# Forest Biomass Information System for Michigan

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30 September 2011

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# Executive Summary

Very high quality forest inventory data are available from the USDA Forest Service Forest Inventory and Analysis Program, for forests under all ownerships in the United States. These data span multiple owners in time and space and are known to be very accurate and of exceptionally high quality. Unfortunately, systems for non-technical users to access these data are not available, and furthermore, spatial analyses especially at small scales are difficult with extant public FIA database tools. In this project, a user-friendly, cross-platform interface to FIA data was developed, based on ESRI ArcGIS server software. Non-technical users, Mac, PC, Linux or other platform, can access the server system using a standard web browser. Both fixed-radius and irregular user-defined query areas are possible for users to define, and the web system presents both graphical and tabular summaries of forest inventory, growth, mortality, removals, net growth after removals, and potential logging residues associated with timber harvest. The new system is robust, stable, and effective at making dense and sparse inventory data available to non-technical users with continuous, 30 m resolution raster coverage for the entire state of Michigan. Analysis of accuracy of the underlying data is presented elsewhere. This report summarizes the functionality of the Forest Biomass Information System (FBIS), the WebGIS software environment and extensions that make the underlying data, developed recently and revised in the future, available to non-technical users.

# Introduction

The best available forest inventory and growth data in Michigan are associated with the USDA Forest Inventory and Analysis (FIA) program (Bechtold and Patterson 2005). FIA is a national program with standardized inventory methods that rest on an extensive network of field samples that is the foundation of the FIA program. These samples are the product of cyclical visits to known forested locations and measurement of current tree inventory and attributes. Through successive visits, changes in inventory attributes, such as tree growth, mortality, and harvest removals can be calculated. Key strengths of FIA are that field plots are established on all forested lands, regardless of ownership. Furthermore, FIA data are of very high quality, and with one notable exception, are freely available to both public and private users and agencies for use in assessment and analysis of forest resources.

The notable exception regarding FIA data availability relates to a very strict policy of privacy regarding the actual geographic location of the field plots (McRoberts et al. 2005). An approximate location of an FIA plot is available, where the approximation is a product of two processes: fuzzing and swapping. Fuzzing means the addition of randomness to the actual coordinates, so that the released coordinate contains error. Swapping means that a proportion of FIA plots are paired with other FIA plots that are similar in forest composition and the fuzzed coordinates are exchanged within the pair. The policy makes precise geospatial analyses using FIA data is impossible with public data. Alternatives include requesting custom spatial analyses performed by FIA staff or using public FIA interfaces. One example is the EVALIDator web system, where users can define spatial queries through a website, which are ultimately processed on FIA servers using actual coordinates.

Existing FIA data and systems, however, have constraints that need to be overcome to make data accessible to demands from an increasing array of often non-technical users. Key constraints are threefold. First, the FIA interface is currently a simple web-based and interactive form-driven query system, suited for occasional users who are familiar with the underlying FIA protocol, definitions, and limitations. Second, while the FIA inventory records the land ownership class at each field plot, no distinction is made between industrial and non-industrial private owners. This prohibits analyses that distinguish between these two very important owner types, who often have very diverse goals and practices.

A third constraint involves the size of spatial domain possible to analyze using FIA plot data. The FIA field plot network is a sample-based system, with a national standard intensity of about 1 plot per 6,000 acres, which was until 2005 intensified to 1 plot per 2,000 acres in the heavily forested parts of the State of Michigan. When used to generate averages for geographic areas of interest, the precision of those averages declines as the size of the area of interest declines. Ultimately, when areas of interest fall below 2,000 acres it is possible that they contain no FIA field plots, preventing any estimation of forest inventory whatsoever.

## Increasing Non-Technical User Access to FIA Data

The Forest Biomass Information System for Michigan (FBIS) is an integration of several efforts to increase the access to FIA data for non-technical users, and to reduce the effect of existing constraints on the possibility for precise spatial analyses.

FBIS has three parts:

1. Geospatial (raster grid) forest inventory model
2. WebGIS server system interface to inventory and availability data
3. Availability module that defines the fraction of inventory that is available for harvest

The focus of this report is on the WebGIS server system, which is the public face to the FBIS for Michigan. Reports that summarize the other two components are available separately. Briefly, an overview of the other tasks is summarized here to provide context.

### *Geospatial Forest Inventory Model*

The geospatial forest inventory is based upon FIA data and generates estimates of forest inventory attributes *in-between existing FIA plots*. The output is a continuous gridded, or "raster" based inventory data set, where the State of Michigan is divided into 30 m square grid pixels and inventory estimates are available for each pixel. This approach offers many advantages. In addition to providing an interpolation of inventory values between known points, the geospatial grid also transforms FIA data to a format and scale that permits seamless interface with other spatial data, such as road networks, soils and ownership. Benefits include facilitating value-added applications, such as spatial-based supply chain analysis and optimization. The geospatial inventory is the data foundation within FBIS, and was developed at Michigan Technological University.

### *Availability Module*

Potential harvest is ultimately defined by forest inventory. However, landowners have many motivations for the harvest of forest products, or may be motivated to not harvest at all. Thus, the amount of forest inventory that is available for harvest may be viewed as a fraction of the potential. If the harvest rate exceeds the growth rate, then forest inventories are depleted. If the harvest rate is less than the growth rate, then forest inventory is accumulating. Generally, sustainable utilization of forest resources generally implies a harvest rate that does not exceed growth rate; i.e., a "growth to removals" ratio of 1:1.

Michigan State University has assessed forest availability, which was intended to act as a set of "filters" in the WebGIS system. These filters act to reduce the havest potentials that come from gross inventory and growth rate, to represent the practical portion of that potential that might actually be realizable, or available for utilization. A variety of scenarios were contemplated, including current restrictions and planned harvest levels that might deviate from past behavior. An objective in the development of the FBIS for Michigan was that these filters would be incorporated into the WebGIS system.

## Developing a Web-based Information System

Once gridded geospatial inventory and availability data are available a range of new possibilities for analysis are possible. For example, defined areas of interest may be overlain on the gridded inventory data set for some attribute of interest, and values for each grid cell summed to provide an area-based total. Filters can be applied to net down inventory, growth, etc., based on assumptions about constraints that limit the available portion of the standing inventory or to limit results to other subpopulations of interest (e.g., a specific forest cover type). All of these are enabled only within appropriate computing environments, such as in the ESRI ArcGIS workstation software, which are very powerful but rarely accessible to non-technical or users outside of institutions.

The approach in this project was to embed the geospatial library within an ArcGIS server system, and develop a custom web application that would deliver essential data management and query functionality through a conventional web browser (Figure 1). The system provides user-friendly WebGIS capabilities that enable customized spatial analyses in real time and in a platform independent way, with similar function regardless of the user's computing environment (i.e., Windows, Mac, Linux or even tablet or smartphone browsers).

The WebGIS interface permits mapping and spatial analyses conceptually similar to the stand-alone GIS implementation entitled FIAMODEL (http://forest.mtu.edu/data/fiamodel/) but with a web browser interface, similar to the USDA Web Soil Survey (http://websoilsurvey.nrcs.usda.gov). Through this interface, users can interactively define areas of interest based on circles or irregular polygons that constrain reports or analytical operations, and display associated forestry data (e.g., inventory, removals). Outputs will include graphical displays and printable reports summarizing the available biomass under that scenario. Our original design imagined users having the option of specifying a set of availability filters that reflect differences in institutional constraints on availability, and gaming the nature of those constraints to reveal spatial utilization outcomes.

We call this system FBIS, and it is accessible at the URL **http://fbis.mtu.edu**.
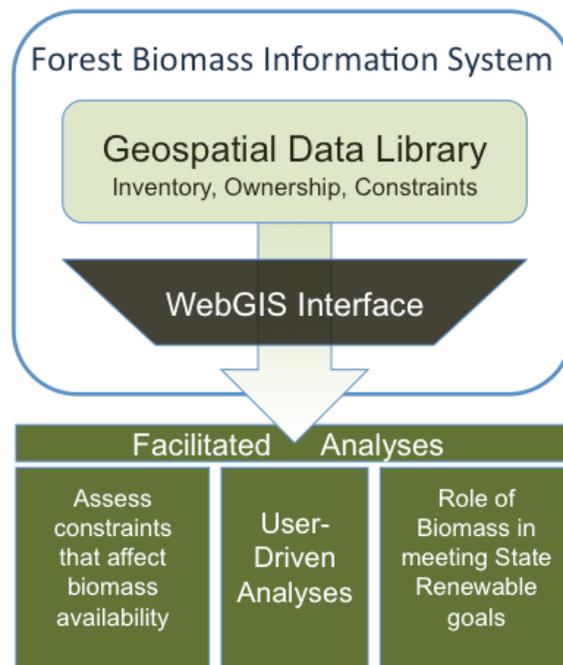


Figure 1. Conceptual model of the FBIS.

## Objectives

The overall goal of this project was to develop and integrated forest inventory and availability data warehousing and analysis system accessible to non-technical users. The system is accessible to users through standard web browser client software (e.g., Safari, Firefox, Internet Explorer) that is essentially operating system independent.

This goal was divided into several objectives:

1. Deployment of the basic software and hardware platform, including ArcGIS server, web server and necessary database back-end
2. A project website, hosted on the FBIS web server
3. Deployment of the WebGIS framework including base data, mapping functionality, availability model and query functionality
4. An embedded help system that acts as a user's guide to the data content and the WebGIS functionality

# Methods

## Geospatial Data

### Forest Inventory

The data foundation for FBIS is a continuous, raster grid output from a geospatial model of the FIA inventory data set. The approach used was to construct a "mapping model". The basic principle behind this approach is to model the relationship between the attributes of interest, which are measured on forest inventory plots (e.g., standing volume), and auxiliary information, such as remote sensing data from satellites (e.g., Landsat, MODIS), digital topographic maps and so forth. The FIA inventory plot data for Michigan was the reference data set used to train the mapping model.

Once the mapping model was developed it was used to predict, or impute, the attributes of interest at all of the points in-between the measured plots, using the auxiliary information, which was continuous. The result is a continuous gridded inventory data set. Technically, what is actually imputed to each pixel is the label of the FIA inventory plot that is most appropriate given the combination of auxiliary data for that pixel, as predicted by the mapping model. Then, forest attributes at the imputed pixel are automatically those associated with the reference plot.

The development of inventory data was involved and only a brief summary is presented here. For more information on please refer to the project report for that task (Deo et al. 2011).

### Forest Land Ownership

Unfortunately, there is no single and convenient source of geospatial land ownership data for the State of Michigan. Data for most public lands are available from those agencies. For state lands, ownership data were obtained from the Michigan Geographic Data Library (http://www.mcgi.state.mi.us/mgdl/). Similarly, data for Federal lands (National Forests) were obtained from the USDA Forest Service.

The remaining two categories of forest land ownership were industrial and non-industrial private owners. Unfortunately here is no public source of geospatial data on these ownerships. Data may be purchased from private companies (e.g., Rockford Map Publishers) who aggregate public records on ownership but these are only available at considerable cost. For this project, we relied upon a geospatial data set developed for research completed at Michigan Tech in 2007, the subject of which was corporate land ownership patterns in the Michigan UP (Froese et al. 2007). In this project a custom geospatial representation of corporate ownership, circa 2005, was developed. Since there are effectively no industrial forest land owners in the Michigan LP the data set was deemed sufficient for this project. Finally, lands that did not fall into the State, Federal or industrial classes is assumed to be  in non-industrial private ownership.

### Additional Spatial Data

Additional spatial data sets were included to provide contextual information that users might find valuable. Display of these sets is optional, on with only ownership included by default. Data were obtained from the Michigan Geographic Data Library and sets available in FBIS include cities, roads, rail, lakes, streams and county lines.

## Server Hardware and Software Environment

The FBIS system resides on a dedicated server running Windows Server 2008 R2. Web services are provided by built-in Microsoft IIS software. The server is hosted at Michigan Technological University, and beyond the termination of the project will be maintained informally as long as time and resources allow.

The FBIS architecture was developed in two stages and released independently as two versions. Version one of FBIS utilized ArcGIS Server (.NET) and the WebADF framework to present a web browser based interface to the user, execute the geoprocessing models and pass the output back to the user. A sample map viewer application produced by ESRI was used as a starting point for development and all code was written in C#.

Version two of FBIS utilizes the ArcGIS Javascript API and REST (representational state transfer) service of ArcGIS Server to present a web browser based interface to the user, execute the geoprocessing models and pass the output back to the user. Sample code from the ESRI Javscript API sample library was utilized as a starting point for development and all code was written in Javascript.

## Geoprocessing

ESRI's ArcMap software was utilized to develop two geoprocessing models to compute aboveground biomass based on a user-selected area.  The first model utilizes a point/buffer specified by the user to determine the area of interest (AOI) to be used in the computation (Figure 2).  The second model utilizes a user drawn polygon for the same purpose (Figure 3).

The underlying data for both models is a raster of integers in which the pixel values represent a unique combination of ownership (corporate, state, federal or NIPF) and above ground biomass.  The raster is clipped to the user specified area and joined to an attribute table (BiomassOwnerTable) that contains the above ground biomass values and ownership by pixel value. The biomass values for the selected area are then summarized by a custom software program, written in the Python programming language, and two sets of output are generated:  (1) a comma delimited text file (.csv) and (2) a set of data values in JSON (Javascript Object Notation).  The JSON output is passed back to the web browser where it is displayed as a chart or table.  A link to the .csv file is also passed back to the web browser thus enabling the user to download the output and perform additional processing.
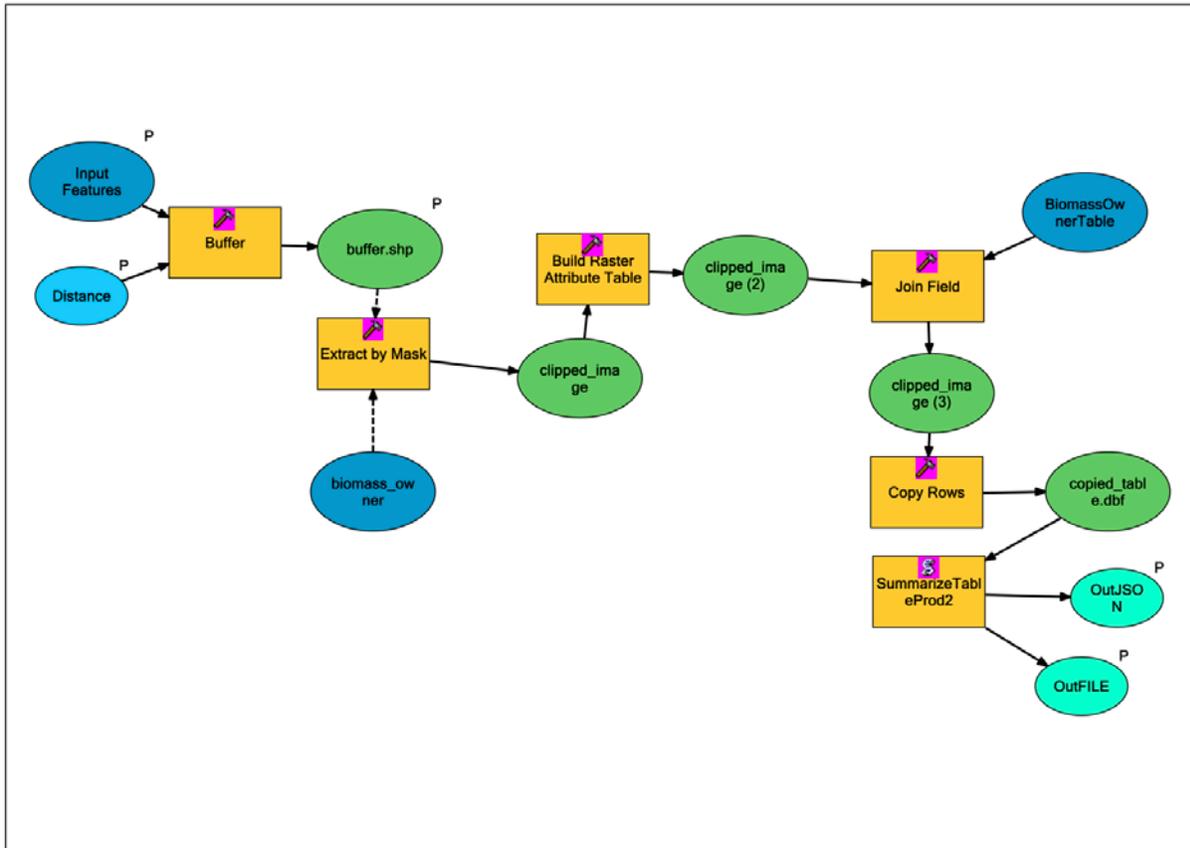
**Figure 2. Geoprocessing model for an area of interest query defined by a point.**
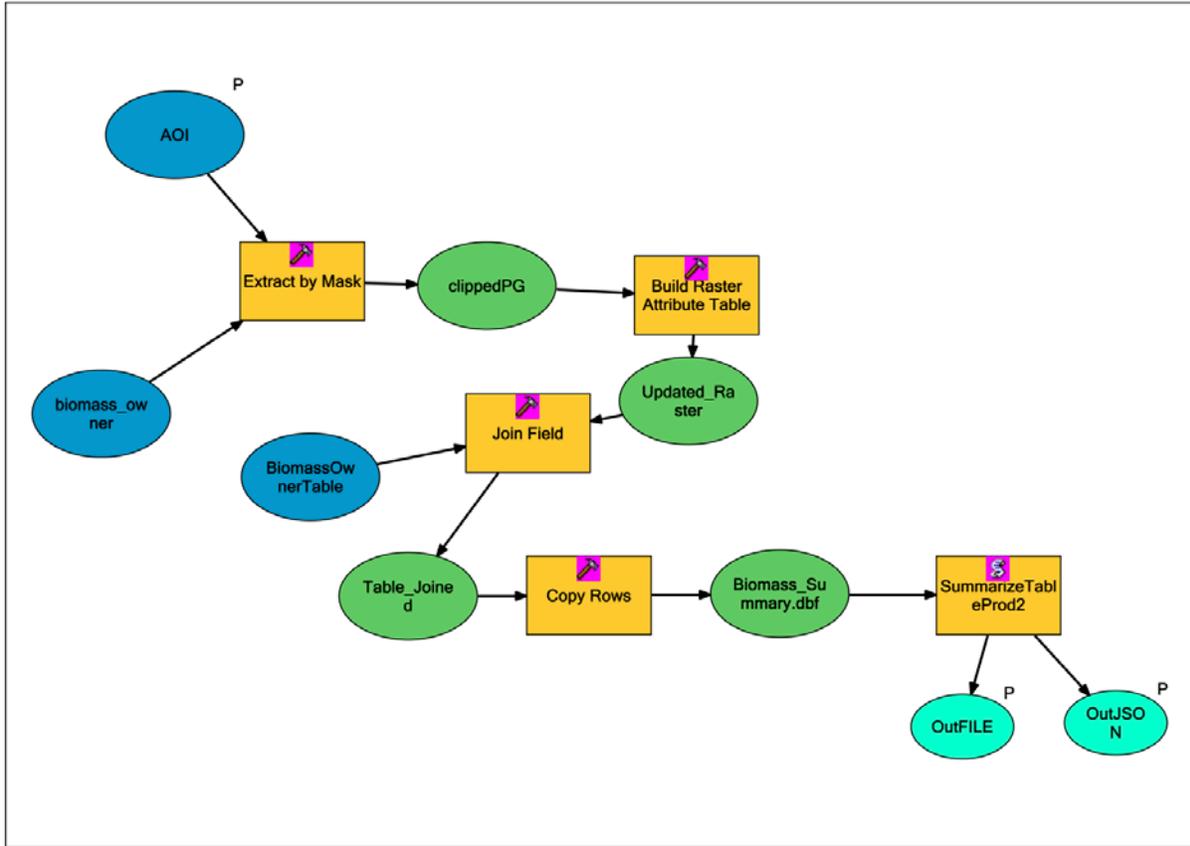
**Figure 3. Geoprocessing model for an area of interest query defined by an irregular user-specified polygon.**

# Results

## Root Website

The root of the FBIS web site is a set of seven web pages. The home page (http://fbis.mtu.edu) presents an attractive introduction to the FBIS collection from which a user may proceed directly to the mapping and query application, or learn more about the FBIS system. Featured prominently on the home page are links to sponsoring agencies (MTU, MEDC, DOE) and a link to the availability research completed by MSU.

Links are also provided to pages that meet specific navigation and information needs:

1. Home page – the "first page" that a user sees and links to other pages
2. What's New – provides a summary of model releases and new features
3. Contact Us – links to email addresses for questions about the web application and underlying data
4. Browser Requirements – enumerates the web browser platforms that are known good
5. FBIS User Guide – a set of "help" or "manual" pages that describes the system
6. Sources of Funding – acknowledgements for MEDC and DOE as sources of funding
7. Disclaimer – text required by DOE

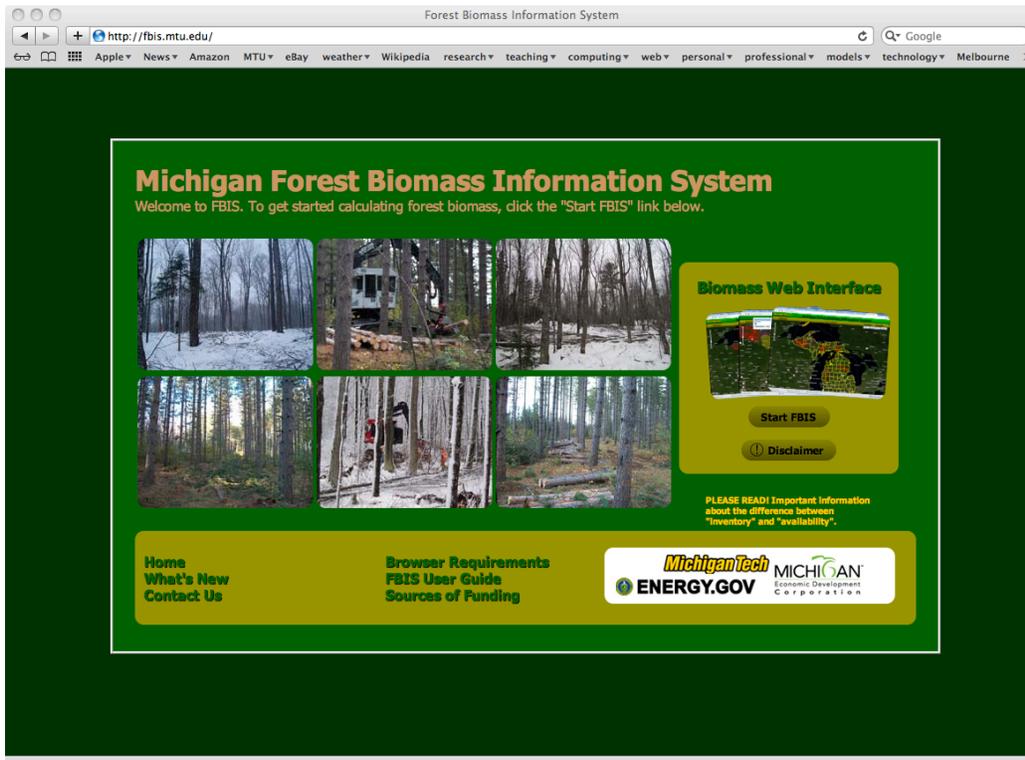Each web page has a link back to the root page so that a user can return to the beginning at any time.
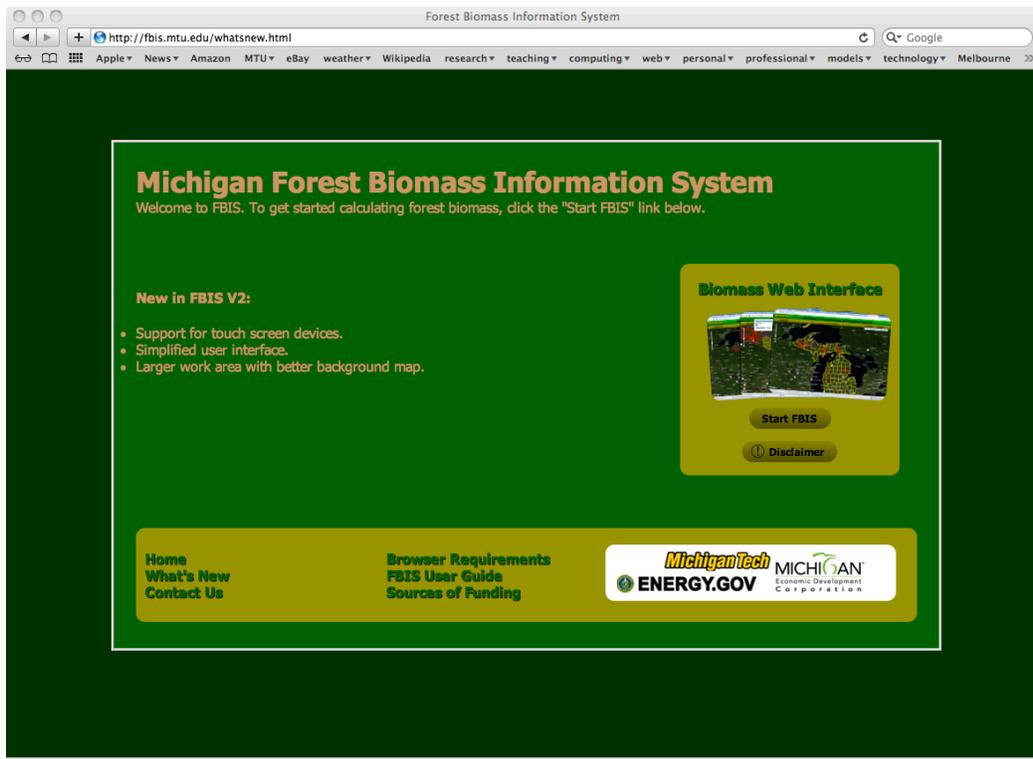


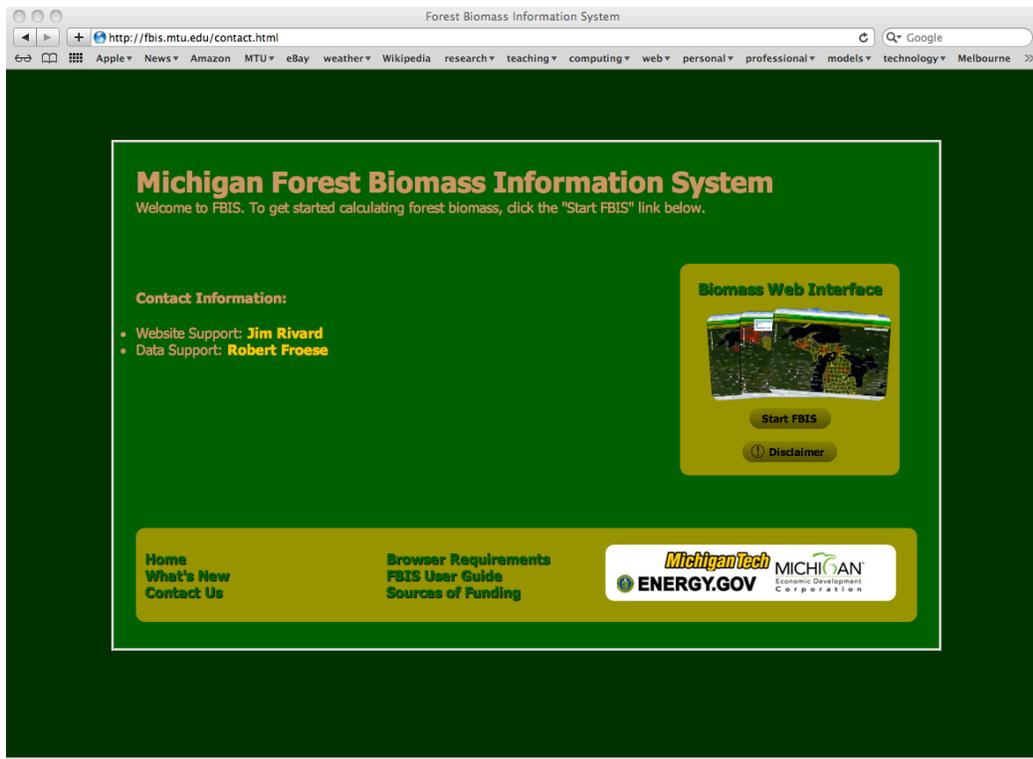**Figure 4. FBIS home page.**

**Figure 5. Web site "What's New" page.**

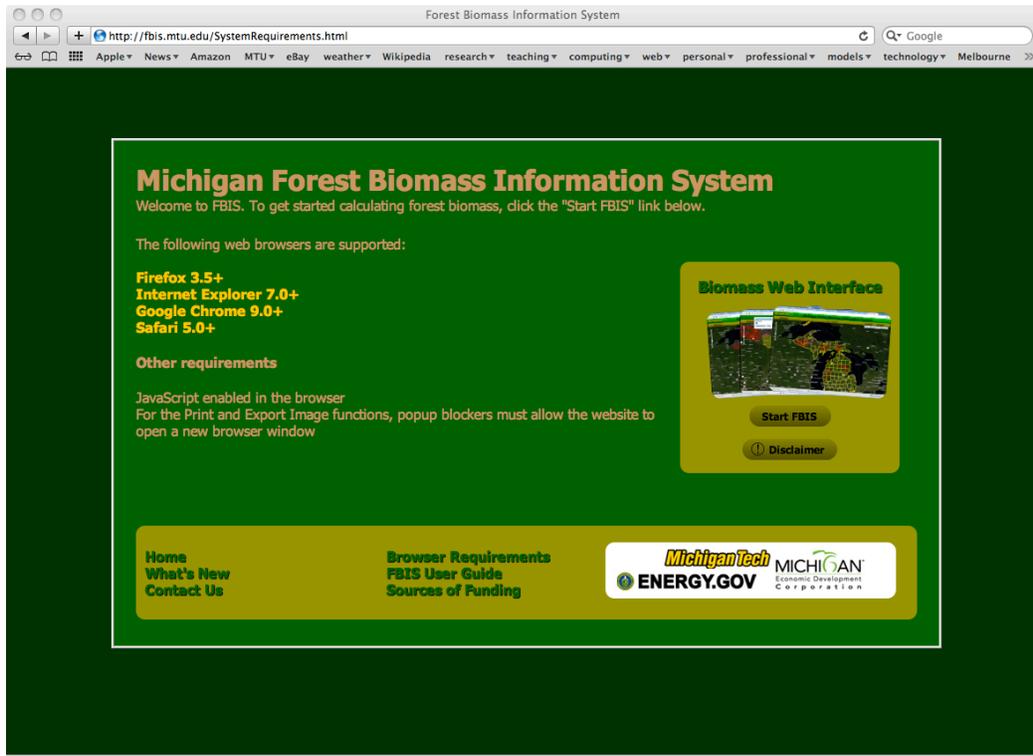**Figure 6. Web site "Contact Us" page.**

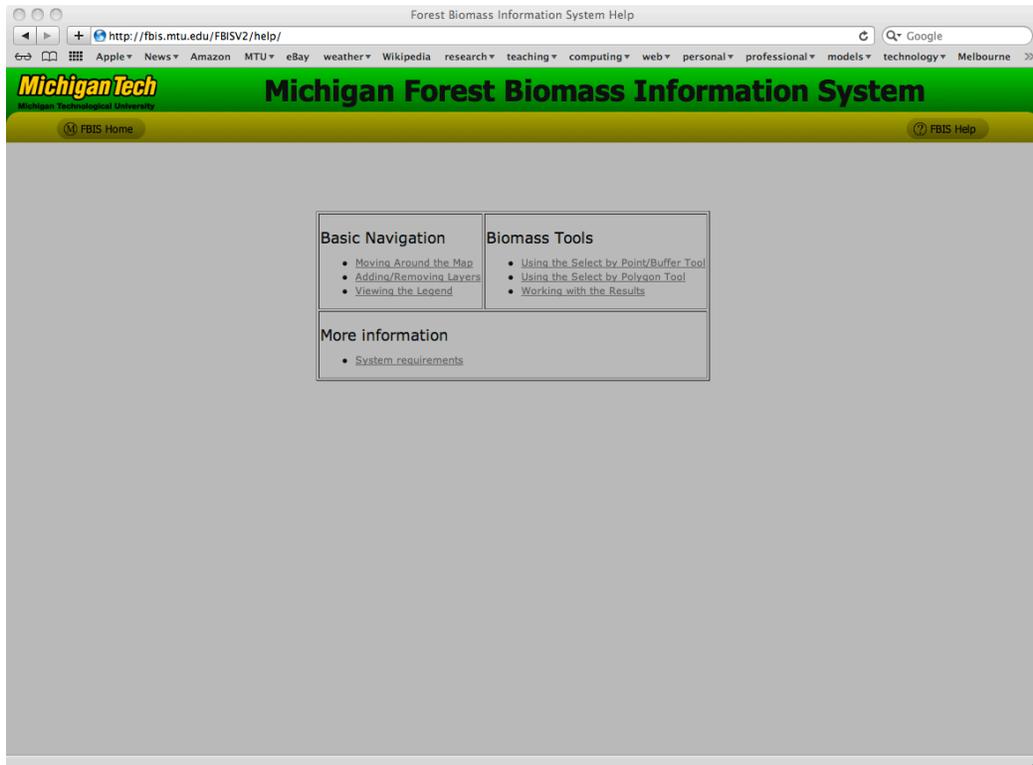**Figure 7. Web site "System Requirements" page.**

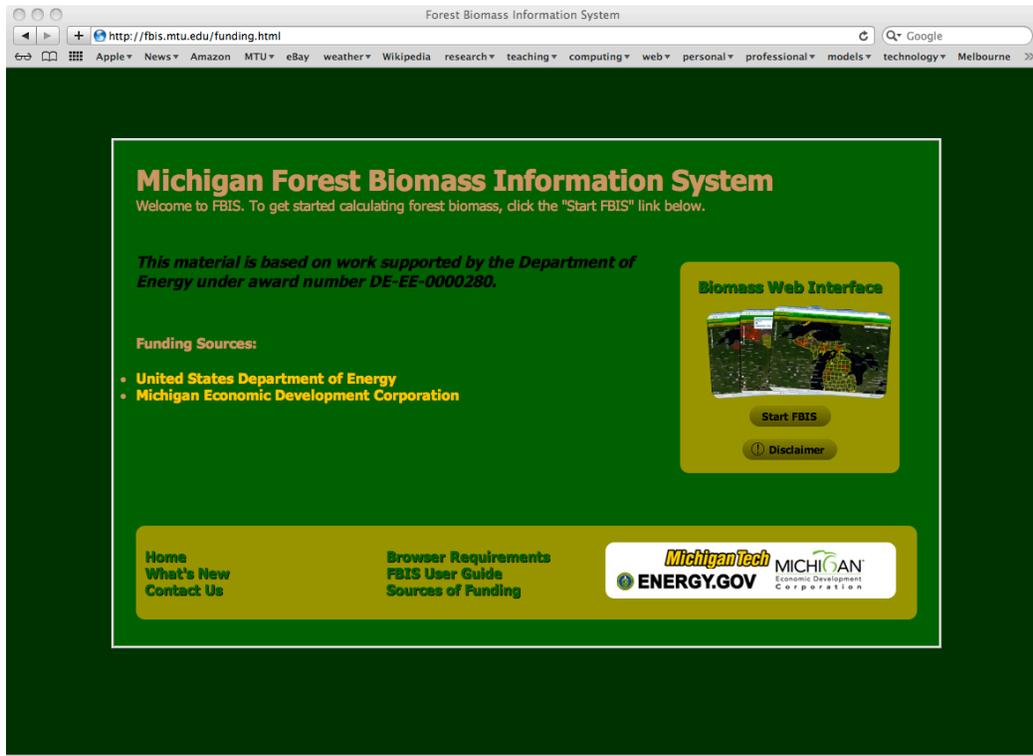**Figure 8. Web site "Help" or "User Gudie" page.**

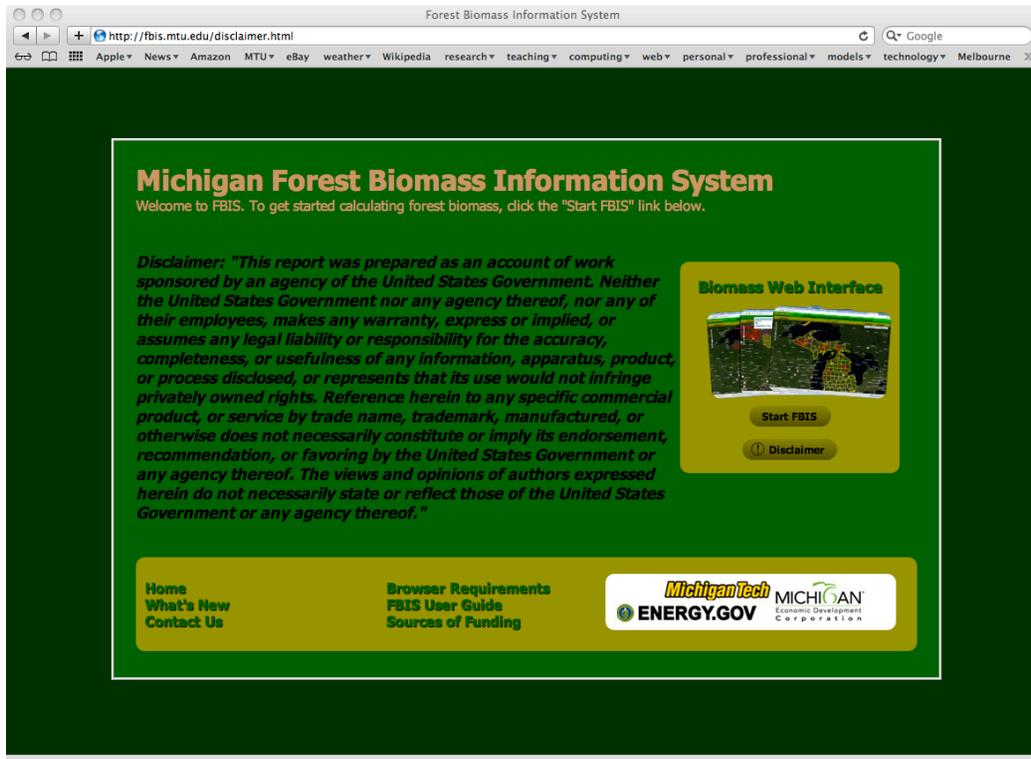**Figure 9. Web site "Sources of Funding" page.**

**Figure 10. Web site "Disclaimer" page.**

## FBIS Query Page

The FBIS query page presents a base image from the Microsoft "Bing" service (Figure 11). Zoom and pan can be controlled with a wheel mouse, or alternatively zoom can be controlled with a slide bar on the top left portion of the map. Controls and the map legend are presented as pull-down menus in the top right hand corner. This interface maximizes the available amount of screen space for map display.

Queries are initiated by selecting one of the biomass tools from the pull-down menus. Queries establish areas of interest for inventory summaries and may take one of two forms: circular or polygon. Circular queries (Figure 12) have a minimum radius of 5 miles and the user may select any location within the UP or northern LP as centroids. For polygon queries (Figure 13) the user draws polygon queries freehand, by clicking on the mouse to establish vertices for the polygon. A double-click on the final vertex completes the polygon. The system obligates a polygon to encapsulate an area of at least 6,000 acres.

Output from the geoprocessing models is rendered in the user's web browser and consists of graphics representing the user selected area, a data table of above ground biomass in cubic feet, and a link to a downloadable .csv file.
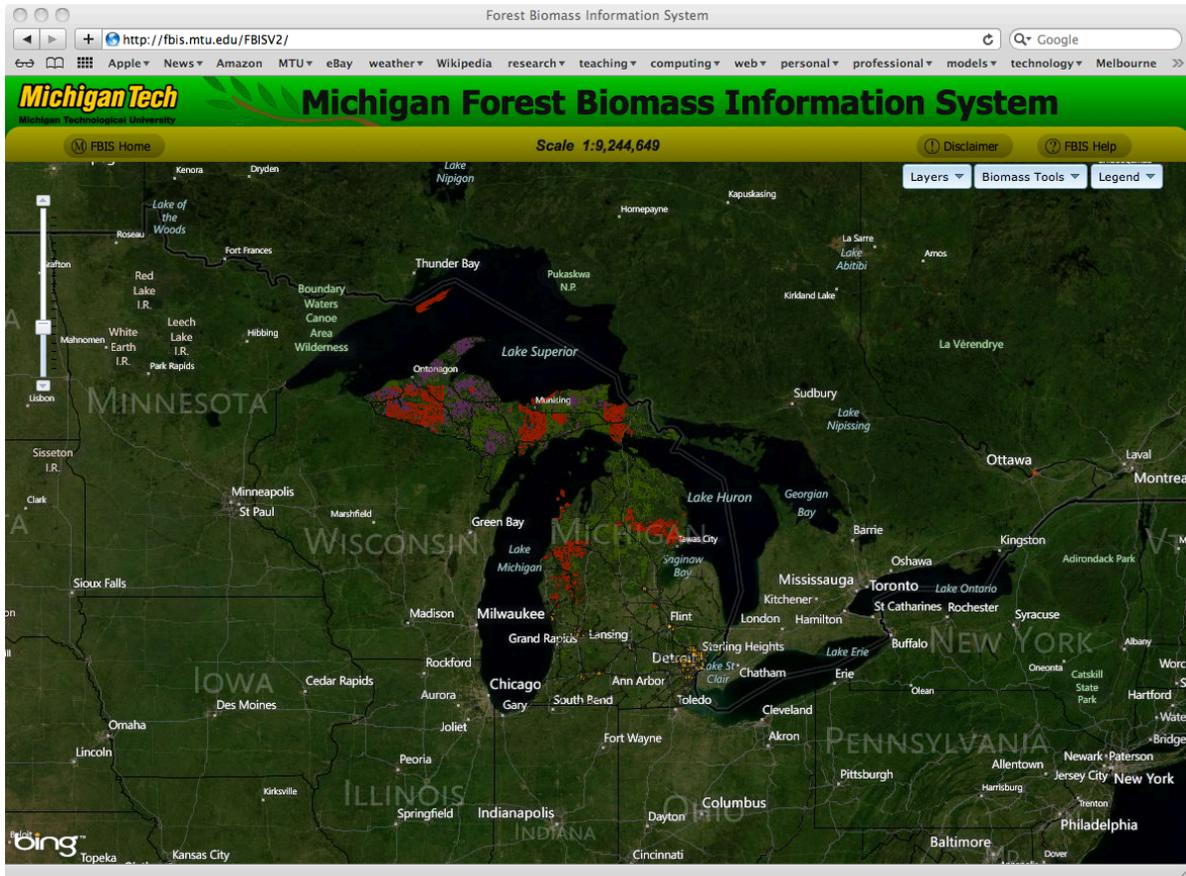
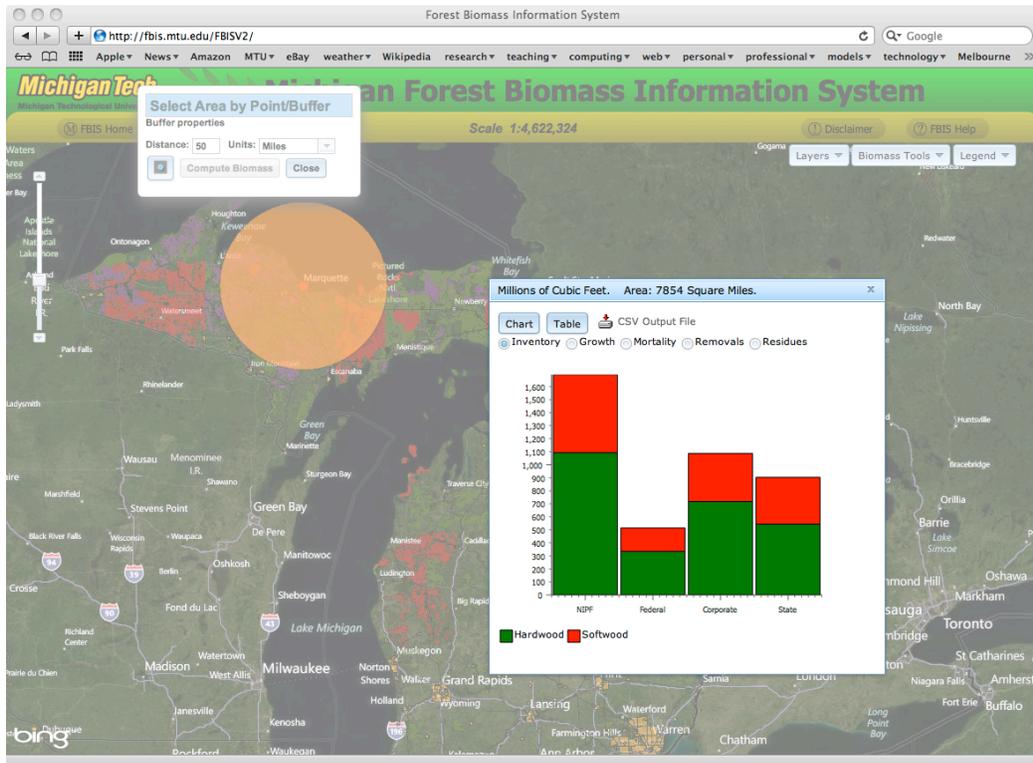**Figure 11. FBIS query page as first presented to the user.**

**Figure 12. Example of a circular area query, defined by a point and buffer.**
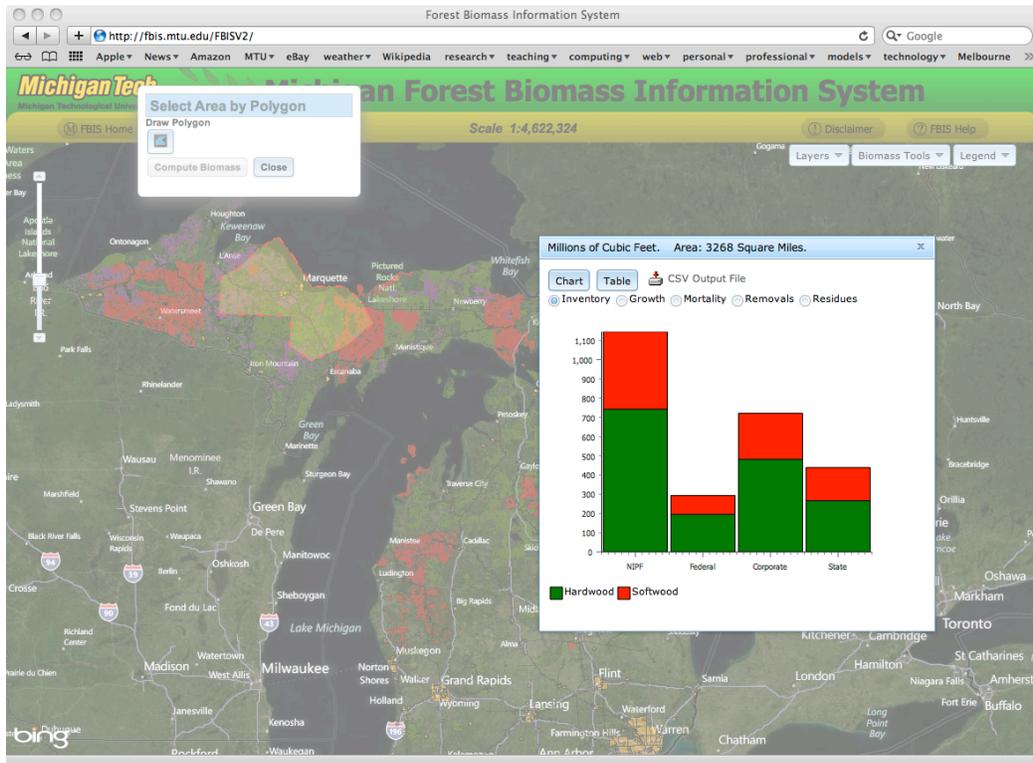
**Figure 13. Example of a polygon based query, drawn by the user.**

## Discussion

The goals of this project were successfully met. The FBIS WebGIS system has proven to be a robust and stable software environment in testing, and meets the design goal of making inventory data available to non-technical users. The final version builds upon new Javascript tools and a linkage to public imagery to produce an application that maximizes user space for visualization.

There are many opportunities to improve the user experience, information available, and capabilities of the entire FBIS system. Some depend on the development of rich base data, improving on the existing geospatial inventory model embedded in the WebGIS environment. The data set available here provides estimates of inventory, growth, mortality, removals and potential logging residues associated with removals, by major species group (hardwood and softwood). Future data products could include further detail, dividing for example major species groups into individual species, like maple, beech, ash, birch, etc. The programming effort to allow this function in the geoprocessing code would be relatively small. However, allowing for the reporting of a larger array of attributes would require modification to the user interface, because graphical or tabular outputs could become too large to display. Thus, more detailed query design would be needed.

The FBIS system presents an attribute called "net growth after removals", which is the amount of annual growth accumulating as new inventory. Since landowner motivations vary, not all of this growth could be available for harvest; some landowners simply have no interest in cutting trees, though the growth of those trees is still accounted for in FBIS. So a plausible scenario for the actual fraction that might be available might be desired, and this is subject to assumptions. The original design for the WebGIS system included functionality where a user could select an availability scenario that reflected e.g., optimism or pessimism about availability assumptions. In a related task, MSU partners developed some information about availability, but it was decided that the decision about availability was best left to model users, and the functionality was not implemented in the WebGIS system. In the future, further information might be available that increases confidence about likely availability assumptions and these could be embedded in the software environment.

Factors other than landowner willingness to harvest ultimately limit the availability of timber and residue harvest. These could include topography, soils, access, wildlife habitat and other non-timber objectives, uncertainty about desired future stand conditions and silvicultural requirements, among many others. Analysis to support the determination of these factors has been completed for some lands in Michigan (e.g., Pederson 2005), and generalized approaches to estimating these for all stands in Michigan are possible. Adding such functionality to FBIS would allow for more realistic, and more certain, estimates of available roundwood and biomass harvests to be determined. This would further reduce uncertainty in the siting and management of new and existing wood products processing facilities, as well as provide the ability to use FBIS to "game" alternative scenarios to reveal possible futures.

As designed, FBIS presents interactive graphics and a downloadable table that includes all inventory attributes for the users' query region. In the future, the user experience would be enhanced if the FBIS system could prepare a custom report, say in PDF format, that could be downloaded in addition to the inventory data. The report might include an attractive map that shows the query area and background map data, graphs and tables that illustrate the inventory attributes, and some interpretive information that

would aid especially novice users. These additions were beyond the scope of this project, but would be relatively straightforward to implement and should be considered in future revisions of the FBIS system.

Many other possible extensions of the FBIS environment are imaginable. The WebGIS environment is amenable to building spatial models of transportation networks and associated time, distance and cost metrics. These could be used to extend the spatial models of availability to spatial models of delivered wood cost, conditional on alternative facility siting options. Similarly, limiting factors to harvest often have a cost component themselves; i.e., steep slopes or wet terrain could mandate seasonal or equipment restrictions that have implicit effect on harvest cost. By combining the existing FBIS base data with new data on terrain, soils, and transportation, a very sophisticated model of roundwood and biomass inventory and availability would be possible.

The most exciting feature of the FBIS WebGIS system, however, is that it makes very extensive and very high-quality forest inventory data available to non-technical users, and in standard desktop computing environments. All of the sophisticated computer processing is off-loaded to the model developers and the web server system, which are external to the user. Whether this system has use for non-technical users remains to be seen, and collecting user-data would also be valuable addition to the WebGIS system.

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