INNOVATIVE WOODY BIOMASS RESOURCE ASSESSMENT USING MULTIPLE RESOLUTION SATELLITE IMAGERY AND GEOBIA TECHNOLOGY

J. W. San Souci [a]

[a] NCDC Imaging, 1235 Lake Plaza Drive, Suite 127, Colorado Springs, CO, USA
jsansouci@ncdcimaging.com

KEY WORDS: Renewable Energy, Biomass, Satellite Imagery, GEOBIA, QuickBird, Landsat, Feature Analyst

ABSTRACT:

The Public Service Company of New Mexico is pursuing biomass electrical generation as its next viable source of renewable energy. Several areas of New Mexico have been the focus of an ongoing study to determine the feasibility of constructing a biomass power plant in the region. The development of the power plant in the region could increase employment opportunities and immediately decrease the risk of catastrophic fire. Biomass resource data is vitally important to the development of biomass power plants. There is a current lack of credible data on location, quantity, and quality of biomass available for these endeavors. This paper addresses these barriers by developing precise, spatially explicit data of existing biomass supplies using state-of-the-art remote sensing and GIS technologies, innovative field sampling methods, and rigorous statistical techniques. These estimates were used to justify the sustainable 30-year fuel supply for a 25 to 35 MW biomass power plant to land management stakeholders, State and Federal agencies and conservation groups.

1. INTRODUCTION

Public Service Company of New Mexico (PNM) is addressing the need to meet Renewable Portfolio Standards and diversification of renewable energy sources within its portfolio. PNM is pursuing biomass electrical generation as its next viable source of renewable energy. The pursued project(s) are classified as open-loop biomass operations. This endeavor includes the soundness of combustion technologies; the environmental, sociopolitical, and operating benefits; the requirements for siting, permitting, and licensing a plant; and the estimated cost and schedule from initiation of developing a site until commercial operation for a 25 to 35 MW plant.

Several areas of New Mexico have been the focus of an ongoing study directed by the Public Service Company of New Mexico ("PNM") with assistance from Native Communities Development Corporation ("NCDC") to determine the feasibility of constructing a biomass power plant in the region. The development of the power plant in the region could increase employment opportunities and immediately decrease the risk of catastrophic fire.

Biomass resource data is vitally important to the development of biomass power plants. There is a current lack of credible data on location, quantity, and quality of biomass available for bioenergy. This project addresses these barriers by developing precise data of existing biomass supplies.

Past management practices of forest fire suppression has resulted in an increase in standing fuel and a decline in overall forest and watershed health. This is characterized by an increase in the amount of diseased timber and an increase in water loss from the affected region. There is a critical and immediate need to improve forest and woodland health and decrease the fire danger. A biomass power plant would provide the incentives needed to sustain immediate and ongoing efforts throughout the Western United States to increase forest and woodland health.

The Biomass Resource Assessment for PNM's Biomass Fueled Electrical Generation Project is ambitious in scope and unique in vision. It is in response to the New Mexico Renewable Energy Act. PNM is the project sponsor with the purpose of quantifying the biomass supply volume of both piñon-juniper woodlands and mixed conifer timberlands within several areas of interest within the state of New Mexico using multiple-resolution satellite remote sensing and geographic information system analysis coupled with both conventional and innovative field methods. These estimates will be used to justify the sustainable 30-year fuel supply for a 25 to 35 MW power plant.

2. LITERATURE REVIEW

Based on the premise that we needed to estimate biomass for several timberland and woodland species using conventional field forestry cruising data, the first step in this analysis was to compile applicable biomass equations for Southwestern United States tree species from the literature. The equations can be split into two groups based on main ecoregions or forest type (timberlands or woodlands). The first set of equations is focused on commercial timber types (ponderosa pine, spruce, fir, etc.) based on diameter at breast height ("DBH") and tree height (Sheppard, 2003). The second set of equations is focused on shrub-like woodland types (piñon-juniper) based on diameter at root collar ("DRC") and tree height. Only during the last decade have researchers successfully characterized the biomass of selected woodland species using allometric equations derived from regression analysis using felled tree samples (Chojnacky, 1994). These equations were used to create spreadsheet applications to calculate volume for each ecoregion (Sheppard, 2003; San Souci, 2005).

The spreadsheet applications created are based on previously developed cruise volume summary applications developed by Wayne Sheppard, PhD of the USFS Rocky Mountain Research Station. BIOCRUZ summarizes fixed radius cruise data from multiple plots and produces a stand table of stem density, cubic,

and Scribner volumes by height and diameter class. Volume equations are from RM Station publications and handles trees 1 to 48 inches DBH and 20 to 120 feet in height. Cubic volumes are for the entire stem, including stump and top. The program recognizes the following species codes:

SPRUCE, FIR, DOUG-FIR
LODGEPOLE PINE
ASPEN
FRONT RANGE PONDEROSA PINE
SOUTHWESTERN PONDEROSA PINE

The application developed to handle the woodland plot data, PJCRUZ, was developed specifically for this project using equations found in the literature (Chojnacky, 1993 and Chjonacky et al, 1994). PJCRUZ summarizes fixed radius cruise data from multiple plots and produces a stand table of cubic volumes (ft3) and handles trees 3 to 20 inches DRC and 4 to 50 feet in height. Cubic volumes are for the whole tree aboveground. The program recognizes the following species codes:

COMMON PIÑON
UTAH JUNIPER
ONESEED JUNIPER
ROCKY MOUNTAIN JUNIPER
ALLIGATOR JUNIPER

Novel to this study is the unique ability to precisely determine crown diameter from high resolution satellite imagery in order to calculate crown width (Figure 2). Significant relationships between crown width and stem diameter are well-established for trees of many species (Bechtold, 2004). The two methods tested for this analysis (Bechtold and Shaw) were similarly structured and yielded comparable results; however, the Shaw method produced a more favorable R^2 statistic and did not require numeric estimation to solve for diameter (Shaw, 2005). In a sense, the Shaw equations are optimized for remote sensing in two ways:

1) They are fitted with diameter as the dependent variable, and
2) Crown width is calculated from crown area

Figure 1. Example of crown delineation from high resolution satellite imagery

3. DATA COLLECTION

Stratification

Topography and forest cover are two major interconnecting factors influencing the finer details of vegetation variation (e.g., structure, biomass) within a forest (Whitmore, 1998). A list of the strata used in this analysis can be found in Figure 2 below.

	Forest Cover	Forest Cover Density
1)	Piñon-Juniper Woodlands	Low (20 - 45% Canopy Closure)
2)	Piñon-Juniper Woodlands	Medium (46 - 75% Canopy Closure)
3)	Piñon-Juniper Woodlands	High (76 - 100% Canopy Closure)
4)	Mixed Conifer Timberland	Low (20 - 45% Canopy Closure)
5)	Mixed Conifer Timberland	Medium (46 - 75% Canopy Closure)
6)	Mixed Conifer Timberland	High (76 - 100% Canopy Closure)

Figure 2: Environmental Strata

The 48 sample plots were created using a hybrid reconnaissance and stratified random sampling strategy. The stratification of the landscape into sampling area and sampling units will, therefore, be a result of both environmental characterization and imagery interpretation. The majority of the plots were located along road corridors to minimize accessibility concerns.
Field Data Collection

Dahl Environmental Services, LLC applied standard forest mensuration practices during the field cruise to determine volumes and cubic measures for forest trees and biomass. All trees were measured for diameter and height. Diameter estimates were obtained using a diameter tape or Biltmore stick. Diameters were taken at root collar (DRC, just above the swelling at the top of the root collar) for piñon pine and common junipers. Diameters were taken at breast height (DBH, 4 ½ feet above the ground) for all other conifers. Total tree heights were measured using either a clinometer or Biltmore stick. Ocular estimates were made to determine total tree heights for trees generally under 20 feet. Ocular estimates were re-calibrated and validated daily using the clinometer.

The strata were inventoried using 1/20th acre fixed radius plots (26.4 feet diameter). Plot locations were predetermined by NCDC and placed on maps. DES utilized GPS units to locate plot centers. A stake was placed at plot center and a 26.4 foot string was straightened, from the stake, and rotated clockwise from north to determine the plot boundary. All trees within the plot circle were tallied. Trees were recorded by number, species, diameter and total height. All recorded field data was later entered into cruising software programs, either BIOCRUZ or PJCRUZ, to determine tree volumes and cubic measures.

Remote Sensing and GIS Data Collection

Remotely sensed data have long promised to facilitate the mapping and monitoring of vegetation at a landscape scale

(Cihlar, 2000). This goal is becoming realistic with the advent of a new generation of sensors which offer significant improvements in the spatial, spectral, and radiometric properties as well as in optics and signal-to-noise ratio of data. High spatial resolution allows for location while high spectral resolution allows identification of features. Recent work with high resolution images have demonstrated the possibility of extracting the location of individual tree crowns from 2 foot multispectral data to produce image maps representing stem densities and crown cover densities.

Conventional methods of vegetation analysis involve identifying species, life-forms, structure (vertical stratification), abundance, basal area, volume, and biomass (Fuller et al. 1998, Garrity and Khan 1994) and require a large number of samples. For large areas, this can be time consuming and require a significant budget for conducting sufficient field surveys. Yet, conventional methods do not have the advantage of the spectral characteristics of remotely sensed data for extrapolation of themes mapped at one location to other similar areas elsewhere. Further, the data gathered through conventional techniques are not inherently spatial, but are brought to spatial mode through geospatial statistics that often fail to capture much of the spatial variability (Isaaks and Srivastava 1989).

With the launch of the QuickBird satellite and subsequent availability of QuickBird imagery in high-resolution, multispectral 11-bit data, remote sensing was ushered into a new era. Other new generation sensors such as Landsat-7 ETM+ have slightly coarser spatial resolution (30 meter) but have more spectral bands than QuickBird. The QuickBird characteristics provide an opportunity for capturing quantitative parameters of floristic changes across small topographic gradients at a very fine spatial resolution to capture spectra from individual units such as a tree crown. The ETM+ captures data in wider number of spectral bands that include the mid infrared portion of the spectrum. This enables possibilities of better spectral relationships with characteristics such as forest cover type. Thereby, an opportunity now exists for the development of more refined vegetation mapping of forest landscapes taking single tree species or homogeneous monocultures of few trees as a unit rather than using heterogeneous landscape units as themes of vegetation, land cover, or land use.

Rules and Constraints

There is a distinct difference in total biomass versus available biomass. There are several constraints that decrease the number of acres available for biomass. These constraints include, but are not limited to:

1)   Inventoried Roadless Areas
   a)   where road construction and reconstruction is prohibited

2)   Special Designated Areas
   a)   NWA = National Wilderness Area
   b)   NPA = National Primitive Area
   c)   NSRA = National Scenic Research Area
   d)   NSA = National Scenic Area
   e)   NWSR = National Wild and Scenic River
   f)   NRA = National Recreation Area
   g)   NGRWP = National Game Refuge and Wildlife Preserve
   h)   NM = National Monument

   i)   NVM = National Volcanic Monument
   j)   NHA = National Historic Area
   k)   WSA = Wilderness Study Area
   l)   RNA = Research Natural Area
   m)   OCD = Other Congressionally Designated Areas

3)   Slope Exclusion Zones
   a)   Defined as areas of greater than 30% slope

These constraints have been modelled in a GIS environment for use in this study.

4. METHODOLOGY

Because of the size of the study area, data available from the USFS Forest Inventory Analysis (FIA) Data Retrieval System describing potentially harvestable forests are not spatially specific and are only accurate on a larger scale than is required for evaluating biomass supply for a power plant. Even if the data were accurate at this scale, there would still be little information as to where the biomass was located. This project was aimed at developing a system to correlate field-based plot biomass estimates with forest biotic parameters obtained through multiple-resolution remote sensing techniques to provide a more robust methodology to estimate biomass. First, plot data was entered into the PJCRUZ or BIOCRUZ spreadsheets, as appropriate, to determine cubic volume which is then converted to dry weight. Figure 3 illustrates the process of converting plot data to dry weight.
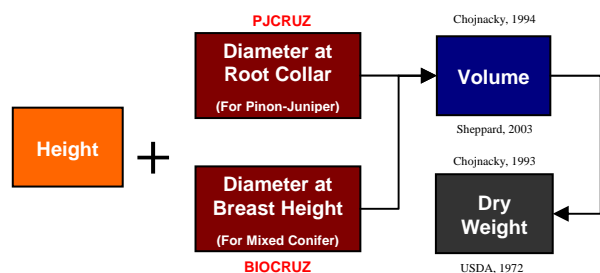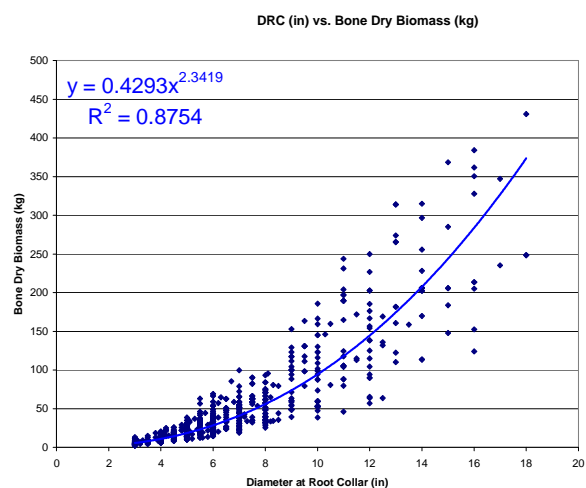

Figure 3: Field Biomass Calculations

Second, the plot-based estimates are used to create a scatter plot with diameter on the x-axis and dry biomass on the y-axis, see Figure 4 below.

Pinon-Juniper Woodlands

DRC (in) vs. Bone Dry Biomass (kg)

$y = 0.4293x^{2.3419}$

$R^2 = 0.8754$

Mixed Conifer Timberland

DBH (in) vs. Bone Dry Biomass (kg)
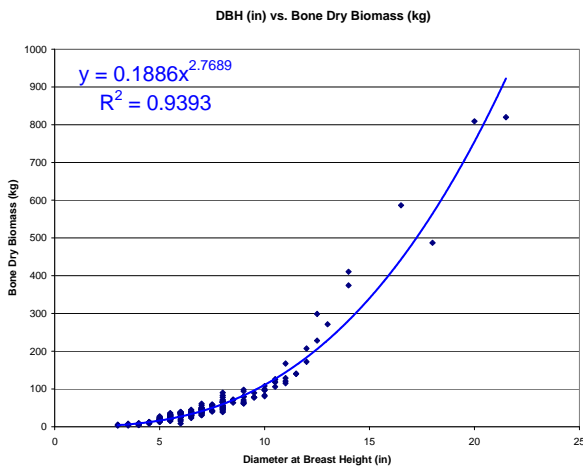

$$y = 0.1886x^{2.7689}$$
$$R^2 = 0.9393$$

Figure 4: Plot-Based Biomass Regression Curves – Diameter vs. Dry Biomass

Next, spreadsheets for each stratum were created which summarized the average crown size, number of acres of total timber, and number of trees for each strata polygon. A strata polygon is a singular, non-adjacent shape that has the same forest cover type and topography. Using the strata polygon data and composite crown cover (from the QuickBird imagery), crown widths were determined using the equation for the area of a circle. The crown widths were then used to calculate diameter using a non-linear model (Shaw, 2005). These diameters can then be used in conjunction with the regression equations created earlier to compute a dry weight.
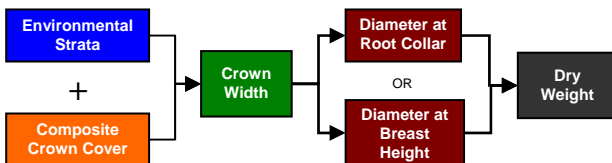

Figure 5: Image Biomass Calculations

Finally, average biomass densities summarized by strata using the high resolution data (QuickBird) are used to calculate the biomass of similar homogeneous areas (strata) in the medium resolution data (Landsat).
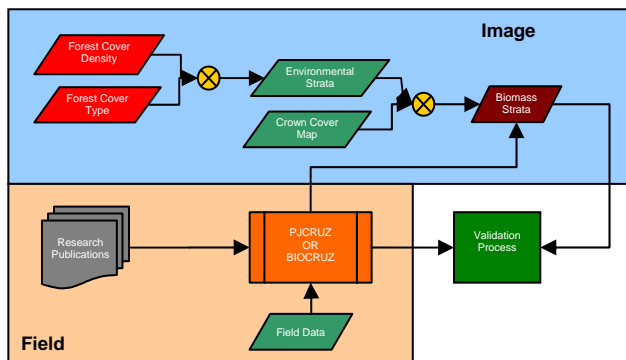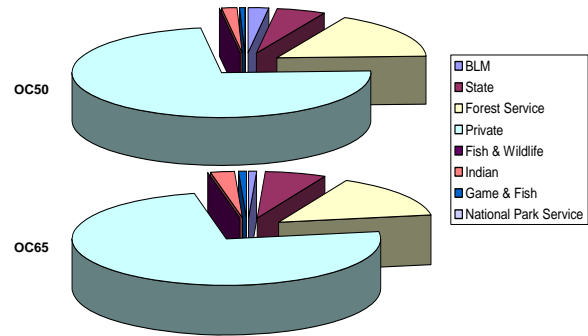

Figure 6: Process Overview

5. RESULTS & DISCUSSION

Biomass Summary

The total available, non-prescribed biomass for this site is 19.8 and 32.2 Million bone dry tons, 50 and 65-mile radius respectively.. In Figure 7, the biomass is summarized by availability and land ownership.

AOI Radius	50 Miles		65 Miles	
	Dry Biomass in Tons			
TOTAL	33,371,241		53,148,529	
AVAILABLE	19,870,437		32,250,240	
Land Owner	**Total**	**Available**	**Total**	**Available**
BLM	505,368	132,285	1,116,272	625,895
State	1,658,849	1,301,097	2,214,617	1,764,197
Forest Service	9,558,694	3,393,252	15,976,199	5,975,689
Private	19,791,218	14,354,016	31,883,906	23,144,294
Fish & Wildlife	2,637	2,617	12,111	9,676
Indian	1,300,711	516,953	1,380,338	556,018
Game & Fish	553,765	170,217	554,658	170,568
National Park Service	--	--	10,429	3,903

Figure 7: Summary of dry biomass by availability and ownership

Data Validation

Comparing field biomass estimates directly to image biomass estimates serves as an important indication of overall methodology accuracy and bias. As can be seen in Figure 9, the image biomass estimate is no more than 10 to 15% lower than the amount of biomass estimated using conventional field methods.

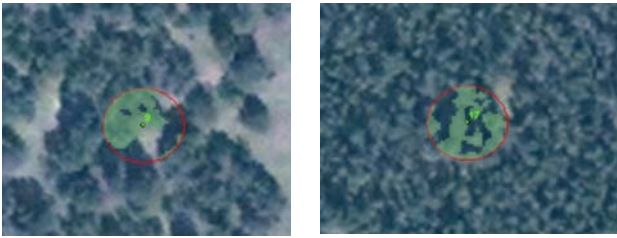| Dry Weight (tons per plot)			
Plot ID	Field Biomass	Image Biomass	Conservative Bias
9	1.51	1.35	(0.16)
14	1.56	1.45	(0.11)
17	2.08	1.95	(0.13)

Figure 8: Field to Image Data Validation

Sources of Conservative Bias

During the course of this project, several simplifying assumptions were made to enhance the conservative nature of these estimates. Below is a list of the sources of conservative bias sorted by stage:

Field :
- 1.5" Minimum Branch Diameter
- Multiple stem at root collar treated as individual trees

QuickBird:
- < 0.005 acre individual tree threshold based on maximum stem sizes observed in the field

Using the results of the data validation and the statistical basis of the sampling design, we estimate that the overall biomass estimates are within 10% of the actual biomass.

6. REFERENCES

Chojnacky, David C.; Moisen, Gretchen G. 1993. Converting Wood Volume to Biomass for Piñon and Juniper. Res. Note INT-411. Ogden, UT:U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 5 p.

Chojnacky, David C. 1994. Volume Equations for New Mexico's Piñon-Juniper Dryland Forests. Res. Pap. INT-471. Ogden, UT:U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 10 p.

Cihlar, J. 2000. Land Cover Mapping Of Large Areas from Satellites: Status and Research Priorities. Int. J. Remote Sens. 21, 1093-1114.

Fuller, R.M., Groom, G.B., Mugisha, S., Ipulet, P., Pomeroy, D., Katende, A., Bailey, R., Ogutu-Ohwaya, R. 1998. The integration of field survey and remote sensing for biodiversity assessment: A case study in the tropical forests and wetlands of Sango Bay, Uganda. Bio. Conserv. 86, 379-391.

Garrity, D.P., Khan, A. 1994. Alternatives to slash-and-burn: a global initiative. Summary report of a research methodology workshop, 25 February to 8 march 1993 Bogor, west Java and Sitiung West Sumatra, Indonesia, International Centre for Research in Agroforestry, Nairobi, Kenya.

Grier, C.C.; Elliot K.J. and McCullough, D.G. 1992. Biomass Distribution and Productivity of Pinus Edulis-Juniperus Monosperma Woodlands of North-Central Arizona. For. Ecol. Manage. 50: 331-350.

Jenkins, Jennifer C.; Chojnacky, David C.; Heath, Linda S.; Birdsey, Richard A. 2004. Comprehensive Database Of Diameter-based Biomass Regressions For North American Tree Species. Gen. Tech. Rep. NE-319. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 45 p. [1 CD-ROM].

San Souci, Jason W. 2005. PJCRUZ Software. Colorado Springs, CO: Native Communities Development Corporation.

Shaw, John D. 2005. Remote Sensing Optimized Crown Width to Diameter Prediction Model. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Sheppard, Wayne. 2003. BIOCRUZ Software. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.