Wisconsin
Wood Supply Assessment

Center for Natural Resources Assessment
& Decision Support
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Virginia Tech
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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, in collaboration with the forestry discipline at the University of Wisconsin-Stevens Point, has completed an analysis of wood supply for the state of Wisconsin. This analysis is part of the Wisconsin Forestry Practices Study, and includes four primary parts: (1) a baseline resource assessment for non-federal forests of Wisconsin, (2) a landowner survey and analysis to assess attitudes of private landowners regarding timber harvest, (3) a logging capacity utilization study to assess the capacity of Wisconsin's logging force and its utilization rates, and (4) a simulation of future wood supplies in Wisconsin under defined sets of assumptions.

Approach: The resource 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. Most datasets reflect conditions at or near the year 2013. Spatial analysis of factors influencing timber availability was used to estimate what proportion of overall forest inventory was "available", or had site and location conditions suitable for harvest. In addition, parcel boundary data were used to assess the parcel size distribution of Wisconsin's private forests.

A landowner survey was sent to 2,000 owners of at least 10 acres of forest in 2015. The survey included questions designed to assess landowner characteristics and motivations for ownership and use of their land. After excluding ineligible cases, the 809 eligible responses received resulted in a response rate of 43%.

The logging capacity utilization study collected profile data on 79 logging businesses representing approximately 120 logging crews. These loggers were contacted by phone to confirm their willingness to participate in further data collection; 44 logging businesses representing 68 logging crews agreed. Thirty logging businesses representing 40 logging crews reported 894 crew-weeks of data and 9,169 loads of timber delivered.

The simulation of future wood supply dynamics employed an agent-based modeling system called the Spatial Wood Supply Simulator (SWSS). This model simulated the behavior of agents in the wood supply system in Wisconsin, including 483,604 forest ownerships and 509 wood-using mills in and around Wisconsin. The SWSS model simulated transactions in the wood market quarterly for a period of 30 years.

Results- resource assessment: The forest parcel analysis indicated that about one-fifth of Wisconsin's private forest area occurs in ownership parcels less than 20 acres, while less than 2% of harvest-like disturbances occur in these smaller forest tracts.

The availability analysis indicated that the primary factors driving the likelihood that a forest may be harvested include percent of the neighboring area that is classified as wetland, distance to a road, density of mills within a 100-mile radius, and the land ownership status (private vs. state or county, and whether enrolled in MFL). Findings show that 62.4% of Wisconsin's non-federal forest acres and 64% of volume may be considered "available".

Table ES-1 provides summary information of the resource assessment for the state. Forest growth in Wisconsin exceeds removals by 3.2 million tons, indicating increasing wood inventory and forest carbon stocks. This results in an overall growth:removals ratio for available timber of 1.4. Among primary product classes, however, there is considerable difference in growth and removals dynamics. The supply of pulpwood is under pressure: harvests exceed growth by 618 thousand tons annually, or 11%. These imbalances among product classes have economic repercussions as pulpwood users face tight supplies.

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

Metric	Hardwood Sawtimber	Softwood Sawtimber	Hardwood Pulpwood	Softwood Pulpwood	Total
Non-federal inventory (k tons)	224,464	78,219	282,754	51,743	637,180
Available non-federal inventory (k tons)	137,469	52,156	181,640	34,390	405,655
Growth on available Inventory (k tons)	4,463	1,807	4,283	1,292	11,844
Removals/harvest (k tons)	1,771	638	4,856	1,336	8,601
Growth:Removals ratio	2.5	2.8	0.9	1.0	1.4
Growth surplus (deficit); (k tons)	2,691	1,169	(574)	(44)	3,243

Results- landowner survey:

Generating income from timber production had the lowest average importance among reasons for owning forest land according to the landowners responding. They also indicated that they are far less likely to engage in timber harvest than other management practices. Factors found to be significant predictors of harvesting probability included the price offered for timber, whether structures were present on the property, number of children, the importance of environmental reasons for ownership (protection of nature, protection of water quality, prevention of soil erosion), and whether the landowner had a written management plan or stewardship plan.

Results- logging capacity utilization study:

Logging capacity utilization averaged 71% for the 48 weeks of the study (excluding shutdowns during spring break-up). Utilization varied by harvesting system with highest rates for feller-buncher systems.

The primary reasons for lost production (outside of spring break-up) were weather and equipment breakdowns. Weather factors impacting woods conditions and forest road conditions reduced production by nearly 12%. Factors related to regulations or seasonal restrictions resulted directly in about 2.4% lost production; additional indirect lost production due to regulatory restrictions is possible. Logging capacity utilization was near the theoretical maximum during the winter, but opportunities exist to increase production during the rest of the year.

Logging efficiency averaged approximately 65% with mechanized systems reporting highest efficiencies. Logging efficiency was highest during the fall and winter, perhaps because timber availability is higher and weather more predictable during these seasons.

Results- wood supply modeling:

Simulation of the Wisconsin wood supply chain depicted an increasingly competitive environment for pulpwood, especially hardwood pulpwood. This environment is characterized by increasing substitution of sawtimber-sized material in the pulpwood supply, rising stumpage prices, and increasing haul distances. Overall, however, forest inventories continue to increase, with much of the volume in the portions of the resource considered “unavailable”, either due to location conditions (such as proximity to wetlands or roads) or temporarily unavailable due to stand conditions such as low volume per acre.

Conclusions:

This analysis, focused on Wisconsin’s non-federal forest resources, indicates a positive overall balance between forest growth and harvests, and evidence of ongoing increases in overall forest inventory. However, harvests of pulpwood-sized trees exceed growth, indicating a constrained supply for specific product classes. Simulation of the wood supply chain indicates this pressure on the pulpwood resource will continue with resulting higher stumpage prices and haul distances. This situation is exacerbated by findings from the landowner survey, which indicate that supplying fiber to the wood supply chain ranks very low among priorities of many of Wisconsin’s private landowners. Furthermore, Wisconsin’s logging force faces challenges in maintaining efficiency and productivity in the face of weather-related and regulatory constraints. The interaction of all of these factors creates a challenging environment for the wood-using industry in Wisconsin, a point reinforced by the announced bankruptcy of two Wisconsin papermills during the writing of this report.

Chapter 1. Context for Study & Report Overview

Context and Need for Study

Wisconsin has one of the largest forest products industries in the nation (Perry et al. 2012). Chief among them is the pulp and paper industry located in the northern and central portions of the state. With nearly 60,000 employees and output of roughly $16 billion annually, the forest products industry ranks in the top five manufacturing industries in the state (Wisconsin's Office of the Governor, 2012). Forests in Wisconsin occupy nearly 50% of the landscape and forest acreage and inventory volumes have been increasing. In 2014, forest acreage was estimated at 17.1 million acres, an increase of roughly 2.1% from 2009, and volume was estimated at 25.1 billion cubic feet, an increase of 6.9% from 2009 (Perry, 2015).

In spite of the large amount of forest resources located in the state, the forest products industry has been experiencing decline with mill closures and reduced roundwood production and increased raw material costs. In 2008, the U.S. Forest Service Timber Product Output Program (TPO) (Haugen, 2013) reported 226 primary wood using facilities, a decrease of 50 mills from 2003. Of that decline, 2 were sawmills that produced more than 5 MMBF/year, 24 were sawmills producing between 1 MMBF/year and 5 MMBF/year, and 24 sawmills produced less than 1 MMBF/year. There were also 2 particle board mills, and 2 veneer mills that closed. Four new mills classified as "Other" were opened in that same time span. Overall roundwood production decreased 23 percent from 11.3 million tons in 2007 to 8.7 million tons in 2012.

The Wisconsin Council on Forestry identified timber supply as one of five priority issues to address, and in 2013, the Great Lakes Timber Professionals Association (GLTPA) and the Wisconsin County Forests Association (WCFA) received a grant to initiate scientific research into aspects of the wood supply chain in Wisconsin. The 2013 Wisconsin Forestry Practices Study issued a request for proposals (RFP) to address three priority topics, the first of which was availability of wood fiber in the state.

The RFP sought "a comprehensive, spatially-explicit analysis that (i) identifies and delineates reserved and non-reserved parcels of forest land in Wisconsin; (ii) classifies reserve and non-reserved parcels by variables known to influence timber productivity (e.g., tract size, ownership, management restrictions, site classification, cover type); and (iii) provides estimates of past (circa 1998), current, and expected future average rates of timber harvest per acre (by timber product class) for each class of non-reserved forest land." Availability of wood fiber was defined in the RFP as including consideration of environmental regulations and guidelines, economic constraints such as tract size, logger capacity, and landowner willingness to harvest.

Our approach and organization of this report

In response to the RFP, a team of scientists at Virginia Tech's Center for Natural Resources Assessment and Decision Support (CeNRADS) and the University of Wisconsin-Stevens Point (UWSP) designed a study to accomplish these goals. The following chapters of this report summarize findings of this research effort in four parts.

The first (Chapter 2) is a forest resource assessment, intended to provide a point-in-time estimate of the availability of wood fiber for commercial harvest in the state, with estimates of annual levels of growth and removals. This effort was conducted by Charlie Wade and Dr. Steve Prisley of CeNRADS with assistance from UWSP in collecting data from Wisconsin counties.

The second part (Chapter 3) is an analysis of a landowner survey to assess the willingness of Wisconsin private landowners to harvest timber. The landowner survey and its analysis and report was done by Dr. Melinda Vokoun of UWSP.

Part three (Chapter 4) is an analysis of Wisconsin's logging capacity utilization. This effort was led by Dr. Joseph Conrad of UWSP with assistance from GLTPA and the Wisconsin Master Logger Program.

The fourth part of the study (Chapter 5) consists of using information and data from the other parts in a projection of the Wisconsin wood supply into the future. This was done using the Spatial Wood Supply Simulator (SWSS) developed at CeNRADS, with contributions by Xiaozheng Yao, Charlie Wade, Dr. Steve Prisley, Joby Kauffman, Dr. Emily Smith-McKenna, and Laura Wade.

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Chapter 2. Forest Resource Assessment

Introduction

Wisconsin's forests support a substantial portion of the state's economy, providing about one-eighth of the jobs and wages in the manufacturing sector. Over 62,200 employees and total wages of over three billion dollars are dependent on these forests (WI DNR, 2015). Comprehensive assessments of Wisconsin's forests have been conducted by the Wisconsin Department of Natural Resources (WDNR 2010) and the US Forest Service (Perry, et al. 2012). 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 Wisconsin, 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 Wisconsin, 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.

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.

Methods & Data

Overview

This assessment of Wisconsin's forest resources 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, but nominally we consider our assessment as representing the year 2013, which is the base year for several key sources of data.

The focus of this assessment is on the contribution of non-federal lands (e.g., individual landowners and corporations, county forests and state forests) to the wood supply in Wisconsin. 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 lands contribute relatively little to wood markets in Wisconsin[1]. In addition, areas under conservation easements that restricted timber harvesting[2] were removed from consideration as available for timber harvest.

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 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 six categories for wood quantities: softwood sawtimber, softwood pulpwood, hardwood sawtimber, hardwood pulpwood and aspen sawtimber and aspen pulpwood. Aspen is distinguished from other hardwood species because of its importance to the forest industry in Wisconsin. In this assessment hardwood encompasses all deciduous trees except the aspen and cottonwood species group and softwood includes all coniferous trees. 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 four primary product classes (hardwood/softwood pulpwood/sawtimber), 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 green 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 Wisconsin vary in regards to land cover type, population density, land ownership, and other factors related to forest management. The WI DNR has divided the state into five distinct regions which we have adopted for reporting purposes. These regions include: Northeastern, Northern, West Central, South Central, and Southeastern (Figure 2-1). The majority of the forest resources and forest industry are located in the northern and central portions of the state in the Northeastern and Northern regions, and to some extent the West Central region. In the more southerly portions of the state agricultural and urban land uses become more dominant.

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[1] From 2009-2013, only about 8% of total removals reported by FIA came from Federal lands.

[2] The protected areas database (PAD) includes a field indicating whether timber harvest is permitted under an easement; this data was used to eliminate such easements from consideration.

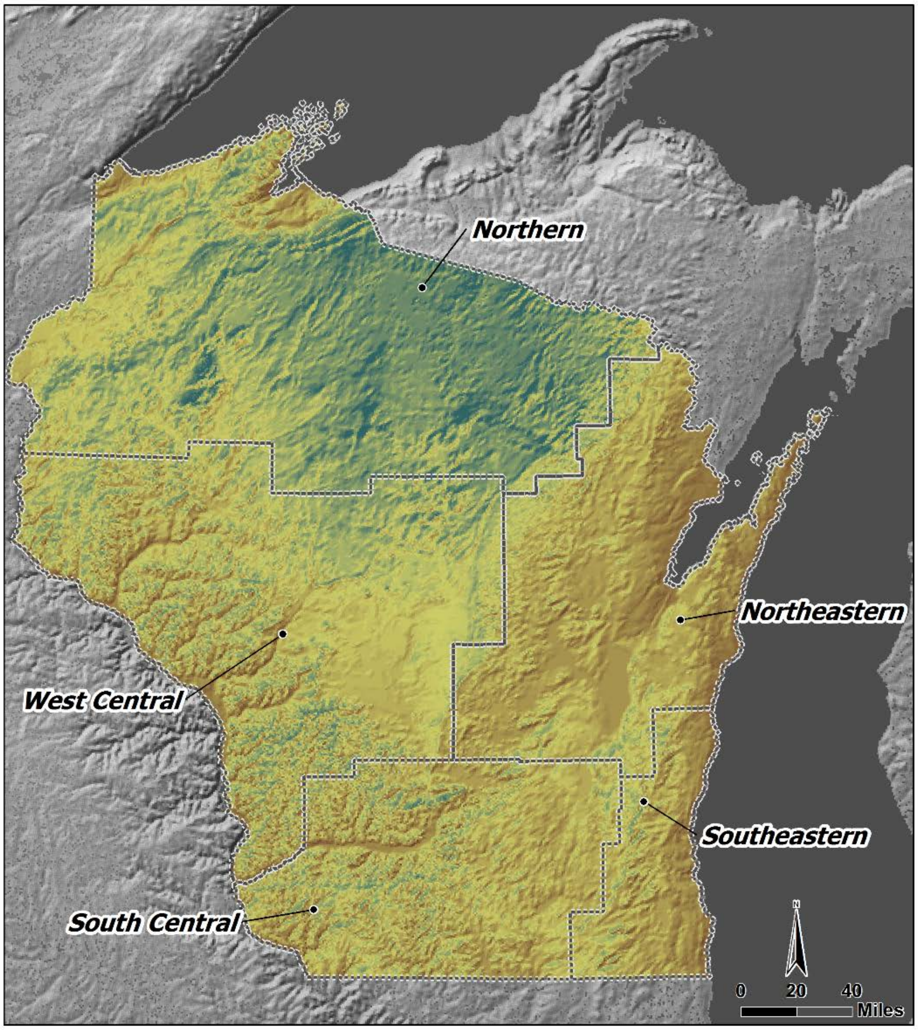

Figure 2-1. Shaded relief map showing the five DNR regions within Wisconsin adopted for reporting in this assessment.

Data Sources

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 tree species, tree sizes, and forest conditions. These plots are measured as part of the US Forest Service's Forest Inventory and Analysis (FIA) program. The land cover data (from US Geological Survey) contain only the broadest classification of forest types, yet have detailed information about spatial distribution of forest. In this assessment, these are analyzed with other spatial data layers and results summarized by region.

Data sources and descriptions are listed in Table 2-1. 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. 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) analyzing the parcel size distribution of private forests, (2) determining average forest volume per acre and growth per acre by forest type and region within the state, (3) estimating the proportion of overall forest inventory that would actually be available (at some point in time) for commercial harvest, (4) estimating forest growth on available private forest lands, and (5) incorporating information about wood demand and utilization by product type and location within the state.

Part 1: Forest parcel size distribution

Forest parcel size plays an important role in determining timber availability for Wisconsin's forest industry. Small parcels are sometimes less likely to supply timber to the forest products industry because of increased harvesting and transaction costs, physical harvesting limitations, and diverse landowner objectives, which may not always include timber harvesting (Hatcher et al. 2013). For example, it costs a logger the same amount of time and money to move equipment to a 5-acre tract as a 25-acre tract, and that cost is spread over fewer tons, so the harvesting cost per ton of wood is much higher on the smaller tract. Therefore, the size of private forest parcels influences forest management decisions and timber availability.

We conducted an analysis to determine the parcel size distribution of Wisconsin's private forests as well as the rate of harvesting by parcel size. In addition, we examined the parcel size distribution of MFL participants.

Twenty eight counties in Wisconsin were randomly selected representing the five Department of Natural Resources (DNR) regions - Northern, Northeastern, South Central, Southeastern, and West Central (Figure 2-1). Digital map data on parcel boundaries were obtained for the counties in our sample. Government-owned parcels were removed from the files in order to evaluate private land exclusively. The ownership parcel boundaries were overlaid with the 2011 NLCD data, allowing us to calculate the acres of forest in each ownership parcel for each county. Using this information, we were able to sort by parcel size class and summarize the forest acres in each size class.

For the purposes of this study, a distinction is made between an ownership parcel and a forest tract. An ownership parcel is the legally defined area of land titled to an individual. For our purposes, a forest tract is an area of forest within an individual ownership parcel. It is important to make this distinction when discussing size classification of forestland in Wisconsin, as many ownership parcels contain multiple land cover types.

We performed this analysis in two different ways, as both are relevant. The first method was performed by selecting all ownership parcels within each size class and summarizing the forested acres in each (ownership parcel method). In this method, if an ownership parcel was 35 acres, but only contained 5 acres of forest, those 5 acres of forest would be counted in the 20-40 acre ownership parcel size class.

The second method was performed by selecting all of the forest tracts within each size class and summarizing the forested acres in those (forest tract method). In this method, if an ownership parcel was 35 acres, but only contained 5 acres of forest, those 5 acres of forest would be counted in the <10 acre forest tract size class.

Part 2. Forest Inventory Volumes per Acre

The goal of this portion of the assessment was to develop per acre volume estimates for each species/product by forest type for each WI DNR Region. The forest types were defined as Deciduous, Evergreen, and Mixed. These simplified forest types were chosen so that FIA data could be matched with NLCD acres. This analysis is focused on forest inventory on private, state, and county owned forestland[3]. The process followed the flow depicted in Figure 2-2.

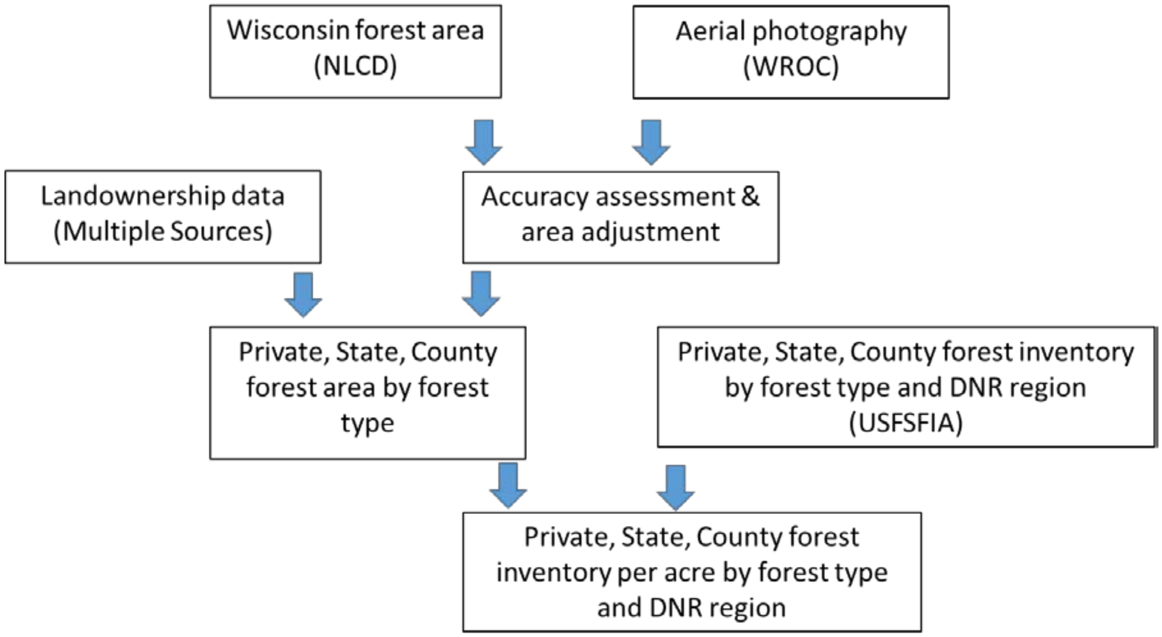

Figure 2-2. Procedure used to develop per acre volume estimates.

[3] FIA distinguishes between forestland and timberland. Forestland is all land stocked with at least 10% tree cover (and not under a non-forest land use such as residential neighborhoods), while timberland is forestland capable of producing at least 20 cu.ft./acre/yr of wood and not withdrawn from timber utilization. According to 2013 FIA data for Wisconsin, there are 15.48 million acres of non-federal forestland and 15.15 million acres of timberland.

Table 2-1. Data Sources

Data Theme	Purpose	Source	Notes
Land Cover	Shows the 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 for 2013 using the downloadable Access Database
DNR Regions	Depicts boundaries of DNR Regions within the state, used for regional summarization	WI DNR: http://dnr.wi.gov/topic/ForestManagement/data.html	
MFL Lands	Depicts lands enrolled in the Managed Forest Law program	WI DNR: http://dnr.wi.gov/topic/ForestManagement/data.html	
DNR and County Owned Land	Depicts lands owned by the Department of Natural Resources and individual Counties	WI DNR: http://dnr.wi.gov/topic/ForestManagement/data.html	
State and County Boundaries	Used for general reference purposes	USDA Geospatial Data Gateway: http://datagateway.nrcs.usda.gov/	
Forest Service Lands	Used to identify Federal Ownership to distinguish from private lands	USDA Forest Service: http://data.fs.usda.gov/geodata/edw/datasets.php	
Conservation Easements	Used to identify lands enrolled in conservation easements that restrict timber harvesting	USGS GAP Analysis Program Protected Areas Database (PAD): http://gapanalysis.usgs.gov/padus/	Only lands enrolled in easements that restrict harvesting were excluded from availability analysis.
Aerial photography	Used for validation of NLCD land cover data	Wisconsin Regional Orthophotography Consortium (WROC): http://www.wisconsinview.org/imagery/imagery_preview.php	WROC 2010 Leaf Off 18"

Data Theme	Purpose	Source	Notes
Terrain	Digital elevation models (DEM) portray land surface terrain, used for deriving slope steepness for forest availability assessment	USGS 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 areas within specified road distance to a wood-using facility	Streetmap Premium (proprietary data) licensed from ESRI: http://www.esri.com/data/streetmap	Road network data with rich attributes (speed limits, weight restrictions, etc.)
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 the presence or proximity to wetlands	US Fish and Wildlife Service National Wetlands Inventory: http://www.fws.gov/Wetlands/NWI/index.html	Polygon delineations of wetlands
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_int4.php	TPO data (2012) 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

Land cover data such as NLCD always contains errors due to misclassification of the satellite imagery used to make the maps. There is currently no available assessment of 2011 NLCD accuracy. However, in a wood supply assessment conducted for the state of Virginia, the 2011 NLCD correctly identified land cover type 70% of the time. Our assessment relies heavily on NLCD data, therefore it was important to perform an accuracy assessment. To assess the accuracy, the NLCD classes were first generalized into ten categories (Table 2-2). A stratified random sample of 1,000 points was then overlaid on the NLCD data. A photo interpreter using digital aerial photographs (WROC 2010 18" Leaf Off obtained from WisconsinView.org) recorded the land cover class that occupied the area around the sample point. The photo interpreter's class assignments were then compared with the NLCD classification to determine an overall accuracy as well as accuracies for each land class. The percent of each land class that was correctly classified by NLCD was then used to adjust the NLCD acreages for each forest type.

Table 2-2. Generalized NLCD Classes and code values used in accuracy assessment.

Land Cover Classification (NLCD code)	
Open Water (NLCD Class 11)	Evergreen Forest (NLCD Class 42)
Developed, Open Space (NLCD Class 21)	Mixed Forest (NLCD Class 43)
Developed, Low/Medium/High intensity (NLCD Classes 22,23,24)	Shrub/Scrub (NLCD Class 52)
Barren Land (NLCD Class 31)	Grassland/Pasture/Crop/Herbaceous Wetland (NLCD Classes 71,81,82,95)
Deciduous Forest (NLCD Class 41)	Woody Wetland (NLCD Class 90)

Deciduous forest, evergreen forest, mixed forest, shrub/scrub, and woody wetland classes were summed for each WI DNR region to determine forest acreage. Shrub/scrub was included because it not only represents a shrubby landscape but also young regenerating forests and open land returning to forested conditions. Woody wetlands were included because they can contain merchantable timber and may at some point be harvested.

To facilitate integration with FIA inventory volumes, the five NLCD classes were further reduced to deciduous forest, evergreen forest, and mixed forest. The area in the shrub/scrub was proportionally allocated to the other three forest types. To determine woody wetland allocation, acreage in deciduous, evergreen, and mixed forest types occurring on hydric sites (as described on FIA plot records) was estimated from FIA data and the woody wetland acres were proportionally allocated to deciduous, evergreen, and mixed.

Inventory volumes were retrieved from the FIA database for Wisconsin, using data from 2013 on nonfederal lands[4]. Due to the nature of the FIA sampling process, area and volume estimates are unreliable (due to high variance) at the individual county level, but provide sound estimates when

[4] The 2013 Wisconsin FIA dataset includes plots measured in 2009, 2010, 2011, 2012, and 2013.

aggregated to the WI DNR regions. Data extracted from the FIA database included inventory volume and net growth, by forest type and product class (sawtimber/pulpwood), and species group (hardwood, softwood, and aspen) for each WI DNR region. These resulting regional FIA volume (and growth) totals were divided by forest area from NLCD to derive an estimate of volume per acre for forest type/region combinations.

Part 3. Available Forest Area

It is widely accepted that not all inventory volume reported by FIA is likely to make it to a forest products market. Physical factors such as slope, distance to road and soil conditions, and socioeconomic factors such as population density, and land ownership are commonly reported constraints to timber harvesting. The goal of this portion of the assessment was to estimate the amount of forest inventory in Wisconsin that might reasonably be expected to contribute to forest products markets.

Our analysis used a logistic regression model to estimate the probability of timber harvest for each 30 meter NLCD forested pixel based on one or more predictor variables. Point locations representing the presence or absence of forest harvests were used as the response variable. Because there is no comprehensive data on forest harvest locations in Wisconsin, we sought to approximate the distribution of forest harvest using forest disturbances from 2000 to 2013 as mapped by the Global Forest Change (GFC) dataset compiled by the University of Maryland (Hansen et al. 2013). This disturbance dataset may contain forest disturbances other than commercial timber harvest (such as storm damage or fire). However, a cursory comparison of these disturbances with county cutting notices, inspection of aerial imagery, and harvests documented on state and county lands[5] indicated that the vast majority of disturbances greater than 1 acre were harvest-related. A total of 77,607 disturbances were included in the final selection. Forest non-harvest points were randomly generated throughout the state and were constrained to forest area at least 1,000 feet from a disturbance point.

We then selected GIS layers to develop a spatial model of harvest probability, based on current scientific literature about factors affecting harvest likelihood. The GIS layers we selected included:

- Percent Wetland – A 30m raster layer created based on data from the National Wetlands Inventory database (NWI), where each grid cell represents the percentage of area within a 50 acre circle that is classified as wetland.
- Distance to Road – Straight line distance to the nearest public road (as recorded in the ESRI StreetMap Premium dataset).
- Mill Density – Density of wood-using mills in a 100 mile radius (mills/mi^2). The mill list was created from public and proprietary datasets as well as input from WI DNR staff.

[5] Cutting notices were collected from 17 counties and included harvests conducted from October 1, 2013 to September 30, 2014. Harvest data on state and county owned lands was obtained through the Wisconsin Forest Inventory Reporting System (WisFIRS).

- OWN – Boundaries of lands enrolled in the Managed Forest Law (MFL) and lands owned and managed by state and county governments were combined in a variable known as OWN. The OWN variable was treated as a factor and consists of three classes: 1) land is privately owned and not enrolled in the MFL program, 2) land is privately owned and enrolled in the MFL program, and 3) land is owned by the State or a County government.

Values for each variable were extracted for each analysis point. A logistic regression analysis was then conducted using the variable values to compute the probability of observing a timber harvest given conditions of proximity to wetlands, roads, and wood using facilities, and ownership/management conditions (Figure 2-3).

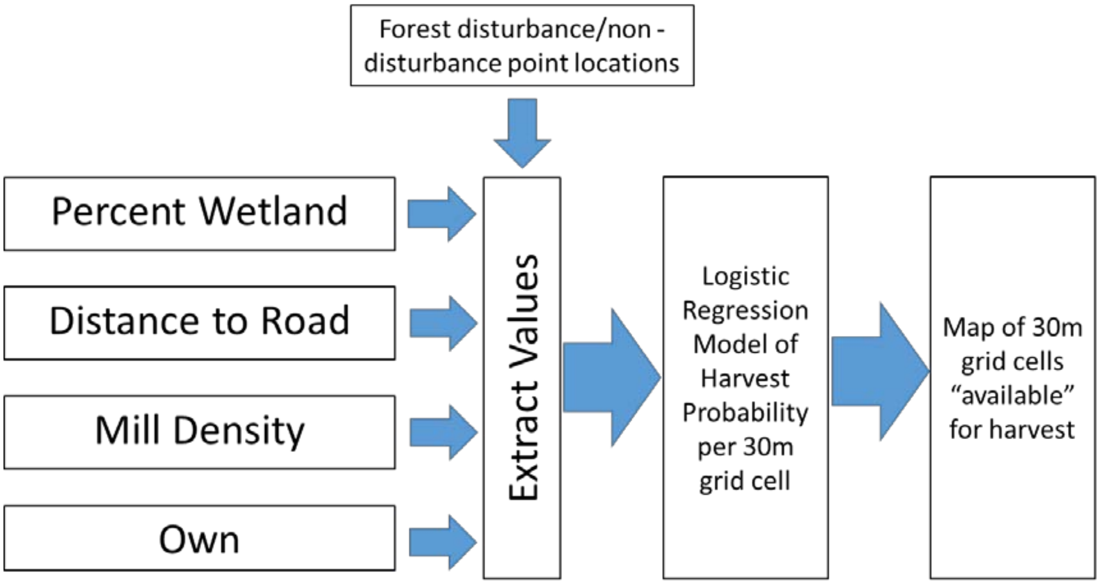

Figure 2-3. Procedure for harvest availability logistic regression model.

The result of the logistic regression analysis of availability was a model that predicted a probability of harvest for each NLCD forest pixel. Next, a threshold was selected to distinguish between lands that had similar characteristics to the lands previously experiencing a harvest to those that had not. For this analysis we chose a predicted probability of 0.4 as the threshold that best minimized false positives and false negatives. Forest area occurring on probabilities less than 0.4 were considered unavailable and forest area on probabilities 0.4 and greater were considered available[6]. Using this threshold we developed a map of available versus unavailable nonfederal forest area (Figure 2-4). Summarizing by region and forest type, we obtained available forest area in each forest type for each DNR region. These acreages were then multiplied by the per acre volumes we obtained in part 1 to derive estimates of available forest inventory.

[6] Checking against the reference data sources, 85% of harvests identified by county cutting notices, and 99% of harvests in state and county harvest datasets, occurred on land considered available.

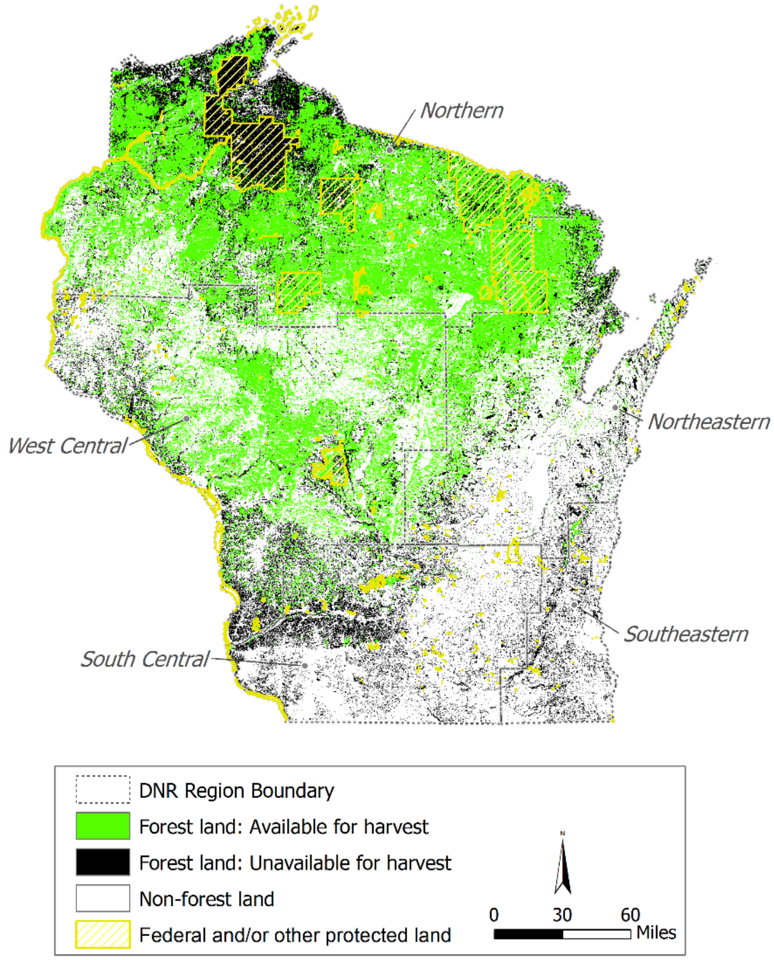

Figure 2-4. Forest land available for harvest, based on a 40 percent threshold.

Part 4. Growth on available forest

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

The growth metric of interest was net growth. FIA defines net growth as the total volume increment on all remeasured trees less 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, state, and county owned forests developed in a similar fashion to the volume estimates from Part 2, and the distribution of available acres from Part 3, we obtained growth on available forest by region and product class.

Part 5. Harvest Removals

One of the most important factors, and most difficult to determine, in a wood supply assessment is harvest removals. Due to the competitive nature of the wood-using industry, most companies are reluctant to release this information, and only do so under strict confidentiality agreements. Therefore it is useful to consult multiple sources of information to determine how much variability there is in estimates. We used three sources of data in this assessment.

The first dataset was FIA plot removals. These estimates are based on plot-level observations where trees have been harvested. The chances of observing a harvest on an FIA plot is relatively rare and the estimates have high variability. Also, since only a portion of FIA plots are measured in a given year, the removal estimates represent a moving average. Even though these estimates have drawbacks, they can provide a useful check against other data sources.

The second dataset used in the assessment was from the Timber Products Output (TPO) portion of the US Forest Service FIA Program. Data was accessed from the online database for 2012 (http://srsfia2.fs.fed.us/php/tpo_2009/tpo_rpa_int1.php, National RPA reports). This national program conducts periodic surveys of wood-using facilities to develop estimates of roundwood production by different product categories and source counties. We used county-level TPO reports (their Core Table 4), 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 was a proprietary database of mill locations and roundwood consumption distributed by the University of Georgia's Wood Demand Research Program (WDRP). The WDRP dataset is updated quarterly and we used demand data from third quarter of 2013. This dataset provides demand estimates in green tons for each mill at 100% capacity. There were 128 mills in Wisconsin included in the dataset and information on the type of mill, type of wood used, and location was provided. The WDRP database specifies the wood type used by each mill in five categories (Table 2-3). We allocated demand to species groups according to the values listed in Table 2-3.

Table 2-3. Allocation of demand to species group for the WDRP wood demand dataset.

WDRP Wood Type	Percent demand allocated to hardwood	Percent demand allocated to softwood
Hardwood	**100**	**0**
Hardwood/Softwood	**70**	**30**
Softwood/Hardwood	**30**	**70**
Softwood	**0**	**100**
Unknown	**50**	**50**

For consistency with repeatable, publicly available data, we selected TPO as the data source for estimating forest removals. Because the WDRP data represents mill capacity rather than actual production, we used TPO production estimates to compute percent capacity for the various product combinations to scale the WDRP demand dataset to match levels reported by TPO. TPO does not differentiate harvest removals originating from federal ownership. Based on the FIA plot removals data roughly 8% of the removals occurred on federal ownership. Since this analysis excludes federal ownership, TPO demands were reduced by 8% in the Northern WI DNR Region, where the majority of federal ownerships are.

Because neither TPO nor the WDRP data describe aspen production by region, aspen removals were estimated for each region by applying the proportion of hardwood removals that were in the aspen species group in FIA plot removals data.

Results

Forest parcel size distribution

Private Ownership Parcel Summary

In all regions in Wisconsin, ownerships in the 20-40 acre size class contained the most forest area (Figure 2-5). Statewide, about one-sixth of Wisconsin's private forest area occured in ownership parcels less than 20 acres.

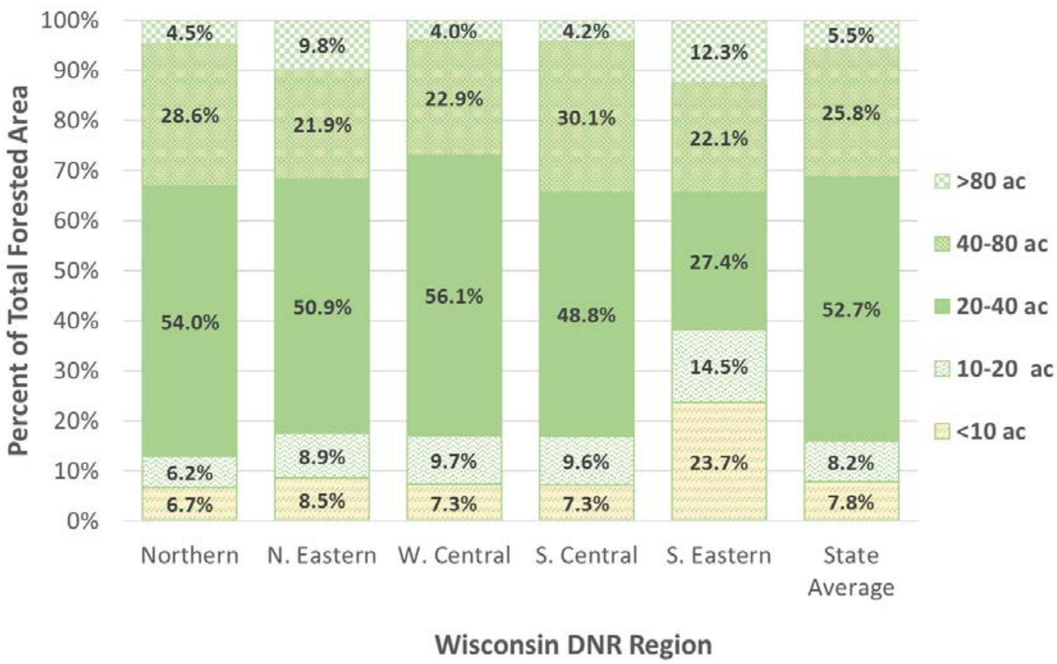

Figure 2-5. Size class distribution of private ownership parcels containing forest in Wisconsin.

Private Forest Tract Summary

The forest tract analysis (Figure 2-6) shows a much higher proportion of forest in the smallest size classes. Statewide, about 30% of private forestland was in tracts smaller than 20 acres.

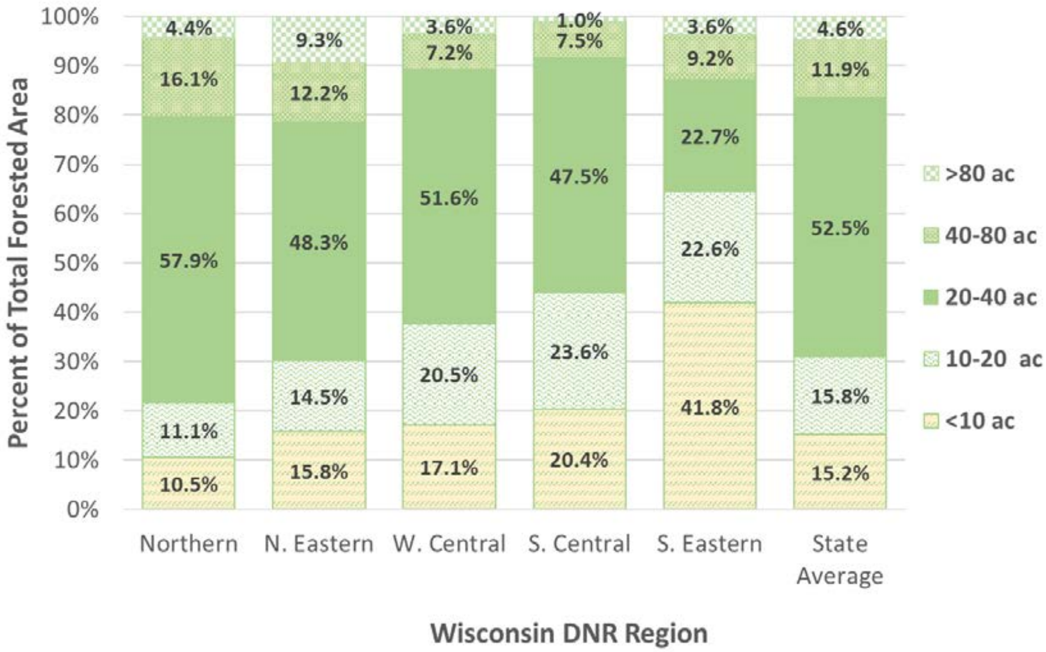

Figure 2-6. Size class distribution of privately owned forested tracts in Wisconsin.

Managed Forest Law Summary

The state of Wisconsin offers a landowner incentive program called the Managed Forest Law (MFL; Wisconsin DNR, 2013). Participants in the MFL program commit to a 25 or 50 year sustainable forest management plan. In return, they receive a tax incentive. Because the MFL spatial data is publicly available, we were able to conduct a similar parcel size analysis for MFL lands (Table 2-4). For this analysis, we analyzed MFL lands exclusively by size class to see if the trends were similar to the size class distributions (either ownership parcel or forest tract) of all private forests in Wisconsin. This shows, for example, that of the private forest acres in the 40 to 80 acre parcel size class, 44.6% (in the Northeastern region) to 71.8% (in the South Central region) are enrolled in MFL.

Table 2-4. The percentage of each forest parcel size class that is enrolled in the Managed Forest Law program by region.

Region	< 10 ac	10-20 ac	20-40 ac	40-80 ac	> 80 ac	Overall
Northern	16.1	29.3	47.2	56.8	37.7	**43.1**
N. Eastern	17.0	32.7	43.6	44.6	36.5	**37.3**
W. Central	20.0	33.4	47.6	58.8	29.9	**40.1**
S. Central	25.8	42.6	58.7	71.8	46.9	**49.0**
S. Eastern	9.1	20.9	26.3	20.6	18.5	**17.1**

Disturbance Event Summary

To determine harvesting patterns by parcel size, we estimated timber harvesting patterns using the Global Forest Change Dataset from 2000-2013 and parcel data (Hansen et al. 2013). Although disturbance events reported in the GFC data can span a wide range of events including timber harvesting, fire, or pest disturbance, we assumed that the majority of these events were timber harvests[7]. The Southeastern region was excluded from this analysis because of its urban nature. Table 2-5 shows the distribution of disturbed forest area in Wisconsin.

Table 2-5. Size class distribution of disturbed area in Wisconsin. Percentages represent the proportion of forest disturbances in a region that are of a given size class (acres).

Region	< 10 ac	10-20 ac	20-40 ac	40-80 ac	> 80 ac
Northern	0.3%	0.9%	36.1%	41.6%	21.1%
Northeastern	0.5%	1.7%	35.4%	32.2%	30.2%
West Central	0.6%	2.2%	32.1%	32.6%	32.5%
South Central	0.6%	2.4%	31.5%	33.2%	32.2%
State	0.4%	1.5%	34.5%	37.2%	26.4%

This analysis shows that very little timber was harvested from forest tracts smaller than 20 acres (<2% of disturbance; Table 2-5). Size classes greater than 20 acres generally had disturbance levels ranging from 25–40%.

Total and available forest area and inventory

The total forest inventory on Wisconsin's nonfederal forest lands is summarized by product and region in Table 2-6. Of about 637 million tons of merchantable wood in Wisconsin's nonfederal forests, 80% was hardwood (including aspen) and 20% was softwood. About 47.5% of total volume was designated in inventory data as sawtimber.

Using adjusted NLCD data, we estimated 15.2 million acres of nonfederal forest area in the state (Table 2-7; FIA reports 15.5 million acres of nonfederal forest, a difference of 2%). Of the nonfederal forest area, 62.4% was considered available based on our model.

We applied the average FIA volumes per acre by forest type and region to the available acres in Table 2-7 to estimate available forest inventory (Table 2-8). Approximately 64% of nonfederal inventory was considered available. Over 80% of the available inventory was in the Northern and West Central regions.

[7] Perry et al. (2012) report that the vast majority of forest disturbances measured by FIA are due to cutting.

Table 2-6. Total nonfederal forest inventory (thousand tons) by region and product class.

	Aspen		Hardwood		Softwood		
DNR Region	**Saw**	**Pulp**	**Saw**	**Pulp**	**Saw**	**Pulp**	***Total***
Northeastern	3,562	5,629	33,776	38,833	22,944	13,865	***118,610***
Northern	12,841	23,321	68,485	98,449	37,044	25,730	***265,869***
West Central	4,662	7,656	65,288	73,612	15,979	10,283	***177,480***
South Central	1,854	1,405	27,133	27,148	1,362	1,281	***60,182***
Southeastern	228	422	6,637	6,279	891	583	***15,039***
State Total	***23,146***	***38,433***	***201,318***	***244,321***	***78,219***	***51,743***	***637,180***

Table 2-7. Non-federal forest area (thousand acres) by forest type in Wisconsin based on 2011 NLCD data.

	Total forest area (thousand acres)			
Region	**Deciduous**	**Evergreen**	**Mixed**	***Total***
Northeastern	1,238	701	558	***2,497***
Northern	3,459	1,561	1,495	***6,515***
West Central	2,738	769	727	***4,234***
South Central	975	224	246	***1,446***
Southeastern	267	111	109	***487***
State Total	***8,676***	***3,367***	***3,136***	***15,179***
	Available (thousand acres) of forest			
Region	**Deciduous**	**Evergreen**	**Mixed**	***Total***
Northeastern	820	394	324	***1,537***
Northern	2,747	1,114	1,106	***4,968***
West Central	1,888	548	504	***2,940***
South Central	22	3	4	***30***
Southeastern	0	0	0	***0***
State Total	***5,478***	***2,059***	***1,939***	***9,476***

Table 2-8. Available nonfederal forest inventory (thousand tons) in Wisconsin, by region and product class.

	Aspen		Hardwood		Softwood		
DNR Region	Saw	Pulp	Saw	Pulp	Saw	Pulp	*Total*
Northeastern	2,308	3,664	22,002	25,210	13,433	8,122	***74,739***
Northern	10,098	18,375	54,089	77,566	27,428	18,973	***206,529***
West Central	3,219	5,293	45,090	50,881	11,271	7,274	***123,028***
South Central	42	31	620	618	23	22	***1,355***
Southeastern	0	0	2	2	0	0	***4***
State Total	***15,666***	***27,363***	***121,802***	***154,277***	***52,156***	***34,390***	***405,655***

Growth and removals

Using average annual rates of net growth per acre from FIA[8], applied to available nonfederal forest acres, we obtained estimates of net forest growth by region and product class for available nonfederal land (Table 2-9). Annual growth on available forest for the state was 11.8 million tons. This represents an annual net increment of about 2.9% of available inventory. Annual softwood growth was about 3.6% of softwood inventory, and annual hardwood growth was about 2.7% of hardwood inventory.

Table 2-9. Average annual net growth (thousand tons) on available nonfederal forestland in Wisconsin, by region and product class.

	Aspen		Hardwood		Softwood		
DNR Region	Saw	Pulp	Saw	Pulp	Saw	Pulp	*Total*
Northeastern	87	115	722	686	469	253	***2,333***
Northern	306	698	1,770	1,330	832	646	***5,582***
West Central	139	178	1,421	1,257	505	391	***3,890***
South Central	1	0	17	18	1	2	***39***
Southeastern	0	0	0	0	0	0	***0***
State Total	***532***	***992***	***3,930***	***3,291***	***1,807***	***1,292***	***11,844***

[8] Wisconsin 2013 FIA growth estimates are based on plots that were remeasured between 2009 and 2013. Growth is estimated based on the increment since a prior plot measurement which would have occurred between 2004 and 2008; so growth estimates derive from data collected between 2004 and 2013.

Table 2-10 summarizes total harvests by region and product class. About 60% of all removals came from the Northern region. Statewide, 77% of removals were hardwood and 23% were softwood. Aspen removals were estimated for each region by applying the proportion of hardwood removals that were in the aspen species group in FIA plot removals data.

Table 2-10. Wisconsin annual forest harvests (thousand tons) by region and product class.

	Aspen		Hardwood		Softwood		
DNR Region	Saw	Pulp	Saw	Pulp	Saw	Pulp	*Total*
Northeastern	59	197	342	431	159	239	***1,426***
Northern	112	1,049	649	2,299	368	672	***5,149***
West Central	64	260	368	571	110	352	***1,724***
South Central	24	13	141	30	1	52	***251***
Southeastern	2	2	11	5	0	21	***41***
State Total	***261***	***1,522***	***1,510***	***3,335***	***638***	***1,336***	***8,601***

One widely-used indicator of the sustainability of harvest levels is the ratio of growth on available forest to removals (assumed to come almost exclusively from available forest). When growth exceeds harvest, the growth:removals (G:R) ratio will be greater than 1.0 and inventory levels will generally be increasing. A ratio at or near one indicates that growth and removals are in balance, while a ratio less than 1.0 indicates that harvested volumes exceed annual growth and that the current harvest rate may not be sustainable (depending, for example, on forest age class distributions). Growth:removals ratios for nonfederal available forest in Wisconsin are depicted in Table 2-11.

Table 2-11. Growth:Removals ratio for available nonfederal forest by product class and region.

	Aspen		Hardwood		Softwood		
DNR Region	Saw	Pulp	Saw	Pulp	Saw	Pulp	*Total*
Northeastern	1.5	0.6	2.1	1.6	2.9	1.1	***1.6***
Northern	2.7	0.7	2.7	0.6	2.3	1.0	***1.1***
West Central	2.2	0.7	3.9	2.2	4.6	1.1	***2.3***
South Central	0.0	0.0	0.1	0.6	1.8	0.0	***0.2***
Southeastern	0.0	0.0	0.0	0.0	0.0	0.0	***0.0***
State Total	***2.0***	***0.7***	***2.6***	***1.0***	***2.8***	***1.0***	***1.4***

Annual growth of Wisconsin's sawtimber resource exceeded annual harvest, both for total forest and when availability was factored in (excluding the Southeastern and South Central DNR regions). Removals of sawtimber (all categories) is far below growth, leading to very positive G:R ratios. For pulpwood, however, harvests of 6.2 million tons exceeds growth of 5.6 million tons, leading to a pulpwood G:R of 0.9. The aspen pulpwood resource is especially heavily utilized, with statewide growth equal to only 65% of removals.

Another way of portraying the balance between growth and harvest removals is to compute "surplus growth", or the amount that growth exceeds harvest. This represents the amount by which harvest could potentially increase without exceeding growth. When this value is negative, it represents the amount by which harvest exceeds growth.

Table 2-12. Surplus growth (thousand tons) on available nonfederal forests in Wisconsin by product class and region. Surplus growth is computed as net growth minus removals.

	Aspen		Hardwood		Softwood		
DNR Region	Saw	Pulp	Saw	Pulp	Saw	Pulp	*Total*
Northeastern	27	(81)	381	255	310	15	***906***
Northern	194	(351)	1,121	(969)	464	(26)	***433***
West Central	75	(83)	1,053	687	395	39	***2,166***
South Central	(23)	(13)	(124)	(12)	1	(50)	***(222)***
Southeastern	(2)	(2)	(11)	(5)	0	(21)	***(40)***
State Total	***271***	***(530)***	***2,420***	***(44)***	***1,169***	***(44)***	***3,243***

Again, we see that harvest of pulpwood statewide exceeded growth by about 618,000 tons annually, or about 0.3% of available pulpwood inventory. The largest surplus growth is in the West Central region, which has two-thirds of the surplus growth in the entire state.

Discussion

While Wisconsin has abundant forest resources, much of it appears to be "out of reach" of the forest industry. Examining spatial data for evidence of patterns in timber harvest resulted in a model that predicted availability as a function of distance to road, land ownership, percent wetlands within a 50-acre circle, and number of mills within 100 square miles. Using this model, we estimated that 62.4% of nonfederal forest acres and 64% of nonfederal forest inventory was available to timber markets. While some harvest does occur on land designated by the model to be unavailable (and on federal lands that were excluded from this analysis), the available resource provides the vast majority of commercial timber in the state.

Focusing on just the available resource provides a more pessimistic picture of growth and removals than other assessments. For example, Perry et al. (2012) reported a G:R of 1.84 statewide in 2009, while our estimate for the available resource was 1.38. Regional disparities are evident, with the West Central region showing much higher surplus growth (and G:R) than other regions in the state.

Product differences also appeared to be substantial, with the pulpwood resource under much greater pressure than the sawtimber resource. Pulpwood accounted for 72% of removals, and pulpwood removals exceeded growth by some 618,000 tons annually. However, interpretation of G:R by product class is challenging for the following reason. Sawtimber inventory is defined in the field primarily based on tree diameter and quality. Pulpwood volumes are computed as total tree volume minus sawtimber volume. However, on the removals side, sawtimber is reported as any wood purchased by a sawmill or veneer mill, while pulpwood is defined as wood purchased by paper mills and wood composite mills. Quite often, when competition for pulpwood is strong, trees that would be considered sawtimber based on diameter by a forest inventory are purchased and used as pulpwood by mills[9]. This is especially true when a pulp mill is closer to a timber harvest than a sawmill, and transportation costs make it financially appropriate to purchase larger diameter trees as pulpwood. Thus, when we compute G:R ratios by product, it is quite likely that some growth that is currently reported in the sawtimber column (based on tree diameter) should be balanced against pulpwood removals. This would have the impact of decreasing sawtimber growth (and thereby G:R) and increasing pulpwood growth (and G:R).

The imbalance between aspen growth and removals is not new, and has been reported in previous assessments (Wisconsin DNR, 2015). The current annual amount by which aspen harvest exceeds growth (on available forest) is 259,000 tons, which represents less than 1% of aspen available inventory.

Summary

This forest resource assessment for Wisconsin was based on extensive analysis of spatial data and forest inventory data. Of Wisconsin's nonfederal forest land, 40% was in forest patches less than 20 acres in size which has implications for the commercial availability of much of the private forest land in the state. Only about 64% of nonfederal forest inventory was on sites similar enough to recent forest harvests to be considered available. While Wisconsin has surplus growth (on available land) of about 3.2 million tons annually, this surplus varies considerably by region and product class, with most surplus in the West Central region and almost exclusively in sawtimber-sized trees. This indicates very constrained conditions for industries relying on pulpwood-sized material in Wisconsin, a highly competitive environment that may be expected to lead to increases in wood cost in the pulpwood sector.

[9] According to discussions with a number of procurement and consulting foresters in the southeastern US, purchase of sawtimber-sized trees for use by manufacturers of pulp or OSB is increasingly common in competitive markets.

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Chapter 3. Predicting harvesting behavior of family forest owners in Wisconsin

Introduction

Forestry in Wisconsin is one of the top ten economic sectors and thus an important contributor to the overall economic growth of the state (Ballweg 2014). To sustain this economic sector, a healthy supply of wood for industrial outputs is needed, as well as trees on the landscape for other environmental services, like recreation and wildlife habitat provision. Roughly 56% of Wisconsin's forests are owned by family forest owners; this ownership is composed of families, individuals, and unincorporated groups whose primary management objectives are related to aesthetics and hunting and fishing (Perry et al. 2012). Thus, there is concern among many that while there appears to be an abundance of timber in Wisconsin, much of this timber will not be available to the forest products industry because many of these private landowners are unwilling to sell timber. Perry et al. (2012) report that 62% of family forest landowners have commercially harvested trees, yet there is growing concern in the state about timber availability, particularly from private lands due in part to low prioritization of timber production amongst family forest owners and decreasing parcel sizes within these ownerships in the state (DeLong 2013).

There is a vast amount of literature that attempts to assess management behavior of family forest owners, particularly when it comes to decisions like harvesting and reforestation, as a result of their majority ownership of the forest resource in parts of the United States, as well as a diversity in their management objectives (summaries are found in: Amacher et al. 2003, Pattanayak et al. 2002). However, specific empirical research on the harvesting and management behavior of Wisconsin landowners is lacking, apart from inclusion in the National Woodland Owner Survey (Leatherberry 2003, Butler 2008) and observations of removals, such as those in USDA Forest Services' Forest Inventory Analysis database (e.g., Perry et al. 2012). Much of the research on Wisconsin family forest landowner objectives and behavior (e.g., Rickenbach et al. 2005, Knoot and Rickenbach 2011) was undertaken to refine and further develop policies and programs targeted at fostering sustainable forest management on these lands, and did not assess the harvesting behavior of landowners under various market conditions (e.g., prices).

Harvesting and management behavior of family forest owners is difficult to assess, as it is not generally observable unless landowners participate in harvesting or some other government sponsored program (such as participation in reforestation and cost-share programs). Thus characteristics and preferences that drive decisions to harvest are either measured *ex post*, over a specific range of time, and/or using variables derived from sources other than landowners themselves (e.g., Dennis 1990, Pattanayak et al. 2003, Kuuluvainen and Salo 1991). There continues to be interest in the behavior of family forest owners with regards to harvesting and management behavior, both within and outside of the state of Wisconsin, as landholdings are becoming more diversified and smaller parcels are becoming more prominent on the landscape (Gobster and Rickenbach 2004, Kelly et al. 2015). We set out to not limit the analysis to determine and define characteristics of those landowners observable through their entrance into the timber market (e.g., through a timber harvest), but rather to understand characteristics of those landowners along with landowners who may not have encountered conditions in the market favorable to their participation. We would expect that landowners on the margin of participating in the market may find an acceptable price offer among those offered in our study, and it is how their preferences and characteristics, as well as land characteristics, factor in this decision that we further explore.

Predicted harvest behavior

We studied landowner behavior regarding the decision to harvest as a binary choice. This was based on a review of literature on landowner harvest decisions (Amacher et al. 2003, Pattanayak et al. 2002, Vokoun et al. 2006). Similar to Vokoun et. al. (2006) we were not interested in specifically determining the price that a landowner would be willing to accept for harvesting of their timber, but rather we examined a hypothetical situation where a landowner was offered a price for harvesting as if there were mature hardwoods on their property at a given point in time. How the landowner reacted to the offered price was thus considered indicative of their choice at a point in time when mature hardwoods were present on the property and the harvest decision was under consideration.

We assumed, as in the literature on landowner harvest decisions, that landowner behavior regarding forest management decisions such as harvesting is based on maximizing utility derived from the forest and land resource. This utility is derived from both timber and amenity outputs. This point-in-time decision of harvest mimics the situation found in the reservation price literature, that the probability of accepting a price will depend on it being greater than or equal to the minimum acceptable price of the forest landowner. The determination of the minimum acceptable price by the landowner stems from the utility maximization assumption.

As a utility maximizer, the landowner was assumed to equate their marginal benefit of delaying harvest to the expected discounted opportunity cost of delaying harvest. Thus the landowner determines whether to harvest timber by assessing the present value of benefits resulting from harvesting, where this includes primarily income generated from harvest as amenity values are assumed to be lost upon removal of timber, as well as the expected costs generated from delaying harvest for an additional year. The expected costs of delaying harvest arise from both timber and amenity values, where they are respectively determined by the present value of stock in terms of additional growth of timber and present value of amenities generated from the standing timber on the landowner's parcel. A landowner is thus presumed to harvest only when the additional benefit from delaying harvest one more year (marginal benefits of delay) is equal to the opportunity cost of delaying harvest an additional year. The latter is essentially the expected cost of delaying harvest in terms of lost timber and amenity benefits that could be had if the landowner let the timber grow an additional year. This follows work by Sullivan et al. (2005) where the probability that a landowner will accept a bid only if it is greater than their reservation price (the equivalent variation) which is known only to the landowner:

$$\Pr(H_t = 1) = \frac{e^{\gamma\tilde{Z}}}{(1+e^{\gamma\tilde{Z}})} \qquad (1)$$

The probability of harvest at time *t* was modeled as a discrete choice, where γ represents the coefficients to estimate for this decision. Given that we asked landowners whether they would be willing to harvest at a specific price, this price should be an explanatory variable in Eq. (1) along with factors that have been found to contribute to landowner entry into timber supply markets such as: net assets of the landowner at the point in time (A), landowner demographic characteristics (D), characteristics of the land (presence of structures, extent of ownership, general terrain, S), landowner preferences and amenities (including reasons for owning forest, O), time (t), and current and future market conditions (M). Thus, the vector of explanatory variables can be expressed using $\tilde{Z} = \{A, S, D, O, P, \mathrm{t}, \mathrm{M}\}$, as this is modeled as a point in time decision with landowners are indicating acceptance or rejection of prices for harvesting one acre of mature hardwood forest.

We assumed that landowners harvested only when their expected value of harvest met or exceeded their expected value of timber income plus the value received from amenities (similar to model developed by Hartman, 1976). Thus, current and future market conditions as well as conditions of existing stock were included as explanatory variables in the model. The coefficients for the explanatory variables were estimated using a logit model conducted with the PROC LOGISTIC in SAS 9.2 (SAS Institute, Cary, N.C.), where the probability of harvest takes on a value of '1' if the landowner accepts the offered bid and zero otherwise. Marginal effects were computed using the change in predicted probabilities method. The change in the probability of a landowner harvesting (e.g., accepting an offered bid) was estimated holding the other explanatory variables at their sample mean.

Methods

Data were obtained using a mail survey conducted during the spring of 2015 of 2,000 forest landowners in Wisconsin. Approximately 500 landowner names were randomly selected from each of four Department of Natural Resources regions where wood production was most likely to occur: Northern (including Polk, Taylor, and Washburn counties), Northeast (including Marinette, Manitowoc, and Outagamie counties), West Central (Chippewa, Pierce, and Wood counties), and South Central (Columbia and Richland counties). These counties were selected due to availability of land ownership records within their publicly available Geographic Information System (GIS) database. Corporate ownerships and ownerships with less than 10 forested acres in size were not included in the sample. The latter constitutes the minimum parcel size that can be included in Wisconsin's Managed Forest Law program, and was considered to be a reasonable screening variable for forest parcels that may constitute a unique set of management actions, if they are managed at all.

The survey was implemented with a modified Dillman (2007) process and included an initial information letter, initial questionnaire with cover letter and self-addressed stamped return envelope, and a final questionnaire package. The response rate was 43% based on the minimum response rate calculation defined by the American Association for Public Opinion Research (2008). All ineligible cases, including non-deliverables, deceased, no longer owned, unable to complete, duplicates, and landowners who replied as not having at least 5 acres of forestland, were removed from the initial total (2000-133 confirmed ineligible cases), resulting in a final sample of 1,867. Of these 1,867 landowners, we received completed responses from 809, resulting in a response rate of 43%. The questionnaire was an eight page booklet with 34 items (some with multiple parts) that asked respondents about characteristics, management, and use of their land parcel, future plans for their land parcel, and demographics. Questions in the survey were adapted from Vokoun et al. (2006) and the National Woodland Owner Survey (USDA Forest Service).

The survey instrument utilized a closed-ended contingent valuation (CECV) approach, where respondents are asked to either accept or reject a specific sum, and was very similar to situations encountered by everyday consumers (Cameron and James 1987). In this survey, respondents were given a description of forests and the services they offer as well as general harvesting and regeneration cycles and a range of harvesting revenues. All landowners were asked to suppose that they had a mature hardwood forest on their property, placing them all in the same position regarding the state of the forest resource on their land. This was followed by the CECV question where the respondent would be willing to participate in timber harvesting. Respondents received one of four possible bids: $1500, $3000, $5000, or $6500, and were asked to accept or reject this bid for harvesting one acre of mature hardwood forest. Landowners selecting either negative option as well as the 'not sure' option to the proposed bid were considered to be no votes in the discrete choice framework. The inclusion of 'not sure' voters amongst the population of 'no' voters is consistent with recommendations on contingent valuation literature (Carson et al. 1998).

Results and Discussion

Selected descriptive statistics are presented in Table 3-1. Respondents owned an average 66-acre forested parcel and 78.1% of respondents had less than one mile of dirt or paved roads on their parcel. Average respondents were 61 years old with 2.4 children and had owned their parcel for 23.5 years. Nearly 35% of respondents resided on their parcel, with only 28% classified as absentee, where they had indicated that their primary residence was more than 50 miles from their parcel. Nearly 44% of respondents were retired and 45% of respondents had completed college (responded highest level of completed education was an associate, bachelor, or advanced degree). Approximate combined family income averaged just over $85,000; the income variable was created using the midpoint value for each range of categorical values (8 range options extending from less than $25,000 to $200,000 or more) offered to respondents. Nearly two-thirds of respondents (63%) plan to give land to heirs, while less than one-quarter (23%) plan to give trees that are now on their land to heirs. A majority of respondents (78.2%) acquired their parcel through purchase. Over 30% of respondents indicated that they had a written management or stewardship plan and/or had hired a forester to help manage their property.

Table 3-1. Means and standard errors, and units of measure (binary variables coded 0 = no, 1 = yes) for selected survey variables from Wisconsin forest landowner survey conducted Winter/Spring 2015.

Variable	Mean	Std. error
Forested land (acres)	66.213	2.24
Age (years)	61.343	0.392
Income ($)	86,474	2161.63
Completed high school (0,1)	0.304	0.163
Completed some college (0,1)	0.222	0.015
Completed college (0,1)	0.449	0.018
Dirt or paved roads (miles)	0.862	0.032
Retired (0,1)	0.439	0.018
Bought land (0,1)	0.782	0.015
Inherited land (0,1)	0.151	0.013
Years owned property	23.540	0.486
Written management or stewardship plan (0,1)	0.332	0.017
Hired forester to help manage property (0,1)	0.317	0.017
Salable trees harvested w/in last 3 years (0,1)	0.171	0.013
Absentee (0,1)	0.283	0.016
Reside on property (0, 1)	0.353	0.017
Give land to heirs (0, 1)	0.632	0.017
Give timber to heirs (0, 1)	0.231	0.015
Number of children	2.4395	0.059

Respondents were asked to rate the importance of 10 reasons for owning land on a five point scale with one indicating not important and five indicating very important. Reasons to provide or improve wildlife habitat, hunting and/or fishing recreation, privacy, scenic beauty, to pass on to future generations, and environmental reasons all had a mean score at or near four indicating they were viewed as important (Table 3-2). Income generating reasons for ownership, such as land investment/real estate income and income from timber production, had average scores that reflected moderate to little importance, respectively. Plans for future management actions on land reflected these preferences. Respondents indicated the likelihood of 11 practices on their property in the next three years on a 1 to 5 scale (1 = extremely unlikely and 5 = extremely likely). Several practices had means at or above three (undecided) including: manage to improve wildlife habitat, cut trees for own use or purposes other than selling, collect products other than trees from the forest, and trail construction or maintenance (Table 3-2).

Table 3-2. Ranked mean values (standard error) of variables corresponding to respondent importance of reasons for owning land and likelihood of undertaking management practices in survey of Wisconsin forest landowners conducted Winter/Spring 2015.

Importance of ownership: Categories: 1 = not important, 2 = of little importance, 3 = moderately important, 4 = important, 5 = very important	
To provide or improve wildlife habitat	4.255 (0.0327)
Hunting and/or fishing recreation	4.085 (0.0429)
Privacy	3.986 (0.0400)
Scenic beauty	3.980 (0.0356)
To pass land on to future generations	3.949 (0.0408)
Environmental reasons (protection of nature, protection of water quality, prevention of erosion)	3.657 (0.0403)
Recreation other than hunting or fishing	3.379 (0.0455)
Land investment/real estate	2.983 (0.0457)
Primary or secondary residence	2.888 (0.0572)
Income from timber production	2.430 (0.0381)
Management Practices: Categories: 1 = extremely unlikely, 2 = unlikely, 3 = undecided, 4 = likely, 5 = extremely likely	
Manage to improve wildlife habitat	3.597 (0.0434)
Cut trees for own use or purposes other than selling	3.387 (0.0522)
Collect products other than trees from the forest	3.121 (0.0525)
Trail construction or maintenance	3.030 (0.0513)
Plant trees	2.896 (0.0489)
Manage to reduce invasive plant species	2.759 (0.0466)
Manage to reduce invasive insects or diseases	2.569 (0.0448)
Manage to improve water quality	2.467 (0.0443)
Cut trees for sale	2.414 (0.0492)
Road construction or maintenance	1.923 (0.0443)
Conduct a prescribed burn to reduce fire hazard or promote forest regeneration	1.496 (0.0298)

Econometric estimation of the parameters that might factor in a landowner's harvesting decision (Eq. 1) can provide a better understanding of the role that bid price, land and owner characteristics, and landowner preferences have amongst this population and their decision to participate, through harvest, in the timber supply market. The overall logit model was significant at a $p<=0.01$, with six of the seventeen variables significant ($p<0.05$).[10] Coefficients for the following variables were significant in predicting probability of harvest at the 5% significance level or better: the constant, bid price, presence of structures, number of children, importance of environmental reasons for ownership, and a written management or stewardship plan (Table 3-3). Model significance overall was p<=0.001 for likelihood ratio, score, and wald tests.

Table 3-3. Logistic regression coefficient estimates for harvesting probability model of Wisconsin woodland landowners (dependent variable is bid acceptance probability), bolded significance when p-level <=0.05.

Variable	Coefficient	Std. error	Significance	Marginal effects
Constant	-1.2908	0.6065	**0.0333**[a]	
Price offered	1.98E-4	5.9E-5	**<0.0001**[a]	**4.45E-5**[a]
Flat terrain	-0.1010	0.1896	0.5943	0.0230
Structures present	0.3826	0.1891	**0.0430**[a]	**0.0869**[a]
Forested acres	2.32E-3	1.57E-3	0.1390	5.26E-3
Number of children	-0.1544	0.0621	**0.0129**[a]	**0.0350**[a]
Years property owned	0.0121	7.79E-3	0.1198	0.0027
Risk perceived with tree loss	-4.82E-3	0.0928	0.9586	-0.001
Risk perceived with growing trees for investment	0.0282	0.0928	0.7614	0.0632
Importance of environmental reasons for ownership	-0.2462	0.0851	**0.0038**[a]	**-0.0558**[a]
Importance of land investment/real estate for ownership	4.13E-3	7.39E-2	0.9554	8.57E-4
Harvested for sale within last 3 years	-0.1335	0.2542	0.5996	-0.0321
Acquired land through purchase	0.2384	0.2322	0.3045	0.0553
Written management plan or stewardship plan	0.5595	0.2053	**0.0064**[a]	**0.1264**[a]
Income	1.97E-6	1.70E-6	0.2468	4.45E-7
Absentee	0.2545	0.2092	0.2237	0.0560
Retired	-0.2851	0.2087	0.1719	-0.0627

[a] bolded significance when p-level <=0.05

As expected, the coefficient on bid price was positive and significant, indicating that a higher price offered for harvesting led to a higher probability of the bid for harvesting an acre of mature hardwood being accepted. Among the amenity and preference characteristics in our model, the coefficient for

[10] Landowners responding positively to a bid offered for harvesting were subsequently asked to respond to a question regarding the percentage of the forested acre they would harvest (three categories were offered, along with an "other" option). At the time of the report initial analyses of these responses were not significant.

importance of environmental reasons for ownership (protection of nature, protection of water quality, prevention of erosion) was negative, thus indicating as the importance of ownership for environmental reasons increases, the lower the probability of accepting a bid. The sign of coefficients on a land characteristic, the presence of permanent structures (e.g., house, cabon, trailer, barn), and a landowner characteristic, number of children (negative) by Wisconsin forest landowners were contrary to results of a similar study of Virginia landowners by Vokoun et al. (2006). However, this difference in the sign of the effect of these variables in the probability of harvest amongst Wisconsin landowners could be the result of difference between the use of just harvest in this model and scale of harvest at the lowest acceptable price in the Virginia model.

The presence of permanent structures might indicate greater familiarity with the resource and thus greater willingness to harvest, as harvest may increase overall accessibility of the parcel. Also, given the increased preferences for wildlife habitat amongst landowners in the sample, an acre of harvest (at any of the proposed harvest scales offered) would create an excellent potential wildlife food plot. Also, landowners with structures on their parcel might pay higher taxes on land due to the "developed" nature of the parcel and thus their overall holding cost becomes higher, thus increasing their eventual probability of conducting a harvest.

The sign on the coefficient on the variable indicating the number of children was negative and significant. Thus landowners with larger numbers of children have a lower probability of accepting the bid for harvesting an acre of mature hardwood forest. This is contrary to the 'Volvo effect' where a landowner might be expected to use their forest as a bank, rather than borrow money, in order to offset expenses that might be generated by an increasing number of offspring (Brazee 2003). The sign on the management plan variable was positive and significant, indicating that those individuals with a written management or stewardship plan are more likely to accept a bid for harvesting timber.

To obtain a better understanding of how changes in these predictor variables might impact the probability of bid acceptance by a representative landowner from our sample, we computed the marginal effects using predicted probabilities at the sample mean (Table 3-3). The marginal effects indicate how probability will change with a one unit change in the predictor variable for categorical and dummy variables while holding all other variables constant at the mean. A similar interpretation can be made for continuous variables, however bid prices are more likely to change on an order of magnitude and the marginal effects adjusted accordingly. Thus, we could say that a landowner with structures on their property was 8.6% more likely to harvest than one whose property contained no structures, holding all other variables at their mean. Landowners with management or stewardship plans were nearly 13% more likely to harvest than those without. An increase in bid price from the mean ($3,984) to the next offer ($5,000) would result in a 0.45% increased probability of acceptance. Landowners who indicated that environmental reasons for ownership were very important (score of 5) were 5.5% less likely than those indicating importance (score of 4) to find an acceptable bid for harvest. Landowners with one additional child were less likely to accept the bid offered (harvest) by 3.5%.

Conclusions

The results indicated that responding landowner probability of harvest was dependent on not only the price offered, but on land and owner characteristics, as well as landowner preferences. As might be expected, landowners responding to the study were more likely to accept bid to harvest if the offer was higher. Our results suggest that landowners whose parcels had structures or who had a written management plan were more likely to find an acceptable bid offer (e.g., exhibit entry through harvest into the timber market). Variables that had a significant and negative impact on the probability of accepting an offered bid were the importance of ownership for environmental reasons and the number of children. Interestingly, variables like income and forested acreage were not significant in this model, as has been the case in past studies of landowner harvesting behavior (Amacher et al. 2003).

The advantage of the approach used here in studying harvesting behavior is that it allowed us to consider the behavior of landowners who may be on the margin, those who have not encountered an optimal price for harvesting in the marketplace. Our results seem rather intuitive, yet also provided something to aim for in terms of policy or educational actions. For instance, an opportunity for education, or “framing the message” in terms of harvest for the purposes of benefiting wildlife, mimicking natural processes, or responsible harvesting that would protect against erosion, existed amongst responding landowners who viewed environmental reasons as important for ownership. Similar messages might be communicated to forest owners with larger families, especially given the high importance of hunting and fishing recreation. Nearly 81% of respondents spent at least one day in this type of activity on their property.

Landowners in Wisconsin may have had lands enrolled in the Managed Forest Law (MFL) or Forest Crop Law programs, which provide incentives in the form of reduced land holding costs (e.g. property tax rates) in exchange for a written management plan including the schedule of harvest activities (and the payment of severance tax upon harvest). This program incentivizes the stream of timber coming from enrolled parcels, many of which are held by family forest owners. Further extensions of the model could identify landowners enrolled in MFL, by examining the land use codes attached to the GIS parcels. We currently have a proxy for this type of landowner in the model, with the variable associated with having a written management or stewardship plan, but this could include landowners that are not currently enrolled in MFL. A logical extension of the analysis conducted here would be to further investigate landowners who selected the ‘not sure’ option to a proposed bid, as it is possible for individuals to have selected this option due to the prescriptive nature and timing of harvests dictated by enrollment in the MFL program and thus selection of this option by these landowners might not necessary indicate disagreement, due to lack of information or characteristics of the land or landowner themselves, but could have been a factor of timing of the survey itself.

Further analysis of this data should explore the validity of the initial model of probability of harvest through a stepwise logit or log-likelihood tests, especially given the lack of significance of previously documented explanatory variables (Amacher et al. 2003). Predicted probabilities of harvest could then be constructed using significant variables in the resulting model, which could be used to forecast the extent of harvesting that might occur on the landscape when a landowner finds a price that met or exceeded their minimum value for the standing timber and amenities. Similarly, predicted likelihood of future management practices by landowners in our sample could be modeled as a factor of landowner preferences and amenities, demographics, and parcel characteristics.

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Chapter 4. Logging Capacity Utilization in Wisconsin

Introduction

There are developing concerns about the adequacy of logging capacity in Wisconsin. Recent studies in Wisconsin and elsewhere indicate that loggers tend to be older than the U.S. population as whole, independent loggers are leaving the industry, and the industry is struggling to attract and retain new logging businesses (Baker and Greene 2008, G.C. and Potter-Witter 2011, Rickenbach et al. 2015). Rickenbach et al. (2015) estimated that 20% of Wisconsin loggers left the industry between 2003 and 2010 and an additional 22% are expected to depart by 2016. If this comes to fruition, the state will have lost more than one-third of its loggers in a little more than a decade.

To date the loss of loggers has not resulted in wood shortages because the logging industry in the U.S. has carried surplus capacity for many years (Loving 1991, LeBel 1993, Greene et al. 2004), and production increases from existing loggers has offset some of the capacity losses resulting from loggers leaving the industry (Greene et al. 2013). However, there is no guarantee that productivity gains from surviving loggers will continue to replace lost capacity. Most Wisconsin loggers are already mechanized (Rickenbach et al. 2015), which makes it unlikely that productivity gains will continue at the pace observed over the past thirty years. Therefore, if loggers continue to leave the industry, it could result in a shortage of logging capacity in Wisconsin.

Logging capacity can be defined as the amount of timber that loggers are capable of harvesting in a specified period of time. Logging capacity utilization refers to the percentage of logging capacity that is actually being used during a given period. Theoretically, 100% logging capacity utilization would minimize the cost of delivered wood; however, achieving this level of utilization is impossible because of weather, mill quotas, regulations, etc. Recent surveys suggest that loggers were producing at 60% and 82% of capacity in Minnesota (Blinn et al. 2015) and Michigan (G.C. and Potter-Witter 2011), respectively. In Wisconsin, logging capacity utilization ranged from 50% for loggers producing less than 1,000 cords per year to 80% for loggers producing more than 15,000 cords per year (Rickenbach et al. 2015). However, this research asked loggers to estimate their capacity utilization; it did not actually measure it.

The majority of logging capacity research was conducted in the U.S. South more than a decade ago. Loving (1991) found that the U.S. South was utilizing only 51-59% of logging capacity in 1988 and 1989. Likewise, logging capacity utilization in the early 1990s was just 70% (LeBel 1993). In the early 2000s, the U.S. South and Maine were utilizing only 65% of their logging capacity, and this inefficiency cost the wood supply chain more than $430 million annually (Greene et al. 2004).

Clearly, there was excess logging capacity in the U.S. South from the late 1980s through the early 2000's because of substantial increases in productivity resulting from mechanization (Loving 1991, LeBel 1993, Greene et al. 2004). Therefore, the loss of loggers in this region in recent years probably made the wood supply chain more efficient by having fewer loggers working closer to capacity. It is unclear whether Wisconsin's loss of logging capacity is having the same effect. If Wisconsin loggers are producing near their capacity today, then continued reductions in logging capacity could make it difficult for Wisconsin mills to procure the wood that they need. Furthermore, independent loggers have historically been the primary purchasers of stumpage in Wisconsin (Rickenbach et al. 2005). Thus, the loss of loggers could have a greater impact than it would in the South where dealer systems are more common (Chumbler 2002, Greene et al. 2013).

The primary causes of unused logging capacity in previous studies were mill quotas, weather, and moving (LeBel 1993, Greene et al. 2004). In these studies, the impact of regulations had a relatively small impact on production; however, regulations have tightened since these studies were conducted as best management practices have been refined and forest certification systems have come into vogue (Ice et al. 2010). It is not known whether these regulations are significantly reducing logging productivity and capacity utilization.

The state of Wisconsin has a number of unique regulations that have the potential to reduce logging capacity utilization. For example, during spring break-up many roads have reduced weight limits (Wisconsin Department of Transportation 2015) that impede the movement of timber from logging sites to mills. In addition, the Wisconsin Department of Natural Resources (WDNR) currently recommends that stands with at least 15 square feet of oak basal area per acre not be harvested between early to mid-April and mid-July if the stand is located in a county that contains oak wilt or is within six miles of a county with oak wilt (WDNR 2015). Finally, Wisconsin loggers correctly implement best management practices (BMPs) for water quality more than 90% of the time (WDNR 2010). While all of these regulations and guidelines may be necessary and useful, they all have the potential to reduce logging capacity utilization.

In summary, the state of Wisconsin faces two challenges regarding logging capacity. First, because loggers are leaving the industry, current and future logging capacity may limit timber availability to Wisconsin mills. Second, barriers such as weather, regulations, and mill quotas may be reducing logging capacity utilization, which would increase harvesting costs and serve as disincentives for loggers to invest in their businesses. Therefore, the goals of this study were to estimate logging capacity utilization in Wisconsin and identify the causes of lost production.

Methods

In order to measure logging capacity utilization, we asked Wisconsin loggers to report their production weekly beginning the week of September 28, 2014 and ending the week of August 29, 2015. We recruited members of the Great Lakes Timber Professionals Association (GLTPA) and the Wisconsin Master Logger Program to participate in this study. Loggers were recruited in-person at the 2014 Great Lakes Logging and Heavy Equipment Expo. GLTPA members that did not agree to participate at the Expo received an invitation letter along with a profile form and return envelope in mid-September of 2014. A similar invitation with an enclosed profile form and return envelope were sent to Wisconsin Master

Loggers in late September of 2014. Loggers were asked to return the profile form with contact information if they were willing to participate in the study. Seventy-nine logging businesses representing approximately 120 logging crews returned the logger profile form. These loggers were contacted by phone to confirm their willingness to participate and to collect information on their timber harvesting equipment; number of employees; typical work schedule; and maximum, target, and break-even production levels. Forty-four logging businesses representing 68 logging crews agreed to participate after a telephone conversation. Thirty logging businesses representing 40 logging crews reported at least one week of data, while twenty-five logging businesses representing 30 logging crews reported at least four weeks of data and were included in the analysis.

Participants were given the choice of reporting production via email, U.S. mail, or fax. Those choosing to report electronically or via fax received a weekly email with a production report template, which they completed and returned. Those electing to report production by mail received production report forms and pre-addressed, postage paid envelopes to facilitate reporting. Participating loggers reported the number of loads of timber delivered each week; hours spent logging; percent of loads hauled by company trucks; average haul distance to the mill; number of moves; type of harvest (thinning, clearcut, etc.); species of timber harvested (hardwood or softwood); and the number of loads that could have been delivered, but were not, along with the reasons the loads were not delivered.

We estimated logging capacity utilization by comparing actual production to the production potential of each crew. Production potential was calculated as the sum of loads actually delivered plus those that loggers reported could have been delivered, but were not, because of weather, breakdowns, etc. We report two measures of logging capacity utilization. The first excludes weeks during which loggers did not work during spring break-up. This analysis assumes that those weeks were not available for harvesting timber. For this analysis, we included logging production reports from all 30 participating logging crews. The second measure of logging capacity utilization included every week during the study. For this analysis, we estimated production lost during spring break-up if it was not reported directly. This measure assumes that each week during the year is theoretically available for timber harvesting. For this analysis, we included only logging crews that reported production both before and after spring break-up. While excluding lost production during spring break-up gives an accurate measure of logging capacity utilization in Wisconsin, the estimate that includes the spring break-up period may be a better metric to compare Wisconsin's logging capacity utilization to other regions with significantly less seasonal down-time, such as the U.S. South.

In addition, we compared the weekly production level of each logger to their stated maximum production potential, their target weekly production level, and their break-even production level. The maximum potential production was a level of production that is only achieved under perfect conditions, while the target weekly production level should have been achievable during average conditions. If a logger did not provide this information, that crew was not included in this part of the analysis.

We compared means among seasons and harvesting systems with analysis of variance (ANOVA) and the Tukey HSD test using SPSS (IMP Corp. 2012). Parametric tests were chosen because sample sizes exceeded 30 production reports for each test. The Levene's test for equality of variance was used to test the assumption of equality of variance. If the variance was not equal between populations, the data were transformed logarithmically prior to analysis. If the variance was unequal after the transformation, we used Welch's ANOVA and the Games-Howell test (Maxwell and Delaney 2004).

Logging efficiency was estimated using stochastic frontier analysis (SFA). SFA creates a production frontier based on observed production of all crews in the study and predicts potential production of each crew based on production inputs of that crew (Coelli et al. 1998). The output variable for the model was loads of timber delivered to the mill in a given week and inputs into the system were capital and labor. Stochastic frontier analysis was conducted using the Frontier package (Coelli and Heningsen 2013) in R version 3.1.3 (R Core Team 2015). Because this model requires that all inputs and outputs be greater than zero, weeks in which loggers did not work or did not deliver timber to a mill were excluded from the analysis.

Labor input was calculated as the number of man-hours worked during a given week. Capital investment was estimated using the machine rate method and published assumptions (e.g. Brinker et al. 2002) (Table 4-1). We calculated an average weekly cost for owning and operating each machine in the system, excluding labor costs. For each machine, we assumed a salvage value of 20% of the purchase price, a fuel cost of $2.45 per gallon for off-road diesel, and a lubrication rate of 36.8% of the fuel cost. For chainsaws, we used the same assumptions except that premium gasoline was assumed to cost $2.90 per gallon and no salvage value was assigned. Fuel costs were estimated using data from the Energy Information Administration (2015) and subtracting taxes from diesel prices to approximate the cost of off-road diesel.

When loggers agreed to participate in the study, they reported the equipment that they operated and the number of employees or subcontractors that worked on their crew(s). Cut-to-length crews generally included two workers and operated a harvester and a forwarder. Chainsaw crews commonly used one or two chainsaw fallers and a cable skidder or forwarder. The feller-buncher crews were generally larger than other crews and included between two and five workers, one or more feller-bunchers, up to three skidders, a loader, slasher saw, and in one case, a chipper that was used to produce whole tree chips for use in a wood-fired power plant.

Inputs, such as labor and capital, are not the only variables that influence logging productivity and efficiency. Type of harvest, haul distance, tract conditions, and weather certainly influence efficiency, but are not considered inputs in the logging production process and may not be under the logger's control in the short term. These types of factors are commonly referred to as environmental variables (Coelli et al. 1998). We attempted to explain some of the inefficiency calculated by including the following environmental variables in the SFA model: harvest prescription (thinning or final harvest), felling technique, species harvested (hardwood or softwood), trucking strategy, whether the crew moved during the week, size of logging firm (single or multi-crew organization), stumpage acquisition strategy, haul distance, logging conditions during the week, and season of harvest. These variables were removed using a backward elimination process until all variables were statistically significant ($\alpha = 0.05$).

The production reports were analyzed as a single cross-section. This approach was chosen because harvesting technology did not change during the study, timber markets vary within the state, and site conditions vary from tract to tract and even week-to-week on the same tract, making weekly observations independent of one another. This approach simplified the analysis and is consistent with previous studies (e.g. Chumbler 2002, Greene et al. 2004).

Table 4-1. Machine rate assumptions for equipment used by logging crews in this study.

	Tracked feller-buncher	Rubber-tired feller-buncher	Loader/ slasher	Chipper	Skidder	Harvester	Forwarder
Purchase price	$430,000	$295,000	$315,000	$260,000	$250,000	$550,000	$370,000
Economic life (years)	5	5	5	5	5	6	6
Interest, insurance, & taxes[1]	9.5%	9.5%	7.5%	11.0%	11.0%	10.0%	10.0%
Fuel consumption [2]	7.9	5.0	4.4	14.0	5.0	5.3	4.5
Maintenance and repair[3]	75%	100%	90%	100%	100%	30%	30%
Utilization	60%	65%	65%	75%	60%	80%	80%

[1]Percent of average annual investment; [2]Gallons per productive machine hour; [3]Percent of depreciation

Results and Discussion

Logger Characteristics and Location

Thirty participating loggers reported 894 crew-weeks of data and 9,169 loads of timber delivered. Of the 30 participating logging crews, 10 were from multi-crew organizations and twenty were from single-crew firms. Seventeen crews were based in the Wisconsin DNR's Northern region, six were located in the West Central region, six were located in the Northeastern region, and two crews were located in the South Central region. The proportion of loggers from each region appears consistent with the proportion of timber harvested from each region.

Twenty logging crews operated cut-to-length harvesting systems, seven used chainsaw systems, and three crews used feller-buncher systems. The distribution of harvesting systems was consistent with the volume of timber harvested by each system in Wisconsin (Rickenbach et al. 2015). Nonetheless, sample sizes were smaller for the chainsaw and feller-buncher systems, and therefore results may not be as representative of these systems as they are for the cut-to-length system.

Participating loggers reported that 51% of the loads they produced were hardwood pulpwood, 20% were hardwood sawtimber, 15% were softwood pulpwood, 8% were softwood sawtimber, and 4.3%

were biomass chips, on average. To simplify reporting and limit the reporting form to one page, aspen was included with hardwood. Participants reported spending at least half of their time thinning in 74% of reported weeks. Loggers delivered wood to an average of three mills each week at an average haul distance of 52 miles.

Logging Production and Capacity Utilization

Production across all systems averaged eleven loads per week during the study (Table 4-2). Feller-buncher crews were significantly more productive than the other two systems and the cut-to-length crews were more productive than chainsaw crews ($P<0.01$). The production level achieved by participating cut-to-length and chainsaw crews were similar to statewide medians reported by loggers in the state, while the feller-buncher crews tended to be more productive than the statewide median (Rickenbach et al. 2015). Of course, the three harvesting systems required different levels of capital investment and do not necessarily target the same tracts of timber for harvest. Past research indicates that feller-buncher systems are more productive and produce wood at a lower per-unit cost than cut-to-length systems (Lang and Mendell 2012); nonetheless, the cut-to-length system is the most commonly used in Wisconsin. Cut-to-length systems may have advantages on small parcels of timber in Wisconsin (Conrad 2014), reduce residual stand damage relative to other systems (Benjamin et al. 2013), reduce ground pressure and extend the working season (Han et al. 2009), and efficiently produce shortwood demanded by many Wisconsin mills (i.e. 100 inch pulp sticks).

Logging capacity utilization averaged 71% for the 48 weeks of the study when spring break-up shut-downs were excluded from the analysis (Table 4-2). This was slightly lower than the utilization level reported in the mid-2000s, and more than 10% below what is considered the maximum sustainable utilization level (Taylor 2007). When spring break-up was included in the analysis, logging capacity utilization was estimated to be only 64%, or twenty percent below the theoretical maximum. Nearly three-quarters of participants did not harvest timber during spring break-up, and so this restriction had a predictably large impact on production.

Cut-to-length crews had lower average capacity utilization than the feller-buncher systems when spring break-up shut-downs were excluded (Table 4-2). When all reported weeks were included, logging capacity utilization fell to 69%, 62%, and 71% for the chainsaw, cut-to-length, and feller-buncher systems, respectively, although differences among systems were not statistically different. The utilization figures for the cut-to-length system are likely the most representative for the state as a whole because this is the most commonly used system and the sample size for this system was the largest.

The primary reasons for production losses outside of spring break-up were weather and equipment breakdowns (Table 4-3). Weather reduced production by nearly 12%. According to precipitation data from the Wisconsin State Climatology Office (2015), monthly precipitation during the study was very similar to the average monthly precipitation from 1981-2010. May of 2015 was the only month in which precipitation was more than one-quarter of an inch above the long-term average, while January, February, March, and July all had precipitation levels at least one-quarter of an inch below the long-term average. This indicates that the weather-related down-time reported in this study was representative of a typical year in Wisconsin.

Table 4-2. Average weekly production, lost production, capacity utilization, and total loads delivered by system and standard errors (in parentheses) for participating Wisconsin loggers between September 28, 2014 and August 29, 2015. This analysis excludes weeks during spring break-up during which loggers did not harvest timber.

Harvesting System	Crew-Weeks Reported	Average production (loads wk-1)	Average lost production (loads wk-1)	Average Capacity utilization (%)	Total loads delivered
Cut-to-length	588	11.9[a] (0.4)	5.3[a] (0.3)	68.8[a] (1.3%)	6,983
Chainsaw	172	3.2[b] (0.2)	1.1[b] (0.2)	74.6[ab] (2.9%)	558
Feller-buncher	76	21.4[c] (1.9)	5.7[a] (1.1)	81.1[b] (3.0%)	1,628
Overall	836	11.0 (0.4)	4.5 (0.2)	71.0 (1.1%)	9,169

[a,b,c]Means not connected by the same letter are statistically different (α=0.05)

Table 4-3. Number of loads lost by reason as reported by participating loggers in Wisconsin between September 28, 2014 and August 29, 2015, excluding weeks that loggers did not work during spring break-up.

Reasons for missed loads	Loads lost per crew per week		Total loads lost during study	Percent of potential loads
	Average	Maximum		
Weather-woods condition	1.17	40	980	7.64
Weather-forest roads	0.64	30	538	4.19
Mechanical-unscheduled	0.57	21	476	3.70
Mechanical-scheduled	0.22	25	182	1.42
Vacation	0.51	25	422	3.29
Labor-amount	0.21	25	174	1.36
Labor-quality	0.14	10	116	0.90
Regulations-mandatory	0.17	18	146	1.14
Regulations-voluntary	0.01	2	11	0.09
Seasonal restrictions	0.17	38	146	1.14
Harvest plan	0.07	5	58	0.45
Mill loading/unloading	0.02	4	18	0.14
Mill closed	0.04	9	34	0.26
Mill quota	0.02	6	16	0.12
Stumpage unavailable	0.02	6	16	0.12
Other[1]	0.47	26	396	3.08
Sum	**4.5**	**--**	**3,729**	**29.04**

[1]Examples include funeral attendance, tract-specific requirements that reduced production, and trucking challenges.

The production lost for weather-related reasons was higher than estimates from other regions. In a similar study by Greene et al. (2004) in the U.S. South and Maine, weather reduced production by only 4% of delivered loads. This is particularly perplexing given the prevalence of the cut-to-length harvesting system in Wisconsin. This system generally has lower ground pressure than other systems and travels on a slash mat, which should enable this system to operate in wetter conditions than the feller-buncher/grapple skidder systems that operate in the South and the Northeast.

Neither the percentage of production lost because of weather conditions nor the percentage of production lost because of equipment breakdowns differed by system ($P>0.10$). The similar production losses by each system may indicate that cut-to-length loggers tended to operate on wetter sites than the other two systems, or the advantage of cut-to-length systems during wet weather may not be as great in Wisconsin as previously thought.

Only 68 loads were lost (compared to 9,169 delivered) because of mill-related reasons. Unfavorable winter conditions during early 2014 followed by a wet summer resulted in low mill inventories during much of the study and, consequently, loggers were able to take advantage of high demand from mills and an absence of restrictive quotas.

Regulations reduced production by approximately one percent. There were three instances of lost production as a direct result of regulations. One logger lost a small amount of production (2 loads) because of gypsy moth quarantine regulations. Another participant reported a loss of 48 loads and shut down his crew for three weeks past spring break-up because of oak wilt restrictions. In another instance, a logging crew lost 101 loads and shut down completely for two weeks because of state threatened species regulations.

In addition to loads lost as a direct result of regulations, it is also possible that regulations play an indirect role in reducing production. For example, the Wisconsin DNR recommends that stands with oak basal area ≥15 ft^2ac^{-1} not be harvested between early to mid-April and July 15th if the stand is located in a county with oak wilt (WDNR 2015). The effect of this regulation is to reduce the supply of stumpage during this time frame. This may encourage loggers to harvest small tracts or tracts that are prone to weather-related shut-downs, either of which would reduce production, but would not have been attributed directly to regulations on the production reports. LeBel (1993) hypothesized that increasing environmental regulations exacerbated the impact of rain on logging operations, which may explain, in part, the high level of weather-related down-time observed in this study.

Production was reduced by three percent because of vacation and other reasons (Table 4-3). Vacation was primarily associated with the nine-day gun deer season and national holidays. The other category included production losses that were not easily classified such as attending funerals, trucking issues, or tract-specific difficulties.

On average, loggers operated 10% above their break-even production level, 26% below their target production level and 43% below their maximum capability during the study (Figure 4-1). Since they operated above their break-even production level on average, presumably most loggers were profitable during the study period. However, loggers reported achieving their break-even production level on just

37% of the reports received. The target production level reported by loggers was supposed to represent a production level that was achievable on a consistent basis, yet during the study period, loggers achieved their target production level in only 21% of the weeks reported.

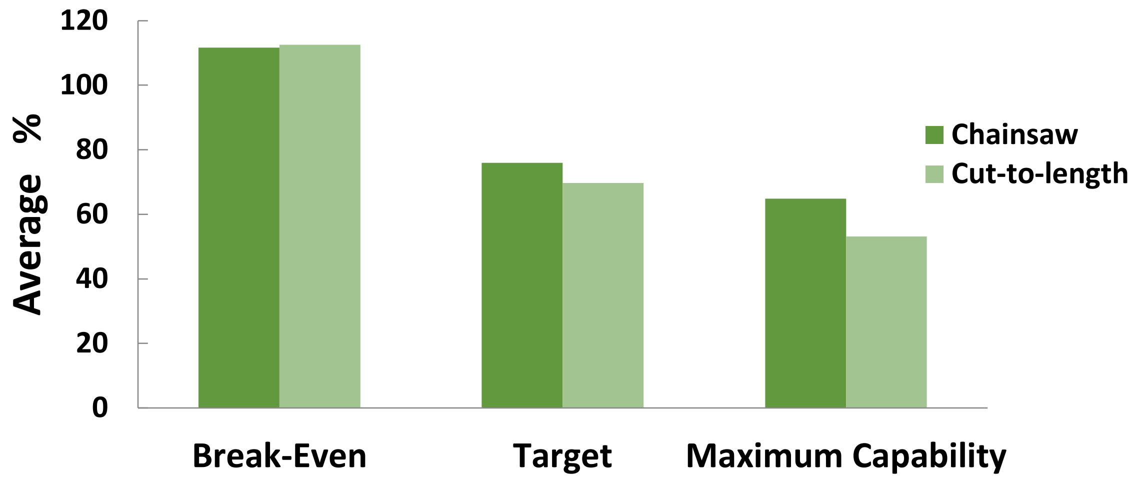

Figure 4-1. Average percent of break-even, target, and maximum capability (stated capacity) achieved weekly by Wisconsin loggers between September 28, 2014 and August 29, 2015. Feller-buncher crews were not included in this figure because several of them did not provide this information.

Seasonal Variations

Productivity was significantly higher during winter compared to the rest of the year (Table 4-4). Logging capacity utilization was almost 80% during winter, which is near the theoretical maximum (Taylor 2007). This indicates that, while opportunities exist to increase production from existing logging crews during much of the year, there is very little opportunity to increase logging production during winter. Procurement foresters sometimes discuss the need for "surge capacity" to deliver wood during periods of low inventories and high demand. It appears from this study that surge capacity does not exist during winter months, and therefore, assuming constant or increasing mill demand, increasing the percentage of timber harvested during winter could result in logging capacity shortages during this time.

Table 4-4. Mean productivity and capacity utilization for the cut-to-length system with standard errors (in parentheses) by season.

Season	Crew-Weeks Reported	Loads per week	Lost loads per week	Lost loads per week due to weather	Average capacity utilization (%)
Fall	201	11.7[a] (0.6)	7.2[a] (0.6)	3.4[a] (0.4)	62.9[a] (2.3%)
Winter	184	15.6[b] (0.9)	3.4[b] (0.3)	0.9[b] (0.2)	79.9[b] (1.8%)
Spring	99	7.8[c] (0.6)	5.1[abc] (0.6)	1.6[bc] (0.4)	63.6[a] (3.7%)
Summer	104	9.5[ac] (0.6	5.1[c] (0.5)	2.1[ac] (0.2)	64.6[a] (2.9%)

[a,b,c]Means not connected by the same letter are statistically different (α=0.05)

Logging Capacity

According to Perry (2014), loggers harvested approximately 303 million cubic feet of timber in 2013. Assuming that logging capacity utilization was similar during this study, increasing logging capacity utilization from 71% to 81% outside of spring break-up would result in a potential harvest level of approximately 346 million cubic feet, which is still 5% less than the volume processed by Wisconsin mills in 2003, but nearly 30% above the volume processed by mills in 2008 (Haugen 2013).

Logging Efficiency

Logging efficiency averaged 64.8% as measured by stochastic frontier analysis. Efficiency ranged from 12.6% to 92.2% with a median of 70.3% (Table 4-5). This level of efficiency was similar to findings of Greene et al. (2004), but lower than results reported by LeBel (1996). This measure shows how efficiently logging crews turn labor and capital into loads of timber delivered to the mill. This may not be an accurate measure of efficiency for each individual logging crew; for example, a logger may sacrifice production to ensure quality when harvesting a veneer stand. However, for the logging population as a whole, this provides a good indication of efficiency.

Table 4-5. Minimum, maximum, and average efficiency with standard errors (in parentheses) for the three harvesting systems for production reported between September 28, 2014 and August 29, 2015.

System	Efficiency		
	Minimum	Maximum	Mean
Cut-to-length	13.1%	91.6%	69.5%[a] (0.8%)
Chainsaw	12.6%	84.5%	43.3%[b] (1.8%)
Feller-buncher	17.6%	92.2%	69.1%[a] (1.9%)
Overall	12.6%	92.2%	64.8% (0.8%)

[a,b] Means not connected by the same letter are statistically different (α=0.05)

Chainsaw felling, thinning, and harvesting during spring and summer were environmental variables associated with reduced efficiency, or inefficiency. These are intuitive results as the shift towards fully mechanized logging crews over the past thirty years is a strong indication that loggers perceive that mechanized crews are more efficient than chainsaw crews. Thinning generally reduces productivity because crews must maneuver around residual trees and are often harvesting smaller diameter trees than during final harvests (Kluender et al. 1998). Furthermore, lost production outside of winter harvesting documented earlier in this report suggests reduced efficiency when harvesting during spring and summer.

Hardwood harvesting, trucking by the logging firm, and being part of a multi-crew organization were associated with increased efficiency, or reduced inefficiency. Greater efficiency for hardwood harvesting than softwood harvesting is counterintuitive, but hardwood pulpwood (including aspen pulpwood) was the most common product harvested during the study and loggers were obviously equipped to handle this material efficiently. Loggers that delivered at least 10% of their loads with their own trucks tended to be more efficient than loggers that contracted all of their trucking to outside entities. Loggers that own their own trucks have greater flexibility in the timing of timber delivery, and perhaps more importantly, they are able to move their logging crew from one harvest site to the next without waiting for a contract trucker to perform the move. This does not imply that all loggers should own at least one truck because the cost of owning and maintaining one or more trucks may exceed the savings from efficiency improvements on the logging crew. The increased efficiency of multi-crew organizations supports the trend of consolidation in the logging industry reported by Greene et al. (2013) and Rickenbach et al. (2015). Multi-crew organizations may enjoy a stronger negotiating position with mills than single crews, sometimes employ one or more foresters to purchase stumpage and lay out timber sales, and may be able to employ cost-saving measures such as truck dispatching, all of which may increase the efficiency of logging crews in multi-crew organizations.

Cut-to-length loggers were more efficient during fall and winter than during spring and summer (Table 4-6). The reason for increased efficiency in the fall relative to summer is unclear. Some seasonal restrictions are lifted by fall, which could increase efficiency; on the other hand, recreation-related restrictions, such as those for deer season, would be expected to reduce efficiency in the fall. It is possible that stumpage availability is greater and weather conditions more predictable during fall than summer, resulting in greater logging productivity or shutting down operations entirely. Because the SFA model was based on hours worked, a crew that did not work during a day would tend to show greater efficiency than a crew that worked all day, but produced a small volume of timber because of weather conditions.

Table 4-6. Minimum, maximum, and average efficiency with standard errors (in parentheses) for the cut-to-length system by season.

Season	Efficiency		
	Minimum	Maximum	Mean
Fall	16.7%	91.6%	73.3%[a] (1.1%)
Winter	13.8%	91.3%	73.2%[a] (1.2%)
Spring	13.1%	89.8%	61.6%[b] (2.3%)
Summer	13.1%	91.4%	62.3%[b] (1.9%)

[a,b] Means not connected by the same letter are statistically different (α=0.05)

Summary and Conclusion

By collecting data from Wisconsin loggers for nearly an entire year, this study provides unique insight into an essential component of the wood supply chain and identified barriers to efficiency. Overall, logging capacity utilization averaged 71% when spring break-up shut-downs were excluded or an estimated 64% when these weeks were included. Logging efficiency averaged approximately 65% during the study.

One of the greatest barriers to efficiency identified was the seasonality of timber harvesting in Wisconsin. Spring break-up caused nearly three-quarters of participants to cease production for approximately six weeks, something Wisconsin's competitors may not experience. However, even outside of spring break-up, this study identified significant production losses because of weather during spring, summer, and fall. Logging capacity utilization did not exceed 65% in any season except winter, with weather the primary cause of lost production (Table 4-3 and Table 4-4).

Not only were seasonal fluctuations significant, but the total percentage of loads lost because of weather conditions was nearly three times as high as it was in the U.S. South during the most recent study, even after spring break-up down-time is excluded (Greene et al. 2004). This level of down-time certainly makes Wisconsin's wood supply chain less competitive and likely results in higher delivered wood costs than would otherwise exist. Wisconsin's BMP manual suggests that the use of low ground pressure equipment may allow operations to continue when other equipment may need to shut down (WDNR 2010). However, Wisconsin loggers operate cut-to-length equipment that travels on slash mats, which should extend the operating season and allow for operations to continue without damaging the soil. Yet, even after this investment, loggers are still experiencing significantly more weather-related down-time than many of their competitors. While some seasonal fluctuations are unavoidable; and damaging harvest sites by operating when conditions are too wet is undesirable; foresters, landowners, and loggers should work together to plan sales to protect water and site quality while also avoiding down-time.

The production lost as a direct result of regulations was relatively low compared to other causes such as weather and equipment breakdowns (Table 4-3); however, it is possible that regulations exacerbate production lost because of weather. Regulations that restrict harvesting seasonally reduce timber supply while the restriction is in place and may cause loggers to harvest sites during summer and fall that are prone to weather-related down-time. Research is underway to quantify the scale of seasonal timber harvesting restrictions in Wisconsin and the results of that research should further inform the impact of regulations on the down-time observed in this study.

The efficiency data supported the shift toward fully mechanized, multi-crew firms. While chainsaw harvesting will always have a role, especially in southwestern Wisconsin, and not every firm should expand to multiple crews, the findings of this study did support the idea that mechanization and consolidation are improving efficiency.

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Chapter 5. Spatial Wood Supply Simulator

Introduction

To go beyond the point-in-time baseline analysis of forest inventory, growth, and harvest data like that reported in Chapter 2, and to enable analysis of different assumptions or scenarios of future conditions, we have developed a simulation model called the Spatial Wood Supply Simulator (SWSS). This model uses the same data developed for the baseline analysis, and then simulates the behavior of different components of the wood supply chain. To do this, we employ a popular, public-domain software package (RePAST) developed at Argonne Labs to perform Agent-Based Modeling (ABM). ABM attempts to generally represent the behavior of "agents" interacting in an environment to assess the impacts of changes in resources or behaviors. It has been widely used in supply chain modeling.

The conceptual structure of the model is depicted in Figure 5-1. The basis for the model is forest inventory data from FIA, spatially dispersed as units of forest. After applying any land use changes and availability analysis, the remaining available forest inventory is periodically offered for sale. "Agents" programmed to behave as buyers of wood for mills engage with agents simulating landowners in a bidding process. Successful completion of a simulated timber harvest results in forest products moving to mills and being removed from forest inventory. The remaining inventory goes through a growth process at the end of a year, and the cycle repeats. Four bidding cycles per year allow opportunity for agents to adjust buying behavior (bid prices and timber offers that are bid on) based on their level of success at procuring wood for their mill. All transactions are recorded, as are all forest conditions annually (age, volume, removals, growth, etc.). These data are then summarized to produce a wide array of outputs, including timber price trends, growth and removals, average haul distances, forest age class distributions, and others.

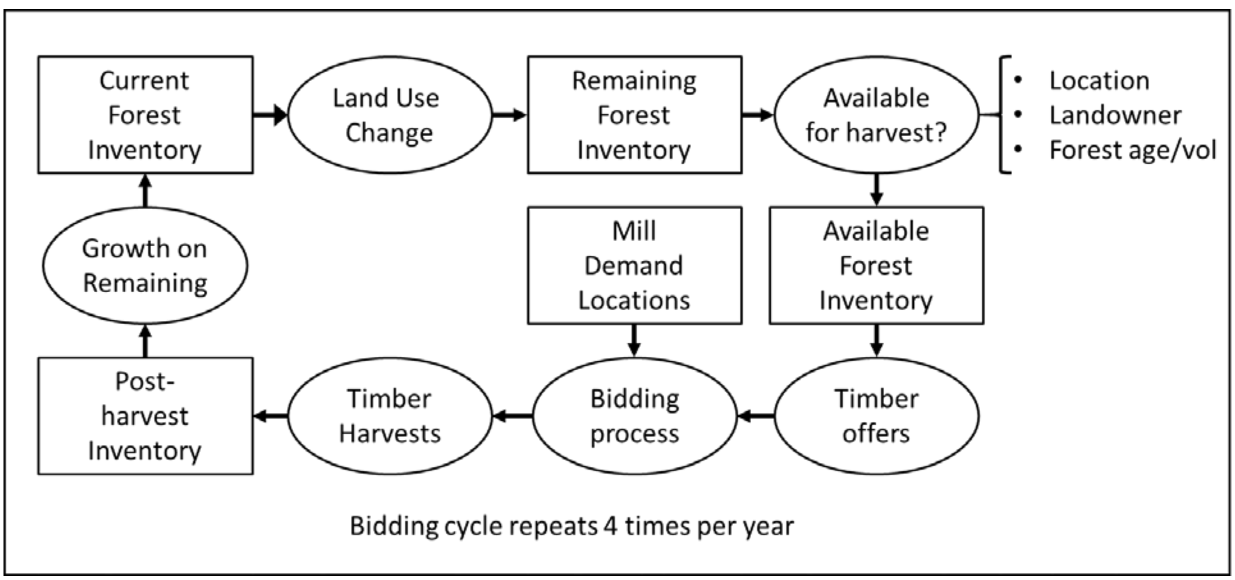

Figure 5-1. Diagram of conceptual flow of the Spatial Wood Supply Simulator model.

Data and Methods

Forest Inventory Data

As in the case of the forest resource assessment, we used forest Inventory data from FIA (consisting of plots measured between 2009 and 2013) for nonfederal lands in Wisconsin. The published location (latitude/longitude) of these plots is only approximate, but sufficient for our purposes. Each plot represents about 3,000 acres. To mimic the parcel size distribution of nonfederal forest lands, we split these inventory plots into "pseudoplots", with varying acreage (adding up to the acres represented by the FIA plot), following the distribution found in the parcel size analysis reported in Chapter 2. Pseudoplots are randomly located near the FIA plot from which they were split. In our baseline analysis, we assumed that no forest parcels less than 10 acres in size would be harvested, so the portion of forest in these small parcels (as identified in Chapter 2) are excluded from the simulation. The final number of pseudoplots representing nonfederal forests in parcels greater than 10 acres was 483,604.

Four forest types were defined, based on the forest type recorded for plots by FIA. These are: (1) aspen, birch, red maple; (2) all other hardwoods, (3) black spruce, tamarack, jack pine, balsam fir, cedar; (4) white spruce, white pine, red pine, hemlock. For each forest type, we used a different growth model based on growth patterns observed in FIA data for the forest types.

Forest availability for harvest in SWSS was considered to be comprised of three factors: (1) location, (2) forest characteristics, and (3) landowner willingness to harvest. We used the availability analysis described in Chapter 2 to determine the locational availability of a site for timber harvest. If a pseudoplot was located on a pixel determined not to be available (based on the threshold of 0.4 probability of harvest), then we assumed the plot would not be harvested (at any time during the simulation), and it was designated as unavailable due to location characteristics.

Next, we considered availability as a function the forest characteristics measured by forest inventory: the forest type, age, and merchantable volume present. We assumed that any forest must be 20 years of age to be eligible for harvest. Table 5-1 presents the assumptions used for minimum volume and percent volume removed for clearcut and partial harvests for the four forest types. The model randomly assigned harvest type to clearcut or partial harvest according to the desired proportions of harvest acres for of each type (as determined by analysis of FIA data).

Third, to simulate the impact of landowner willingness to harvest, we used estimated proportions of landowners willing to participate in wood markets based on their forest parcel size. In this way, we accounted for the documented relationship between ownership size and harvest likelihood. For our baseline analysis, we assumed all landowners were willing and equally likely to harvest their timber. In a sensitivity analysis (not reported here), we tested the impact of reduced willingness to harvest based on results from the landowner survey reported in Chapter 3.

Table 5-1. Assumptions about minimum volumes, percent volume removed, and proportion of all harvest acres for partial harvests and clearcuts, by forest type.

Forest Type	Clearcut Harvests			Partial Harvests		
	Min. Vol (tons/ac)	% Volume Removed	% of Harvest Ac.	Min. Vol. (tons/ac)	% Volume Removed	% of Harvest Ac.
Aspen/Birch/Maple	50	100	97	50	30 – 35	3
Other Hardwood	70	100	28	60	30 – 35	72
Black spruce/ Jack pine/white-cedar	50	100	94	50	30 – 35	6
White spruce/ white pine/red pine	70	100	42	60	30 – 35	58

Wood Demand Data

The UGA WDRP dataset for mill locations was used, primarily because the locations of mills in that dataset were determined to be more accurate than the TPO dataset, and there was more detail on roundwood products used at each mill and associated quantities. However, this dataset contains mill capacity rather than current demand. We estimated mill demand for each of four roundwood product types (hardwood pulpwood, hardwood sawtimber, softwood pulpwood and softwood sawtimber) by scaling demand for each mill group (sawmills, papermills, etc.) until demand matched the 2012 TPO reported roundwood production. We were not able to distinguish aspen demand because neither the UGA WDRP dataset nor the TPO dataset reported aspen demand by mill; so aspen was included in the hardwood product categories.

For the simulation of wood supply, we also considered mills outside Wisconsin that procure wood within the state, as well as mills within Wisconsin that buy wood from out of state. We use forest inventory data only from Wisconsin. To estimate demand that was sourced from within Wisconsin, we apportioned demand based on "service areas" (similar to procurement territories) which were delineated using ESRI's Street Map Premium dataset in conjunction with the Network Analyst tool set in ArcMap. For in-state mills, the demands were apportioned to reflect the percentage of their service areas that fell within the state, based on county, state and privately owned forest area. For example, if 80% of the forest area in a service area was in Wisconsin, then 80% of the demand was allocated to Wisconsin. Likewise, demand estimates for out-of-state mills were adjusted based on the percentage of their procurement zones that fell within Wisconsin. Service areas were defined based on the mill type and size, as depicted in Table 5-2and Table 5-3. The final mill demand dataset included 507 mills.

From this analysis we estimated the amount of wood Wisconsin mills sourced from the state (93%) versus from out of state (7%). We also estimated the amount of wood harvested in Wisconsin that was utilized by in-state mills (78%). As a comparison, TPO data indicates that 87% of the demand of

Wisconsin mills comes from in-state, and that 76% of the wood harvested in Wisconsin is utilized by Wisconsin mills.

Table 5-2. Service area maximum distances based on mill demand.

Mill Size	Annual Production (green tons)	Service Area Radius (miles)
Small	0-40,000	75
Medium	40,000-400,000	120
Large	400,000 +	150

Table 5-3. Apportionment of mill demand to service areas based on mill demand.

Small Mills (75 Miles Total)		Medium Mills (120 Miles Total)		Large Mills (150 Miles Total)	
Radius (miles)	% of Sourced Material	Radius (miles)	% of Sourced Material	Radius (miles)	% of Sourced Material
0-25	50	0-40	50	0-50	50
25-50	25	40-80	25	50-100	25
50-75	25	80-120	25	100-150	25

Road Distance Data

Because transportation is a major component of the cost of wood delivered to a mill, it is important to use accurate estimates of transportation costs. To do this, we developed a matrix containing the road distance in miles from every forest inventory location (pseudoplot) to every mill within the maximum procurement distance (Table 5-2). This distance was obtained using GIS network analysis with the proprietary StreetMap Premium data from ESRI. The resulting matrix of distances from all forest pseudoplots to all mills included 507 mills and 483,604 pseudoplots for a total of about 245 million distance measures.

Simulation of Bidding Process

The simulation began with a target delivered price for each mill based on mill type. These delivered prices came from Timber Mart North (Timber Mart North, 2012). When a pseudoplot was offered for sale, mills that needed roundwood products (pulpwood/sawtimber, hardwood/softwood) on the plot bid for the timber. The model simulated bidding behavior by computing a transportation cost for the timber as $7.60 per ton plus $0.19 per ton-mile beyond 40 miles, obtaining the haul distance from the road distance matrix described above. Logging costs were estimated as depicted in Table 5-4. Subtracting the transportation cost and logging cost per ton from the target delivered price per ton, the mill computed a maximum stumpage bid per ton. A stumpage bid was based on a random number close to this computed price.

Next, the model determined whether the sum of bids for all products was sufficiently high for the landowner to accept the bids. Landowners may have a "reserve price" beneath which they would not sell their timber. We set the reserve price using a factor (such as 80%, set at the beginning of the simulation) which is multiplied by the product values to arrive at a value for the sale. Product values used the regional average stumpage price per ton (initially from TimberMart North, later from simulation results). If the sum of all bids was greater than the reserve price, then the landowner agreed to sell the products to the highest bidder for each product type. In the example in Table 5-5, four products existed on the plot, and the "market value" for the timber was $3,960 per acre (using current average stumpage rates). Using a factor of 80%, the reserve price was $3,168 per acre. If four mills bid the stumpage prices shown in the rightmost column of Table 5-5, the landowner would receive $3,790 per acre, which was more than their reserve price and they would therefore carry out the timber sale, awarding the sale of four products to the four winning bidders.

Table 5-4. Assumed logging costs by product.

Product	Logging Cost ($/ton)
Hardwood Sawtimber	$17.70
Softwood Sawtimber	$17.79
Hardwood Pulpwood	$16.51
Softwood Pulpwood	$16.39

Table 5-5. Hypothetical example computation of landowner's reserve price and determination of a successful timber sale.

Product	Tons/Ac on plot	Current avg. stumpage price per ton	Computation of reserve price @ 80%	Highest bids from mills ($/ton)
Hardwood sawtimber	100	$30	100 tons x $30 x 0.8 = $2,400	$28 x 100 tons = $2,800
Hardwood pulpwood	40	$10	40 tons x $10 x 0.8 = $320	$12 x 40 tons = $480
Softwood sawtimber	30	$12	30 tons x $12 x 0.8 = $288	$13 x 30 tons = $390
Softwood pulpwood	10	$20	10 tons x $20 x 0.8 = $160	$12 x 10 tons = $120
Total			**$3,168 per acre**	**$3,790 per acre**

The model determined the outcome of all timber sales offered during a cycle, recording all transactions (with the ID of the pseudoplot sold, the volumes delivered to mills, and prices paid). Mills updated their demand for the next cycle, adding the demand for the next cycle and reducing demand by volumes purchased during the completed cycle. If the total volumes purchased by a mill during a cycle were less than the demand, the mill had a shortfall and raised its target delivered price for the next cycle to attempt winning more bids. If a mill purchased more timber than needed to satisfy its demand, it reduced the next cycle demand by the excess purchased and lowered its target delivered price.

The bidding process for timber sales was simulated for four cycles in a calendar year. The purpose of simulating multiple cycles is to allow interaction between buyers and sellers in the market, providing opportunity for buyers to adjust their bid prices, and for landowners to have additional opportunities to market their timber. In addition, conducting quarterly cycles for timber transactions enabled us to simulate seasonal effects on markets, such as logging restrictions during certain times of the year, or to simulate weather-related market impacts.

Sawtimber Substitution for Pulpwood

A reality of the wood supply chain is that trees that may be defined as “sawtimber” in a forest inventory are often harvested for use as pulpwood. The reverse is rarely true, since use of a tree as sawtimber requires minimum diameter specifications, so smaller-diameter trees classified in inventory as pulpwood would rarely, if ever, be used by a sawmill. There are several reasons for the use of sawtimber-sized material in pulpwood markets. These include distance considerations (pulp mill is closer than a sawtimber market), quality or grade specifications (sawmills having higher quality requirements), and availability considerations. In order to simulate the use of inventoried sawtimber in pulpwood or composite markets, we considered that buyers requiring pulpwood can offer pulpwood prices for sawtimber-sized material and frequently will win bids. When this happened, we called the purchased product “sawtimber substitution”; it derived from the sawtimber portion of the forest inventory, but showed up in the pulpwood purchases.

Growth Simulation

After each timber harvest, volumes are removed from inventory. If the harvest was designated as a clearcut, all volumes were removed, and the forest age was reset to zero. If land use change was being simulated, the pseudoplot may be removed permanently from forest inventory to mimic a land use change from forest to nonforest. If the harvest was designated as a partial harvest, the harvested portion of stand volume was removed but the age was not reset. At the end of a year (four cycles), all pseudoplots went through a process to increment inventory to reflect forest growth.

Simple growth factors were derived for each forest type using growth computed on FIA plots. Total plot volumes were multiplied by a percent growth factor based on forest age. Total volume growth was then partitioned into hardwood and softwood based on the initial proportions of hardwood and softwood volumes on the plot. Growth was further apportioned into sawtimber and pulpwood volumes based on percent sawtimber factors derived from FIA data, by forest type and age. Age for the plot was then incremented by one year and the cycle was repeated for the next simulation year.

Model outputs

During a simulation process, output was recorded in text files during each bidding and annual cycle. Transaction results from each bidding cycle included identifiers for the pseudoplots on which timber was sold, the type of harvest, the quantity and stumpage prices of products sold, and the destination (mill identifier) for each product harvested. Summarizing this data yielded product price trends, geographically-specific stumpage prices, forest harvest levels, logging and transportation expenditures, and haul distances. Similarly, for each year of the simulation (after four cycles), the model saved inventory data for all plots, including availability status, plot volume, growth, and harvest. This data produced summaries of forest acres by age class, forest type, and year; growth and removals; and residual inventory.

Results

In the following sections, we report simulation results by year for the various products statewide. Similar results by region, forest type, etc., are available through an interactive reporting tool on a website[11]. As seen in almost all graphs, the simulation model required 3 to 5 years of simulated transactions to reach a steady-state. This period of model equilibration reflects the interaction of simulated agents rather than anticipated rapid price changes, or dramatic changes to forest inventory conditions.

Five iterations ("runs") of the simulation were conducted to assess variability of results, and some charts show dotted lines representing the standard deviation for the five runs.

Harvest levels and stumpage prices

Figure 5-2 and Figure 5-3 show timber harvest levels by product over the simulation period of 30 years. Figure 5-2 shows the harvested volume by end-use, with sawtimber substitution included in the pulpwood lines (sawtimber trees used harvested for use as pulpwood). Figure 5-3 reports harvested volume by inventoried product: the sawtimber line reflects tons of trees recorded as sawtimber in the forest inventory (including sawtimber and sawtimber substitution). The fairly stable, minimally-fluctuating lines in Figure 5-2 indicate that demands of the mills (as shown in Table 2-10) were met (after the model equilibration period). However, Figure 5-3 shows a marked increase in the harvest of hardwood sawtimber inventory, and a less dramatic increase in the harvest of softwood sawtimber inventory, indicating that in order to meet pulpwood demands, substantial amounts of sawtimber inventory were being harvested and substituted for pulpwood.

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[11] Visit: https://vtcenrads.shinyapps.io/wisconsin/ The website is password protected; enter "cenrads" (lowercase, no quotes) for the Username and "wisconsin" (lower case, no quotes) for the password.

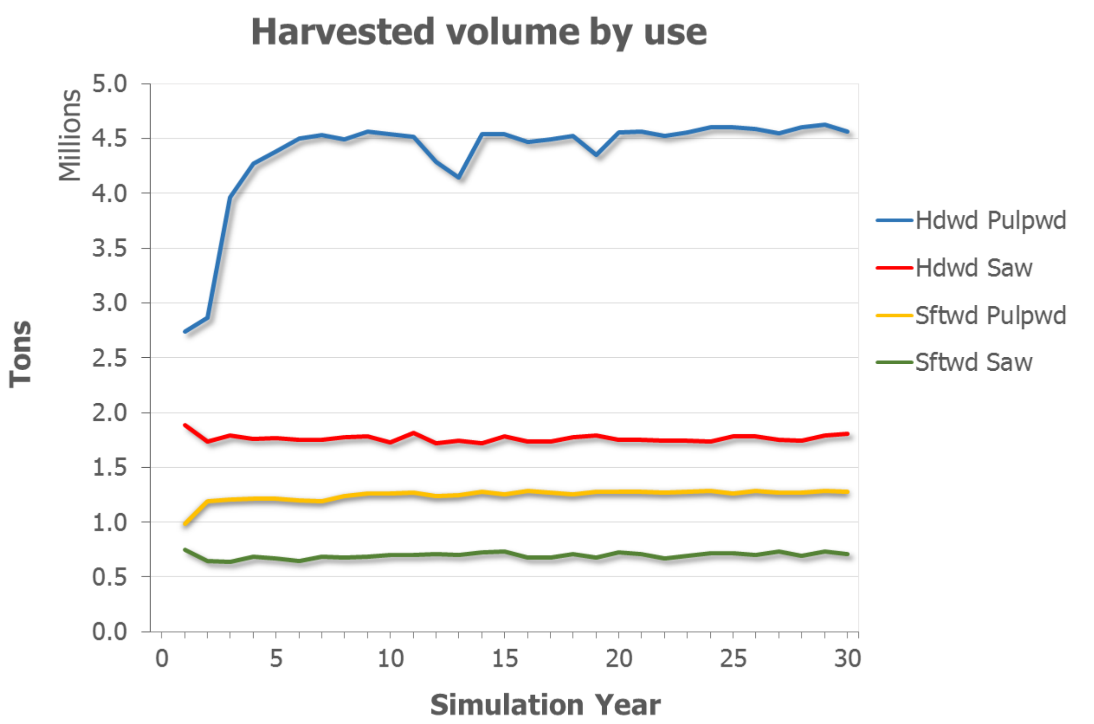

Figure 5-2. **Harvested tons by products according to end-use. Sawtimber substitution is included in the pulpwood lines.**

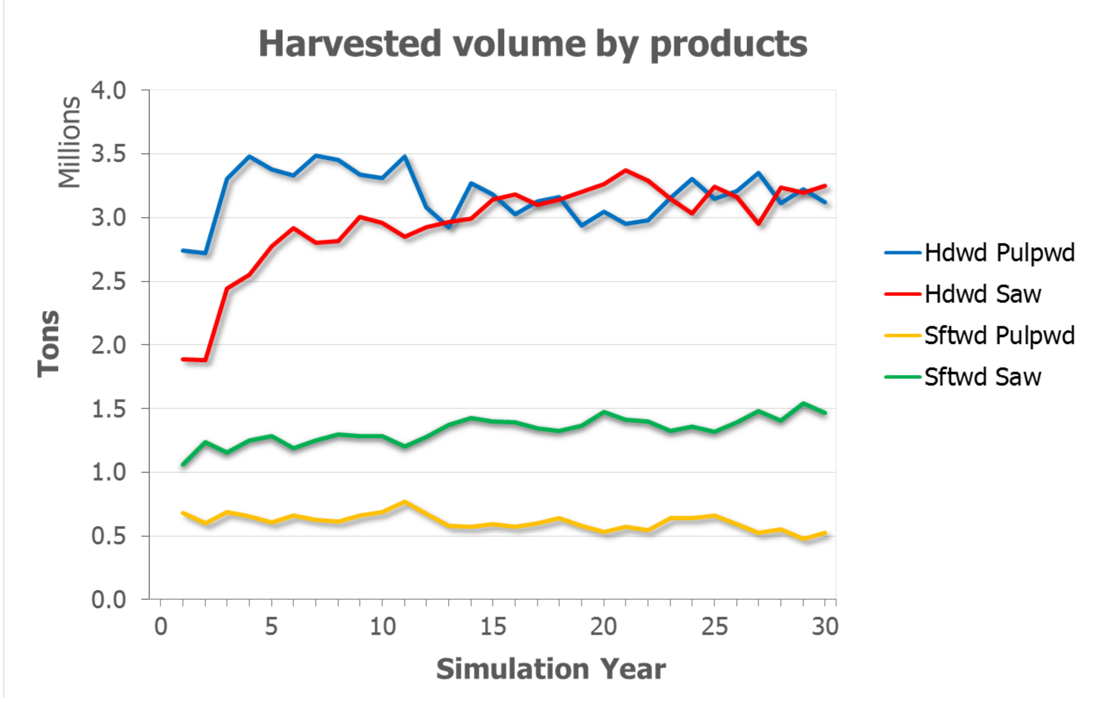

Figure 5-3. **Harvested tons by products according to forest inventory designations. Sawtimber substitution is included in the sawtimber lines.**

Figure 5-4 shows the simulated stumpage prices for the four products. After a model equilibration period, stumpage prices for hardwood (pulpwood and sawtimber) converged and increased from about $20/ton to around $30/ton. The rise of hardwood pulpwood prices to nearly sawtimber price levels also reflects competition in the hardwood pulpwood market, leading to higher levels of hardwood sawtimber substitution and less price differentiation between sawtimber and pulpwood prices. In comparison, softwood prices experienced a more subtle increase and maintained stronger differentiation.

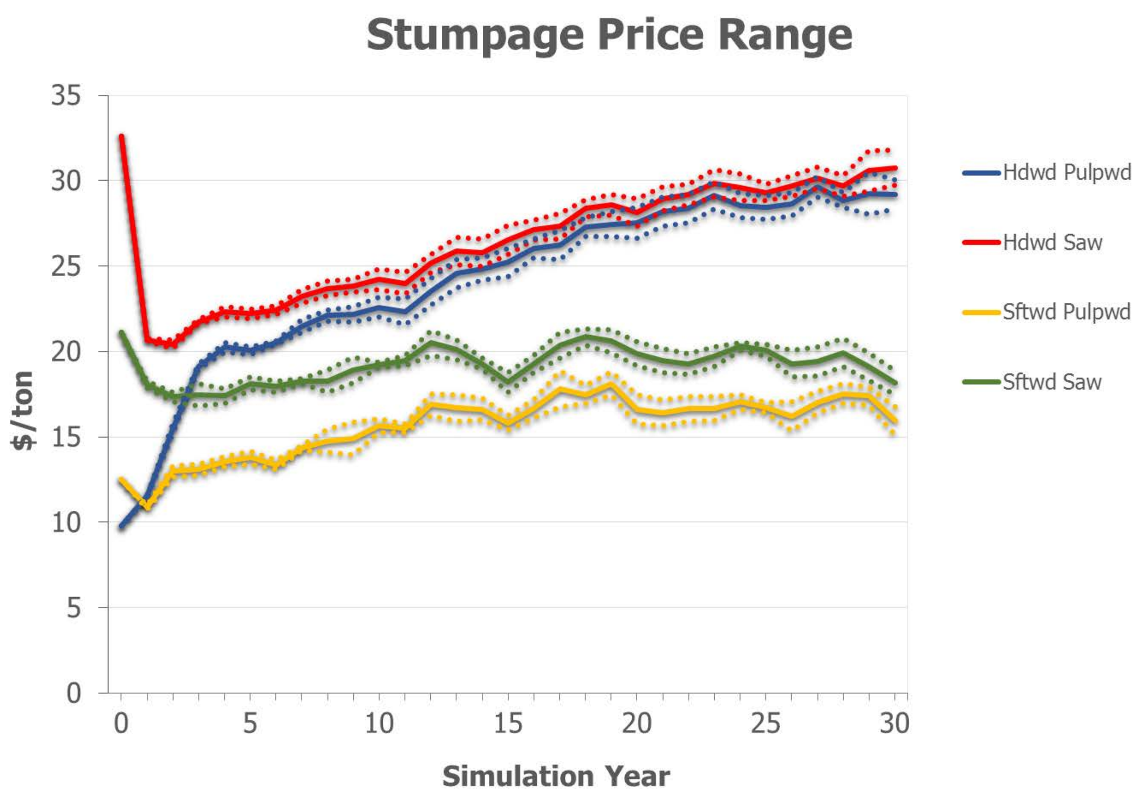

Figure 5-4. Simulated stumpage prices for forest products. Dotted lines represent one standard deviation in either direction from the mean (solid line) from five iterations.

Forest inventory and availability

Simulation results project increasing forest inventory over the simulation period (Figure 5-5). This is consistent with recent history showing Wisconsin with a growing forest inventory (Perry et al. 2012) over time. However, available inventory is more relevant to wood supply than total inventory, and inventory may be unavailable for several reasons, as discussed earlier. In this simulation, we assumed all landowners were willing to sell timber to the market, so unavailability was due to either (a) *location conditions* modeled spatially as described in Chapter 2, and (b) *temporary forest stand conditions* of insufficient age or volume per acre to support a commercial harvest (based on assumptions listed in Table 5-1). Note that in the Chapter 2 discussion of availability, we did not exclude unavailability due to temporary conditions such as age or insufficient volume. However, these are included for discussion here due to the dynamic nature of this simulation model.

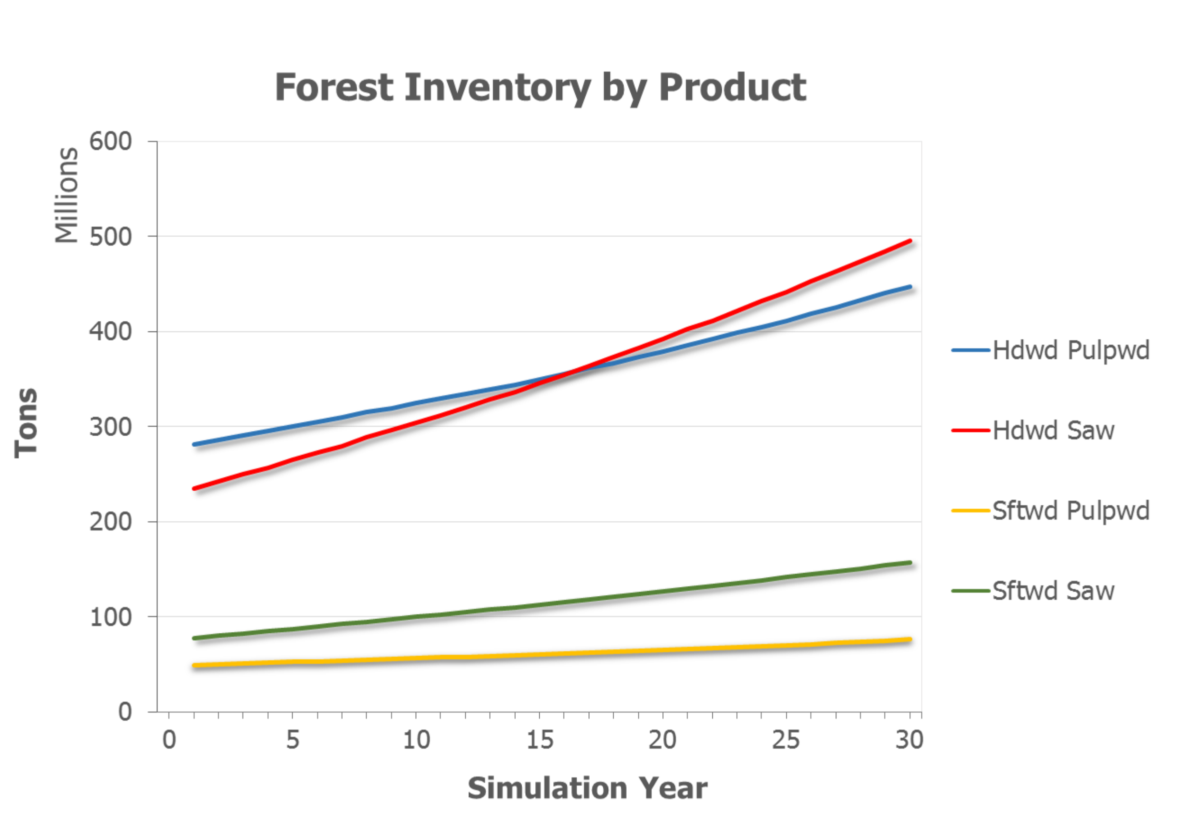

Figure 5-5. **Simulated total forest inventory levels by year and product type**.

Figure 5-6 shows inventory volume for hardwood pulpwood as either unavailable due to location conditions, temporarily unavailable due to forest stand conditions, or available. Inventory unavailability due to location conditions started at about 97 million tons (as shown in the different between total hardwood pulp in Table 2-6 and available hardwood pulp in Table 2-8. Due to the steady growth of this "reserved" resource, by the end of the simulation the inventory unavailable due to location was about 200 million tons. The next category, temporarily unavailable due to forest stand conditions, fluctuated over time as cohorts of even-aged timber moved through time and partially harvested stands add growth. Finally, only the remaining 76 million tons of hardwood pulpwood was considered truly available for harvest at the beginning of this simulation. Available hardwood inventory increased over the 30-year simulation period from about 76 million tons to about 185 million tons. Other product classes had similar patterns. Inventory by availability category for the beginning and end of the 30-year simulation for the four product classes are shown in Table 5-6. Clearly, focusing on total forest inventory hides the disparity in what is truly available to wood markets based on location and stand characteristics conducive to commercial forest harvest.

Figure 5-6. Hardwood pulpwood inventory by availability type.

Table 5-6. Simulated inventory levels by availability category and product class at beginning and end of simulation (million tons).

Million tons	Simulation Beginning (Year 1)			Simulation Ending (Year 30)		
Product class	Unavail. Location*	Unavail. Stand*	Available	Unavail. Location*	Unavail. Stand*	Available
Hardwood Sawtimber	82.4	82.8	69.5	232.8	59.1	203.4
Softwood Sawtimber	19.3	34.0	24.7	55.8	26.4	75.2
Hardwood Pulpwood	96.8	107.9	76.3	201.9	60.6	184.9
Softwood Pulpwood	12.6	24.4	11.8	26.3	15.8	34.4
Total	211.0	249.1	182.3	516.8	161.9	498.0

* Location unavailability refers to location factors such as proximity to roads and wetlands, while stand unavailability refers to temporary stand conditions such as age or volume that limit harvest.

Harvest types and haul distances

Simulation of forest harvest by type of harvest (clearcut versus partial harvest) was dictated by the settings in Table 5-1 regarding minimum volumes. Using these values, clearcut harvests in the simulation produced about 6 million tons annually and partial harvests produced about 2 million tons, with fairly stable levels across the simulation period (Figure 5-7).

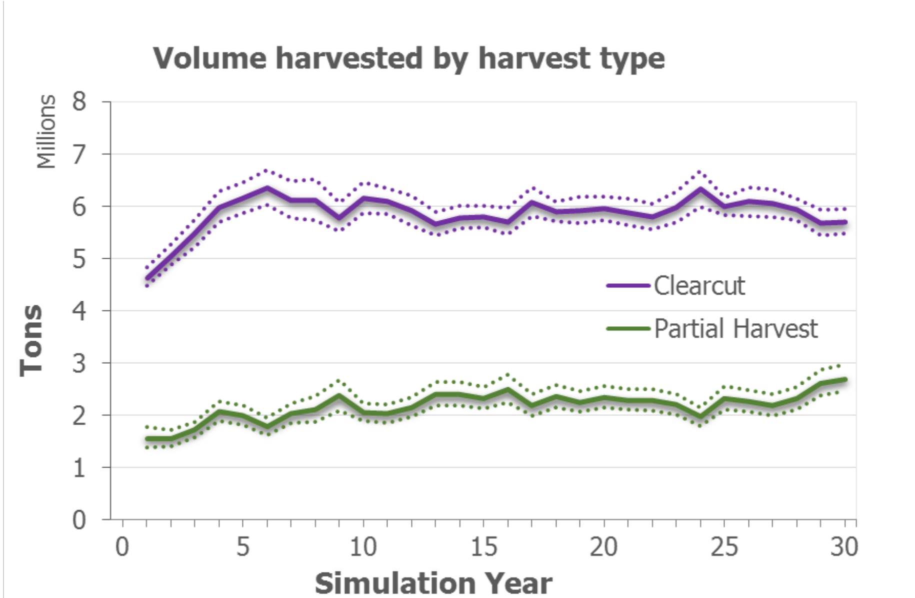

Figure 5-7. Volume harvested by type of harvest.

Timber scarcity or competition may be reflected in prices (Figure 5-4) but also in the average haul distance that wood must be transported between the forest and the mill. Figures 5-8 to 5-11 depict the average haul distance simulated by SWSS for the four products. For pulpwood, haul distances increased to slightly more than 60 miles for hardwood and between 70 and 80 for softwood over the simulation period. The average haul distance for hardwood sawtimber reached 80 miles by the end of the simulation; for softwood sawtimber it fluctuated without a discernible trend over the simulation period.

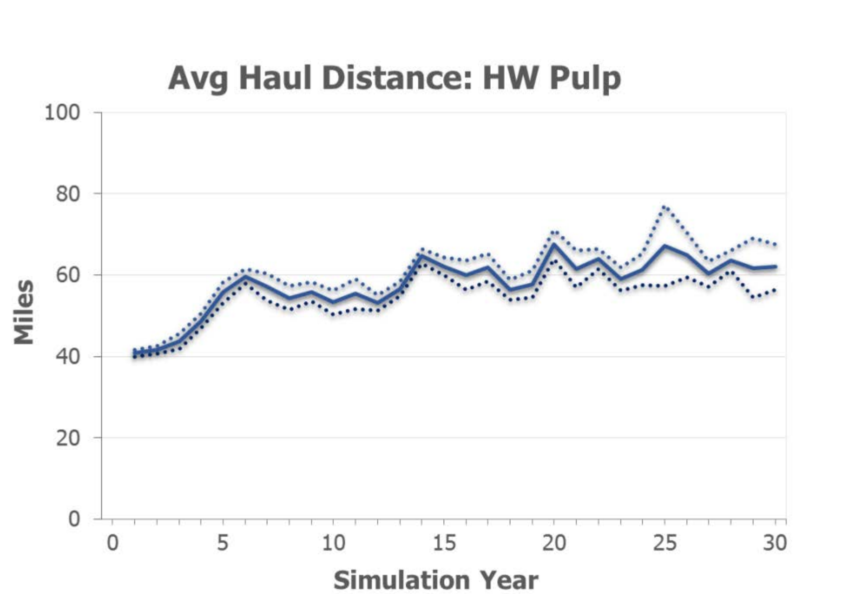

Figure 5-8. Average haul distance for hardwood pulpwood.

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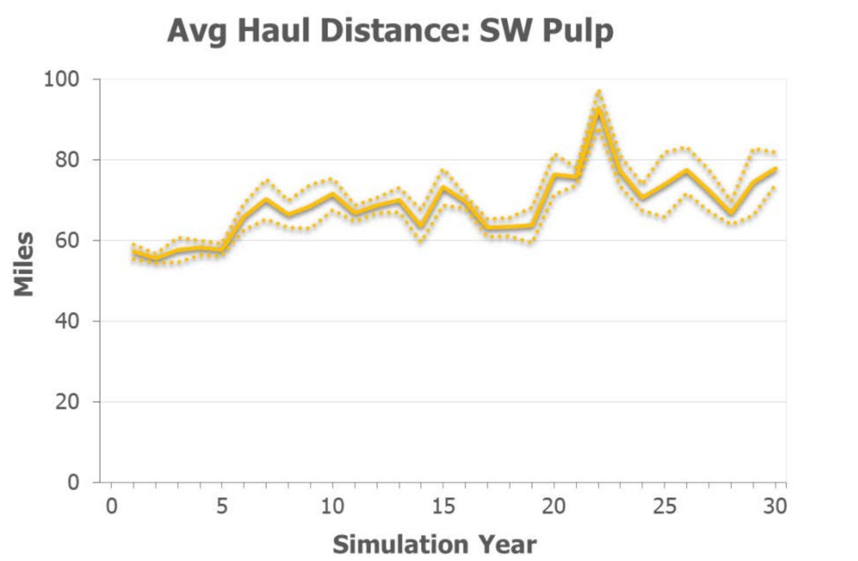

Figure 5-9. Average haul distance for softwood pulpwood.

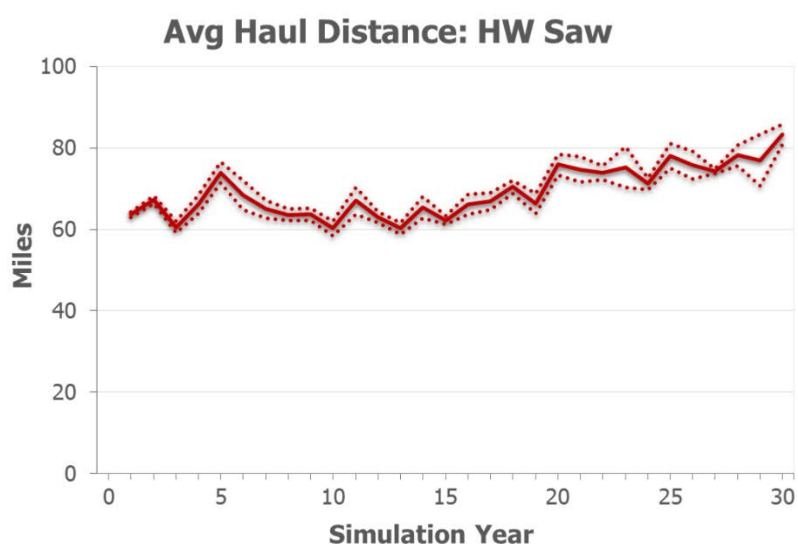

Figure 5-10. Average haul distance for hardwood sawtimber.

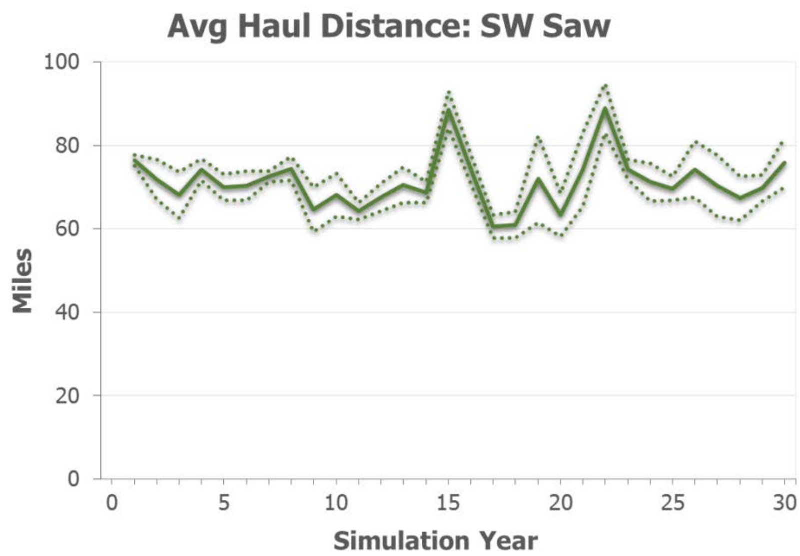

Figure 5-11. Average haul distance for softwood sawtimber.

Aggregate impacts

Over the simulation period, transportation expenses for roundwood delivery to mills increased to about $100 million annually and stumpage costs paid to landowners increased from $100 million to over $200 million annually (Figure 5-12).

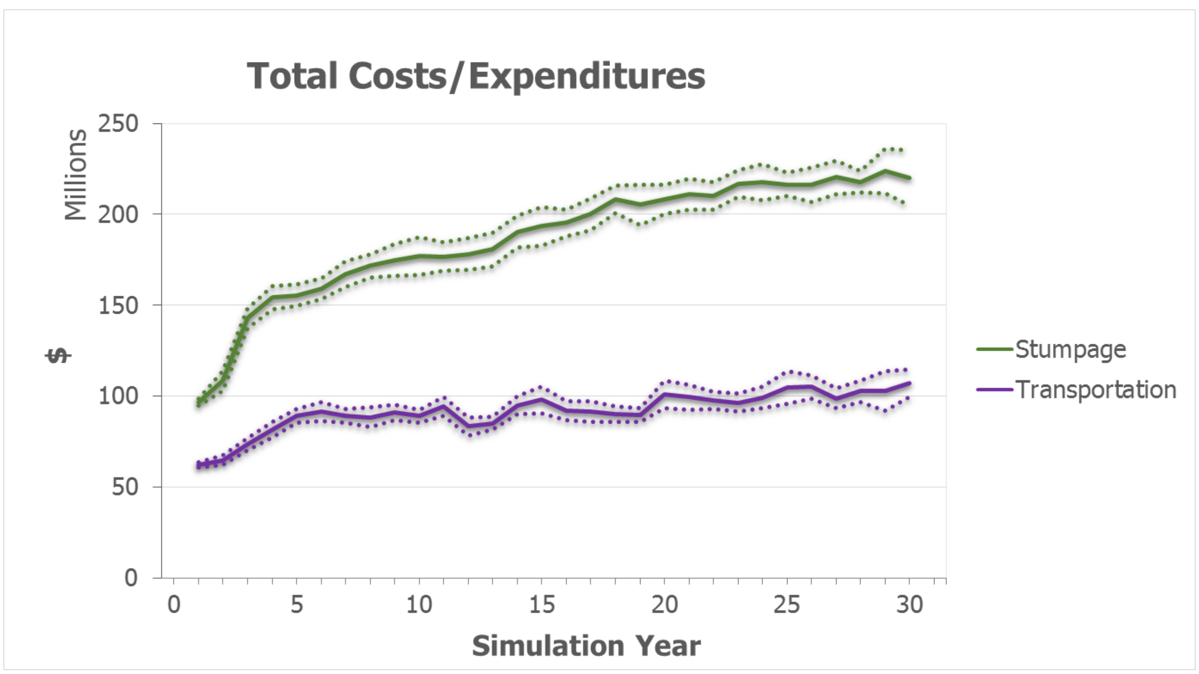

Figure 5-12. Total costs for stumpage and transportation across simulation time frame.

Discussion

The simulation of Wisconsin's wood supply using SWSS and the assumptions laid out in the Methods section reveals an increasingly challenging environment for procurement of pulpwood. As noted in Chapter 2, harvest levels of pulpwood are already higher than annual growth of pulpwood, although this picture is complicated by the way that growth is measured based on standing timber specifications, and removals are measured based on deliveries to mills. Trees inventoried as sawtimber but purchased as pulpwood confuse the situation by having their growth recorded in the sawtimber category but their removals recorded in the pulpwood category.

Our simulations suggest that there is potential for the constrained pulpwood situation described in Chapter 2 to worsen over time. While wood demand targets met for all product categories (Figure 5-2), this happened only with increasing removals of sawtimber-sized trees for use as pulpwood products (especially for hardwood; Figure 5-3). The constrained pulpwood supply resulted in steadily rising stumpage prices paid for pulpwood, and the high levels of hardwood sawtimber substitution resulted in competitive pressure for hardwood sawtimber which raised those prices as well.

It is important to note that the heavy pressure on the pulpwood supply does not imply unsustainability in the use of the overall forest resource: inventory levels continued to rise steadily and substantially. However, much of this increase in inventory was in the portions of the resource that are considered unavailable, either due to location or temporary stand conditions that restrict harvest. Furthermore, much of the available resource may have been far enough from consuming mills that high transportation costs would lead to low stumpage bids. Over the course of the simulation, clearcut harvests resulted in regenerated even-aged stands that regrew and became available to the supply chain. This is why we projected increasing levels of available inventory and decreasing levels of temporary unavailability due to stand conditions in Figure 5-6.

As a further indication of the competitive market for pulpwood, the simulation resulted in increasing average haul distances for both hardwood and softwood pulpwood, with fairly stable haul distances for sawtimber products.

The simulation results reported here cannot be construed as a prediction or forecast. Too many factors that impact wood supply dynamics are beyond the scope of models such as this. For example, international trade in wood products, domestic consumption levels, and other macroeconomic influences are not modeled here: demand is assumed to be static. Furthermore, SWSS does not simulate the failure or closure of individual wood manufacturing facilities. But the wood industry cannot accommodate increasing raw material costs without repercussions. Indeed, during the time this report was being written, major Wisconsin paper mills have declared bankruptcy.

It is also important to note that this "baseline" scenario is overly optimistic: it is assumed that all landowners are willing to harvest timber, which we know from the landowner survey is a false assumption. However, this serves as a baseline for comparison which will be described in a followup report.

Further spatial analysis of the simulation results is possible, and may yield insights into the spatial dynamics of supply shortages for pulpwood. Regional results can be reviewed on the interactive website referenced in the beginning of the Results section of this chapter.

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