Social versus Biophysical Availability of Wood in the Northern United States

Brett J. Butler, Zhao Ma, David B. Kittredge, and Paul Catanzaro

ABSTRACT

The availability of wood, be it harvested for sawlogs, pulpwood, biomass, or other products, is constrained by social and biophysical factors. Knowing the difference between social and biophysical availability is important for understanding what can realistically be extracted. This study focuses on the wood located in family forests across the northern United States. Family forest owners control 54% of the 7,685 million dry tons of wood in the region. To estimate availability, we begin with the total resource and then apply constraints related to slope, drainage, site productivity, tree size, size of forest holdings, distance to roads, harvesting restrictions, population pressures, and ownership attitudes. These constraints reduce wood availability significantly, by nearly two-thirds according to our calculations. The vast majority of this reduction is due to social factors, in particular owner attitudes. The greatest state-level reductions in wood availability are in Connecticut, Delaware, Maryland, New Jersey, and Rhode Island, all of which have estimated reductions of more than 75%.

Keywords: timber harvesting, family forest owners, forest inventory, landowner survey

Wood is the dominant feature of the forest. In situ, it provides aesthetics, wildlife habitat, carbon storage, and other ecosystem services. Extracted, it is used for products ranging from veneer to biomass to mulch. The availability of wood for these and countless other uses is dependent on biophysical and social factors. The biophysical characteristics describe the quantity, quality, and composition of the resource and the natural setting in which it exists. The social factors determine the desirability of the potential goods and services and the propensity for those who control a resource, such as wood, to use it themselves, allow others to do so, or do nothing with it.

According to the US Forest Service, there are an estimated 7,685 million dry tons of wood across the northern United States (Miles 2009; Figure 1). This estimate includes the boles, tops, and limbs of all trees of at least 1.0 in. dbh on forestland. However, if one were interested in extracting part of this resource, how much is actually available? The answer depends on what one wants to extract, how many other people also want it, the physical characteristics of the location, and the willingness of the people who control the resource to provide it. In this article, we examine the availability of wood from family forestlands in the northern United States by considering a range of biophysical and social factors that affect the availability of wood, including people's willingness to provide it.

We focus on family forestlands because collectively they control 94.0 million forested acres, or 55% of all forestland in the region (Butler 2008). Another 20% of the region's forestland is owned by corporations and other private groups, and the other 25% is publicly owned. The importance of family forestlands for providing wood and other forest resources is increasing because of restrictions on harvesting on public lands, rapid urbanization, and large-scale divestiture of industrial forest holdings (Vokoun et al. 2006). Although an individual owner's willingness to provide wood and other forest resources may not significantly affect general resource availability, many owners' decisions across the landscape and over time will influence the future of the nation's forests and the public benefits they provide.

Although demand for wood is an important factor, we focus on the supply side of wood availability. Wood is harvested for an immense variety of products and uses. The demand for it varies temporally and geographically depending on local, regional, and international markets, proximity to processing plants, and other factors. Increased demand, as manifested in higher stumpage prices, will motivate additional owners to harvest, but this is just one of many motivating factors, and previous research has been inconclusive on its impact on family forest owners' harvesting decisions (Beach et al. 2005). Our analysis of wood availability is based on two assumptions: wood is a raw material widely demanded for various uses, and, given certain levels of market price for various wood products, the extent to which wood is harvested or merchandised depends on a wide range of external factors beyond the market.

Forest resources are located across lands with widely varying biophysical and social characteristics. The raw numbers most often cited fail to capture the full suite of factors that constrain resource availability. For example, 54% of the wood in the northern United States is owned by 4.8 million family forest owners, and the average forest holding size of these owners is less than 20 ac (Butler 2008). Researchers have shown that parcel size is an important determinant affecting wood availability; it is directly related to the scale at which harvesting is economically feasible (Row 1978). Generally speaking,

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Brett Butler (bbutler01@fs.fed.us), US Forest Service, Northern Research Station, 160 Holdsworth Way, Amherst, MA 01003. Zhao Ma, Department of Environment and Society, Utah State University, Logan, UT 84322. David B. Kittredge, Department of Environmental Conservation, University of Massachusetts–Amherst, Amherst, MA 01003, and Harvard Forest, Harvard University, Petersham, MA 01366. Paul Catanzaro, Department of Environmental Conservation, University of Massachusetts–Amherst, Amherst, MA 01003. *We are very grateful to the three anonymous reviewers whose comments greatly improved the manuscript. This report is a product of the Family Forest Research Center (www.familyforestresearchcenter.org), a joint venture between the US Forest Service and the University of Massachusetts-Amherst.*

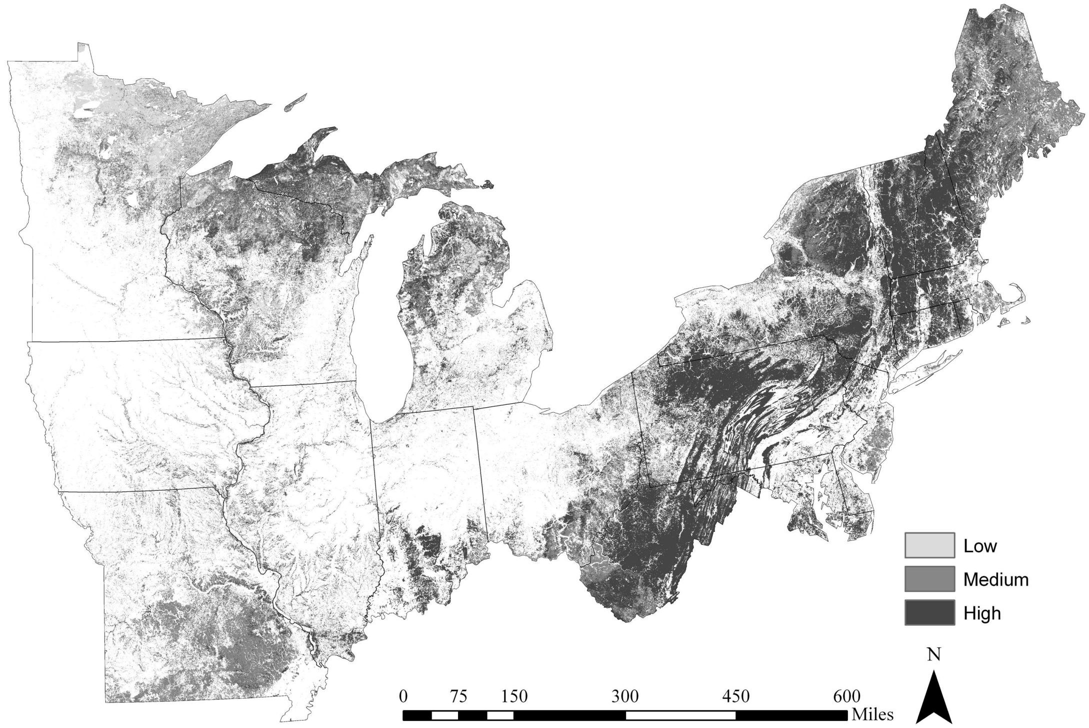

Figure 1. Distribution of wood (estimated weight per area) across the northern United States (Blackard et al. 2008).

traditional harvesting techniques become uneconomical when parcel size is below a certain threshold, for example 30 ac, because of costs associated with moving and operating large machinery and issues that arise with multiple owners abutting a harvest area and operating in more populated areas (Catanzaro et al. 2007).

Considering the large number of family forest owners and the small average holding size of family forest owners across the northern United States, several questions arise. What are the biophysical and social factors that most influence the availability of this resource? How much of this wood is available for harvesting? We address these questions by reviewing the existing literature, presenting a model that describes biophysical and social constraints, applying these constraints to wood across the northern United States, and discussing the implications of our findings.

Background

Most studies examining the availability of forest resources have concentrated on timber supply (Beach et al. 2005), but a few have looked at other products and services, such as biomass (Galik et al. 2009) and recreation (Hunt 2002). The timber supply studies have generally used econometric approaches to model either aggregate or individual harvesting behavior of specific types of forest owners, such as industrial owners (Newman and Wear 1993) or family forest owners (Binkley 1981). The first empirical studies of the harvesting behavior of family or nonindustrial private forest owners goes back to the 1980s with the theoretical and empirical modeling done by Binkley (1981). Numerous other studies have subsequently been conducted in the northern United States (Holmes 1986, Dennis 1989), other parts of the United States (Prestemon and Wear 2000, Pattanayak et al. 2002), and other countries (Salkie et al. 1995, Bolkesjo and Baardsen 2002, Favada et al. 2009).

A thorough review of econometric studies of family forest owners' harvesting behavior is provided by Beach et al. (2005). Unfortunately, the variables included in these studies vary widely, and the relationships between the variables and timber harvesting are often inconsistent. These inconsistencies are likely related to where and when the studies were conducted, the data availability and quality, and the specific analyses conducted.

Factors that have been shown to be significantly correlated with harvesting behavior include land characteristics, landowner characteristics, and various economic and political factors. Size of forest holdings has been shown to be positively related to harvesting probabilities (McDonald et al. 2006) because of economies of scale (Row 1978) and the many attributes to which this characteristic is correlated (Butler 2008). The quantity of growing stock and site quality have, in general, been shown to be positively correlated with harvesting (Løyland et al. 1995, Kuuluvanien et al. 1996). Stumpage prices and the consequent stand values have mixed correlations with harvesting: Binkley (1981), Boklesjo and Baarden (2002), and Patanayak et al. (2003) reported positive relationships; Dennis (1989), Kuuluvanien et al. (1996) and Prestemon and Wear (2000) found no significant relationship; and one study, Hyberg and Holthausen (1989), found a negative relationship.

The social context within which forests exist has also been shown to be a significant determinant. As population pressures increase, as measured by population density (Wear et al. 1999), housing density (Liu et al. 2003), urbanization (Barlow et al. 1998), or road density (McDonald et al. 2006), harvesting probabilities decrease. Zhang (2004) has shown that political factors can also be important. For instance, landowners whose forests are close to a known or perceived endangered species habitat tend to have higher probabilities to harvest. They do so to avoid perceived future limitations that would otherwise be imposed by the Endangered Species Act. Other studies have shown a positive impact of assistance programs and/or cost share programs on harvesting (Boyd 1984, Hyberg and Holthausen 1989, Kilgore and Blinn 2004).

The attitudes and demographics of the landowners matter as well. Many studies have shown that family forest owners value the natural beauty, privacy, and other nontimber amenities provided by their forests, and in general, timber production is not a primary ownership objective (Kuuluvainen et al. 1996, Finley and Kittredge 2006, Butler 2008); this may be another key that helps us understand resource availability. Owners who are wealthier and more educated appear to be less likely to harvest (Dennis 1989, McDonald et al. 2006). How long someone has owned the land and whether they live on it have been shown to be positively correlated with harvesting (Vokoun et al. 2006).

Total wood inventory does not equal the amount of wood that is actually available for conversion into wood products. Building on the existing literature, our study identifies biophysical and social factors that may constrain wood availability on family forests in the northern United States and provides an estimate of how much wood is really available taking into account these constraints.

Methods

The quantity we are trying to estimate is the amount of wood on family forestlands in the northern United States that is available for harvesting. Wood is defined as the dry tons of boles, tops, and limbs of all trees at least 1.0 in. dbh on forestland. Stumps, nontree aboveground biomass, and all below ground biomass are not included. Family forest owners are defined as "families, individuals, trusts, estates, family partnerships, and other unincorporated groups of individuals that own forestland" (Butler 2008, p. 3). Forestland is defined as "land at least 10 percent stocked by forest trees of any size, including land that formerly had such tree cover and that will be naturally or artificially regenerated. The minimum area for classification of forestland is 1 acre (Butler 2008, p. 3)."

This analysis could have been conducted using weight or volume metrics for the wood. We did both and the results were very similar. For the analysis presented here, we chose weight because it is the broader of the two measurements. The results are presented in terms of percentages, a metric-neutral measure that can be used to extrapolate our findings.

Estimates of the amount of wood come from data collected by the US Forest Service Forest Inventory and Analysis (FIA) program (Bechtold and Patterson 2005). FIA has established a set of stratified, random inventory plots across the United States to estimate, among other attributes, species composition, forest health, timber volume, and biomass. The United States was divided into hexagons of approximately 6,000 ac, and a randomly located sampling point was established within each hexagon. This point serves as the center for a permanent inventory plot. If any part of the plot is determined to be forested, based on remotely sensed imagery and field verification, a field crew will collect data on the trees and other site variables (US Forest Service 2005). Because each plot is randomly selected, the measured attributes can be used to estimate population-level statistics. A total of 18,078 plots from the most recent FIA surveys in the region were used for this analysis. The sampling error for the estimated amount of wood across the northern United States is less than 1%.

Along with the biophysical inventory, FIA conducts a survey of forest landowners, the National Woodland Owner Survey (NWOS; Butler et al. 2005). For those inventory plots that are determined to be forested and privately owned, the owner of record, as listed in public tax records, is identified. The NWOS then uses this sampling frame to contact the owners and ascertain information related to ownership objectives, management practices, and landowner demographics. A self-administered, mail questionnaire is used following the implementation methods prescribed by Dillman (2001). The overall cooperation rate for the region was 56%. Details of the findings are available in Butler (2008).

The relationship between the FIA forest plot and ownership survey can be thought of as a many-to-one relationship. The NWOS respondent corresponds to the person or group that owns the plot center of the forest inventory plot. If an inventory plot spanned multiple ownerships, all plot attributes were assigned to plot center. On the NWOS, respondents are asked to respond for all of the land they own in a state. An FIA plot represents only a fraction of an owner's holdings, but the owner's characteristics correspond to all of his or her acres.

We began with FIA's estimate of wood on family forestlands and then systematically reduced, or screened, these values based on biophysical and social constraints. Mathematically, this can be represented by:

$$\mathrm{Wood}_A = \sum_{i=1}^{n}\left(\left(\prod_{j=1}^{m}(1-\mathrm{ReductionRate}_{ij})\right)\mathrm{Wood}_i\right), \qquad (1)$$

where total available wood, Wood_A, is equal to the sum of the wood represented by each plot, Wood_i, multiplied by the product of the availability constraints. The reduction rate for each constraint at each point, $\mathrm{ReductionRate}_{ij}$, takes on a value between 0 and 1. If no constraints affect a given point, $\mathrm{ReductionRate}_{ij} = 0$, $\prod_{j=1}^{m}(1 - \mathrm{ReductionRate}_{ij}) = 1$, and the wood is considered fully available. If one constraint is present, the probability of the wood being available is $(1 - \mathrm{ReductionRate}_{ij})$. If more than one constraint is present, the probability is $\prod_{j=1}^{m}(1 - \mathrm{ReductionRate}_{ij})$. The multiplicative nature of this approach progressively reduces the probability of wood being available when multiple constraints are observed for a given plot. A simple example of this model is included at the end of this article.

The presence of a biophysical or social constraint will reduce the probability of wood being available, but it is unlikely to reduce the probability to zero. Initially, ReductionRate is set to 0.75 if a constraint is present, which implies that it is unlikely that the wood is available, but not impossible. For instance, although harvesting from plots with standing water is uncommon in the region, these sites could be logged under frozen water conditions. A sensitivity analysis, described below, is used to explore the impact of changing the value of ReductionRate.

The selection of empirical variables to represent the theoretical constraints was dictated by the applicability and availability of data and the literature. As with the theoretical model, we divided the variables into biophysical and social constraint categories. Summary statistics for the four biophysical and six social constraint variables are presented in Table 1. Figure 2 shows the distribution of wood as a function of each constraint.

Slope, physiographic class, site productivity, and tree size represent the physical constraints. These variables were measured on the plots by FIA (US Forest Service 2005). As discussed above, a physical constraint is considered present if a plot is permanently inundated with water, classified as hydric by FIA (US Forest Service 2005). The availability of wood on plots with a productivity level of less than 20 ft^3/ac per year was classified as constrained, because

Table 1. **Descriptions of the variables used to analyze the availability of biomass from family forests of the northern United States.**

Variable	Units/codes	Data type	Mean	SE	Median	Minimum	Maximum
Biophysical							
Slope	Percent	Continuous	11.0	13.7	6.0	0	150
Physiographic class	1 = xeric 2 = mesic 3 = hydric	Nominal				1	3
Site productivity (ft^3/ac per year)	1 = 225+ 2 = 165–224 3 = 120–164 4 = 85–119 5 = 50–84 6 = 20–49 7 = 0–19	Ordinal			5	1	7
Tree size	1 = large 2 = medium 3 = small 4 = nonstocked	Ordinal			1	1	4
Social							
Size of forest holdings	Acres	Continuous	235	2,279	74	1	160,000
Road distance	Miles	Continuous	0.18	0.17	0.13	0.0	1.2
Riparian buffers	Feet	Continuous	1,558	1,380	1,177	0.1	6,562
Population density	People per square mile	Continuous	17.4	49.6	7.0	0	1,752
Population gravity index	Population divided by miles squared	Continuous	492	2,129	157	11	193,060
Owner attitude	See text	Ordinal			1	0	3

plots that have low productivity are unlikely to be sustainably managed. This threshold, along with reserved status, is used by the US Forest Service to distinguish between forestland and timberland (Smith et al. 2009).

Forests located on steep slopes are less operable and therefore less likely to be harvested. Best management practices in Massachusetts stipulate restrictions on slopes of 60% or more (Kittredge and Parker 1999), and in New York, slopes of 30% or more are expected to receive special treatment (New York Department of Environmental Conservation [NY DEC] 2009). The exact percentages vary across states, and 50% is representative of the values. In our study, a slope of 50% or more is considered a physical constraint. In the sensitivity analysis, we also test 25 and 75% slopes. Slope was measured by FIA field crew at plot center and represents the average incline or decline (US Forest Service 2005).

Depending on the desired end products and harvesting techniques, the size of the trees can be a limiting factor. The availability of wood on plots categorized as being nonstocked or dominated by small trees was considered constrained. Small is synonymous with what FIA classifies as seedling/sapling stands—forestland dominated by trees less than 5.0 in. dbh (Smith et al. 2009). FIA defines medium, or poletimber, stands as forestland dominated by softwoods between 5.0 and 9.0 in. dbh or hardwoods between 5.0 and 11.0 in. dbh. Large, or sawtimber, stands include forestland dominated by either softwoods at least 9.0 in. dbh or hardwoods at least 11.0 in. dbh. The size of the trees was also measured on the plots by FIA (US Forest Service 2005).

Economies of scale are an important consideration in harvesting trees, particularly given the large costs associated with modern harvesting equipment and the transportation and setup times they require. The minimum operable size of a forest holding varies, but we selected 20 ac on the basis of a review of existing literature. For example, Catanzaro et al. (2007, p. 11) reported that "15-acre, and increasingly the 30-acre, ownerships are becoming uneconomical to harvest" and Rickenbach and Steele (2008, p. 2) reported "a minimum harvest size of approximately 7 hectares [17 ac] assuming conventional harvesting practices and average stocking and quality levels." Size of forest holdings was taken from the NWOS. In the sensitivity analysis, we test the effect of a 10-ac threshold, a common minimum for public programs, as well as 30 ac.

Wood is commercially unavailable if it is too far from existing infrastructure to be economically removed and transported. New roads can be built, but as the extraction costs increase, the probability of harvesting is reduced. The availability of wood on plots that are 1.0 mi or more from existing roads, as defined by the US Geological Survey (1999), was considered constrained. Other road distances tested were 0.5 and 1.5 mi.

One manner by which society influences harvesting options is through regulations. At the broad scale, there are often state-level rules that limit or influence where harvesting can occur through either mandatory or voluntary best management practices (BMP). Many of these regulations are related to water issues, such as riparian buffers. In this study, we considered the availability of wood from plots within 100 ft of a stream, river, lake, or other water body included in the National Atlas of the United States (2005) constrained. The appropriate buffer width is dependent on the function(s) being protected and local circumstances, such as slope. One hundred feet is deemed sufficient for most functions (Wenger 1999) and is within the bounds prescribed by many BMPs (Kittredge and Parker 1999, NY DEC 2009). In addition, 50- and 150-ft buffers were tested.

At the municipal level, zoning regulations can make harvesting difficult, if not impossible. We assume that these zoning restrictions are greatest in areas of high population densities. Wear et al. (1999) suggested that harvesting probabilities were reduced to 25% with population densities of 70 people/mi^2 and approached zero at 150 people/mi^2. Therefore, we considered the availability of wood from plots located within US Census block groups with population densities of at least 100 people/mi^2 (US Geological Survey 2003) constrained. Population densities of 50 and 150 people/mi^2 were also examined.

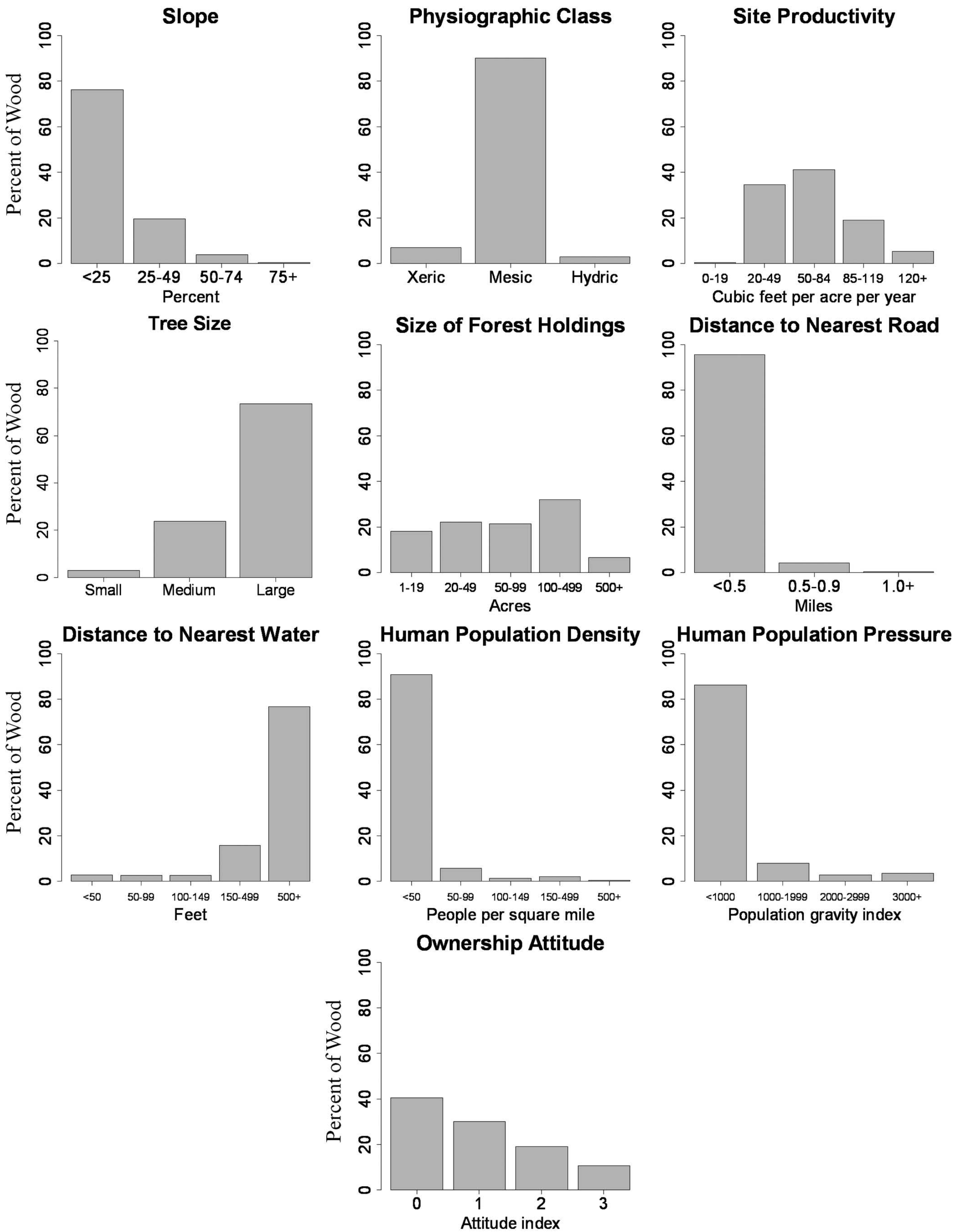

Figure 2. Distribution of wood by biophysical and social characteristics for family forests of the northern United States.

To account for development pressures, we used a population gravity index (Haynes and Fotheringham 1984) calculated as

$$\text{PopulationGravityIndex}_i = \frac{\text{Population}_j}{\text{Distance}_{ij}^2}, \qquad (2)$$

where the population gravity index for plot *i* is equal to the population of city/town/place *j* divided by the square of the distance, measured in miles, between plot *i* and city/town/place *j*. The distance is squared to account for proximity effects. For each plot *i*, population gravity indices were calculated using all cities, towns, and places of 2,500 people or more in the study area and surrounding states and provinces (Environmental Systems Research Institute 2002, Statistics Canada 2006), and the highest value was assigned to plot *i* as the final value for the population gravity index. If the index was 2,000 or greater, the availability of wood was considered constrained. A population gravity index value of 2,000 is equal to a plot being 5 mi from a city of 50,000 people. Population gravity indices of 1,000 and 3,000 were also examined.

Even if no other factors constrain wood availability, it is the owner who ultimately decides whether or not to harvest. Their decisions will be influenced by their ownership objectives, past experiences, current needs, and long-term plans. Owners' attitudes toward harvesting were quantified as

$$\begin{aligned}&\text{HarvestingAttitude}_i\\ &\quad = \text{OwnershipObjectives}_i + \text{HarvestingExperience}_i\\ &\qquad + \text{HarvestingIntentions}_i, \qquad (3)\end{aligned}$$

where $\text{OwnershipObjectives}_i = 1$ if the owner of the plot indicated timber production was a very important or important ownership objective (1 or 2 on a 7-point Likert scale, with 1 defined as very important and 7 as not important) and 0 otherwise; $\text{HarvestingExperience}_i = 1$ if the owner reported having harvested sawtimber, pulpwood, or veneer logs and 0 otherwise; and $\text{HarvestingIntentions}_i = 1$ if the owner indicated an intension to harvest sawlogs, veneer logs, or pulpwood in the next 5 years and 0 otherwise. These variables were taken from the NWOS. If $\text{HarvestingAttitude}_i \leq 1$, the availability of wood from the plot was considered constrained. $\text{HarvestingAttitude}_i = 0$ and $\text{HarvestingAttitude}_i \leq 2$ were also tested.

Sensitivity Analysis

The constraint thresholds and reduction rates were assessed using sensitivity analyses. In general, lower and higher threshold levels were selected by increasing and decreasing the base values by 50%. This bracketing was not appropriate for all constraints; the specific values used are discussed above and are included in Table 3. In addition to the 0.75 reduction rate, 1.00 and 0.50 were tested (Table 4). A reduction rate of 1.00 implies that if a given constraint is present, no wood is available. A reduction rate of 0.50 implies a 50/50 chance that it is available.

Results

There are an estimated 7,685 million dry tons of wood in the forests of the northern United States. A majority (54%) of this wood is owned by family forest owners (Figure 3).

Of the 4,150 million dry tons of wood on family forestlands, we estimate that only 38% is both biophysically and socially available—a 62% reduction in availability. Table 2 shows the reductions caused by individual constraints respectively, all the biophysical constraints cumulatively, all the social constraints cumulatively, and all the biophysical and social constraints cumulatively. The biophysical constraints collectively reduced availability by 8%, and the social constraints collectively reduced availability by 60%. The combined availability reduction is not equal to the sum of these two values because of the multiplicative nature of Equation 1 and the fact that both biophysical and social constraints were present at some locations.

Of the social variables, owner attitudes had the greatest impact, with an estimated availability reduction of 53%. Size of forest holdings had the next greatest impact, and it resulted in an estimated reduction of 14%. The population gravity index, riparian buffers, and population density reduced availability by 5, 4, and 3%, respectively. Distance to roads had a very small impact on availability, with an estimated reduction of less than 0.5%.

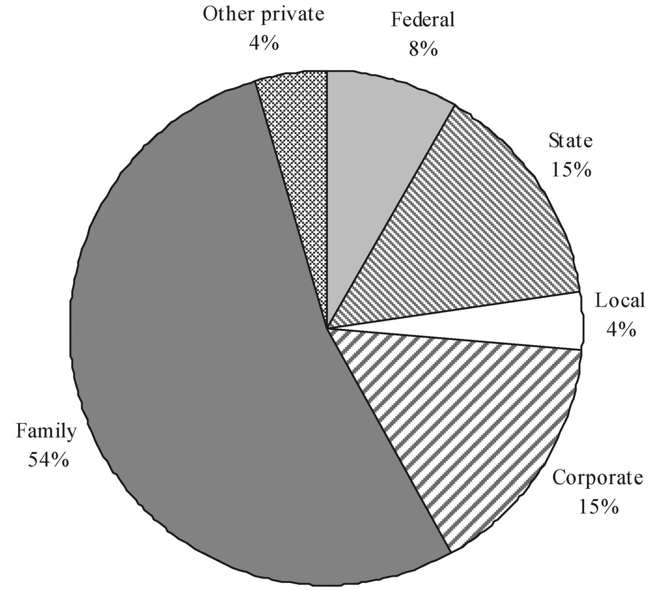

Figure 3. Distribution of wood for the northern United States by broad ownership groups.

Table 2. Estimated reductions in wood availability from family forests of the northern United States as a function of biophysical and social constraints.

Constraint (reduced availability if ...)	Reduction in wood availability (%)
Biophysical	
Slope (≥50%)	3.2
Physiographic class (hydric)	2.3
Site productivity (<20 ft^3/ac per year)	0.3
Tree size (small)	2.2
Cumulative reduction due to biophysical constraints[a]	7.6
Social	
Size of forest holdings (<20 ac)	13.7
Road distance (≥1 mi)	0.2
Riparian buffers (<100 ft)	3.8
Population density (≥100 people/mi^2)	2.6
Population gravity index (≥2,000)	4.6
Owner attitude index (0, 1)	52.8
Cumulative reduction due to social constraints[a]	59.6
Cumulative reduction due to biophysical and social constraints[a]	61.9

[a] Because multiple constraints are present at some locations, values are not additive.

Table 3. Sensitivity of estimated reduction in wood availability from family forests of the northern United States to changes in thresholds of biophysical and social constraints.

	Threshold level[a]					
	Reduced availability if ...			Reduction in wood availability (%)		
Constraint	Lower	Base	Higher	Lower	Base	Higher
Biophysical						
Slope (%)	≥25	≥50	≥75	17.8	3.2	0.3
Physiographic class		Hydric			2.3	
Site productivity (ft^3/ac per year)	<50	<20		26.1	0.3	
Tree size		Small			2.2	
Cumulative reduction due to biophysical constraints[b]				41.6	7.6	4.7
Social						
Size of forest holdings (acres)	<30	<20	<10	19.2	13.7	7.0
Road distance (miles)	≥0.5	≥1	≥1.5	3.2	0.2	0.0
Riparian buffers (feet)	<150	<100	<50	5.6	3.8	1.9
Population density (people/mi^2)	≥50	≥100	≥150	6.8	2.6	1.6
Population gravity index	≥1,000	≥2,000	≥3,000	10.3	4.6	2.6
Owner attitude	0, 1, 2	0, 1	0	67.0	52.8	30.4
Cumulative reduction due to social constraints[b]				76.8	59.6	37.5
Cumulative reduction due to biophysical and social constraints[b]				85.7	61.9	40.4

[a] The lower the threshold at which a constraint is applied, the more land it applies to and consequently the greater the reduction in wood availability. The corollary to this is that the higher the threshold, the less land it applies to and the higher the wood availability.
[b] Because multiple constraints are present at some locations, values are not additive.

Table 4. Sensitivity of estimated reductions in wood availability from family forests of the northern United States to changes in the biomass availability reduction rates by biophysical and social constraints.

	Reduction rate		
Constraint (reduced availability if ...)	1.00	0.75	0.50
	. . . . Reduction in wood availability (%)		
Biophysical			
Slope (≥50%)	4.3	3.2	2.1
Physiographic class (hydric)	3.0	2.3	1.5
Site productivity (<20 ft^3/ac per year)	0.4	0.3	0.2
Tree size (small)	2.9	2.2	1.4
Cumulative reduction due to biophysical constraints[a]	10.1	7.6	5.1
Social			
Size of forest holdings (<20 ac)	18.2	13.7	9.1
Road distance (≥1 mi)	0.3	0.2	0.1
Riparian buffers (<100 ft)	5.1	3.8	2.5
Population density (≥100 people/mi^2)	3.5	2.6	1.7
Population gravity index (≥2,000)	6.1	4.6	3.0
Owner attitude index (0, 1)	70.5	52.8	35.2
Cumulative reduction due to social constraints[a]	73.9	59.6	42.9
Cumulative reduction due to biophysical and social constraints[a]	75.7	61.9	45.2

[a] Because multiple constraints are present at some locations, values are not additive.

Of the biophysical variables, slope caused the greatest reduction, 3%. Physiographic class and tree size each had estimated reduction rates of 2%. Site productivity had a very small impact on availability, with an estimated reduction of less than 0.5%.

Changing constraint thresholds resulted in changes in estimated wood availability from 40% with more restrictive thresholds to 86% with less restrictive thresholds, compared with the base scenario under which the estimated overall availability is 62% (Table 3). The sensitivity of constraint thresholds is a function of the magnitude of changes in threshold values and the overall impact of the constraint on wood availability. By lowering the level of a threshold, the amount of land that is classified as constrained increases and hence the availability decreases. Conversely, a higher threshold level implies that less land is classified as constrained, and the availability is higher. Changes in threshold values used for ownership attitudes had the greatest impact on availability, with resulting reductions between 30 and 67%. Changes in the threshold values used to define site productivity, slope, and size of forest holdings constraints also had relatively large impacts on availability.

Wood availability estimates were less sensitive to changes in the values of reduction rates, with estimated overall reduction rates that varied from 45 to 75% (Table 4). Ownership attitudes was again the most sensitive to these changes, with availability reductions ranging from 35 to 70% depending on the reduction rate. Size of forest holdings was the only other constraint to show a difference in availability reductions of more than 5%.

The availability of wood from family forests and the relative reductions due to biophysical versus social constraints varied considerably among states (Table 5). For all states, social constraints caused larger reductions in wood availability than biophysical constraints. Reductions of more than 75% were estimated for Connecticut, Delaware, Maryland, New Jersey, and Rhode Island, primarily due to social constraints. The greatest biophysical constraints, which reduced wood availability by 10%

Table 5. Estimated reductions in wood availability from family forests in the northern United States as a function of biophysical and social constraints by state.

State	Reduction in wood availability (%)		
	Biophysical	Social	Total[a]
Connecticut	7.7	78.7	80.0
Delaware	1.5	93.8	93.8
Illinois	4.3	67.0	68.5
Indiana	5.0	66.6	67.7
Iowa	8.4	61.4	65.0
Maine	6.4	47.2	49.8
Maryland	4.1	80.5	80.6
Massachusetts	5.8	67.7	68.2
Michigan	11.5	61.0	65.3
Minnesota	10.7	63.6	67.7
Missouri	4.1	62.8	64.0
New Hampshire	4.1	55.6	56.7
New Jersey	5.2	85.5	85.5
New York	6.5	56.9	58.7
Ohio	5.5	63.6	64.8
Pennsylvania	5.2	60.2	61.9
Rhode Island	9.2	78.4	78.6
Vermont	5.2	40.9	42.9
West Virginia	16.9	64.0	66.0
Wisconsin	11.0	51.9	56.8
Northern United States	7.6	59.6	61.9

[a] Because multiple constraints are present at some locations, values are not additive.

or more, were found in Michigan, Minnesota, West Virginia, and Wisconsin.

Discussion

It is clear that family forest owners are a critical component of estimating and understanding wood availability in the northern United States—they control 54% of it. Because of declines in harvesting on public land, rapid urbanization, and large-scale divestiture of industrial forest holdings, this importance is likely to increase (Vokoun et al. 2006).

It is also clear that much of this resource is not readily available given current circumstances. The reduction in availability is primarily due to social constraints. In particular, many family forest owners have not harvested, do not intend to harvest, and do not have timber production as a major ownership objective. In addition, a high percentage of family forests have been parcelized, and as the size decreases, so does the probability of actively managing forests (Butler 2008), for economic and attitudinal reasons.

The availability of wood in the long run will be strongly influenced by the overall amount of forestland that is being lost to development across many parts of the northern United States. In fact, Stein et al. (2005) estimated that the United States loses 2,500 ac of forest per day to this largely irreversible change. A number of the watersheds most vulnerable to land use change are in the northern United States. Once forestland is lost, availability (and all other forestry) issues are irrelevant for those acres and for the remaining acres, the likelihood of commercial harvesting declines (Wear et al. 1999, McDonald et al. 2006). We account for this in our modeling by including population density and a population gravity index. Current trends indicate that the area of forestland will decline in the region (Alig et al. 2003). This implies that wood availability is subject to further reduction considering that the overall potential pool of forestlands on which the constraints are acting will shrink.

The demand side of the equation was intentionally excluded from our analysis. This article describes a snapshot of what is available under our estimated constraints and given current conditions. As stated earlier, the demand depends on market preferences, proximity to processing facilities, and other factors that vary across the region and over time. Additional work is required to describe the supply-demand dynamics, which is outside the scope of this study.

The estimates reported here are just that—estimates. We used the best available data that span the study area, and we think of the approach presented here as a first approximation of an estimate of regional wood availability from family forests. The sensitivity analyses show the potential range of wood availability, but the overall trend of large reductions in availability due to social constraints is consistent. It is hoped that this article will encourage additional research that refines the models and uses better data as they become available. More empirical research is needed to better define the thresholds for specific constraints and the appropriate reduction rates. Likewise, it may be appropriate to generate these estimates at the state level, to take advantage of data that are not consistently available across the wider 20-state region. The NWOS data provided some information about harvesting propensities, but more direct measures, through contingent valuation or other methods, would be useful to explore. Although it may be logistically infeasible, it would also be useful to have the owners respond for the specific inventory plot and not their land as a whole. Hydrographic and physical data are constantly being improved. The roads and water body data we used likely underestimated the number of small roads and water bodies in the region, and this can be rectified as newer and better data are developed.

Conclusions

Understanding and estimating the constraints of wood availability is important for developing sound forest policies, promoting active forest management, shaping realistic expectations of the role wood might play in our future, and, in general, ensuring the continued, sustainable flow of forest resources. The results of this study should help policy makers and agency officials, forest industries, community planners, landowner organizations, and natural resource professionals better understand current conditions and future trends of forest resources in the northern United States. They will then be able to better balance the needs for extractive resources and the various ecosystem services provided by forests.

Although we selected wood availability on family forestlands in the northern United States as our focus, this approach is applicable to other regions and other resources. Similar methods could be used to quantify the availability of forest resources in the southern United States, western United States, or other countries with only slight modifications. For those interested in knowing the availability of lands for recreation, mineral extraction, or other resources, this general approach can likewise be used. For the nonextractive, nonwood resources, the specific biophysical and social constraints will need to be reconsidered, but it is hoped that this article provides a framework for guiding and expediting those analyses.

Example Calculation

Below is a simplified example of our approach for estimating wood availability using Equation 1. For this example, we use three plots ($n = 3$), three constraints ($k = 3$), and the values specified below.

Plot 1

$ReductionRate_{1,1} = 0$

$ReductionRate_{1,2} = 0$ $\quad Wood_{A,1} =$

$ReductionRate_{1,3} = 0$ $\quad ((1-0)\times(1-0)\times(1-0))\times 100 =$

$Wood_1 = 100$ $\quad (1\times1\times1)\times100 =$

$\therefore Wood_{A,1} = 100$ $\quad 1\times100 = 100$

Plot 2

$ReductionRate_{2,1} = 0.75$

$ReductionRate_{2,2} = 0$ $\quad Wood_{A,2} =$

$ReductionRate_{2,3} = 0$ $\quad ((1-0.75)\times(1-0)\times(1-0))\times100 =$

$Wood_2 = 100$ $\quad (0.25\times1\times1)\times100 =$

$\therefore Wood_{A,2} = 25$ $\quad 0.25\times100 = 25$

Plot 3

$ReductionRate_{3,1} = 0.75$

$ReductionRate_{3,2} = 0.75$ $\quad Wood_{A,3} =$

$ReductionRate_{3,3} = 0.75$ $\quad ((1-0.75)\times(1-0.75)\times(1-0.75))\times100 =$

$Wood_3 = 100$ $\quad (0.25\times0.25\times0.25)\times100 =$

$\therefore Wood_{A,3} = 1.56$ $\quad 0.0156\times100 = 1.56$

Total Wood Availability

$Wood_A = Wood_{A,1} + Wood_{A,2} + Wood_{A,3} =$

$100 + 25 + 1.56 = 126.56$

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