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Exploring the assumed invariance of implied emission factors for forest biomass in greenhouse gas inventories

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ABSTRACT

Reviews of each nation's annual greenhouse gas inventory submissions including forest-land are part of the ongoing reporting process of the United Nations Framework Convention on Climate Change. Goals of these reviews include improving quality and consistency within and among reports. One method of facilitating comparisons is the use of a standard index such as an implied emission factor (IEF), which for forest biomass indicates net rate of carbon emission or sequestration per area. Guidance on the use of IEFs in reviews is limited, but there is an expectation that values should be relatively constant both over time and across spatial scales. To address this hypothesis, we examine IEFs over time, derived from U.S. forests at plot-, state-, and national-levels. Results show that at increasingly aggregated levels, relative heterogeneity decreases but can still be substantial. A net increase in U.S. whole-forest IEFs over time is consistent with results from temperate forests of nations in the European Community. IEFs are better viewed as a distribution of values rather than one constant value principally because of sensitivities to productivity, disturbance, and land use change, which can all vary considerably across a nation's forest land.

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1. Introduction

Forest land in the United States is currently a significant carbon sink, as reported in the official inventory of U.S. greenhouse gas (GHG) emissions and sinks (U.S. EPA, 2008). These inventories are compiled and prepared annually by the United States Environmental Protection Agency (U.S. EPA) as a part of the United States commitment to the United Nations Framework Convention on Climate Change (UNFCCC), and span the years 1990 to the current year. Although other greenhouse gases such as methane and nitrous oxide from wildfires are included, the focus in forest ecosystems is on carbon. The forest carbon estimates are based on data from the extensive survey of U.S. forest land conducted by the U.S. Forest Service (U.S. Forest Service, 2009a), augmented by additional carbon pool information (see Woodbury et al., 2007).

Improved accuracy of international and global GHG assessments is increasingly possible through the combined contributions of UNFCCC national reports. However, the value of such reports depends on quality and consistency within and among reports (Todorova et al., 2003; Swart et al., 2007). Ensuring comparability and transparency is one role of the UNFCCC annual reviews of national GHG submissions (UNFCCC, 2008, 2009a). In pursuit of that goal, the review of the U.S. submission for 2008 (UNFCCC, 2009b) included a concern[1] about the increase in ''implied emission factor'' (IEF) values for carbon stock change in living biomass on total forest land, which was 36 percent greater in 2006 relative to 1990. Implied emission factors are the emissions, or sequestration, implied by annual changes in forest carbon stocks. Although the UNFCCC does not provide explicit guidance about the use of these top-down ratios within national reviews (UNFCCC,

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[1] See paragraphs 84 and 85 of UNFCCC (2009b).

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2003), the ratios are used as a basis for standardized comparisons. Deviations from expectations in the comparisons apparently indicate lack of consistency or comparability in the reported values, even though it has been suggested (Gillenwater et al., 2007) that emission factors are expected to have a distribution of values. The recommendation (UNFCCC, 2009b) that the Party (the United States) re-examine sensitivity of IEFs that "are representative of the Party's whole territory" was the impetus for this study.

The purpose of this study is to provide a basis for and understanding of observed trends and sensitivities in IEFs. First, background information on GHG reporting and the role of forest inventories in the U.S. report are provided in the following three sections. Processes implemented by the UNFCCC help to assure good practice and consistency among national GHG reports. Forest carbon estimates for the United States are based on inventory data, and the IEFs are functions of successive inventory-to-carbon conversion. The next two sections provide results and discussion. In the section "IEF-biomass from the FIA inventory database," we calculate IEFs directly from the U.S. forest inventory data at different scales, from plot-level to national totals. This illustrates the range of influences on IEFs and the resulting range of values assumed by IEFs across landscapes and over time. In "IEFs in national GHG reporting" we illustrate how the U.S. forest carbon report is constructed as an aggregation of inventories implemented at the state-level, which produces a parallel aggregation of many separate IEFs. The IEF-from-inventory calculations are extended to illustrate sensitivity in the 1990–2006 stock and change values reported for forests in U.S. EPA (2008), which is the focus of UNFCCC (2009b). Finally, we compare variability and trends from the United States with similar IEF summaries as obtained from 24 national GHG reports of European Community nations.

1.1. *UNFCCC reporting, emission factors, and expert reviews*

The national GHG inventories submitted to the UNFCCC for 2008 by the United States and a number of other Annex I countries, are available on the Internet (UNFCCC, 2009c). The site also includes common reporting format (CRF) tabular summaries of submitted data and links to inventories in the respective countries, which for the United States is published as U.S. EPA (2008). An important part of validation for greenhouse gas inventories is the international expert review (UNFCCC, 2008). A focus of these reviews is consistency in reporting emissions (Swart et al., 2007), which derives from conformity to good practice (Penman et al., 2003). Two of the forms of reviews are "centralized" or "in-county" in which expert review teams (ERTs) examine a nation's greenhouse gas inventory, consult with the submitting agencies or individuals within the country, and provide a written review (see UNFCCC, 2009d and associated Internet pages). Examination of IEFs from each nation's CRF tables is a prescribed part of these reviews (UNFCCC, 2003). Comparisons among IEFs allow the ERTs to readily identify potential issues of consistency and comparability (Todorova et al., 2003). However, guidance in evaluating comparisons between IEFs is limited; for example, see UNFCCC (2003) and the various national review reports for 2008 (UNFCCC, 2009a).

Good practice guidance on reporting of forest carbon within these national inventories identifies two basic methodological approaches (Penman et al., 2003), which allows for flexibility for specific country conditions. Here, stocks are defined as tonnes of carbon (1 t = 1 Mg). One approach, the "Stock Change Method," estimates change as the difference between successive stocks and depends on consistency in quantifying stocks. In the other approach, the "Default Method," change is based on the products of activity data and emission factors. In the case of forest ecosystems, activity data are areas of forest land (hectares) as defined by categories such as type (e.g., conifers) or management (e.g., plantations harvested at 30 years), and emission factors are the corresponding net annual change of carbon stock per unit area (t C ha^{-1} yr^{-1}). These emission factors are particularly useful for modeling GHG inventories where data are limited. Because alternate methodologies to achieve the same end are possible, transparency and consistent application of methods are necessary to assure comparable GHG inventories. In the stock change method, an IEF is an emission factor back-calculated from summary data, usually the GHG summaries within a particular sector for a reporting nation. The IEF represents the total net change in forest carbon stock in terms of average per unit area per year, which is calculated as the difference in successive total carbon stocks (stock in year 2 minus that in year 1) divided by forest area (at year 1) divided by the time interval (year 2 minus year 1). In the default method, the IEF is often assumed or calculated first and then used to sum up to the totals. Because IEFs are quantities that can be based on overall reported totals, they provide a standard measure for comparisons among GHG inventories and are included in UNFCCC inventory review reports (UNFCCC, 2003; Swart et al., 2007).

Carbon in live biomass (including tree and understory vegetation, both above- and belowground) is the basis for an IEF based on net change of carbon stock per unit of forest area (IEF-biomass, hereafter) as calculated in the CRF tables submitted to the UNFCCC by the United States in 2008 (U.S. EPA, 2008; UNFCCC, 2009c). The IEF-biomass for 1990 is 0.38 t C ha^{-1} yr^{-1}, whereas the IEF-biomass for 2006 is 0.52 t C ha^{-1} yr^{-1}. This represents a 36 percent increase over the 16 years, which is the relative change that the ERT singled out as symptomatic of the potential for an underlying problem with this forest carbon submission (UNFCCC, 2009b). The ERT expressed doubt that IEF-biomass can be so dramatically affected by the separate state-by-state stock change calculations from forest inventory data (Smith et al., 2007; U.S. EPA, 2008). In addition to IEF-biomass, the ERT noted with concern that IEFs of dead organic matter were similarly subject to change over time (UNFCCC, 2009b). Although we focus on IEF-biomass, the data, trends, and influences on IEFs discussed below are generally applicable to all forest carbon pools.

1.2. *Forest carbon from U.S. forest inventory*

The forest carbon portion of the GHG submission is primarily based on the publicly available forest inventory database of the USDA Forest Service Forest Inventory and Analysis (FIA) Program. The Forest Inventory and Analysis Database (FIADB) and documentation are freely available on the Internet (USDA Forest Service, 2009a,b). The FIA Program was legislated by the

U.S. Congress to make and keep a comprehensive inventory and analysis for the renewable resources of the forest and rangelands of the United States (McSweeney-McNary Act of 1928) (Bechtold and Patterson, 2005). We focus on currently available data from most-recent inventories extending back to those dated just before 1990, the base year for GHG inventory. Forest inventories are traditionally a two-phase effort, with the first phase using remote sensing or aerial photographs to help determine forest area and increase precision of the estimates, and the second phase consisting of visits to plots in the field. In the past, all forest lands within a state were periodically inventoried, usually at intervals of 5–10 years. Methods and frequency varied according to state or region. In 1999, FIA initiated a nationally consistent annual inventory, which replaced the periodic inventories. Approximately 20 percent of the plots in a state are now measured each year, resulting in a plot being remeasured after approximately 5 years, although for some states the remeasurement period is 10 years. Permanent forest inventory plots are established for about every 2428 ha of land, with about 130,000 forests plots being measured in the 48 conterminous states (USDA Forest Service, 2009b). Estimates of U.S. forest ecosystem carbon stocks are based on these data. To assure comparability among stocks, carbon estimation methods specifically account for historical changes in inventory and data (Smith et al., 2007).

The U.S. forest carbon inventory is built on the FIA forest inventory structure according to the ''Stock Change Method'' described by Penman et al. (2003). This means a very large number of separate plot-level carbon estimates are the bases for forest ecosystem carbon stock and change as reported by the United States (U.S. EPA, 2008). The methods that convert plot-level FIA data to carbon stocks, and compilation of the 1990-to-present series are described in Smith et al. (2007), and the forest sections of the land use change and forestry chapter of U.S. EPA (2008), including the corresponding annex of the same document. These same methods were also used to produce all carbon estimates in this study. Carbon stocks are initially determined at the level of forest inventory plots. The plot-level carbon is aggregated using the appropriate weighting factors to define aggregate stocks for populations, whole-states, or U.S. totals (Smith et al., 2007; USDA Forest Service, 2009b). The important aspect of this aggregation from the perspective of this study is that inventory data from multiple plots are converted to carbon stocks, each representing a defined forest area at a specific time. It is these consistent series of carbon stocks that are used to determine net annual stock change (the ''Stock Change Method'') and, in turn, the IEFs.

1.3. *Methods for deriving IEF-biomass estimates*

Net annual carbon stock change is the mass difference between successive stocks as defined and aggregated from forest inventory data, which is then divided by the interval in years between stocks (Penman et al., 2003). In turn, the annual change is divided by forest area to calculate the IEF. One specific exception to this method is IEFs determined for individual inventory plots over the interval between measurements. In this case, the IEF is simply the difference in successive carbon densities (t C ha^{-1}) divided by the interval between measurements. Differences among IEFs are affected by all influences on net stock change over an interval. For example, a disturbance such as a pest outbreak can significantly affect the net change in carbon stock over an interval, but the level of influence on the IEF depends on the size of the disturbance relative to the entire forested system under consideration. The fewer or more easily identified effects at plot-level become a less well-defined mosaic of influences as estimates are aggregated to landscapes or regions. We examine these aggregate effects by presenting IEFs at the plot-level as well as substate and national level.

All IEFs in this study represent net annual change in carbon stock divided by the corresponding forest area, at the scale of interest. To illustrate effects of boundaries defined for stock change, we present an example which first derives IEFs from paired measurements on permanent plots, remeasured after an interval of approximately 5 years. The full set of inventory data are also aggregated to forest type group and whole-state carbon stock summaries, with IEFs calculated at each scale. Some remeasured plot data are only recently available in the FIADB and include some periodic data, but remeasurements from the newer annual data are from a consistent plot design (USDA Forest Service, 2009b) and readily identified. Data from remeasured plots were obtained from the FIADB version 4.0 for representative forest type groups in two states, Alabama and Minnesota (data accessed on the Internet in May 2009, see USDA Forest Service, 2009a). Note for this example, the IEF-biomass is based on tree biomass only. However, carbon in understory vegetation is minor, and this is not expected to affect the results.

IEFs are often derived from reported national totals (UNFCCC, 2009c). Our example national-scale IEF calculations include both intermediate results and national totals developed for U.S. forests (Smith et al., 2007). Because we focus on the U.S. national inventory submission for 2008 (U.S. EPA, 2008; UNFCCC, 2009c), we also derive nationally based IEFs from the specific inventory data associated with that report (FIADB 2.1 available on the Internet in September 2007). These data are no longer available online, but the process and results are documented in Smith et al. (2007), including a data archive, and U.S. EPA (2008).

2. Results and discussion

2.1. *IEF-biomass from the FIA inventory database*

The plot-level IEF-biomass values calculated on remeasured plots are summarized for the major forest type groups in Alabama and Minnesota in Table 1. The first set of IEF-biomass is based on all available remeasured plots. Mean IEF-biomass varies among type groups and between regions, but all mean values are positive (a net increase in carbon in biomass) for the 10 example types. The range of values between the 5th and 95th percentiles includes negative IEFs on some plots of all types. Negative IEF-biomass is possible if loss of biomass, for whatever reason, is greater than gains due to growth. Loss of biomass can occur through individual tree mortality or removals such as timber harvesting. Disturbances such as

Table 1 – IEF-biomass (t C ha^{-1} yr^{-1}) calculated for remeasured plots by example state and forest type group. Negative values indicate a decrease carbon in forest biomass. Carbon in understory vegetation is not included.

State	Forest type group	All remeasured plots		Subset of remeasured plots with no evidence of disturbance	
		IEF-biomass (t C ha^{-1} yr^{-1})	Range of values for 90% of plots, number of plots	IEF-biomass (t C ha^{-1} yr^{-1})	Range of values for 90% of plots, number of plots
Alabama	Loblolly/shortleaf pine (natural regeneration)	2.1	(−5.3 to 7.5, 176)	2.9	(−2.7 to 8.2, 136)
Alabama	Loblolly/shortleaf pine (planted)	2.8	(−5.8 to 8.9, 322)	5.0	(1.0 to 9.9, 192)
Alabama	Oak/gum/cypress	0.7	(−7.7 to 5.5, 141)	1.3	(−6.8 to 5.8, 112)
Alabama	Oak/hickory	1.8	(−3.7 to 6.0, 467)	2.1	(−1.6 to 6.0, 425)
Alabama	Oak/pine	2.0	(−3.8 to 6.1, 119)	2.3	(−1.4 to 5.9, 105)
Minnesota	Aspen/birch	0.8	(−3.4 to 4.1, 1274)	0.9	(−3.0 to 4.1, 1214)
Minnesota	Maple/beech/birch	0.8	(−5.0 to 4.6, 262)	1.0	(−4.2 to 4.6, 213)
Minnesota	Oak/hickory	1.2	(−4.7 to 6.0, 230)	1.4	(−4.8 to 6.1, 213)
Minnesota	Spruce/fir	0.5	(−2.8 to 3.1, 696)	0.6	(−2.2 to 3.1, 674)
Minnesota	White/red/jack pine	0.8	(−2.1 to 4.8, 107)	0.8	(−2.1 to 4.8, 105)

fire, pest outbreaks, or storm damage can also cause forests to become net carbon emitters – a negative IEF-biomass. Some of the additional plot-level information included in the FIADB identifies plots subject to disturbance during the interval between measurements. Refining the full set of remeasured plots to exclude those with evidence of harvest or disturbance produces a subset of plots where net change more closely resembles gross growth. This recalculation is shown on the right side of Table 1. The subset of plots with no evidence of disturbance showed an increase in IEF-biomass. Occasional ‘‘background’’ mortality of individual trees is the only process for reducing carbon density on these plots between measurements. Nonetheless, nine of the ten forest types still included some plots with negative IEF-biomass. These estimates are due to individual tree mortality.

Stand age is another factor that affects an IEF calculated at this scale, because forest growth rates vary with age (Böttcher et al., 2008). Data from planted loblolly/shortleaf pine plots (without evidence of disturbance) used in Table 1 are displayed in Fig. 1. These data feature a mean IEF-biomass of 5.0 t C ha^{-1} yr^{-1}.

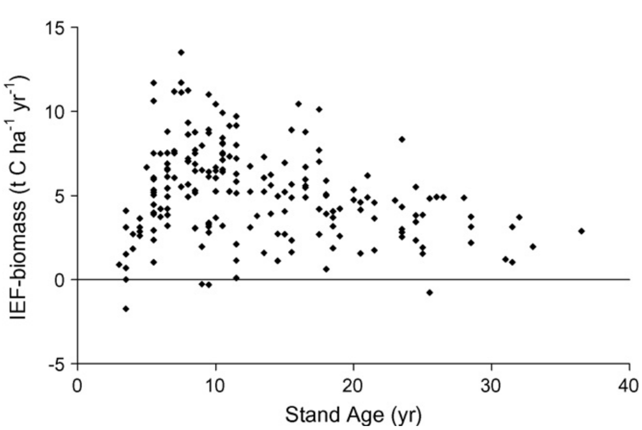

Fig. 1 – IEF-biomass for planted loblolly/shortleaf pine in Alabama based on remeasured plots without evidence of disturbance during the interval between measurements. Negative values indicate a decrease carbon in forest biomass. Carbon in understory vegetation is not included.

Determining forest carbon change based on tracking individual plots through a series of remeasurements is not currently possible for estimates encompassing all U.S. forest lands because a sequence of such plots through the 1990s is not available (Smith et al., 2007). In practice, carbon change is based on series of carbon stocks, which are summarized to represent totals according to the specific forest inventories conducted for each state. As plots are summed to represent population totals, the forest type and regional influences on IEFs derived from these totals are reflected in the calculations as averages over all forest land.

Whole-state aggregate carbon in biomass stocks were determined for a series of three successive inventories for the example states and forest types. That is, data from 1990, 2000, and 2005, were used for Alabama, and data for 1990, 2003, and 2007 were summarized for Minnesota.[2] The resulting IEF-biomass estimates from these aggregate stocks over two intervals are provided in Table 2. Some of these whole-state-within-type IEF-biomass estimates are negative, but the general differences according to type group are still apparent. These aggregate IEFs are influenced by the range of disturbances, stand age, and stand structure over all forest land included in the calculations. While IEF-biomass calculations for Tables 1 and 2 are both defined as annual net change in stock divided by area at the beginning of the interval, the methods of obtaining that ratio are different. Table 1 IEFs are average annual density changes on the remeasured plots. Table 2 IEFs are based on first summarizing total carbon stock for a series of three successive inventories according to Smith et al. (2007); the difference in aggregate stocks is divided by

[2] Note that the years mentioned here and in Table 2 for Alabama and Minnesota inventories are nominal years as used in the FIADB to identify a specific inventory summary. They are not meant to represent a specific carbon stock for a designated year as in Figs. 2–5.

Table 2 – IEF-biomass (t C ha^{-1} yr^{-1}) aggregated for example state and forest type group. Values represent all forest land of each type group within each state and are based on net stock change between successive inventories, with years indicating the intervals between inventories. Negative values indicate a decrease carbon in forest biomass. Carbon in understory vegetation is not included.

State	Forest type group	IEF-biomass from net difference between successive stocks (t C ha^{-1} yr^{-1})	
		1990–2000	2000–2005
Alabama	Loblolly/shortleaf pine (natural regeneration)	−0.6	1.6
Alabama	Loblolly/shortleaf pine (planted)	2.3	2.4
Alabama	Oak/gum/cypress	2.6	−1.6
Alabama	Oak/hickory	0.7	0.2
Alabama	Oak/pine	−0.7	−2.5
State	Forest type group	IEF-biomass from net difference between successive stocks (t C ha^{-1} yr^{-1})	
		1990–2003	2003–2007
Minnesota	Aspen/birch	−0.6	−0.6
Minnesota	Maple/beech/birch	1.3	0.5
Minnesota	Oak/hickory	0.5	4.0
Minnesota	Spruce/fir	−0.6	0.2
Minnesota	White/red/jack pine	−0.5	0.6

aggregate forest area and the number of years in the interval. Thus, in addition to the potential for encompassing greater influence of disturbances, Table 2 values are directly affected by changes in land use, which can have an effect independent of actual changes in forest carbon density. That is, a sufficient loss of forest land over an interval between surveys can offset what would otherwise be carbon gain through increases in biomass density.

An important consideration for the use of IEFs summarized from total carbon stocks is evident in Table 2. Factors determined for successive intervals within type and state can feature abrupt step changes in the trend. For example, the naturally regenerated loblolly/shortleaf pine group appears as a slight carbon emitter during the 1990s, but is apparently sequestering carbon since 2000. With this level of summary values, it is not possible to determine if the basis for the trend or change in trend is related to productivity, disturbance, area change, or a combination of all influences. In general, the changes in IEF associated with stock change (Table 2) are somewhat dampened as stocks are aggregated to whole-state values. For example, the corresponding IEF-biomass values for all Alabama forests over the two intervals were 0.6 and 0.2 t C ha^{-1} yr^{-1}. Similarly, the IEF-biomass estimates for Minnesota forests were −0.1 and 0.4 t C ha^{-1} yr^{-1}. Collectively, the whole-state changes over the intervals for Alabama and Minnesota were −0.4 and +0.5 t C ha^{-1} yr^{-1}, respectively (Table 2).

2.2. IEFs in national GHG reporting

The forest ecosystem carbon stock change calculations as reported for U.S. forests are based on a series of state or substate stocks as described in Smith et al. (2007), and reported in U.S. EPA (2008). Examples from four Northeastern states are used to illustrate the process (Fig. 2a–c). Interpolation and extrapolation of stocks provide a series of estimated annual stocks for 1990 to the present year (Table 2a), which was 2007 in this case (U.S. EPA 2008). The slope of each line is the net stock change. Total carbon stock and annual change is based on summing the stocks and slopes from Fig. 2a as well as the 79 additional state or substate series identified in U.S. EPA (2008). Similar to the stock estimates, a 1990-to-present interpolated sequence is presented for forest area (Fig. 2b). The information in Fig. 2a and b are, in turn, used to calculate IEF-biomass for each series (Fig. 2c).

Two characteristics of the IEF-biomass values in Fig. 2c are useful to note as background to additional results presented below. First, IEF values change at the years defined for carbon stocks – compare the stocks (diamonds) in Fig. 2a with changes in Fig. 2c. (Note this does not apply to the final stock in each sequence because annualized estimates are extrapolated from the final two measured stocks. Stocks prior to 1990 are not shown in Fig. 2a.) Second, the average IEFs of the components, weighted by area, represents the IEF of the entire system, such as the four-state area represented in Fig. 2. From the information in Fig. 2c, the collective IEF-biomass for the four states is not constant between 1990 and 2006. This total is not shown in the figure, but its maximum value is in 1996 after the small but heavily weighted increase in Maine, and before the larger but less weighted decrease in Vermont.

The weighted average of all IEFs (including the corresponding additional 79 series not illustrated in Fig. 2c, see U.S. EPA (2008) for the complete list of the 84) produces the 0.38 and 0.52 t C ha^{-1} yr^{-1} IEF-biomass estimates for 1990 and 2006, respectively (UNFCCC, 2009b). Forty two of the 84 state or substate series (including Maine and New Hampshire in Fig. 2c) showed a net increase in IEF-biomass over the interval (2006 relative to 1990) as did the overall change for carbon in biomass. The collective distributions of IEFs for these 84 subcomponents are very similar at 1990 and 2006 (Fig. 3) with

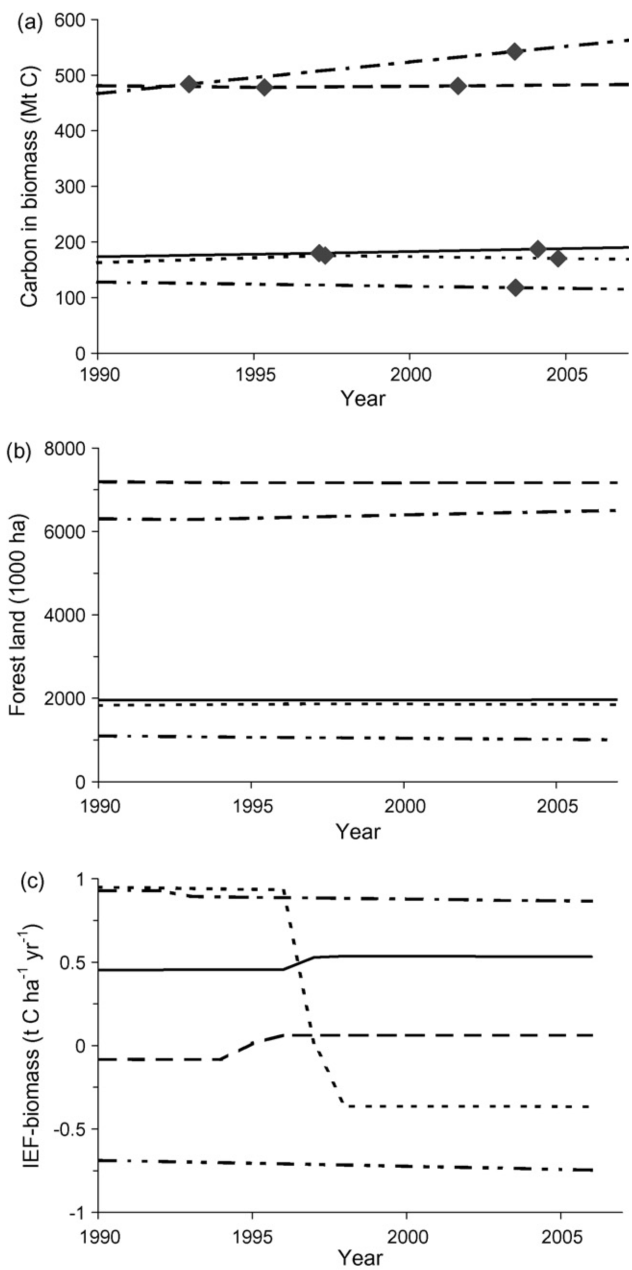

Fig. 2 – (a) Annualized carbon stocks in biomass (Mt C) estimated for 1990–2007 for 5 example state or substate forest classes. Diamonds represent the post-1990 carbon stocks; annualized values are based on interpolation or extrapolation: Maine (dashed line), New Hampshire (solid line), New York, nonreserved (dashed with 1-dot line), New York, reserved (dashed with 2-dot line), and Vermont (dotted line). (b) Forest areas (1000 ha), which correspond to the carbon stock examples provided in (a). (c) IEF-biomass (t C ha^{-1} yr^{-1}) determined as the annual carbon increment (from (a)) divided by forest area (b). Negative values indicate a decrease carbon in forest biomass.

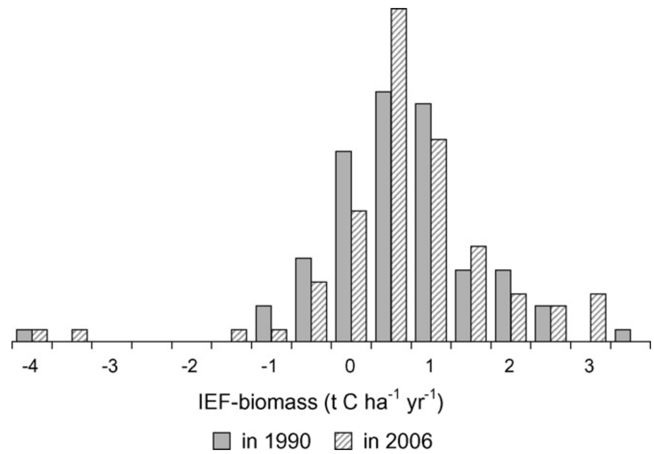

Fig. 3 – Frequency distributions of IEF-biomass from the 84 state and substate forest classifications compiled for U.S. greenhouse gas estimates for 1990 and 2006. Negative values indicate a decrease carbon in forest biomass.

95 percent of the values falling between −1.4 and +2.6 t C ha^{-1} yr^{-1}. States exceeding 2.6 t C ha^{-1} yr^{-1} in either 1990 or 2006 were Delaware, Indiana, Iowa, and Ohio. Some of the substate components from Arizona, Idaho, Washington and Wyoming had IEF-biomass below −1.4 t C ha^{-1} yr^{-1} in either 1990 or 2006.

2.3. *Sensitivity of IEFs to underlying forest inventory data*

The ERT's evaluation specifically mentioned sensitivity to U.S. forest inventory data. In terms of determining changes in IEF-biomass, can an individual state or substate be influential enough to notice on results for the entire US (UNFCCC, 2009b)? To address this question and illustrate sensitivity, we systematically identify an influential state and quantify the effect of a single inventory of that state.

The 2008 submission was based on 84 state or substate forest classifications. As illustrated in Fig. 2a–c, calculations for 84 separate series of annualized carbon stocks were developed for the years 1990–2007 (Smith et al., 2007; U.S. EPA, 2008). Multiple forest inventories were available for most of these 84 classes so that a total of 236 carbon stock summaries contributed to the national total series for 1990–2007 (e.g., see 9 of the 236 separate stock summaries represented by the diamonds in Fig. 2a). The sensitivity of total US forest carbon estimates to each of these 236 stocks varies considerably according to size of carbon stock, relative rate or direction of stock change, date of inventory, or even occasional interaction with other substate forest classifications.

The ERT identified a net 36 percent increase in IEF-biomass between 1990 and 2006 as perhaps being symptomatic of a problem in the forest carbon values. Fig. 4 illustrates the trend of the IEF-biomass values for 1990 through 2006 (solid line). The 36 percent difference is based on the 2006 value relative to 1990, and the greatest annual percent change occurred during the interval from 2000 to 2001, which was over 9 percent. Based on the example illustrated by Fig. 2 above, the most influential states are likely to be those with carbon stocks – and thus IEF change – in or near the year 2000 (change between 2000 and 2001 takes place during the year 2000 by definition). Carbon stock summaries declined in 2000 for three (out of the 84) series, these were state-wide summaries for North Carolina,

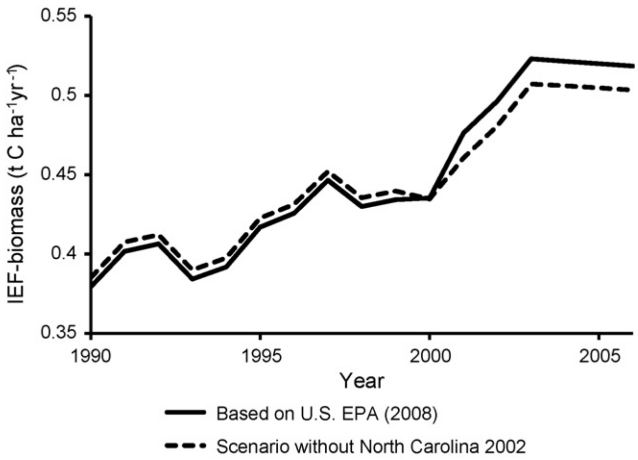

Fig. 4 – IEF-biomass for 1990–2006 and the recalculated values based on a scenario of removing the North Carolina 2002 reporting year data (one of the 236 survey summaries used for U.S. EPA, 2008).

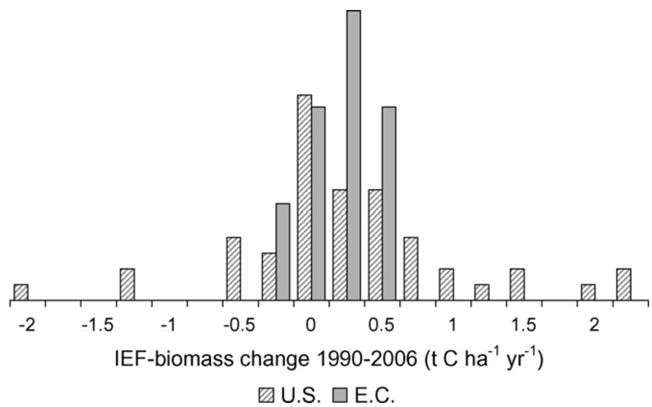

Fig. 5 – Frequency distribution of change in IEF-biomass between 1990 and 2006 for the 49 states included in the United States (U.S.) report and 24 reporting nations within the European Community (E.C.). Net change for the U.S. over the interval was 0.14 t C ha^{-1} yr^{-1}, and net change for the set of 24 reporting nations within the E.C. over this interval was 0.12 t C ha^{-1} yr^{-1}. Negative values indicate a decrease carbon in forest biomass.

South Carolina, and West Virginia. We removed the first of these on the list – North Carolina – and recalculated carbon and IEF-biomass based on the remaining 235 stock summaries. By removing only the North Carolina inventory for the nominal inventory of 2002 (which resolved to a carbon stock in the year 2000), the trend for North Carolina was then based on interpolating between carbon stocks derived from the 1990 and 2005 inventories. The net result for IEF-biomass on U.S. forests is the dashed line in Fig. 4. The change in that single inventory in North Carolina reduced the 2000–2001 rate of change in IEF-biomass from greater than 9 percent to less than 6 percent, and reduced the overall IEF-biomass for 2006 from 0.52 to 0.50 t C ha^{-1} yr^{-1}. That is, the change in one single inventory reduced the overall IEF-biomass by 4 percent for the entire United States 6 years later. North Carolina's forests were still included in the overall inventory; only the middle of three inventories was removed so that the all estimates were determined by the two endpoint inventories. It is also notable that the one-state change in 2000 had almost no effect on stock in 2007 – reduced by only 0.05 percent – but it did affect net annual biomass change by 2.9 percent (data not shown).

Finally, for perspective on the 36 percent change in IEF-biomass from 0.38 to 0.52 t C ha^{-1} yr^{-1} (Fig. 4) and the heterogeneity in the underlying states or substates (Fig. 3), we compared changes in U.S. forest IEF-biomass to IEF-biomass distributions from nations with similar temperate forests. The European Community (E.C.) provided a convenient example with IEF-biomass for each of the reporting nations as well as an aggregate for the whole of the European Community. The source of E.C. values for net change on total forest land were the 1990 and 2006 CRF tables for 2008 (UNFCCC, 2009c), which included forest land tables for 24 national reports as well as whole-E.C. tables. Overall, the IEF-biomass changes between 1990 and 2006 were +0.14 and +0.12 t C ha^{-1} yr^{-1} for the United States and European Community, respectively. Fig. 5 shows the frequency distribution of the change for the 49 U.S. states and 24 E.C. nations. The range of values for the U.S. was greater, but the central tendencies were similar. Overall, the trend in IEF-biomass for the United State between 1990 and 2006 (Fig. 4) is near the middle of variability in the subtotals of U.S. and E.C. results (Fig. 5).

3. Conclusions

Emission factors as applied to develop GHG inventories are often necessarily invariant when used to substitute for county- or system-specific factors where such information is limited. However, our study indicates there are reasons that IEFs summarized from a nation's CRF tables should be thought of as a distribution rather than a constant. IEF's determined from the subtotals for the United States' stock change calculations indicated considerable heterogeneity. The IEF-biomass increase from 0.38 to 0.52 t C ha^{-1} yr^{-1} represents a change in relative rate of increase of slightly less than 0.2 percent for carbon in live trees averaged over all of U.S. forest lands. This is based on an average biomass density of approximately 74 t C ha^{-1} (U.S. EPA, 2008) and includes the net effects of growth, mortality, disturbances, harvests, and area change. From this moderate rate and from the perspective of a stock change approach estimating carbon emission or sequestration, these IEF-biomass values (0.38 and 0.52 t C ha^{-1} yr^{-1}) are both very much on the middle of a much wider range of values common at all levels of the inventory based estimates. IEF-biomass results from the E.C. exhibit similar behavior.

Comparing individual summary values such as IEFs may be useful for making general comparisons within or among greenhouse gas inventories, but it is somewhat less informative as a diagnostic measure. The primary reason for the ERT to identify and compare the IEFs is to facilitate the identification of errors, misunderstandings, or omissions within the inventories (UNFCCC, 2003). They also provide a way to examine time-series consistencies within the inventory (Swart et al., 2007). However, the range of values and influences on those values associated with forest inventories suggests limits to the interpretation of estimates of general summaries for evaluating time series. Similar to plot-level values that represent small areas, nations of smaller area may exhibit IEFs of a wider range than nations of large areas of forest. When comparing IEFs of forests, the area of forest should be considered.

One implication from results of this study is that those inventories exhibiting constant assumed IEFs over time especially for large areas of forest should perhaps be viewed by the review team as the more unusual inventories that need further consideration. IEFs for forests are not invariant over time. A second implication is that examining change relative to the overall variability in IEF-biomass may be more useful than just examining change described as simply a percentage increase over an interval. However, the necessary information for this comparison is not available from the CRF tables. If this type of comparison is warranted, countries would have to provide additional information.

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