Assessment of the Landbase Suitable for Sustainable Forest Biomass Harvest and the Wood Biomass Resource Supply

Addison County Five Towns and Mad River Valley Towns

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Executive Summary

An analysis of the forestlands suitable and available for sustainable wood biomass harvest was conducted for two study areas: the Addison County Five Towns area consisting of Bristol, Lincoln, Monkton, New Haven and Starksboro, and the Mad River Valley Towns area consisting of Fayston, Moretown, Waitsfield and Warren. To model forestlands that are suitable for sustainable wood biomass harvesting we used ArcGIS and existing spatial data. The analysis yielded a suitable forest landbase by excluding lands judged to be unsuitable based on the following criteria: limited to very limited forestry potential (forest land value groups determined by NRCS provided this metric), slopes greater than 60%, surface waters and wetlands and adjacent 75' buffers, and legal protections from timber extraction. Additionally, we separated lands of slopes 30-60%, which require extra precautions in logging operations and may in many cases be unsuitable for sustainable extraction. We also separated private and public ownerships for information purposes. To account for unmapped ecologically significant features and the forest access network we subtracted 10% from the suitable landbase. After calculating the suitable forestland acreages for the two study areas, we estimated the likely per acre annual growth in green tons of low-quality wood using growth rates from several sources. It is difficult to accurately estimate biomass production because of wide variability in published growth rates and variability in the proportions of low-quality and sawtimber-quality wood in different forest parcels. To account for such uncertainty, we provided a range of values.

The Addison County Five Towns' suitable woodshed consisted of 37,900 acres, which was 28% of the total study area and 47% of the forested lands in the area. Limited and very limited forestry potential was the single criterion responsible for excluding the most forest area, 37%. Water, wetlands and their buffers accounted for excluding 9% of the forested lands. Slopes of 30-60% covered 9% of the suitable landbase. Sixteen percent of the suitable landbase was in public ownership. Calculating based on a growth rate of 1.2 green tons/acre/year and 38% of the harvest as low-quality wood, we estimated an annual growth slightly greater than 17,000 green tons/year on the suitable forestlands. Using a growth rate of 1.2 green tons/acre/year and assuming 48% of the wood biomass to be low quality, the Addison County Five Towns woodshed was estimated to grow approximately 22,000 green tons/year of low-quality wood. Calculating based on a high growth rate of 1.7 green tons/acre/year and assuming 58% of the wood biomass to be low quality, we estimated a growth of 37,000 green tons/year. Hence, it appears to be reasonable to expect a range of 17,000-37,000 green tons/year of low-quality wood growth in the Five Towns' suitable woodshed.

The Mad River Valley Towns' suitable woodshed consisted of 50,300 acres, which was 55% of the total study area and 68% of the forested lands in the area. Limited and very limited forestry potential was the single criterion responsible for excluding the most forest area, 14%. Water, wetlands and their buffers accounted for excluding 10% of the forested lands. Slopes of 30-60% covered 15% of the suitable landbase. Nine percent of the suitable landbase was in public ownership. Using a growth rate of 1.2 green tons/acre/year and assuming 38% of the wood biomass to be low quality, the Mad River Valley Towns woodshed was estimated to grow approximately 23,000 green tons/year of

low-quality wood. Calculating based on a high growth rate of 1.7 green tons/acre/year and assuming 58% of the wood biomass to be low quality, we estimated a growth of 50,000 green tons/year. Hence, it appears to be reasonable to expect a range of approximately 23,000-50,000 green tons/year of low-quality wood growth in the Mad River Valley Towns suitable woodshed.

Since the forests are still in recovery from past land-clearing and heavy logging, we do not suggest that harvesting at the rate of annual growth is necessarily ecologically sustainable. The history of forest clearing and many unsustainable harvest practices has resulted in current forests with altered forest structure and lower tree biomass than would be the condition had the forests been managed sustainably in the past. Nevertheless, the results generated by our modeling provide a starting point from which to consider land suitability for biomass harvesting and potential sustainable harvest amounts in these two local woodsheds.

Purpose

This analysis was undertaken to evaluate the forest landbase suitable for sustainable extraction of forest biomass and to estimate low-quality wood biomass production for two study areas defined by town boundaries—the Addison County Five Towns area, consisting of Bristol, Lincoln, Monkton, New Haven and Starksboro, and the Mad River Valley Towns area, consisting of Fayston, Moretown, Waitsfield, and Warren. Within this report we use the adjective ‘suitable’ to denote the landbase of currently forested lands that have met the sustainability filter that our modeling employed and are legally available for timber extraction.

The amount of interest Vermonters have expressed concerning procurement of energy from local Vermont landscapes has increased dramatically over the past several years, and installation of wood-burning devices to generate heat and, in limited cases, co-generate electricity seems to be increasing as well. Increases in use of fuelwood, be it in the form of chips, split logs, or pellets, have been accompanied by increased concern that wood biomass harvest be conducted sustainably (Evans and Perschel 2009). Sustainable harvest of forest products includes matters of where, when, how, and how much is taken from a forest area. This study evaluated the ‘where’ of sustainable harvest by applying GIS modeling to exclude areas considered to be unsuitable for tree harvest based on site characteristics such as soils, slopes, elevation, surface waters, wetlands, and conservation protections. After calculating the suitable forest landbases, we utilized growth estimates from previously published models to estimate broad ranges of ‘how much’ low-quality wood could be sustainably extracted annually.

As every person who works with land and resources knows, each site and landscape has its own unique conditions, which include geophysical and ecological characteristics as well as human values related to forests and lands. Our analysis is a landscape-level modeling exercise, and although we have generated maps to depict the two forest landbases suitable for sustainable tree harvest, these maps were not intended to be used at the site level for forest management planning. Nevertheless, in presenting a set of criteria to use in assessing which forestlands are suitable for sustainable biomass extraction, this analysis may be thought of as a starting point for evaluating individual sites. On-the-ground investigation of site and stand conditions would be required to accurately map the landscape and to fully evaluate the capabilities of any given forest tract.

On a theoretical note, many have pondered and written about sustainable use and management of forests. It is not our intent here to defend any one view of sustainability, but it is useful to state some of our fundamental assumptions and some documented information about Vermont forests. Foremost, we believe that sustainability is a goal to strive for, and as human knowledge and understanding of earth and its natural systems continue into the future, ideas about what actually constitutes sustainability will change. The present analysis is one moment in a long path. Moving from theory to the actual land, we acknowledge that the forest ecosystems that presently occur in the northern New England landscape are much changed from those that existed prior to forest harvest and clearing by peoples of European descent. The current forests have quite different stand composition (Cogbill 2000, Cogbill et al. 2002) as well as stand structure (Tyrell and Crow 1994, Woods 2000, Lorimer et al. 2001, Schwarz et al.

2001, Lapin 2005). Ecologists have shown that the current forests are composed of trees with a younger average age and a smaller average size, as well as lower live-tree biomass. These forests also have a reduced biomass of woody debris, the storehouse of moisture and nutrients and provider of habitats for many organisms (Harmon et al. 1986). The point here is that if we take the current forest structure as a starting point of 'what happens' in our forests, we are skewing our perspective from the outset. Growth rate is correlated to structure, and structure at any given time obviously depends to a great extent on past occurrences (human activities and natural disturbances) and growth rates. The present analysis makes no assumption that maintaining the structure that the forests currently exhibit is a basic building block of sustainable forest management. The current forests on the specific landscapes that are the subject of this analysis are very clearly still recovering from the well-documented uses and abuses of the past two centuries. Hence, analyses that document that tree biomass is growing at a rate substantially greater than the rate at which it is harvested say little about long-term sustainability. One must question the baseline to fully explore the matter of sustainability. Are we as a society satisfied with maintaining forest ecosystems that have younger and smaller trees than those that grew when Vermont's first European settlers felled the forests? How do we balance that question with our need to wean ourselves from the fossil-fuel addiction? Forest sustainability must be considered in such large contexts, but it is not the purpose of this report to answer such matters.

This study contributes to the action research project "Enhancing the sustainability of community-based biomass production and use for local energy through university-community partnerships," funded by the Northeastern States Research Cooperative, US Forest Service and the University of Vermont. The three-year effort seeks to develop models for community-based forest biomass and indicators for assessing their sustainability. This report is one of a suite of studies intended to assess wood biomass production and consumption. These studies include an analysis of landowner preferences and harvesting, loggers' role in the wood supply chains, residential consumption of wood energy and institutional consumption of wood energy. For more information about the project, please see: http://www.uvm.edu/~susagctr/?Page=biomass.html=

Sustainable Forestlands: Defining the Suitable, Available Woodshed

Rationale for the Lands Sustainability Criteria [1]

Sustainability criteria for the use and management of forests include ecological, social, and economic components. This forestland suitability analysis focuses explicitly on environmental factors. Neither economic nor social factors, such as landowner management objectives and preferences regarding forest aesthetics, have been addressed in our woodshed analysis, but such factors, of course, play large roles in determining the available wood supply. We use the word 'suitable' to denote the forestland area that has characteristics indicating that wood could be harvested

[1] Lands sustainability criteria are the same as those utilized by Biomass Assessment Team (2004).

sustainably and does not carry legal protections prohibiting timber extraction. That is, if timber harvest were conducted, it could be done so on those lands in ways to avoid degrading soils, tree productivity, water quality, and high-elevation lands.

Ecological criteria for sustainability refer to forest health, productive capacity, soil and water, biodiversity, and carbon and nutrient budgets (Raison 2002). These criteria cover the spectrum of a forest's organisms, land-, air-, and water-scapes, and ecological processes. Therefore, sustainable resource extraction is based upon not only how a forest is managed and utilized, but where in a forest different types and intensities of utilization occur. It is widely accepted that some forestlands are not capable of sustainable timber extraction, and among those that are capable, not all extraction systems are equally suited to all lands (Seymour and Hunter 1999, Lindenmayer and Franklin 2002). It is also recognized that for ecological sustainability there is a need to preserve representatives of all ecological land types—even those that may be highly suited to sustainable resource extraction—with conservation protections that prohibit resource extraction (Pressey et al. 1993, Noss and Cooperider 1994, Poiana et al. 2000).

Numerous physical site characteristics may be used to define and delineate lands suitable for sustainable intensive forestry. Our analysis has used characteristics for which spatial data were readily available. Given the wealth of geographic information available for Vermont, we were able to account for the most important physical factors. We were not able to include information about exemplary representations of different ecosystems (i.e., natural communities) because of the lack of available field-verified information regarding presence and location of such lands in the study areas.

Soils characteristics, topography, and elevation are of paramount importance in determining which lands are suitable for sustainable biomass harvest, because the productive capacity of a forest and the resilience or fragility of a site are intimately linked to these physical characteristics (Richter 2000). The greater the removal of biomass from a site, the more likelihood there is for greatly altering the nutrient status and physical and chemical characteristics of the soil (Hendrickson 1988, Hornbeck 1992, Martin et al. 2000). Therefore, when harvests include removals of substantial amounts of low-quality wood for biofuel, it is especially important to be aware of the site's ability to retain nutrients and the soil's ability to maintain its physical structure and nutrient-holding capacity. Forest land value group (USDA-Soil Conservation Service 1991), slope, and elevation data were used in the land suitability analysis to account for these important physical characteristics.

Water quality and aquatic ecosystems can be detrimentally affected by timber harvest activities in a forest; more intensive harvesting leads to increased leaching of nutrients into streams and increased stream temperatures (Hornbeck et al. 1986, Hornbeck et al. 1990, Richter 2000, Schaberg 2002). Streamside management zones that include riparian buffers and strict adherence to state-sanctioned Acceptable Management Practices (AMPs) for stream crossings are very effective at reducing impacts on aquatic ecosystems (Hornbeck et al. 1986, Southern Center For Sustainable Forests 2000). On lands with 0-60% slope, Vermont AMPs call for 50-150' buffers around streams, lakes, and ponds, with the wider buffers needed on steeper lands (Vermont Department of Forests, Parks and Recreation 1987). Our analysis incorporated a standard 75' buffer around all surface waters. Wetlands were also buffered to a width of 75', as wetlands are recognized both as being important breeding and feeding habitat for numerous animals and as serving important functions for maintaining water quality and supply (Water Resources Board 1990).

In Addison and Washington counties, some forestland, both publicly and privately owned, is conserved by legal means. Conserved lands include both areas that are available for resource extraction and those that are not. The USGS Gap Analysis Program (GAP) has developed a classification that denotes the level of ecological protection applied to conserved parcels (Crist 2000). Protection status one and two indicate that resource extraction is prohibited or very strictly limited (i.e., sometimes permitting tree removal for restoration purposes, including removal of invasive exotics); lands with status three or four are available for resource extraction. The analysis of suitable lands, therefore, excluded all lands with protection status one or two. Such lands are typically reserves where natural ecological processes are permitted to operate with little human manipulation of vegetation; those areas are important contributors to ecological sustainability and biodiversity protection at the landscape scale.

Suitable Landbase Methodology

The analysis to identify the forested lands suitable for biomass harvesting was conducted using ArcGIS 9.3 (ESRI 2008) in the Middlebury College Geography Department's GIS (Geographic Information System) Laboratory. Land suitability was based on criteria discussed above in the rationale. Physical characteristics considered were slope, elevation, soils, and surface waters and wetlands with adjacent 75' buffers (Table 1). Legal protection status of conserved lands was also considered, which allowed us to determine which lands would be available for legal harvest.

Table 1. GIS layers used in the analysis.

Information	Data Layer Name	Source
Land cover	LCLU_2002	Vermont Center for Geographic Information (VCGI)
Town boundaries	BoundaryOther_TWNBNDS	VCGI
Slope and elevation	ElevationDEM_DEM24	VCGI
Soils	soil_vt001; soil_vt_023	USDA Natural Resources Conservation Service
Conservation status	conspri_120104_polygon	University of Vermont Spatial Analysis Laboratory
Surface waters	WaterHydro_VHD	VCGI
Wetlands	Wetland_vswi	VCGI

All data layers were constrained or "clipped" to the study area. To conduct analyses, all data layers that were not published in raster (pixel-based) format were rasterized at a 30m pixel resolution, except for the river features and their buffers, which were rasterized at 5m pixel resolution in order to capture those narrow features. Forest cover, derived from the land cover layer (LCLU_2002), was pooled into one type to include deciduous, coniferous, and mixed forest cover types. A slope model with categories of <30%, 30-60%, and >60% was developed from the digital elevation model (DEM_24). Similarly, elevation classes of <2500' and >2500' were constructed. Prior to rasterizing, wetlands and surface waters were buffered with a radius of 75'; thus, riparian buffers along streams and rivers extended 75' on either side of the stream centerline, and wetlands and ponds were buffered to 75' around the periphery of the feature. Soils were grouped according to their "forest land value group" into two forest value categories—limited/very limited forestry potential (groups 6 and 7) and the more productive, less fragile lands (groups 1-5) (USDA-Soil Conservation Service 1991, USDA-Natural Resources Conservation Service 2003). Forest value groups are an integrated measure based on productivity and limitations of soils for timber harvesting; factors included in the classification are similar to and overlap with single characteristics that were used in the lands suitability analysis, such as slope and elevation, but also include soil drainage, organic soils, and shallowness of soils. Forest land value groups six and seven comprise approximately 15% of the land in Vermont and represent soils with a relative value of 0 to 31, with 100 as the maximum value. It is noteworthy that the soils information for Addison County is based on soils mapping that was conducted in the 1960s and was published originally in 1971, whereas the soils mapping for Washington County was conducted in the 1990s and was originally published in digital form in 1996. The soils interpretations that were applied by soils scientists and the amount of attention given to forested lands had changed throughout that time; also, the accuracy of spatial data improved. Because of these different vintages of soils mapping, we acknowledge probable differences in accuracy, resolution, and soils interpretations between the two study areas. Were the Addison County soils to be remapped, we would expect to find some minor shifting in our modeled suitable landbase, but would not expect that the overall results would differ to a great extent. One large forested area in the Addison County study area, known as The Hogback, was fully excluded due to forest land value group; it is likely that with better soils mapping of that mountain, some deeper soil portions would be characterized as suitable.

The final layer used in modeling provided conservation status information that was used to exclude lands that are protected from resource extraction (GAP protection status one and two (Crist 2000)). The conserved lands layer was also used to distinguish between publicly and privately owned lands.

Our suitable lands model was developed from these data layers. Beginning with all forested lands, raster calculations were employed sequentially to exclude lands that did not meet sustainability criteria. The final calculations both divided the lands into public and private ownerships and divided them among the GAP categories in order to depict different levels of conservation protection, including those lands that are legally protected from timber extraction. Additionally, we estimated that 10% of the suitable woodshed would be required for the forest road network and to protect sensitive features such as vernal pools, forest seeps and ecologically significant natural communities; such features are not available in published GIS data layers and thus were not included in our suitability model.

Those familiar with the data layers utilized will understand their imperfections. Maps and spatial data derived from whatever source are merely models of the real landscape. All models are simplifications of reality and, hence, have their weaknesses and actual errors. Nevertheless, for practicality purposes when analyzing landscapes of the size in our analysis, approximately 100,000 acres, in order to understand the geophysical constraints on sustainable forest management it is useful to work with the spatial data that are available and to rely on the expertise of the authors of those data. We acknowledge that one could improve the existing data based on local knowledge; that approach has its own weaknesses as it does not provide systematic refinement of the data, but rather magnifies individual places that are known and ignores others that are less well known. It is unclear whether such refinement would substantially alter the suitable forest landbase acreages that our modeling yields; testing that would certainly be of interest. Given the resolution and accuracy of the spatial data, rounding to the nearest thousand acres is certainly appropriate, as that is within 1% of the study areas' total acreages.

Suitable Forestland Analysis Results

Addison County Five Towns Woodshed

The Addison County Five Towns area is 60% forested, and of that forested landbase 52%, or 42,100 acres, was found to be suitable and available for extraction per the sustainability criteria (Table 2, Figure 1). Private landowners own 84% (35,000 acres) of the suitable woodshed, and public ownership accounts for 16% of the forested lands that are available for sustainable wood biomass extraction.

The criterion responsible for excluding the largest amount of forested lands from the suitable woodshed was forest land value group, which integrates measures such as soil depth, nutrient-retention capacity, and soil drainage (Table 3). That forest productivity measure accounted for exclusion of 36.6% of the forested area in the Five Towns woodshed. None of the other criteria evaluated individually (i.e., not accounting for overlap with other criteria) excluded over 10% of the forested lands. Surface waters, wetlands, and their 75' buffers accounted for 8.5% of the forested landbase, and 5.4% of the forested area was above the 2500' elevation limit. Extraction is prohibited by legal protections on 9% of the forested landbase, an area that is almost entirely comprised of National Wilderness and the Long Trail Corridor.

Overall, the analysis revealed that the woodshed suitable and available for sustainable biomass harvest in the Addison County Five Towns area consists of 42,100 acres. Of these lands, approximately 9%, or 3,950 acres, have slopes between 30% and 60%. Such gradients may constrain operability and call for very careful silvicultural prescriptions to protect soil and water; many of those areas may be found to be unsuitable. After 10% of the acreage was subtracted to account for access roads and unmapped fragile features, the suitable forest landbase was estimated to be 37,900 acres.

Mad River Valley Towns Woodshed

The Mad River Valley Towns study area is 81% forested; of that forested landbase 75%, or 55,900 acres, was found to be suitable for extraction per the sustainability criteria (Table 4, Figure 2). Private landowners own 91% (45,900 acres) of the suitable forestlands. Extraction is prohibited by legal protections on 5% of the forested landbase, an area almost entirely comprised of protected state land and the Long Trail

Corridor. Public ownership accounts for slightly less than 9% of the forested lands that are available for sustainable timber extraction.

The criterion responsible for excluding the largest amount of forested lands from the suitable woodshed was forest land value group; that forest productivity measure accounted for exclusion of 13.6% of the forested area from the suitable forestlands (Table 5). Surface waters, wetlands, and their 75' buffers excluded 10.3% of the forested landbase, and 6.1% of the forested area was above the 2500' elevation limit. Very steep slopes were found on 0.4% of the forested lands.

Table 2. Landbase available for sustainable forest biomass harvest, Addison County Five Towns.

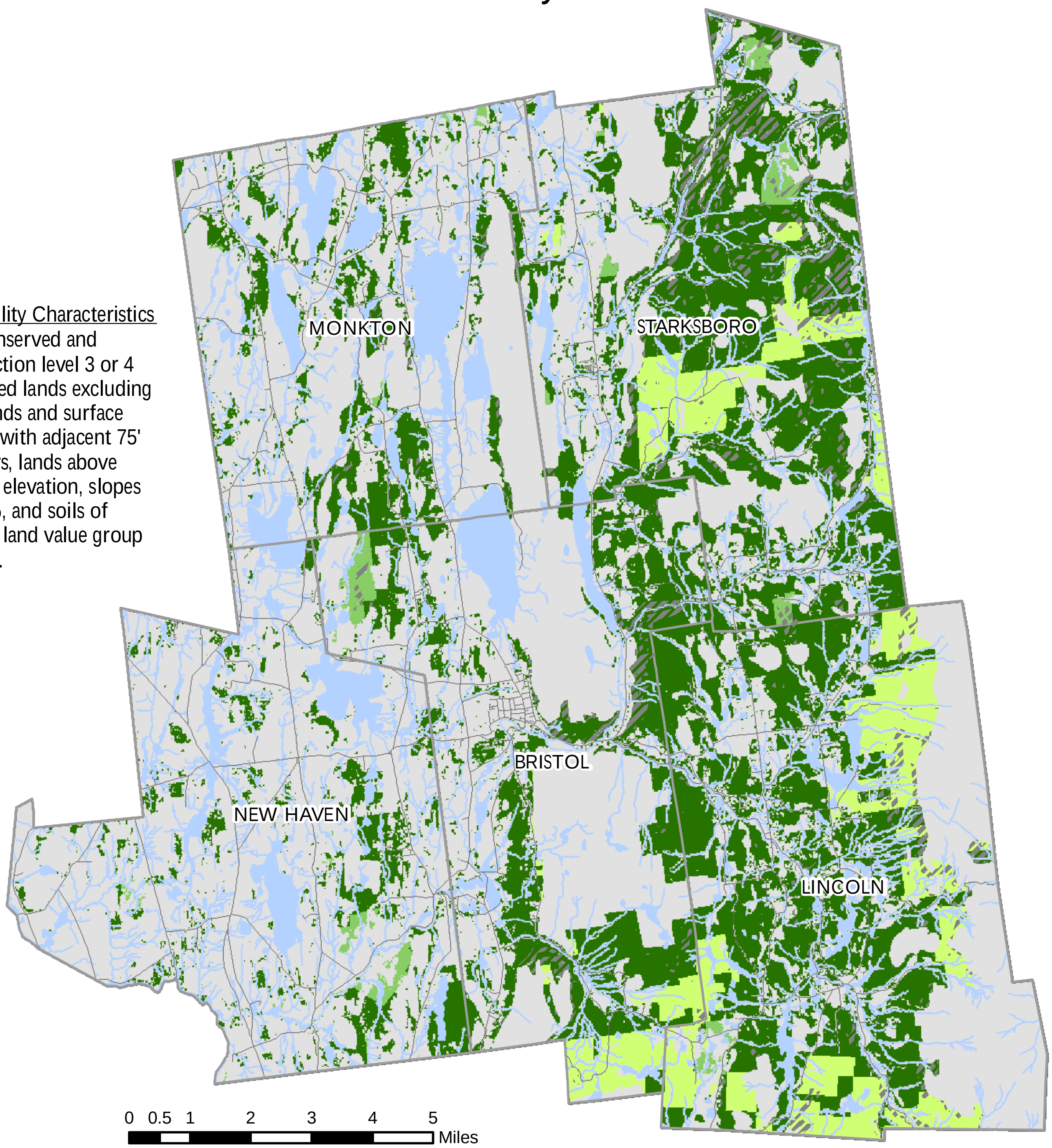
Land Type	Area (acres)	Percent of total study area	Percent of forested area	Percent of suitable forestlands	Percent of suitable forestlands with 30-60% Slopes	Area with slopes 30-60% (acres)
Addison County Five Towns Study Area	134,600					
Forested lands	81,100	60%				
Suitable forestlands	42,114	31%	52%		9.4%	3,950
Subsets						
Suitable public lands	6,918	5%	9%	16%	1.7%	700
Suitable private conserved lands	1,278	1%	2%	3%	0.4%	150
Suitable unconserved lands	33,918	25%	42%	81%	7.4%	3,100
10% subtraction for roads and unmapped features	(4,211)					
Total estimated suitable landbase:	37,903	28%	47%			

Table 3. Land exclusion amounts and percentages by individual sustainability criterion, Addison County Five Towns. Summing columns yields figures greater than the total amounts excluded, because some lands were excluded on account of more than one individual criterion.

Criterion	Forested land excluded (acres)	Percent of total forested area	Percent of total study area
Above 2500'	4,401	5.4%	3.4%
Slope greater than 60%	716	0.9%	0.5%
Waters and wetlands and buffers	6,924	8.5%	5.1%
Limited/very limited forestry potential	29,687	36.6%	22.1%
Extraction prohibited by conservation restrictions	8,074	9%	6%

Figure 1
Forestlands Suitable for Sustainable Biomass Harvesting: Addison County Five Towns

<u>Suitability Characteristics</u>
Unconserved and protection level 3 or 4 forested lands excluding wetlands and surface water with adjacent 75' buffers, lands above 2,500' elevation, slopes >60%, and soils of forest land value group 6 or 7.



Suitable Forest Landbase
- Private unconserved lands
- Private conserved lands
- Public lands
- Potentially suitable, 30-60% slopes

Unsuitable Areas
- Water, wetlands, and 75' buffers
- Unsuitable uplands
- Roads

GIS analysis and map
by Marc Lapin and Chris Rodgers
April 2009

Table 4. Landbase available for sustainable forest biomass harvest in the Mad River Valley Towns.

Land Type	Area (acres)	Percent of total study area	Percent of forested area	Percent of suitable forestlands	Percent of suitable forestlands with 30-60% Slopes	Area with slopes 30-60% (acres)
Mad River Valley Study Area	91,380					
Forested lands	74,002	81%				
Suitable forestlands	55,859	61%	75%		15%	8,200
Subsets						
Suitable public lands	4,811	5%	7%	9%	1%	1,100
Suitable private conserved lands	2,706	3%	4%	5%	1%	400
Suitable unconserved lands	48,343	53%	65%	86%	9%	6,700
10% subtraction for roads and unmapped features	(5,586)					
Total estimated suitable landbase:	50,273	55%	68%			

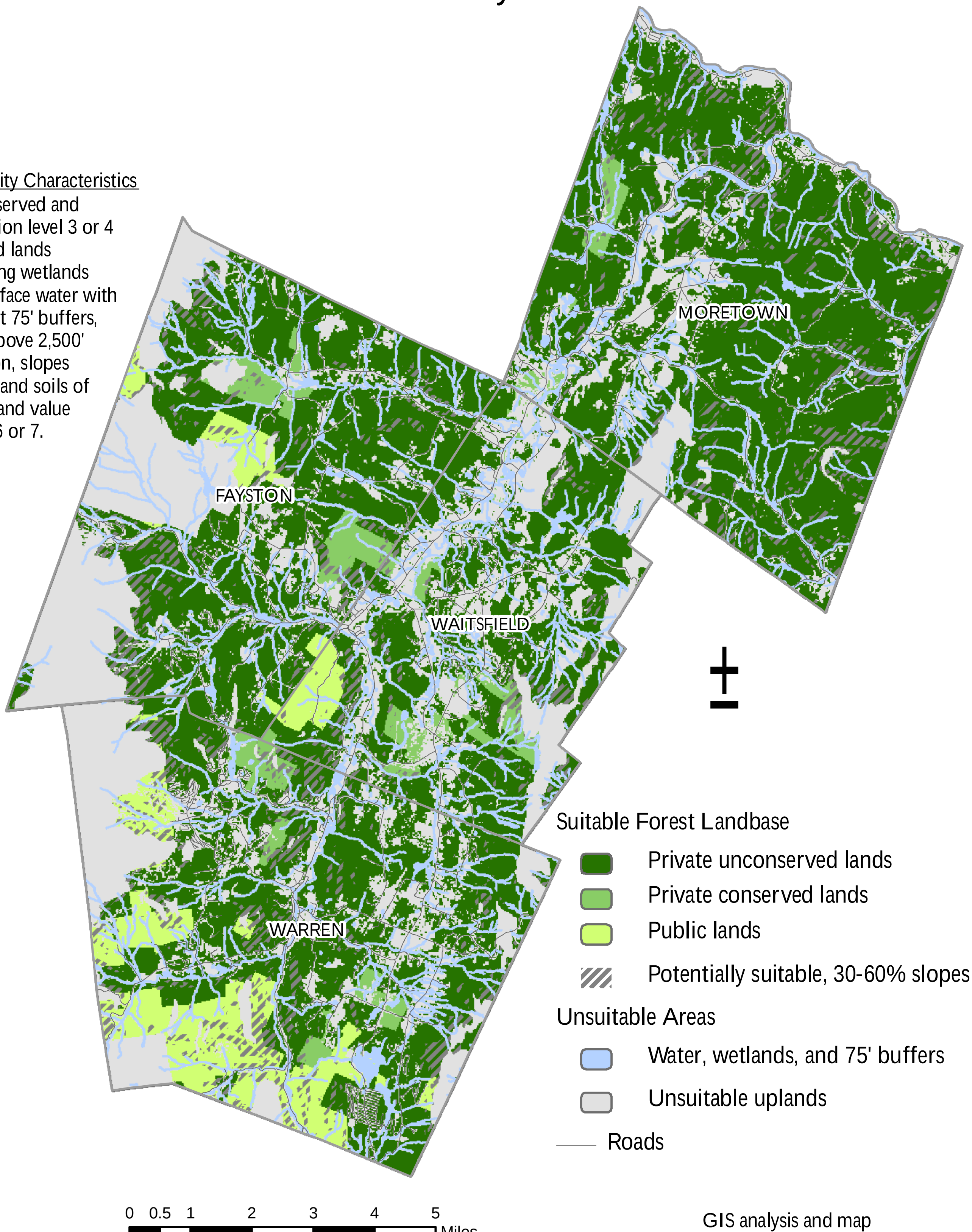
Table 5. Land exclusion amounts and percentages by sustainability criterion in the Mad River Valley Towns. Summing columns yields figures greater than the total amounts excluded, because some lands were excluded on account of more than one individual criterion.

Criterion	Forested land excluded (acres)	Percent of total forested area	Percent of total study area
Above 2500'	5,200	6.1%	5.7%
Slope greater than 60%	300	0.4%	0.3%
Waters and wetlands and buffers	6,100	10.3%	6.7%
Limited/very limited forestry potential	10,700	13.6%	11.7%
Extraction prohibited by conservation restrictions	3,490	5%	4%

Figure 2
Forestlands Suitable for Sustainable Biomass Harvesting: Mad River Valley Towns

Suitability Characteristics

Unconserved and protection level 3 or 4 forested lands excluding wetlands and surface water with adjacent 75' buffers, lands above 2,500' elevation, slopes >60%, and soils of forest land value group 6 or 7.



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Overall, our analysis revealed that the suitable landbase in the Mad River Valley Towns consists of 55,860 acres. Of these lands, approximately 15%, or 8,200 acres, have slopes between 30% and 60%, which may constrain operability and call for very careful silvicultural prescriptions to protect soil and water; some of that 8,200 acres may be found to be unsuitable after site-based analysis. We allowed that 10% of the woodshed would be required for the forest road network and to protect sensitive features such as vernal pools, forest seeps and ecologically significant natural communities. After the 10% subtraction, the suitable forest landbase was estimated to be 50,270 acres.

Sustainable Supply of Fuelwood Biomass in the Woodshed

Fuelwood Biomass Supply Methodology

We calculated the amount of annual wood growth in the suitable landbase using three forest growth rates. Two growth rates were based on Forest Service models presented in the northern hardwood silvicultural guide (Leak et al. 1987); those models simulate both intensively managed and unmanaged stands in the northeastern United States. The third growth rate we utilized was from Sherman's (2007) statewide wood fuel supply study. Sherman based his model on 1997 Forest Inventory and Analysis (FIA) plot data. FIA is a system of nationwide permanent forest plots that reveal forest conditions and changes over time at a regional level (USDA Forest Service 2009).

Models presented in the Forest Service silvicultural guide for northern hardwoods (Leak et al. 1987) translated to a growth rate of 1.7 green tons/acre/year for intensively managed stands. This is based on growth of 2,449 ft^3 (30.6 cords) and 10,289 BF (board feet) (20 cords) after 107 years of growth, plus thinnings that totaled 23 cords. The total growth in this model was 73.6 cords/acre/107 years, which equals 0.68 cords/acre/year. With a conversion factor of approximately 2.5 green tons/cord, the growth rate equaled 1.7 green tons/acre/year. Using similar calculations, the Leak et al. model for unmanaged stands yielded a growth rate of 1.2 green tons/acre/year.

According to Frieswyk and Widman's (2000) summary of Vermont forest statistics from the 1980s and 1990s, forest growth over the past several decades indicates that the Leak et al. models represent Vermont forests relatively accurately, but may overestimate actual growth. Frieswyk and Widman calculate approximately 1.25 green tons/acre/year growth for Vermont. That this amount is in line with Leak et al.'s unmanaged scenario perhaps enforces the fact that Vermont's forests are not intensively managed for timber production. More recent data appear to indicate a decrease in the growth since the 2000 summary (DeGeus, personal communication). Hence, what we present as our low figures for each woodshed may be the most accurate values and may be overestimates based on current management systems.

Sherman (2007) calculated the statewide rate of growth to be 2.41 green tons/acre/year of aboveground tree biomass, an amount that is almost certainly a large overestimate of the resource. His county level analysis revealed that Addison County had 2.8 green tons/acre/year forest biomass growth, slightly above the state average. Additionally, Sherman calculated that the annual growth was comprised of 93% bole growth and 7% growth of tree tops and limbs. In our calculations we excluded the 7% per year biomass growth contributed by tree tops and limbs, because we believe that harvesting tops and limbs would lead to diminished site productivity due to excessive removal of organic matter and nutrients. Hence, 93% of 2.8 left us with an Addison County growth rate of 2.6 green tons/acre/year of forest biomass growth in stems larger than 5” diameter at breast height (dbh). Sherman showed that Washington County had more growth, 3.1 green tons/acre/year forest biomass. Similar calculations resulted in a Washington County rate of growth in tree boles of 2.9 green tons/acre/year.

We utilized Sherman’s growth rates since they are presented in a published report that has been widely distributed and is intended to portray conditions statewide. Many foresters question the reliability of using such high growth rates and do not believe that they represent actual growth. Nevertheless, they are incorporated here to represent a very high-end figure based on a recently published, albeit inaccurate, growth rate.

Some of the lands in the study woodsheds are not northern hardwood forest, but we have applied the same growth rates for all lands based on the following rationale. The Forest Service silvicultural guide for spruce-fir forests (Frank and Bjorkbom 1973) presents a yield of 78.7 ft^3/acre/year for 100-year-old second-growth red spruce stands on productive sites. Based on 34% moisture content for green weight and a specific gravity of 0.38, that yield translates to 1.25 green tons/acre/year, nearly identical to the Leak et al. value for unmanaged northern hardwoods. Frank and Bjorkbom additionally state that with more intensive management the yields over a stand rotation would be “substantially higher.” Thus, given that we do not have data on current stand stocking or simulations on management intensity throughout future rotations, the range of growth rates we utilized would appear to be appropriate for red spruce in the woodsheds also. Additionally, we considered that much of the conifer component in the suitable portions of the woodsheds may be hemlock. Solomon and Leak (1999) reported that they found little difference in biomass per acre in 100-year-old hardwood and softwood stands. Given that we have no reliable data on the composition of the conifer component in mixed or softwood forests in the suitable landbases, and that biomass differences appear to be negligible, we chose to calculate the estimates based on the same three growth rates for all lands in the woodsheds.

An additional factor that needs to be considered in assessing a woodshed for sustainable biomass fuel supply is the amount of wood considered to be low quality and, therefore, not suitable for use as sawlogs and the value-added products that can be made from high-quality timber. Leak et al. (1987) indicated that in a poorly managed northern hardwood stand only about 32% of the volume would be sawtimber quality, whereas in a stand managed intensively for sawtimber for approximately 50 years one could expect about 52% of the volume to be sawtimber quality logs. They noted that in mixed-wood stands the sawtimber yields are at least 15% to 25% greater. Peters et al. (2009) found that 38% of the 2005-2008 harvest from the four Mad River Valley towns was low-quality wood, whereas the low-quality wood harvested from the Addison County Five Towns woodshed accounted for 45% of the total harvest. It is unknown if these harvested amounts are representative of the proportions of low-quality and sawtimber-quality wood in the forests at the present time or if they only reflect proportions that were harvested. Hence, in an attempt to thoroughly explore the range of likely yields, we calculated fuelwood biomass supply based on three scenarios of low-quality wood percentages—38%, 48% and 58% of the standing volume as low-quality wood, that which would be suitable for use as fuelwood or pulp. It should be noted that when forests are managed for decades for the highest value commodity, sawtimber, the percentage of low-quality wood in a stand typically decreases.

Our methodology is not intended to estimate the amount of low-quality wood available currently, but rather to portray availability of low-quality wood into the future. Although there are many uncertainties with estimating tree growth, we have used previously published per acre growth rates to model the growth of the wood resource supply in the two suitable woodsheds. Certainly, estimating volumes of standing low-quality wood in the study areas is an alternative approach that has merit. Perhaps a future study will approach the sustainable biomass supply question by estimating standing volume of low-quality wood and modeling rates of tree harvest rather than tree growth. For purposes of this report, however, we present estimates of the amounts of low-quality wood growth rather than estimates of standing stock on the suitable forestlands.

Sustainable Fuelwood Biomass Supply Results

Addison County Five Towns Woodshed

The suitable landbase in the Addison County Five Towns woodshed consists of 37,900 acres. At the very high end, calculated at an annual growth of 2.6 green tons/acre, for the 58% low-quality wood scenario we estimated available low-quality wood supply of 57,200 green tons/year (Table 6). Using a more conservative 1.7 green tons/acre annual rate and the same percentage of low-quality wood, 37,400 green tons/year was estimated to grow in the suitable woodshed. The low end of our range utilized a growth rate of 1.2 green tons/year and estimated 38% low-quality wood. That scenario resulted in growth of 17,300 green tons/year. Using the same growth rate but estimating 48% of the wood harvested being of low-quality, the annual estimated growth in the Five Towns' woodshed was 21,800 green tons/year, a figure which appears to best represent the conditions in the forest based on the most recent location specific information available. In all scenarios, it is noteworthy that approximately one-sixth of the wood biomass was growing on public lands.

As Sherman (2007) noted, the calculations of available wood for biomass harvest are very sensitive to growth rates utilized in the calculations, as well as to proportion of low-quality wood estimated. Our calculations showed that the biomass wood supply estimates for managed forests with 38%, 48% and 58% low-quality wood ranged from 17,300 to 57,200 green tons/year. We believe that it is very unlikely that the high end of the range could be achieved. Based on proportions of low-quality wood harvested in recent years (Peters et al. 2009), and growth rates that have been recently verified, it appears more likely that growth of low-quality wood would be in the lower half of the range, approximately 17,000 to 37,000 green tons/year.

Mad River Valley Towns Woodshed

The suitable landbase in the Mad River Valley Towns' woodshed consists of 50,270 acres. Calculated at the very high annual growth of 2.9 green tons/acre and 58% low-quality wood, we estimated available low-quality wood supply of 84,600 green tons/year (Table 7). Using a more conservative 1.7 green tons/acre annual rate at the same percentage of low-quality wood the result was 49,600 green tons/year. At a growth rate of 1.2 green tons/acre/year, under the same low-quality wood scenario the woodshed was estimated to yield 35,000 green tons/year. Applying a smaller percentage of low-quality wood, 38%, as suggested by Peters et al. (2009), the resulting growth estimate was 22,900 green tons/year, which appears to best represent the conditions based on the most recent location-specific information available. In all scenarios, it is noteworthy that less than one-tenth of the wood biomass was growing on public lands.

Calculations of available wood for biomass harvest are very sensitive to growth rates utilized in the calculations, as well as to proportion of low-quality wood estimated. It is seen in our model that the biomass wood supply estimates for managed forests with varying amounts of low-quality wood ranged from 23,000 to 84,600 green tons/year, nearly a four-fold difference. Echoing our thoughts stated above for the Addison County Five Towns Woodshed, it is very unlikely the high end of that range could be achieved. The more realistic lower half of the estimate range yields a probable low-quality wood growth of approximately 23,000 to 50,000 green tons/year.

Conclusion

The information about wood biomass supplies is limited and highly uncertain. Growth rates of trees in the forest and amounts of low-quality wood are difficult to estimate on large scales. Despite variation in data quality and gaps in information, modeling a forest land base suitable for sustainable wood biomass extraction is more reliable than estimating the actual amount of wood or growth of wood in the woodshed, given the available data. To more reliably estimate low-quality wood growth or volume in the two study areas would require collection of data from forest stands in the woodsheds. In the absence of such site-based data, we have provided broad estimates based on what appear to be the approximate rates of growth and proportions of low-quality wood biomass in the Addison County Five Towns and Mad River Valley Towns suitable woodsheds.

Table 6. Annual wood biomass supply per two growth rates and three wood-quality scenarios for the Addison County Five Towns.

	Land Type	Landbase (suitable acres -10%)	Growth rate (green tons/ac/yr)	Total growth (green tons/yr)	Scenario: 38% low-quality wood (green tons/yr)	Scenario: 48% low-quality wood (green tons/yr)	Scenario: 58% low-quality wood (green tons/yr)
Leak et al.'s (1987) unmanaged stand growth model	Public	6,226		7,472	2,839	3,586	4,334
	Private	31,676	1.2	38,011	14,444	18,245	22,047
	All Lands	**37,903**		**45,483**	**17,284**	**21,832**	**26,380**
Leak et al.'s (1987) intensively managed stand growth model	Public	6,226		10,585	4,022	5,081	6,139
	Private	31,676	1.7	53,850	20,463	25,848	31,233
	All Lands	**37,903**		**64,434**	**24,485**	**30,928**	**37,372**
Sherman's (2007) Addison County growth rate	Public	6,226		16,188	6,152	7,770	9,389
	Private	31,676	2.6	82,358	31,296	39,532	47,768
	All Lands	**37,903**		**98,547**	**37,448**	**47,302**	**57,157**

Table 7. Annual wood biomass supply per two growth rates and three wood-quality scenarios for the Mad River Valley Towns.

	Land Type	Landbase (suitable acres -10%)	Growth rate (green tons/ac/yr)	Total growth (green tons/yr)	Scenario: 38% low-quality wood (green tons/yr)	Scenario: 48% low-quality wood (green tons/yr)	Scenario: 58% low-quality wood (green tons/yr)
Leak et al.'s (1987) unmanaged stand growth model	Public	4,330		5,196	1,974	2,494	3,014
	Private	45,943	1.2	55,132	20,950	26,463	31,977
	All Lands	**50,273**		**60,328**	**22,925**	**28,957**	**34,990**
Leak et al.'s (1987) intensively managed stand growth model	Public	4,330		7,361	2,797	3,533	4,269
	Private	45,943	1.7	78,104	29,679	37,490	45,300
	All Lands	**50,273**		**85,465**	**32,477**	**41,023**	**49,569**
Sherman's (2007) Addison County growth rate	Public	4,330		12,557	4,772	6,027	7,283
	Private	45,943	2.9	133,236	50,630	63,953	77,277
	All Lands	**50,273**		**145,793**	**55,401**	**69,980**	**84,560**

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