Baseline Analysis of Virginia's Commercial Wood Supply

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Executive Summary

Context: The Center for Natural Resources Assessment and Decision Support (CeNRADS) in the College of Natural Resources and Environment at Virginia Tech has completed a baseline analysis of the commercial wood supply in the state of Virginia. This analysis is a point-in-time estimate of the commercial forest resources of Virginia, examined in conjunction with demand for those resources from wood-using facilities inside and adjacent to Virginia.

Forests in Virginia provide abundant economic and ecosystem benefits. Products and services from our forests are in high demand, and attention to the sustainability of our forest uses is warranted. Assessments of Virginia's forest resources are conducted periodically by federal (US Forest Service: Rose, 2013) and state agencies (VDOF, 2010). This analysis differs somewhat from these other assessments in the following ways:

1. The purpose of this wood supply assessment is to serve as a *baseline* for ongoing modeling efforts. This static analysis of conditions at a fixed point in time will be used in a simulation model that will make resource projections under different sets of assumptions, allowing us to compare outcomes of different scenarios.
2. The focus of this analysis is on the commercial wood supply in Virginia, and therefore does not address many of the other resource values and benefits coming from forests.
3. Because private forests dominate the wood supply in Virginia, this assessment is based on privately-owned forest resources.
4. Landowner objectives and biophysical conditions affect whether wood from a forest will be sold in a forest products market. Thus, geospatial datasets are analyzed to determine what proportion of existing forest inventory might be considered available to wood markets.
5. To the extent possible, this analysis uses multiple types of publicly-available data from nationally consistent sources so that the process provides a template that could be applied elsewhere in the US.

Approach: The assessment is based on compilation and analysis of large public-domain and proprietary datasets. Key among these are spatially-detailed land cover maps from the US Geological Survey (NLCD: National Land Cover Dataset) and forest inventory data from field measurements under the US Forest Service's Forest Inventory and Analysis (FIA) Program. Additional critical data on forest harvesting in Virginia comes from the Virginia Department of Forestry (VDOF). Most datasets reflect conditions at or near the year 2011.

Our focus for this assessment is on the privately-owned forest resource, as this segment provides over 95% of the commercial wood supply in the state. The assessment process estimated what proportion of overall forest inventory in the state can be considered available for commercial use. This availability analysis used VDOF harvest data to identify conditions (slope, population density, etc.) that corresponded with areas experiencing timber harvest over the last five years. After identifying available inventory, and growth and removals from that

inventory, we derived some indicators of the dynamics of the wood supply situation. Results were computed at the county level and summarized for five geographic regions in the state.

Results: Table ES-1 provides summary information for the entire state. The forest growth in the state exceeded removals by 13.3 million tons, indicating increasing wood inventory and forest carbon stocks. If carbon neutrality is indicated by increasing forest carbon stocks (as the current EPA framework for biogenic CO_2 emissions applies the concept), then Virginia's use of forest feedstocks for renewable energy production is considered carbon-neutral.

Table ES-1. State summary of inventory and metrics of wood supply dynamics.

Metric	Softwood Sawtimber	Softwood Pulpwood	Hardwood Sawtimber	Hardwood Pulpwood	Total
Private Inventory (k tons)	131,192	74,813	409,936	298,217	914,158
Available Private Inventory (k tons)	124,681	71,435	371,518	270,493	838,126
Growth on Available Inventory (k tons)	8,576	3,200	12,908	4,065	28,748
Removals/Harvest (k tons)	2,536	5,676	3,259	3,944	15,414
Growth:Removals ratio	3.4	0.6	4.0	1.0	1.9
Growth surplus (deficit); (k tons)	6,040	(2,476)	9,649	121	13,334

Forest products are often categorized into classes based on species groups (hardwood and softwood) and product size classes (pulpwood and sawtimber). Among primary product classes, there is considerable difference in growth and removals dynamics. The supply of softwood pulpwood is under tremendous pressure: harvests exceed growth by 2.5 million tons annually, or 77%. The hardwood pulpwood situation is only slightly better; hardwood pulpwood growth exceeds removals by only 3%. These imbalances among product classes have economic repercussions as pulpwood users face tight supplies.

Growth:removals ratios (G:R) are widely used as indicators of sustainability; ratios greater than 1.0 indicate more wood is grown annually than is used. The G:R of 1.9 for the state is a very positive sign. However, it has been shown that even in perfectly sustainable management regimes, temporary drops in the ratio can happen due to short-term management changes or extreme events (Prisley and Malmquist, 2002). Thus, the G:R of 0.6 for softwood pulpwood is an indicator that the situation for this product class warrants further attention.

Based on publicly available information, there is no indication of near-term relief of the softwood pulpwood supply; the forest age-class distribution for mixed and evergreen forests shows a decline of 6% in area of the primary commercial age classes (15 to 30 years old) in the next five years. Furthermore, there are indications that softwood pulpwood harvests have increased from the levels reported in the 2011 data on which this assessment was based.

Conclusions: This analysis, focused on an economically important sector of Virginia's forest resources, indicates a positive overall balance between forest growth and harvests. However, harvests of pulpwood-sized trees exceeds growth, indicating a constrained supply for specific product classes. While recent data show that there are reasons for concern about the near-term supply dynamics for these forest products, additional research is needed to determine the extent and what steps would be most effective to address these concerns. The point-in-time assessment reported here has limitations, due to the dynamic nature of forest growth and forest products markets, the interchangeable nature of some forest products (pulpwood and small sawtimber), and the spatial and temporal variability in forest inventory and demand. Thus, ongoing research is focused on applying a simulation model to make projections of future conditions.

Introduction

Virginia is home to abundant forest resources. Over 60% of Virginia's land area is forested (Rose, 2013); these forests play a significant role in Virginia's economy as a source of raw materials for industry and as a source of ecosystem services and environmental amenities that draw tourists and recreationists. The forestry sector in Virginia has a total impact of $23.4 billion in output and employs over 104,000 (Rephann, 2013). Virginia's forest landowners annually receive more than $276 million for sale of timber (VDOF, 2010).

Pressures on Virginia's forests are increasing. The primary cause of forest loss in Virginia is conversion of forest land to development (VDOF, 2010); this pressure is expected to lead to the loss of 0.74 to 1.28 million acres of forest in Virginia by 2060 (Wear 2011). Furthermore, woody biomass from the Commonwealth's forests is increasingly used for generation of renewable energy both domestically and internationally[1]. To ensure that Virginia's forests continue to thrive and provide their myriad benefits to society, it is critical to periodically assess the condition of the forest resource and the demands placed upon it.

Comprehensive assessments of Virginia's forests have been conducted by the Virginia Department of Forestry (VDOF, 2010) and the US Forest Service (Rose, 2013). This analysis differs somewhat from these other assessments in the following ways:

1. The purpose of this assessment is to serve as a *baseline* for ongoing modeling efforts. This static analysis of conditions at a fixed point in time will be used in a simulation model that will make resource projections under different sets of assumptions, which will allow us to compare outcomes of different scenarios.
2. The focus of this analysis is on the commercial wood supply in Virginia, and therefore does not address many of the other values and benefits coming from forests.
3. Because private forests dominate the wood supply situation in Virginia, this assessment is based on privately-owned forest resources.
4. Landowner objectives and biophysical conditions affect whether wood from a forest will enter a forest products market. Thus, geospatial datasets are analyzed here to determine what proportion of existing forest inventory might be considered available to wood markets.
5. To the extent possible, this analysis uses multiple types of publicly available data from nationally consistent sources so that the process provides a template that could be applied elsewhere in the US.

[1] In spring 2014, Virginia ranked third in the nation in total anticipated wood utilization for bioenergy projects, behind Georgia and Florida, according to the Wood Bioenergy US newsletter (Forisk, 2014).

Assessing the status and trends of commercial forest resources requires compilation and analysis of data on resources and wood markets. Key components include data on the geographic distribution of forests from land cover mapping programs, data on forest inventory, growth, and removals from field plots, and data on the use of harvested wood products by a wide variety of mills. Knowledge of the spatial distribution of wood supply and wood demand is critical, so a geographically-specific analysis approach is needed.

The Virginia Tech Center for Natural Resources Assessment and Decision Support has a mission to develop and apply analytical tools and sound scientific information to answer crucial questions about the sustainability of natural resources. With financial support from a wide array of stakeholders, and in-kind support from the Virginia Department of Forestry, the USDA Forest Service, and the Virginia Tech Department of Forest Resources and Environmental Conservation, the Center has completed a baseline analysis of Virginia's commercial forest resources. This report documents the methodology and summarizes the results of this analysis.

Methods & Data

Overview

This analysis of Virginia's commercial wood supply involved a quantitative and spatial analysis of publicly-available and proprietary data from a variety of sources. We attempted to use the most recent available data for each dataset, but nominally we consider our assessment as representing the year 2011, which is the base year for several key sources of data.

The focus of this assessment is on the contribution of private lands (e.g., individual landowners and corporations) to the wood supply in Virginia. While many state lands (especially State Forests) supply wood for production of forest products, the proportion from state lands is fairly small overall. Federal lands, including National Forests, National Parks, military installations, and Wildlife Refuges, may be reserved from commercial timber harvest by regulation, or may have management objectives that call for minimal harvesting. In either case, Federal and state lands contribute relatively little to wood markets in Virginia[2].

Forests are harvested for a wide variety of wood and non-wood products. Wood products harvested from forests may take several forms, but typically are categorized by tree species group and general product class. Tree species groups include hardwood (mostly deciduous, broadleaf trees such as oak, hickory, maple, or poplar) and softwood (mostly coniferous, evergreen trees such as pine, spruce, or fir). General product classes are sawtimber and

[2] In 2009, only about 3.5% of total roundwood output came from any public lands: federal, state, or municipal (Cooper et al., 2011).

pulpwood. Sawtimber refers to older, larger-diameter trees that are of sufficient size and quality to be sawn into lumber or peeled into sheets of veneer. Pulpwood refers to smaller diameter trees (or larger trees of poor form or quality) that are chipped in the woods or at a mill for use in pellet production, pulping (for paper or paperboard), or composite materials such as particleboard or oriented strand board (OSB). Because of their age, size, and quality, trees sold for sawtimber usually command a higher price per ton than trees sold for pulpwood.

This assessment uses four categories for wood quantities: softwood sawtimber, softwood pulpwood, hardwood sawtimber, and hardwood pulpwood. Other classes of products exist, such as woody biomass from harvesting residues which may be used as a feedstock for electricity production. However, existing databases that track wood from forests to mills use the four primary product classes, and data on biomass markets is not widely available. While forest products markets use a wide array of units to report quantities of wood bought and sold (tons, board feet, cords, and others), forest inventories commonly report volumes of wood in the forest as cubic feet. For this assessment, we report forest area estimates in acres and wood quantity estimates in tons. Cubic feet to tons conversions were developed for forest inventory data using FIA summaries that report the same quantities in both cubic feet and tons.

Regions within Virginia vary in the types of forest present, the terrain, the human population density, land ownership, and other factors relevant to a forest resources assessment. The US Forest Service FIA program identifies five survey units within Virginia which we have adopted for reporting purposes. They are: the Coastal Plain, Southern Piedmont, Northern Piedmont, Northern Mountains, and Southern Mountains (Figure 1). The forests of the Coastal Plain and Piedmont are the most significant producers of wood products in the state. They have substantial areas of fast-growing pine plantation interspersed with upland and bottomland hardwoods. Their proximity to ports and interstate highways make them an attractive location of wood-based industries. The Northern Piedmont reaches from Richmond to Washington, DC, and includes some of the most densely populated portions of the state. Proximity to densely populated areas has been shown to correspond with lower levels of timber production (Barlow et al., 1998; Wear et al., 1999; Butler et al., 2010). The Northern Mountains region contains large portions of the George Washington and Jefferson National Forest as well as the largely agricultural lands of the Shenandoah Valley. Hence, it is generally lower in commercially productive forests than the other regions. Finally, the Southern Mountains region of the state contains some of the most complex terrain and the most inaccessible (by road) areas in Virginia. Forest area in this region is greater than the Northern Mountains and Northern Piedmont but less than the Southern Piedmont and Coastal Plain, and there are fewer wood production facilities in the region.

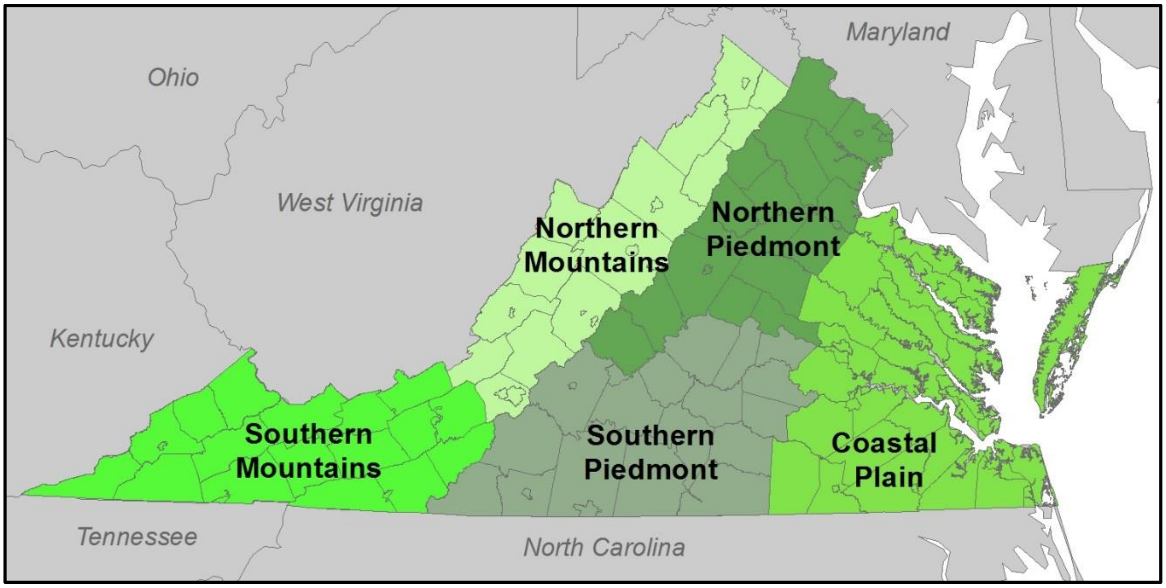


Figure 1. Map of the five FIA survey units within Virginia used as regions for reporting in this assessment.

Because there is an integral connection between forests, renewable energy, and climate change, it is important to be able to express forest dynamics in terms of quantities of stored CO_2 and to evaluate forest dynamics in light of the carbon neutrality of bioenergy from forest feedstock. Using tons as the primary unit for inventory makes this easier[3]. Thus, wood growth and removal is directly comparable to the increase and decrease of forest carbon stocks for the assessment of carbon dynamics. An accounting framework (currently under review at the US EPA) for dealing with CO_2 emissions from bioenergy calls for calculation of growth and removals of woody biomass from "working forests" (defined in our assessment as the "available" wood supply) in the determination of carbon neutrality of emissions from forest feedstocks.

The foundation of this assessment involves merging detailed information on the spatial distribution of forests from remotely sensed products (land cover maps) with the highly detailed tree-level information from forest inventory field plots. The field plots represent a relatively sparse sample of forest locations, but contain a great deal of detailed information about the tree species and sizes and forest conditions. These plots are measured as part of the US Forest Service's Forest Inventory and Analysis (FIA) program, conducted in Virginia in cooperation with the Virginia Department of Forestry. The land cover data (from US Geological Survey) contain only the broadest classification of forest types, yet have detailed information about spatial

[3] A useful rule of thumb is that 1 ton (green weight) of forest biomass contains about 0.5 tons (dry weight) of wood fiber, which contains about 50% elemental carbon by weight. So one ton of wood in the forest will contain 0.25 tons of carbon (Heath, 2013). One ton of stored carbon represents about 3.67 tons of CO_2.

distribution of forest. In this assessment, these are analyzed with other spatial data layers and results summarized at a county level.

Data sources and descriptions are listed in Table 1. These data are combined in a series of quantitative and spatial operations as described in the following sections to arrive at estimates of forest inventory (acres and tons of wood by forest type and wood product type), annual growth, and annual removals (harvests), for private lands by county. From these baseline estimates, other indicators such as growth-to-removals ratios are computed as indicators of the sustainability of forest resources. The next sections detail the processes involved in (1) determining average forest volume per acre and growth per acre by forest type and region within the state, (2) estimating the proportion of overall forest inventory that would actually be available (at some point in time) for commercial harvest, (3) estimating forest growth on available private forest lands, (4) incorporating information about wood demand and utilization by product type and location within the state, and (5) integrating all of the above to develop indicators of the sustainability of wood supply.

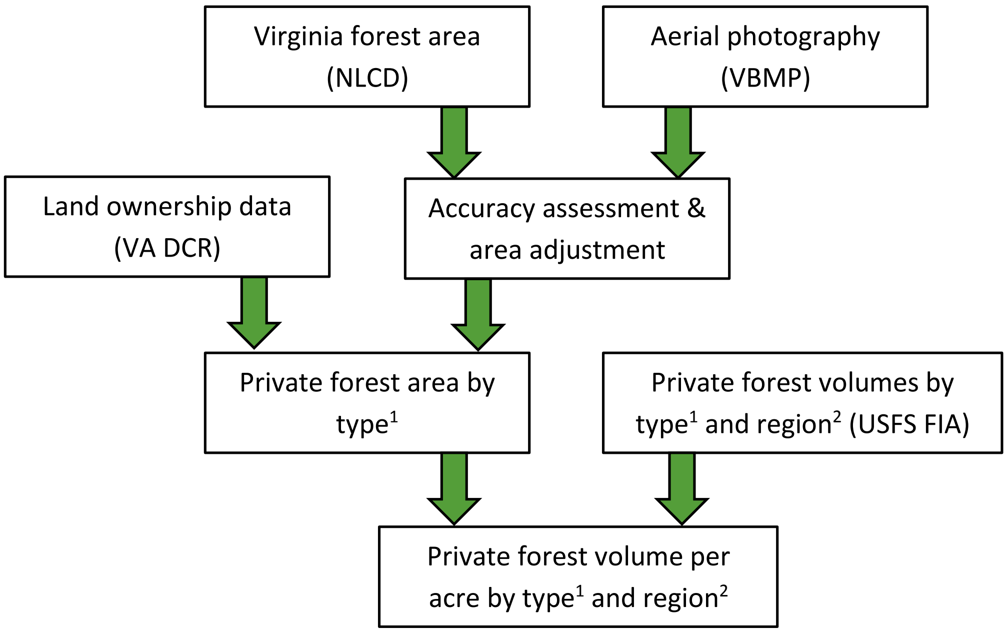
Table 1. Descriptions and sources of data used in the assessment.

Data Theme	Purpose	Source	Notes
Land cover	Shows spatial distribution of land cover types such as forest, agriculture, and urban areas	US Geological Survey National Land Cover Dataset (NLCD): http://www.mrlc.gov/nlcd2011.php	Data for 2011; 30m grid cell resolution
Forest inventory	Field data from forest measurements are aggregated to produce average quantities of wood volume (cubic feet) by forest types and product classes (e.g., pulpwood, sawtimber).	USDA Forest Service Forest Inventory and Analysis (FIA) program: http://www.fia.fs.fed.us/	Data were compiled from the FIA "Evalidator" tool for 2012.
Land ownership	Identifies land areas owned by federal and state government agencies as well as conservation easements and other protected lands	Virginia Department of Conservation and Recreation (DCR) Conservation Lands Database: http://www.dcr.virginia.gov/land_conservation/tools02a.shtml	Contains polygons of land ownership boundaries
Aerial photography	Used for validation of NLCD land cover data	Virginia Tech Geospatial Archive Resource and Data Exchange Network: http://garden.gis.vt.edu/	Imagery from Virginia Base Map Photography program (VBMP), various years.
Terrain	Digital elevation models (DEM) portray land surface terrain, used for deriving slope steepness for forest availability assessment.	US Geological Survey National Elevation Dataset (NED): http://ned.usgs.gov/	Data in 30m grid cells
Population	Demographic data by US Census Block used to compute population density for forest availability assessment	US Census Bureau: https://www.census.gov/geo/maps-data/data/tiger.html	Census block polygon data from 2010 census
Roads	Used for forest availability assessment and to determine	Streetmap Premium (proprietary data) licensed from ESRI: http://www.esri.com/data/streetmap	Road network data with rich attributes (speed limits, weight restrictions, etc.)

Data Theme	Purpose	Source	Notes
	areas within specified road miles of a wood-using facility		
Soils	Used to assess whether forest harvest was influenced by presence of poorly drained soils	USDA Natural Resources Conservation Service gridded Soil Survey Geographic Database (gSSURGO): http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_053628	Soil survey data summarized and combined from county level to nationwide 30m grid cell database
Wetlands	Used to assess whether forest harvest was influenced by presence or proximity of wetlands	US Fish and Wildlife Service National Wetlands Inventory: http://www.fws.gov/Wetlands/NWI/index.html	Polygon delineations of wetlands
Forest harvest locations	Used to characterize areas suitable for forest harvest for forest availability assessment	Virginia Department of Forestry harvest notification dataset: http://www.dof.virginia.gov/	Point locations for timber harvests, 2009 to 2014, as reported under Virginia's harvest notification regulations
Virginia harvest volume	Used to estimate annual harvest by product class and county	Virginia Department of Forestry harvest volume and value: http://www.dof.virginia.gov/harvest/data/index.htm	Data from 2011 were used for comparison with USFS TPO.
Wood mill demand by county	Used to identify spatial regions from which timber is harvested to meet mill demands	US Forest Service Timber Product Output (TPO) program: http://srsfia2.fs.fed.us/php/tpo_2009/tpo_rpa_int1.php	TPO data (2011; Bentley et al. 2014) include county-level summaries of roundwood production based on mill survey responses.
Wood mill locations and demand	Identifies levels of demand (wood usage) associated with mills and accurate mill locations	Proprietary data from University of Georgia Wood Demand Research Program (WDRP): http://www.ugacfb.com/research/wdrp/	WDRP data (2013) contains more accurate locations for wood processing facilities than the TPO data, and were used for mapping purposes.

Part 1: Forest inventory volumes per acre

The goal of this portion of the analysis was to obtain estimates of private forest volumes per acre, for each of the NLCD forest classes, for each of the FIA regions. The process followed the flow depicted in Figure 2.



[1] Forest types in NLCD data include deciduous, evergreen, mixed, and woody wetlands. In addition, areas designated as shrub by NLCD are assumed to be regenerating forests.
[2] Regions are FIA survey units as shown in Figure 1.

Figure 2. Process for determining forest inventory volumes per acre.

First, an accuracy assessment was conducted for the NLCD land cover map, since no such accuracy evaluation has yet been published for this dataset, and it is known that misclassifications in land cover maps can have an impact on area estimates (Czaplewski, 1992). The accuracy assessment involved checking the land cover classes assigned by NLCD against the land cover is observed on aerial photographs, using 1,000 randomly located check points across the state. Using error rates from the accuracy assessment, acreage adjustment factors each land cover class are calculated.

Next, state and federal lands were excluded from the analysis using the Virginia Department of Conservation and Recreation's Conservation Lands GIS layer. Lands indicated as having a conservation easement are included in available private lands; most conservation easements do not preclude timber harvest. The remaining forest lands (private forests only) were summarized by county and forest type.

The USFS FIA web tool "Evalidator" was then used to extract information from the FIA database for Virginia, using data from 2012[4] on private lands. Due to the nature of the FIA sampling process, area and volume estimates are unreliable at the individual county level, but provide sound estimates when aggregated to the FIA regions. Data extracted from the FIA database included inventory volume and net growth, by forest type (more detailed classes that were aggregated to the NLCD classes), by region, by product class (sawtimber/pulpwood, hardwood/softwood). These resulting regional FIA volume (and growth) totals for private lands were divided by the private forest areas from NLCD to obtain an estimate of volume per acre for forest class/region combinations.

Part 2: Available forest inventory

The goal of this portion of the analysis was to obtain estimates of the portion of total forest inventory that might be expected to be available for harvest under current physical and economic conditions. It is widely recognized that physical and socioeconomic factors constrain timber harvesting such that not all volume reported in inventory summaries is likely to reach a forest products market. Physical factors such as slope, soil conditions, and distance to roads, and socioeconomic factors such as land ownership, population density, and distance to markets are commonly-reported availability constraints (Braff, 2014). Our analysis used actual harvest notification data from the Virginia Department of Forestry and GIS layers representing potential constraint factors to assess which variables were associated with harvesting activity. The process of assessing available forest inventory is depicted in Figure 3.

Harvest locations from the VDOF harvest notifications dataset included a geographic coordinate for a point location where harvests occurred since 2009 (to the beginning of this analysis in early 2014). Over 25,000 harvests are recorded in this dataset, including information on whether harvests were clearcut, partial harvest, or biomass removal. Also included was an indicator of whether the harvest was silvicultural (i.e., a part of forest management with expectation that the area would be regenerated to forest). This dataset provided an excellent spatial reference for where forest harvests actually have occurred in Virginia over this five-year period.

We then selected GIS layers to develop a spatial model of harvest probability, based on current scientific literature about factors affecting forest harvest likelihood. Because the VDOF harvest notification dataset contained points representing varying harvest areas (which averaged 45 acres in size), we computed neighborhood averages for spatial datasets such that grid cell values represented the average conditions within a 45-acre circular area around each grid cell. These layers included:

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[4] The 2012 FIA dataset represents the most recent available for Virginia at the time this assessment began. This dataset includes plots measured in 2008, 2009, 2010, 2011, and 2012.

- Soils: values representing the average percent of poorly drained or very poorly drained soils within a 45-acre circular area around each point,
- Wetlands: values representing the percent of wetlands (as delineated by NWI) within a 45-acre circular area around each point,
- Slope: values representing the average percent terrain slope within a 45-acre circular area around each point,
- Road distance: values representing the average distance (in meters) to the nearest road, computed for a 45-acre circular area around each point,
- Population density: the population density (in people per square mile) for the census block in which a point lies.

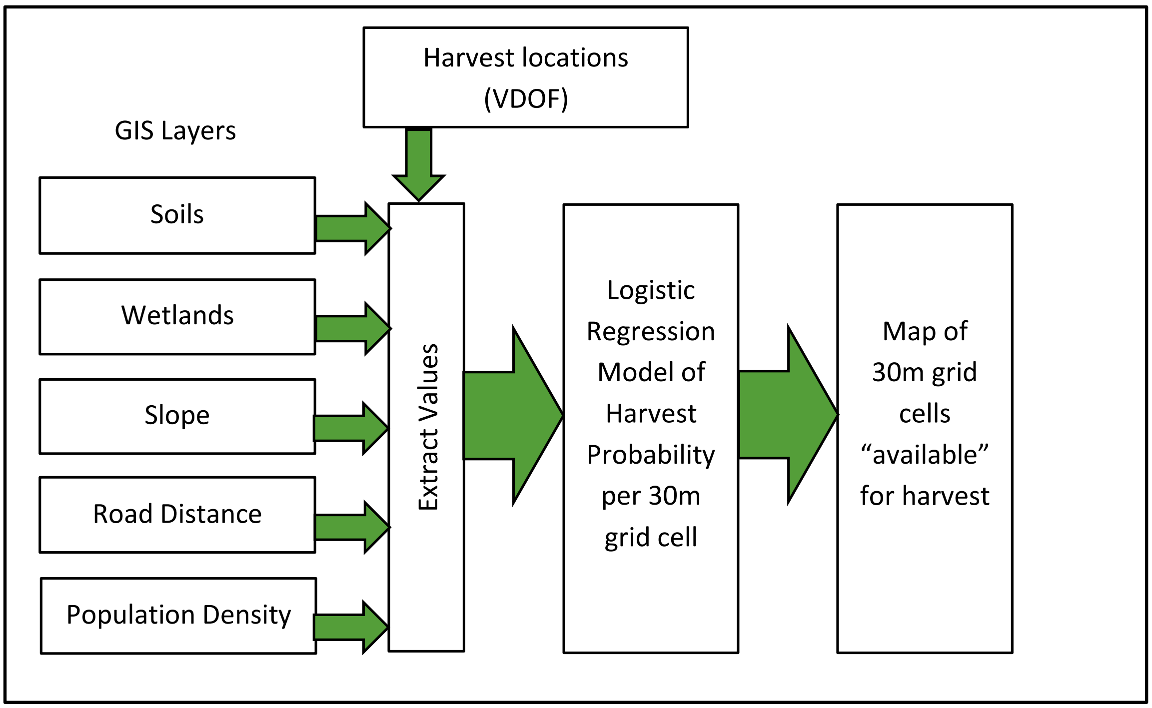

Figure 3. Process for determining available forest inventory.

Values from the GIS layers were extracted for each harvest location. The data were used to conduct resource selection analysis, in which we determine whether harvests occur across the landscape in the same proportion as some underlying variable. If they do, there is no evidence that the variable influences the distribution of harvest. For example, in Figure 4, the forest area distribution by slope class in Virginia is shown (the first bar in each group). If harvests occurred without any influence by slope class, we would see a similar distribution of harvest area (the second bar in each group). However, the distribution by slope class of harvest areas reported in the harvest notification data is quite different: far more acres are harvested in low slope classes than would be expected if slope had no influence (third bar in each group). For example, while about 25% of Virginia's forest area is on land with less than 7.5% slopes, half of the reported harvest area occurs on these lands. Thus, there is strong evidence that slope affects harvest distribution: low slopes are harvested much more frequently than steep slopes.

In a similar way, all variables were examined for evidence of resource selection. Only slope, population density, and distance to roads exhibited evidence that these variables affect the likelihood of harvest[5]. Thus, these three variables were included in a logistic regression analysis in which we compute the probability of observing a timber harvest given conditions of slope, population density, and road proximity.

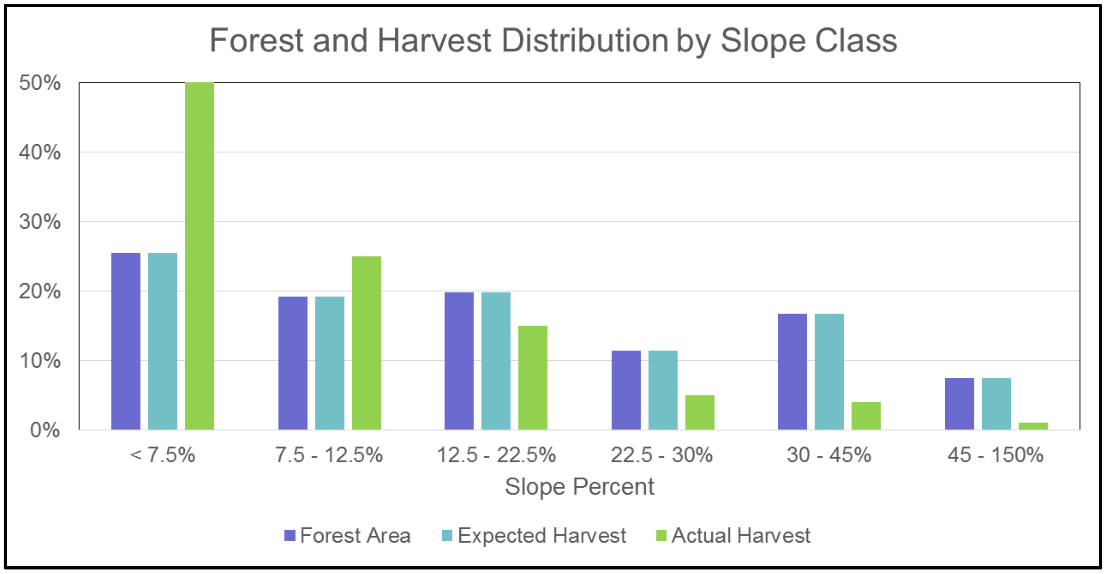

Figure 4. Example of resource selection analysis examining distribution of forest harvests across slope classes. This chart indicates that actual harvests occurred far more frequently in lower slope classes than would have been expected if harvests occurred proportionally to land area across slope classes.

The result of the logistic regression analysis of availability is an equation that predicts a probability of harvest for each 30m grid cell in a map. Then, a threshold is selected to represent the most likely locations as which a timber harvest could occur, based on the relevant variables. For this analysis, we chose a predicted probability level of 0.2. This represents a cutoff value below which we would consider forests as unavailable for harvest. Checking against the harvest notification data, about 3% of harvested areas were in locations modeled as unavailable. Using this threshold we were able to develop a map (using 30m grid cells) of available versus unavailable private forest area. Summarizing by county and forest type, we obtained county-level estimates of available private forest area for each forest type. Multiplying these areas by volumes per acre determined in part 1, we obtained estimates of available forest inventory for each county.

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[5] Resource selection analysis does not indicate that soil drainage and presence of wetlands are irrelevant to forest harvest. They can limit the timing (season) and conditions under which harvests can take place. However, over a long period of time (such as the five-year period for which we have harvest data), they do not *preclude* harvest, so they do not show up as statistically significant factors in overall availability.

Part 3: Growth on available forest

Once available forest inventory estimates are obtained, we follow a similar process to estimate the amount of annual net growth[6] occurring on the portion of the forest deemed to be available. The reason for estimating growth on just this portion of the forest is that most of removals are expected to be derived from available forest. Thus, if growth and removals are in balance on the available portion of the forest (or if growth exceeds removals), there is a strong indication that current harvest levels are sustainable indefinitely.

The growth metric of interest is "net growth". FIA defines net growth as the total volume increment (change) on all remeasured trees minus any volume lost due to mortality. Thus, when events such as insects, disease, fire, or weather cause mortality in forests, large volume losses can offset growth and result in negative net growth. If we assume removals for commercial wood products focus on live trees, it is appropriate to compare *net* growth with the removals.

Using the estimates of net growth per acre on private forests developed in a similar fashion to the volumes estimates from Part 1, and the distribution of available acres from Part 2, we obtain growth on available forest by region and product class.

Part 4: Harvest removals

Estimating annual harvest is the most challenging part of a wood supply assessment. Much of the information about wood products trade is deemed confidential by companies, and shared with surveys voluntarily only under strict confidentiality agreements. Thus, it is useful to obtain data from multiple sources to assess the variability of estimates. Four datasets have been consulted to provide the data used in this assessment.

First, estimates of removals from FIA plot data are based on observations of plots where trees have been harvested. Because harvest is a relatively rare event (only 1.6% of Virginia's forest area is harvested annually), FIA plot removals represent a very sparse sample and estimates developed from them have high variability. Furthermore, because it takes five or more years to collect a complete sample of Virginia's FIA plots, the estimates developed from them represent a five-year moving average. However, FIA plot removals are useful as a check against other data sources.

The second dataset used in this assessment is from the Timber Products Output (TPO) portion of the US Forest Service FIA program (Cooper et al., 2011). This national program conducts periodic surveys of wood-using facilities to develop estimates of roundwood production by different product categories and source counties. The TPO data used in this assessment are

[6] Growth estimates from FIA are based on inventory plots remeasured between 2008 and 2012.

from 2011. We used the county-level TPO reports, aggregating the more detailed TPO products into the four product classes used in this assessment, converting the reported cubic foot production to tons for compatibility.

The third dataset comes from the Virginia Department of Forestry's annual report of harvest volumes and values. We used data from 2011 to serve as a comparison with the TPO data. These data are derived from tax reporting and are tied to the fiscal year; thus, they represent the time period from July 2011 to June 2012.

The fourth dataset is a proprietary database of mill locations and roundwood consumption distributed by the University of Georgia's Wood Demand Research Program (WDRP). This dataset contains estimates of roundwood consumption by mill, but cannot specify the source area for the wood. In order to estimate source counties for this consumption, we applied estimates of the proportion of wood consumption that different mill classes purchase from different radii (distances in miles) from the mill. Applying these proportions to mills within and near Virginia allows us to estimate the roundwood consumption originating from Virginia counties, by product, depending on the type of mill.

Part 5: Integrating data for supply metrics

At this point in the process, we have estimates (for each county) of (1) the available private forest inventory, (2) the annual net growth on available private forest land, and (3) the annual harvest removals of wood from available private forest land. Values are reported for the four product classes: softwood sawtimber, softwood pulpwood, hardwood sawtimber, and hardwood pulpwood. From these estimates, we derive a variety of metrics that provide insight into the supply dynamics of Virginia's forests for wood production.

The first metric of interest is a **growth-removals ratio** (G:R; sometimes called the growth-drain ratio). This is simply the annual net growth divided by the annual removals. It can be computed for each product class for any geographic region of interest: county, region, or state. Because of the variability of the sample data used to derive these estimates, county-level growth-removals estimates are not reliable. However, displaying G:R estimates by county in a map can highlight relative differences. The G:R is intuitively appealing as a sustainability metric. When growth exceeds removals (ratio is greater than 1), it indicates that the forest inventory should be increasing: the forest is growing more than is removed by harvest, even after taking mortality into consideration. Because it is a ratio, however, areas with low removals (due to limited markets for wood or other reasons) may have very high growth-removals ratios, even if the amount of net growth is lower than many other areas. Furthermore, it has been shown (Prisley and Malmquist, 2002) that even in perfectly regulated forests (equal acres in each age class; a model of sustainable management), changes in management such as a reduction in the effective rotation age can lead to years or decades of G:R ratios below 1.0. An example of the dynamic nature of forest G:R comes from South Carolina, where shortly after Hurricane Hugo caused extensive damage to the forest resource in 1989, G:R went from 0.722 in 1993 (Connor, 1998) to 1.478 in 2006 (Conner et al., 2009), even while removals increased by 12%.

The next metric of interest is the amount of **surplus growth**; the annual net growth minus the annual removals. This follows the same idea as the growth-removals ratio, but is expressed in a quantity of wood: the amount by which growth exceeds removals. Thus, whenever this number is greater than zero, it indicates the forest inventory should be increasing. When surplus is negative, it indicates harvests exceed growth and signals that inventory can be expected to decline. Note that this may be due not simply to high levels of harvesting, but to any circumstances that result in high natural mortality (and subsequently low or negative net growth), such as insects, fire, disease, or weather damage.

It is important to note that all of these metrics are derived from static, point-in-time estimates of inventory, growth, and removals. Because forests take decades to reach commercial ages, and because forest regeneration rates vary from year to year, the picture derived from a point-in-time estimate may not reflect the conditions to be expected even in the near future. For example, if large areas of young forest are about to reach harvestable ages, a deficit could quickly turn into a surplus. If the forest age class distribution shows fewer acres in near-merchantable ages, then the situation may be less sustainable than current estimates would indicate.

Results

Total and available forest area and inventory

The total forest inventory on Virginia's private forest lands is summarized by product and region in Table 2. Of about 900 million tons of wood in Virginia's private forests, 22.5% is softwood and 77.5% is hardwood. About 60% of total volume is sawtimber.

Table 2. Total private forest inventory (thousand tons) by region and product class.

	Thousand tons				
Region	Softwood Sawtimber	Softwood Pulpwood	Hardwood Sawtimber	Hardwood Pulpwood	Total
Coastal Plain	65,619	30,245	78,543	61,402	235,809
Southern Piedmont	35,625	26,480	88,047	66,818	216,971
Northern Piedmont	13,342	10,429	95,311	56,468	175,551
Northern Mountains	6,627	3,670	52,686	43,840	106,823
Southern Mountains	9,978	3,988	95,350	69,689	179,005
State Total	**131,192**	**74,813**	**409,936**	**298,217**	**914,158**

When we assess forest land area across the state using adjusted NLCD data, we obtain a forest area estimate of 16.4 million acres (which is within 3% of the FIA sample forest area estimate). Of the total forest area, 15% is public and 85% is private (Table 3). Of the private forest area, 92% is considered available based on our model.

Table 3. Forest area (thousand acres) in Virginia by region, ownership, and availability class.

Region	Thousand acres of forest				
	Public Available	Public Unavailable	Private Available	Private Unavailable	Total
Coastal Plain	224	83	3,367	149	3,822
Southern Piedmont	123	22	3,530	113	3,788
Northern Piedmont	206	112	2,213	173	2,704
Northern Mountains	641	572	1,491	208	2,912
Southern Mountains	308	230	2,178	474	3,189
State Total	**1,502**	**1,019**	**12,778**	**1,117**	**16,416**

When we apply the average FIA volumes per acre by forest type and region to the available acres in Table 3, we obtain an estimate of available forest inventory (Table 4, Figure A-1). Over half of the available inventory is in the Coastal Plain and Southern Piedmont regions.

Table 4. Available private forest inventory (thousand tons) in Virginia's private forests, by region and product class.

Region	Thousand tons				
	Softwood Sawtimber	Softwood Pulpwood	Hardwood Sawtimber	Hardwood Pulpwood	Total
Coastal Plain	62,978	29,037	75,124	58,759	225,898
Southern Piedmont	34,789	25,876	85,112	64,654	210,431
Northern Piedmont	12,533	9,821	87,964	52,159	162,476
Northern Mountains	5,928	3,306	45,705	38,106	93,046
Southern Mountains	8,454	3,395	77,613	56,814	146,276
State Total	**124,681**	**71,435**	**371,518**	**270,493**	**838,126**

Growth and removals

Using average annual rates of net growth per acre from FIA, applied to available private forest acres, we obtain estimates of net forest growth by region and product class for available private land (Table 5, Figure A-2). Annual growth on available forest for the state is 28.75 million tons. This represents an annual net increment of about 3.4% of available inventory. Annual softwood growth is about 6% of softwood inventory, and annual hardwood growth is about 2.6% of hardwood inventory. We therefore see higher overall annual growth rates in the softwood-rich Coastal Plain and Southern Piedmont (4%) and lower growth rates (about 2.8%) elsewhere.

Table 5. Average annual net growth (thousand tons, 2008-2012) on available private forestland in Virginia, by region and product class.

	Thousand tons				
Region	Softwood Sawtimber	Softwood Pulpwood	Hardwood Sawtimber	Hardwood Pulpwood	Total
Coastal Plain	4,363	1,499	2,338	1,101	9,301
Southern Piedmont	2,746	1,215	3,137	1,271	8,369
Northern Piedmont	734	439	2,817	503	4,494
Northern Mountains	244	16	1,740	519	2,519
Southern Mountains	488	31	2,876	671	4,066
State Total	**8,576**	**3,200**	**12,908**	**4,065**	**28,748**

Table 6 summarizes the state total removals by product class according to the four datasets evaluated in this assessment. The time represented by these data sources varies. Estimates from FIA removals reflect an average for the period 2008 to 2012 (the interval during which plots were measured for these estimates). TPO data reflect responses from a survey for 2011, and the VDOF data reflect harvest volumes from tax receipts for a fiscal year (July 2011 to June 2012).

Table 6. Virginia forest harvests (thousand tons) by product class and data source.

	Thousand tons				
Data Source	Softwood Sawtimber	Softwood Pulpwood	Hardwood Sawtimber	Hardwood Pulpwood	Total
FIA 2012 Removals- All	3,798	3,432	5,106	3,971	16,308
FIA 2012 Private Rem.	3,385	3,216	4,467	3,179	14,247
USFS 2011 TPO	2,614	5,851	3,360	4,066	15,891
VDOF 2011 Data	3,189	5,609	5,076	2,967	16,841
WDRP 2013	2,275	4,658	1,356	3,644	11,933

The WDRP data are more recent, from the third quarter of 2013. For the WDRP data, we estimated the proportion of total mill consumption that came from Virginia forests, based on mill location and assumptions about wood sourcing by distance. Table 7 portrays the estimates of Virginia roundwood harvest going to mills within Virginia and outside Virginia according to our distance-based allocation of sourcing. These figures suggest that 87% of roundwood harvested in Virginia was retained for processing at Virginia mills[7].

Table 7. Virginia forest harvest apportioned to mills inside and outside Virginia, based on WDRP data.

	Thousand tons				
	Softwood Sawtimber	Softwood Pulpwood	Hardwood Sawtimber	Hardwood Pulpwood	Total
Used by Virginia mills	1,898	4,049	1,091	3,396	10,433
Used by other mills	377	609	265	248	1,500
Total	2,275	4,658	1,356	3,644	11,933

FIA data allow for reporting of removals from all forests (which would be consistent with other sources of removals data) or for private lands alone. We report both in Table 6. FIA data show approximately 13% of total removals coming from public lands, but these sample estimates have high variability (sampling errors over 10%). No data are available for TPO or VDOF on what portion of the 2011 harvests came from private lands. However, a prior TPO report (2009) indicated that 3.5% of reported roundwood output (2% of softwood and 5% of hardwood) originated on public lands.

We chose to use the TPO dataset for county estimates, as it seemed to correspond fairly well with both FIA removals and VDOF harvest estimates. Furthermore, we try when possible to use nationally-available, public-domain datasets so that the analysis process can be replicated in other states. Note, however, that TPO tends to overstate pulpwood harvest relative to FIA and VDOF, and understate sawtimber harvest. It also understates overall harvest by 6% compared to VDOF estimates. In order to acknowledge that some of the harvest volume reported by TPO includes wood harvested from public lands and from areas deemed unavailable in this assessment, we deducted 3% of the reported TPO harvest quantities for use in comparison with growth on available and available private inventory volumes (Table 8).

The Coastal Plain and Southern Piedmont are Virginia's woodbasket: they contain just over half of the state's inventory yet contribute nearly 3/4ths of the harvests within the state (Figure A-3). About 53% of harvests are softwood, and about 70% of the softwood harvest is pulpwood. Combining both hardwood and softwood, pulpwood harvests account for more than 60% of harvests according to the TPO data (VDOF data shows pulpwood accounts for about 50% of harvests, and FIA removals indicates pulpwood harvests make up 45% of the total).

[7] A report on 2009 TPO (Cooper et al., 2011) indicates retention of only 80% of roundwood harvests for processing in Virginia.

Table 8. Estimated Virginia harvest (thousand tons) on private lands by region and product class. TPO 2011 harvest data were used with a 3% deduction for volumes assumed to be harvested from public lands or lands deemed unavailable.

	Thousand tons				
Region	**Softwood Sawtimber**	**Softwood Pulpwood**	**Hardwood Sawtimber**	**Hardwood Pulpwood**	**Total**
Coastal Plain	1,084	2,927	559	947	5,517
Southern Piedmont	1,012	2,049	978	1,719	5,757
Northern Piedmont	315	547	423	437	1,722
Northern Mountains	10	111	699	408	1,228
Southern Mountains	114	43	600	434	1,191
State Total	**2,536**	**5,676**	**3,259**	**3,944**	**15,414**

Supply metrics

Based on the data reported in tables 4, 5, and 8, we compute wood supply metrics. The first of these is the growth-removals ratio (Table 9), for which numbers greater than 1.0 indicate removals less than growth and an increasing inventory. The Coastal Plain and Southern Piedmont have the lowest growth-removals ratios in the state. While the state overall has a favorable growth-removals ratio (with growth approximately twice the level of removals), there is a dramatic difference when looking at pulpwood versus sawtimber (Figure 5, Figure A-4). While sawtimber growth dramatically exceeds harvest, softwood pulpwood growth is only 60% of what is currently being harvested, and hardwood pulpwood growth is just barely in balance with removals. Combining softwood and hardwood across the state, the growth-removals ratio for sawtimber is 3.6 and for pulpwood is 0.7[8].

Next, we can examine the computed surplus growth by product and region (Table 10, Figure A-5). Statewide, forests grow 13.3 million more tons of wood annually than are harvested. However, as noted with the growth-removals ratio, the situation with pulpwood products is different. We are harvesting about 2.5 million more tons of softwood pulpwood annually than is being grown, and hardwood pulpwood growth exceeds harvest by only a few percent.

[8] These estimates change only somewhat using the VDOF harvest data for removals estimates, which indicates an overall harvest level 6% higher than TPO (Table 6). The growth-removals ratio using VDOF harvest data for sawtimber statewide is 2.6 and for pulpwood is 0.85.

Table 9. Growth-removals ratios for available private forest land in Virginia, by region and product class.

Region	Softwood Sawtimber	Softwood Pulpwood	Hardwood Sawtimber	Hardwood Pulpwood	Total
Coastal Plain	4.0	0.5	4.2	1.2	1.7
Southern Piedmont	2.7	0.6	3.2	0.7	1.5
Northern Piedmont	2.3	0.8	6.7	1.2	2.6
Northern Mountains	24.1	0.1	2.5	1.3	2.1
Southern Mountains	4.3	0.7	4.8	1.5	3.4
State Total	**3.4**	**0.6**	**4.0**	**1.0**	**1.9**

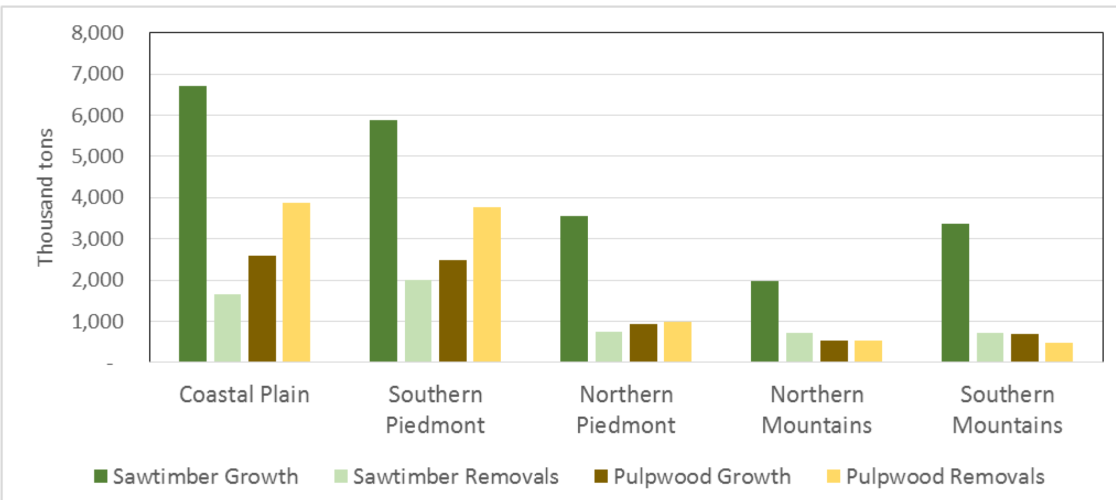

Figure 5. Sawtimber and pulpwood growth and removals by region.

Table 10. Surplus growth (annual net growth minus annual removals) by product class and region.

	Thousand tons				
Region	Softwood Sawtimber	Softwood Pulpwood	Hardwood Sawtimber	Hardwood Pulpwood	Total
Coastal Plain	3,280	(1,428)	1,778	154	3,784
Southern Piedmont	1,734	(834)	2,159	(447)	2,612
Northern Piedmont	419	(107)	2,394	66	2,772
Northern Mountains	234	(95)	1,041	111	1,291
Southern Mountains	373	(12)	2,276	237	2,875
State Total	**6,040**	**(2,476)**	**9,649**	**121**	**13,334**

The inventory and sustainability metrics from Tables 2, 4, 5, 8, 9, and 10 for the state of Virginia are summarized in Table 11.

Table 11. State summary of inventory and sustainability metrics.

Metric	Softwood Sawtimber	Softwood Pulpwood	Hardwood Sawtimber	Hardwood Pulpwood	Total
Private Inventory (k tons)	131,192	74,813	409,936	298,217	914,158
Available Private Inventory (k tons)	124,681	71,435	371,518	270,493	838,126
Growth on Available Inventory (k tons)	8,576	3,200	12,908	4,065	28,748
Removals/Harvest (from TPO; k tons)	2,536	5,676	3,259	3,944	15,414
Growth to Removals ratio	3.4	0.6	4.0	1.0	1.9
Surplus growth (k tons)	6,040	(2,476)	9,649	121	13,334

Discussion

Virginia's forests are growing 13.3 million tons more wood than is being harvested annually. The growth-to-removals ratio for the private available forest is 1.9, indicative of a forest resource that is increasing (in volume terms) annually. Positive increases in forest carbon stocks have long been viewed as a key indicator of the carbon neutrality of bioenergy (Miner et al. 2014). In the carbon terms relevant to renewable energy and carbon neutrality, the carbon stocks in Virginia's forests are increasing annually more than enough to compensate for wood used for energy production. This is important, as the recently-released EPA framework for biogenic emissions (EPA, 2014) indicates that emissions factors will be computed using inventory information on growth and removals[9]. Thus, while it is too early to know how EPA will develop rules for determining carbon neutrality of biogenic CO2 emissions for regulatory purposes, the current accounting framework indicates that Virginia's bioenergy emissions from forest roundwood feedstocks would be considered carbon neutral.

However, this assessment of Virginia's forests highlights some concerns about the relative availability of components of the resource for wood production. Metrics such as the growth-

[9] The EPA draft framework for biogenic emissions suggests that accounting for emissions from combustion of harvest *residues* will result in a negative (<0) biogenic accounting factor (BAF), indicating that the use of this feedstock will "more than fully counterbalance the direct biogenic CO_2 emissions at the stationary source". For *roundwood* harvested for energy production, the BAF will be negative when growth exceeds removals in the feedstock source region (EPA, 2014).

removals ratio indicate that while the overall forest is growing more wood annually than is being harvested, there is substantial imbalance when looking at product classes. The sawtimber inventory continues to increase, while pulpwood is being harvested at or beyond the rate at which it is growing. This imbalance between pulpwood and sawtimber product classes has economic consequences. While small sawtimber can substitute for pulpwood, it usually commands a higher price and pulpwood users could see substantially increased costs due to this limited supply. Regionally, the Coastal Plain and Southern Piedmont of Virginia are under the greatest pressure.

There are limits to the type of static, point-in-time assessment reported here. Because forests are long-lived, dynamic, and renewable, a "snapshot" of the forest condition based on recent inventory results can mislead. The inventory plot data used in this assessment were collected during the period 2008 to 2012, and estimates of growth and removals rely on previous measurements of those plots, measurements which date back to 2002. Likewise, data on harvest levels vary from source to source and over time (Table 6).

It is important, therefore, to consider what may be changing in the near future with respect to the resource and our utilization of it. To anticipate what changes are likely, we can examine the age-class distribution of the forest and look for evidence of trends in utilization.

From the same FIA data used in this assessment, we can construct age-class distributions of the forest, showing acres of forest of different types in different age classes. Figures 6, 7, and 8 illustrate the age-class distribution of Virginia's evergreen, mixed, and deciduous forests on private lands, respectively. Evergreen forests are the source of the majority of softwood, and are more frequently regenerated by clearcut harvesting and replanting, resulting in cohorts of even-aged trees. Deciduous forests contain the bulk of the hardwood resource, and are often harvested using partial cutting approaches and uneven-aged management. Mixed forests may occur when softwood plantations have a substantial hardwood component, or when natural regeneration results in stands with a mixture of species. From figure 6 it is evident that the private evergreen forest area in the Coastal Plain and Southern Piedmont contains about 300,000 acres in the three 5-year age classes from age 16 to 30. These are the forest ages from which we extract the majority of the softwood pulpwood harvested from pine plantations. If we look forward 15 years, the acres in these age classes will be replaced by the forest areas currently less than 16 years old. We will go from currently having about 900,000 acres to having 800,000 acres in the 16 to 30 year ages in the woodbasket of Virginia; a decline of more than 10%. These figures echo the 2010 Virginia Statewide Assessment of Forest Resources (VDOF, 2010) that noted a decline in reforestation in the early 2000s. The mixed forest area (Figure 7) shows large forest areas in these younger age classes in the Coastal Plain and Southern Piedmont, perhaps resulting from natural regeneration of clearcuts. The 140,000 acres of mixed forest in the Coastal Plain and Southern Piedmont could contribute softwood volumes to help make up the shortfall in evergreen forest area.

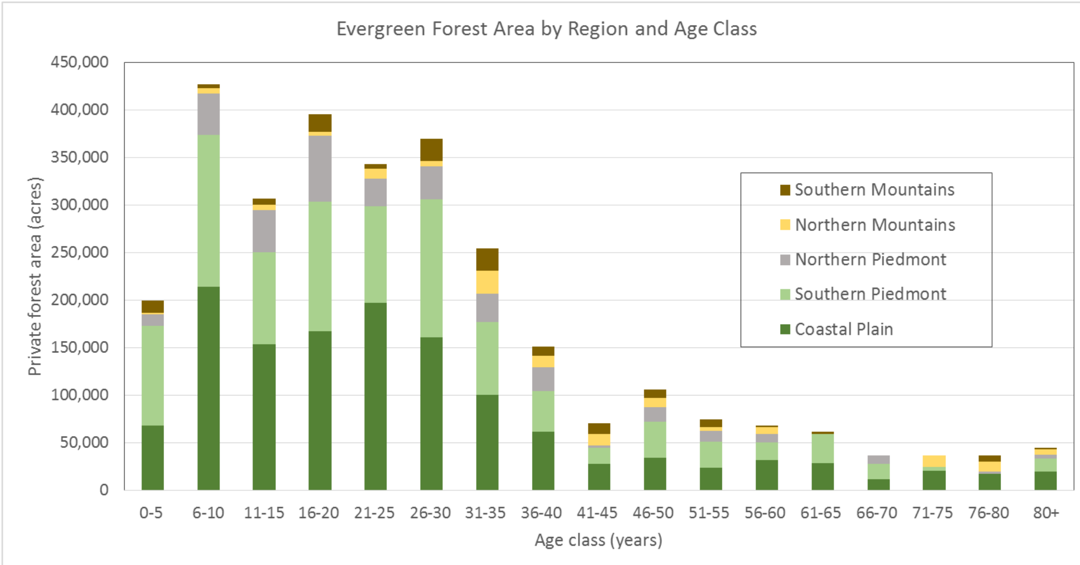

Figure 6. Acres of private evergreen forest in Virginia by region and age class. Source: FIA.

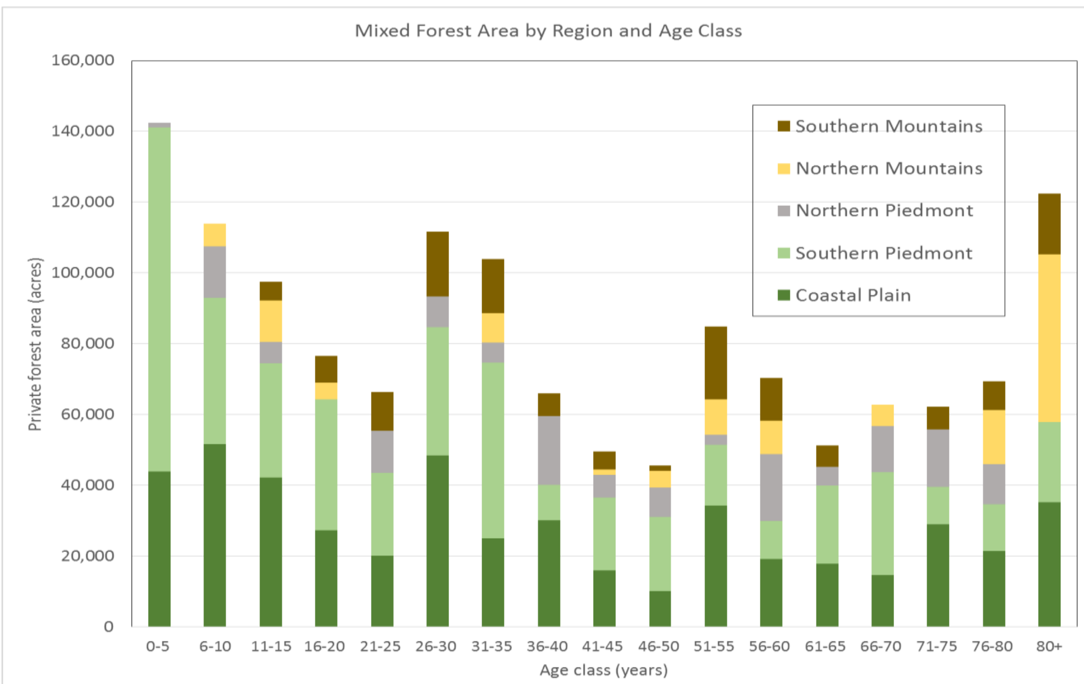

Figure 7. Acres of private mixed forest in Virginia by region and age class. Source: FIA.

In deciduous forests, we see a different pattern in the Coastal Plain and Southern Piedmont forests, with average area per 5-year age class increasing from about 165,000 acres in the 16-30 year classes to 237,000 acres in the 0 – 15 year classes, an increase of about 43%. However, much of this land is likely naturally regenerated to mixed hardwood forests with much lower productivity (tons per acre per year) than is typical in pine plantations. Furthermore, deciduous forests are often harvested at much older ages than evergreen forests, and we see a trough in the deciduous forest ages from 16 to 40 years old that will progress over time through the age-class distribution. Summarizing, there is no evidence to suggest a dramatic increase in softwood inventory is likely to come from large acreages entering commercial age classes in the next few years.

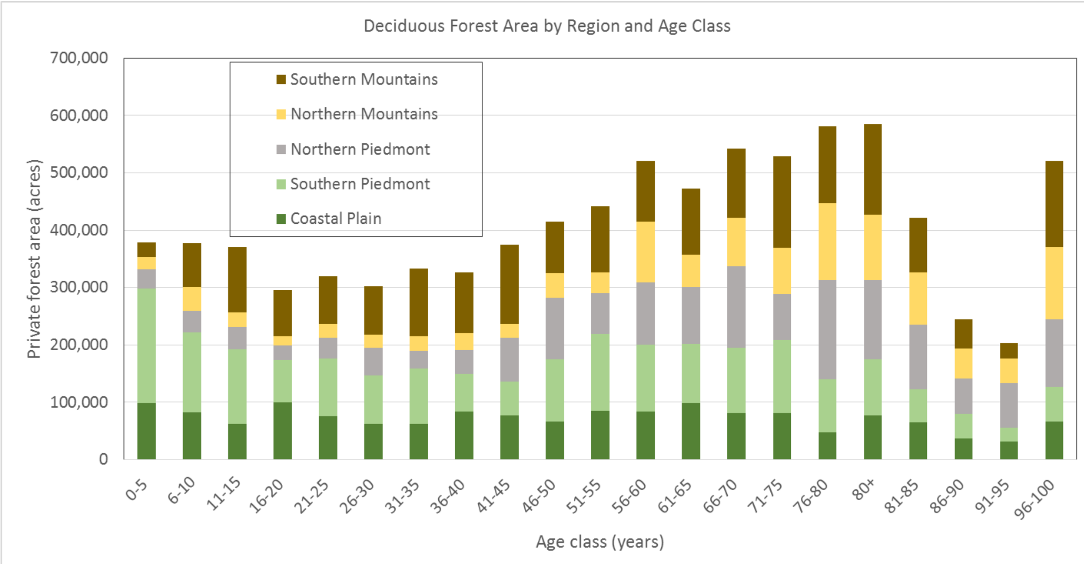

Figure 8. Acres of private deciduous forest in Virginia by region and age class. Source: FIA.

Next, in terms of demand, we can examine trends from several data sources that might indicate the direction demand is moving. From the VDOF harvest data based on tax information, overall harvest levels increased from 2011 to 2012 by 8.8% (Figure 9). Sawtimber harvests increased by 8% and pulpwood harvests increased by 9.6%. Almost all of the increase was in softwood harvest, which increased by 15% while hardwood harvest increased only 2%. Data for 2013 were not yet available at the time of this report. At the same time, VDOF (2014) reports harvest area (acres) decreasing slightly from 2011 to 2013. More volume being harvested from fewer acres is consistent with changes in the type of harvest. Harvest notification data indicate that clearcut harvest acres increased statewide by 6.3% from 2011 to 2013 while partial cut acres (including thinnings) decreased by 17.4%.

Finally, we determine whether the increasing scarcity implied by inventory and demand estimates is reflected in market prices. Using data from Timber Mart South[10] on pine pulpwood stumpage[11] prices paid for Virginia timber from 2009 to 2014 (Q3), we compute a price index using the average price in first quarter of 2009 as a baseline (= 100). Figure 10 indicates that pine pulpwood prices have increased 50% to 100% in four years in Virginia, with an average price increase of about 75%. Much of that price increase has occurred since the end of 2011.

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[10] http://www.timbermart-south.com/

[11] Stumpage price is the price paid to the landowner for timber, and therefore does not include harvest and hauling costs.

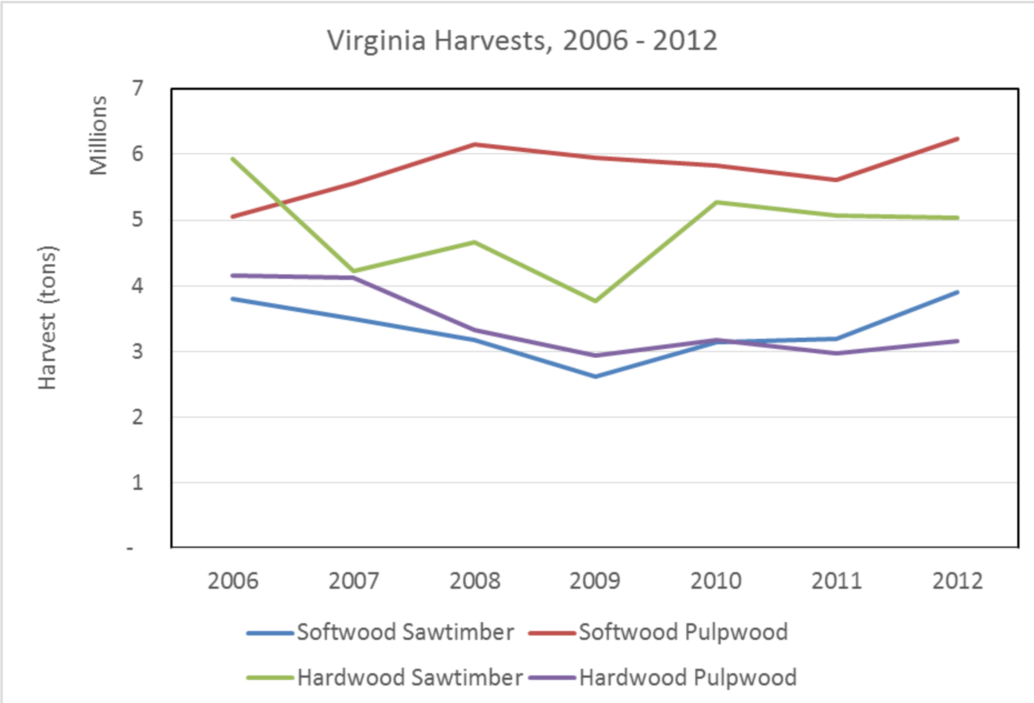

Figure 9. Virginia harvests (tons) by year and product class, 2006 to 2012. Source: VDOF harvest data from tax reporting; years are fiscal years (e.g., 2011 is July 2011 to June 2012).

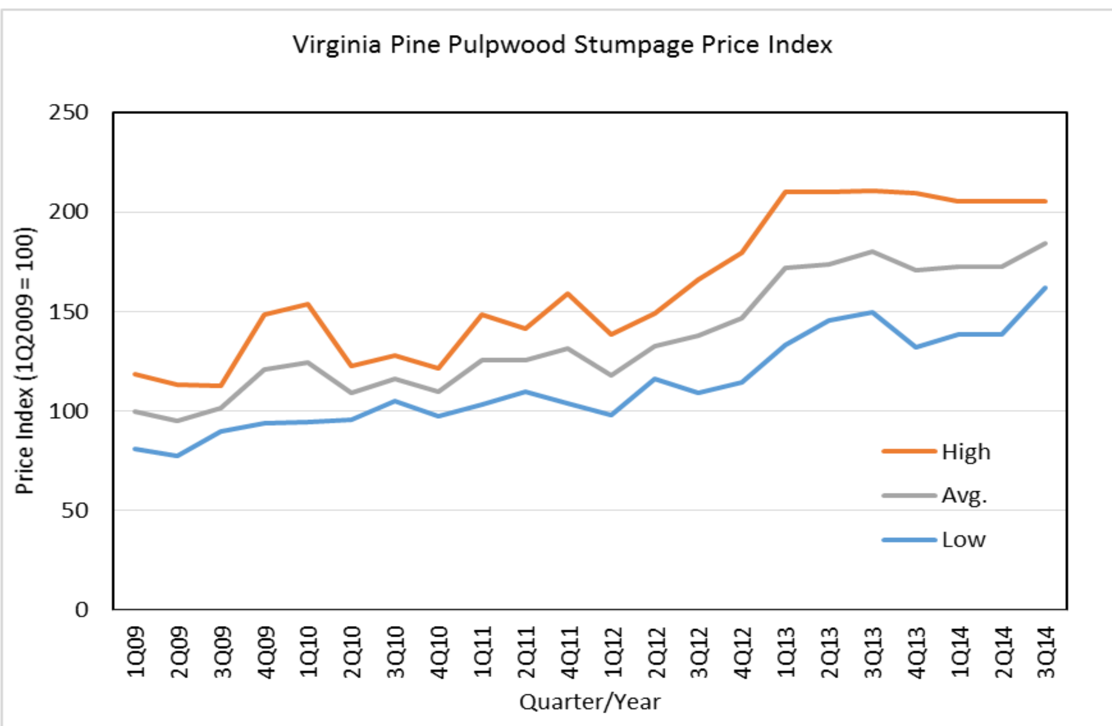

Figure 10. Pine pulpwood stumpage price index for Virginia, 2009 to 2014. Source: Timber Mart South.

Looking forward, then, there is no evidence of dramatically increasing supply of pulpwood in Virginia in the next five years (i.e., there are no large acreages about to enter commercial age classes) and recent trends are for increased pressure on the pulpwood resource. This situation mirrors that described by Abt et al. (2010) in their analysis of the impacts of bioenergy markets in North Carolina. They modeled increased utilization of harvest residues and smaller-diameter roundwood to satisfy the demand for renewable energy from forest biomass and they projected a doubling of pulpwood prices over an even longer term.

Some positive steps can be taken to mitigate the supply deficit. Other indicators suggest that reforestation rates may be improving over the levels evidenced by FIA sample data[12]. In addition, more intensive forest management has been shown to dramatically improve forest productivity (Fox et al., 2007). Efforts to expand the use of more intensive silviculture by landowners will reap the benefit of increased volume production from a fixed forest land base. This process of assisting forest landowners in improving silvicultural practices can be enhanced with cost-share programs, forestry research, and landowner education and extension programs. However, it should be acknowledged that these efforts will exhibit a lag between the time a practice is implemented and the time that a resulting wood volume increase can be observed; efforts in these areas are therefore crucial and time-critical.

Uncertainties

As noted in the Methods section, this assessment is the result of compilation of a wide array of disparate natural resources data. These data vary in source agency, scale and/or resolution, date, and measurement units. Where possible, we have attempted to use common units (acres and tons), and common time intervals. Regardless, unmeasurable uncertainties are introduced into an analysis when such a range of source data is used. As a simple example, a tree measured in a field inventory is classified as pulpwood or sawtimber based on diameter and form, but when the tree is harvested and used by a mill, the product class may be different. Field inventory data are based on a sample design and have quantifiable confidence levels, while data from mill surveys do not. Hence, it is impossible to define a confidence interval in a measure such as the growth-removals ratio.

In this assessment, spatial scale is related to confidence in results. For example, forest inventory estimates are derived from a sparse sample and have very large variances (uncertainty) when reporting results for small spatial areas, such as counties. This assessment process used inventory estimates at the regional level rather than the county level for this reason. County estimates were developed from these regional estimates based on the forest area in each county derived from NLCD data (see Figure 2), which are more reliable at the county scale. Because county inventory numbers have higher uncertainty, we do not report numeric

[12] VDOF tracks reforestation and tree seedling sales, both of which have shown recent improvements.

estimates by county, but use county-level data only in map products to portray spatial differences in forest inventory, growth, and harvest.

One approach used in this assessment to frame the reliability of results has been to compare results with other sources (such as referencing other resource assessments) and to compare results based on different data sources (such as noting only minor differences in growth:removals ratios based on TPO versus VDOF harvest levels).

Summary and Conclusions

The Center for Natural Resources Assessment and Decision Support has completed an initial assessment of the commercial wood supply from private forests in Virginia. Spatial resource data and wood market data have been compiled from an array of public domain and proprietary sources. These data have been analyzed quantitatively and spatially to gain insights into the sustainability of the wood supply from Virginia's private forests.

Virginia’s forests are growing more wood each year than natural mortality and harvest are taking away; Virginia’s forest carbon stocks are increasing. However, there is cause for concern about the supply of smaller-diameter pulpwood-sized trees, especially for softwood species such as pine. Harvests of softwood pulpwood exceed growth by 77%. Reduction in the volume of trees in younger age classes means that fewer trees remain to grow into the sawtimber resource in years to come. Examination of forest age class distributions and recent trends in harvesting show no evidence that the situation is likely to change in the near term. This is of concern not only for current users of pulpwood, but for future users of sawtimber as well.

This assessment represents a point-in-time snapshot of conditions captured in recent datasets. In reality, forests are dynamic and change in predictable ways. Knowledge of growth rates, acres regenerated, and spatial distribution of resources and harvests provides the basis for making projections of forest conditions into the future. This baseline analysis will be followed with a dynamic projection of Virginia’s resources using a simulation modeling approach built on the data reported herein.

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Glossary

Available inventory: The amount of wood considered to be available for timber harvest. This determination is made by examining conditions (biophysical and socio-economic) under which timber has been harvested in the past, and evaluating the proportion of current forest inventory that meets those conditions.

Forestland: Land at least 10 percent stocked by forest trees of any size, or formerly having such tree cover, and not currently developed for non-forest use. The minimum area considered for classification is one acre. Forested strips must be at least 120 feet wide.

Growth: The amount of increase of woody biomass measured on forest plots between two inventories, expressed as an annual amount. **Gross growth** is the amount of increase in wood volume on all measured trees. **Net growth** is gross growth minus volume in trees that have died (mortality) between inventories.

Growth-removals ratio: The ratio of annual net growth to annual removals. Ratios greater than 1.0 are generally considered an indicator of sustainable levels of harvest.

Hardwood: Trees belonging to specific botanical divisions, usually broad-leaved (rather than needle-leaved) and deciduous (rather than evergreen). Examples include oak, hickory, yellow poplar, and maple.

Inventory volume: The quantity of wood in forest trees, computed from tree measurements on forest plots. Volume is usually expressed in cubic feet, but sometimes "inventory volume" may also refer to quantities of wood measured by weight (e.g., green tons).

Mortality: The volume of trees that die from human or natural causes between inventories, usually expressed on an annual basis.

Pulpwood: The amount of wood in smaller-diameter trees (usually 5 to 9" for softwood and 5 to 11" for hardwood), and in the tops or larger-diameter trees, harvested primarily for use in industrial processes in which logs are chipped before being used.

Removals: The volume of trees removed from inventory, expressed on an annual basis. Removals may be harvest removals, where trees are cut and removed but the land remains as forest, or other removals, in which trees are removed during a land clearing operation rather than a commercial forestry operation.

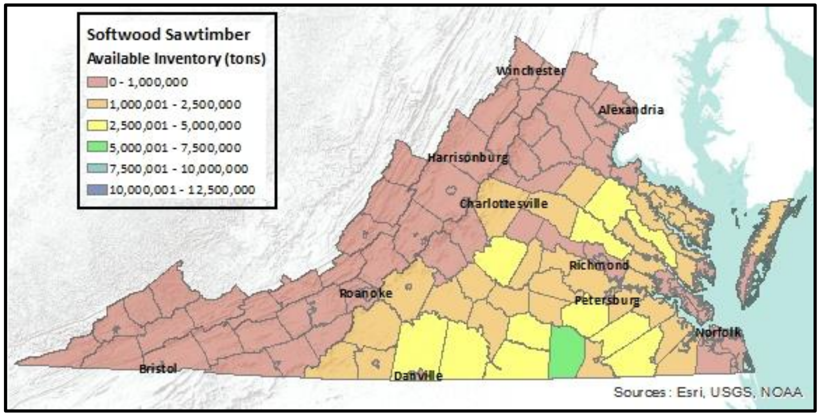
Roundwood: Wood volume in log form; generally used to refer to sawtimber and pulpwood trees removed from the forest, as opposed to operations in which trees are chipped in the forest and wood volume is removed as chips.

Sawtimber: The amount of wood in larger-diameter trees (usually >9" for softwood and >11" for hardwood) of appropriate species and form to be harvested for use in sawmills or veneer mills. Sawtimber trees refer to trees of proper species, size, and grade to be harvested for solid wood products. Sawtimber volume refers to the volume of that portion of the tree which meets specifications (usually above a minimum diameter).

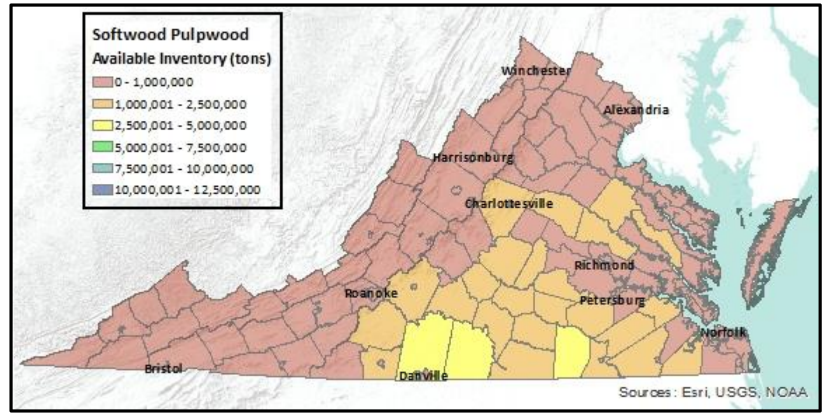
Softwood: Trees belonging to specific botanical divisions, usually needle-leaved (rather than broadleaved), cone-bearing (coniferous), and evergreen (rather than deciduous). Examples include pines, cedars, hemlock, and spruce.

Surplus growth: Annual net growth minus annual removals. Negative surplus is considered a deficit. Positive surplus growth corresponds to growth-to-removals ratios greater than 1.0.

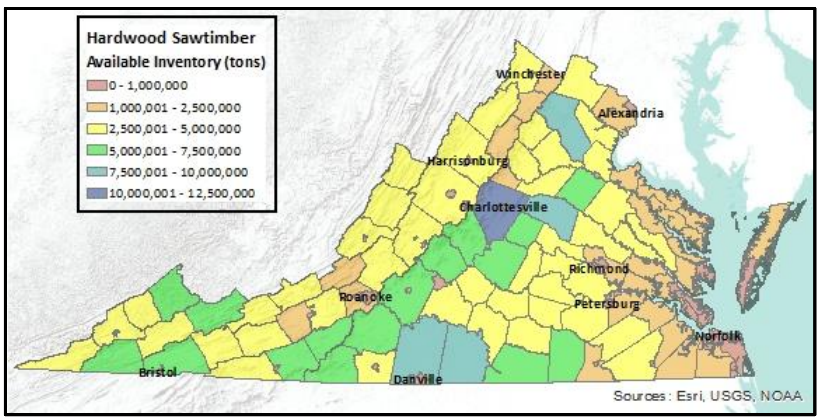
Appendix: Maps



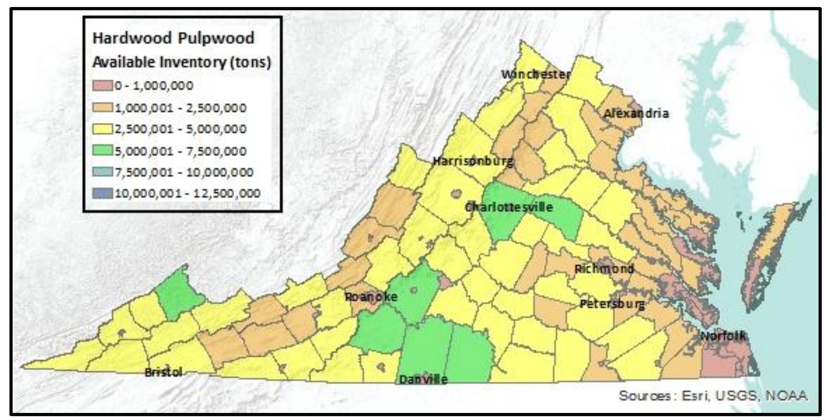
(a) Softwood sawtimber



(b) Softwood pulpwood

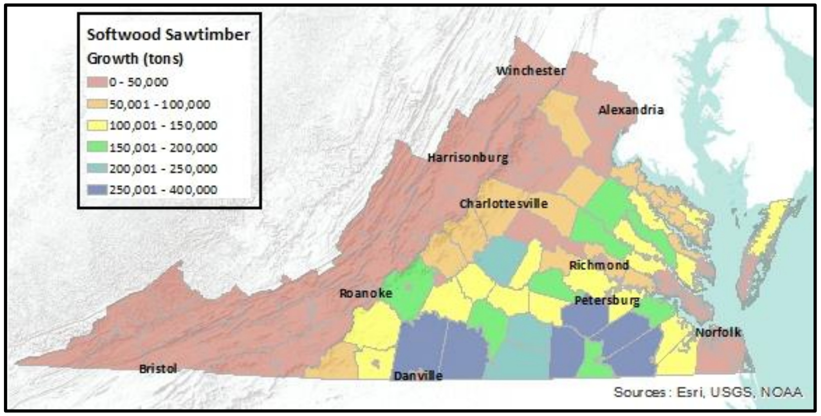


(b) Hardwood sawtimber

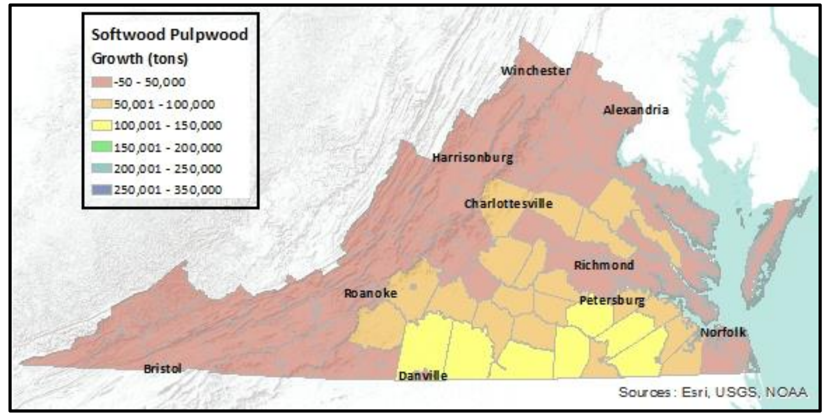


(d) Hardwood Pulpwood

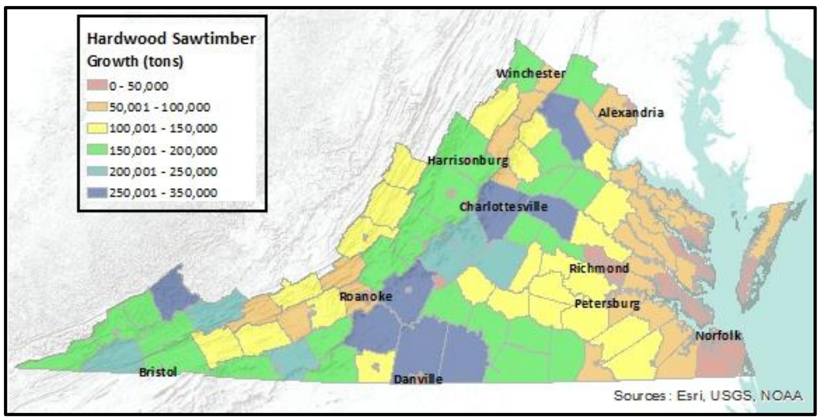
Figure A-1. Maps of available inventory on private forest lands, in tons.



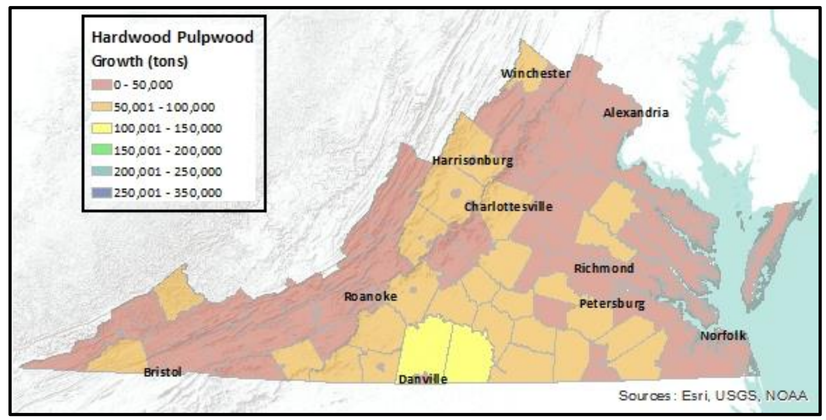
(a) Softwood sawtimber



(b) Softwood pulpwood

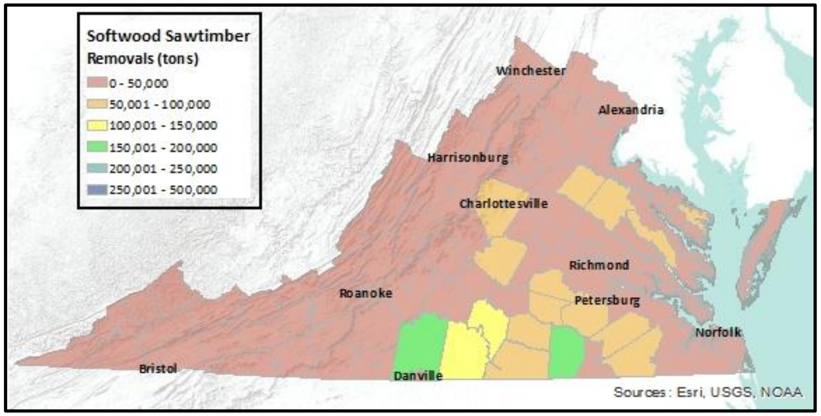


(b) Hardwood sawtimber

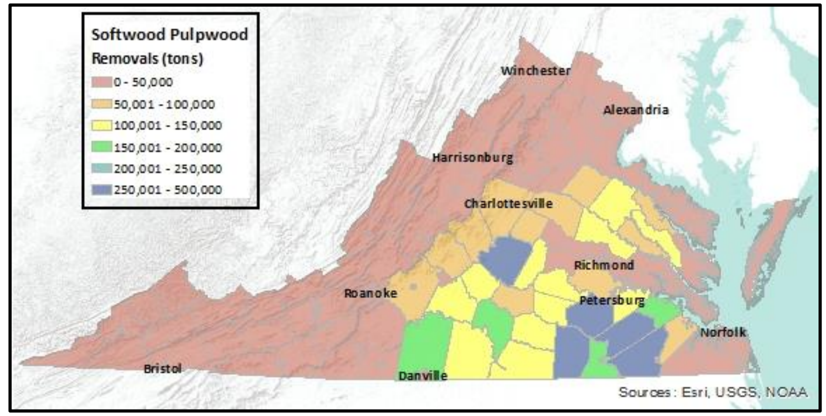


(d) Hardwood Pulpwood

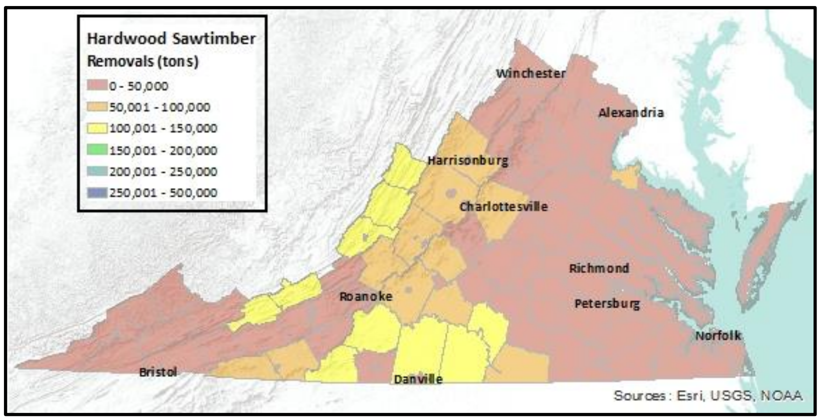
Figure A-2. Maps of annual growth on available inventory on private forest lands, in tons.



(a) Softwood sawtimber



(b) Softwood pulpwood



(b) Hardwood sawtimber

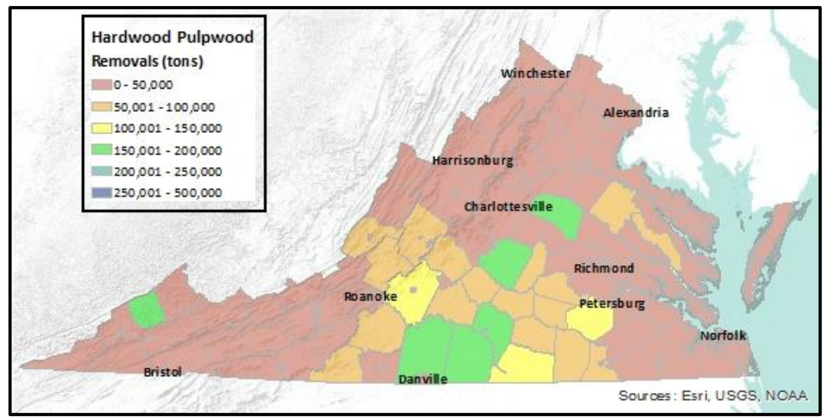


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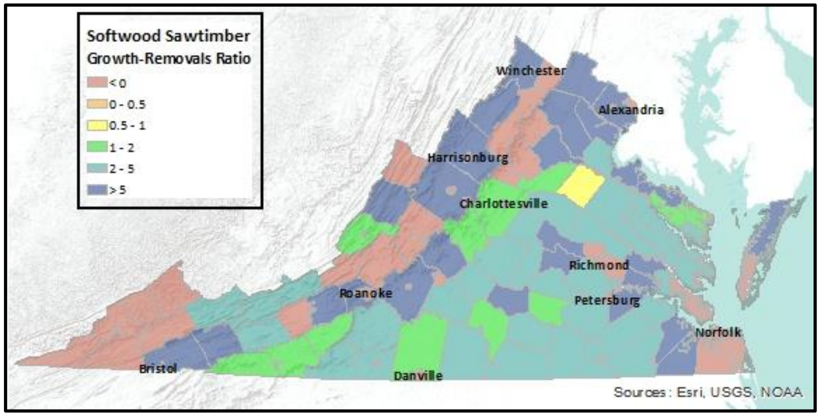
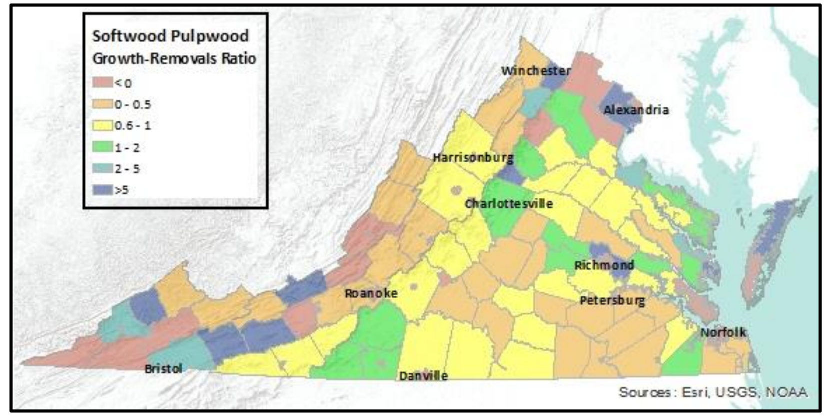
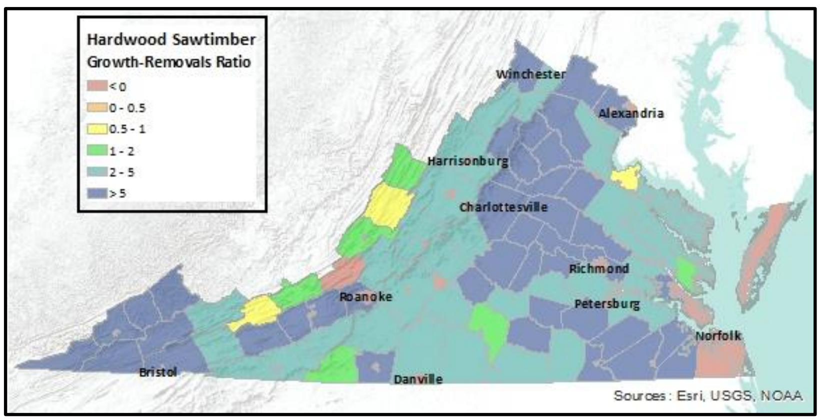
Figure A-3. Maps of annual removals (harvests) on private forest lands, in tons.



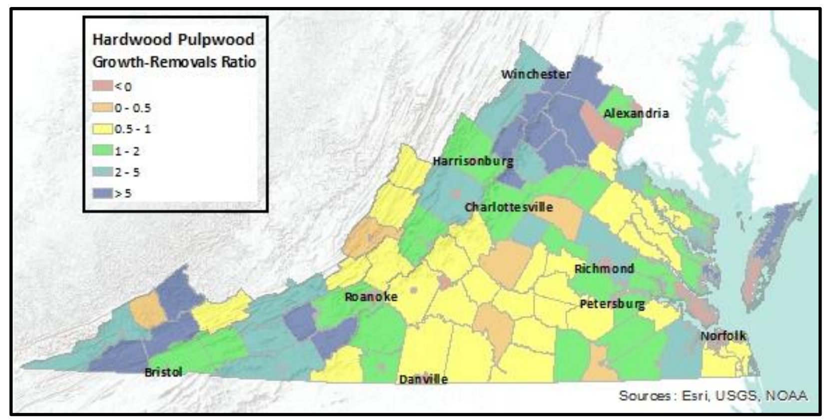
(a) Softwood sawtimber



(b) Softwood pulpwood

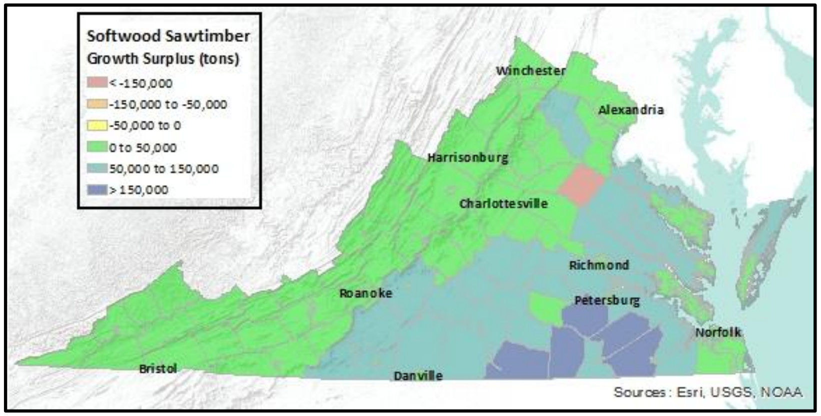


(b) Hardwood sawtimber

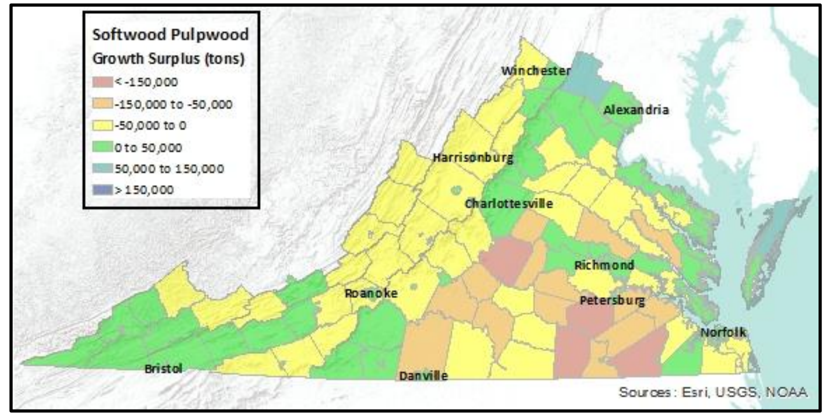


(d) Hardwood Pulpwood

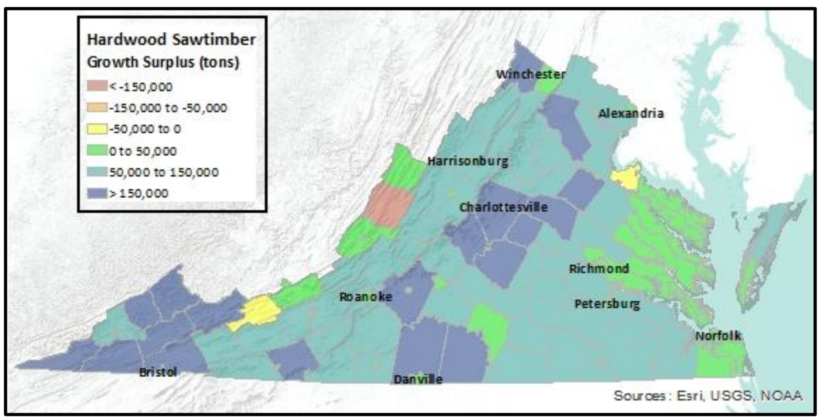
Figure A-4. Maps of growth-removals ratio on private forest lands.



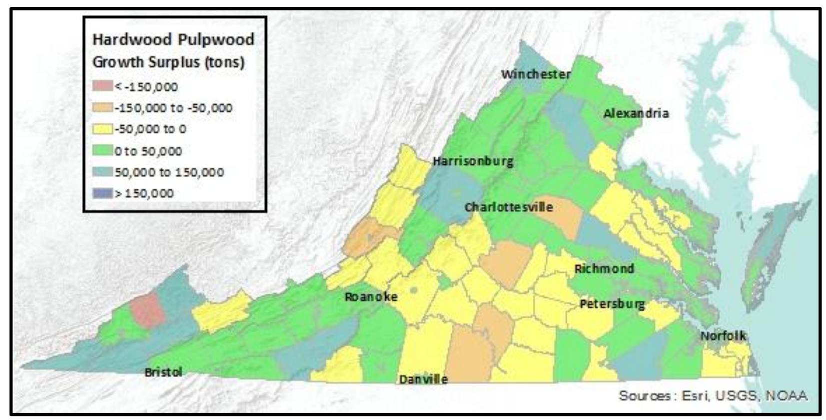
(a) Softwood sawtimber



(b) Softwood pulpwood



(b) Hardwood sawtimber



(d) Hardwood Pulpwood

Figure A-5. Annual growth surplus (annual growth – removals, in tons) on private forest lands.