg C/ha, former pastures lose 75 Mg/ha and the former woodlots showed an increase of 20 Mg C/ha. Former plowed fields, pasture, and woodlot sites all lost significant amounts of carbon in the upper 20 cm of mineral soil, yet the pattern varied with land-use at greater depths. At depths greater than 20 cm, woodlots gained 78 Mg C/ha, plowed fields gained 16 Mg C/ha, and pastures lost 2 Mg C/ha. This discrepancy is attributable to buried carbon-rich horizons, suggesting that a driving force behind soil carbon loss is the fate of the top soil and forest floor (e.g. whether it is scraped off or buried).

INTRODUCTION

Carbon, in the form of carbon dioxide (CO_2), is being released into our atmosphere at rates unprecedented in recent geological history (Karl, 2003). The concentration of CO_2 has already increased by approximately 30 percent since the start of the industrial revolution (Houghton, 2003). Some consequences of this increase include a rising of the earth's average temperature, disruption of climate patterns, changing of population ranges of plants and animals, and rising of global sea-level (Karl, 2003). The scales of these changes are of increasing concern to scientists and policy makers alike, yet we are only beginning to understand the long-term implications of global climate change. In fact, there are still great uncertainties regarding the global carbon cycle, e.g. the size of CO_2 terrestrial sinks, rates of release of CO_2 from terrestrial sinks, and the consequences of increased CO_2 concentrations in our atmosphere on source-sink relationships (House, 2003; Houghton, 1999).

While the majority of anthropogenic CO_2 emissions results from the burning of fossil fuels, about 25% of current emissions result from net changes in land use (Houghton, 1999). Carbon loss from land conversion occurs when vegetation and soil is perturbed through forest clearing and cultivation. Increased mineralization and reduced inputs of new organic matter cause decomposition to exceed litter production (Batjes, 1997). Additionally, the removal of topsoil and disruption of soil structure can result in increased accessibility of soil organic matter to decomposing organisms (Batjes, 1997).

There is a hysteresis in the patterns of carbon release and re-accumulation, though carbon leaves the terrestrial ecosystem at a greater rate than it is fixed.

Between 1850 and 2000 approximately 156 Pg C were lost globally due to land use change, 60% of it in the tropics (Hackler, 2000). On the other hand, it has been determined that there is a carbon sink resulting from reforestation and forest aggradation which was approximately 2 to 3 Pg C annually during the 1990s (Hackler, 2000; Houghton, 2005). Mid-latitude forests in the northern hemisphere contain one third of the globe’s forest and woodland area but account for more than 80% of this observed annual carbon sequestration (Goodale, 2002). This disproportionate net flux in temperate regions relative to boreal regions, where much more of the carbon stocks are located, is most likely due to the temperate zone’s legacy of widespread land-use change over the last century, which has led to increased re-growth and concomitant carbon sequestration (Goodale, 2002).

The net US carbon sink of between 0.3 and 0.7 Pg C/yr (Pacala, 2001), is largely the product of regrowth and biomass accumulation in forests following abandonment of agricultural or pasture land (Caspersen, 2000). After accounting for the increased uptake associated with forest re-growth in the twentieth century, land use conversions within the United States released approximately 25 Pg C to the atmosphere between 1700 and 1990 (Houghton, 1999). Defining the nature and location of these sources and sinks is critical to managing the carbon cycle.

In the northeast region of the United States between 1775 and 1850, the major land use conversions from forested land were for subsistence agriculture (Hamburg, 1984). In New Hampshire, for example, more than 60% of forested land had been cleared for agriculture by 1850 (Cogbill, 2002). The pulse of forest harvesting between 1775 and the early 1900's removed a substantial amount of carbon and nitrogen from forest soils (Goodale, 2001); cultivation of temperate forest soils reduces soil carbon by an average of 30% through increased decomposition rates, fewer plant inputs and greater erosion of surface horizons (Compton, 2000).

Much of the land used for agriculture in New England was abandoned in the second half of the 19th century, when industrialization began to dominate the economy of the region. Forests naturally regenerated on this abandoned farmland and forest biomass approached pre-disturbance levels within 80 years (Hamburg, 1984). Today between 70% and 90% of the lands used for agriculture in the 19th century now support aggrading forests (Compton, 2000) which act as a significant sink for atmospheric carbon (Goodale, 2001). However, although above ground biomass levels have increased and regained much of their pre-settlement carbon, recovery of soil carbon occurs more slowly. Within the soils of reforested post-agricultural sites carbon accumulates primarily in the forest floor rather than in the deeper mineral soil (Hooker, 2003). It is estimated that the time required for the carbon levels in the soil to return to their original levels can be as great as 200 years or more (Hamburg, 1984).

In the northeast region of the United States the trend of forest aggradation and associated carbon sequestration is being offset by a counter trend of suburban and exurban development. The trend is common to many areas in the northeast, and has been a driving force of land use change in central New Hampshire. This study focused on two towns in central New Hampshire that are currently classified as exurban, with between 15-124 people/km^2 (Theobald, 2003). The populations of these two towns, Campton (20 people/km^2) and Thornton (15 people/km^2), have grown 132% and 230% since 1970, respectively (USCB, 2000). Since the early 1970s when Interstate 93 opened the area up to recreational tourism, the number of second homes in these two towns has grown even more rapidly than the population; Campton has had a 280% increase in single family homes while Thornton has experienced a 535% increase since 1970 (NHOEP, 2005). Corresponding with these development trends, and similar trends in the more suburban southern region of the state, New Hampshire’s forested area declined from 87% to 83% between 1983 and 1993 and is expected to decline to 80% by 2020 (SPNHF, 2005).

The impacts of land conversion to developed uses on the carbon cycle are not well understood, nor are they as easily quantified as other forms of carbon emissions (Karl, 2003). Changes in soil carbon stocks are the least certain components of the budgets because these pools have not been routinely measured in inventories of carbon storage (Goodale, 2001). In order to more accurately predict carbon dynamics in the Northeast region of the US we need to examine changes in soil carbon pools as a result of the most prevalent land use change, exurbanization.

To do this, we must also take into account the legacy effects of past land use activities. Patterns of land-use within rural New England towns have resulted in a legacy of less intensive disturbances in the more remote areas of each town and greater disturbance in more centralized areas. At the farm level there is an intricate pattern of disturbance based primarily on individual site characteristics; in general there is an inverse relationship between disturbance intensity and distance from the farmhouse site. The variations at the town and farm level demonstrate that when examining soil carbon at the regional level, using current methods, the spatial complexity of disturbance prevents generalization.

Understanding these long-term impacts of disturbance on carbon cycling and storage in recovering forests, specifically in soils, is an important step for projecting the potential amount of additional carbon that may be stored in forest systems in the face of current development (Hooker, 2003). This study attempts to determine change in carbon pools as a result of exurban development by quantifying the magnitude of existing soil carbon pools in the exurban ecosystems in Campton and Thornton, New Hampshire and comparing these values to information on predisturbance soil carbon levels (Hamburg, unpublished). It also quantifies the variation in carbon pools across different types of land use histories in the once heavily agricultural landscape, including abandoned plowed fields, pastures, and woodlots.

There is a gradient of decreasing soil carbon in the upper 20 cm of the soil profile with increasing historical land use disturbance (Hamburg, 1984). The nature of house construction disturbance led us to hypothesize that a greater amount of carbon would be lost in areas with the most soil carbon; therefore woodlots would lose the most carbon, pastures an intermediate amount and plowed fields would lose the least. One implication of this discrepancy is that more carbon was lost in the 19th century, because there was more carbon present in primary forests, than will be lost in the 21st century. Additionally, woodlots are the least disturbed land areas in the region and the areas that represent most closely pre-settlement vegetation structure (Rhoads, 2005). A secondary implication of a potential discrepancy in carbon flux due to house development is that conservation efforts focused on habitat preservation or scenic areas management may indirectly have a positive influence on carbon storage in northeast ecosystems because these conservation efforts would also preserve carbon rich soils and biomass.

SITE DESRIPTION

Study sites were located in two adjacent towns, Campton and Thornton, in Grafton County, New Hampshire, USA. Both towns are adjacent to the southern edge of the White Mountain National Forest, 10-20 km southeast of the Hubbard Brook Experimental Forest, 200 km north of Boston, Massachusetts and 110 km northwest of the Atlantic Ocean. Both towns are bisected by the national highway, Interstate 93, which was constructed in the early 1970s.

The study towns receive 140 cm of precipitation uniformly throughout the year, about 40 cm of which is snow. The average January temperature is -9°C and the July temperature is 18°C (Bailey, 2002). The region is underlain by a complex assemblage of metasedimentary and igneous rocks and is characterized by hilly and occasionally steep topography. The highest elevations are nearly 800 m in the mountainous and least disturbed areas of the towns and the lowest elevations range to 160 m in the Pemigewasset River valley which bisects both towns and which Interstate 93 parallels. Pleistocene era continental glaciers retreated approximately 13,000 years ago leaving relatively course textured un-weathered till derived soils across almost the entire study region. Depth of till derived soils averages a couple of meters, but ranges from 0 m on ridge tops and in stream valleys to 50m in some locations. In the study area the soils can be characterized as shallow acidic, well-drained Spodosols with sandy loam textures (Typic Hapllorthods) with a well developed profile of less than 75 cm on average (HBES, 2006). Northern hardwood forests predominate at lower elevation while spruce-fir forests dominate the vegetation at higher elevations. The most common deciduous northern hardwoods include sugar maple (*Acer saccharum*), beech (*Fagus grandifolia*), yellow birch (*Betula allegheniensis*), and some white ash (*Fraxinus americana*) (Bormann, 1970).

METHODS

We examined 16 house lots in order to determine land use history and quantify soil carbon stock changes associated with house construction. Sites were chosen to represent the range of house ages, lot sizes, and development styles present in the region's landscape. In order to determine land use history, vegetation in the undisturbed forest surrounding each house was examined for trends indicating past land use, including dominant tree species, presence of stumps, and determination of tree age from tree cores. Each lot was also inspected for indications of the intensity and timing of human activity in the form of built environment, which includes rock walls, rock piles, old house foundations and graveyards. The final, and in some cases most indicative, step in the land use history analysis was an examination of soil profiles at each site. Three soil profiles were examined, the O, E (if present), Ap (if present) and B horizons were characterized, and depths were recorded.

The area of each lot was determined from municipal tax records. The area of the disturbed house site was quantified using a Dell X50 handheld computer running ESRI's ArcPad 6 software with an attached TeleType GPS receiver. The filled area of the house site, determined by visually examining the topography of the disturbed area, was quantified in the same way.

Two types of soil sampling methods were employed; a quantitative pit technique based on Hamburg (1984) was used at five sites to produce an accurate estimate of total soil carbon. These estimates were in turn compared to an auger method used at all 16 sites. The auger method involves taking samples with a 3.1 cm diameter auger to a depth of 20 cm. We collected three samples in the disturbed area, at 10, 20 and 30 m from the house site in the direction of greatest disturbance. Three auger samples were then taken in the undisturbed forested area for comparison. Samples in the undisturbed area were taken at least 5 meters from the forest edge and from any structure (e.g. rock wall) in an area that was not obstructed by fallen trees, rocks, etc. Additionally, we took an auger sample at the site of each quantitative pit prior to digging in order to determine the accuracy of the carbon concentrations generated using the auger method.

We dug two quantitative soil pits, one between 2 and 20 meters from the house site in order to represent the filled area nearest the house, and a second between 5 and 50 meters from the house in an unfilled area. The quantitative method involves placing a ½ m^2 template at each location and removing all aboveground biomass. Soil in the frame's area is then excavated to a depth of 20 cm, and all material removed is sieved to 12 mm. Coarse fraction and soil are weighed separately, and the fine material is then homogenized and a subsample is taken for further processing. This method is repeated for the 20-50cm layer and the 50-C horizon layer; subsamples taken from each layer and a final grab sample of the C horizon are collected for analysis.

Soil Samples were air dried until dry, at least 72 hours, and then sieved to 2 mm. The coarse fraction was archived and the fine material was sub-sampled using a riffle box splitter and oven dried at 105ºC for an additional 72 hours. Sub-samples were pulverized using a SPEX 5300 mixer mill and Carbon concentrations of 10 mg subsamples were determined using a Carlo Erba NC2100 model C/N analyzer (Carlo Erba Instruments, Milan, Italy). 180 soil samples from the 16 lots were analyzed using Acetanilide, Cyclohexane, Mag1, and Montana Soil as calibration standards and as reference material every 10th analysis. Every sample from two of the quantitative pits was run in triplicate to assess the precision of the method.

Carbon loss was estimated by comparing data from the area disturbed by house construction with data from the undisturbed area (in the case of the auger samples), or with reference data (in the case of the ten quantitative pits). This reference results came from 14 sites in the region that we assume to be similar to the pre-development areas of our house lots (Hamburg, unpublished). At each of these 14 reference sites three full quantitative pits were taken to the C horizon. In order to make the pits comparable we averaged total carbon content from 0-20 cm and between 20 cm and the C horizon.

The percent change in carbon content between disturbed and undisturbed sites determined by the auger and quantitative pit methods were compared. For both the auger and quantitative pit method calculations we used z tests for different sample sizes to compare disturbed and undisturbed carbon content within each land use history classification. Additionally we used ANOVA single factor tests to quantify the difference in carbon loss using land use history as the dependent factor.

RESULTS

Auger Method Results

Comparison of the carbon content of the auger samples and those from the paired quantitative pit shows a reasonably strong linear relationship, with a slope of 1.00, for the 0-20cm layer (R^2 = 0.56, Figure 1). The relationship between the average carbon content of all of the auger samples and the quantitative pits 0-20 cm carbon content had a slope less than 1, which indicates that the auger method is slightly overestimating the amount of carbon at the site (R^2= 0.51, Figure 2).

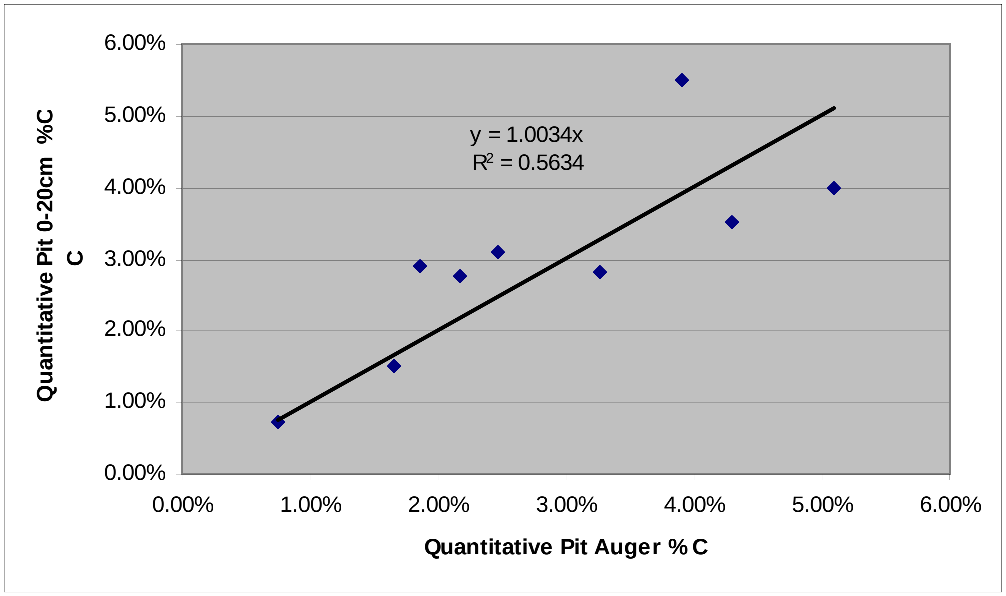

Figure 1. Relationship between carbon content in auger samples taken within the quantitative pit site and the carbon content of the quantitative pit 0-20 cm layer (one-to-one line shown).

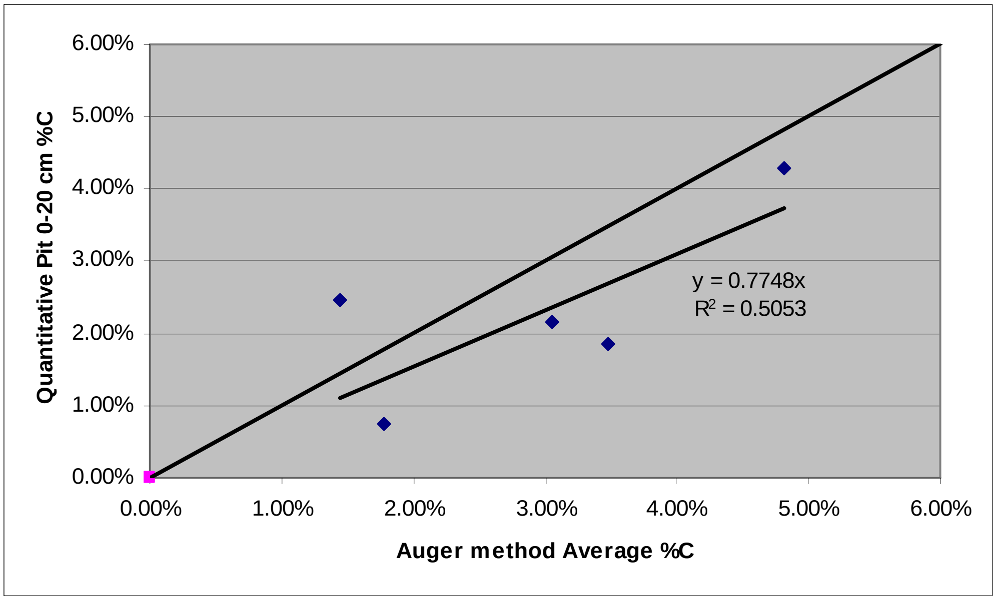

Figure 2. Relationship between average carbon content of all the auger samples taken at the house site and the carbon content of the quantitative pit 0-20 cm layer.

According to the auger method an average of 24% of the carbon originally present at depths of 0-20 cm at a house site is removed when the house is constructed. The original percent carbon on plowed, pasture and woodlot sites is 3.6 ± 0.8, 4.6 ± 1.3 and 5.9 ± 3.3, respectively. This is reduced to 3.0 ± 1.2, 3.6 ± 1.5 and 3.9 ± 2.2 when a house is developed. Taking land use history into account, approximately 17% of the carbon is lost on a former plowed field, 22% on a pasture, and 34% at a woodlot site (Table 1). An ANOVA single factor test for difference between auger method carbon content based on land use history resulted in a non significant P value of 0.41. Z-tests for difference between disturbed and undisturbed carbon content were also non significant, with p-values ranging from 0.41 to 0.46, though the results follow the expected pattern of greater carbon loss in soils that have the most carbon stock present pre-disturbance (Table 1).

Land Use	% Carbon Disturbed	% Carbon Undisturbed	Difference	P value	Proportion Change
Plowed	3.0 ± 1.2	3.6 ± 0.8	- 0.6 ± 1.4	0.46	- 17 %
Pasture	3.6 ± 1.5	4.6 ± 1.3	- 1.0 ± 1.8	0.45	- 22 %
Woodlot	3.9 ± 2.2	5.9 ± 3.3	- 2.0 ± 1.9	0.41	- 34 %

Table 1. Auger method differences between disturbed and undisturbed carbon percentage.

The auger method demonstrated a disturbance gradient with distance from the house site at all pre-development disturbance levels. Additionally, we found that measurements using the auger method demonstrated increasing variability with distance from the house site (Figure 3).

Figure 3. Auger method carbon content as a function of distance from the house site.

Quantitative Pit Method Results

Pre-disturbance, the average total carbon content on a lot is 136 ± 12 Mg C/ha, with an average of 143 ± 38 Mg C/ha on former plowed fields, 137 ± 34 Mg C/ha on former pastures, and 120 ± 44 Mg C/ha on woodlots. This pattern of greater carbon on more disturbed lots can be attributed to the temporary storage of carbon rich soils that have been mixed into deeper horizons while carbon rich O horizons accumulate (Hooker, 2003). After house construction, the average total carbon at a site in these two towns is 96 ± 39 Mg/ha; former plowed field sites have an average of 108 ± 38 Mg/ha, pasture sites have 62 ± 7 Mg/ha, and woodlot sites have 139 ± 20 Mg/ha (Table 2). An ANOVA single factor test for difference in the amount of carbon at a house site depending on the degree of historic land use intensity resulted in a significant P value of 0.03.

		Disturbed (MgC/ha)	**Undisturbed (Mg C/ ha)**	**Difference (MgC/ha)**	**P- value**	**Percent Change**
Total	**Plowed**	108 ± 38	143 ± 38	-35 ± 76	0.08	-24%
	Pasture	62 ± 7	137 ± 34	-76 ± 41	<0.01	-54%
	Woodlot	139 ± 20	120 ± 45	20 ± 65	0.26	16%
	Average	96 ± 39	136 ± 12	-40 ± 51	<0.01	- 20%
0-20 cm	**Plowed**	37 ± 14	88 ± 22	-51 ± 36	<0.01	-58%
	Pasture	34 ± 3	84 ± 13	-50 ± 16	<0.01	-59%
	Woodlot	46 ± 7	110 ± 35	-64 ± 42	<0.01	-58%
	Average	38 ± 10	92 ± 24	-55 ± 34	<0.01	-59%
> 20 cm	**Plowed**	71 ± 32	55 ± 28	16 ± 60	0.21	29%
	Pasture	28 ± 4	30 ± 21	-2 ± 25	0.44	-6%
	Woodlot	93 ± 28	15 ± 13	78 ± 41	<0.01	526%
	Average	59 ± 34	41 ± 28	17 ± 62	0.10	42%

Table 2. Carbon loss by land use history and depth.

The comparison of carbon content from an undisturbed area and from an area disturbed by house construction shows a loss of approximately 40 ± 51 Mg/ha (P<0.01). The carbon loss due to construction on a former plowed field is 35 ± 76 Mg/ha (P = 0.08) and on a former pasture is 76 ± 41 Mg/ha (P < 0.01). Our woodlot site indicated an insignificant net carbon increase of almost 20 ± 65 Mg/ha (P = 0.26, Table 2).

Overall, carbon decreased by 55 ± 34 Mg/ha in the 0-20 cm layer in an area disturbed by house construction (P < 0.01), but increased by about 17 ± 62 Mg C/ha at depths greater than 20 cm (P = 0.10). This pattern is less prominent on former plowed and pasture sites, where carbon loss is significant from 0-20 cm at 51 ± 36 Mg/ha and 50 ± 16 Mg/ha, respectively, but carbon change at depths greater than 20 cm are non significant at 16 ± 60 Mg/ha and -2 ± 25 Mg/ha, respectively. However, this pattern is very evident on woodlot sites where carbon loss is 64 ± 42 Mg/ha from 0-20 cm (P < 0.01) and carbon gain is 78 ± 41 Mg C/ha at depths greater than 20 cm (P < 0.01, Table 2). ANOVA single-factor tests demonstrate a significant difference in the amount of carbon at a house site depending on the degree of historic land use intensity at depths greater than 20 cm (P = 0.03) but a non significant difference between historic land use from 0-20 cm (P = 0.43)

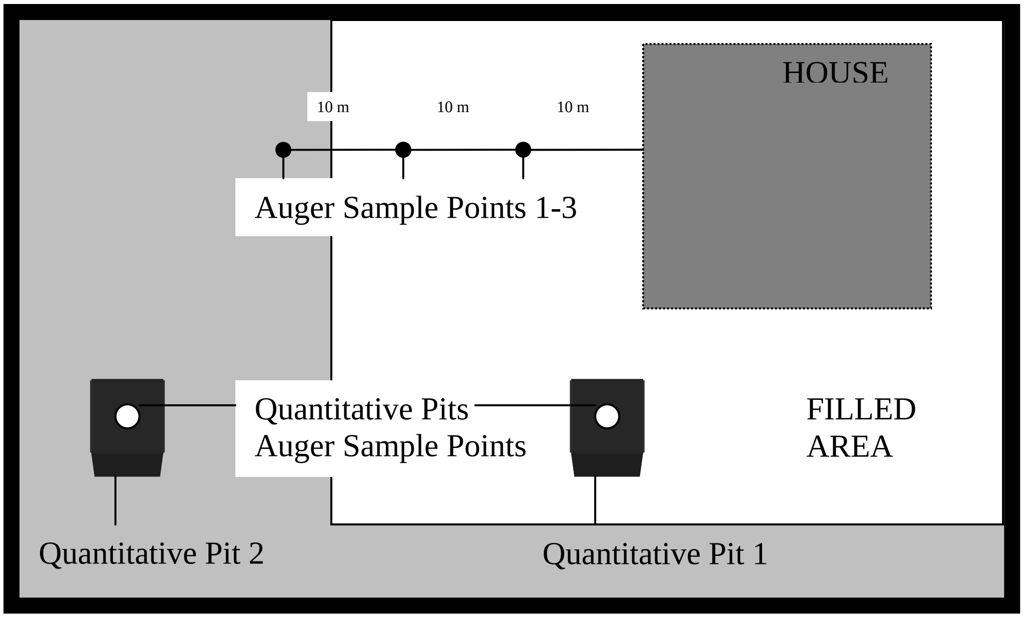

Figure 4. Diagram of Sample Sites on a Simplified House Lot.

The average filled area of a house lot was 50% of the total cleared area, so the mean of our two sampling sites provided a weighted average identical to the average of the two quantitative pit sites (Figure 4). The average area disturbed by house development was determined to be 0.25 ha, or approximately 10% of the entire lot. Combining this estimate with the average carbon loss per lot indicates that house development will result in a carbon loss of 10 Mg C from the soil per house. House construction on a former plowed field will result in a loss of 9 Mg C while construction on a former pasture will result in a loss of 19 Mg C and construction on a woodlot site will result in an increase of 5 Mg C.

There were approximately 48,000 homes built in New Hampshire between 2000 and 2005 (NHOEP, 2005). Assuming an average loss of 10 Mg C at each house site, this construction resulted in a net loss of approximately 480,000 Mg C. This five-year loss is equivalent to a loss of almost 96,000 Mg C per year, or about 360,000 Mg Carbon dioxide (MGCDE). These carbon dioxide emissions are equivalent to 2.0% of New Hampshire’s annual carbon emissions due to fossil fuel combustion (NHDES, 2001).

DISCUSSION

This study demonstrates that land use history does have an influence on carbon loss due to house development. The auger method indicates that the amount of carbon lost at a house site depends on the land use history, and that more carbon is lost on those sites where there is more carbon present pre-disturbance. The quantitative pit method supported these findings by demonstrating a statistically significant difference in carbon lost due to land use history. However, the quantitative pit method did not demonstrate the expected pattern of more carbon lost on sites with more carbon present pre-disturbance.

It is difficult to identify generalizable patterns because development at the house level adds another layer of spatial variability on top of an already very complex system of soil carbon. Yet despite these challenges and a very limited data set, some patterns have emerged. One important finding was auger method results demonstrating a continuum of increasing carbon content with increasing distance from the house location.

The pattern of carbon change due to development is more pronounced if we examine carbon stocks at different depths. The auger sampling technique was employed only for taking samples from 0-20 cm and was not used for greater depths. Had deeper sampling been done this may have provided a larger data set from which to draw conclusions. Nevertheless, the quantitative pit technique was sufficient to demonstrate that there is a general trend of carbon storage at greater depths in the soil profile.

This pattern of carbon accumulation may have occurred to some degree due to mixing of more organic horizons into lower depths, but it is most likely caused by carbon rich horizons that are capped by fill material. This occurred at 4 of our 10 quantitative pits. Due to the importance of capped carbon rich layers, building technique, e.g. whether a house site is filled in or whether soil is removed, may be an important factor in determining the difference in carbon content between disturbed and undisturbed sites. Also, fill material in urban systems has been shown to vary from between 29 Mg C/ha in loamy fill to 1 Mg C/ha in older sandy fill (Pouyat, 2002). While we did not measure the carbon content of fill material alone at our study sites, differences in the carbon content of fill could have influenced our findings. A key finding here is that shallow sampling can often overestimate the impact of development.

This study demonstrated significant carbon loss from 0-20 cm due to house construction at all three levels of historic land use intensity. Studies have shown that when agricultural land is abandoned in previously forested areas, regrowth has resulted in the slow but gradual recovery of soil carbon pools (Hamburg, 1984). However, it is suspected that the changes occurring in soil carbon storage at the study sites will be more persistent than other land use conversions because house lot conversions often result in cleared areas with little plant growth and thus fewer carbon rich inputs (Pouyat, 2002). We believe that the potential for nitrogen fertilization to increase sequestration in our study sites is minimal due to non-intensive lawn care practices characteristic of the area (Schlesinger 2000).

We estimate that soil carbon flux due to residential development in central New Hampshire is approximately 360,000 Mg carbon dioxide equivalent per year, based on average carbon lost per house site and average number of houses built per year. Incorporating loss due to removal of above ground biomass and lost sequestration potential over a fifty year period adds 1,050,000 Mg (0.00105 Pg) carbon dioxide equivalent to this estimate for a total of 1,410,000 Mg (0.00141 Pg) CO2 (Weinert, 2006). This figure is approximately 8% of New Hampshire's annual CO2 emissions due to fossil fuels (NHDES, 2001).

Policy Implications

Including the contribution of land conversion to net carbon releases is essential for planning policy approaches which fully account for, and mitigate the buildup of CO_2 in the atmosphere (IPCC, 2000). We have demonstrated that a significant amount of carbon is emitted as a result of land conversions yet soil carbon dynamics are still not included in large scale carbon mitigation schemes like the Regional Greenhouse Gas Initiative (RGGI) in the US northeast states. While RGGI currently mandates emissions standards for electricity generating facilities, it aims to achieve reductions through projects outside of the power sector (RGGI, 2006). More precise quantification of soil carbon loss due to development can facilitate the incorporation of carbon loss due to land use conversion into emissions reduction schemes. However, this study demonstrates the challenges an effort of that nature would face; all sources and sinks would need to be included and accounting may be very difficult.

Land use decisions are largely made with little regard for valuable ecosystem services, particularly in the Northeast where the overwhelming majority of the land is privately owned (UNHCE, 1998). However, communities that are undergoing rapid development, like Campton and Thornton, are beginning to address issues of land use conversions within their boundaries (Elson, 2006). These towns are focusing on issues such as the conservation of wildlife habitat and water quality, and the preservation of scenic views and the rural character of the towns. Preserving the rural character of these exurban towns can indirectly reinforce and strengthen the role of these second growth forests in mitigating climate change. Thus, while land use has generally been considered a local environmental issue, it is becoming a force of global importance due to the worldwide implications of carbon emissions (Foley, 2005). Conversely, a clear presentation of the mechanisms controlling carbon exchange can be used to influence land use management in a manner that complements current conservation efforts. Incorporating carbon stock preservation into land use plans will have additional benefits such as reducing suburban sprawl and habitat fragmentation.

Another chapter in a long history of land use change in central New Hampshire is currently being written. However, unlike during previous land use changes, scientists and policy makers have the capacity to determine the global consequences of local land conversion decisions. We understand more about the nature of carbon sinks, including their distribution, longevity, and reliability when faced with current conversions. This important information should be incorporated into policy locally in New Hampshire and regionally in the northeast.

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