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How is wood-based pellet production affecting forest conditions in the southeastern United States?

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Exports of woody pellets from the southeastern United States (US) for European power plants have expanded since 2009, leading to concerns about major negative environmental effects. US exports of wood pellets have grown from essentially nothing in 2008 to 4.6 million metric tons in 2015, with 99% of US pellets being shipped to Europe. To examine effects of this recent expansion of the pellet industry on forest conditions, we use US Department of Agriculture Forest Service (USFS) Forest Inventory and Analysis (FIA) annual survey data for 2002–2014 to analyze changes in timberland trends since 2009 for two fuelsheds supplying pellets to the ports of Chesapeake, Virginia, and Savannah, Georgia. This analysis reveals that the Chesapeake fuelshed had significant increases in acreage of large trees and harvestable carbon after 2009. Furthermore, the timberland volume within plantations increased in the Chesapeake fuelshed after 2009. The Savannah fuelshed had significant increases in volume, areas with large trees, and all carbon pools after 2008. Increases in carbon in live trees for the Chesapeake fuelshed and all carbon pools for the Savannah fuelshed for the years before and after 2009 provide empirical support to prior estimates that production of wood-based pellets in the southeast US can enhance greenhouse gas sequestration. Both fuelsheds retained more naturally regenerating stands than plantations; however the number of standing dead trees increased within naturally regenerating stands and declined within plantations (but only significantly for the Savannah fuelshed). While the decrease in the number of standing dead trees per hectare for the Savannah fuelshed plantations after 2009 warrants investigation into its effects on biodiversity, others have recommended thinning and hardwood mid-story control within pine plantations to provide habitat for regionally declining bird species, which is consistent with use of biomass for energy and reducing the risk of fire. While all energy use affects the environment, these results show that benefits accrue when sustainable forest management provides wood pellets for energy that keep fossil fuel in the ground. By contrast urbanization is the greatest cause of forest loss in the SE US. It is essential to consistently monitor and assess forest conditions to assess changes, for exports of wood-based pellets for the southern US are expected to grow. Even though use of pellets for energy has more than doubled, the pellet industry constitutes < 1% of US forest products by weight. Therefore, any recent changes in SE US forest conditions are more likely related to the 2008 declines in the housing market. Continued analysis of annual FIA data using the methods outlined in this manuscript provides a scientifically valid approach for ongoing assessment.

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1. Introduction

Using wood-based pellets for bioenergy provides opportunities to replace consumption of fossil fuel with a renewable resource. Spurred by climate and renewable energy goals, several European nations have been using wood pellets to displace coal as fuel in large electric power plants. From 2009 to 2015, almost all wood pellets exported from the United States (US) were sourced from the southeastern US (SE) and transported across the Atlantic Ocean by tankers, to generate electricity in the United Kingdom, the Netherlands and Belgium (USITC, 2016). The global trade in pellets has doubled from 2012 to 2016 (Walker, 2016).

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Wood pellets in the southeast (SE) US are sourced either from byproducts of timber harvested for lumber, paper and pulp or from timberlands that would have been harvested for pulp but are left without a market where local pulp mills have shut down (Abt et al., 2014) (Fig. 1). Historic land use, ownership, slope, and other social, biophysical and environmental conditions influence current forest types, structures and age classes (forest biomass supply). Investments in site preparation, fertilization and thinning also influence biomass supplies. Investment decisions are made by forest landowners who vary from corporation to individuals and families, the latter representing about 85% of private timber area in the southeast US (Wear and Greis, 2013). For commercial harvesting, non-corporate owners typically rely on external loggers who determine which trees to harvest. All pellet mills in the SE US that export pellets require feedstock to originate from sites supervised by logging professionals (National Association of State Foresters, 2015). Trees and residues considered unprofitable to transport are left in the forest to slowly decompose or are burned. The harvested timber is sold preferentially to highest value markets: e.g., solid lumber, pulp and paper, and specialty markets such as small logs exported to China for scaffolding. Sawmill residues are often used onsite to generate electrical energy or sold for mulch, animal bedding, or making particle board and fiberboard. Woody material that cannot be sold more profitably elsewhere is available at low cost for pellet mills. This type of woody material is available in the SE US, where pulp mills have closed and feedstocks are left economically stranded. Uncertainty about future markets can inhibit investments in systems to more efficiently and fully utilize available woody resources.

Feedstock supply for SE US wood pellet exports primarily consists of woody residues, thinnings and other trees that do not meet specifications for higher value markets. Forest thinning entails harvesting to reduce tree density, which improves the health and growth of remaining trees and reduces risk of insect damage or fire (Agee and Skinner, 2005). Thinning also improves soil carbon sequestration by increasing stand productivity (Jandl et al., 2007) and benefits biodiversity by reducing risks from pests, disease and intense wildfire (Thomas et al., 1999).

Yet concerns are still raised about the effects of wood-based pellet production on forest conditions in the SE US (Dale et al., 2017). Some environmental groups worry that, with rising wood based pellet production, native forest ecosystems and bottomland forests with high biodiversity will be jeopardized and that greenhouse gas (GHG) emission reduction objectives will be undermined (Cornwall, 2017). In addition, there is strong interest in ensuring that water quality, biodiversity, and scenic and recreational values of forested lands are maintained (Evans et al., 2013). For example, environmental groups claim "that burning trees for energy ... destroys our forests" (Dogwood Alliance, 2016). Hence documenting how the production and export of wood-based pellets has affected SE US forest conditions to date can provide evidence to help address these concerns.

This analysis uses the United States Department of Agriculture Forest Service (USFS) Forest Inventory and Analysis (FIA) annual inventory data (Miles, 2016; O'Connell et al., 2014) to examine effects of the expanding wood pellet market on SE US forest conditions by asking the question, "How does the expanding SE US pellet production industry differ from a business-as-usual case for two fuelsheds in the SE US?" Our null hypothesis is that no significant changes have occurred in timberland volume, timberland stand size distributions, number of standing dead trees, or carbon storage for our study area, either for naturally regenerating stands or plantations, since the rapid increase in the SE pellet industry around 2009.

2. Methods

This study evaluates trends in forest conditions for two forest production areas or "fuelsheds" that supply wood-based pellets to the ports of Savannah, Georgia, and Chesapeake, Virginia (Fig. 2). The fuelsheds were defined as counties containing land within a 120 km (75 mile) radius of mills producing export pellets as of September 2014, the typical sourcing distance for pellet mills in this region (Stewart, 2015). The Savannah fuelshed encompasses 10.6 million ha and contains 22 South Carolina counties, 54 Georgia counties, and 7 Florida counties. The Savannah fuelshed timberlands are primarily pine, or softwood, plantations. The Chesapeake fuelshed encompasses 8.5 million ha and includes 33 North Carolina counties and 69 Virginia counties. The Chesapeake fuelshed biomass is derived primarily from mixed hardwood timberlands that, until recent mill closures, supplied pulp for the paper industry in the region.

To investigate forest changes in these study fuelsheds, conditions pre- and post- development of the trans-Atlantic wood pellet

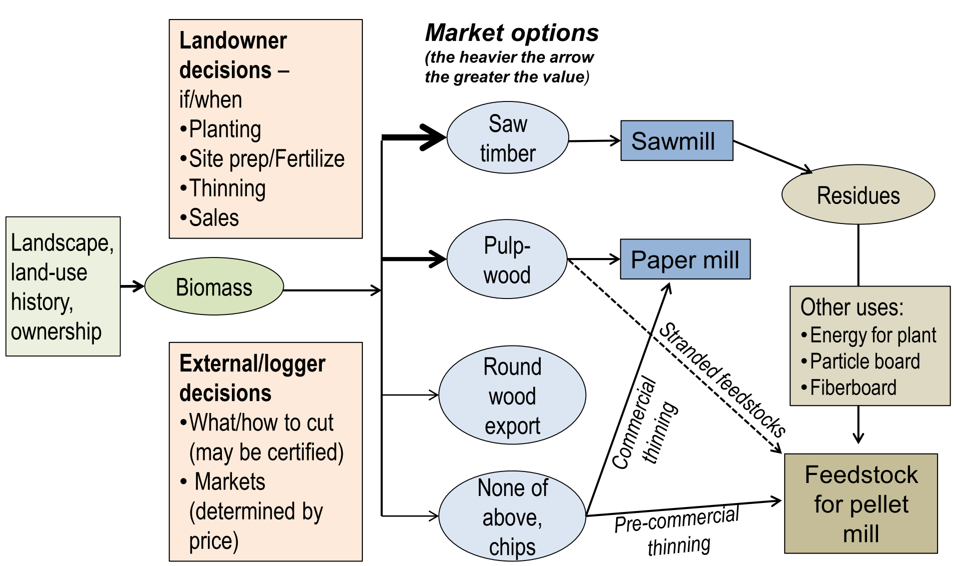

Fig. 1. Factors affecting availability of woody feedstocks for pellets in the SE US. The heaviness of the line indicates the size of the flow.

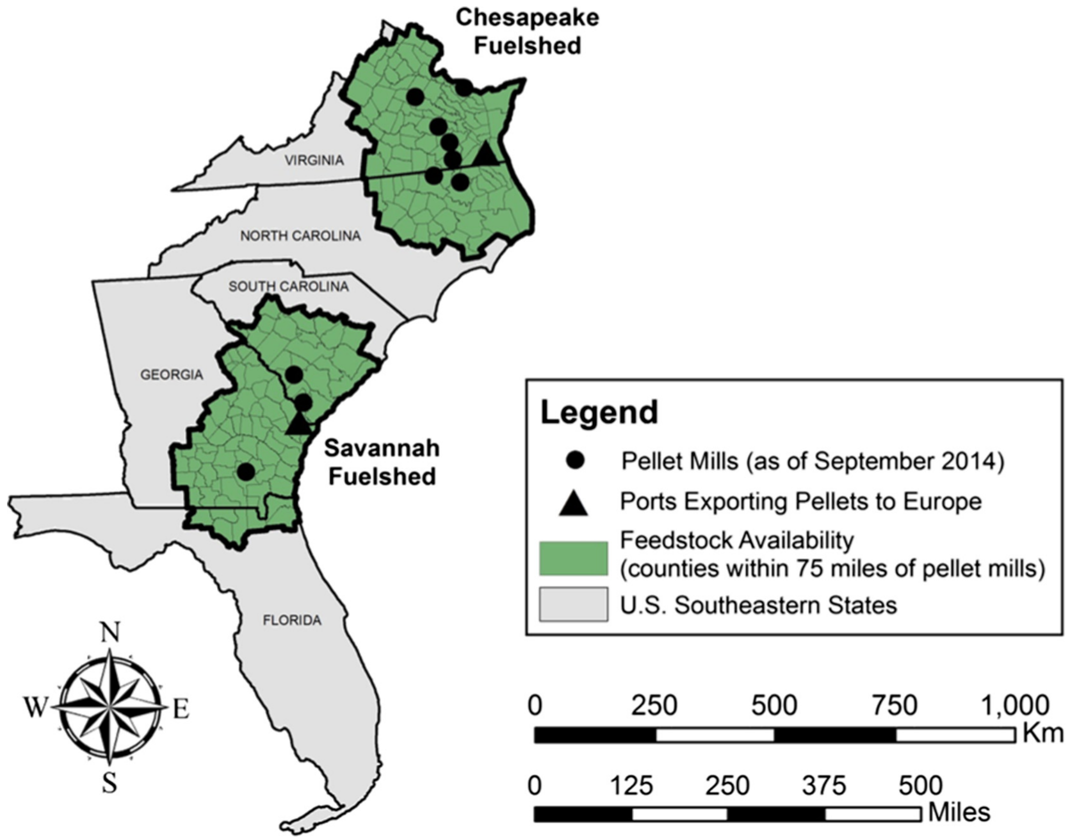

Fig. 2. Map of southeast United States counties and pellet mills comprising two fuelsheds that supply wood pellets to Europe via the ports of Chesapeake, Virginia, and Savannah, Georgia.

trade were analyzed using annual FIA data collected by the USDA Forest Service (USFS) and made available through the FIA database and EVALIDator tool interface (Miles, 2016; O'Connell et al., 2014). Details of the data extraction and analyses are provided in the data in brief article "Use of Forest Inventory and Analysis (FIA) data to analyze timberland conditions in the vicinity of two ports in the Southeastern United States" by Parish et al. (submitted for publication-a).

The FIA long-term survey of the forests in the US provides information on status and trends in forest area and location; species, size, and health of trees; total tree growth, mortality, and removals by harvest; wood production and utilization rates by various products; and forest land ownership. FIA data are currently collected by each state on an annual rotating schedule such that a full inventory cycle is completed every 5–7 years in the eastern US, depending on the state. This standardized collection process began in 2002 for the states included in this analysis; so we consider FIA data for 2002 through 2014. The inventories for years 2004 and 2008 were not complete for Chesapeake and therefore were excluded from the analyses. Data were complete for 2002 for the Savannah fuelshed and for 2006 for the Chesapeake fuelshed but were excluded because several of the values were outliers (see companion "Data in Brief" by Parish et al., submitted for publication-a).

The FIA annual inventory data were queried to consider year-by-year changes in timberland volume and area for the counties comprising each fuelshed. Timberland is defined as "nonreserved forest land capable of producing at least 20 cubic feet of wood volume per acre per year" (O'Connell et al., 2014). Timberland is a subset of forest land and was used for all queries since wood is primarily harvested within timberland areas (O'Connell et al., 2014). We also examined all of the FIA data according to "stand origin," a term that refers to the method of stand regeneration and is defined as either regenerating via seeds or sprouts or showing "clear evidence of artificial regeneration" (i.e., established through direct planting or artificial seeding). These two types of timberland are referred to as "naturally regenerating stands" or "plantations."

In the FIA stand diameter size categories (i.e., large, medium, and small) serve as an indicator of stand age (personal communication with Sam Lambert of the USFS SRS on June 18, 2015). Per O'Connell et al. (2014), large trees are at least 27.9 cm (11 in.) in diameter for hardwoods and at least 22.8 cm (9 in.) in diameter for softwoods. Medium trees are at least 12.7 cm (5 in.) in diameter for all trees, and smaller than large trees. Small trees are less than 12.7 cm (5 in.) in diameter. Large diameter stands are defined as having "more than 50 percent of the stocking in medium and large diameter trees; and with the stocking of large diameter trees equal to or greater than the stocking of medium diameter trees." Medium diameter stands are defined as having "more than 50 percent of the stocking in medium and large diameter trees; and with the stocking of large diameter trees less than the stocking of medium diameter trees." Small diameter stands are defined as having "at least 50 percent of the stocking is in small diameter trees."

Standing dead trees are a contributor to carbon accumulation and provide habitat for some woodpeckers and other species. Therefore we examined the number and volume of standing dead trees according to stand origin and timberland type. Timberland types were determined through use of the forest type ("fortype") code: hardwood = fortype codes 500–995, softwood = fortype codes 100–391, and mixed forest = fortype codes 400–409.

Timberland carbon trends were determined by aggregating the FIA carbon data into three categories: leaf litter plus organic soil, non-harvestable material, and harvestable material. "Leaf litter plus organic soil" includes carbon found in the organic material on the forest floor, such as fine woody debris and humus, and the carbon found in the fine organic material below the soil surface to a depth of 1 m. "Non-harvestable" material includes understory carbon found above and below ground and standing and downed dead trees. Harvestable material includes carbon found in live standing trees at least 1 in. (2.5 cm) in diameter at breast height.

The FIA data were pulled for each fuelshed using customized filters provided by USDA Southern Research Station (SRS) staff. These filters enabled the data to be aggregated across the multiple states included in the fuelsheds, thereby reducing the sampling errors associated with the inventory results. To produce standard error bars, we used summaries of sampling percent error automatically generated by the EVALIDator tool for each of our queries based upon the number of included plots (Miles, 2016). Since the reported sampling error only equates to 67% confidence, we multiplied each error estimates by 1.94 in order to get 95% confidence bounds for each result (based on personal communication with Jeffrey Turner of the USFS SRS on February 1, 2016). Sampling errors increased as the data were binned into subcategories, such as hardwood versus softwood and publicly owned versus privately owned. Years were eliminated from the analysis for which any forest attribute was determined to be an outlier because it was either more than two standard deviations from the mean or 1.5 times the interquartile range (see companion "Data in Brief" by Parish et al., submitted for publication-a).

Paired t-tests were used to compare the means of the ten FIA timberland variables calculated for each fuelshed before and after 2009, the time of sharp increase in wood pellet exports. If the calculated p value was less than 0.05, we rejected the null hypothesis that the populations had equal means before and after 2009.

3. Results

Timberland forest trends (2002–2014) in two southeast US fuelshed areas supplying wood pellets to the ports of Savannah and Chesapeake illustrate steady or slightly increasing timberland area, volume and carbon stocks over the past six years (Fig. 3). Neither fuelshed showed a decrease in timberland volume (Fig. 3a) or area (Fig. 3b) for plantations or naturally regenerating stands over the years 2002–2015, a period that includes the ramp-up of the export pellet industry that began in 2009 (Spelter and Toth, 2009). Both fuelsheds retained more naturally regenerating stands than plantations (Fig. 3a). The Chesapeake fuelshed experienced a significant ($\rho < 0.05$) increase in the overall area with large diameter trees and carbon in live trees but a decrease in the number of standing dead trees within plantations for the years 2009–2015 compared to 2002–2008 (Table 1). Comparing the same periods, the Savannah fuelshed had increases in volume, area supporting large diameter trees, number of standing dead trees within naturally regenerating stands, and all three carbon pools but a decrease in the number of standing dead trees within plantations (Table 1).

4. Discussion

Contrary to concerns publicized by some environmental groups (e.g., Dogwood Alliance, 2016), the FIA data show that the Chesapeake and Savannah fuelsheds continue to support healthy and naturally regenerating forests even with the rise in wood-pellet exports. Even though there has been recent expansion of pine plantations in the SE US, this does not seem to have come at the expense of naturally regenerating forests. Furthermore, Singleton et al. (2013) point out that SE pine plantations have helped remediate historic biodiversity declines that have been attributed to prior loss of open pine grassland forests.

Increases in carbon in live trees for the Chesapeake fuelshed and all carbon pools for the Savannah fuelshed for the years 2009–2015 compared to 2002–2008 provide empirical support to prior estimates that production of wood-based pellets in the SE US can enhance GHG sequestration (Dwivedi et al., 2014; Ter-Mikaelian et al., 2015). Calculating the effects of wood-based energy on total GHG emissions is complicated by choices of modeling techniques and system boundaries (Buchholz et al., 2014). However, these results support the claim that the ecological objective of reducing GHGs in the SE US can be achieved through use of wood pellets (Dale et al., 2015b) since forests that are sustainably managed for wood products and energy can reduce total atmospheric carbon dioxide (CO_2) concentrations over the long term (Dwivedi et al., 2014; Ter-Mikaelian et al., 2015).

The decrease in the number of standing dead trees per hectare for both the Chesapeake and Savannah plantations after 2009 warrants further investigation to examine long-term effects on biodiversity. However Singleton et al. (2013) recommend thinning and hardwood mid-story control within pine plantations to provide habitat for a suite of regionally declining bird species: practices that are compatible with use of biomass for energy and reduce the risk of fire. Furthermore, snag densities are typically higher in hardwood stand types than pine plantations and, within a stand type, in intermediate-aged forests rather than in younger or older ones (Moorman et al., 1998). Hence pine plantations managed on short rotations (<25 years) do not provide abundant snags (Moorman et al., 1999) independent of any removal of biomass for wood pellets.

Most of the forest practices in the SE US are driven by harvesting for saw timber and paper, so it is reasonable that there are few effects to date of the wood-based pellet industry on forest conditions. Despite this exponential growth of the pellet industry, in 2014 wood pellets comprised <1% of total US forest products by weight and <0.5% of total US forest products exports by value (as we calculated from data in FAOSTAT, 2016 – see Parish et al., submitted for publication-b). Saw timber, the highest value component of forest industry market, determines most forest harvesting activities, but pulpwood is the major driver of harvesting of small trees in some areas. The pellet industry is relatively new and a small part of the US forest products industry (FAOSTAT, 2016).

Beginning in 2007, there was a decline in demand for wood from the SE US as the housing market collapsed and paper manufacturing declined (Ince and Nepal, 2012; Wear et al., 2013). Hence, it is possible that the observed increase in timberland volume, area and carbon pools for 2009–2015 relative to 2002–2008 for the study fuelsheds is related to the slowdown of the US housing market that began with the 2008 recession. This relationship warrants further evaluation as the housing markets is reestablished.

This analysis is made in view of the background that SE US is dominated by diverse temperate forests that provide critical habitat protection for endangered species and enhanced water quality. These forests currently provide saw timber and pulp, and ongoing forest resource demands are an incentive to maintain SE US land in forests that provide diverse ecosystem services (Sims et al., 2013). Managed forests can limit the spread of wildfires as well as insect and pathogen outbreaks, thereby protecting neighboring landscapes and enhancing other ecosystem services (Dale et al., 2015a). Little old-growth forest remains, for the SE has been highly disturbed by humans and natural events for centuries (Davis, 1996).

EU policy objectives include (1) halting loss and degradation of forests, (2) halting and adapting to climate change, and (3) promoting a low carbon, resource efficient circular bioeconomy, which reduces wastes by design and includes renewable energy resources (Olesen et al., 2016). These objectives are linked to environmental

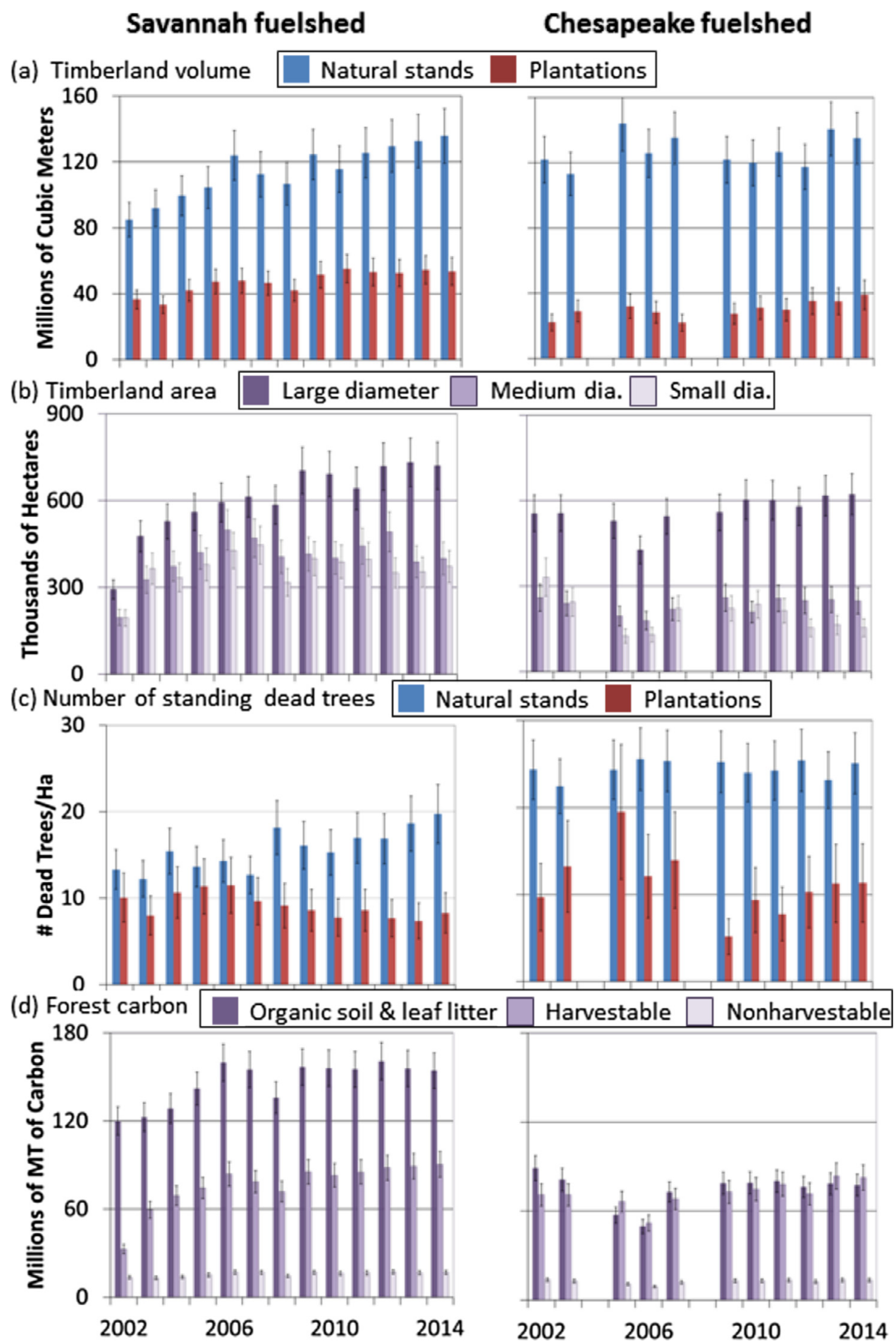

Fig. 3. Timberland forest trends (2002–2014) for the fuelshed areas supplying the ports of Savannah and Chesapeake from the USFS Forest Inventory and Analysis (FIA) annual survey with sampling error bars at the 95% confidence level. Missing bars indicate an incomplete inventory for that year. The histograms show timberland volume for naturally regenerating stands versus plantations (a), timberland area by stand size (b), number of standing dead trees per hectare of timberland (c), and total carbon mass as reported across FIA categories (litter and below ground, above ground harvestable, and above and below ground non-harvestable) (d).

implications of the effects of producing wood-based pellets in the SE US. Policy risks are considered to be nonattainment of these and other objectives because of the impacts of increased pellet demand (Olesen et al., 2016). However, the presumption that loss or degradation of SE US is due to wood pellet production is not supported by this analysis.

Other pressures in the SE US may have more effects on forest conditions than the pellet industry. In particular, urbanization is the greatest cause of forest loss in the SE US (Wear et al., 2013). Furthermore, as paper use decreases, there is a decline in demand for pulpwood and the forests that support them. Hence having a market for those wood products that become economically stranded upon closure of a pulp mill provides a reason to keep land in forest as well as supports rural jobs. In addition, forest conditions in the SE US are being affected by changes in precipitation

Table 1A
Results of paired T-test for USDA FIA timberland for the Savannah fuelshed before and after growth of the wood pellet export industry (2003–2008 compared to 2009–2014) (i.e., 6 observations each).

	Volume (millions of cubic meters)		Number of standing dead trees per ha		Areas with tree diameters in each category (thousands of ha)			Carbon content (millions of metric tons)		
	Naturally regenerating stands	Plantations	Naturally regenerating stands	Plantations	Large	Medium	Small	Soil and leaf litter	Harvestable (live) material	Non-harvestable (dead) material
Mean:										
Pre(2003–2008)	106.61	43.25	14.40	10.04	559.65	415.97	378.08	140.69	72.91	15.13
Post (2009–2014)	127.37	53.46	17.27	8.04	701.72	423.47	376.56	156.48	86.94	16.78
Variance:										
Pre (2003–2008)	121.10	30.52	4.70	1.88	2513.81	3941.23	2583.61	213.61	70.40	2.61
Post (2009–2014)	50.65	1.69	2.72	0.26	1042.12	1488.26	477.21	5.21	7.99	0.10
Pearson correlation	0.51	0.42	0.43	−0.30	0.34	0.48	−0.62	0.49	0.48	0.30
t Stat	−5.33	−4.89	−3.37	3.07	−7.03	−0.33	0.06	−2.84	−4.61	−2.61
P(T ≤ t) two-tail	0.00	0.00	0.02	0.03	0.00	0.76	0.96	0.04	0.01	0.05
Accept/reject null hypothesis that means are equal	Reject	Reject	Reject	Reject	Reject	Accept	Accept	Reject	Reject	Reject

Table 1B
Results of paired T-test for USDA FIA timberland for the Chesapeake fuelshed before and after growth of the wood pellet export industry (Pre = 2002, 2003, 2005, 2007, 2009 versus Post = 2010–2014) (i.e., 5 observations each).

	Volume (millions of cubic meters)		Number of standing dead trees per ha		Areas with tree diameters in each category (thousands of ha)			Carbon content (millions of metric tons)		
	Naturally regenerating stands	Plantations	Naturally regenerating stands	Plantations	Large	Medium	Small	Soil and leaf litter	Harvestable (live) material	Non-harvestable (dead) material
Mean:										
Pre (2002, 2003, 2005, 2007, 2009)	127.25	26.54	24.34	12.31	548.50	234.26	228.66	75.82	69.88	12.48
Post (2010–2014)	127.96	34.07	24.38	10.00	604.67	243.36	184.09	78.34	78.14	13.23
Variance:										
Pre (2002, 2003, 2005, 2007, 2009)	150.02	19.61	1.37	28.18	149.41	756.50	5427.31	140.41	6.64	1.17
Post (2010–2014)	97.36	13.32	0.80	2.24	285.53	379.13	1440.27	2.31	25.62	0.24
Pearson correlation	−0.11	0.14	−0.09	12.12	0.73	−0.49	0.83	0.77	0.45	0.45
t Stat	−0.10	−3.16	−0.07	0.89	−10.82	−0.50	2.10	−0.53	−4.08	−1.28
P(T ≤ t) two-tail	0.93	0.03	0.95	0.42	0.00	0.64	0.10	0.63	0.02	0.16
Accept/reject null hypothesis that means are equal	Accept	Reject	Accept	Accept	Reject	Accept	Accept	Accept	Reject	Accept

and temperature patterns and increasing intensity and duration of disturbances (Dale et al., 2015a).

Bottomland hardwood forests are a particular concern in the SE US, for they provide habitat to a variety of rare species. An independent analysis of bottomland hardwood forest in Virginia and North Carolina using FIA data found that between 2002 and 2014 the area of large-diameter sized stands increased, while that of medium- and small-diameter stands decreased, indicating that the resource is maturing (Rose and Meadows, 2016).

Despite the lack of pronounced negative effects to date, there are concerns that continued growth of export pellet demand might induce future effects. Increased demand for wood pellets in the SE US might be met through short-rotation tree plantations, thinning and harvest of planted and natural forests, or forest harvest residues, and each option has unique effects on wildlife habitat (Tarr et al., 2016). However woody biomass harvests for wood pellets in intensively managed pine forests of North Carolina had no effect on the winter bird community (Grodsky et al., 2016). Meeting increased demand out to 2050 for biomass from conventional forestry in North Carolina is projected to result in more total forest land compared to a baseline, business-as-usual scenario (Costanza et al., 2016).

Although some industry analysts expect the pellet market to continue to grow (Goetzl, 2015), recent EU market and policy developments may stall or reverse the growth in pellet exports (Dogwood Alliance, 2016). Either way, the total amount of wood that might ultimately be used for energy is small – largely because of its low value. Furthermore, in the future less of Europe's demand for pellets may be met by the SE US (Walker, 2016). A change in the demand for saw timber (such as the sharp decline in the US housing industry experienced starting in 2008) is probably the most important factor to consider, since it affects the availability of thinnings and residues for other uses. However, it is possible that Southeast timberland area may increase if there is a rise in demand for woody feedstock for pellets or if more plantations become established on marginal agricultural land (Abt et al., 2014).

5. Conclusions

Development and use of all energy pathways affect water and air quality or biodiversity. The challenge, therefore, is to develop means to address tradeoffs in the costs and benefits in energy choices while considering effects on both environmental and socioeconomic aspects of sustainability. Compared to the fossil fuel alternative, use of wood-based pellets provide a pathway to reduced GHG emissions while retaining land in forests that provide ecosystem services. However to retain or enhance benefits in the face of a potential growth in exports of wood-based pellets, it is essential to consistently monitor and assess forest conditions. Continued analysis of annual FIA data using the methods outlined in this manuscript provides a scientifically valid approach for ongoing assessment. Use of remotely sensed data to compare forest cover trends in SE US fuelsheds that have produced pellets since 2009 with other potential SE fuelsheds that have not yet produced pellets may also prove helpful in assessing long-term effects of the growing pellet industry.

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