Spatial Forest Inventory Analysis for Kinross, MI

Robert E. Froese and Zane C. Abbott

School of Forest Resources and Environmental Science
Michigan Technological University, Houghton, MI 49931, U.S.A.

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Introduction

A quantitative and specific understanding of nature of the resource that might supply the Kinross, MI facility under development by Frontier Renewable Resources LLC (hereafter FRR) is important for the sustainable development of the new enterprise. There are many reasons why resource assessment is important. Of interest to FRR is the likely availability of raw materials – feedstock – that will be essential for production of bioethanol and success of the business venture. Of interest to local communities and the logging industry is the possibility for new jobs and economic development afforded by a new consumer of Michigan's forest resources. Also of great interest to the broader community is the capacity of Michigan's forests to meet the additional demands that will be placed on the resource, while simultaneously protecting the forests' productive capacity for an array of values, including timber, wildlife, recreation, water, biodiversity and environmental sustainability. An appraisal of forest resources in the likely supply area is an important part of addressing all of these interests.

To address FRR's needs the company commissioned independent resource analyses that drew from data available under the USDA Forest Service Forest Inventory and Analysis Program (FIA; McRoberts et al. 2005). The first was completed by Tessa Systems in 2009 and updated by Leefers and Vasievich in 2010. These reports present a comprehensive set of summaries of the many resource attributes available in the FIA program for an area of interest defined by FRR as 150-miles straight line radius centred on Kinross, MI.

The FIA program is a statistical survey of forest conditions involving ground sampling of field plots located on a systematic grid across the entire United States. All ownerships and all forest conditions are sampled so that the inventory may by design provide statistically unbiased estimates of forest inventory attributes, such as timber inventory, and their uncertainty. In Michigan, plots are re-visited and re-measured every five years and therefore the FIA program is also able to estimate the change in inventory parameters, including tree growth, mortality and removal rates. With a sampling intensity of not less than one field plot for every 6,000 acres the inventory provides a large and rich dataset capable of providing powerful and statistically defensible estimates of forest condition. The inventory can supply information necessary for business planning as well as monitoring forest condition and sustainability of forest land management practices.

Despite FIA's many strengths, questions may be asked of the forest resource that the FIA system is not well suited to answer. For example, the intensity of the FIA inventory in Michigan is, at present, one plot per 6,000 acres. This intensity is more than adequate for generating defensible estimates (i.e., with reasonable sampling errors) at scales of counties or regions (e.g., the Upper Peninsula) up to the entire State. But for areas of interest much smaller than counties the error estimates can become quite large, and obviously for areas less than 6,000 acres it is conceivable that not a single FIA plot might be found. This has limited analyses that depend on the design of the FIA inventory to use relatively large areas of interest; e.g., the 30-mile distance bands used by Leefers and Vasievich (2010) centered on Kinross. Also, since relatively large areas must be used there has been little utility in modelling transport (haul) distance directly, i.e. following road networks rather than using straight-line distance as a proxy, since the complexity of road networks is swamped by large areas of interest.

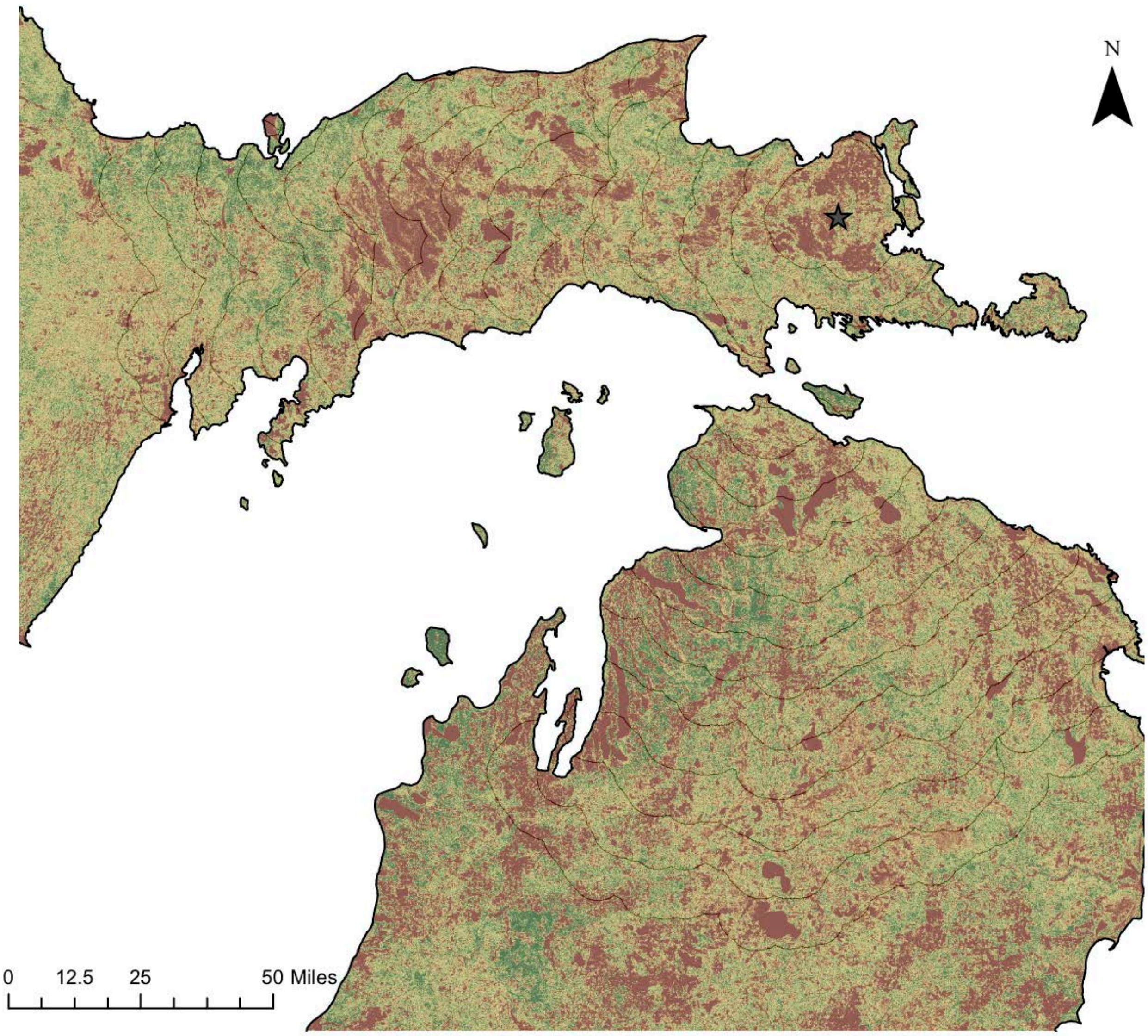

Figure 1. High-resolution forest inventory map for the Western Upper Peninsula and Northern Lower Peninsula, Michigan. Potential source areas defined by the road network leading to Kinross are shown in 10-mile increments, overlain in black.

Thus there has been a growing interest in methods that can generalize from the existing FIA plots to the unknown areas in-between, to generate what have been called "small area estimates" (Falkowski et al. 2010; McRoberts et al 2007; Riemann et al. 2010). An ideal product is a continuous model of the FIA inventory, perhaps in a raster (or grid cell) format, in which each raster cell contains an estimate of the likely forest inventory values. A variety of techniques are available to generate similar kinds of estimates (Brosofske et al., in prep) and many share the common theme of characterizing the relationship between measured values at forest plots and other attributes known across the entire spatial extent (model building), and then applying the relationship across the entire area of interest (prediction or imputation).

Examples of readily available and spatially-continuous attributes are datasets derived from remote sensing methods, such as Landsat TM satellite observations, space-based RADAR sensors, or even locally collected LIDAR data.

Spatial Forest Inventory Model

Recently, a spatial inventory model was developed for Michigan as one of the tasks within the Forestry Biofuel Statewide Collaboration Center (FBSCC; see http://michiganforestbiofuels.org and Deo et al. 2011). Briefly, in that project a geospatial model of the measured forest inventory data from FIA was developed. The model was constructed and applied using two data sets. The first was a training data set composed of a set of field plots from the FIA program (2005-2009), which have been measured and have known forest inventory values, as well as spatial coordinates. The second was a prediction data set, which was composed of a set of continuous geospatial data layers (grid or raster data) derived from remote sensing measurements, such as Landsat TM and the Shuttle Radar Topography Mission (Walker et al. 2007). Using the spatial coordinates for the FIA plots the values from the prediction set were attached to each of the plots in the training set. Then, a non-parametric statistical model was developed that allowed us to predict the likely FIA attributes based on the remote sensing data. Once the model was trained (developed), it was applied to the entire prediction data set to generate a spatially continuous 30 metre raster "map" for the entire State of Michigan (Figure 1). In effect, the likely value of forest inventory parameters were imputed in-between the known values at the FIA field plots.

Deo et al.'s (2011) model is confined to estimates of growing stock trees on forestland, per the standard FIA definitions. No distinction was made between lands available or administratively withdrawn from harvest; i.e., the inventory includes trees in parks and protected areas. Interested readers are directed towards the FBSCC Task A1 report by Deo et al. (2011) for additional detail.

Objectives

The overall goal of this task was to demonstrate the potential for advanced inventory modelling in a spatial framework for resource analysis. Within our goal we had two objectives. The first was to draw from the spatial inventory modelling completed under the FBSCC project to generate a resource assessment enhanced by the additional detail afforded by the continuous nature of the new inventory. The second was to leverage the small-area estimates possible from the spatial inventory by constructing a conceptualization of feedstock supply areas which were defined by road-networks, rather than straight line radius from Kinross. Because the new inventory no longer relies upon a minimum area for valid estimates (as is required using the design-based FIA approach) relatively small increments in feedstock supply area along a transportation network should generate model-unbiased estimates of inventory attributes.

Methods

Study Area

The area of interest established by FRR early in the project was a 150-mile circular radius around the proposed facility site at Kinross, at the east end of Michigan's Upper Peninsula. Areas within this radius that were part of Canada were excluded. In the various analyses completed for the Frontier CoEE the 150-mile area was subdivided into feedstock supply zones, defined differently depending on the individual analyses completed by participants in the project. For example, the timber resources report competed for FRR by Leefers and Vasievich (2010) used five concentric circular buffers in 30-mile increments. We illustrate a similar representation in Figure 2, in this case using six concentric buffers in 25-mile increments. Obviously these zones do not provide an accurate estimate of the expected road transport distance to points within the zone, because straight-line distance is an imperfect proxy for actual road distance. Also some areas such as the Leelanau peninsula illustrate how local geography can cause concentric circular buffers to be particularly poor proxies.

For this analysis we re-defined the study area into feedstock supply zones defined by actual road transportation distance, in 10-mile increments, outward from the Kinross site. To identify these areas we used the network analysis functionality within ArcGIS 10 desktop GIS system, and a road network spatial data layer obtained from collaborators within the CoEE project at MTU. The network analysis tool allows us to define a "service area", which is traced along the road network outwards from the Kinross site to pre-determined distances. To account for the additional reach that might be expected on logging roads we buffered the 10-mile service areas by an additional five miles. This is an imperfect representation but makes the service area definition more realistic. Thus, the feedstock supply area was ultimately divided into 15 zones, the first approximately 15 miles transport distance from the Kinross site (at least 10 miles on road and up to 5 miles off road), and subsequent zones an increment of 10 miles outward to a total of 155 miles.

Generation of Inventory Estimates

Generating inventory estimates for the feedstock supply zones was a relatively simple operation in GIS once Deo et al.'s (2011) inventory model output raster and our new supply zones were available. The zones, defined using the network analysis, were used to mask the inventory raster, and then the totals of the inventory attributes were generated by tabular sum across the raster area. Notably, ownership was not considered in the modelling process, but rather was explicitly defined by a spatial join using independent data on land ownership after the inventory model output raster was generated. Ownership was treated as a factor and thus the raster cells were actually cross tabulated, by owner and feedstock zone.

For this project, we used an updated version of the inventory model described by Deo et al. (2011), developed in fall 2011 and much more accurate than the original. Ownership data for state and federal lands were obtained from public sources, for corporate land from a proprietary database available to the MTU investigators, and for other private lands assumed to be those lands not falling into one of the three preceding classes. The FIA data used to develop this model were from a complete five-year panel spanning the years 2005-2009. All spatial data processing was completed in ArcGIS Version 10 while the mapping model was developed using the `yaimpute()` package in the R Environment for Statistical Computing (R Development Core Team 2011).

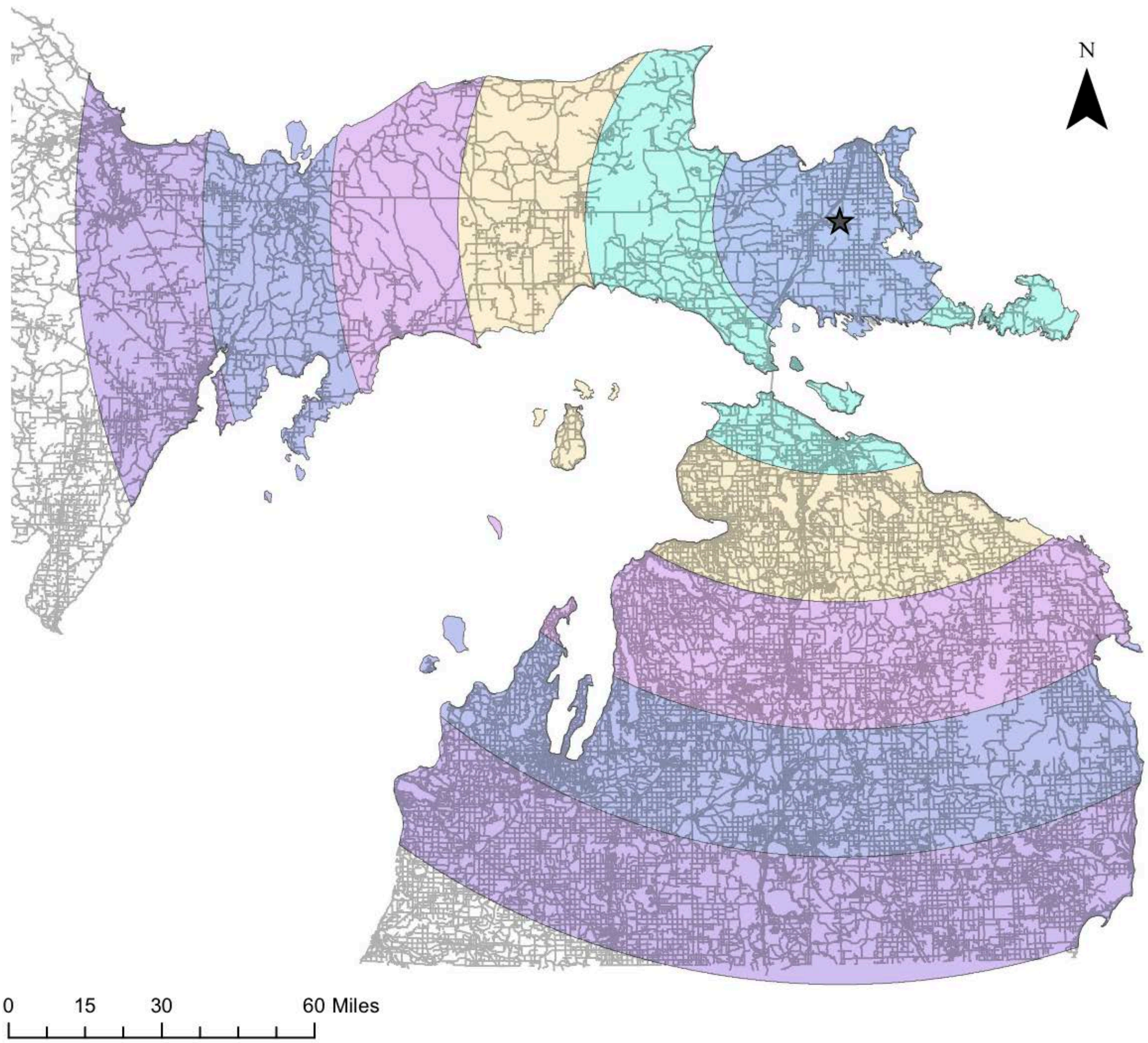

Figure 2. Conceptualization of feedstock supply areas defined by simple 25-mile radius circular areas centred on Kinross, MI.

Results

Not surprisingly, road-based feedstock supply zones appear quite different from concentric circles (Figure 3). The combined effect of generating service areas based strictly on roads and then buffering them by five miles generates a smoothed appearance. However, the effect of peculiarities in the road network is still evident, with a restriction at about 50 miles in the Upper Peninsula causing discontinuity in the 50-60 and 60-70 mile zones (note the yellow and pink bands are discontinuous southwest of Whitefish Point). A similar discontinuity in the 130-140 mile zones is evident in the eastern Lower Peninsula, near the town of Hillman.

An artifact of the buffer procedure is that areas on islands have been included but only to the extent that they lay within five miles of a road segment on the mainland. See e.g., Mackinac Island, the western tip of Drummond Island, and Grand Island near Munising, MI (Figure 3).

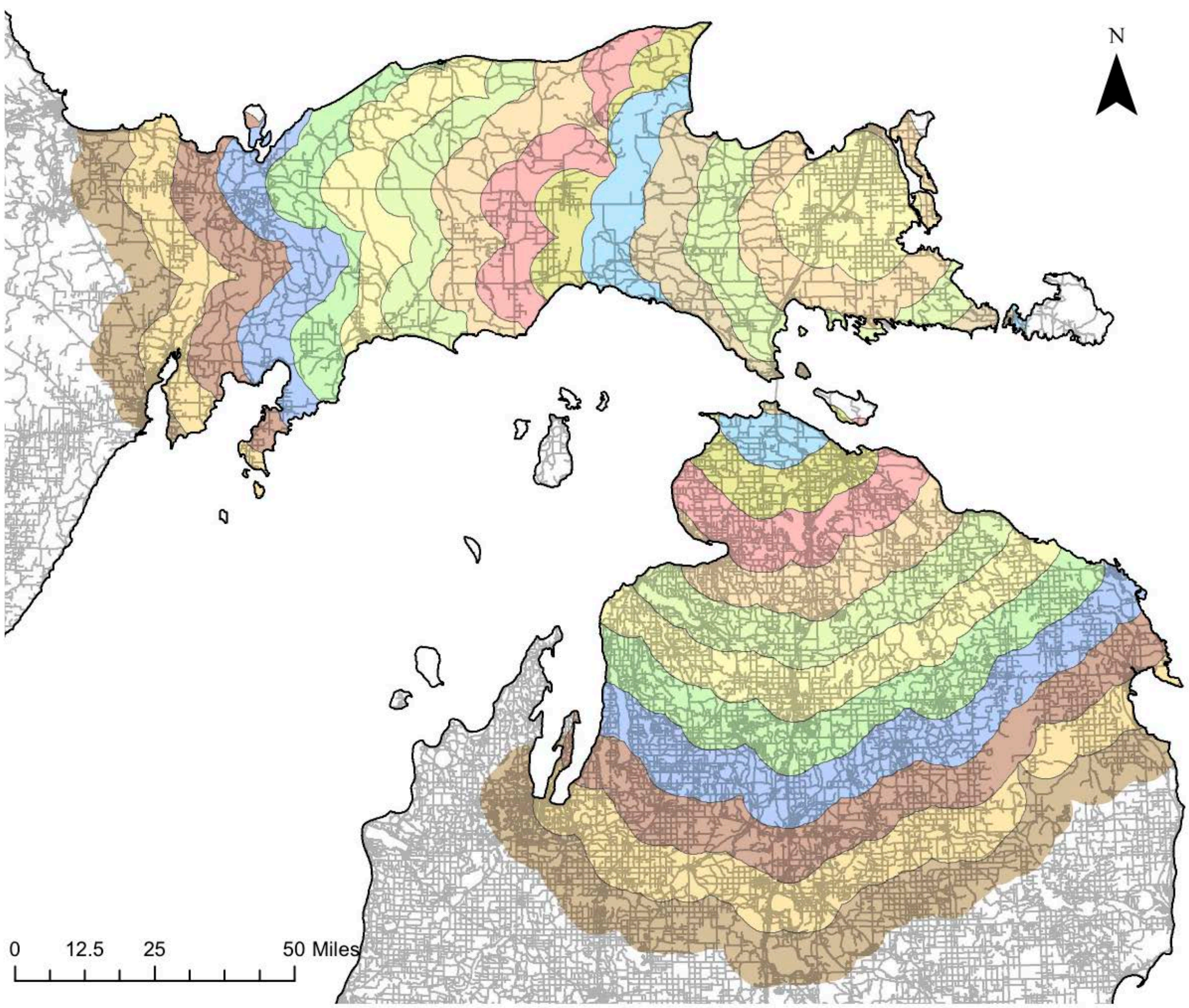

Figure 3. An alternative definition of feedstock supply areas defined by transport distance along the road network, in 10-mile increments, centred on Kinross, MI.

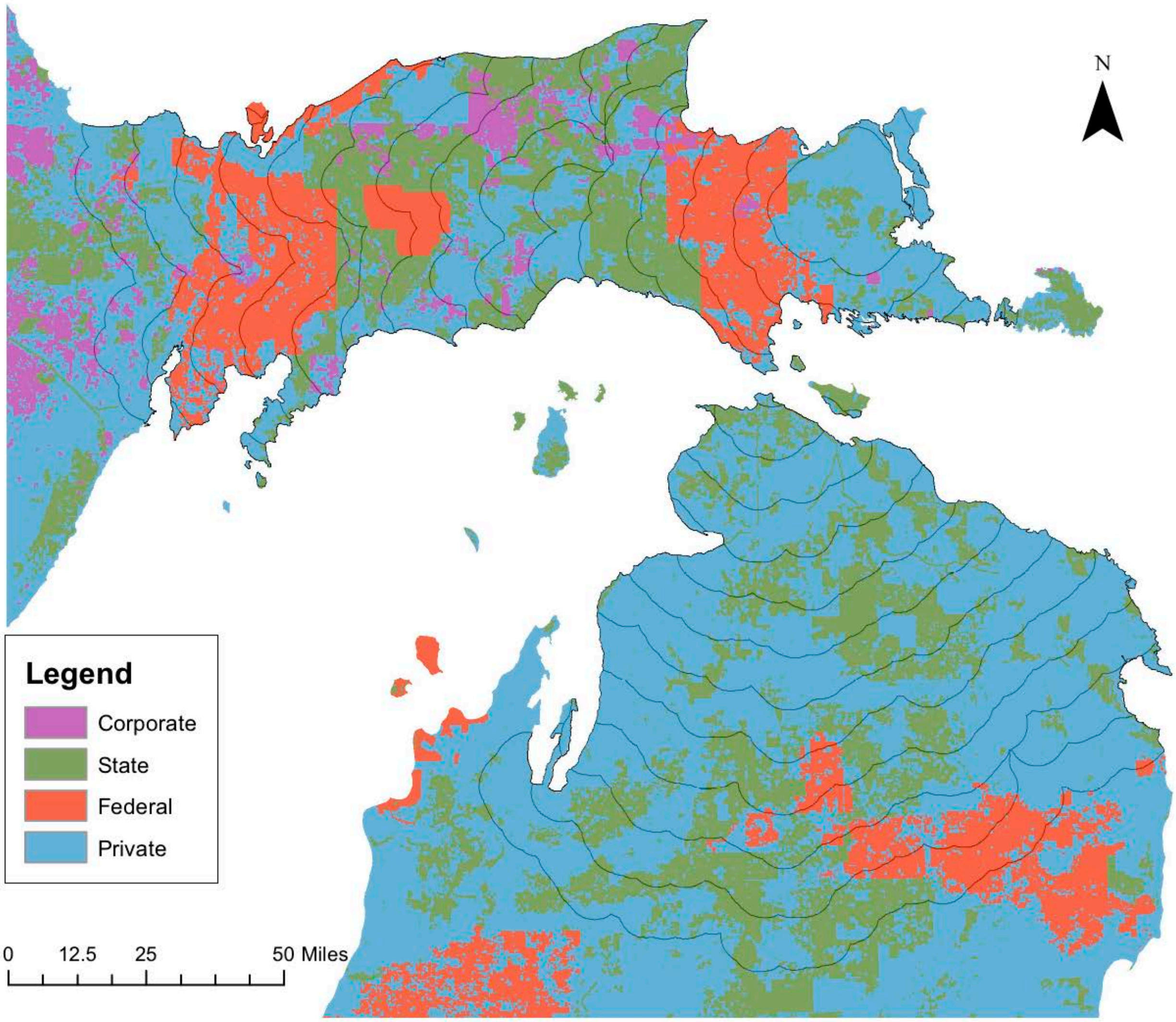

Figure 4. Land ownership for the Western Upper Peninsula and Northern Lower Peninsula, Michigan. Potential source areas defined by the road network leading to Kinross are shown in 10-mile increments, overlain in black

The general distribution of land ownership within the feedstock supply area is commonly understood (Figure 4). The non-industrial private owner class largely holds the lands immediately around Kinross. The eastern block of the Hiawatha National Forest is contained within the 10-40 mile supply zones (15-45 miles including buffers), and the western block within the 110-140 mile zones (115-145 miles including buffers). State-owned lands are mixed in a matrix with corporate and non-industrial lands in the Upper Peninsula, and with only non-industrial private lands in the northern Lower Peninsula. There are little, if any, corporate lands in the Lower Peninsula; none were explicitly defined in the data set used in this project.

Table 1. Forestland inventory attributes accumulated across a 150-mile road network originating at Kinross, MI. All values refer to merchantable bolewood only.

Owner	Inventory ('000 ft^3)	Net Growth ('000 ft^3yr^{-1})	Mortality ('000 ft^3yr^{-1})	Removal ('000 ft^3yr^{-1})	NGAR ('000 ft^3yr^{-1})	Residues ('000 ft^3yr^{-1})	NG:R[1]	GG:R
Hardwood Species Only								
Corporate	289,270	5,991	2,069	3,774	3,921	55	1.6	2.1
State	1,897,789	37,007	16,624	28,012	20,383	405	1.3	1.9
Federal	1,039,106	18,659	9,103	12,606	9,556	182	1.5	2.2
Private	4,047,086	78,852	32,119	60,737	46,733	878	1.3	1.8
Subtotal	7,273,251	140,509	59,915	105,129	80,593	1,520	1.3	1.9
Softwood Species Only								
Corporate	189,063	4,421	1,981	1,214	2,440	7	3.6	5.3
State	1,666,880	36,684	19,999	11,473	16,685	67	3.2	4.9
Federal	1,033,596	23,750	11,505	7,129	12,245	41	3.3	4.9
Private	2,343,206	47,694	28,200	22,047	19,494	128	2.2	3.4
Subtotal	5,232,745	112,549	61,685	41,863	50,864	243	2.7	4.2
All Species Combined								
Corporate	478,333	10,412	4,050	4,988	6,361	62	2.1	2.9
State	3,564,669	73,691	36,623	39,485	37,068	472	1.9	2.8
Federal	2,072,702	42,409	20,608	19,735	21,801	223	2.1	3.2
Private	6,390,292	126,546	60,319	82,784	66,227	1,006	1.5	2.3
Grand Total	12,505,996	253,058	121,600	146,992	131,457	1,763	1.7	2.5

[1]NG:R is the ratio of net growth to removals, where *net growth* is net of mortality; GG:R is the ratio of gross growth to removals, where mortality is added back to growth before the calculation.

A detailed cross-tabulation of accumulated inventory attributes across the entire 150-mile feedstock supply zone (155 miles with buffers) is presented in Table 1. Total standing volume of merchantable-sized timber exceeds 12.5 billion ft^3, comprised of about 58% hardwood and 44% softwood species. Net growth (gross growth on live trees less the total volume lost to mortality) is about 253 million ft^3 per year, of which 56% is hardwood species.

Because net growth exceeds removals for all species and owner classes, forests are uniformly increasing in inventory across the study area. Net Growth to Removal ratios are about 1.3 and 2.7 for hardwood and softwood species, respectively, illustrating the relatively greater utilization of the hardwood resource within the study area. Net growth after removals is about 130 million ft^3 per year, of which about 61% is hardwood species. About half of the total net growth after removals is accumulating on non-industrial private lands.

Additional detail showing the cumulative values across each successive 10-mile increment in feedstock supply zone are available electronically (in Microsoft Excel format).

Individual Inventory Attributes

We re-tabulated individual inventory attributes by owner class and species group to present graphically the cumulative values as transport distance increases from Kinross (Figures 5-10). Some general trends are apparent. On non-industrial private land the rate of accumulation for all attributes, for both softwood and hardwood, increases sharply at about 50 miles road distance from Kinross. The increase is sharper for hardwood species. For example, cumulative removals of hardwood species are about 5 million ft^3/year at 50 road miles from Kinross, or about 0.10 million ft^3/year/mile. Between 50 and 150 road miles from Kinross cumulative removals increase to about 60 million ft^3/year, a difference of 55 million ft^3/year and corresponding to about 0.55 million ft^3/year/mile for the area beyond 50 miles. Note that the Mackinac Bridge is about 40 miles from Kinross (Figure 3).

Inventory

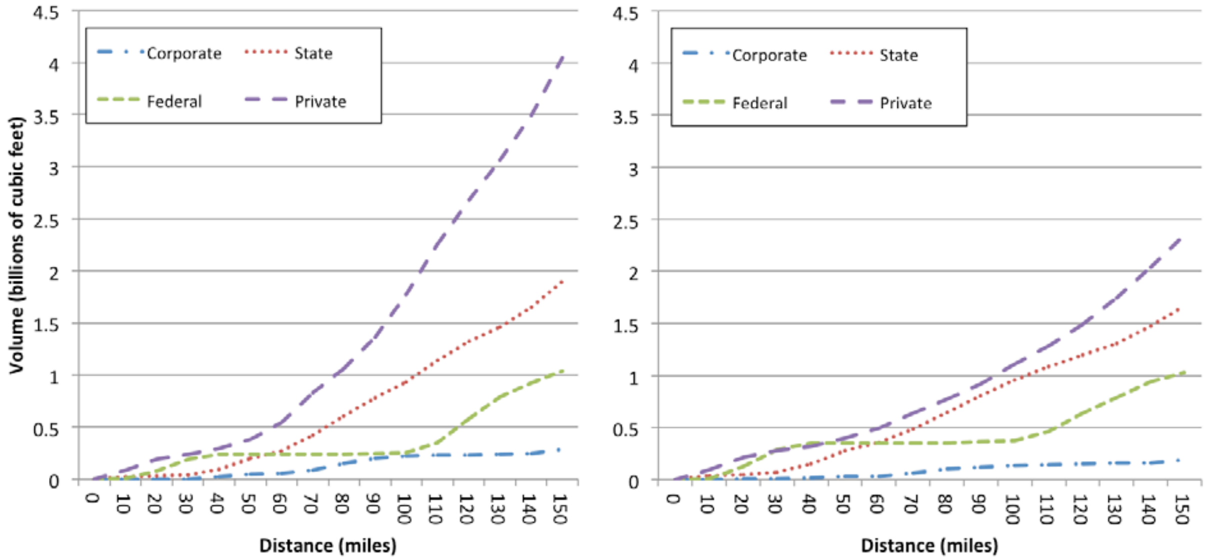

Figure 5. Standing forest inventory (volume), cumulative by increasing transport distance from Kinross. Volume is expressed in millions of cubic feet per year. Data for hardwood species are shown at left and softwood species at right.

Growth net of Mortality

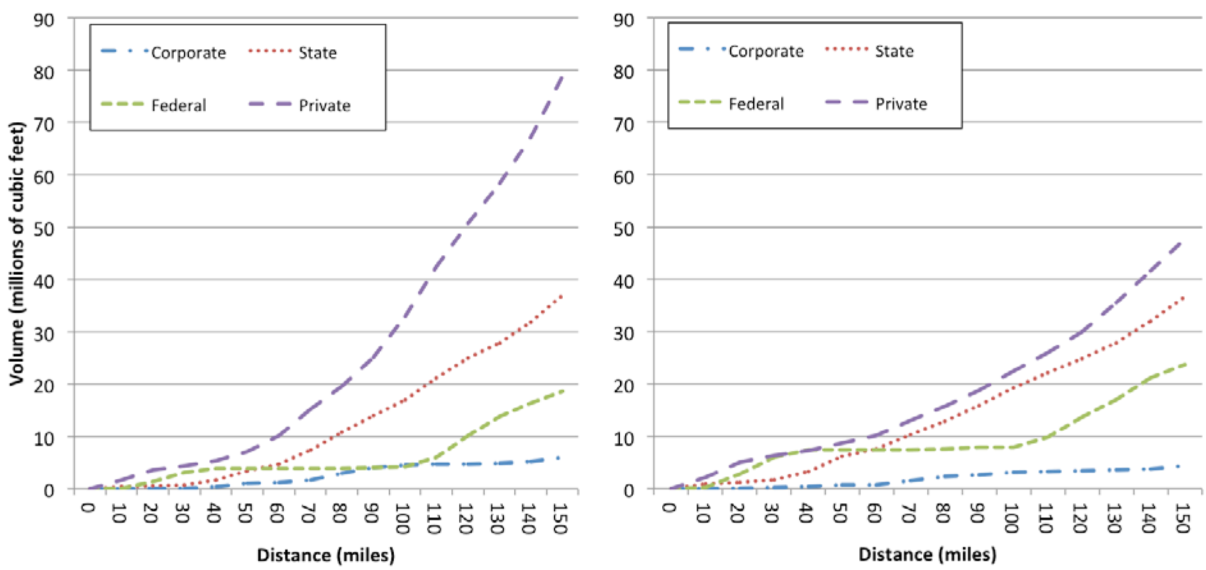

Figure 6. Growth, net of mortality, cumulative by increasing transport distance from Kinross. Volume is expressed in millions of cubic feet per year. Data for hardwood species are shown at left and softwood species at right.

Mortality

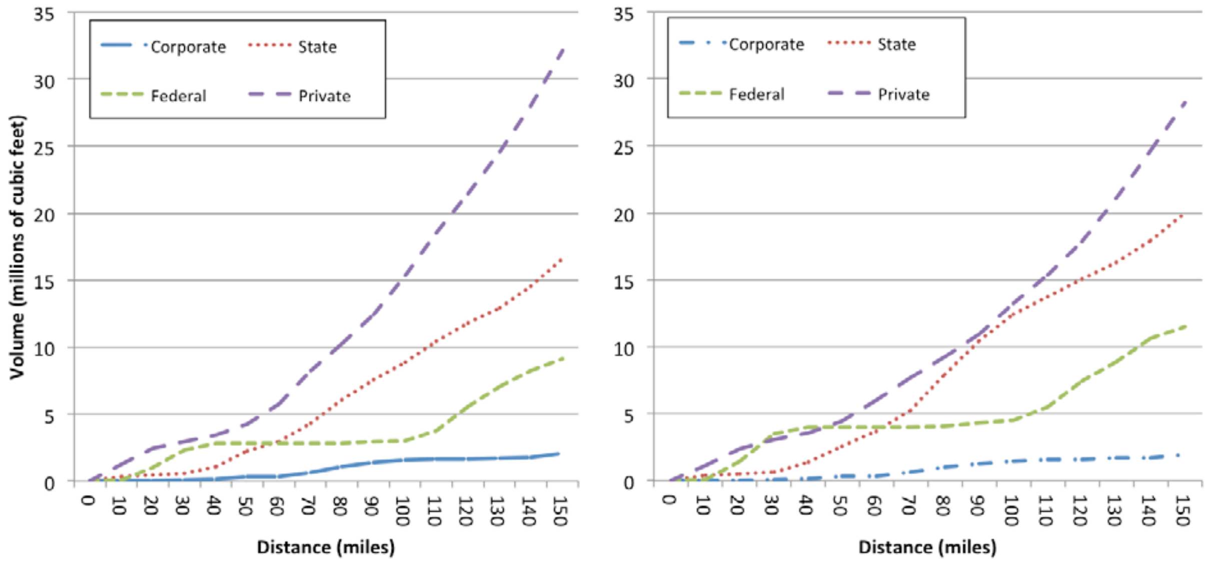

Figure 7. Natural tree mortality, cumulative by increasing transport distance from Kinross. Volume is expressed in millions of cubic feet per year. Data for hardwood species are shown at left and softwood species at right.

Removals

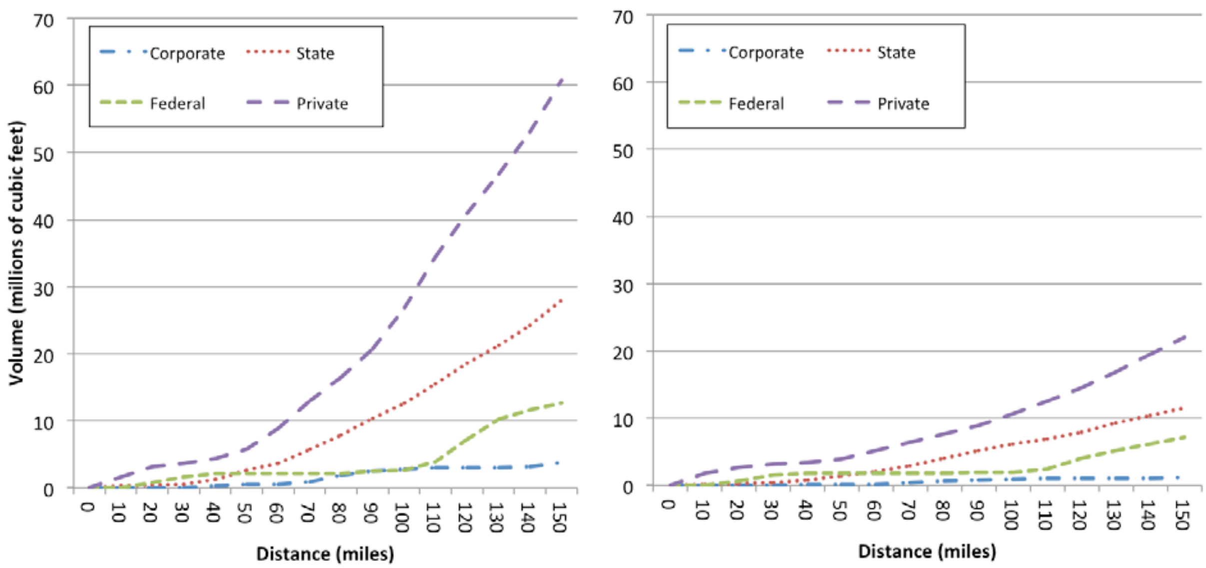

Figure 8. Removals (harvest and other), cumulative by increasing transport distance from Kinross. Volume is expressed in millions of cubic feet per year. Data for hardwood species are shown at left and softwood species at right.

Net Growth After Removals

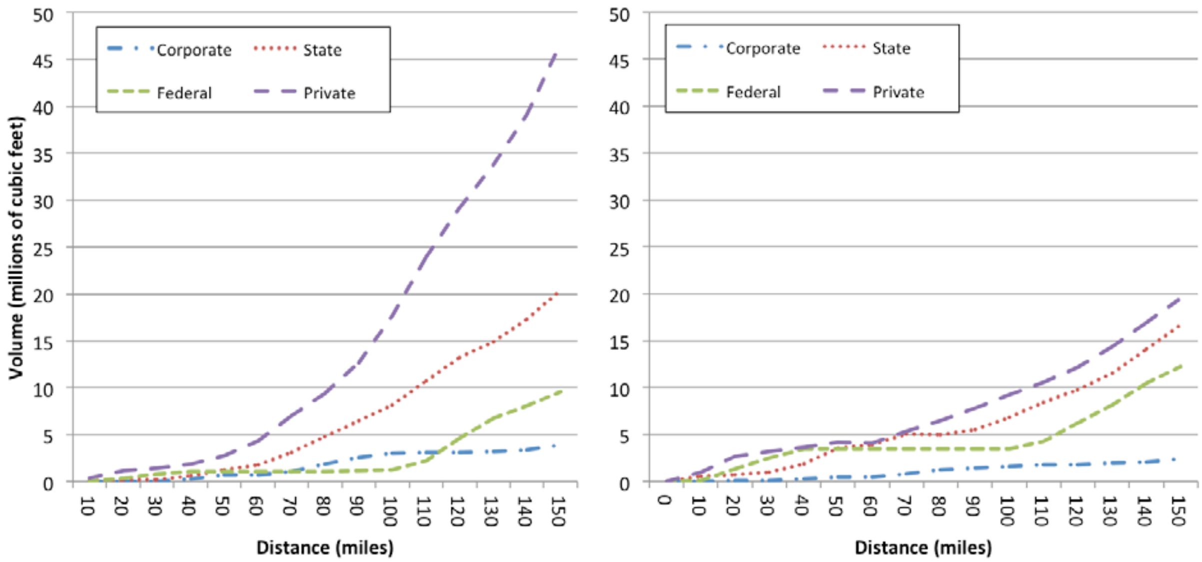

Figure 9. Net growth after removals, cumulative by increasing transport distance from Kinross. Volume is expressed in millions of cubic feet per year. Data for hardwood species are shown at left and softwood species at right.

Logging Residues

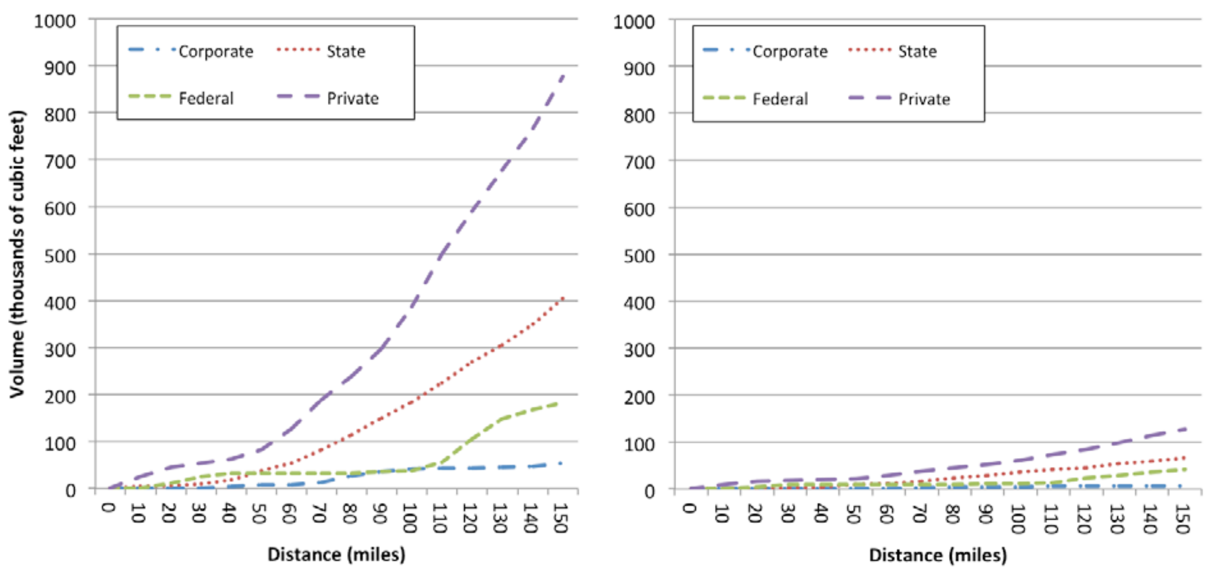

Figure 10. Estimated gross production of logging residues, cumulative by increasing transport distance from Kinross. Volume is expressed in millions of cubic feet per year. Data for hardwood species are shown at left and softwood species at right.

Discussion

Completing a spatial inventory assessment is surprisingly easy once the inventory models, ownership and road network data are available. The necessary tools are included in ArcGIS desktop GIS extensions (network analyst; spatial analyst) and are straightforward to use for an analyst modestly comfortable with the software. The results from spatial analysis are detailed, transport-distance based data on forest inventory attributes, which could be especially powerful for economic, life-cycle or supply chain analysis and optimization. More sophisticated spatial domains such as geographic priority areas could be defined, or additional spatial qualifiers like seasonal road restrictions could be specified, which further refine the analysis. Alternative software environments could be used with the spatial inventory model, such as spatial forest planning software like Remsoft Spatial Planning System (Remsoft 2011), which can solve for optimal procurement solutions based on minimizing delivered wood cost or optimizing carbon sequestration.

Ultimately, the accuracy of the spatial analysis depends on the accuracy of the data components, including the road network, land ownership data, and the forest inventory model. We have little reason to doubt the accuracy of the road network, at least at the scale or in the way we used it in this analysis. Minor errors are likely overwhelmed by the decision to add a five-mile buffer to the service area defined by the road network. We know the ownership data to be limited both by the lack of distinction between operable and protected forest areas and by the underlying accuracy of the property classification, especially for the corporate class. Corporate ownership was created for a different project conducted at MTU in 2005-06 using best available data at that time, which at times dated back to 2002. Again, at the scale or in the way we used the data in this analysis any errors in the ownership data were likely swamped by buffering and the size of the feedstock supply zones. While the zones we used were much smaller than those in prior analyses, they were still large enough to total 200,000 acres or more.

An analysis of the accuracy of the underlying spatial inventory model is beyond the scope of this project. Evaluation of the original mapping model is documented by Deo et al. (2011). Work in progress at MTU (data not shown) has shown that the revised model used in this analysis is less biased and much more sensitive to the actual spatial pattern in inventory attributes than the earlier model. A simple comparison to the values reported by Leefers and Vasievich (2010) shows that the values reported here are at minimum comparable to those generated following the design based FIA inventory calculations. For example, total growing stock volume for the 150-mile transport-distance based zone defined in this project was 12.5 billion ft^3 (Table 1). This compares well with the value reported by Leefers and Vasievich for a 150-mile circular radius, which was 11.4 billion ft^3. (Leefers and Vasievich 2010, Table 7, page 12). Notably, the latter was for timberland only, which is a subset of the lands for which the estimates were generated in this project, and therefore it is not surprising that the value is smaller.

Yet there remains a clear need to refine the inventory model, which presently doesn't use ownership as part of the imputation process. Structuring the model so that it is sensitive to disturbance is a particular challenge, because partial disturbances are common in the forest types in Michigan and there is no powerful "signature" of disturbance that we have yet discerned from the remote sensing data products we have used. While the model appears unbiased overall with regard to removals, the spatial sensitivity to disturbance is less than for standing inventory. The effect is that small area estimates of disturbance are less accurate. This is illustrated by the difference in net growth to removal ratios across owner classes.

We know from the design-based FIA inventory estimates that growth to removal ratios for the Hiawatha National Forest and Huron-Manistee National forest range from about 3 to 15, depending on forest and species (data not shown). Yet the estimates for the 150-mile transport distance based zone in this study range from 1.5 to 3.3, despite including all of the Hiawatha and portions of the Huron-Manistee. If ownership could be included in the inventory model, instead of simply imposed on the generalized inventory as done here, the model would likely be more sensitive to differences in harvest behavior that are owner- or agency-specific.

To improve future analyses, refinements should be made to the inventory model and the ownership data. The foundations for these improvements are already set. The data and software systems used to build the mapping model are all in place at MTU and further improvements depend largely on the availability of staff resources to undertake the work. Refinements to corporate land ownership data have been made elsewhere in the CoEE project and were simply not available in time to be incorporated into this analysis. Perhaps most novel and most powerful would be to incorporate the "service area" functionality used in the desktop GIS, to complete this report, into the dynamic server GIS environment that is the Forest Biomass Information System (FBIS; see http://fbis.mtu.edu). Preliminary work has suggested that this would be straightforward.

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