

Geographic Information System-Based Spatial Analysis of Sawmill Wood Procurement

Nathaniel M. Anderson, René H. Germain, and
Eddie Bevilacqua

ABSTRACT

In the sawmill sector of the forest products industry, the clustering of mills and wide variation in forest stocking and ownership result in sawlog markets that are complex and spatially differentiated. Despite the inherent spatial attributes of markets for stumpage and logs, few studies have used geospatial methods to examine wood procurement in detail across political boundaries. This article provides a visual representation of wood procurement pressure across the Northern Forest region of the northeastern United States based on a spatial analysis of woodshed maps provided by 273 sawmills in the United States and Canada. The analysis also includes the predicted woodsheds of 280 nonrespondent mills, which were modeled based on mill characteristics and location. In general, maps emphasize the magnitude of softwood procurement on industrial and investment-oriented forestlands in northern Maine, but also highlight distinct spatial procurement patterns in New York, Vermont, and New Hampshire. Sensitivity analyses of woodshed boundary uncertainty suggest that procurement pressure in existing hotspots will intensify if procurement range is restricted by high transportation costs. The methods used to visualize resource procurement in this study have the potential to benefit a broad range of stakeholders including industry, policymakers, and landowners.

Keywords: wood procurement, spatial analysis, land use

Understanding spatial patterns of wood procurement has important implications for the forest products industry, forest landowners, and policymakers. Although most sawmill managers are highly cognizant of local roundwood market conditions, there are few tools available for evaluating and visualizing variation in aggregate wood procurement at regional scales. The capacity to model and predict trends in procurement can enhance the effi-

ciency of wood supply chains, inform land-use decisions, and improve our ability to anticipate conflicts related to natural resource use. Useful empirical models are especially important in procurement environments that are characterized by uncertainty about the future wood supply, short ownership tenure, and rapid land-use change. Recent research has documented exactly these conditions in the northeastern United States (Alig et al. 2003, Nowak et al. 2005, Ger-

main et al. 2006, McDonald et al. 2006, Anderson and Germain 2007, Egan et al. 2007, Vickery et al. 2009).

Regardless of the specific procurement environment, the profitability of sawmills often hinges on the cost of sawlogs, which includes stumpage price, harvesting costs, and transportation costs. Because the cost of transporting logs is relatively high, the sawmill sector is dependent on the flow of timber from local forests to meet production requirements (Murray and Prestemon 2003). For example, most sawmills in the northeastern United States procure the majority of their roundwood from within 30–70 miles of the mill, depending on the quantity and type of products being manufactured (Anderson and Germain 2007). Dependency on local wood suppliers has two important spatial outcomes. Sawlog markets tend to be spatially differentiated (Murray and Prestemon 2003, Luppold and Bumgardner 2004) and the spatial distribution of sawmills tends to be clustered, with agglomerations of firms located near raw materials (Bowe et al. 2004, Aguilar 2008).

Despite the importance of local wood supplies to sawmills and the inherent spatial attributes of sawlog markets, few studies

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Nathaniel M. Anderson (nmanderson@fs.fed.us) is postdoctoral research forester, University of Montana, US Forest Service Rocky Mountain Research Station, 800 East Broadway, Missoula, MT 59807. René H. Germain (rhgermai@esf.edu) is professor, and Eddie Bevilacqua (ebevilacqua@esf.edu) is associate professor, State University of New York, College of Environmental Science and Forestry, 1 Forest Drive, Syracuse, NY 13210. This research was funded by the Northeastern States Research Cooperative. The authors thank the hundreds of sawmill managers and industry professionals throughout the United States and Canada who participated in this study.

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have examined procurement using spatial methods. Most studies of wood procurement rely on generalized stumpage price reports (Spelter 2005), data collected from mail surveys and telephone interviews (Wagner et al. 2004, Anderson and Germain 2007, Egan et al. 2007), and US Forest Service Forest Inventory and Analysis (FIA) data, which is limited in its application to relatively large scales (Smith et al. 2004). In one of the earliest studies to address procurement using spatial methods, Smith (1983) combined linear programming and early geographic information system (GIS) technology to model the use of aspen in Minnesota. About the same time, GIS was being used to develop spatial wood supply models in Canada (Baskent and Jordan 1991, Jordan and Baskent 1992), Brinker and Jackson (1991) used GIS to develop spatial techniques focused on modeling pulpwood procurement in northwestern Louisiana. More recently, market factors and land-use projections have been incorporated into models of timber supply for northern New England and New York (Sendak et al. 2003). In addition, Harouff et al. (2008) modeled the efficiency of roundwood delivery in West Virginia using theoretical “sawmill service areas” based on a transportation network analysis. Other studies have incorporated spatial reference data into econometric analyses of southern pulpwood markets (Polyakov et al. 2005, Polyakov and Teeter 2007), timber harvesting margins (Sun and Zhang 2006), price equilibrium in softwood lumber trade (Mogus et al. 2006), the clustering of firms in the softwood lumber industry (Aguilar 2008), and the availability of biomass residues in Virginia (Parhizkar and Smith 2008).

A variety of studies have examined wood procurement in the United States using industry surveys, FIA data, and stumpage reports. Some have modeled procurement using theoretical wood procurement regions. However, there is a lack of analysis focused on procurement in the Northeast and a scarcity of spatial modeling of wood procurement in general. No previous study in any region has used spatially explicit data provided by industry to examine patterns of resource procurement at the landscape level. The research presented here used geospatial analysis in GIS to visualize wood procurement in four northeastern states and used sensitivity analysis to illustrate how procurement pressure may change in the future, de-

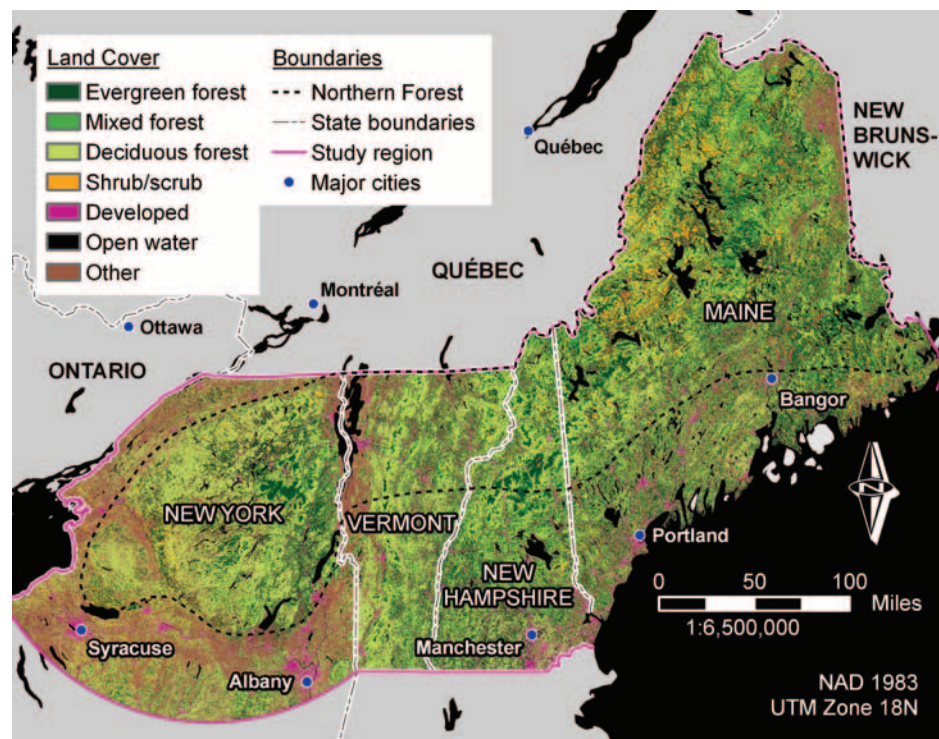


Figure 1. Land cover and other features in the study region. Land cover designations are based on Multi-Resolution Land Characteristics Consortium (2001).

pending on changes in the procurement operations of mills in this region.

Methods

The Study Region

Analysis and visualization of procurement pressure was focused on the four Northern Forest states (Figure 1). The study region includes all of Maine, New Hampshire, Vermont, and about one-half the total area of New York (Figure 1). Western and downstate regions of New York are not included. The delineation of the Northern Forest as an ecological and political unit occurred around 1990 as a result of several government efforts focused on examining social and economic change in the region (Northern Forest Lands Council [NFLC] 1994). This area includes 26 million ac of relatively contiguous mixed hardwood and coniferous forest that stretches 450 mi across these four states. Land cover in the Northern Forest is 83% forest, with 40% of this forestland classified as deciduous, 28% as coniferous, and 32% as mixed deciduous and coniferous (Figure 1). In addition, although pockets of natural shrub/scrub communities exist throughout the Northeast, much of the shrub/scrub land cover that appears in Figure 1 is representative of clearcuts in the

early stages of regeneration. Landownership in the Northern Forest is predominantly private, with individuals, families, and corporations holding approximately 85% of forestlands (NFLC 1994, Hagan et al. 2005). Public ownership accounts for most of the rest and includes the large government holdings of the Adirondack Park (New York), Green Mountain National Forest (Vermont), White Mountain National Forest (New Hampshire and Maine), and Baxter State Park (Maine). Although relatively small by comparison, nongovernment organization holdings through fee simple ownership and conservation easement have grown considerably since the early 1990s (Hagan et al. 2005).

Traditional land use in the Northern Forest has been oriented toward forest products and recreation. According to the North East State Foresters Association (2007), forest-based industry in the four Northern Forest states accounts for \$14.4 billion in manufacturing shipments, 7.3% of combined manufacturing sales, and over 90,000 jobs, with a combined payroll of over \$3.4 billion. Including small proprietary and seasonal sawmills, Prestemon et al. (2005) located 417 sawmills within the boundary of the Northern Forest. However, according to the most recent estimate, the number of year-round sawmills producing more than

100 mbf yr⁻¹ in this region is closer to 150 (Anderson and Germain 2007).

Spatial Analysis of Wood Procurement

This study used GIS-based geospatial analysis of sawmill wood procurement regions (also known as “woodsheds”) to visualize procurement pressure across the study region. Paper woodshed maps were provided by sawmill managers in the United States and Canada as part of a mail survey of sawmills within 100 mi of the Northern Forest boundary (Anderson and Germain 2007). A comprehensive treatment of survey methods and nonresponse bias is included in studies by Anderson and Germain (2007), Anderson (2008), and Anderson et al. (2009). The survey was performed in 2006 using Dillman’s (2000) Tailored Design Method on a sample frame of 553 mills. The sample frame was developed using state and provincial sawmill directories, industry association directories, Internet listings, and other sources, including Prestemon et al. (2005).

Each survey questionnaire included a detailed 6.0 × 6.5-in., 1:4,500,000 map that was centered on the location of the responding mill. In the context of a series of open-ended questions focused on defining the geographic extent of procurement operations in 2005, respondents were instructed to “outline your woodshed by drawing a line around your mill that shows the area where the closest 90% of your total log volume originates.” In all, 197 mills in the United States and 76 mills in Canada provided woodshed maps (Table 1). This result represents a 49% response rate for this portion of the survey. These woodsheds varied considerably in shape and detail. Some woodsheds were drawn as a nearly perfect circle around the responding mill, and others displayed complex shapes that followed transportation networks, major water bodies, and other landscape features. Individual paper woodshed maps were digitized in ArcMap 9.2 (ESRI, Inc., Redlands, CA) at the same scale and projection as the analog map. Then, digital woodshed maps were merged into a single feature class and linked to a variety of procurement and production data (Anderson and Germain 2007, Anderson et al. 2009).

Within the survey range, approximately 205 US mills and 75 Canadian mills did not respond to the survey (Table 1). To accurately visualize wood procurement across the study region, it was necessary to model the woodsheds of these 280 mills. For nonre-

Table 1. Sample sizes of respondents (known woodsheds) and nonrespondents (modeled woodsheds) by country and mill type.

Respondent type	Country/mill type	United States	Canada	Total
Respondents	Hardwood	85	27 (11)	112
	Softwood	112	49 (20)	161
	Total respondents	197	76 (31)	273
Nonrespondents	Hardwood	113	15 (11)	128
	Softwood	92	60 (37)	152
	Total nonrespondents	205	75 (48)	280

The number in parentheses is the number of Canadian mills known (respondents) or predicted (nonrespondents) to have US log sources.

spondent mills located in the United States, woodshed area was predicted for each mill based on ordinary least squares linear regression of mill type and annual procurement volume, with log transformation used to normalize the distributions of woodshed area and annual volume. The woodshed area of each nonrespondent US mill was calculated as

$$\ln(A_m) = \beta_0 + \beta_1 \cdot T_m + \beta_2 \cdot \ln(V_m) + \beta_3 \cdot T_m \cdot \ln(V_m), \quad (1)$$

where A_m denotes woodshed area of mill m , T_m is a categorical dummy variable for mill type (softwood = 0 and hardwood = 1), V_m is the mill’s annual production volume, and $\ln$ represents the natural log. The last term, $T_m \cdot \ln(V_m)$, is the interaction term, with β_0 , β_1 , β_2 , and β_3 as parameters to be estimated. Values for the independent variables used for prediction were extracted from published sources, including mill directories. In the event that annual production was reported as a range rather than a discrete value, the midpoint of the range was used in prediction. With the exception of four large American mills known to procure wood in Canada, all US mills with modeled woodsheds were assumed to procure 100% of their log supply in the United States.

Based on regression analysis of survey data, mill size and mill type are not significant predictors of woodshed area for Canadian mills (Anderson et al. 2009). Therefore, the median woodshed area for all Canadian respondents with US wood supplies (26,795 mi²) was used as the predicted woodshed area for Canadian nonrespondents. However, based on previous analysis, the distance from the US border is a significant predictor of the proportion of wood supply procured from US sources (Anderson et al. 2009). Therefore, although the total

woodshed area for all nonrespondent Canadian mills is a constant, the proportion of wood supply procured from the United States is variable and was predicted based on distance from the border:

$$\ln(U_m) = \beta_0 + \beta_1 \cdot \ln(D_m), \quad (2)$$

where U_m denotes the proportion of mill m ’s wood supply from US sources and D_m is the distance of mill m from the border, with β_0 and β_1 as parameters to be estimated.

Spatial analysis was performed using woodshed rasters in the Model Builder environment of ArcMap 9.2. In preparation for this analysis, each woodshed polygon was converted into a raster coverage at 1-km resolution, with cells falling outside the woodshed given a value of zero. The value of cells within each woodshed was calculated as

$$P_m = V_m \cdot U_m \cdot A_m^{-1}, \quad (3)$$

where P_m is the cell value for procurement pressure for mill m , V_m is the mill’s annual volume, U_m is the proportion of volume from sources within the United States, and A_m is the area of the woodshed within the United States. This calculation weights each mill’s woodshed by its annual procurement volume, with P_m in units of 1,000 board feet per square mile.

To create the composite rasters used to map procurement pressure, woodshed rasters for individual mills of the same type (hardwood or softwood) were summed using an equally weighted sum overlay. Cell values in the composite raster equal the sum of all procurement based on overlapping woodsheds weighted by annual volume:

$$P_{\text{total}} = \sum_{m=1}^M P_m, \quad (4)$$

where P_{total} is the cell value for total procurement pressure, P_m is the procurement pressure of mill m , and M is the number of mills in the grouping (hardwood or softwood).

Although the resulting composite ras-

ters extend well beyond the area shown in the figures, the study region visualized on these maps represents the area of analysis that can be interpreted to be free of edge effects related to procurement by mills that were not included in the survey. Based on the average woodshed area reported by large sawmills in the United States and Canada, sawmills outside the survey range are not expected to purchase significant volumes of sawlogs and stumpage within the area visualized.

Sensitivity Analysis

One of the greatest sources of error in this analysis is generated by the sampling design. It is very difficult to determine if the maps provided by sawmill managers accurately represent the true woodsheds of their mills. It is possible that survey respondents systematically overestimated or underestimated the geographic extent of their procurement operations when mapping their woodsheds. To model the effects of uncertainty or fuzziness in woodshed boundaries related to this and other sources of error, we performed a sensitivity analysis. In this sensitivity analysis we repeated the geospatial analysis exactly as it has been described, but assumed that the true woodsheds of the sawmills in the study were either smaller or larger than the woodsheds mill managers drew on their paper maps.

Because of constraints related to buffering operations in ArcMap, we based woodshed expansion and contraction on fixed proportions of the woodshed radius rather than on proportions of the woodshed area. In addition to addressing technical constraints, an emphasis on distance rather than area conforms well with the importance of trucking distance as a determinant of procurement range (Bressler and King 1970, Harourff et al. 2008). Each woodshed was expanded or contracted (buffered) by a linear distance equal to ± 10 and $\pm 20\%$ of its radius. The 10% factor was chosen because it is approximately equal to double the standard error of the mean radius, expressed as a percentage of the mean, for all respondent US sawmills. The 20% factor is approximately equal to four times the standard error of the mean radius, expressed as a percentage of the mean. The same contraction and expansion factor was applied to all the woodsheds in each sensitivity analysis, and woodsheds were buffered evenly around the entire woodshed polygon. The methods used to create and visualize the procurement

Table 2. Summary statistics for woodshed area for the respondent mills included in this analysis.

Country	Mill type	n	Woodshed area (mi ²)		
			Mean	SE	Median
United States	Hardwood	85	5,400	674	3,362
	Softwood	112	3,240	516	1,642
	All mills	197	4,230	409	2,439
Canada (w/US supply)	Hardwood	11	39,190	9,748	28,180
	Softwood	20	45,700	11,777	25,950
	All mills	31	43,210	8,089	26,795

Statistics for Canadian mills include only those mills with wood procurement in the United States.

Table 3. Model parameters for predicting woodshed area for US nonrespondent sawmills based on mill type and annual volume.

Variable (parameter)	df	Estimate	SE	t-Value	P Value
Intercept (β_0)	1	6.9642	0.1088	64.02	<0.0001
Mill type (β_1)	1	0.5089	0.1533	3.32	0.0011
Annual volume (β_2)	1	0.4978	0.0480	10.37	<0.0001

Interaction between mill type and annual volume was not significant ($P = 0.9466$), so the term was dropped from the prediction model.

pressure rasters in this sensitivity analysis were identical to those used for the baseline analysis.

To visualize the results of the sensitivity analysis, we present eight additional maps, four for hardwood procurement and four for softwood procurement, that represent the -20% , -10% , $+10\%$, and $+20\%$ scenarios. The resulting maps show procurement pressure as it appears when all woodsheds in the analysis are expanded or contracted by the specified factor. To facilitate comparison between these maps and the baseline map for each procurement type (hardwood or softwood), the baseline map is included alongside the maps produced in the sensitivity analysis and the difference between each scenario and the baseline map is visualized in a difference map. These difference maps were created by subtracting the baseline raster from the sensitivity analysis raster for each factor and show specific areas where procurement pressure would intensify, diffuse, or remain the same under the different scenarios. In addition to assessing the effects of error, this analysis is useful in predicting the procurement impacts of factors that either expand or contract procurement range, including transportation costs.

Results

The average woodshed area for respondent mills was 4,230 mi², with a median area of 2,439 mi² (Table 2). The median woodshed areas of softwood and hardwood mills in the United States differed signifi-

cantly from one another, with median areas of 1,642 mi² and 3,362 mi², respectively (Kruskal-Wallis chi-square = 10.57; $P = 0.0011$). Canadian respondents with US log sources averaged 43,210 mi², with a median of 26,795 mi². Softwood and hardwood mills in Canada are not significantly different with regard to woodshed area (Kruskal-Wallis chi-square = 0.0314; $P = 0.8594$). It is worth noting here that, on average, mills are much larger in Canada than in the United States. The US sample included many small and medium-sized mills (annual production, <5.0 mmbf yr⁻¹), and mill size is positively correlated with woodshed area for US mills (Anderson and Germain 2007). However, large mills in the United States had similar woodshed areas compared with Canadian mills in the same size class (Anderson et al. 2009).

Coefficients for the regression equation used to predict the woodshed areas of non-respondent US mills based on mill type and annual volume are shown in Table 3. This model accounts for approximately 40% of the variation observed in woodshed area (adjusted $R^2 = 0.4145$). A regression equation was also used to predict the proportion of log supply originating in the United States for nonrespondent Canadian mills. Coefficients for this model are shown in Table 4. The model, which uses distance from the border as a predictor of proportion of supply originating in the United States, accounts for about 45% of the variation ob-

Table 4. Model parameters for predicting proportion of wood supply from US sources for nonrespondent Canadian mills based on distance from the United States–Canadian border.

Variable (parameter)	df	Estimate	SE	t-Value	P Value
Intercept (β_0)	1	5.7971	0.5418	10.70	<0.0001
Dist. to border (β_1)	1	-1.1317	0.1432	-7.90	<0.0001

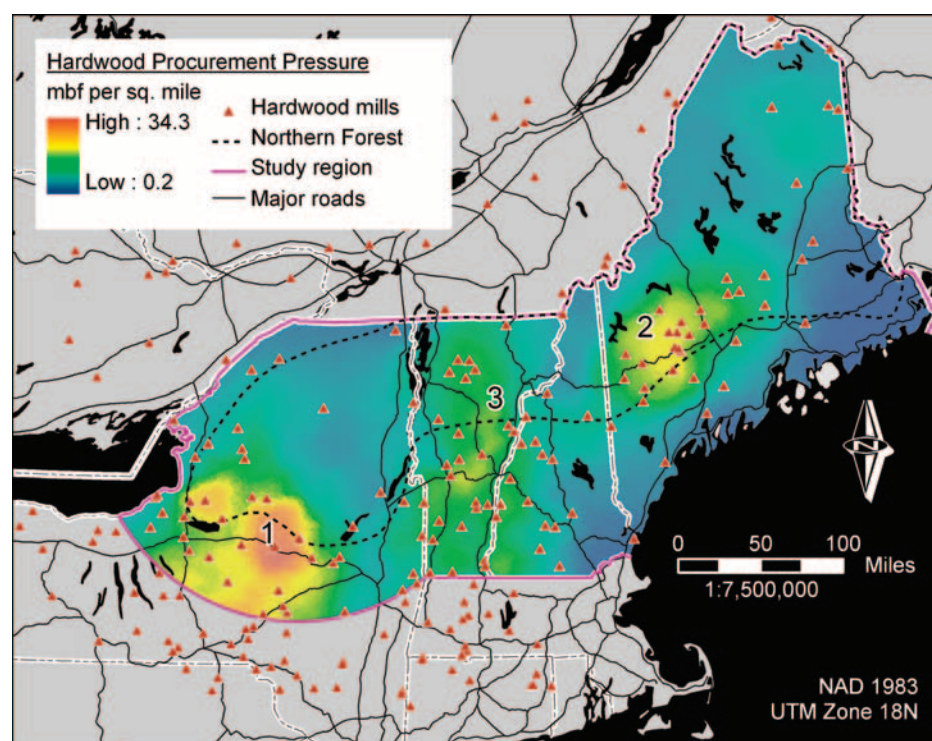


Figure 2. Map of hardwood procurement pressure. Numbers 1, 2, and 3 label areas of interest with relatively high hardwood procurement pressure.

served in the response variable (adjusted $R^2 = 0.4570$).

Hardwood procurement pressure ranged from 0.3 to 34.3 mbf mi^{-2} , with the highest pressure occurring in southern Herkimer County, New York (Figure 2, zone 1). Hardwood procurement pressure in western Maine also appeared higher than in the surrounding areas (Figure 2, zone 2). The highest softwood procurement pressure, measuring 92.1 mbf mi^{-2} , was observed near the Canadian border in Maine in Somerset and Piscataquis counties, north of Moosehead Lake (Figure 3, zone 1). With the exception of midrange pressure in northern and southwestern New Hampshire (Figure 3, zones 2 and 3), softwood procurement pressure was relatively lower across the rest of the study region when compared with this hotspot in Maine. Combining the woodsheds of hardwood and softwood mills, the heaviest procurement pressure was in northern Maine on the western border with

Canada (Figure 4, zone 1). However, a relatively small hotspot of pressure also appeared in southwestern New Hampshire (Figure 4, zone 2). The lowest levels of procurement pressure occur along the coast of Maine and in the Adirondack Park region of New York (Figure 4, zone 3).

Sensitivity analyses of expanding and contracting woodsheds exhibited similar trends for both hardwood and softwood procurement pressure (Figures 5 and 6). In general, as woodsheds contract, procurement pressure becomes more concentrated on hotspots. For individual mills, woodshed contraction results in the same procurement volume spread over a smaller area. This trend leads to higher pressure around clusters of mills. Conversely, as woodsheds expand, the same procurement pressure is spread over larger areas and overall procurement pressure becomes more diffuse. Some exceptions to this general pattern are discussed in the following section. The differ-

ence maps on the right of Figures 5 and 6 quantify the changes in procurement pressure under the different expansion and contraction scenarios and show areas where pressure is expected to intensify, diffuse, or stay the same under these scenarios.

Discussion

Industrial forestlands and large parcel, investment-oriented ownerships dominate the Northern Forest in Maine. These spruce-fir forests are the most intensively managed in the Northeast and have harvest levels that are comparable with industrial lands in the Southeast and Pacific Northwest (Smith et al. 2004). The intensity of harvesting on industrial and investment-oriented lands in northern Maine is clearly reflected in the maps of wood procurement. Large softwood sawmills operating in Maine and across the border in Quebec and New Brunswick depend on these lands to meet production requirements. Procurement by these mills produced a hotspot of procurement pressure as high as 103 mbf mi^{-2} , with the most intense pressure occurring between Moosehead Lake and the Canadian border, as well as to the north and east of Chesuncook Lake (Figure 4, zone 1). In comparison, most of the rest of the study region has relatively lower procurement pressure (Figure 4).

Sensitivity analysis indicates that, under conditions of contracting procurement range, procurement pressure in this region would be bifurcated into two zones, with one zone on the western border serving the mills located along the Maine-Quebec border and a second zone located in the northeast corner of the state serving mills located in the Caribou/Presque Isle area on the eastern edge of the state and across the border in New Brunswick (Figure 6). Under these conditions, a zone of lower pressure is predicted to expand around the region roughly centered on Baxter State Park, in the north central part of the state (Figure 6). To the extent that transportation costs limit wood procurement range, if higher transportation costs lead to smaller woodsheds, all else being equal, the predicted pattern may be accurate. However, production levels at most mills have dropped dramatically during the course of the current recession, primarily in response to collapsed housing markets in the United States. This analysis does not account for declining production, but is based on 2005 production levels. Results should be interpreted accordingly.

In addition to having the highest pro-

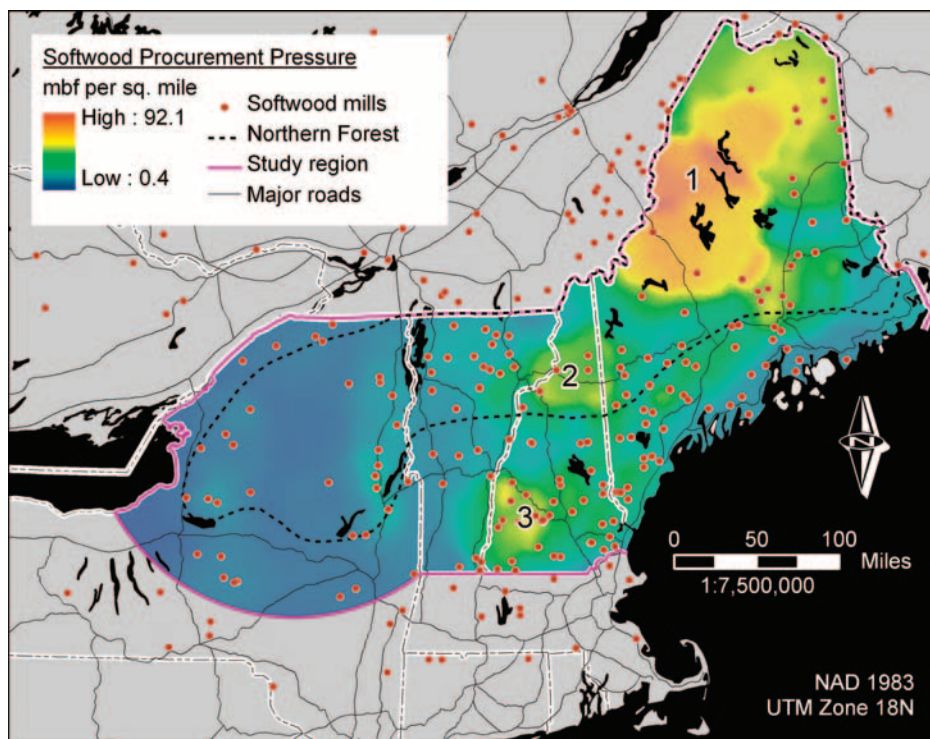


Figure 3. Map of softwood procurement pressure. Numbers 1, 2, and 3 label areas of interest with relatively high softwood procurement pressure.

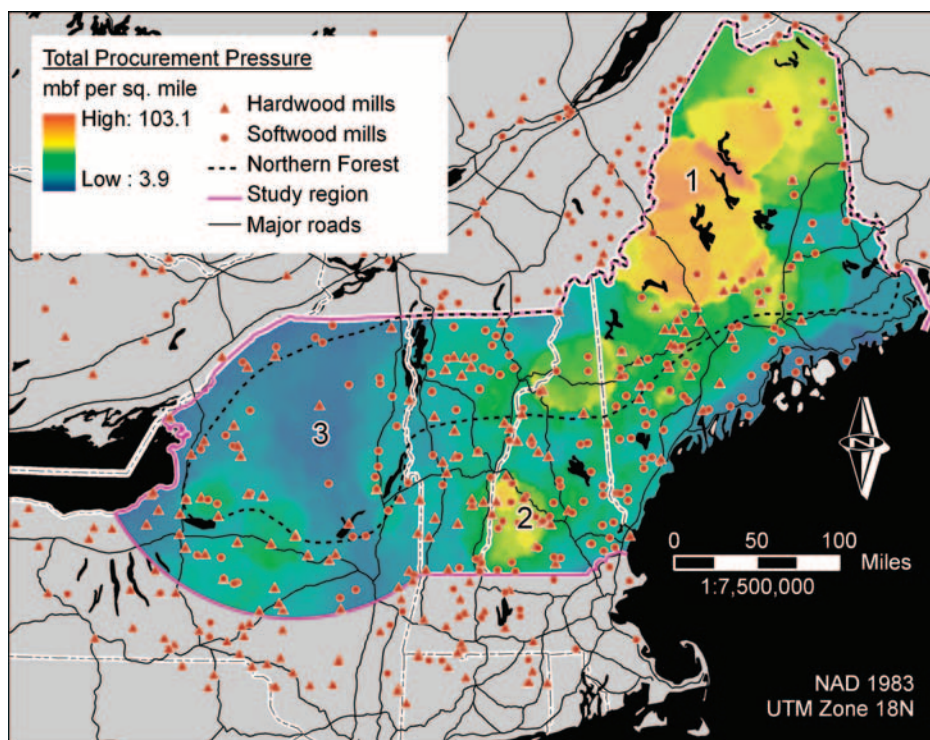


Figure 4. Map of total wood procurement pressure by all mills. Numbers 1 and 2 label areas of interest with relatively high total procurement pressure. Number 3 labels the Adirondack Park region of New York, which has relatively low total procurement pressure.

curement pressure observed in this study, the area of Maine near Moosehead Lake also has the potential to become a nucleus for future development of residential and tour-

ist facilities on lands formerly owned by industry (Land Use and Regulation Commission 2008). Given the unique history of industrial land use in Maine, the effects of

such development on wood procurement are difficult to predict, but based on the intensity of procurement in this region, any negative effects on wood flow have the potential to impact sawmills in both the United States and Canada.

The most intense hardwood procurement pressure in the Northern Forest was observed in the southwest corner of the study region (Figure 2, zone 1). This area falls within the woodsheds of many of the large hardwood mills operating in southern New York and northeast Pennsylvania, and offers abundant stocks of high-value hardwoods, including sugar maple (*Acer saccharum*) and black cherry (*Prunus serotina*). Although the sensitivity analysis pictured in Figure 5 indicates that woodshed expansion may diffuse some of this pressure northward and farther into the Northern Forest, this scenario is unlikely. On all maps, the Adirondack Park region of New York stands out as a low pressure region. Mills in this area are clustered on the periphery of the park, with few mills located in the interior. Although the park was not officially established until 1892, this pattern of location dates back to at least the early 1800s (Dinsdale 1965).

About one-half of the 6 million ac inside the park boundary are owned by New York State and are off limits to harvesting under a legislative designation as a "forever wild" forest preserve. Private land within the park boundary is subject to land-use controls that regulate harvesting activities, particularly in riparian areas (Adirondack Park Agency 2005). However, working forests are present inside the park, most significantly, over 500,000 ac formerly owned by Domtar, Inc., International Paper Company, and Finch, Pruyn & Company, Inc., that have been purchased by forestland investment companies and conservation groups in recent years. Despite these large holdings, our analysis indicates that, as a whole, the Adirondack Park region provides relatively little wood to the sawmill sector when compared with other parts of the study region. Even so, sawlogs from the private forests of the Adirondacks are critically important to the mills located there.

Vermont and New Hampshire also exhibited some notable patterns in wood procurement. Vermont, in general, and northern Vermont, especially, is home to a high density of small sawmills. Although the number of mills is high, the aggregate procurement pressure in Vermont is relatively

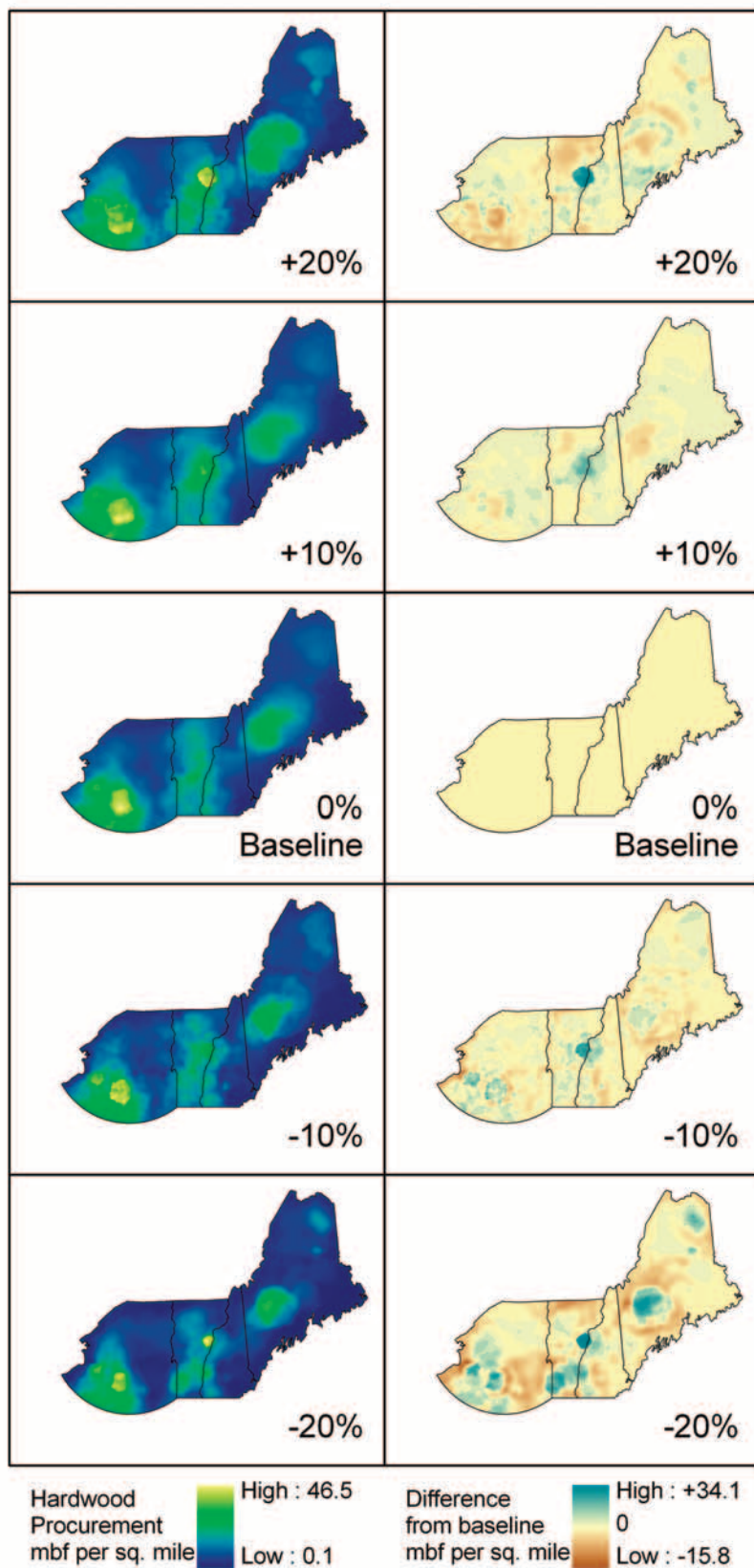


Figure 5. Sensitivity analysis for hardwood procurement pressure. For each factor, the map on the left visualizes hardwood procurement pressure if all woodsheds in the analysis are expanded or contracted by that factor. The map on the right visualizes the difference between the map on the left and the baseline case, which is shown in the center as expansion factor zero.

low. However, overlapping clusters of small hardwood mills appears to be responsible for the small hotspot of hardwood pressure observed on the Vermont–New Hampshire border (Figure 2, zone 3, and Figure 5). In contrast with a general trend showing more diffuse pressure with woodshed expansion, this hotspot appears to intensify with woodshed expansion (Figure 5). At 20% expansion, two clusters of small mills overlap enough to intensify procurement pressure. Given the proximity of this zone to the Canadian border, it is also likely that procurement pressure by Canadian mills is higher here with woodshed expansion. A similar hotspot appears in Maine, where a sliver of intensified softwood procurement pressure appears in the north at 20% expansion (Figure 6). This is likely caused by the overlap of the woodsheds of large Canadian mills that do not overlap in the baseline scenario, including mills that are relatively distant from the border.

The bulk of New Hampshire's industrial forests and several large mills are located in the extreme north of the state, north of the White Mountain National Forest. Mills in Maine, Vermont, and Quebec also procure wood in this area. As a result, a band of moderate softwood pressure appears in the Berlin, New Hampshire, area, along and north of Route 2 (Figure 3, zone 2). However, a hotspot of softwood pressure is also present in the southwest corner of the state, in Cheshire and Sullivan counties (Figure 3, zone 3). When combined with hardwood pressure, this region stands out as one of the only hotspots of procurement pressure occurring outside the Northern Forest boundary (Figure 4, zone 2).

This area of New Hampshire is located near the intersection of two major interstate highways, I-89 and I-91, and is known to supply wood to mills in at least six states and two provinces. Throughout this region, the four component species of the northern hardwood assemblage—sugar maple, red maple (*Acer rubrum*), yellow birch (*Betula alleghaniensis*), and American beech (*Fagus grandifolia*)—are commonly complimented by a number of commercially valuable associate species such as black cherry, white pine (*Pinus strobus*), white ash (*Fraxinus Americana*), red spruce (*Picea rubens*), eastern hemlock (*Tsuga canadensis*), several oak species (*Quercus* spp.), and others. The region is dominated by nonindustrial private forest but is bracketed by the Green Mountain National Forest to the west, the White Moun-

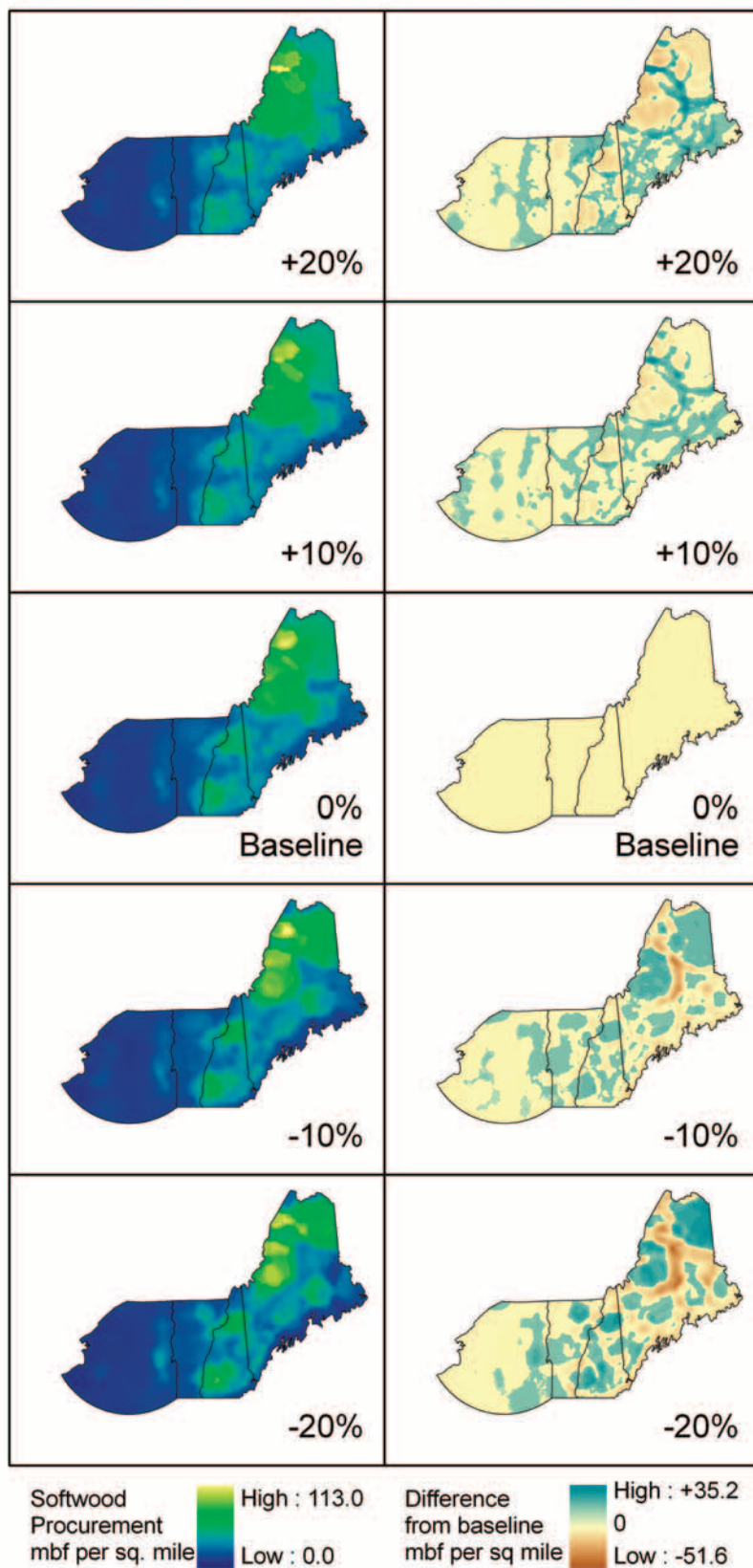


Figure 6. Sensitivity analysis for softwood procurement pressure. For each factor, the map on the left visualizes softwood procurement pressure if all woodsheds in the analysis are expanded or contracted by that factor. The map on the right visualizes the difference between the map on the left and the baseline case, which is shown in the center as expansion factor zero.

tain National Forest to the northeast, and New Hampshire's Lakes Region to the east. Although mill density does not appear to be higher in this region than in other areas, a diverse mix of species combined with good transportation infrastructure, favorable location, and placement between large tracts of public forest with administrative restrictions on timber harvesting may contribute to making this area of New Hampshire an attractive market for logs and stumpage.

This region also highlights the uncertainty in wood supply associated with trends in urbanization. The upper Connecticut River Valley, including southwestern New Hampshire, is expected to experience a high rate of urbanization over the next 10 years, with most new development occurring on forestland (Nowak and Walton 2005). In the short term, wood flow from liquidation harvests associated with real estate development is likely to keep this area a viable wood basket (Anderson 2008). However, the long-term implications for timber stocks and flow are likely to be negative. The advancement of the urban fringe brings a variety of land use and ownership changes that favor non-forest use over forest use and nontimber values over management for forest products (Dennis 1989, Cubbage et al. 2003, Nowak and Walton 2005). Given that this area of the state is a hotspot of wood procurement for the sawmill industry, such changes could bring higher procurement costs and lower profits to a large number of mills.

Conclusions

The Northern Forest is one of the largest contiguous tracts of forest cover east of the Great Plains. Spatial analysis of sawmill woodsheds shows that this region, although relatively homogenous with regard to percent forest cover, is highly variable with regard to wood procurement. This variability is closely linked to a variety of factors, including spatial variation in species composition, forest stocking, industry structure, and forest landownership and use. Although the Northeast represents one of the most diverse and perhaps one of the most challenging procurement environments in the country, the methods for spatial analysis presented here have potential for broad application to wood procurement in other regions. Given the relatively rapid changes in industry structure, land use, and forest cover that have occurred nationwide over the last 20 years, developing dynamic models to visualize wood procurement across political

boundaries will benefit not only the forest products industry, but policymakers and landowners as well.

We recommend that future studies of wood procurement expand spatial models to include more detailed consideration of the full diversity of forest cover types, roundwood products, and landownership. Furthermore, there is limited empirical evidence linking the intensity of competition for roundwood to forest management practices. We have already begun research to determine the extent to which the procurement hotspots visualized in this analysis may be dominated by exploitative harvesting or intensive silviculture. Combining spatial analysis of procurement with remote sensing data and field measurements will allow researchers to test hypotheses about the impact of market trends on forest inventories and sustained yield management. Incorporating more precision in this regard will enhance the predictive power of such models, thereby improving their usefulness to all parties interested in maintaining and enhancing the flow of resources from forestland.

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