Carbon Stock Changes in Soil and Aboveground Biomass from House Lot Development in King County, Washington, USA

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Fossil fuel burning and deforestation have driven dramatic increases in atmospheric CO_2 since the industrial revolution. However, forests in the northern temperate region sequester a substantial (~0.6 Pg·yr^{-1}) amount of carbon (C), largely through the regrowth of secondary forests that were originally cleared for timber over one hundred years ago. In the United States, however, some regions are approaching a maximum regrowth as forests are cleared again, this time for suburban and exurban development. Here we explore the effects of such development on C stocks in King County, WA, an area with high forest cover but rapid suburban expansion. We measured soil and biomass C on 18 paired-house/forest lots, and found house lots stored ~80 Mg·C·ha^{-1} less soil C, and between 130 and 280 Mg·C·ha^{-1} less above-ground biomass C than adjacent forest lots. Combining soil C losses with estimates of C emissions from forest products yields average C emissions of 130 - 280 Mg·C·ha^{-1}, with the majority of losses occurring at the time of lot conversion. As a comparison, suburban dwellers drive ~30% more than city residents, but this increase in annual emissions from increased driving is 1% - 2.5% of the losses of C associated with converting forests to house lots. If forestland conversion in the Seattle area continues apace, in the coming decades C emissions each year from that land-use conversion will equal ~4% of King County's 2008 C emissions.

Keywords: Land-Use Change; Carbon; Urban Soils; Emissions; Urban Growth; Development

Introduction

Land-use change and the burning of fossil fuels have dramatically increased atmospheric carbon dioxide (CO_2) concentrations since the industrial revolution, to a level not seen during the past 650 thousand years (IPCC 2007). Carbon (C) sequestration in regrowing forests, particularly in the northern temperate forest of North America and Europe, has partially offset these emissions (Pacala et al., 2001; Schimel et al., 2001; Houghton, 2007). However, as reforestation in some areas reaches a peak, and suburban and exurban development begins to reverse forest regrowth (Wienert 2006; Dwyer et al., 2000), rates of C sequestration may slow. In the United States, most current deforestation for suburban development occurs in forests that were previously cleared, either for agriculture or silviculture. Since urban and exurban landscapes account for 1.5 million·km^2, or about 25% of the conterminous US, and have grown at an average rate of 24,600 km^2·yr^{-1} for the past fifty years (Brown et al., 2005), the fate of C in secondary forested landscapes undergoing conversion to housing bears closer examination.

Despite its potential importance, the effects of suburban development on soil and biomass C has only recently been assessed in several regions of the US (Pouyat et al., 2002). In two northeastern temperate cities, Boston and Syracuse, urban soils contained ~60% less C than was stored belowground pre-evelopment, while in Chicago and Oakland soil C was slightly higher (4% - 6%) in urban soils (Pouyat et al., 2006). In more arid regions, including Phoenix (Oleson et al., 2006) and the

Colorado Front Range (Kaye et al., 2005; Golubiewski, 2006; Qian & Follett, 2002), C was higher in residential soils than native grass or desert soils. Similar results from Larimer County, CO suggest that surface soils in urban lawns can contain as much as 65% more C than shortgrass steppe soils (Kaye et al., 2005), which is not surprising given low organic C in semi-arid systems and the increased growth on lawns in response to water and fertilizer. In general, urban areas in arid regions have higher soil C than surrounding ecosystems and urban areas in wet, forested regions have lower soil C (Pataki et al., 2006). Whether changes in soil carbon content translates to emissions to the atmosphere is less well understood. For example, in King County, WA, large developments (>4 houses) typically remove all topsoil and ship it to a topsoil dump, whereas single house developments typically remove soil from a 60 cm foundation footprint and spread it around the rest of the lot. The emission C from these soils to the atmosphere may be quite different.

Similarly, quantifying development-driven C fluxes to the atmosphere for above ground biomass (AGB) depends on more than documenting differences in C stocks pre and post development, since the fate of forest products must be considered when calculating atmospheric C emissions from that land use change. The fate of woody biomass can vary (lumber, paper, mulch, fuel, non-harvest residue), and with it the C released to the atmosphere. Estimates of C losses to the atmosphere from post-harvest biomass range between 30% - 77% over 90 years (Harmon et al., 1996; Heath et al., 1996; Perez-Garcia et al., 2006). Scaling up quantified plot-level C affects is also difficult

given the spatial patchiness and complexity of urban landscape mosaics (Kaye et al., 2006).

The goal of this study was to explore the effects of forest to house lot conversion on soil and biomass C stocks in King County, Washington, US, an area with high forest cover but rapid suburban expansion. Like many local governments in the US, King County is trying to assess the sources of its greenhouse gas emissions, and has set the aggressive emission reduction target of bringing annual emissions 80% below 2007 levels by 2050 (http://your.kingcounty.gov/exec/news/2007/pdf/ClimatePlan.pdf). However, while the county recognizes that deforestation increases emissions and has taken some action to curb urban encroachment into forests, the county does not currently include potential soil and biomass C losses associated with development in its estimates of emissions. Thus we explored these C losses from development represented a substantial fraction of regional emissions given potential projected growth scenarios.

Methods

Site Description

Our 18 study sites were all in or around the City of Issaquah, Washington, US which covers an area of about 22 km^2 in east-central King County to the east of Seattle and Lake Washington, in the foothills of the Northern Cascades. The climate is temperate, with an annual precipitation of 150 cm (Brown, 2008). The region is in the western hemlock zone, and supports a humid coniferous forest (Franklin & Dyrness, 1973). The area is largely forested, with a mixture of private forestland and state forest; most of the forest was logged in the late 1800s and early 1900s, and thus is ~100 year old secondary growth (Robbins, 1985).

The population of King County grew from 1.3 million to 1.7 million between 1980 and 2000 and is expected to grow to 2.2 million by 2030 (http://www.wsdot.wa.gov/planning/wtp/data-library/population/PopGrowthCounty.htm). An estimated 18,000 ha of King County forestland were converted to urban and suburban uses between 1979 and 1989 (MacLean & Bolsinger, 1997) and 36,400 ha were converted between 1988 and 2004 (Erickson & Rogers, 2008). Similarly, some projections suggest that 21% of population growth in King County between 2000 and 2040 (362,000 people) will occur in unincorporated areas, many of which are forested (Puget Sound Regional Council, 2008).

King County estimates that development of individual lots for single family residences constituted ~50% of all residential building permits for unincorporated areas (where much of the construction on forestland occurs) between 1998-2008 (King County Department of Development and Environmental Services, pers. Comm.). Across development types, fossil-fuel intensive lawnmowers, pesticides and fertilizers are sometimes used for lawn maintenance, and while this certainly would affect a lifecycle C analysis of development, we limit our analysis here to soil and biomass C loss. We focused our study on single home developments, because it was not possible to assess the fate of excavated topsoil that was transported off site (as is often done in larger housing developments in the region).

The sites we sampled spanned urban (>386 people·km^{-2}), suburban (115 - 385 people·km^{-2}), and exurban (19 - 114 people·km^{-2}) areas, though the majority were in suburban settings (http://www.census.gov/population/censusdata/urdef.txt). We selected only sites whose lots had been cleared for the development of <5 homes (15 of 18 were cleared as single house lots), which makes it probable that soil was not removed from the pro-perty during construction. Most of the houses were in hilly areas, because we restricted our analysis to forest-to-home conversions, and much of the flat land in the region had been previously cleared for agriculture. The house lots ranged in elevation from 23 m - 330 m a.m.s.l. The underlying soils were Inceptisols and Entisols (Alderwood, Everett, Beausite, & Neilton soil series; Soil Survey Staff, 2008), which are typical of the glacial till-rich soils of the region.

The house lots ranged from 1 - 88 years since development (mean 28 years). Lot size (including uncleared forest areas) ranged from 590 m^2 - 28,000 m^2, while the total area cleared ranged from 400 m^2 - 5300 m^2, and the house footprint from 130 m^2 - 340 m^2. The majority of the cleared area at each site was lawn, but the cleared area also included gardens, planted trees and shrubs, and lone trees left standing during the clearing process. Gardens accounted for ~6% of cleared area on the average house lot. We drew house lot soil C samples from the lawn, and at two sites we also drew samples from gardens for comparison. We assumed that the intact forest left in place on the property did not lose any C during development.

Soil Carbon Determination

At each house lot we took three soil samples from the lawn (at 1, 5, and 10 m perpendicular from the house) and one sample from an adjacent forest site within 200 m of the lawn. There was no difference in soil C between lawns and gardens (**Appendix 1**), so these were combined in further analyses. We used a hammer core to a depth of 25 cm to determine bulk density (Grossman & Reinsch, 2002). Bulk density is notoriously difficult to measure in rocky soils (Vincent & Chadwick, 1994), and it was not possible to get home owner permission for the preferred method of excavating large areas quantitatively. Our use of a hammer core certainly introduces error to our bulk density measurements, but that error is equally distributed between our two land use types. In the hole created by the hammer corer we used a twist auger to collect three samples to a total depth of 75 cm (25 cm - 42 cm, 42 cm - 59 cm, and 59 cm - 75 cm). Because of the high rock and gravel content of the soil we were unable to sample to 75 cm at every location, but we collected at least one core per house, and one per forest, to a depth of 42 cm and to a depth of 59 cm for all but four houses and four forests. Since there were no differences in either bulk density or soil C in house lot soils as a function of distance from the house (**Appendix 1**), we averaged our house lot samples and considered a paired house lot/forest for each site.

We assumed, based on ten interviews with contractors, that 60 cm of soil was excavated from the house foundation and spread around the site (and therefore included in the soil C values for the lawn). Since the mean house size was only 20% of the mean cleared lot size (**Appendix 1**), this assumption is unlikely to substantially influence our results. We conservatively assumed no soil C loss from beneath the driveway.

All samples were air-dried at room temperature for a minimum of 48 hours and sieved through a 2 mm screen. We determined bulk density of the <2 mm fraction for the 0 cm - 25 cm core, and assumed bulk density did not change below 25 cm. This assumption underestimates soil losses from house lots, since surface soils were significantly less dense in forests than in house lots (0.77 vs 1.0 g·cm^{-3}, respectively, p = .003; **Appendix 1**), and this difference likely gets smaller with depth. A subsample of each sample was ground in an agate mortar and pestle, dried at 65°C for at least 48 hours, and analyzed for C concentration on

a Carlo Erba NC2100 model C/N analyzer. A second subsample was dried at 105°C and all stocks are reported per 105°C oven-dried mass. Samples were run in duplicate, and 10% were run in triplicate. Ninety-five percent of the standards run as unknowns were within 5% of their accepted value. All reported values are means ± 1 S.E. unless otherwise noted. Statistical comparisons between forest and house lots were done in Matlab (Version 7.4, Mathworks, Inc.) via a paired t-test or ANOVA after testing that the data did not violate the assumptions of normality.

Carbon in Biomass

We did not measure biomass in forest lots adjacent to house lots, but instead calculated changes in AGB by comparing AGB on each house site with the range of forest AGB values reported for the Pacific Northwest (140 - 290 Mg·C·ha^{-1}; Adams et al., 2005; Binkley et al., 1992; Hutyra et al., 2011), though more recent estimates are somewhat lower. We chose to use a biomass range, rather than to measure forest biomass directly for two reasons: 1) allometric equations developed for tree species in the region are problematic (Harrison et al., 2009); and 2) biomass lost at the time of clearing would not be the same as biomass in adjacent forests today, particularly for older home sites. Rather than include a non-random error in our assessment we chose to assess a reasonable range of biomasses that could give us an idea of the importance of soil relative to biomass C losses.

Estimates of how much AGB C ends up as atmospheric C post-harvest also vary considerably, and we chose a range that encompasses the majority of the literature for these estimates. Heath et al. (1996) argued that 30% of biomass C from cleared forests in the United States is emitted as CO_2 over 90 years by decomposition of wood products, and another 35% is emitted from biomass burning for energy. Because the latter likely replaces fossil fuels that would have been used anyway we do not consider this an additional loss of C associated with development per se, and use 30% over 90 years as a lower bound of AGB loss. For an upper bound, we use an estimate of 77% loss (Harmon et al., 1996). Thus we assume that 40 - 222 Mg·C·ha^{-1}, less the amount of biomass still on the cleared portion of the house lot, are lost to the atmosphere in the 90 years after house development. We use 90 years as a time frame because it is appropriate for this study (the oldest house is ~90 years) and because both Heath et al. (1996) and Harmon et al. (1996) give aggregate emissions estimates based on C fate in forest products over this time period, since the collection period of the harvest data from the Forest Service was 1900-1990.

Biomass on each house lot was calculated by measuring diameter at breast height (DBH) for all trees on the site and using a generic allometric equation to determine biomass (Jenkins et al., 2004):

$$\text{Above Ground Biomass} = \text{Exp}\left(B_0 + B_1 \ln dbh\right) \qquad (1)$$

where $B_0 = -2.4800$ and $B_1 = 2.4835$; these parameters are mean values for mixed hardwoods (most house lots contained a broad mix of native softwoods and non-native planted hardwoods). While these parameters are meant specifically for trees growing in a canopied forest, using other common estimates for B_0 and B_1 in this type of system resulted in changes of <5 Mg·C·ha^{-1}. While some studies have shown that using allometric equations appropriate for trees in a canopied forest can overestimate biomass of urban trees by ~20% (Nowak, 2004), to our knowledge this issue has not been explored in the Pacific Northwest, and other authors have argued that standard allometry may either over or under-

estimate actual urban biomass (McHale et al., 2009). Regardless, there was so little biomass (mean 8 Mg·C·ha^{-1}) in house lots relative to forests (or soils) that the choice of allometric equation has very little influence on our results. We assumed AGB was 50% C (Schlesinger, 1997), and omitted both grass and shrubs under 1 m tall, since they account for <2% of total biomass in urban and suburban settings (Golubiewski, 2006; Jo & McPherson, 1995). Finally, we conservatively assumed no belowground biomass loss because there was insufficient data to make a more nuanced estimate.

Results

Soil Carbon

The mean surface (0 cm - 25 cm) soil C concentration was significantly higher in forests (6.4% ± .78%) than on house lots (3.8% ± .29%; p = .00005; **Figure 1**). Similarly, the 25 cm - 75 cm soils were significantly more C rich in forests than lawns (3.6% ± .65% versus 1.9% ± .20%; p = .006). The mean bulk densities for the forest and house lots also differed significantly at .77 ± .24 and 1.0 ± .05 g·cm^{-3}, respectively (p = .003, n = 18). These data indicate that forest soils stored ~80 Mg more C ha^{-1} than house lot soils (240 ± 25 vs 160 ± 11 Mg·C·ha^{-1}, respectively, p = .002). There was no significant difference in C concentration between the three depths for the 25 cm - 75 cm samples (p = .71) nor in bulk density or the means of the C concentration among the three distances from the house (p = .55 and .18 respectively). Finally, there was no correlation between house age, or lot size, and soil C concentration (p = .4 and .2, respectively).

Carbon in Biomass

The aboveground C in biomass on the house lots ranged from 0 Mg - 44 Mg, with a mean of 8.0 ± 3.0 Mg·C·ha^{-1} (**Figure 2**). Native trees, left behind on clearing, made up ~40% of the this biomass. There was no correlation between age and biomass on house sites ($r^2 = .05$, p = .38). Forest AGB C estimates drawn from the literature suggest that there is 140 - 290 Mg·C·ha^{-1} in AGB (Adams et al., 2005; Binkley et al., 1992; Hutyra et al., 2011). Assuming between 30% and 77% C emitted from this AGB over 90 years (Heath et al., 1996; Harmon et al., 1996) after conversion from forest to house lot, between 40 - 220 Mg·C·ha^{-1} are likely lost to the atmosphere over this time. If loss rates are invariant over 90 years, this suggests emissions of .40 - 2.4 Mg·C·ha^{-1}·yr^{-1}.
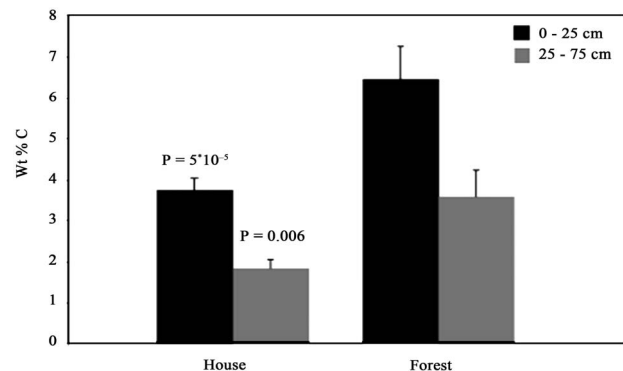

Figure 1.
Percent carbon in house lot soils and forest soils. The error bars represent 1 SE. p-values are from comparisons of forest and house soils at a given depth.
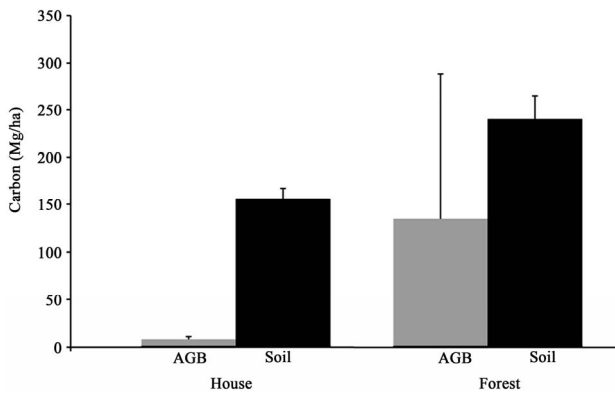
Figure 2.
Mean carbon stores in soil and aboveground biomass in house and forest lots. The error bars for the house lots and the forest soil represent 1 SE. The error bar on forest AGB represent the range found in the literature for this region.

Discussion

Soil Carbon and Biomass Loss

Given the trajectory of suburban encroachment onto forests or reforested land, our results are important for those calculating greenhouse gas budgets in the Pacific Northwest. Our data suggest that a pulse of C is released from the soils of a house lot during development that does not re-accumulate over time. Furthermore, the soil C loss associated with lot development is large (mean 80 Mg·ha^{-1}), roughly 30% - 60% of the aboveground C loss. This finding is consistent with those of Pouyat et al. (2006) in cities with climates similar to that of this study, but contrasts with those of Golubiewski (2006), Kaye (2005) and Qian and Follett (2002), which found relatively higher C in urban soils in drier and/or warmer climates. Similarly, the lack of correlation between age of development and soil C contrasts with the results of those studies. We hypothesize that in wetter environments, such as the one in our study, development stimulates a pulse of decomposition that tapers off as the new land use is in place. In contrast, poor arid soils accumulate C over time as water and nutrients are continually provided. These results support the review by Pataki et al. (2006) and Pouyat et al. (2009), both of which suggest that affect of development on soil C varies by ecosystem. Given the low biomass on house lots, the vast majority (>90%) of C in house lots is stored in soils (**Figure 2**). Similar C distributions have been observed in other urban areas (Jo & McPherson, 1995).

Assumptions

While understanding the C footprint of development is critical for planning how best to reduce emissions, there is considerable uncertainty in determining losses that bear closer examination here. Perhaps most importantly, we assume that soil C losses from the site result in C emissions to the atmosphere in the form of CO_2 or that C originally in forest soils was decomposed and respired upon conversion to house lots. However, some fraction of house lot soil C that we measure as missing may actually have been transported off of the site via erosion of topsoil. The fate of such C is unclear, and likely depends on processing in rivers and estuaries (Berhe et al., 2007). This may lead us to overestimate emissions from soil C.

We also assume that bulk density was the same from 25 cm to 75 cm as it was from 0 cm - 25 cm at each site, which propagates the higher bulk density in house lots to depth. If compaction did not affect the lower house lot horizons, and bulk density in the lower soil is similar between pairs of sites, we will overestimate the amount of C in house lots by ~10%.

In addition, the fate of AGB removed from the house lot greatly influences the magnitude of C lost. There is a dearth of data on the fate of C in harvested wood products, particularly on how long wood products used in construction take to decompose, and how that varies with wood type, specific use, and region. In addition, the time scale of these losses is poorly constrained. We took 90 years of losses as our benchmark, based on the available literature and the age of the homes in our study area. However, if these losses occur more rapidly, or if losses decrease exponentially with time, we may be considerably underestimating losses from house lot clearing.

Lost Carbon Sequestration Potential

Many of the forestlands into which Seattle is expanding were last logged in the late 1800s and early 1900s, meaning that most of these stands are currently around 100 years old (Robbins, 1985). Stands of Northwest evergreens, such as Douglas-fir and Western Hemlock, take up to 250 years to mature after being logged, and some conifers can live up to 700 years (Spies & Franklin, 1996). Smithwick et al. (2002) found that on average an additional 338 Mg·C·ha^{-1} would be stored in the biomass and soils of coastal Washington and Oregon forests if second growth stands were allowed to return to their maximum C holding capacity, and that the upper bound C potential for just the biomass of these old growth forest is 380 Mg·C·ha^{-1}.

For C losses, and loss rates, we have used a range of between 140 Mg·C·ha^{-1} and 290 Mg·C·ha^{-1} to estimate preclearing biomass (Adams et al., 2005; Binkley et al., 1992; Hutrya et al., 2011). However, the development of housing on regrowing forestland also represents a lost C uptake in the future. Assuming that the forests reach their full C holding potential after an additional 150 years (given an average stand age of ~100 years; Smithwick et al., 2002; Franklin et al., 1986), the lost sequestration potential (LSP) is the difference between the biomass at the time of removal and the assumed biomass of a fully grown forest. Lost sequestration potential at our sites ranges from 92 - 245 Mg·C·ha^{-1} developed, or .6 - 1.6 Mg·C·ha^{-1}·yr^{-1} for the next 150 years. From the perspective of King County's emissions, this LSP represents a C sink that is lost by development that otherwise would have helped King County to reach its net C emissions reduction goals. Instead of this forested land acting as a C sink as the forest matures, when it is developed it acts as a C source as the biomass and soil C is emitted.

Carbon Emissions in Context

Although there are considerable uncertainties in the estimate, the C loss due to development is substantial, even when LSP or fossil fuel intensive inputs such as fertilizer and pesticides are left out of the equation. Assuming lower bound forest C and loss rates, 120 ± 31 Mg·C·ha^{-1} is liberated from soils and AGB within 90 years of conversion, while upper bound estimates suggest a 300 ± 31 Mg·C·ha^{-1} loss (**Figure 2**). This loss is comparable to other major C costs of suburban development (**Figure 3**). For example, for every house that is built on a forest lot rather than
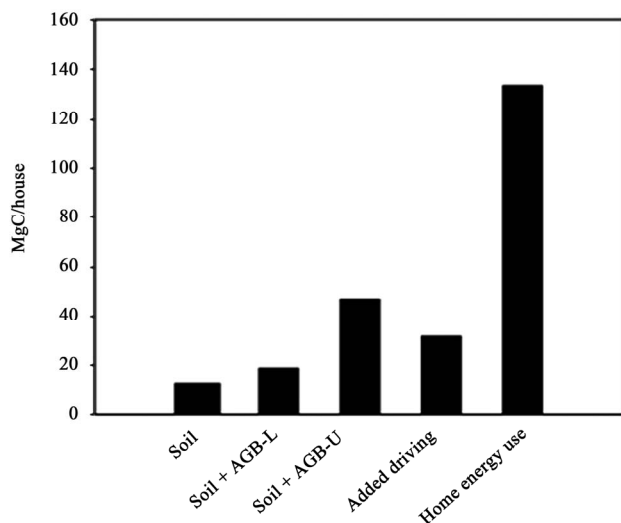
Figure 3.
Estimates for emissions from house lots over a time period of 90 years assuming a mean houselot size of .16 ha. Soil, above ground biomass low and high calculations as described in the text. Additional emissions from driving calculated assuming suburban households drive 31% more than urban households.

dense urban infill, there is on average a 31% increase in the number of miles that that particular household drives (Kahn, 2000). If the average person in the Puget Sound region drives ~13,500 km·yr^{-1} (Overby, 2008), a household with two drivers travels an additional 8000 km yr^{-1} by building in suburbia compared to a similar household living in a denser urban area. Assuming an average car gets the 2004 CAFÉ standard of 11.7 km·l^{-1} (27.5 miles per gallon) (EPA, 2003) and that emissions are 633 g·C·l^{-1} (EPA, 2003), given a 99% combustion efficiency, then the transportation-based C impact of building a single family home in the forest instead of as urban infill is .43 Mg·C·yr^{-1} (**Figure 3**). Thus it would take 30 years for the emissions from increased driving to equal just the soil C emissions from clearing 0.16 ha of forest, the mean area cleared at our sites (**Figure 3**, **Appendix 1**). It would take 43 - 107 years for increased tailpipe emissions to equal emissions from soil and biomass combined over 90 years, and even longer for driving emissions to equal soil and biomass emissions if LSP was included.

Implications for King County and Future Directions

Although the recent economic downturn and a new national awareness of environmental issues could slow Seattle's growth into forestland, it is likely that suburban encroachment into forest will still occur in the coming decades. Assuming that growth will roughly continue at the 1988-2004 pace, ~36,000 ha will be converted from forestland to suburbs in the next 15 years in King County (Erickson & Rogers, 2008). This means that emissions from soil and biomass C will likely be between 210,000 - 240,000 Mg·C·yr^{-1}, or ~4% King County's annual emissions, based on the county's 2008 emissions.

Such extrapolation is subject to considerable uncertainty. Not all of the land which is converted from forest to suburbs will be deforested and built as single house lots; according to estimates from the King County Department of Development and Environmental Services, single house lots likely represent just over half of total homes developed in the past decade around Issa-

quah and similar suburbs. In large subdivisions or shopping centers the treatment of biomass and especially of soils is different, and therefore the C emissions may vary. Different soil types may respond to development differently, and because the sites in this study were located primarily in highland areas, riparian and other particularly soil C-rich areas were excluded. Despite this variation in both initial conditions and owner decision-making, these data demonstrate that emissions from house lot development can be a measureable fraction of total emissions in some regions. Given the rapid rate of suburban expansion in this country, we suggest the fate of biomass and soil C from different settings be a priority of future research across ecosystems.

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Appendix 1. Soil Carbon, Bulk Density, Above Ground Biomass (AGB) and Selected Site Attribute Measurements.

					HOUSE				
Site	Distance from house m	BD g·cm^{-3}	wt%·C 0 - 25 cm	wt%·C 25 - 75 cm	Lawn Soil C 0 - 75 cm Mg·ha^{-1}	Cleared Area ha*	House Area ha	Total Soil C Mg·ha^{-1}	AGB-C Mg·ha^{-1}
1	1	1.0	1.4	1.2	100				
1	5	.88	3.3	1.7	150				
1	10	.70	2.7	1.0	83				
Site 1 mean		.87	2.5	1.3	110	.053	.028	83	6
2	1	1.4	1.9	.79	120				
2	5	1.1	.87	.74	63				
2	10	1.1	4.2	1.4	180				
Site 2 mean		1.7	2.3	1.0	190	.082	.013	170	20
3	1	1.0	2.1	2.6	190				
3	5	1.2	2.9						
3	10	.71	1.7	1.4	78				
Site 3 mean		1.5	2.2	2.0	230	.042	.025	150	.5
4	1	.90	3.0	2.8	190				
4	5	.93	3.3						
4	10	1.0	3.0	2.6	210				
Site 4 mean		1.0	3.1	2.7	200	.20	.070	160	.09
5	1	1.0	2.7	.84	110				
5	5	1.0	2.9	1.0	120				
Site 5 mean		1.0	2.8	1.5	140	.061	.018	120	10
6	1	1.3	2.9						
6	5	1.0	2.8	.34	86				
6	10	.83	2.8	.37	73				
Site 6 mean		1.0	2.8	.36	91	.021	.022	59	30
7	1	1.0	6.1	1.4	230				
7	5	1.0	5.6	1.3	220				
7	10	1.0	7.2	2.2	300				
Site 7 mean		1.0	6.3	1.7	250	.018	.018	170	.3
8	1	.77	3.5	.63	92				
8	5	1.4	4.6						
8	10	.84	5.4	1.3	170				
Site 8 mean		1.0	4.5	1.0	160	.035	.022	121	40
9	1	1.3	3.9						
9	5	1.3							
9	10	1.0	3.4	1.4	160				
Site 9 mean		1.2	3.7	1.4	190	.20	.053	170	8**
10	1	1.0	5.0	3.1	290				
10	5	1.3	5.4						
10	10	.89	4.5						
Site 10 mean		1.1	5.0	3.1	300	.070	.018	240	8**
11	1	.92	3.8						
11	5	1.0	3.2	1.6	150				
11	10	.95	5.6	6.4	440				
Site 11 mean		.95	4.2	4.0	290	.073	.021	240	5
12	1	.67	6.8	3.5	230				
12	5	.58	7.6	2.1	170				
12	10	.67	4.8	2.3	160				
Site 12 mean		.64	6.4	2.6	190	.021	.015	140	.1
13	1	.92	2.8	1.8	140				
13	5	.80	4.5						

Continued

Site									
13	10	1.0	4.4						
Site 13 mean		.90	3.9	1.8	170	.20	.019	150	.1
14	1	1.1	3.8	2.4	240				
14	5	1.0	3.2						
14	10	1.3	4.2						
Site 14 mean		1.1	3.7	2.4	250	.10	.016	220	1
15	1	1.0	2.6	2.0	170				
15	5	.93	3.0	3.3	230				
15	10	.67	2.9	1.3	91				
Site 15 mean		.88	2.8	2.2	160	.037	.029	110	4
16	1	1.0	2.8	1.5	140				
16	5	1.1	3.1						
16	10	1.0	4.2	1.4	170				
Site 16 mean		1.0	3.4	1.5	160	.34	.034	150	10
17	1	1.0	4.3	1.8	400				
17	5	1.4	3.8						
17	10	.87	4.0	1.0	130				
Site 17 mean		1.1	4.1	1.4	190	.34	.030	180	1
18	1	1.0	3.6	.79	130				
18	5	1.1	4.2						
18	10	1.0	3.6	2.1	$2.0*10^2$				
Site 18 mean		1.0	3.8	1.4	170	.48	.021	170	.8
MEAN		1.0	3.8	1.9	190	.13	.026	160	8
S.E.		.050	.29	.20	13	.03	.003	11	3.0

[*]Cleared area values do not include the house footprint; they show total cleared area less the house footprint. Total cleared area = cleared area + house footprint. [**]No data-value assumed to be the mean of the dataset.

		FOREST		
Site	Bulk density g·cm^{-3}	wt% C 0 - 25 cm	wt% C 25 - 75 cm	Total Soil C Mg·ha^{-1}
1	.63	3.8	2.5	140
2	.48	8.8	2.8	170
3	1.0	2.0	.86	98
4	.70	5.4	1.4	140
5	1.0	3.0	2.5	$2.0*10^2$
6	.46	5.3	3.5	140
7	.77	4.5	7.9	390
8	.67	11	3.0	290
9	.53	11	5.5	290
10	.39	12	2.5	160
11	.47	11	12.4	420
12	1.0	9.6	3.7	420
13	.93	5.1	2.3	230
14	1.1	1.5	.94	92
15	.86	5.6	2.6	230
16	1.1	3.7	3.8	320
17	.91	8.5	3.2	340
18	.91	5.0	2.7	240
MEAN	.77	6.4	3.6	240
Standard Error	.24	.78	.65	25