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An analysis of forest land use, forest land cover and change at policy-relevant scales

John W. Coulston[1]*, Gregory A. Reams[2], David N. Wear[3] and C. Kenneth Brewer[2]

[1]*USDA Forest Service, 4700 Old Kingston Pike, Knoxville, TN 37919, USA*
[2]*USDA Forest Service, 1601 N. Kent Street, Arlington, VA 22209, USA*
[3]*USDA Forest Service, North Carolina State University, Campus box 8008, Raleigh, NC 27695, USA*

*Corresponding author. Tel.: +1 8658622008; E-mail: jcoulston@fs.fed.us

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Quantifying the amount of forest and change in the amount of forest are key to ensure that appropriate management practices and policies are in place to maintain the array of ecosystem services provided by forests. There are a range of analytical techniques and data available to estimate these forest parameters, however, not all 'forest' is the same and various components of change have been presented. Forest as defined by use and forest as defined by cover are different, although it is common for scientists and policy makers to infer one from the other. We compare and contrast estimates of forest land cover, forest land use, extent and change at policy-relevant scales in the southeastern US. We found that estimates of forest land use extent and forest land cover extent were not significantly correlated. Estimates of net change based on forest land cover and forest land use were only moderately correlated and net change estimates were independent of gross forest cover loss estimates.

Introduction

Quantifying forest extent and change in forest extent are important in environmental research and monitoring across a range of geopolitical scales. Forests support the flow of essential ecosystem services such as fibre, energy, recreation, biodiversity, carbon storage and flux and water (Nelson *et al*., 2009). Efforts to maintain and/or enhance ecosystem services must start with a clear understanding of the forest land base that provides these services and how that land base is changing. Globally, however, there are difficulties in tracking forest trends. These difficulties arise from technical issues such as changes in statistical design and error propagation (Grainger, 2008; Rautiainen *et al*., 2011) as well as inconsistent definitions of forest categories (Mather, 2005). This results in a reduced ability to draw inferences not only on forest extent and forest transitions but also on the impact of the transitions on ecosystem services.

In the US, for example, there are discordant estimates of forest extent and forest change across a range of spatial and temporal scales. This partially arises because some broad-scale monitoring and assessment efforts rely on forest extent as defined by use (Smith *et al*., 2009; Rautiainen *et al*., 2011) while other assessments rely on forest extent as defined by cover (Drummond and Loveland, 2010; Hansen *et al*., 2010; Fry *et al*., 2011). Additionally, forest change has been reported in terms of gross change, gross loss or net change. Our goal is to clarify the differences between forest use and forest cover, as well as various metrics of forest change, so that in the future we can quantify the status and trends of forest extent more succinctly and, in turn, understand the implications of observed changes on the range of goods and services forests provide.

Forest definitions

Lund (2002) identified 624 definitions of 'forest' but most (86 per cent) either arise from a cover or use perspective. Forest land use is a function of the social and economic purposes for which land is managed while forest land cover is a human definition of the biological cover observed on the land (Watson *et al*., 2000). The differences between cover-based and use-based definitions of forest can be illustrated by examining descriptions from two broad-scale publically available databases: forest land use as defined by the USDA Forest Service Forest Inventory and Analysis (FIA) program and forest cover as defined by the National Land Cover Database (NLCD). The NLCD forest cover definition is 'Areas dominated by trees generally >5 m tall and >20 per cent of total vegetation cover' (Homer *et al*., 2004). The reported minimum mapping unit of the NLCD is ~0.4047 ha. Based on the FIA definition, land is considered as forest land use if the area is 0.4047 ha in size, at least 36.6 m wide and at least 10 per cent stocked by trees of any size or has been at least 10 per cent stocked in the past. Additionally, the area is not subject to nonforest use(s) that prevent normal tree regeneration and succession such as regular mowing, intensive grazing or recreation activities (Bechtold and Patterson, 2005). Stocking can generally be defined as the ratio of current tree vegetation density to a theoretical maximum tree vegetation density; is essentially a use concept. The decision to use a forest cover-based definition or to employ a forest use definition should ultimately depend on the specific question being posed or ecosystem service being assessed.

The main points of divergence between these 'forest' definitions are time and intent. With respect to time, a forest cover-based definition generally relies on observed tree cover at a single (or approximate) point in time and because these definitions are typically implemented via remote sensing, information about intent is generally not available. A forest use-based definition requires an interpretation of the conditions on the ground at a single point in time with respect to intended use over a broader time-period. These divergences can lead to differences in both the amount of forest and the change in forest area reported during monitoring and assessment activities (Drummond and Loveland, 2010). To illustrate, suppose a 100 ha forest tract in the coastal plain of the southeastern US was harvested and replanted in 2003. Based on most forest cover definitions this area would have been classified as forest in say 2001. In 2006, following the harvest, this area would likely be classified as shrub/scrub based on standard cover definitions (Homer *et al*., 2004). From a land cover-based definition this provides an example of a forest loss due to a transitory change in tree canopy cover but from a land use-based definition there is no change in use rather the changes occurred as part of the land management. Clearly use-based and cover-based perspectives differ but, these perspectives have different meanings for different services. Ideally, access to both forest land use and forest land cover information is needed to adequately inform multi-resource management and natural resource policy, and to assess societal needs for fibre, recreation, water and biodiversity.

Forest change

Once forest extent has been quantified at two points in time, quantifying change is the same operation whether extent was measured in terms of land use or land cover. The most basic conceptual forest system model can be represented as:

$$\text{Forest extent}_{\text{current}} = \text{Forest extent}_{\text{previous}} + \text{gain} - \text{loss}$$

where *gain* is the gross gain in forest extent and *loss* is the gross loss. Additionally this model can be used to estimate net change (*gain* − *loss*) and gross change (*gain* + *loss*). There are examples in the literature where the various components of change have been reported.

Hansen *et al*. (2010) quantified change using gross forest cover loss. Drummond and Loveland (2010) quantified gross forest cover change and net forest cover change. Fry *et al*. (2011) quantified gross loss, gross gain and net change for forest cover. *Smith et al*. (2009) quantified net forest land use change. Reams *et al*. (2010) examined the forest change estimates for the southern US presented by Smith *et al*. (2009) and Hansen *et al*. (2010) and found that the two estimates were different in both magnitude and direction. The differences in reported forest change were in the order of 4 million ha.

While all the above components of change are related to flows of different ecosystem services, generally speaking, broad-scale monitoring and assessment activities minimally address fundamental definitional issues regarding forest extent: what was considered forest, how change was calculated and the relevant ecosystem service that drive the chosen definition of forest and change. A common perception is that 'forest' and 'change' are universally defined across research and assessment efforts when in fact they are different. The end result is conflicting forest statistics which do not consistently inform policy.

Land use and land cover change are particularly important in the southeastern US because of the pressures exerted on the forest land base and sustainability concerns. For example, in Georgia, North Carolina, South Carolina and Virginia, the human population increased 16.5 per cent between 2000 and 2010 according to the US Census Bureau. At the same time, these four states accounted for 31 per cent of pulpwood harvest volume in the US (Johnson *et al*., 2011). The dynamic nature of the southeastern US, as driven by population growth and urbanization as well as an active forestry sector, is expected to continue (Wear and Greis, 2013). Understanding forest land change as driven by population and market demands for food, water and natural resources such as those supplied by forests is an important component when addressing sustainability concerns.

We explore the relationship between forest extent (cover and use) and forest change (cover and use) estimates in the southeastern US by: (1) examining the distribution of forest land use within traditional land cover classes; (2) comparing estimates of forest land use, forest land cover, net change and gross loss from 2001–2006; (3) discussing key similarities and differences between forest land use and forest land cover statistics.

Methods

Our 48 million ha study area covered Virginia, North Carolina, South Carolina, Georgia and part of Tennessee. The area was further broken down into three Level I physiographic zones (coastal plain, mountains and piedmont) and 18 Level II physiographic zones (Figure 1). There are several publicly available broad-scale databases to examine status and trends of forest extent. For our case analyses we procured two widely used databases: the FIA Database for forest land use information and the NLCD for forest land cover information.

The NLCD provides a 16 class land cover classification mapped at a 30 m resolution for the US. We use the classifications from ∼2001 to ∼2006 (Fry *et al*., 2011). Of the 16 land cover classes, we considered the deciduous forest class (41), the evergreen forest class (42) and the mixed forest class (43) as forest land cover (Table 1). This was consistent with forest cover analyses performed by Fry *et al*. (2011). We quantified the forest land cover extent by Level I physiographic zone, Level II physiographic zone and for the entire study area for 2001 and 2006. From this we also calculated the 2001–2006 forest land cover net change and gross loss by Level I physiographic zone, Level II physiographic zone and for the entire study area.

Forest land use data were provided by the FIA program. FIA employs a repeated measure rotating panel survey design and the nominal sampling intensity was approximately one 674.5 m^2 ground plot per 2403 ha of land area (Bechtold and Patterson, 2005). Typically in the southeastern US plots are remeasured every 5 years. Each sample location is classified as either forest land use or non-forest land use (in whole or in part) and those locations meeting the forest land use definition (in whole or in part) have additional measurements taken to quantify per cent forest and other salient components of biomass, structure, community type and health. We used data from 2000 to 2010 to estimate the trends in forest land use extent from 2001 to 2006 for each Level II physiographic zone. This was accomplished using a Generalized Least Squares procedure where population-level forest land use extent, net change estimates and standard errors were obtained from linear models for repeated measurement (Bechtold and Patterson, 2005). While the linear model was parameterized with a longer time-series only estimates of forest land use extent and change

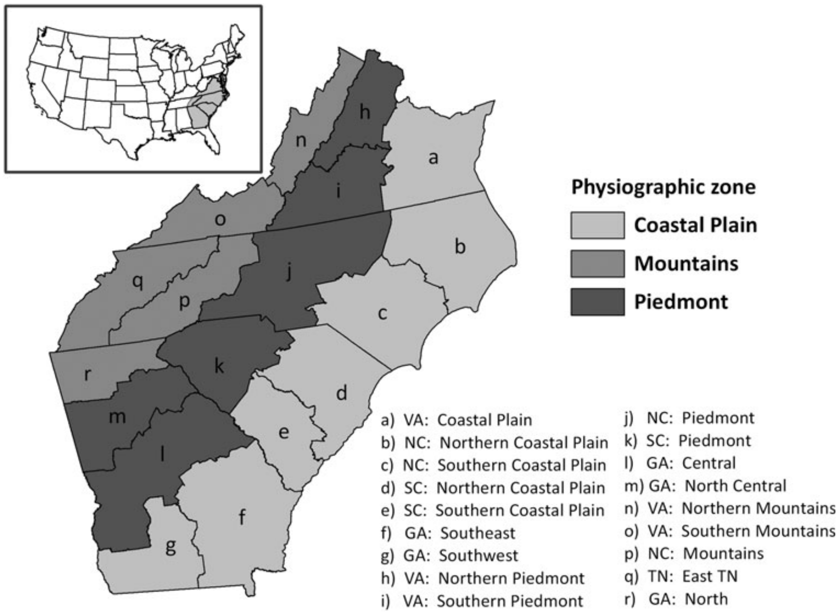

Figure 1 Study area, Level I and Level II physiographic zones.

from 2001 to 2006 were retained. From these estimates we also constructed estimates and standard errors by Level I physiographic zone and across the study area.

To examine the distribution of forest land use among land cover classes we extracted the 2006 NLCD classification for each FIA monitoring location irrespective of land use (forest land use or non-forest land use). From this the percentage of ground observations classified as forest land use were calculated for by collapsed land cover class (Table 1). This was not intended to be an accuracy assessment but rather to provide information about the distribution of forest land use among land cover classes within the study area.

In many cases, inferences are drawn about forest land use extent and change based on forest land cover extent and change from summary statistics at policy-relevant scales (e.g. broad ecological or geopolitical regions). For this reason we compared estimates of forest extent and change by Level II physiographic zone, Level I physiographic zone and across the study area. We also posed the following basic questions: (1) are estimates of forest land use extent correlated with forest land cover extent estimates? (2) Are estimates of net change in forest land use extent and net change in forest land cover extent correlated? (3) Are estimates of gross forest cover loss correlated with either net change in forest land use or net change in forest land cover? The correlation was calculated based on the 18 Level II physiographic zones. Because of the small number of observations a bootstrap approach, with 5000 bootstrap samples, was employed to estimate the correlation coefficients and 95 per cent confidence intervals (CIs) (Efron and Tibshirani, 1993). To interpret the results of the correlation analysis we also examined the results graphically by Level I physiographic zone (Coastal Plain, Piedmont and Mountains).

Results

The distribution of forest land use among land cover classes provided insight on how much the two forest definitions differed. Forest land use was observed in all land cover classes (Figure 2). Within the study area, the per cent of land in forest use varied by land cover class and physiographic zone. Across all physiographic zones, the per cent forest land use within the forest cover class ranged from 95 to 97 per cent. The forest cover class accounted for ∼23.5 million ha in the study area. Additionally, the per cent forest land use in the woody wetland forest land cover class (5.2 million ha) was 97, 97 and 82 per cent in the Coastal Plain, Piedmont and Mountains physiographic zones, respectively. The per cent forest land use in the scrub/scrub land cover class (2 million ha) was 91 , 90 and 75 per cent in the Coastal Plain, Piedmont, and Mountains, respectively. The per cent forest land use in the grassland/herbaceous class (2.2 million ha) ranged from 55 per cent in the Mountains to ∼80 per cent in the Piedmont and Coastal Plain. Interestingly, the per cent forest land use within the developed land cover class (4.5 million ha) was typically 20 per cent across physiographic zones. Most of the forest land use was observed in the developed open space class.

Based on Figure 2, we expected relatively large differences between forest land use estimates and forest land cover estimates particularly in areas where non-forest land covers were both expansive and had a high proportion of forest land use. For example the Coastal Plain, where woody wetlands are an expansive land cover class, was 63 per cent forest land use in 2001 as compared with 32 per cent forest land cover. In the Coastal Plain forest land use estimates were statistically different ($\alpha = 0.05$) from the forest land cover estimates (Figure 3). The discrepancies between forest land use and forest land cover extent were smaller in the Piedmont where in 2001 the area was 63 and 56 per cent forest based on forest use and forest cover definitions, respectively. In the Piedmont 3 out of 6 Level II physiographic zone estimates were statistically different ($\alpha = 0.05$). Forest land use and forest land cover estimates were the most consistent in the Mountains where they were 67 and 68 per cent, respectively. Across physiographic zones the correlation among point-in-time forest land use estimates and forest land cover estimates was $r = 0.39$ ($P > 0.05$) and only 22 per cent of the per cent forest land cover estimates fell within the 95 per cent C.I. of their corresponding per cent

Table 1 Original NLCD classes, class definitions and collapsed land cover classes

NLCD Code	NLCD category	NLCD definition	Collapsed code	Collapsed category
11	Open water	All areas of open water, generally with <25% cover of vegetation or soil.	1	Open water
12	Perennial ice/snow	All areas characterized by a perennial cover of ice and/or snow, generally >25% of total cover.	NA	Developed
21	Developed, open space	Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for <20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses and vegetation planted in developed settings for recreation, erosion control or aesthetic purposes.	3	Developed
22	Developed, low intensity	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20–49% of total cover. These areas most commonly include single-family housing units.	3	Developed
23	Developed, medium intensity	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50–79% of the total cover. These areas most commonly include single-family housing units.	3	Developed
24	Developed, high intensity	Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80–100% of the total cover.	3	Developed
31	Barren Land	Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for <15% of total cover.	4	Barren land
41	Deciduous forest	Areas dominated by trees generally >5 m tall and >20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.	9	Forest
42	Evergreen forest	Areas dominated by trees generally >5 m tall, and >20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.	9	Forest
43	Mixed forest	Areas dominated by trees generally >5 m tall, and >20%of total vegetation cover. Neither deciduous nor evergreen species are >75% of total tree cover.	9	Forest
52	Shrub/scrub	Areas dominated by shrubs; <5 m tall with shrub canopy typically >20%of total vegetation. This class includes true shrubs, young trees in an early successional stage, or trees stunted from environmental conditions.	7	Shrub/scrub
71	Grassland/herbaceous	Areas dominated by grammanoid or herbaceous vegetation, generally >80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.	6	Grassland/ herbaceous
81	Pasture/hay	Areas of grasses, legumes or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for >20% of total vegetation.	2	Agriculture
82	Cultivated Crops	Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for >20% of total vegetation. This class also includes all land being actively tilled.	2	Agriculture
90	Woody wetlands	Areas where forest or shrubland vegetation accounts for >20 per cent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.	8	Woody wetlands
95	Emergent herbaceous wetlands	Areas where perennial herbaceous vegetation accounts for >80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.	5	Emergent herbaceous wetlands

forest land use estimate. Considering the entire study area, these differences resulted in a 7.5 million ha discrepancy in the forest land base.

From 2001 to 2006 net forest land cover change was negative indicating decreases in the Coastal Plain, Piedmont and Mountains of −0.23 , −0.42 and −0.41 per cent, respectively. We observed corresponding estimates of net forest land use change in the Piedmont (−0.29 per cent) but forest land use increased in both the Mountains (0.08 per cent) and the Coastal Plain (0.13 per cent). The correlation between 2001 and 2006 forest land cover net change and forest land use net change was $r = 0.46$ ($P < 0.05$), indicating low to moderate significant correlation. The Piedmont physiographic zone exhibited the best correspondence between forest land cover net change and forest land use net change (Figure 3). However, the results were spurious overall. The estimates of net change differed in direction (increase *vs* decrease) in 8 of 18 Level II physiographic zones (Figure 3). Typically these disagreements occurred when the forest land use net change increased and the forest land cover net change decreased. Eight of 18 Level II physiographic zones had forest land use and forest land cover net change estimates that were statistically different ($\alpha = 0.05$). In the Coastal Plain, 5 of 7 Level II physiographic zones had statistically significant estimates of forest land use net change. In addition, only 4 of 18 Level II physiographic zones (two in the Coastal Plain, one in the Mountains and one in the Piedmont) had forest land use net change estimates that significantly differed from zero ($\alpha = 0.05$). The impact of these differences on forest net change statistics across the study area was 0.15 million ha.

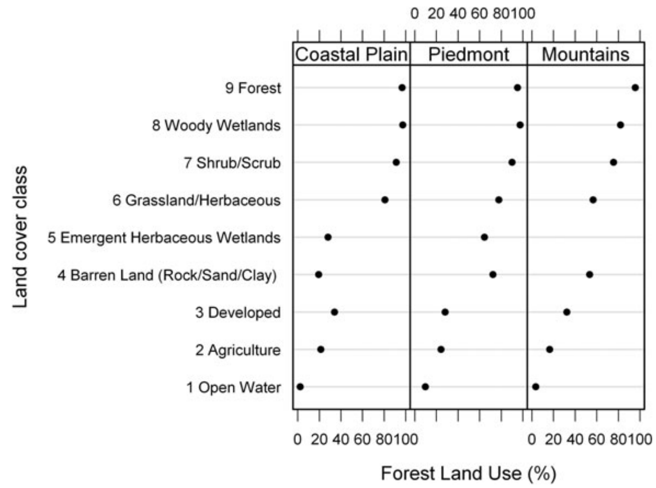

Figure 2 Percentage of each collapsed land cover class in forest land use by physiographic zone.

Gross forest land cover loss from 2001 to 2006 was 2.67 , 2.27 and 0.74 per cent in the Coastal Plain, Piedmont and Mountains,

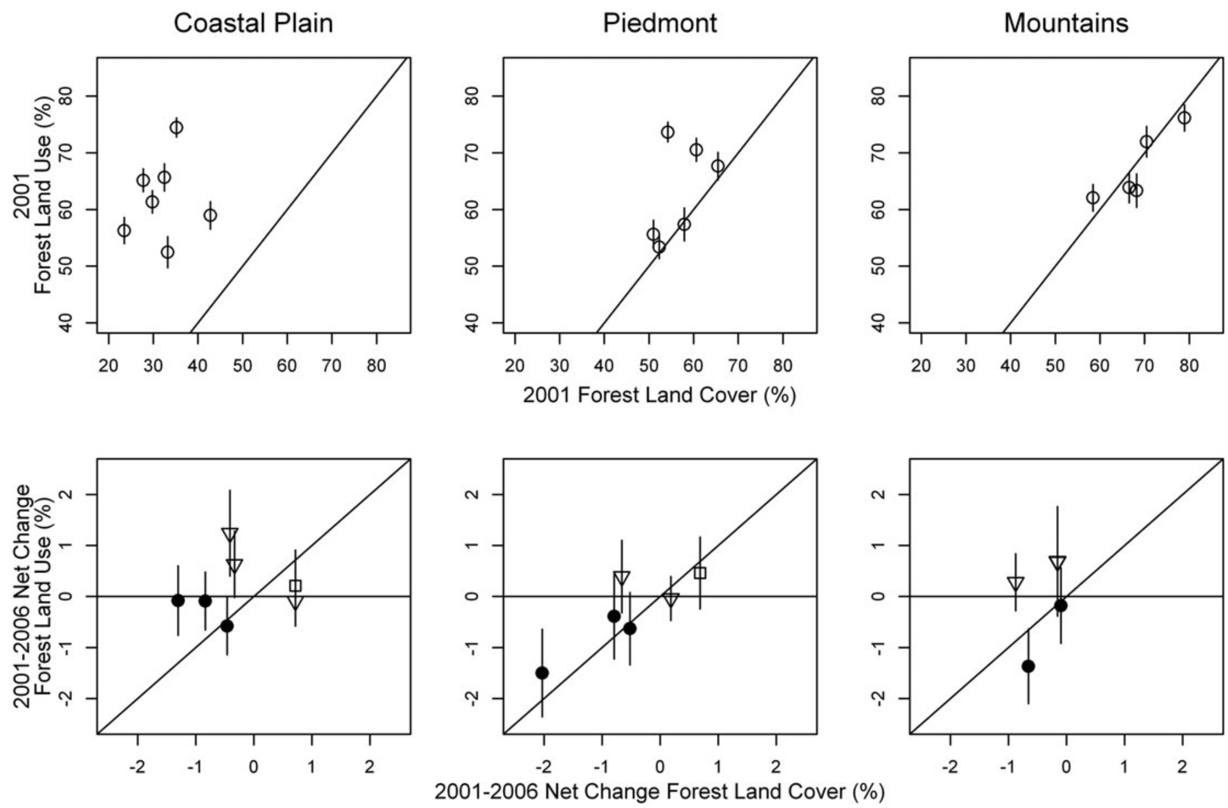

Figure 3 Comparison of 2001 forest land use and forest land cover extent (top row). Comparison of 2001–2006 net change in forest land cover and forest land use (bottom row). The vertical lines denote the 95 per cent CI for forest land use and forest land use change estimates. The diagonal line is the 1 : 1 line. In the change panels (bottom row) corresponding forest land use loss and forest land cover loss is denoted by circles, corresponding forest land use increase and forest land cover increase is denoted by squares, disagreement in direction (loss *vs* increase) is denoted by inverted triangles.

respectively. The correlation between Level II physiographic zone net forest land cover change and gross forest land cover loss estimates was $r = 0.09$ ($P > 0.05$). When comparing estimates of gross forest land cover loss with net forest land use change by Level II physiographic zones the correlation was $r = 0.22$ ($P > 0.05$). These results verify that examining gross forest cover change was independent of net forest change in the southeastern US. In terms of area, the difference between forest land use net change and forest land cover gross loss was 1 million ha and the difference between forest land cover net change and forest land cover gross loss was 0.85 million ha.

Discussion

Understanding uncertainty is important when examining information from resource assessments. We provide 95 per cent CIs for forest land use status and change estimates to convey the uncertainty. However, we could not construct corresponding CIs for the estimates of status and change in forest land cover arising from the NLCD. Wickham *et al*. (2013) conducted an accuracy assessment of the NLCD products. Their NLCD accuracy assessment units that overlapped the Mountains and Piedmont physiographic zones used in this analysis had user's accuracies of 79 and 80 per cent for forest land cover gain and loss, respectively. The NLCD accuracy assessment units that overlapped the Coastal Plain physiographic zone used in this study had user's accuracies of 75 and 89 per cent for forest land cover gain and loss, respectively. While Wickham *et al*. (2013) present an accuracy assessment for the NLCD, this type of accuracy assessment quantifies pixel-level modelling accuracy. Pixel-level accuracy is related albeit different from the accuracy of compositional information (e.g. per cent forest cover) and net change in composition in an area of interest. Stehman (2009) discusses this issue and suggests appropriate accuracy assessment techniques for quantifying error in compositional data and net change.

The results from our case study illustrate three major points. (1) In the southeastern US, forest land use is distributed across all land cover classes. (2) Forest cover is not always equal to forest use. (3) Net forest cover change and net forest use change are not always equal and gross forest cover loss is independent from both of these. These points are important because they demonstrate that forest use cannot consistently be inferred from forest cover and likewise net forest cover change, net forest use change and gross forest cover loss cannot be consistently inferred from each other. This is particularly relevant given the rapid increase in broad-scale forest cover and forest cover change assessments. However, in order to synthesize and integrate forest use, forest cover and change information we must begin to understand the drivers of the differences, the dynamics of the differences over broader temporal scales and the implications for strategic assessments and policy development.

Drivers of convergence and divergence

There is a suite of drivers that cause estimates of forest land use and forest land cover extent to diverge and/or converge, and these drivers are dependent upon the classification scheme used, human activities and natural disturbances (Figure 4). Our

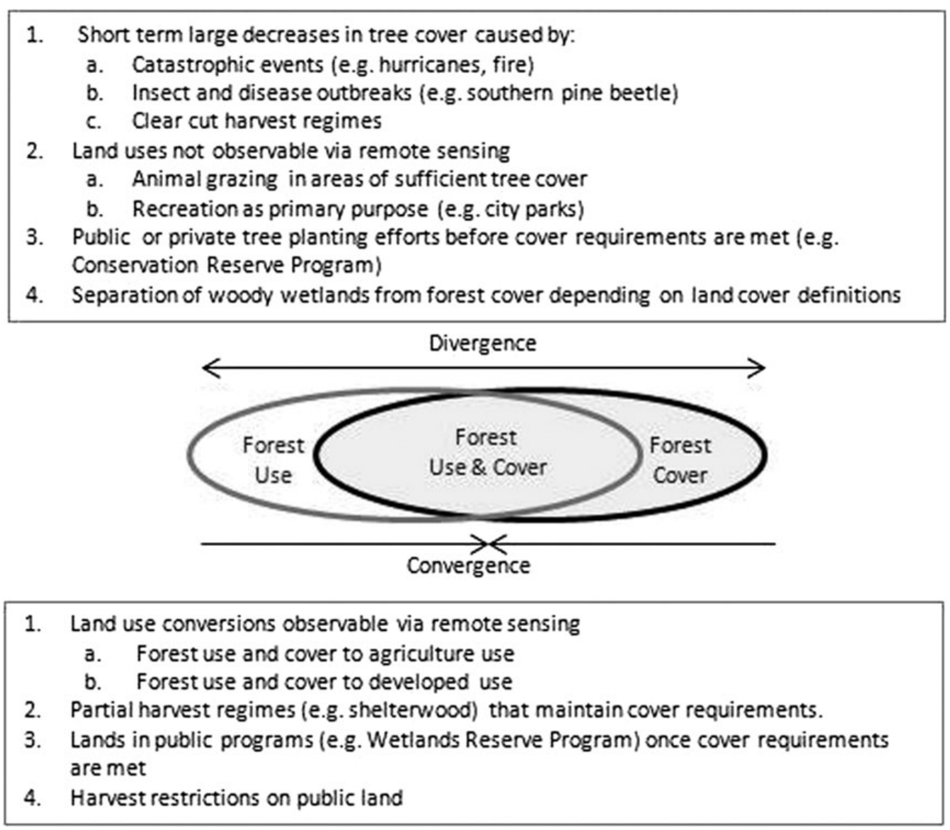

Figure 4 Drivers of divergence and convergence in the southeastern US between forest land use and forest land.

results indicated that point-in-time estimates of forest land cover and forest land use extent were not significantly correlated, however, graphically, the relationship differed by physiographic zone (Figure 3). Separating woody wetlands from the forest cover class had a substantial impact on the correlation among point-in-time estimates, particularly in the Coastal Plain physiographic zone. We chose to separate these classes because other researchers (Drummond and Loveland, 2010; Fry *et al*., 2011) followed this procedure. Woody wetlands are a combination of both forest cover and shrub cover (Table 1). Including woody wetlands as forest would imply that shrub cover, in non-wetland areas should also be included as forest. Putting that issue aside, we re-performed our analysis including woody wetlands as forest cover (Figure 5). This increased the correlation between 2001 point-in-time estimates of per cent forest land use and per cent forest land cover from $r = 0.39$ ($P > 0.05$) to $r = 0.74$ ($P < 0.05$), and had a negligible influence on correlation of net change estimates ($r = 0.43$, $P > 0.05$). The correlation between net change estimates only changed slightly because of the implicit notion of intent in the use-based definition of forest. For example, forest management practices, such as clear-cut harvest and replanting, and natural disturbances, such as hurricanes and insect outbreaks, generally do not change the overall management intent. However, they do cause short-term fluctuations in tree canopy cover which is considered as a change from a land cover perspective (Figure 4). Areas with a temporary reduction in tree cover are still managed as part of the forest land use base although their biological properties have been altered. This illustrates the importance of understanding the specific classification systems employed by broad-scale monitoring programs and understanding what is considered change. Increased understanding will facilitate more focused research on maintaining and enhancing the goods and services that these ecosystems provide.

Several human activities cause estimates of forest cover and forest use to converge (Figure 4). Interestingly, broad-scale public tree planting programs (e.g. Conservation Reserve Program) cause long-term convergence but short-term divergence. This occurs because once an area is planted it is considered to be in forest use, whereas the area is not considered forest cover until the tree cover and height requirements are met. Land use conversions (e.g. forest use and cover to urban, forest use and cover to agriculture) that are observable via remote sensing are convergence drivers because they often change both the use and the cover of an area. To illustrate, consider the Level II physiographic zone which contains the Atlanta metropolitan area. This particular area is ~2.5 million ha and from 2001 to 2006 was developing rapidly (Miller, 2012). Both from a land cover and land use perspective forest decreased. The 2001–2006 net change was −2.03 per cent based on forest land cover and −1.50 per cent (SE 0.44 per cent) based on forest land use. We do expect such convergences to occur, but drivers of convergence and divergence act simultaneously at policy-relevant scales. This complicates future land

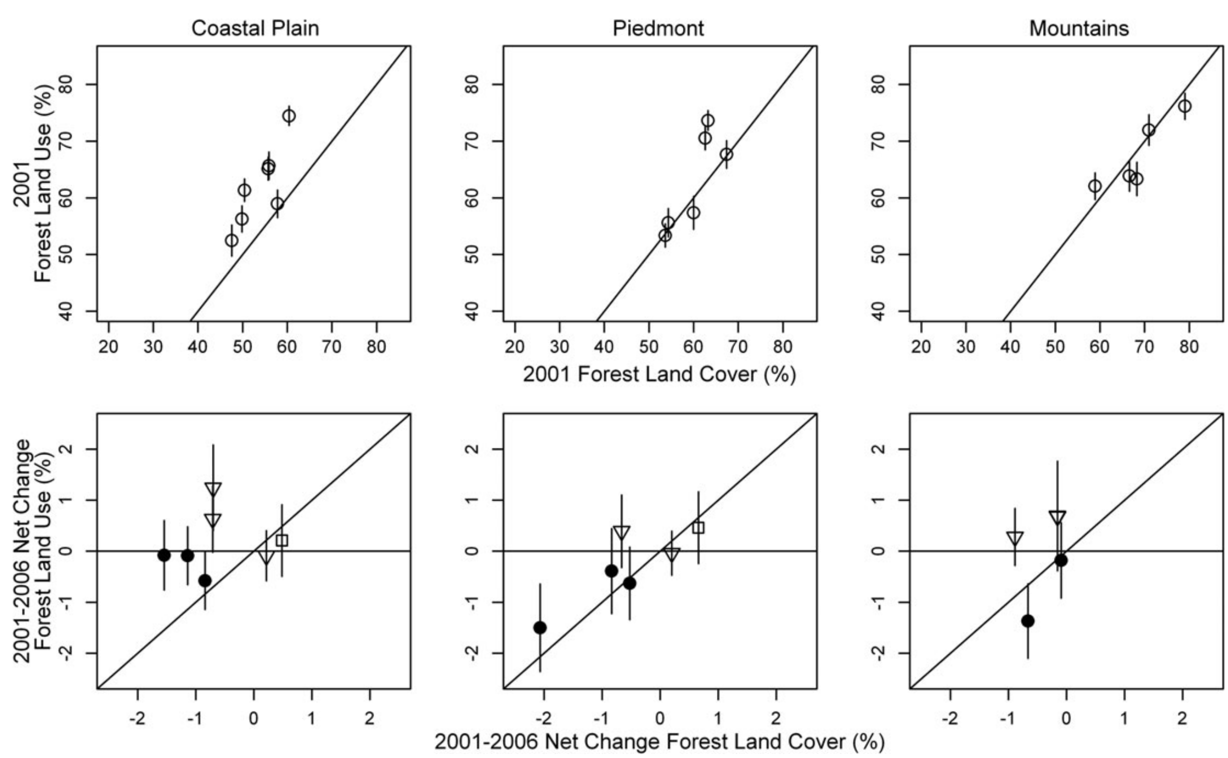

Figure 5 Revised comparison of forest use and forest cover status and change when considering woody wetlands as forest cover. Comparison of 2001 forest land use and forest land cover extent (top row). Comparison of 2001–2006 net change in forest land cover and forest land use (bottom row). The vertical lines denote the 95% CI for forest land use and forest land use change estimates. The diagonal line is the 1 : 1 line. In the change panels (bottom row) corresponding forest land use loss and forest land cover loss is denoted by circles, corresponding forest land use increase and forest land cover increase is denoted by squares, disagreement in direction (loss *vs* increase) is denoted by inverted triangles.

change modelling and forecasting efforts if both forest cover and forest use are to be considered and integrated because of the increase in required feedback loops.

Temporal dynamics

Over a broader temporal scale (e.g. decades) both net forest land cover losses and net forest land use losses were noted in several studies (Smith *et al*., 2009; Drummond and Loveland 2010; Rautiainen *et al*., 2011). While the magnitude of the change may differ we do expect consistency in the direction of net change (loss or gain). This is because over long time frames the magnitude of the total net change overshadows the net change caused by short-term changes in tree canopy cover. Drummond and Loveland (2010) suggested that land use pressure has transitioned the eastern US to a forest cover loss scenario and described some uncertainty with respect to post 2000. In contrast, we observed some increases in forest land use and forest land cover between 2001 and 2006. Nevertheless, other areas, particularly around the Atlanta metropolitan region, clearly decreased in forest land use and forest land cover. Our results suggest that the spatial scale of forest land use change is substantially finer than the ecoregion-scale analysis by Drummond and Loveland (2010) or the Southeast-wide analysis by Smith *et al*. (2009). This poses a challenge to assessment efforts because the pressures driving the changes operate across a range of spatial and temporal scales, while the assessments of the conditions on the ground are typically presented at a single scale.

The research presented by Hansen *et al*. (2010) led to some concerns regarding their use of gross forest cover loss as a sole metric to quantify forest change (Kurz, 2010; Reams *et al*., 2010; Wernick *et al*., 2010). We found that gross forest cover loss in the southeastern US was not significantly correlated with either net forest land use change or net forest cover change. Also, the current forest land base is not calculable from estimates of gross loss alone. Gross forest cover loss may be more relevant when considering habitat needs of specific species or in other areas of the world such as the tropics where changes in forest cover are more indicative of change in land use but not in areas such as the southeastern US where forest regeneration commonly follows forest harvesting and disturbances. The forest land cover data we examined masked forest dynamics such as growth and regeneration, and more importantly, the dynamics one would observe following harvest or natural disturbance actually trigger a change in land cover class. This is a particular issue when considering working forests which are analogous to other agricultural systems but operate over a longer time horizon. In the southeastern US, pine plantations achieve heights of 10 m and full canopy closure by age seven (Peduzzi *et al*., 2010). The management intent for these systems is to provide fibre and therefore the land use does not change because of harvest. From a forest land cover perspective, this cropping aspect of forestry causes class transitions regardless of the management intent. Hypothetically, harvested areas in forest land use would cycle through the barren land, herbaceous class to the shrub class and back into the forest land cover classes as part of the cycle of harvest, natural regeneration or replanting, and regrowth. Areas that were naturally disturbed (e.g. tornado and major hurricane) are likely to follow the same scenario depending on the severity of the disturbance. Because of these cyclic patterns, the opportunity exists to retrospectively construct a forest land use product from a time series of land cover and tree canopy cover products. Conversely, most forest land use data also have tree-level information which would facilitate estimating forest cover. Cross-validating these estimates will help identify additional drivers of convergence and divergence and help identify gaps in monitoring networks and programs.

Carbon and strategic assessments

Quantifying forest extent is a fundamental step when estimating carbon storage, forecasting land change and forecasting future carbon pools. There is a broad body of literature related to these topics. For discussion consider the Consolidated Appropriations Act of 2008 P.L. 110–161, the Energy Independence and Security Act of 2007 P.L. 110–140 and the Forest and Rangeland Renewable Resources Planning Act of 1974 P.L. 93–378. The Consolidated Appropriations Act mandates the maintenance of a national greenhouse gas inventory. The Energy Independence and Security Act mandates the assessment and forecasting of carbon stocks, sequestration and greenhouse gas fluxes. The Renewable Resources Planning Act mandates the assessment and forecasting of the uses, demand and supply of renewable resources (see USDA Forest Service, 2012).

Each of these efforts requires defining forest extent and carbon associated with the forest base. Additionally the forecasting components of the Energy Independence and Security Act and Renewable Resources Planning Act efforts require land change estimates over time so that the future forest base and forest carbon storage can be forecasted. While there does seem to be some acknowledgement of differences between forecasts derived from land cover and those derived from land use (Zhu, 2011), there is no discussion or further thought on the impacts and reasons for the differences. Because one of the purposes of the forecasts is to strategically evaluate alternative land management approaches under the various Intergovernmental Panel on Climate Change (IPCC) scenarios, starting from different baselines may also result in conflicting management recommendations in an effort to control the overall carbon budget. Clearly broad-scale management recommendations would be strengthened by integrating or synthesizing results from the land cover and land use perspective.

While the examples discussed above arise from US laws, the points are relevant to other countries that have ratified the United Nations Framework Convention on Climate Change (UNFCCC). One of the core UNFCCC greenhouse gas inventory reporting elements is estimating emissions and removals of greenhouse gases with respect to land use, land use change and forestry. The conversion of forest land to other uses is an important part of this element. IPCC good practice guidelines indicate that that the land classification system should be capable of capturing change without being unduly influenced by rotational or cyclical patterns that may arise during harvest and regrowth cycles (Penman *et al*., 2003). In our case study we used the NLCD land cover data and that particular classification system was not well suited to deal with cyclical patterns in forests that arise due to disturbance and management, although we hypothesized that these cyclic patterns are discernible from a time series of NLCD data. Other land cover classification, such as used by Drummond and Loveland (2010), may be better suited than the NLCD because they include categories such as mechanically disturbed and non-mechanically disturbed forest cover. These additional land cover classes allow users the option to consider these disturbed areas as forest land which is more in line with IPCC good practice guidelines.

The future extent and condition of forests are tied in part to population growth, climate change, forest products demand, and invasive plants, insects and diseases. Human population growth triggers land use change that can lead to conversion of forest land to developed land. The dynamics of how much forest land converts to developed land is also dependent on the availability of agricultural lands for urban use (Wear, 2011). Several recent remote-sensing-based studies have attempted to show declines in forest extent for the southeastern US through the use of short-term changes in forest canopy cover (Hansen *et al*., 2010; Fry *et al*., 2011). These studies have yet to examine whether short-term transitory changes in tree canopy lead to forest land use change. Monitoring approaches that track actual changes in land use along with information from monitoring of tree canopies will aid our understanding of land use and cover dynamics.

Conclusion

Our objective was to examine similarities and differences between forest extent and change statistics derived under a use-based forest definition and those derived under a cover-based forest definition. The primary lessons and recommendations arising from this effort were:

(1) Forest land use is unequal to forest land cover in many areas. There are both natural and human drivers that cause these attributes to converge and diverge. Inferring forest land use from forest land cover and/or forest land use change from forest land cover change can lead to erroneous conclusions. Therefore, it is incumbent upon scientists to clearly articulate the questions relevant to their chosen definitions and methodologies. Inventory and monitoring programs should likewise be clear with respect to the information they provide.
(2) At a minimum, net change in forest extent (either use or cover definition) should be presented consistently. Reporting net change along with other relevant components will provide a more consistent baseline when examining resource issues.
(3) There are opportunities to develop forest land use data from a time-series of forest land cover. This can be done retrospectively by examining the cover class transitions over time. The specific cover class transitions that may identify forest land use may differ by region and will be related to the drivers of forest land use and forest land cover divergence and convergence. Likewise, there are opportunities to develop forest cover data from forest land use data using tree-level information collected at *in situ* sample locations. This cross-validation would help identify gaps in monitoring networks as well as provide information on how to synthesize and integrate forest land use and forest land cover data to assess multiple goods and services provided by forests.
(4) Because forest extent provides the base by which other attributes, such as carbon, are summarized, stocks and flux estimates will also differ depending on whether a forest use or forest cover definition is used. This has implications for greenhouse gas inventories, forecasting carbon storage and sequestration on forest land, and land change science.
(5) The ability to track actual changes in forest land use along with information from monitoring of tree canopies will aid our understanding of land use and cover dynamics.

Globally, forests provide the land base available to support forest ecosystem services and monitoring this land base is important. However, the distinction between forest use and forest cover is often lost when communicating status and change in both science and policy arenas. We illustrated the differences between forest use and forest cover concepts and provided lessons and recommendations that clarify forest use, forest cover, change perspectives, and statistics. Contemporary forestry issues, such as plantation expansion (Rudel, 2009), loss of biodiversity (Mendenhall *et al*., 2012), demands for biomass for bioenergy (Tromborg *et al*., 2013) and carbon flux (Pan *et al*., 2011) require a firm understanding of both land use and land cover concepts as they relate to these forestry issues. The development of land use policies that will address these issues and provide for a balance of land uses which maintain and enhance ecosystem services requires accurate tracking of land use and land cover but also requires the ability to distinguish between and in some cases integrate use and cover concepts.

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Conflict of interest statement

None declared.

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