WHAT DOES NONFOREST LAND CONTRIBUTE TO THE GLOBAL CARBON BALANCE?

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ABSTRACT.—An inventory of land traditionally called "nonforest" and therefore not sampled by the Forest Inventory and Analysis (FIA) program was implemented by the FIA unit at the Northeastern Station in 1999 for five counties in Maryland. Biomass and biomass increment were estimated from the nonforest inventory data using techniques developed for application to large-scale inventory data. Results were compared to estimates for forested land in Maryland. We conclude from this work that carbon (C) stocks and fluxes on nonforest land could add substantially to current estimates of local, regional, and national C balances, which are currently based on forest land only.

Attempts to quantify the global carbon (C) budget have focused heavily on the role of forest growth and regrowth in C uptake (Caspersen and others 2000, Pacala and others 2001, Wofsy 2001). The forest inventory approach, because it is typically based on ground-measured data for a comprehensive, unbiased sample of forest land, has widely been accepted as the most reliable approach for large-scale and comprehensive estimation of forest C stocks and fluxes (Goodale and others 2002, Hicke and others 2002, Pacala and others 2001). The United States (U.S.) forest C budget (Birdsey and Heath 1995, U.S. Government 2000), however, is based exclusively on land defined by the U.S. Department of Agriculture (USDA) Forest Service Forest Inventory and Analysis (FIA) program as "forest."

FIA defines a stand of forest land as: a) at least 1 acre in size; b) at least 120 feet wide; c) at least 10 percent stocked; and d) not developed for another use (such as residential, recreational, or agricultural) (Hansen and others 1992). Based on this definition, roughly two-thirds (67%) of the U.S. land base is considered nonforest (Smith and others 2001). This nonforest figure includes range and desert land in the arid interior of the country; this arid land would not normally support forest vegetation. Still, this definition of forest has critical gaps with respect to large-scale C cycle estimation, especially for regions such as the Northeastern U.S., where trees and other vegetation are ubiquitous on land being used for all types of purposes.

While inventories of trees in urban areas do exist (Nowak 1994, Nowak and Crane 2002), these urban samples have been almost exclusively conducted within the city limits. As a result, they do not include those areas missed from the FIA "forest" sample in suburban, rural-residential, and rural-agricultural areas outside the city limits. In this study, we examined the potential implications of excluding nonforest land from the land base used to develop large-scale C budgets.

METHODS

The Maryland Nonforest Inventory

In 1999, a pilot study was undertaken to inventory the plots classified by FIA as "nonforest" in five Maryland counties: Anne Arundel, Baltimore, Carroll, Harford, and Howard (fig. 1). This five-county area covers 2,237 mi^2 and is home to 2,512,431 persons, according to the 2000 U.S. Census. It was selected to capture a gradient of population density, urbanization, and land use. In addition, the region is identical to the five-county area designated as the research site for the Baltimore Ecosystem Study (BES), one of 24 Long-Term Ecological Research (LTER) study sites across the U.S.

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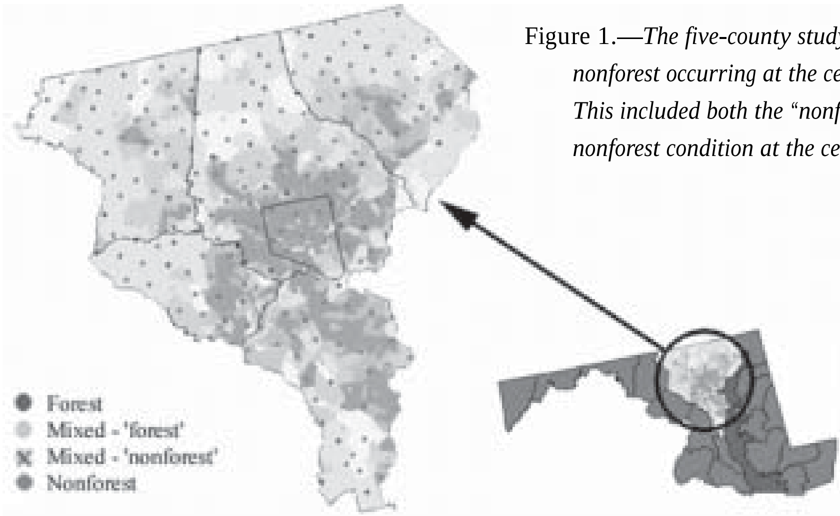

Figure 1.—*The five-county study area and all 243 FIA plots. Any FIA plot with nonforest occurring at the center subplot was visited by the nonforest crew. This included both the "nonforest" and "mixed-nonforest" plots (i.e., some nonforest condition at the center subplot). From Riemann (2001).*

Within the study area, the city of Baltimore is entirely urban, while large areas of suburban development occur in four of the five counties. Population density ranges from 336 to 8,059 persons per square mile in rural-agricultural Carroll County and Baltimore City, respectively. The pilot nonforest inventory was conducted concomitant with the Maryland inventory in 1999; this timing increased the efficiency of data collection, because the nonforest field crews collected the standard FIA plot variables for nonforest plots as well as the additional variables required by the nonforest inventory. By collecting data for the forest and nonforest inventory simultaneously, we also ensured that the two inventory samples would be comparable.

Details of the nonforest inventory procedure are given in Riemann (2003). Briefly, the nonforest inventory used the regular FIA plot grid in Maryland. A one-tenth-acre (37-ft-radius circular) nonforest plot was established around the center of subplot 1 if any nonforest condition occurred on that subplot (fig. 2). The nonforest portion of that one-tenth-acre plot was then inventoried by the nonforest field crew. A nonforest plot was not established if the center subplot was entirely forested, even if nonforest conditions did occur on any of the other subplots. The inventory methods and protocols used by the FIA nonforest inventory crew were identical to the standard FIA protocols wherever possible (USDA Forest Service 2000).

In 1999, there were 243 forest and nonforest FIA plots in the five-county study region. Of these, 146 were classified as nonforest, 44 as forest, and 53 as mixed (i.e., containing both forest and nonforest conditions). The mixed category contained 25 plots that were entirely forested on subplot 1 and 28 plots that had some nonforest on subplot 1. The nonforest crew inventoried 162 of these plots: 138 of the nonforest plots and 24 of the mixed plots. Thus, eight of the nonforest plots and four of the mixed plots were not sampled by the nonforest crew; these plots are considered "missing," and we assume that their exclusion does not bias this analysis.

On each plot, a subset of the standard FIA variables was collected, plus some variables designed to better describe the tree health, biodiversity, and ground cover of trees in nonforest areas. Those regular FIA variables that were considered to be less useful in nonforest areas, such as the timber-related variables of cull and board feet, were excluded from the nonforest sample. To better distinguish the types of areas in which the nonforest plots and areas of high tree basal area were found, three additional variables were added: detailed land use class, detailed owner class, and reason for nonforest status.

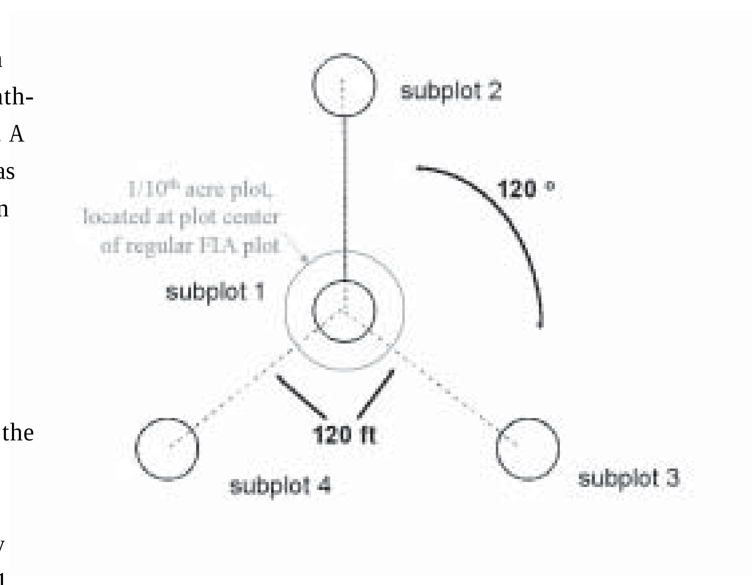

Figure 2.—*Nonforest inventory plot design compared to standard FIA plot design. From Riemann (2001).*

Biomass and NPP from Nonforest Inventory Data

Net primary production (NPP) is the rate at which C is accumulated by autotrophs and is expressed as the difference between gross photosynthesis and autotrophic respiration. Complete measurements of total NPP include annual aboveground and belowground production in both woody and non-woody biomass. In this study we focused on annual biomass increment only, also known as wood NPP (WNPP), for two reasons: a) we knew of no data on litterfall and root production for nonforest areas, and b) the wood component of NPP is the equivalent of annual C sequestration and storage, since wood biomass turns over much more slowly than the non-woody biomass compartments.

Total tree biomass and wood net primary production (WNPP) were computed from plot- and tree-level inventory data for the 162 nonforest plots in the five-county area in Maryland, using methods as described in Jenkins and others (2001a). WNPP was defined per tree as

$$\text{Wood production per tree (kg yr}^{-1}\text{)} = [\text{aboveground biomass (kg)} (t_1) - \text{aboveground biomass (kg)} (t_0)]/[t_1 - t_0 \text{ (yr)}] \quad (1)$$

where t_1 refers to the current year, and t_0 refers to the year at the beginning of the inventory period (in this analysis we assumed a 1-year sampling interval, and found d.b.h.$_{t0}$ from d.b.h.$_{t1}$ as described below). Biomass estimates for current conditions (t_1) were found on a tree-by-tree basis from diameter at breast height (d.b.h.) using species-group regression equations as described by Jenkins and others (2003). To find biomass and biomass increment on a per unit area basis from tree-level measurements, the tree-level estimates were multiplied by the expansion factor representing the number of trees per unit area represented by that individual stem.

Because these nonforest plots have been censused only once, to obtain estimates of growth it was necessary to estimate d.b.h. growth for all trees. This was accomplished using linear algorithms developed for mid-Atlantic forests, which relate current diameter to predicted diameter increment (Jenkins and others 2001)

$$\text{d.b.h.}_{t0} \text{ (cm)} = \text{d.b.h.}_{t1} \text{ (cm)} - [\text{average d.b.h. growth rate (cm yr}^{-1}\text{)}] * [\text{remeasurement period (yr)}]. \quad (2)$$

Biomass values were converted to C using 0.475 as the proportion C in biomass (Raich and others 1991).

For comparison, biomass and WNPP were also computed for 316 remeasured forested plots in Maryland from the 1985 inventory using the same techniques. These values were further compared to biomass and WNPP data obtained using methods originally described by (Birdsey 1992), applied to timber volume growth and mortality data for Maryland and the entire Northeastern Region from the 1997 Resource Planning Act (RPA) assessment (tables at http://www.fs.fed.us/fia/).

To aggregate the nonforest inventory information from the five counties to the State level, an average nonforest biomass and WNPP value per unit area was computed for all 162 plots. No attempt was made to select plots with trees or on particular land types; as a result, this sample is assumed to be representative of the tree cover on an average piece of "nonforest" land in Maryland. This average per unit area biomass and WNPP value was multiplied by the nonforest land area in that State to approximate the aggregate State-level biomass and WNPP totals on nonforest land. A parallel procedure was followed for forest land in Maryland, except that the sample of forest plots was representative of forest land over the entire State rather than the smaller five-county region.

RESULTS

Maryland

Tree biomass stocks for Maryland forests computed using the Jenkins and Birdsey methods were comparable (table 1). The larger biomass stocks computed from the RPA data most likely occurred because the RPA data apply exclusively to timberland, which is selected for its high productivity. Tree biomass stocks for nonforest land in Maryland were, per unit area, roughly 25 percent of the biomass computed for forested land as computed for all forests (table 2). However, because there is a substantial amount of nonforest land in Maryland, the ratio of total biomass stocks on nonforest: forest land in Maryland was roughly 0.33 (table 2).

Per unit area wood production values for Maryland forests were also similar when computed using the Jenkins and

Table 1.—*Biomass and WNPP statistics for Maryland and the Northeast*

Forest	Maryland (Jenkins) (all forest)	Northeast (Birdsey) (RPA/timberland)	Maryland (Birdsey) (RPA/timberland)
Land area (thousand ac)	2,701	78,923	2,423
Average biomass (Mg C/ha)	72.25	67.01	81.07
Wood-biomass increment (Mg C/ha/yr)	1.90	1.91	2.87
Total C storage (x 10^6 Mg C)	78.96	2,141.31	79.50
Annual C storage (x 10^6 Mg C/yr)	2.08	61.06	2.82
Nonforest	**Maryland (Jenkins)**	**Northeast**	
Nonforest land area (thousand ac)	3,594	41,330	
Average biomass (Mg C/ha)	17.80	16.75	
Wood-biomass increment (Mg C/ha/yr)	0.42	0.42	
Total C storage (x 10^6 Mg C)	25.92	280.23	
Annual C storage (x 10^6 Mg C/yr)	0.61	14.45	

Table 2.—*Ratios of nonforest: forest statistics for Maryland and the Northeast*

	Maryland	Northeast
Forest land (thousand ac)	2,701	85,484
Nonforest land (thousand ac)	3,594	41,333
Nonforest: forest land area	1.33	0.48
Per unit area ratios		
Nonforest: forest biomass	0.25	*assume 25%*
Nonforest: forest WNPP	0.22	*assume 22%*
Aggregate State & region-level		
Nonforest: forest biomass	0.33	0.13
Nonforest: forest WNPP	0.29	0.24

Birdsey methods (table 1). The RPA data predicted somewhat larger wood-biomass increments; this is probably (again) due to the exclusion of nonproductive forests from the RPA sample. Per unit area, wood production on nonforest land was approximately 22 percent of wood production on forested land (table 2). As with forest C stocks, however, because of the large proportion of nonforest land in Maryland, the ratio of total annual C storage on nonforest: forest land was higher than this (table 2).

Northeast

To aggregate these values to the regional level for large-scale comparisons, we assumed that the Maryland ratios of nonforest: forest C stocks and fluxes are true for the region. Per unit area WNPP on all nonforest land in the region was therefore assumed to be 22 percent of wood production on forested land, and per unit area biomass on nonforest land was assumed to total 25 percent of biomass on forest land. In the Northeast Region (as defined by RPA), we calculate that nonforest land contributes about 280 million metric tons of C in tree biomass (one metric ton = 1 Mg = 10^6 g), or about 14 million metric tons every year (table 1). This adds to roughly 13 percent of the biomass and 24 percent of the WNPP on forested land (table 2).

DISCUSSION

There is widespread consensus that a “missing” carbon sink (i.e., the difference between C emitted from anthropogenic and non-anthropogenic activities on the surface of Earth, and the C sequestered in terrestrial and oceanic ecosystems or stored in wood products) of up to 1-2 Pg C yr^{-1} (1 Pg = 10^{15} g) exists in terrestrial systems in the northern midlatitudes. Ongoing efforts to find the missing C using different measurement methods have yielded conflicting results (Birdsey and Heath 1995, Fan and others 1998, Schimel and others 2000), although current estimates are converging toward a U.S. sink between 0.35 and 0.90 Pg C yr^{-1} (Pacala and others 2001). Forest inventory measurements currently suggest that forest trees in the United States remove between 0.11 and 0.15 Pg C yr^{-1} from the atmosphere, but these estimates are currently based only on land classified by FIA as forest. If we assume that the ratios of forest: nonforest WNPP and forest: nonforest land are similar for the rest of the United States, then nonforest land could add an additional 24 percent to this value. In other words, based on the results of this analysis, it is possible that trees on non-forest land are storing an additional 0.03 to 0.04 Pg C yr^{-1}. This could amount to 10 percent of the existing “missing” sink of 0.35 to 0.90 Pg C yr^{-1}.

While these results suggest that trees on nonforest land almost certainly contribute to overall C sequestration, much more research is needed to understand the dynamics of C stocks and fluxes in nonforest areas. For example, in this analysis, we have excluded all consideration of ornamental shrubs and grasses, which must sequester additional C. Soils in gardens and other cultivated non-agricultural areas are likely to harbor C as well, in near-direct proportion to the types of management these lands experience.

The diameter growth algorithms and the biomass regression equations used in this analysis were developed for forest trees. Research on urban trees suggests that open-grown urban trees have larger crowns but lower biomass values than forest trees (Nowak 1996). Their diameter growth rates are likely to be higher than those of forest trees, however. The chances are good that the WNPP values presented here for nonforest land in Maryland are too low, but the biomass values may be too high.

It is difficult to extrapolate the results of this analysis to the entire United States because the patterns of urbanization and land use change are likely to differ from region to region. For example, there may be very little nonforest land in rural states such as Maine. In arid regions, there may be little difference between biomass and WNPP in residential and non-residential areas. But these relationships may also be much more complex: it is possible that irrigation in arid regions may increase residential woody biomass and production. An analysis such as this one, conducted for urban areas in different regions across the country, should help to resolve the issue of nonforest, non-agricultural C sequestration.

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