

LIDAR Based Delineation in Forest Stands

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1. Introduction

Forestry has been undergoing a shift from traditional forest measurement techniques, and field work to the use of remotely sensed data beyond aerial photography and analysis in Geographic Information Systems (GIS) for the last several decades. New applications of technologies such as Light Detection and Ranging (LIDAR) have begun to change the direction of how companies, agencies and consulting firms approach forest management questions. LIDAR has provided information about terrain and earth surfaces for many years, but the use of this three dimensional data for forest management and inventory applications is still developing. However, “increasing costs of field surveys, coupled with ever-increasing demands for collection of both timely and more detailed information, are directing resource professionals to consider significant changes in their approaches to forest assessments”(Evans et al. 2004) which has put LIDAR at the leading edge of this change.

A push toward deriving forest inventory and delineation of stands from remotely-sensed data has been investigated for many years. A great body of research is available investigating the use of various types of imagery to derive forest characteristics. Much of this research focuses on the use of high-resolution imagery to identify individual tree crowns and derive forest inventory information (Leckie et al. 2003, Gougeon, 1995, Brandtberg & Walter 1998). The delineation of stands as a secondary step after crown delineation has also been explored with high-resolution imagery (Gougeon 1997, Gougeon & Leckie 2003). Other research has directly addressed the goal of stand delineation with high resolution imagery (Warnick et al. 2006, Van Coillie 2006). The use of satellite imagery such as Ikonos-2 and Landsat- TM for stand characterization has also been explored (Bergen et al 2000, Green 2000, Waring & Running 1999). However, this research has limited applicability to operational-level processes and methods due to the complexity and costs associated with acquisition and processing of imagery.

In recent years, LIDAR has been a focus of research for forestry and land management applications. While this type of sensor has been used for terrain mapping applications for 10-15 years (Reutebuch et al. 2003), it is still a relatively new technology in forestry. The majority of research has been focused on measuring individual tree parameters and producing stand summaries (Andersen 2003, Holmgren & Persson 2004, Naesset & Okland 2002). Less attention has been given to practical, operational-level uses of LIDAR data.

The next step in this process is to investigate the use of LIDAR at the operational level to replace traditional field and aerial photography based inventories. This research looks at the first step in a process leading to LIDAR based forest inventory. The central focus of this project was to develop a procedure to delineate forest stands with LIDAR and was funded by the Oregon Bureau of Land Management.

The Bureau of Land Management (BLM) is interested in the use of LIDAR to achieve their mandate of “sustaining the health, diversity, and productivity of the public lands for the use and enjoyment of present and future generations” (BLM website, 2008, About the BLM). Part of this mandate is to continue to develop more effective land management practices and improve efficiency as well (BLM website, 2008, About the BLM). The BLM is facing the task of managing large areas of forest land in conjunction with aging inventory data, and reduced staffing levels due to retirement. To meet the requirements of their operational mandate, the BLM would like to develop a method that will allow them to respond to this challenge in a timely and effective way. The final objective for the BLM will be to derive forest inventory metrics necessary for forest management from LIDAR data.

The method developed for this research is the first step towards an LIDAR-based inventory system and will allow for a timelier and dynamic generation of forest stand information. Forest stands are the base unit of inventory and management practices, and

provide essential information for planning. Therefore, delineation of forest stands prior to developing a procedure for forest inventory is an important first step.

This method will not only be of use to the BLM, but any agency, company or consultant looking to develop a more efficient way to delineate and analyze forest stands. An important advantage to this method is that it can be employed every time a LIDAR mission is flown and will provide a more effective means to track landscape level changes over time. This method is also flexible and additional information layers can be added as LIDAR research progresses.

2. Background

2.1 Importance of stand delineation

Forest stand delineation is an integral process in forest inventory and forest management. The idea of what constitutes a “forest stand” is dependent on the landowner and their particular operational goals. In general, stands can be defined as a “contiguous group of trees sufficiently uniform in species composition, arrangement of age classes, site quality and condition to be a distinguishable unit” (Smith et al. 1997). Stands are the operational unit at which forest managers make silvicultural decisions, and perform financial analysis. Forest stands are the base unit of inventory and management practices, and provide essential information for planning. Inventories rely on the stand unit to record and store forest conditions, track treatments and project future growth and structural changes. Stands also provide the basic unit of analysis when examining landscape level conditions for ecological and habitat considerations.

Stand delineation has always been a subjective process dictated by the needs of the company, agency or organization that is managing the land (Paine 1981). Franklin (2001), describes current methods of stand mapping as follows “it seems increasingly obvious that the rules of forest mapping as practiced over the past few decades are not particularly logical at all, but are strongly dependant on the skill of the analyst, the local nature of the forest condition, and cultural tradition in the particular jurisdiction responsible for fulfilling demands for forest information.” Parameters that are considered in defining stands vary based on this principle as well. Depending on the management goals of the agency, company or organization the definition of what is a stand can vary greatly (Smith et al. 1997). Common parameters considered in stand delineation include trees per acre (tpa), basal area (BA), percent cover, stand volume, average height, age and species composition (Smith & Anson 1968, Smelser & Patterson 1975, Avery 1978).

2.2 Existing methods for stand delineation

Methods for delineating forest stands are based off of photogrammetric techniques utilizing aerial photography of the land ownership. Many of these techniques date back to post World War II and are continued to be used (Sisam 1947, Spurr 1948). Stand delineation with aerial photographs requires an analyst with formal training in photogrammetry and extensive coverage of ownership with aerial photographs. The specific techniques for stand delineation change depending on the parameters the landowner wishes to use for the delineation. Techniques for determining these parameters are well documented in several manuals that have been published by the USDA Forest Service and other agencies (Smelser & Patteson 1975). While many companies and agencies have access to image processing software, the accuracy of current methods are still expected to be about 80% to 90% and these accuracies depend greatly on the skill of the analyst, quality of data and tools used in the process (Terry Curtis, pers. comm., WA State Dept. of Natural Resources, July, 1, 2008).

While stand delineation from aerial photographs is the accepted practice in the forest industry, it is widely recognized that there are significant limitations to this approach. Accuracy of the stand delineation is a primary concern of this process and can lead to severe economic impacts for the landowner (Naesset 1999). In addition to concerns about accuracy, this process can be costly in time and resources, can deliver inconsistent results, may not be reproducible and often does not deliver the detail or accuracy of results needed for management (Chubey et al. 2006). Franklin (2001) also mentions that “classification and mapping are always done for some purpose; it is that purpose, and the skill of the analyst, which exert perhaps the strongest influence on the accuracy and utility of the final products.” Even with such criticism, a more reliable method that covers large scale areas has not been adopted by the forest industry in general.

2.3 Overview of airborne laser scanners (LIDAR)

Airborne laser scanning systems also known as Light Detection and Ranging (LIDAR) sensors are used in this research. These systems are active sensors that emit a laser pulse and record the information about the pulse as it returns to the sensor (Wehr & Lohr 1999). The aircraft carrying the sensor is equipped with a highly accurate “position and orientation system (POS), realized by an integrated differential GPS (DGPS) and an inertial measurement unit (IMU)” (Wehr & Lohr 1999). This allows for accurate spatial reference of the collected returns. Currently, LIDAR sensor manufacturers report errors for height measurement of approximately .15m to .20 m and range errors of .05 m to .15 m (Baltsavias 1999b). The returns from the laser pulse come back to the sensor and provide measurements in the form of three dimensional point data, with highly accurate positional coordinates. These data points collectively are referred to as “point clouds” and it is these point clouds that are used in analysis.

2.4 LIDAR in forest management applications

The primary use of LIDAR has been for the mapping of terrain in both forested and non-forested areas (Reutebuch et al., 2003). The use of LIDAR-derived Digital Elevation Models (DEM) has been demonstrated in a number of cases and has been applied to operational and harvest plans (Schiess & Krogstad 2003, Schiess 2005). In these cases, LIDAR derived products have been applied to harvest and road design for improved efficiency in operational planning. Other uses for LIDAR at the operational level are starting to emerge in the realm of forest inventory and landscape analysis. The use of LIDAR in applications other than terrain modeling in forest management is still in the developmental stages and remains in an active research area.

In recent years, the idea of using LIDAR for forest inventory and structure measurement has been under investigation. Techniques for measuring both individual tree attributes and plot level forest structure measurement have been investigated and are continuing to be developed (Reutebuch et al. 2005). Efforts in LIDAR research are now focusing on assessing stand data and individual tree parameters. Recent work shows the use of LIDAR to define canopy structure through a computer graphic approach (Kato et al. 2006, Kato et al. 2007) which is an important factor in operational activities, fire modeling and habitat assessment. Other research has examined LIDAR derived tree parameters in relation to cable logging systems (Kato & Schiess 2006) and critical forest parameters for fire behavior modeling (Riaño et al. 2003).

A focus in current research is investigating the use of LIDAR for plot level measurements of forests. The work relating to this topic has demonstrated that LIDAR has a comparable or better accuracy for certain measurements than field or photo interpretation techniques. Individual tree height has been the most common metric to be derived from LIDAR data and the accuracy has been well documented in the literature (Holmgren 2004, Naesset 2004, Andersen et al. 2006, Maltamo et al. 2006). Other individual tree measurements include canopy height and bulk for fire modeling (Andersen et al. 2005) and stem

volumes (Holmgren et al. 2003). Research into individual tree species has also been investigated and produced results of varying success (Brandtberg 2007).

Stand level measurements from LIDAR data have been extensively studied in the past decade. Naesset (1997) states that “the current study has shown that laser scanner data may be used to obtain estimates of forest stand heights with an accuracy equal to, or even higher than, those provided by present inventory methods based on aerial photo interpretation.” Measures of vegetation height, cover and canopy structure have also been shown to be accurately derived from LIDAR data (Lefsky et al. 2002). Stand level measurements of height, canopy closure, basal area and volume were investigated by Means et al. (2000) and concluded that “empirical relationships can be developed that have significant potential for predicting important stand characteristics.” Other work also explores the use of LIDAR to predict stand level estimates of timber volume and basal area (Magnusson 2006).

Other research has looked at LIDAR in conjunction or compared with aerial photographs. One study investigates the use of LIDAR and aerial photographs together to produce estimates for timber volume, bare earth models and canopy modeling (Suarez et al. 2005). This study demonstrated how coupling of the two technologies could produce more accurate results for estimated parameters. In a study conducted in 1999 by Baltsavias, aerial photographs and LIDAR were compared for use in forest mapping and terrain modeling. The results of the study showed that LIDAR had a clear advantage over aerial photography in mapping applications but had a disadvantage in cost per acre flown (Baltsavias 1999a). A cost-plus-loss analysis of photo inventories and LIDAR inventories was performed by Eid et al. (2004) and examined basal area, dominant height and trees per hectare. The cost-plus-loss analysis method also took into account the cost associated with the errors of miscalculation of future harvests based on errors in the inventory. The results show that LIDAR generally produces a more accurate estimate of these factors at a lower cost (Eid et al. 2004).

This body of previous research has begun the process of moving toward a functional, operational level forest inventory procedure using LIDAR data. However, these prior investigations do not address the specific objectives of this project and therefore there is still a demonstrated need for research into the use of LIDAR as an operational tool in forest inventory. In two studies examining the use of LIDAR for forest inventory, stand delineation was performed using aerial photography techniques to determine the various stand classes and design a sampling procedure (Naesset 2004b, Eid et al. 2004) These papers also demonstrate the cost lost to inefficiencies in inventories done with photo interpretation techniques:

“The costs applied in the present study reflect fairly well the cost structure in the Nordic market around the year 2000. In photo-interpretation, approximately 60% of the costs are related to labor-intensive operations, such as stereoscopic measurement and image interpretation. This is the core of forest inventory using aerial photography, and with a tendency towards increased costs for manual labor seen in general, it is reasonable to expect a gradual increase in costs for photo-interpretation over time. In the method based on laser scanning, approximately 50% of the total costs are related to laser scanning and laser data processing. These costs are expected to decrease as the capacity of laser scanning systems increases. With increased capacity, the required flying time to cover a given area with laser data of a certain sampling density decreases” (Eid et al. 2004).

2.5 Object orientated image classification for land cover classification

The classification method used in this research is called object-oriented image classification. Object-oriented image classification is a technique that was developed for classifying images into user-defined classes (Blaschke et al. 2000). This classification method works with image objects (aggregates of pixels), rather than on a pixel-by-pixel basis used in traditional image classification techniques (Chubey et al. 2006). This classification technique was chosen over pixel-by-pixel classification because it incorporates the spatial relation among pixels and their neighbors to segment the image (Camara 1996).

A software package is used to segment and classify images. Segmentation of objects is based on user defined parameters. Classification is then accomplished by training the software program with a sample of objects that meet the specifications of the user defined classes. This training procedure usually utilizes “training sites” that often consist of field verified examples of the classes. Once the training is complete, the software package then classifies the image based on the training objects. These classifications can be adjusted through refinements in training procedures and hierarchal classifications that consider classes incrementally. The final result is a map of the various classes that can be used for a variety of purposes. One of the most common uses for this technique is to classify land cover types for mapping, change detection or monitoring programs.

In the case of this project, this classification technique is used in a slightly different way. The images that are segmented for this research are generated from LIDAR point clouds and then converted to raster images to be used in the classification software package. Generally, images used in this type of classification are collected from passive optical or hyperspectral instruments and do not require information to be extracted before they are used in the software package. A recent study by Antonarakis et al. (2008) explored a similar technique of deriving information from LIDAR data and rasterizing the information for image classification of land cover types around river meanders in France. This paper reported overall classification accuracies of 94% and 95%, their method

utilized low density LIDAR data (~1.9 returns per square meter) and hierarchical classification techniques. While this study has similarities to the research presented in this project, there are important differences between the end goals of the studies and the classification techniques used. This project utilizes a higher density LIDAR data set (~ 4 returns per square meter) and does not use a hierarchal classification method. Also, the end goal is to classify forest stands, rather than land cover types.

3. Objectives

The primary goal of this project is to develop a process that will generate data to improve the BLM's current forest management practices. To meet the requirements of their operational mandate, the BLM would like to develop methods and practices that will allow them to respond to this challenge in a timely and effective way. Recent research suggests that the tools to meet this mandate are available, but have yet to be applied to practical methods for operations in large scale, North American forest ownerships. This project begins the development process for these methods.

The specific objective of this project will be to develop a method to delineate forest stands using LIDAR data and evaluate the accuracy of the results. An important component of this project is to develop a method that will be repeatable with a variety of forest types and datasets. This will serve as the basis for future work by the BLM to extract inventory parameters from LIDAR data.

4. Methods

4.1 Blue Ridge study site

The field site chosen for this project was the Blue Ridge site in Capitol Forest west of Olympia, Washington. The Blue Ridge site was chosen based on location, forest type and availability of LIDAR data, plot measurements and aerial photographs. Figure 1 is an aerial photograph of the study site taken in 1999. This site is representative of the forest type managed by the BLM in Oregon and provided a variety of stand conditions. The site has been covered with two high density LIDAR flights allowing for grid cell derivations as detailed as 2 feet, as well as established survey control points and plot locations.

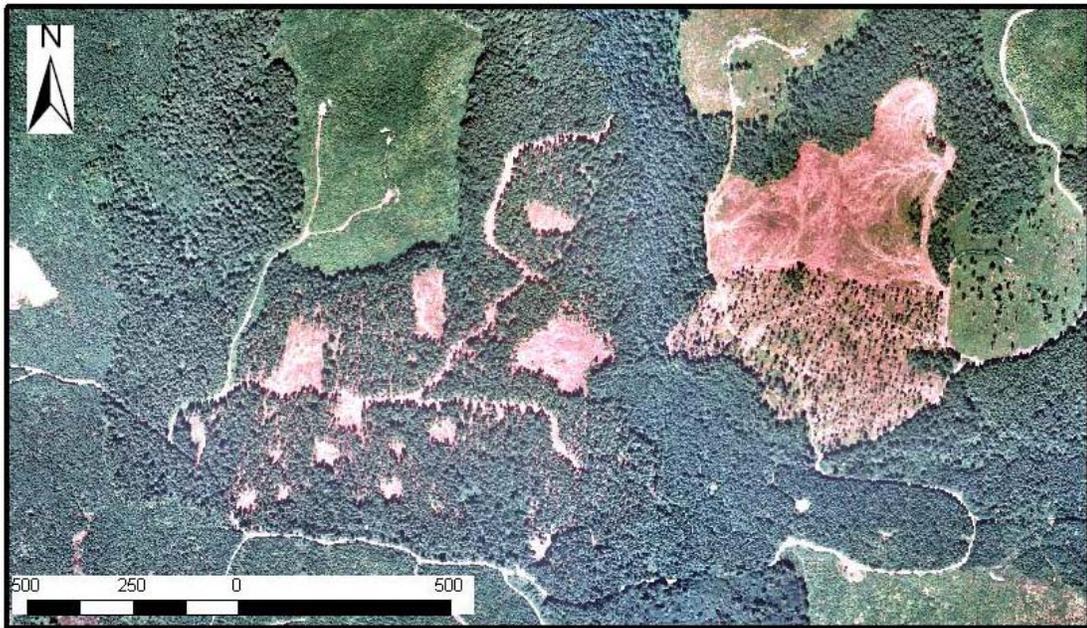


Figure 1 – Study Site.

Blue Ridge Study site located in the Capitol State Forest west of Olympia, WA. This photograph was taken in 1999 and orthorectified. The study area has a variety of silvicultural treatments including clearcuts, patchcuts, group selection and thinning. This study site also has several of stand conditions representative of forests in Western Oregon and Washington. Map units are in meters.

4.2 LIDAR Data

LIDAR data for the study area was acquired in 1999 and 2003 with a high density airborne sensor. Two datasets allowed for comparison of consistency of the method. The

two LIDAR datasets are similar in the point densities per square meter and in leaf-off conditions. The table 1 outlines the specifications for the datasets.

Table 1- Specifications for LIDAR acquisitions of the Blue Ridge study site.
From (Andersen et al. 2005).

Acquisition Parameters	1999	2003
Acquisition Date	March	August
Laser Scanner	Saab Topeye	Terrapoint ALTMS
Flying Height	200 m	900 m
Laser Pulse density	3.1pulses/m ²	4.9 pulses/m ²
Max. returns per pulse	4	4
Platform	Helicopter	Fixed-wing aircraft

4.3 Plot information

As part of another study conducted by the Pacific Northwest Research Station of the USDA Forest Service, plot locations were established in the study site. The measurements on the plots are described in detail in “Silvicultural Options for Young-Growth Douglas-Fir Forests: The Capitol Forest Study - Establishment and First Results” (Curtis et al. 2004). The plots were measured in both 1999 and 2003 to correspond to the LIDAR flights. The classes for this project were determined by the available plot data for the site. To define the individual classes, information about trees per acre (tpa), average diameter of the 40-largest (by dbh) per acre (D40), average height of the 40-largest (by dbh) per acre (H40) were used. Species information not included as it is not available from LIDAR data at this time. The classes were broad classifications of forest stand types. It is expected that the classes will change based on the management practices of the landowner and forest types present. Table 2 below, describes these classifications. Each of the plots has a surveyed, spatially-accurate location. Therefore, plots that met class descriptions could be used as guides for training after the image was segmented.

Table 2- Description of stand classes.

This table shows criteria used to create the stand classes. The plot information contains a minimum trees per acre (TPA min) and a maximum trees per acre (TPA Max) for each class. Information measured in inches about the minimum diameter at breast height of the forty largest trees (D40 Min) and maximum value for the diameter at breast height of the forty largest trees (D40 Max). The final criteria was the minimum and maximum values for the heights of the forty largest trees by diameter (H40 min and H40 Max) for each class measured in feet.

Stand Type/Class	Plot Values					
	TPA Min	TPA Max	D40 Min (in)	D40 Max (in)	H40 Min (ft)	H40 Max (ft)
Mature	50	210	26.7	31.2	141.2	152
Thinned	15	20	21.9	24.1	134	150.3
Intermediate	355	755	4.6	7.1	45.6	49.2
Young 1	no data	no data	no data	no data	no data	no data
Young 2	222	533	4.7	4.7	26.75	29.9
Clearcut/ Road	0	0	0	0	0	0

4.4 Software

This study utilizes three software packages to perform the analysis. These programs were chosen based on accessibility and cost of the software packages. A brief description of each program is included in this section, a more detailed description of the programs are contained in Appendix 1.

FUSION - Is a free software developed by the USDA Forest Service Pacific Northwest Research Station and distributed by the USDA Forest Service Remote Sensing Applications Center (McGaughey, R. J. 2007). This software package was chosen as the data preparation tool due to its public availability and access. It is also based on non proprietary algorithms and methods that allow for user adjustment and the processes that are used are documented in publicly available literature. FUSION uses the bare earth model and raw LIDAR points to generate the final stem density, percent cover and average height raster files.

ESRI ArcMap- This Geographical Information System (GIS) is the most commonly used GIS package and is the GIS package used by the Oregon BLM. A recent study of GIS users from GISjobs.com reported that 78% of the respondents used ESRI products in their work (User survey, 2008). This demonstrates the popularity and availability of the

ESRI products and why this software was chosen for this research. ArcMap is used primarily as a viewing tool for data after it has been created.

SPRING- This program was developed by Brazil's National Institute for Space Research and is available as a free download (Camara et al. 1996). This software provides a tool to perform object oriented image segmentation, training of the segmentation and final classification. The output from this program is a shapefile that can be viewed in ESRI ArcMap or other GIS programs.

4.5 Data Preparation

The choice of the metrics used in this analysis was based on a literature review of forest inventory and photointerpretation manuals. Percent cover, stem density and average height are common forest stand metrics used to delineate stands (Franklin 2001, Spurr 1948, Smelser & Patterson 1975). In addition to their use in traditional forest mapping procedures, these parameters were chosen because they can be derived reliably from LIDAR data using FUSION. Although previous studies have shown the potential for using LIDAR intensity and structural information to classify species types (Holmgren & Persson 2004), individual tree species cannot be reliably and consistently derived from LIDAR datasets, and therefore was not included in this study. In the future, the addition of species or intensity information could be added as additional data layers.

The data preparation for our method is described in the flow chart in figure 2. The flow chart describes the steps and processes used to create raster layers for input into SPRING. Appendix 1 provides a detailed, step-by-step description of the tools used to produce these layers in FUSION. The purpose of this section is to briefly outline the technical details and reasoning behind the steps used in data preparation.

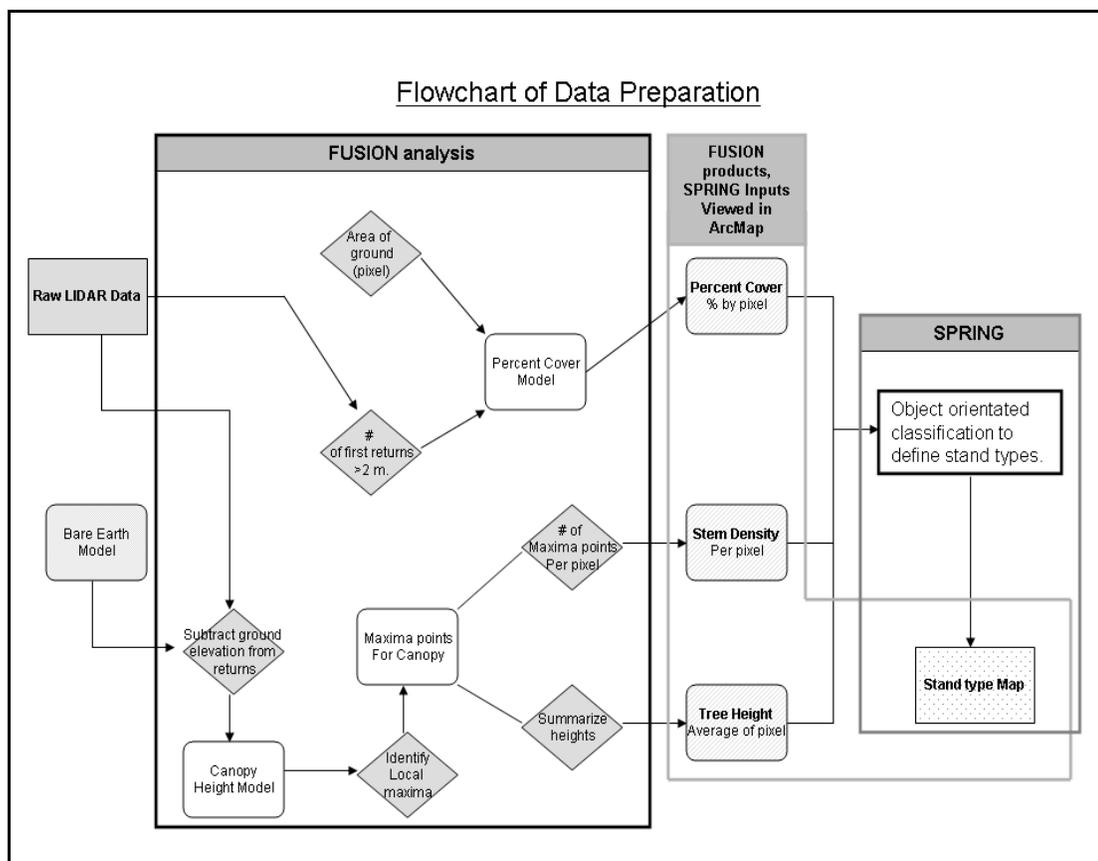


Figure 2- Flowchart of data preparation and analysis.

The data preparation and analysis is divided into two main steps. The bulk of the analysis is done within the FUSION software package and the resulting raster datasets (percent cover, stem density, average tree height) are then used in the SPRING software package to perform the image segmentation and classification. The raster datasets and output from the SPRING classification are viewed using ESRI ArcMap. The raw LIDAR point cloud is used in the first two steps of the data processing. To create the percent cover raster dataset, the cover tool in FUSION is used that calculates the number of points above a height specification divided by the total number of points in the cell (McGaughey, R.J., 2007). The raw LIDAR points along with the bare earth model are used to create the canopy height model which is the intermediate layer required for the canopy maxima tool. The canopy maxima tool creates a list of canopy maxima points which is the dataset used to derive the remaining raster datasets, stem density and average height. A detailed description of the data preparation process is described in Appendix 1.

Percent Cover – This raster dataset is created with the cover tool in FUSION. This tool utilizes the raw LIDAR point cloud and the ground surface model to compute an estimate for canopy closure. The value for this metric is defined as “the number of returns over a specified height threshold divided by the total number of returns within each cell” (McGaughey, 2007). The cell size and height break are specified by the user. The height break parameter used in this analysis 2 meters or approximately 6 feet to capture the

percent cover of the tree canopy and to simulate the height of a field observer's eye to make the measurement comparable to traditional percent cover measurements.

Canopy Height Model – The canopy height model (CHM) is a product of the raw LIDAR points and the bare earth model. The canopy model tool uses a switch to include the bare earth model to subtract the ground elevations from the return elevations. This creates a CHM that allows for comparison of tree heights without the effect of elevation. This is an important difference with the canopy surface model (CSM) which does not account for the effect of elevation in tree height (McGaughey 2007). The CHM is an important intermediate and is the input for the canopy maxima tool.

Canopy Maxima Tool- This tool generates a point layer containing the canopy maxima points within the analysis area. The basic concept behind this tool is to identify the highest LIDAR point within a crown area. The concept and technical details behind the tool used in FUSION can be found in Kini & Popescu (2004). The parameters used in this tool will be highly dependant on each dataset and forest type contained in the dataset and the output does vary significantly depending on the parameters. This tool creates a list of points with X, Y, and Z coordinates that are then used in the following steps to create the final two raster datasets.

Stem Density- The number of canopy maxima points in each pixel is counted and a value for stem density is assigned to the pixel. This count is a relative measure of density between forest stands.

Average Height – The Z coordinates of the point layer created by the canopy maxima tool represent the height of the point above the ground surface. The Z coordinate values for all of the points falling in a pixel are averaged and, this average becomes the value for the pixel or the average height for the pixel.

4.5 Products of data preparation

The results from the data preparation process are raster layers in the GeoTiff format with a pixel size of approximately 8.9916 m by 8.9916 m (29 ft by 29 ft) or about 1/50th acre. The choice of pixel size was based on the conditions present in the test site and standard conventions for forest inventory. The most important consideration for pixel size in this study was to ensure that the pixel size fell in a range that was large enough to include a complete canopy of an individual mature tree and small enough to detect variation of young stands. Examples of the final data layers are shown in figures 3, 4, and 5.

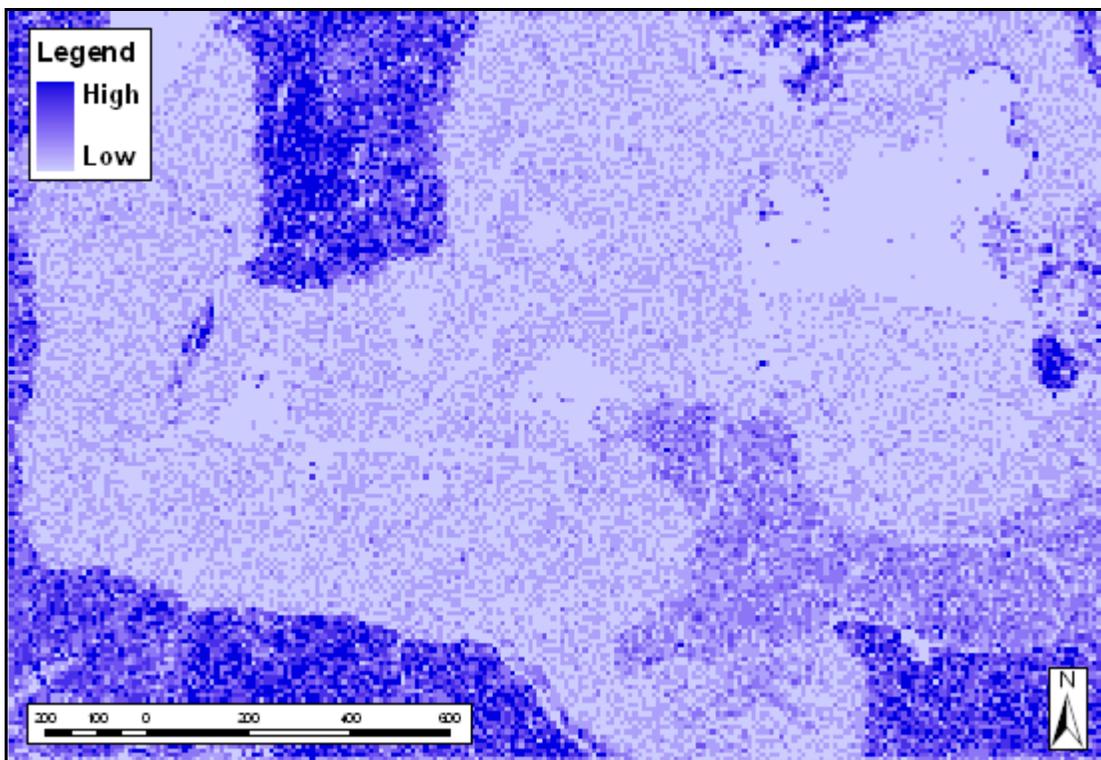


Figure 3- Stem density raster data layer.

Example of the GeoTiff image created for stem density from FUSION. The darker blue represents high stem density and lighter color represents lower stem density. Map units in meters.

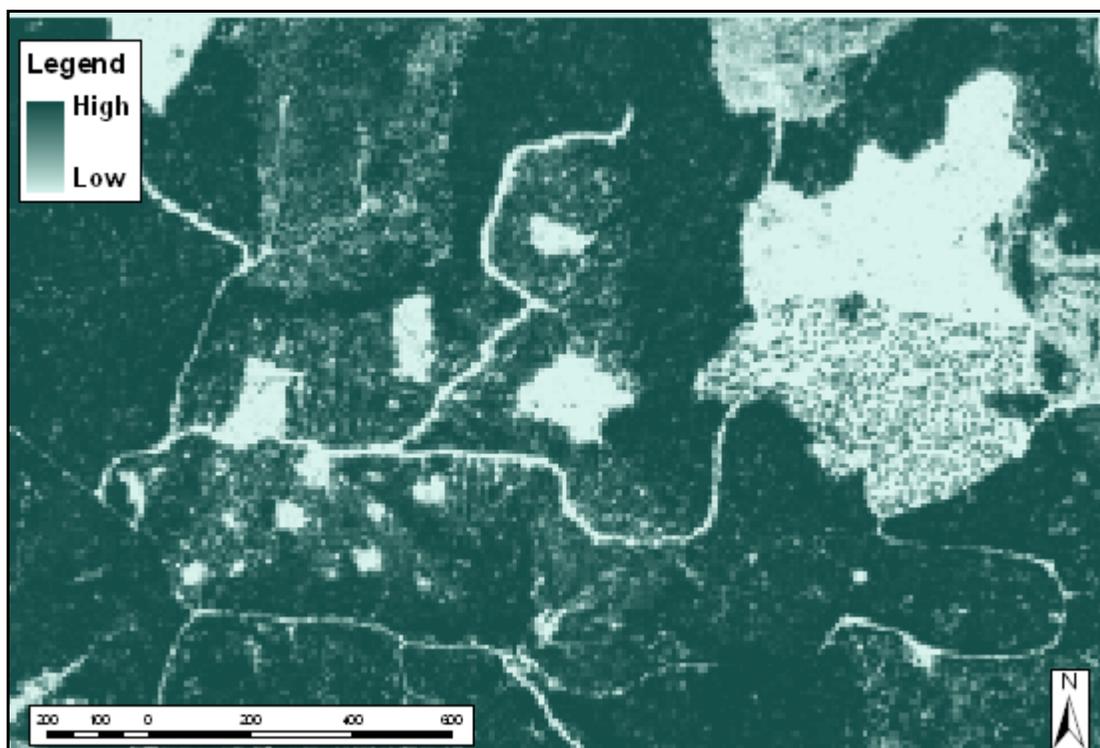


Figure 4- Percent Cover raster data layer.

Example of the percent cover GeoTiff image created from FUSION. The darker green colors represent higher percent cover and lighter green represents lower percent cover. Map units in meters.

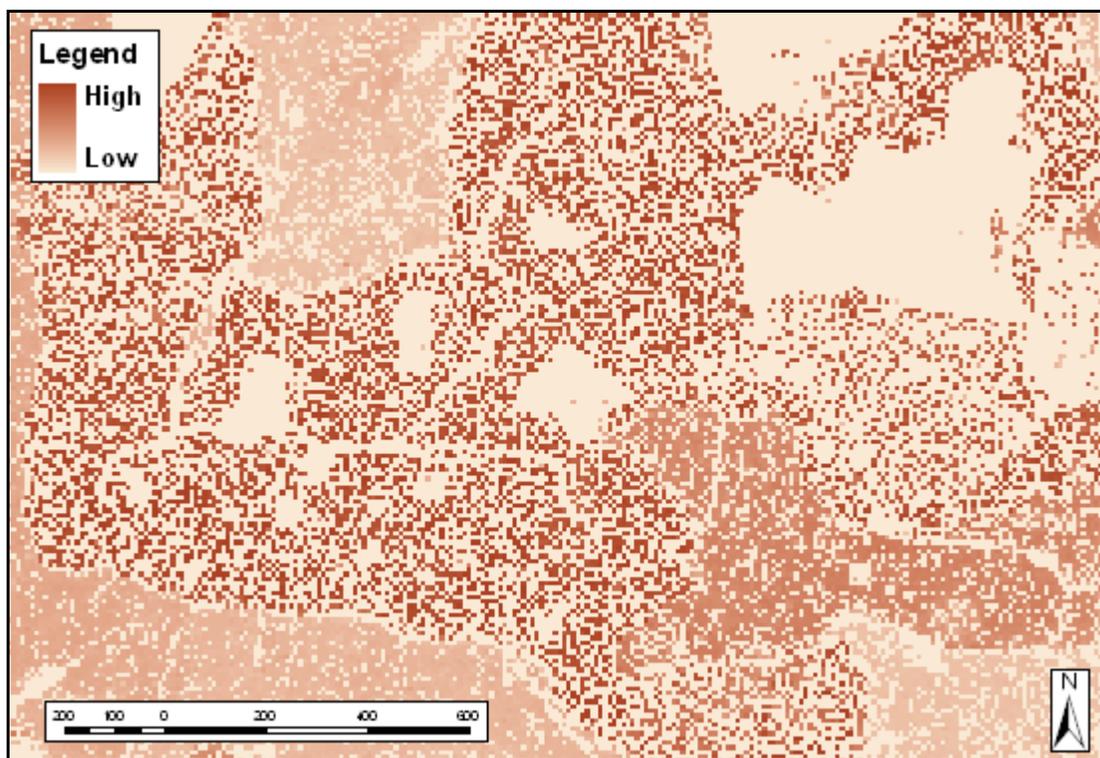


Figure 5-Average Height raster data layer.

Example of the percent cover GeoTiff image created from FUSION. The darker pink colors represent greater average height and lighter pink represents lower average height. Map units in meters.

There are a few important considerations when interpreting these data sets. The first is the measurement of stem density. This data set is meant to provide a measure of the relative difference in stem densities between forest stand types. The process used to create this dataset is the reason for this concern. The step prior to creating the stem density per pixel is to use the canopy maxima tool in FUSION which identifies the apex of individual trees. The number of canopy maxima points is then counted per pixel, giving the value for stem density. The algorithms that are used in this tool have a tendency to work well for one type of forest, but lose accuracy when analyzing multiple forest types. The primary consideration for this dataset becomes accuracy of the stem count as compared to true stem density. However, for this application, the actual number of trees is not the main concern; it is the ability to distinguish the relative difference between the densities of various stand conditions. For example, a mature stand will generally have a lower stem density than a young plantation, the data set reflects this

difference and is therefore still useful in this application even though it is underestimating the true “on the ground” stem densities.

Similar conditions exist for the average height dataset. The goal of this dataset is to detect the differences in height between forest stand classes, not the field accuracy of the metric. It is well documented that LIDAR height measurements generally underestimate the true height of the tree, but not to a significant level to affect operational use (Holmgren 2004, Naesset 2004, Andersen et al. 2006). The percent cover estimation generated in FUSION has been shown to provide accurate data for the study area.

4.6 Object oriented classification

The classification procedure for this project closely follows a tutorial released by the US Department of Fish and Wildlife Service (USFWS). This tutorial provided the basic information about how to use the SPRING program and classification of land cover types. The tutorial is available online through the USFWS and is free to download (Lindsey & Donnelly 2006). While tutorial was used as a guide, there are several differences in the procedure used for this project which are outlined in Appendix 1.

The first step in image classification is to segment the image into objects; this procedure is performed by the software package and produces a visual representation of the objects. SPRING uses two parameters to segment objects. The first is a minimum difference between pixels that determines if neighboring pixels are considered to be the same object and the other is a minimum size of an object. The minimum difference is a Euclidean distance between values in the pixels (Camara, et al., 1996). The minimum size is given in number of pixels, so a value of 10 would prevent the program from creating objects less than 10 pixels.

The segmentation values for this dataset were chosen based on visual inspection of the segmentation and desired scale of the classification. For both datasets a minimum distance of 5 and a minimum size of 10 pixels were chosen after several trials of various

values. These values were chosen because they provided enough detail to identify smaller classes of interest such as roads, and were not too large to lose distinction between similar stand types.

The training phase of the classification process was done with the aid of aerial photographs and plot information. Objects within areas containing plot information were used as the training objects for each class. The segmented images for 1999 and 2003 were trained independently, but an attempt was made to use similar areas in the two datasets. Due to the nature of segmentation, objects will differ between datasets, so use of exactly the same spatial areas was impossible. Once the training was complete, the classification of the image was performed. The final classifications were then exported out of SPRING and brought into ArcMap as shapefiles for accuracy assessment.

4.7 Accuracy assessment

To evaluate the accuracy of the classification, error matrices were generated for each classification. Accuracy assessment using an error matrix is a standard accuracy assessment procedure for image classification (Congalton & Green 1999, Smith et al. 2003, Campbell 2007, Lillesand & Kiefer et al. 2008). From the error matrix accuracies for each class can be calculated as producer's and user's accuracies. Producer's accuracy describes the accuracy by class, of the classification by the classification program. The user's accuracy describes the accuracy a user could expect if they went to a pixel of that classification on the ground.

Another important accuracy assessment is Kappa analysis. This analysis is calculated from the error matrix and is a "discrete multivariate technique used in accuracy assessment for statistically determining if one error matrix is significantly different than another" (Bishop et al. 1975). The Kappa analysis produces a KHAT statistic that is a measure of agreement between the "actual agreement in the error matrix (i.e., the agreement between the remotely sensed classification and the reference data indicated by the major diagonal) and chance agreement indicated by the row and column totals"

(Congalton & Green 1999). The KHAT value allows for comparison of the overall accuracy between different classifications and is a useful tool for evaluating results across dates (Lillesand & Kiefer et al. 2008).

To perform this analysis, a sample of the classified pixels was randomly chosen. A uniform grid of 600 points was generated through the Hawth's Tools extension in ArcMap at a spacing of 75 meters by 75 meters (Beyer, 2004). This grid was overlaid on the classified images; pixels that contained points from the grid were evaluated for accuracy of classification by visual inspection of an ortho-rectified aerial photograph and comparison to plot data where available, the configuration of the grid is shown in figure 6. Pixels with mixed classifications within the pixel were thrown out and not considered in the accuracy assessment. The results of the visual classifications are explained in the following section. From the completed error matrices, a KHAT accuracy value was calculated for each matrix along with the overall accuracy of the matrix, producer's accuracy and user's accuracy of each class (Congalton, R. G. and Green, K. 1999).

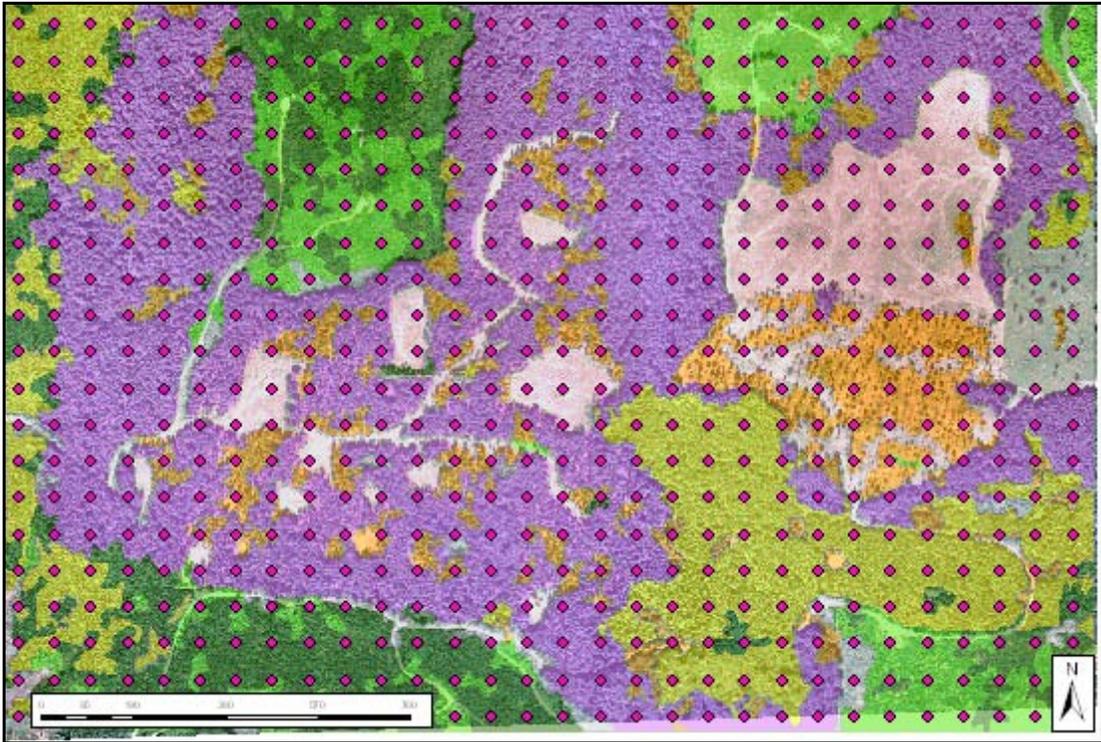


Figure 6- Location of accuracy assessment points.

This map shows the accuracy assessment grid overlaid on the SPRING classification and 1999 orthophotograph. There are 600 accuracy assessment points displayed in light blue circles across the study area. Map units in meters.

To test the significance of the classifications, a Z-statistics was calculated. The Z-statistic was calculated from the KHAT values and their variance. The process used to compute these Z-statistic is described in Congalton & Green (1999) and is a standard process for evaluating image classifications (Smith et al. 2003). The Z-statistic was calculated for both classifications to test if the classification was significantly different than a random classification (Congalton & Green 1999).

5. Results

5.1 Classification results

The final results from this research are stand type maps produced from the classification process. These maps demonstrate the method developed through this project and provide an initial assessment of the accuracy of the method. The results from the classifications are shown in Figure 7 and 8. These results demonstrate the ability of this method to detect changes due to operational activities. The 2003 classification detected a new clear-cut and road in the northwestern corner as well as a new road in southeastern portion of the study site highlighted by the red circles. The ability of this method to detect changes due to operational activities is critical as a tool for harvest tracking and planning. Other important results from the stand maps are the changes observed in forest condition which are reflected in change of classification. The “young 1” classifications progressed to the “young 2” class in many areas, this is most apparent change occurs in the northern unit above the patch cut area. Another progression occurred in the southwestern corner of the study area, the many of the “young 2” classifications progressed to the “intermediate” class.

Other changes between the classifications can be attributed to several sources related to the datasets and methods. While the data layers for each dataset were created using the same method, the LIDAR acquisitions between dates have slight differences that effect final classification. For example, changes in young stands will affect the values for the average height and percent cover data layers more than the older classes since growth rates are much greater in younger stands. It would be expected that the height growth in these young stands will change the metrics enough to give different average height values between dates.

Another factor contributing to the difference between classifications is related to the object-oriented classification method. Objects are created based on the parameters set by the user and the pixel values in the data sets. While the segmentation parameters were the same between datasets, the data layers comprising the datasets for each date are not, thus

creating unique objects for each date. This affects the training procedure as well because the objects are not spatially the same, and slightly different areas are used for training sites. This in turn affects the final classification and explains some of the differences between classifications.

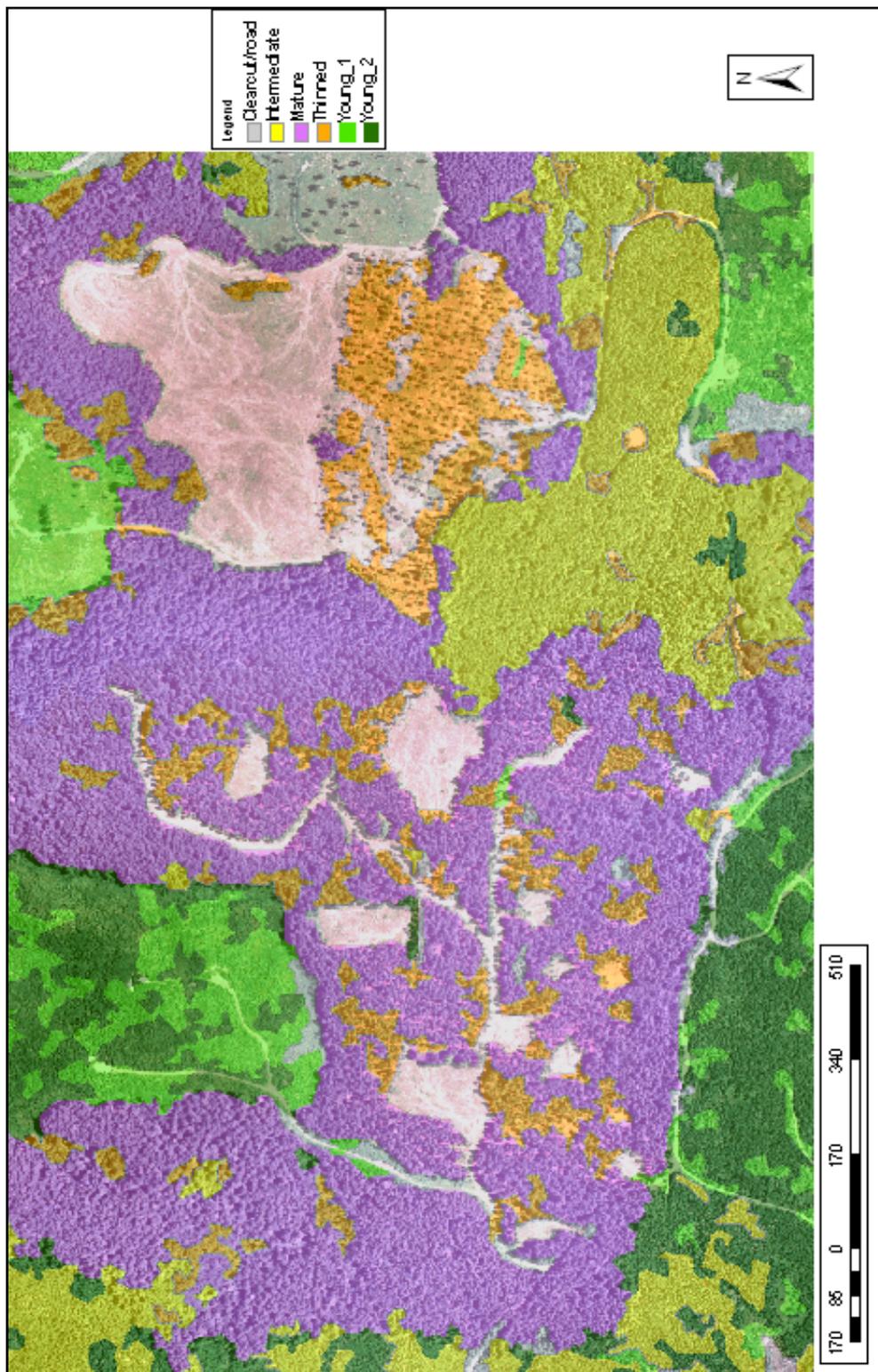


Figure 7-1999 Classification results.

This map depicts the final classification results for the 1999 LIDAR acquisition. The stand map is overlaid on the 1999 orthophotograph. Map units in meters.

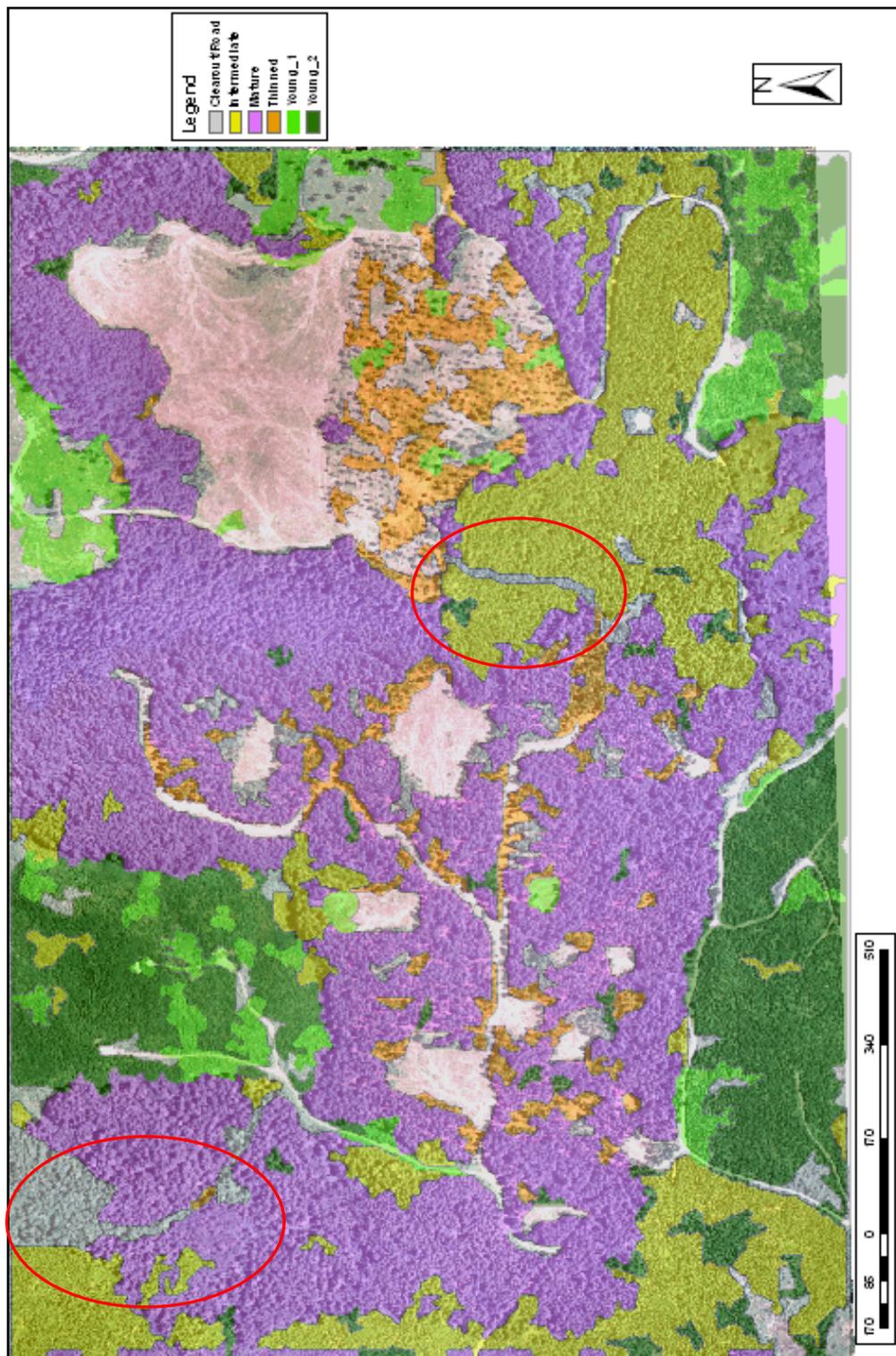


Figure 8- 2003 Classification results.

This map depicts the final classification results for the 2003 LIDAR acquisition. The stand map is overlaid on the 1999 orthophotograph. Areas of new operational activities detected in the classification are circled in red. Map units in meters.

5.2 Accuracy Assessment of Classifications

To perform the accuracy assessment, a sample of the classified pixels were chosen be evaluated. A uniform grid of 600 points was generated through the Hawth's Tools extension in ArcMap (Beyer 2004) at a spacing of 246 ft by 246 ft. This grid was overlaid on the classified images; pixels that contained points from the grid were evaluated for accuracy of classification by visual inspection of the ortho-rectified aerial photograph and comparison to plot data where available. Pixels with mixed classifications within the pixel were not considered in the accuracy assessment. This sample of pixels was used to construct the error matrices for each date. The results of the accuracy assessment process are shown in figures 9 and 10. These figures give a visual representation of the visual classification of each sample pixel in relation to the classification.

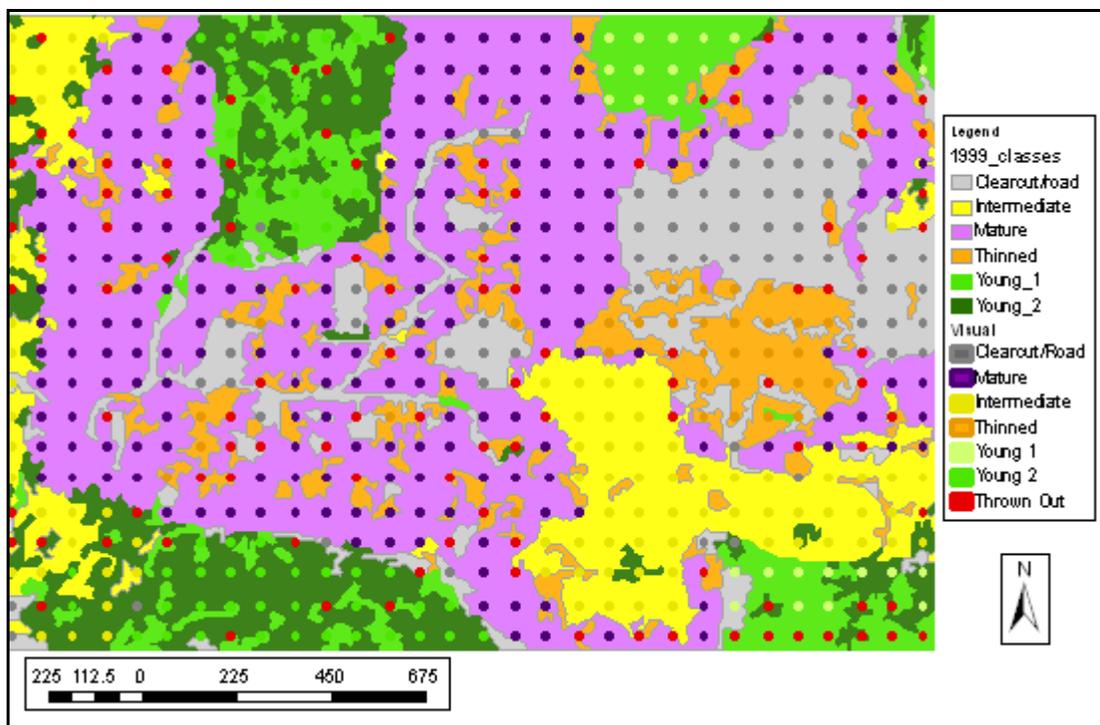


Figure 9-Results of accuracy assessment for 1999 classification.

This map displays the pixels that were used in the accuracy assessment of the 1999 classification. The colored pixels represent the class given from visual classification. The red pixels represent pixels that were not used in the accuracy assessment because they contained more than one class within the pixel. Map units in meters.

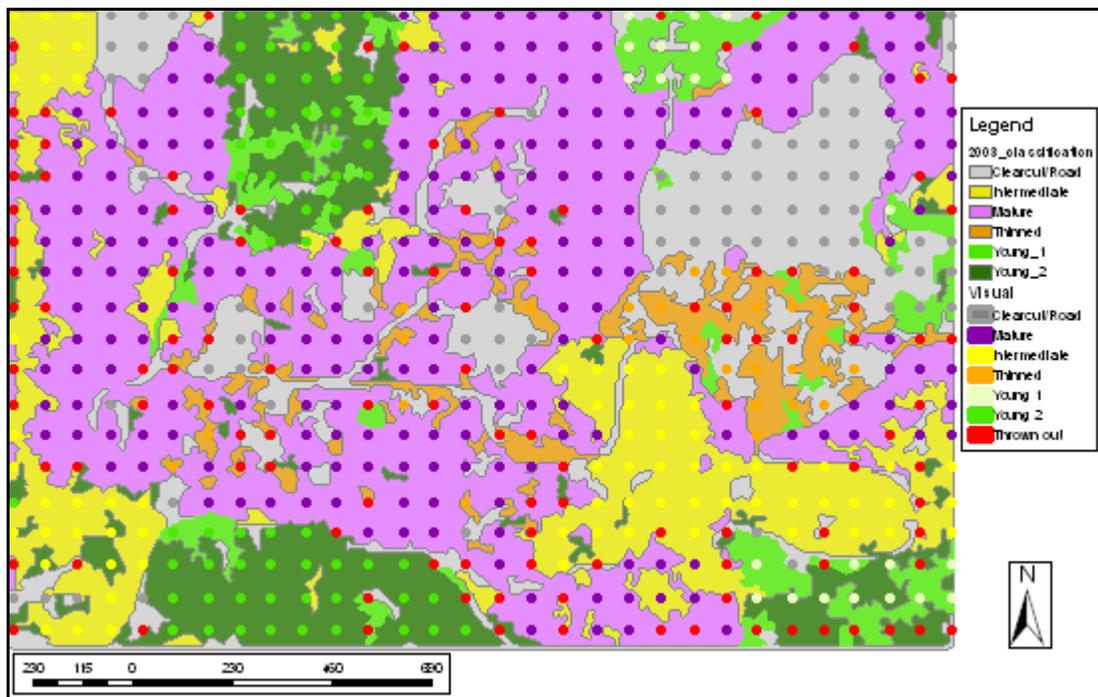


Figure 10-Results of accuracy assessment for 2003 classification.

This map displays the pixels that were used in the accuracy assessment of the 2003 classification. The colored pixels represent the class given from visual classification. The red pixels represent pixels that were not used in the accuracy assessment because they contained more than one class within the pixel. Map units in meters.

The results of the accuracy assessment for both datasets are shown in the following tables. The complete error matrix for the 1999 and 2003 datasets are reported in table 3. The error matrix reports a variety of information about the accuracy of a classification. The columns of the error matrix represent the reference data (visual verification), the rows represent the classification and the major diagonal represented in bold numbers reports the correctly classified sample pixels (Congalton & Green 1999).

Table 3- Blue Ridge classification error matrices.

The error matrix generated from the accuracy assessment process. The error matrix is then used to calculate the producer's accuracy, user's accuracy and KHAT value for the classification. The bold diagonal numbers show the number of correctly classified sample pixels. Table A is the error matrix for the 1999 dataset and table B is for 2003.

A) Error matrix for 1999 classification.

Visual Classification							
SPRING Classification	Mature	Thinned	Intermediate	Young 1	Young 2	Clearcut/road	Row Total
Mature	196	0	0	0	0	0	196
Thinned	16	27	2	0	0	0	45
Intermediate	5	0	66	0	0	1	72
Young 1	0	0	0	17	19	1	37
Young 2	0	0	14	5	43	2	64
Clearcut/road	4	5	1	2	3	62	77
Column Total	221	32	83	24	65	66	491

B) Error matrix for 2003 classification.

Visual Classification							
SPRING Classification	Mature	Thinned	Intermediate	Young 1	Young 2	Clearcut/road	Row Total
Mature	215	0	0	0	0	0	215
Thinned	2	16	0	0	0	0	18
Intermediate	11	0	62	0	2	0	75
Young 1	0	0	0	13	7	5	25
Young 2	2	0	3	5	52	0	62
Clearcut/road	4	8	0	4	0	68	84
Column Total	234	24	65	22	61	73	479

The error matrix is the basis for calculating the producer's accuracies, user's accuracies, KHAT and Z-statistics for each dataset. The producer's accuracy, users accuracy, overall and KHAT value for each dataset are shown in table 4. These accuracy assessments show promising results for the method developed in this research. Current techniques used for forest stand delineation are variable across landowners and are expected to produce accuracies of about 80% to 90%; these accuracies depend greatly on the skill of the

analyst, quality of data and tools used in the process (Terry Curtis, pers. comm., WA State Dept. of Natural Resources, July, 1, 2008). In addition, Landis and Koch (1977) characterize KHAT values greater than 80% as representing strong agreement and KHAT values between 40% and 80% as having moderate agreement. The KHAT value for 1999 is 78.20% and the KHAT value for 2003 is 84.46% which represents a moderate agreement for 1999 and a strong agreement for 2003.

Table 4- Accuracies for Blue Ridge classifications.

This table reports the accuracies and KHAT values for the 1999 and 2003 classifications. Producer's accuracy describes the accuracy by class, of the classification by the classification program. The user's accuracy describes the accuracy a user could expect if they went to a pixel of that classification on the ground. The overall accuracy describes the overall accuracy attributed to the individual classification and the standardized KHAT value allows for comparison of overall accuracies between classifications.

A) 1999 classification accuracies and KHAT values.

Class	Producers	Users
Mature	88.69%	100.00%
Thinned	84.38%	60.00%
Intermediate	79.52%	91.67%
Young 1	70.83%	45.95%
Young 2	66.15%	67.19%
Clearcut/road	93.94%	80.52%
Overall Accuracy		83.71%
KHAT		78.20%
KHAT Variance		0.0001088

B) 2003 classification accuracies and KHAT values.

Class	Producers	Users
Mature	91.88%	100.00%
Thinned	66.67%	88.89%
Intermediate	95.38%	82.67%
Young 1	59.09%	52.00%
Young 2	85.25%	83.87%
Clearcut/road	93.15%	80.95%
Overall Accuracy		88.49%
KHAT		84.46%
KHAT Variance		0.0000878

The final assessment was to calculate a Z-statistic to test if the classifications were significantly different than a random classification. This test is a two-tailed Z-test which assumes infinite degrees of freedom and is tested at the 95% confidence level (Congalton & Green 1999). In this case a Z- statistic value greater than 1.96 proves that the

classification is significantly different than random. The Z-value for 1999 was calculated to be 74.96 and the Z-value for the 2003 classification was 90.13, so both classifications are significantly different than a random classification.

6. Discussion

6.1 Implications for operational use

The intended application of this method is to generate stand type maps to be used in operational level forest planning and management. Therefore, the user's accuracy will impact on the quality and usefulness of the final product. In this section, examples of classes with low user's accuracy will be examined and explained. The first example is the relatively low user's accuracies associated with the "Thinned" class in the 1999 classification. This may be attributed to confusion of open areas within a mature stand. This confusion is apparent from the error matrix; the greatest number of misclassified pixels in the "thinned" were classified as "mature" in the visual classification. While at the pixel level, there is a gap or an obvious lower density of trees, the surrounding stand is "mature" and was visually classified as such. Figure 11 depicts a case where a "thinned" pixel is located in an otherwise "mature" stand.

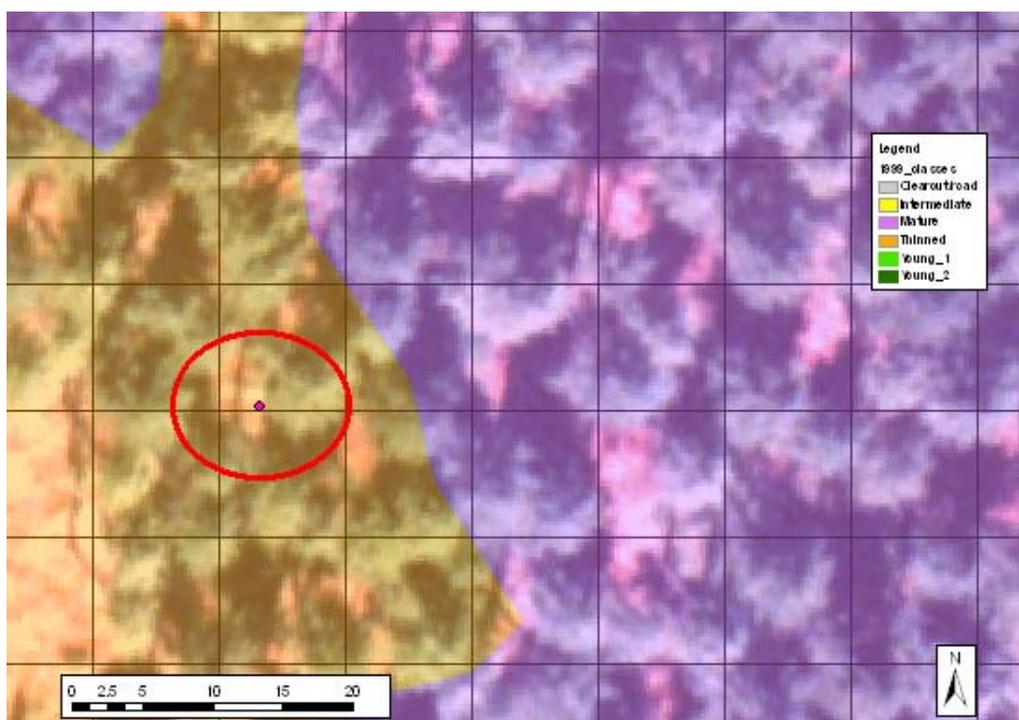


Figure 11-Misclassified pixel, "thinned" class.

This graphic is an example of a condition affecting the accuracy of the "thinned" class in the 1999 classification. The pink dot represents a sample point, and the pixel containing that point was evaluated for accuracy of classification. In this case, the sample point falls in a pixel classified as "thinned" in orange

when it should have been classified as “mature” in purple due to the mature trees and surrounding stand conditions. Map units in meters.

Another factor contributing to the low user’s accuracy of the “thinned” class in the 1999 data is the stand that received a thinning treatment. The low user’s accuracy could result from the adjacent clear cut area and confusion between pixels containing no trees in the thinned area. At the pixel level, the thinned area pixels that do not contain any vegetation and could be classified as either class. However, on a stand level, these pixels present a problem, even if there is no vegetation in the pixels within the thinned area, it should be considered “thinned” rather than “clearcut/road” because of the association with the treatment in that area. Figure 12 below demonstrates the problem of pixels with no vegetation being classified incorrectly in the thinned area.

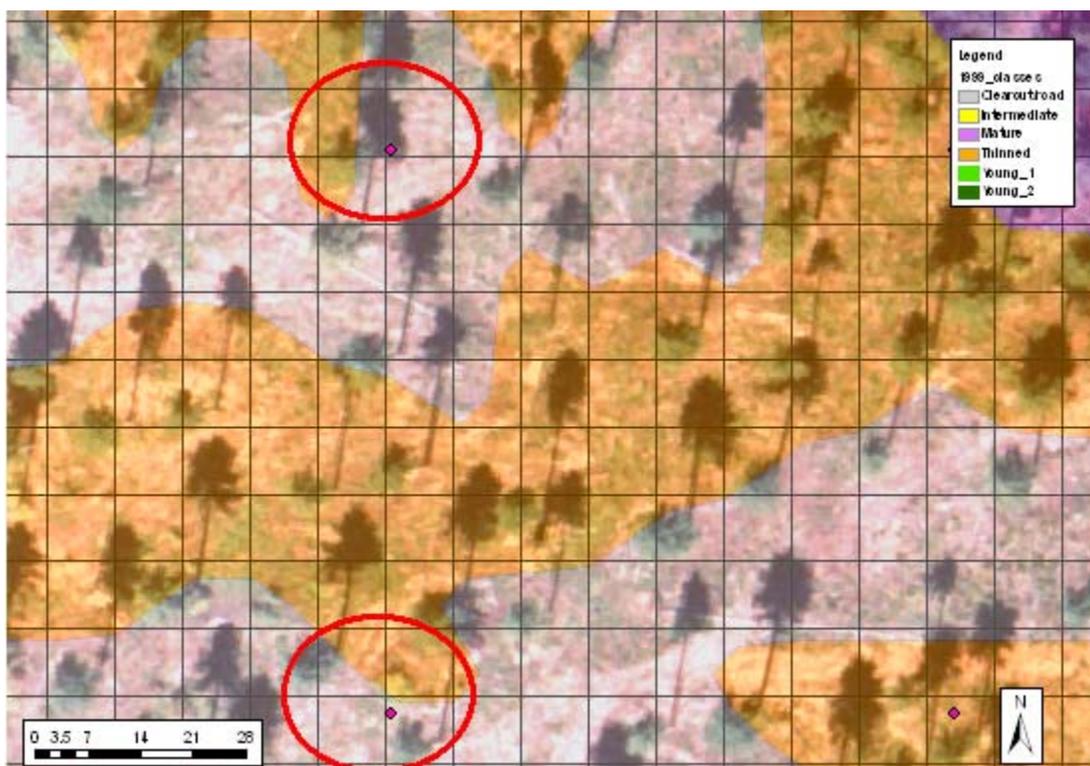


Figure 12- Incorrectly classified pixel in thinned stand.

This graphic describes another factor affecting the accuracy of the “thinned” class in the 1999 data. The pink dot represents a sample point, and the pixels containing a point are evaluated for accuracy of classification. This example depicts the misclassification of a pixel in the thinned stand on the eastern half of the study area as “clearcut/road” denoted by the gray coloring. This example represents an interesting condition as it is not classified incorrectly if it is simply evaluated at the pixel level, it is clear from the orthophotograph that there is no vegetation in the pixel. However, in the greater context, this pixel is misclassified because it is in the center of the thinned treatment block and is not associated with a clear cut or road. Map units in meters.

Another area of low user's accuracy in the 1999 classification is the "young 1" and "young 2" classifications. The confusion between the two classifications is evident from the error matrix, more pixels were classified incorrectly in the "young 1" class than were classified correctly, and almost all of the misclassified pixels should have been "young 2." This confusion between the two classes can be explained by the presence of gaps in areas of both classes and the relative similarity between both of these classes. The scenario that gaps are causing lower accuracy in these classes is shown in figure 13. This area is in the northwestern portion of the study area and is a young stand that should fall in the "young 2" class. However, areas where gaps in the stem density and percent cover exist due to brush pockets or possibly failed seedlings, have been classified as "young 1." This example represents a common problem with the "young 1" and "young 2" classes and greatly affects the user's accuracy of these classes.



Figure 13- Incorrectly classified pixels in "young 2" stand.

This graphic describes the primary factor affecting the accuracy of the "young 1" class in the 1999 data. The pink dot represents a sample point, and the pixel containing that point is evaluated for accuracy of classification. This example depicts the misclassification of pixels in a "young 2" stand, the pixels circled in red are incorrectly classified as "young 1." This is possibly due to the presence of brush pockets, failed

seedlings or other factors. This example represents a common problem with the “young 1” and “young 2” classes and greatly affects the user’s accuracy of these classes. Map units in meters.

The primary source of confusion in the “young 2” classification for the 1999 data is with the “intermediate” class. While the error matrix shows that there were some pixels misclassified in other categories, the greatest numbers of misclassified pixels were with the “intermediate” class. Figure 14 gives an example of this type of misclassification. The cause of this misclassification is possibly due to a slight change in the forest structure causing a reduction in crown cover, or stem density changing the classification.

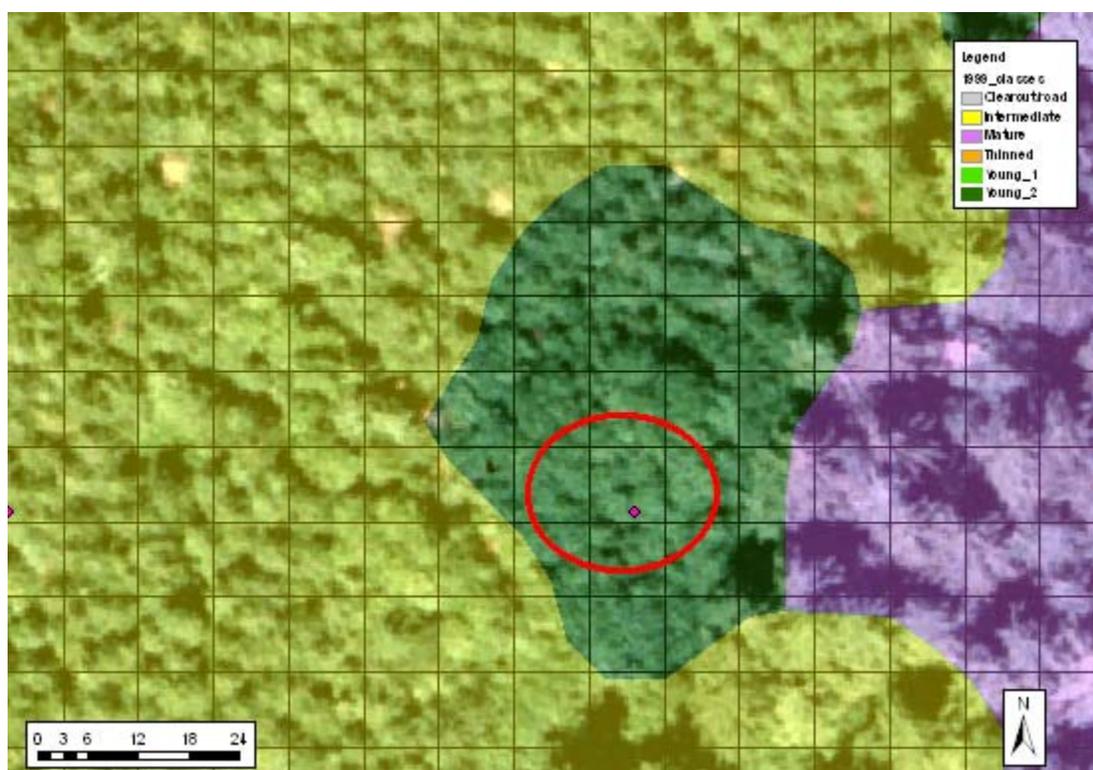


Figure 14- Incorrectly classified pixels in “intermediate” stand.

This graphic describes the primary factor affecting the accuracy of the “young 2” class in the 1999 data. The pink dot represents a sample point, and the pixel containing that point is evaluated for accuracy of classification. This example depicts the misclassification of a pixel in an “intermediate” stand, the pixel circled in red is incorrectly classified as “young 2” possibly due to a slight change in stem density or percent cover. Map units in meters.

A similar scenario exists with the “young 1” class in the 2003 classification. In the case of the 2003 data, there are areas on the edges of clear cuts that are being classified as “young 1” due to the presence of brush and opportunistic vegetation entering these areas.

Figure 15 gives an example of a clear cut area with pockets of “young 1” classification near the edge of the cut and in an area of brush regeneration resulting in a misclassified pixel. Also, the same case with confusion between “young 1” and “young 2” classes exists in the 2003 classification as in the 1999 classification. Areas of lower density, brush or gaps in the “young 2” stands are classified as “young 1” due lower density or height values associated with open areas or brush pockets. These areas may also represent areas of high seedling mortality due to poor planting techniques, overtopping by brush or animal browse.

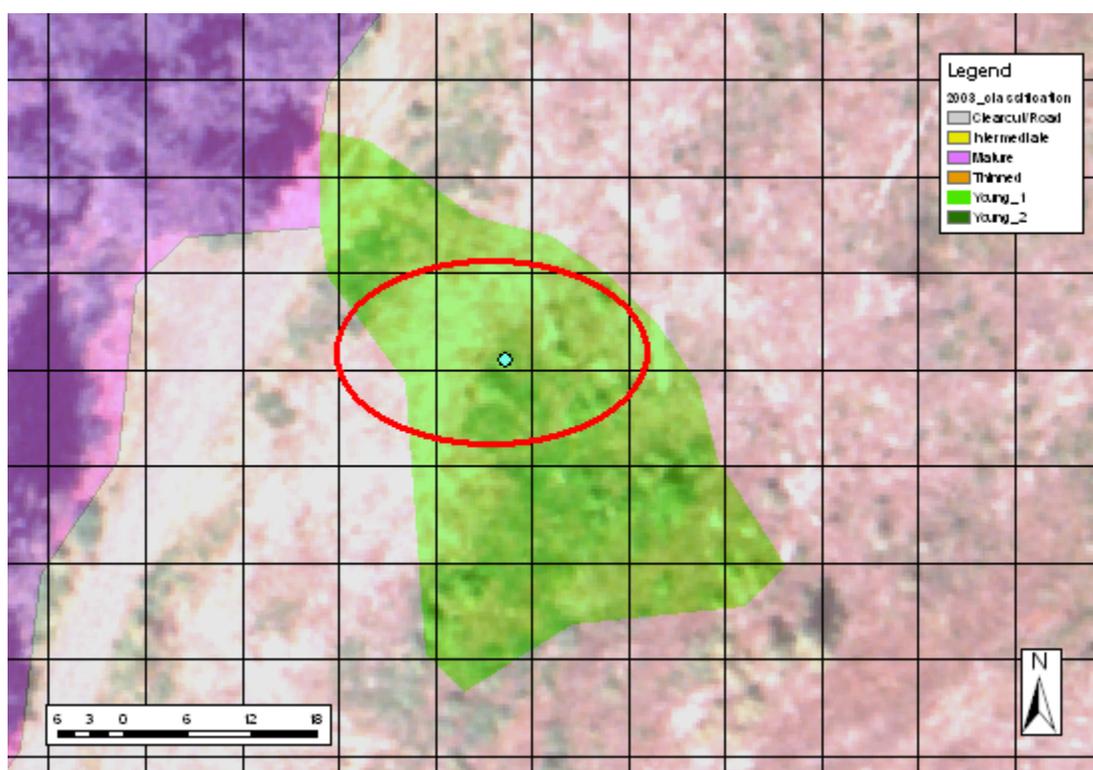


Figure 15- Misclassification in a clear cut.

An example of misclassification of the “young 1” class in the 2003 classification. The blue dot represents a sample point, and the pixel containing that point is evaluated for accuracy of classification. In this example, an area within the large clearcut in the eastern half of the study area is misclassified as “young 1” in light green. This misclassification is likely due to the presence of opportunistic brush growing in the clear-cut. Map units in meters.

The examples listed above are conditions that the users of these stand maps need to consider. This method is not intended to replace local knowledge and field verification, but to provide a tool to generate stand information in less time and with greater or equal

quality than current practices that rely heavily on manual interpretation. Another benefit of this method is that it will help the analyst identify marginal areas that will require additional verification quickly and more easily. Areas with low user's accuracy will vary depending on many factors and will be different for every dataset and forest type. Keeping these potential sources of variability in mind, the user's accuracies listed in this example should be adequate for use by managers and field staff for stand typing for forest inventory design or operational forest planning decision making.

6.2 Method development and repeatability

The primary objective of this project was to develop and test a method for forest stand delineation with LIDAR data. This objective was met through various aspects of this project. The first step to achieving the objectives of this research was to develop the method for stand delineation from LIDAR. The methods described are the products of a development effort that included software choice, development of procedures and desired data products. The second aspect to meeting the stated objectives was to test the methods developed on the Blue Ridge study site and assess the accuracy of the classifications; this was met through the use of an error matrix and reporting accuracies associated with each classification.

The final and most challenging aspect to meeting the objectives of this study was to create a repeatable process for the methods that were developed through this research. This final objective was met through Appendix 1, which serves as a user's manual for the method. Repeatability of this method has not been tested with multiple users. This is the last step in completely meeting the objectives of this research. The testing of this method will be in its operational use for the BLM and other individuals or agencies that have access to this research. It is expected that adjustments and slight changes to the method will occur when it is put into large scale operational use.

6.3 Limitations

The limitations of this method relate to the data extraction and software used in developing the method. The identification of canopy maxima points to derive stem density and average height per pixel is one such limitation. The algorithm used by FUSION to identify canopy maxima points is based on a paper in 2004 by Kini and Popescu and uses a variable window to identify tree crowns and canopy maxima. This is only one of many methods to identify canopy maxima. The method used in FUSION has a known limitation in forests of varying conditions. This problem manifests itself by underestimating canopy maxima points for one forest condition, while producing an acceptable prediction for another forest condition. For example, FUSION will underestimate mature forest canopy maxima points and give a good estimation of young forest conditions or vice versa, but not both.

The identification of canopy maxima points and the known problem with FUSION leads to another challenge with the values of the stem density and average height raster layers. These layers are derived from the information contained in the canopy maxima points, so the underestimation of individual canopy maxima points then underestimates the stem density and average height in the associated data layers. This is a problem when comparing the derived stem density and average height to ground measurements. The method used to segment and classify stand classes does not need to have accurate actual values, but instead accurate relative values between datasets to determine stand classes. This means that it is not important to have the actual tree counts or heights, just that the values in the dataset represent a consistent difference between stand classes.

Another weakness to this method is the choice of the image segmentation and classification package used for analysis. SPRING was chosen due to financial constraints and the relative ease of learning the software. Along with this however, SPRING does not have the full functionality for hierarchical classification available in commercial packages such as eCognition or Feature Analyst. Hierarchical classification allows for classes to be defined in steps rather than through one training exercise. For example,

clear-cuts and roads could be segmented and classified first, then masked and the next class could be segmented and classified and so on. This would allow for a more refined classification and could possibly address some of the misclassifications seen in this research. Another weakness of SPRING is the lack of ability to import shapefiles into the analysis for training. While the tool is present in the program, it did not appear to work, one of the challenges with using an unsupported software package. This tool would have been useful in precisely defining objects that contained plot locations to improve training consistency. Again, commercial packages have the functionality to import shapefiles such as plot locations to assist with training before classification.

The final limitation to consider is the skill of the analyst using this method. The method was designed for an analyst with a strong foundation in GIS, image interpretation, a basic understanding of LIDAR data and knowledge of forest management. Familiarity with local forest conditions, regional silviculture and agency or company management objectives is necessary to appropriately perform this method. Therefore a person or team of people with field experience in the area and a background in geospatial analysis is necessary. It is not unrealistic to expect to find the necessary technical skills and field knowledge within an agency or company to use this method; it may however represent a significant amount of time spent in collaboration or training of an individual to complete the analysis.

7. Recommendations

In the process of designing and implementing this method, a few ideas were generated for expanding and improving this work. The first, as mentioned in the previous section, is to invest in commercial image classification software to increase the functionality available for analysis. This would be most feasible for large companies or agencies that have the financial ability and personnel to dedicate to learning the software. In many cases, large natural resource companies or agencies already own a license for one of these software packages. In the case of smaller agencies or companies looking to use this method, the best choice may be to use SPRING and be aware of the limitations.

One of the limitations of this method is that only one method for identifying canopy maxima was used. Investigation of other methods for identifying canopy maxima and comparing the classification results may provide interesting insight into which methods work best. In addition, these canopy maxima methods should be tried across a variety of forest types and management operations to discover the most appropriate canopy maxima method for various conditions. It is likely that regional or ownership level algorithms will need to be developed to improve upon canopy maxima identification.

The third recommendation involves future research. This method should be tried on a large scale, operational size land area. At the moment, this is limited by access to LIDAR data acquisitions of such ownerships. Large scale acquisitions will have a much greater variety of forest conditions and management operations. Classification classes will have to consider the variation present in an analysis area and the management objectives. In the case of the BLM, the analysis of large scale acquisitions may need to be scaled down to a district or partial district level to produce information useful at the operational level.

The final recommendation is to investigate the addition of other stand parameters into the segmentation and classification. As LIDAR data processing improves, it may be possible to add additional raster layers that will give more information about the stand and

therefore improve the ability to classify stands. Information about species, diameter at breast height (dbh), basal area and height to live crown are common metrics measured in field sampling, but at the moment are not possible to directly measure from LIDAR data. This additional information may allow for more specific descriptions of stands and a finer scale to differentiate stand types.

8. Conclusion

While there has been much research in the use of LIDAR data for forest management measurements, little of this research has focused on the operational use of these methods. With LIDAR acquisitions continuing to become more accessible and moving towards a standard in the forest industry, companies and agencies will be investing in methods to utilize the data. Current stand delineation methods utilizing aerial photograph interpretation have long been criticized for the time, cost and dependency on the interpreter to produce stand maps. Stand metrics necessary to delineate forest stands can now be derived from LIDAR using automated software packages. These metrics can be segmented and classified by an analyst, saving considerable time and cost for the land owner. The method presented is a first step in meeting the goals of the BLM and other agencies and companies looking to move forward with LIDAR as a forest management tool.

Bibliography:

Andersen, H.-E. 2003. *Estimation of critical forest structure metrics through the spatial analysis of airborne laser scanner data*. Ph.D. dissertation. University of Washington, Seattle, WA, USA.

Andersen, H.-E.; Foster, J.R. and S.E Reutebuch. 2003. Estimating forest structure parameters within Fort Lewis Military Reservation using airborne laser scanner (LIDAR) data. In: *Proceedings, 2nd Inter-national Precision Forestry Symposium. Seattle, Washington*. University of Washington, College of Forest Resources: 45-53.

Andersen, H.-E., McGaughey, R.J. and S.E. Reutebuch. 2005. Forest Measurement and Monitoring Using High-Resolution Airborne Lidar. *Productivity of Western Forests: A Forest Products Focus*. C. A. Harrington and S. H. Schoenholtz. Portland, Or, Pacific Northwest Research Station.

Andersen, H.-E., Reutebuch, S.E. and R.J. McGaughey. 2006. A Rigorous Assessment of Tree Height Measurements Obtained Using Airborne Lidar and Conventional Field Methods. *Canadian Journal of Remote Sensing*. 32(5).

Andersen, H.-E., McGaughey, R.J. and S.E. Reutebuch. 2005. Estimating Forest Canopy Fuel Parameters Using Lidar Data. *Remote sensing of the environment*. 94: 441-449.

Antonarakis, A. S., Richards, K.S. and J. Brasington. 2008. Object-based land cover classification using airborne LiDAR. *Remote Sensing of Environment*. (in press).

Avery, T.E. 1978. *Forester's Guide to Aerial Photo Interpretation*. United States Dept. of Agriculture, Forest Service. Washington, D.C.,

Baltsavias, E.P. 1999 a. A Comparison between Photogrammetry and Laser Scanning. *Journal of Photogrammetry and Remote Sensing*. 54(1999): 83-94.

Baltsavias, E.P. 1999 b. Airborne Laser Scanning: Existing Systems and Firms and Other Resources. *Journal of Photogrammetry and Remote Sensing*. 54: 164-198.

Blaschke, T., Lang, S., Lorup, E., Strobl, J. and P. Zeil. 2000. Object-Oriented Image Processing in an Intergrated GIS/Remote Sensing Environment and Perspectives for Environmental Applications. *Umweltinformation Für Planung, Politik Und Öffentlichkeit / Environmental Information for Planning, Politics and the Public*. Verlag. 2: 555-570.

Bergen, K., J. Colwell, and F. Sapio. 2000. Remote sensing and forestry: Collaborative implementation for a new century of forest information solutions, *Journal of Forestry*. 98(6):4-9.

- Bishop, Y., Fienburg, S. and P. Holland. 1975. *Discrete Multivariate Analysis: Theory and Practice*. MIT Press, Cambridge, MA.
- Brandtberg, T., and Walter, F. 1998. Automated delineation of individual tree crowns in high spatial resolution aerial images by multiple-scale analysis. *Machine Vision and Applications*. 11: 64–73.
- Brandtberg, T. 2007. Classifying Individual Tree Species under Leaf-Off and Leaf-on Conditions Using Airborne Lidar. *ISPRS Journal of Photogrammetry & Remote Sensing*. 61: 325-340.
- Bureau of Land Management. 2007. About the BLM. <http://www.blm.gov/or/blmfacts.php> last accessed March 10, 2008.
- Camara, G., Souza, R., Freitas, U. and J. Garrido. 1996. Spring: Integrating Remote Sensing and Gis by Object-Oriented Data Modeling. *Computers and Graphics*. 20(3): 395-403.
- Campbell, J.B. 2007. *Introduction to Remote Sensing*. Guildford Press, New York.
- Chubey, M.S., Franklin, S.E., and M.A. Wulder. 2006. Object based Analysis of Ikonos-2 Imagery for Extraction of Forest Inventory Parameters. *Photogrammetric Engineering and Remote Sensing*. 72 (4): 383-394.
- Congalton, R.G. and K. Green. 1999. *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices*. Lewis Publishers, Boca Raton, FL.
- Curtis, R. O., Marshall, D. D., and D.S. DeBell. 2004. *Silvicultural options for young-growth Douglas-fir forests the Capitol Forest study--establishment and first results*. United States Dept. of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.
- Eid, T., Gobakken, T. and E. Naesset. 2004. Comparing Stand Inventories for Large Areas Based on Photo-Interpretation and Laser Scanning by Means of Cost-Plus-Loss Analyses. *Scandinavian Journal of Forest Research*. 19: 512-523.
- Evans, D., Roberts, S.D. and R.C. Parker. 2004. Lidar – a New Tool for Forest Measurements? Proc. *One forest under two flags, Edmonton, Alberta*.
- Franklin, S. E. 2001. *Remote Sensing For Sustainable Forest Management*. Lewis Publishers, New York.
- Gougeon, F. A. 1995. A crown-following approach to the automatic delineation of individual tree crowns in high spatial resolution aerial images. *Canadian Journal of Remote Sensing*. 21(3): 274– 284.

- Gougeon, F. A. 1997. Recognizing the forest from the trees: individual tree crown delineation, classification and regrouping for inventory purposes. Proc. *Third international airborne remote sensing conference and exhibition, Copenhagen, Denmark*, July 7–10, 1997, vol. II (pp. 807–814).
- Green, K. 2000. Selecting and interpreting high-resolution images, *Journal of Forestry*, 98(6):37–39.
- Holmgren, J. 2004. Prediction of Tree Height, Basal Area and Stem Volume in Forest Stands Using Airborne Laser Scanning. *Scandinavian Journal of Forest Research*. 19(6): 543-553.
- Holmgren, J., Nilsson, M. and Olsson, H. 2003. Estimation of Tree Heights and Stem Volumes on Plots Using Airborne Laser Scanning. *Forest Science*. 49(3).
- Holmgren, J. and Å. Persson. 2004. Identifying species of individual trees using Airborne Laser Scanner. *Remote Sensing of Environment*. 90(4): 415-423.
- Kato, A., Calhoun, D., Schreuder, G.F. and P. Schiess. 2006. Estimating Crown Volume through Implicit Surface Reconstruction from Lidar Points for Forest Fire Simulation. *MAPPs/ASPRS 2006 Specialty Conference, San Antonio, TX*.
- Kato, A. and P. Schiess. 2007. LIDAR Derived Tree Parameters for Optimal Cable Logging System Design. *Proceedings of the International Mountain Logging and 13th Pacific Northwest Skyline Symposium, Corvallis, OR*.
- Kato, A., Schreuder, G.F., Calhoun, D., Schiess, P. and W. Stuetzel. 2007. Digital Surface Model of Tree Canopy Structure from Lidar Data through Implicit Surface Reconstruction. *ASPRS 2007 Annual Conference, Tampa, FL*.
- Kini, A.U. and S.C. Popescu. 2004. Treevaw: A versatile tool for analyzing forest canopy LIDAR data- A preview with an eye towards the future. *2004 ASPRS Images to Decisions: Remote sensing for GIS applications conference, Kansas City, MO*.
- Landis, J. and G. Koch. 1977. The measurement of observer agreement for categorical data. *Biometrics*. 33: 159-174.
- Leckie, D., Gougeon, F., Walsworth, N. and D. Paradine. 2003. Stand delineation and composition estimation using semi-automated individual tree crown analysis. *Remote Sensing of the Environment*. 85: 355–369.
- Lefsky, M.A., Cohen, W.B., Parker, G.G. and D. J. Harding. 2002. Lidar Remote Sensing for Ecosystems Studies. *BioScience*. 52(1).

- Lillesand, T.M., Kiefer, R.W. and J.W. Chipman. 2008. *Remote Sensing and Image Interpretation*. John Wiley & Sons, Hoboken, NJ.
- Lindsey, D. and P. Donnelly. 2006. Vegetation/Habitat Mapping: Object Based Image Classification Using Spring Software. *Spatial Inventory and Monitoring on National Wildlife Refuges*. Accessed from:
<http://www.fws.gov/data/documents/SPRING%20Manual%20022306.pdf>.
- Magnusson, M. 2006. *Evaluation of Remote Sensing Techniques for Estimation of Forest Variables at Stand Level*. Ph.D dissertation. Umea, Swedish University of Agricultural Sciences.
- Maltamo, M., Hyyppa, J. and J. Malinen. 2006. A Comparative Study of the Use of Laser Scanner Data and Field Measurements in the Prediction of Crown Height in Boreal Forests. *Scandinavian Journal of Forest Research*. 21(3): 231-238.
- McGaughey, R. J. 2007. *FUSION/LDV: Software for LIDAR Data Analysis and Visualization*. Electronic Manual, USDA Forest Service. Accessed from:
<http://www.fs.fed.us/eng/rsac/fusion/>
- Means, J.E; Acker, S.A; Fitt, B.J., Renslow, M., Emerson, L. and C.J. Hendrix. 2000. Predicting forest stand characteristics with Airborne Scanning Lidar. *Photogrammetric Engineering & Remote Sensing*. 66 (11): 1367-1371.
- Naesset, E. 1997. Determination of mean tree height of forest stands using airborne laser scanner data. *ISPRS Journal of Photogrammetry & Remote Sensing*. 52: 49-56.
- Naesset, E. 1999. Effects of Delineation Errors in Forest Stand Boundaries on Estimated Area and Timber Volumes. *Scandinavian Journal of Forest Research*. 14(6): 558-566.
- Naesset, E. and T. Okland. 2002. Estimating tree height and tree crown properties using airborne scanning laser in boreal nature reserve. *Remote Sensing of the Environment*. 79:105-115.
- Naesset, E. 2004 a. Accuracy of Forest Inventory Using Airborne Laser Scanning: Evaluating the First Nordic Full-Scale Operational Project. *Scandinavian Journal of Forest Research*. 19(6): 554-557.
- Naesset, E. 2004 b. Practical Large-Scale Forest Stand Inventory Using Small-Footprint Airborne Scanning Laser. *Scandinavian Journal of Forest Research*. 19(2): 164-179.
- Paine, D.P. 1981. *Aerial Photography and Image Interpretation for Resource Management*. John Wiley & Sons, Inc, New York.

- Reutebuch, S.E., Andersen, H.E. and R.J. McGaughey. 2005. Light Detection and Ranging (Lidar): An Emerging Too for Multiple Resource Inventory. *Journal of Forestry*. 103(6): 286-292.
- Reutebuch, S.E., McGaughey, R.J., Andersen, H.-E. and W.W. Carson. 2003. Accuracy of High-Resolution Lidar Terrain Model under a Conifer Forest Canopy. *Canadian Journal of Remote Sensing*. 29(5): 527-535.
- Riaño, D., Meier, E., Allgöer, B., Chuvieco, E. and S.L. Ustin. 2003. Modeling Airborne Laser Scanning Data for the Spatial Generation of Critical Forest Parameters in Fire Behavior Modeling. *Remote Sensing of the Environment*. 86(2): 177-186.
- Schiess, P. 2005. The Application of Spatially Explicit Digital Elevation and Canopy Surface Data for Harvest Planning: Moving from Coarse Digital Elevation Models and Stand Averages to Detailed Ground and Canopy Surface Models in the Design of Forest Transportation Systems. *FORMEC 2005, Innovationen in Der Forsttechnik Durch Wissenschaftliche Kooperation*. University of Ljubljana, Ljubljana, SLO.
- Schiess, P. and F. Krogstad. 2003. Lidar-Based Topographic Maps Improve Agreement between Office-Designed and Field-Verified Road Locations. *26th Annual Meeting of the Council on Forest Engineering, Bar Harbor, Maine*.
- Sisam, J.W.B. 1947. *The Use of Aerial Survey in Forestry and Agriculture*. Imperial Forestry Bureau. Oxford, England.
- Smelser, R.L. and A.W. Patterson. 1975. *Photointerpretation guide for Forest Resource Inventories*. National Aeronautics and Space Administration and U.S. Forest Service.
- Smith, D.M., Larson, B.C., Kelty, M.J. and P.M.S. Ashton. 1997. *The Practice of Silviculture: Applied Forest Ecology*. John Wiley & Sons, Inc, New York.
- Smith, J.H., Wickham, J.D., Stehman, S.V. and L. Yang. 2003. Effects of Landscape Characteristics on Land Cover Class Accuracy. *Remote sensing of the Environment*. 84(3): 342-349.
- Smith, J.T. and A. Anson. 1968. *Manual of Color Aerial Photography*. Falls Church, Va.
- Spurr, S.H. 1948. *Aerial Photographs in Forestry*. The Ronald Press Company.
- Suarez, J.C., Ontiveros, C., Smith, S. and S. Snape. 2005. Use of Airborne Lidar and Aerial Photography in the Estimation of Individual Tree Heights in Forestry. *Computers and Science*. 31: 253-262.

User survey. 2008. Retrieved on February 1, 2008, from GISjobs.com:
<http://www.gisjobs.com/survey/responses.jsp?countryLoc=all&sal=N>

Van Coillie, F.M.B., Verbeke, L. P.C., and R.R. De Wulf. 2006. Semi-automated forest stand delineation using wavelet-based segmentation of very high resolution optical imagery in Flanders, *Belgium. Proc. of 1st International Conference on Object-based Image Analysis (OBIA 2006)*.

Waring, R.H., and S.W. Running, 1999. Remote sensing requirements to drive ecosystem models at the landscape and regional scale. *Integrating Hydrology, Ecosystem Dynamics, and Biogeochemistry in Complex Landscapes* (J.D. Tenhunen and P. Kabat, editors). John Wiley & Sons, Inc, New York.

Warnick, R.M., Brewer, K., Finco, M., Megown, K. Schwind, B., Warbington, R., and J. Barber. 2006. Texture metric comparison of manual forest stand delineation and image segmentation. *Proc. Of Eleventh Biennial Forest Service Remote Sensing Applications conference*. April 24-28, 2006. Salt Lake City, UT.

Wehr, A. and U. Lohr. 1999. Airborne Laser Scanning - an Introduction and Overview. *ISPRS Journal of Photogrammetry & Remote Sensing*. 54: 68-82.

Appendix 1- User's guide for LIDAR based Stand Delineation

About this User's Manual- This manual is designed for use with ArcMap 9.2. There are three additional software packages that can be downloaded for free from the world wide web. This user's manual and required programs are designed for the Windows operating system.

Programs Required:

- ArcMap 9.2
- SPRING 4.x
- FUSION- Current Version
- Hawth's tools

Data:

- The data used in the tutorial is the FUSION example data. It is available for download at <http://forsys.cfr.washington.edu/fusion/fusionlatest.html>
This data is courtesy of Robert J. McGaughey at the Forest Service Pacific Northwest Research Station.
-

Part I - Downloads:

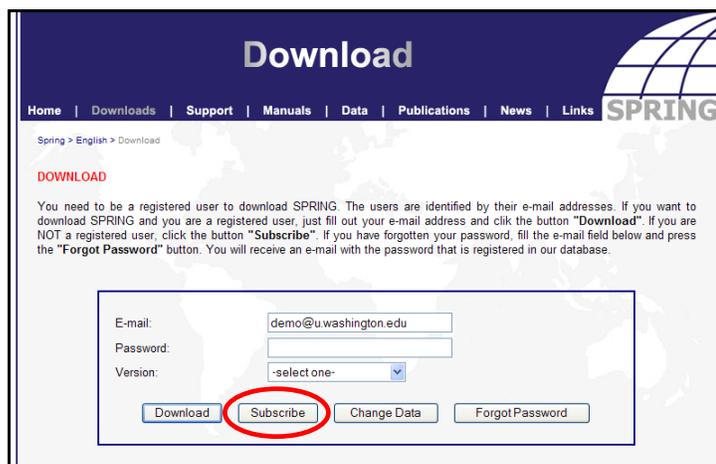
1.1 SPRING- This software was developed by Brazil's National Institute for Space Research as a “a state-of-the-art GIS and remote sensing image processing system with an object-oriented data model which provides for the integration of raster and vector data representations in a single environment.” (SPRING website). SPRING is available for download in English at: <http://www.dpi.inpe.br/spring/english/index.html>.

To set up SPRING on your computer, please follow these steps.

1. Go to <http://www.dpi.inpe.br/spring/english/index.html> and click on the “downloads” tab at the top of the page.



2. On the “Download” page you will be asked to register before you can download the software. Please enter a valid email address and click on the “Subscribe” button.



- 3. The following screen will appear, please fill out the required information and click

- 4. You will now be able to download the current version of SPRING. Go back to the download page and enter your email and password and choose the correct version for your operating system and click “Download.”

5. From this screen choose the “Install.exe” from one of the download sites. Make sure to choose the version in English!

Download

Home | Downloads | Support | Manuals | Data | Publications | News | Links **SPRING**

Spring > English > Download > SPRING 4.3.3 for WINDOWS

WELCOME! Here you can download SPRING 4.3.3 for WINDOWS

SPRING WIN environment is composed by the following programs:

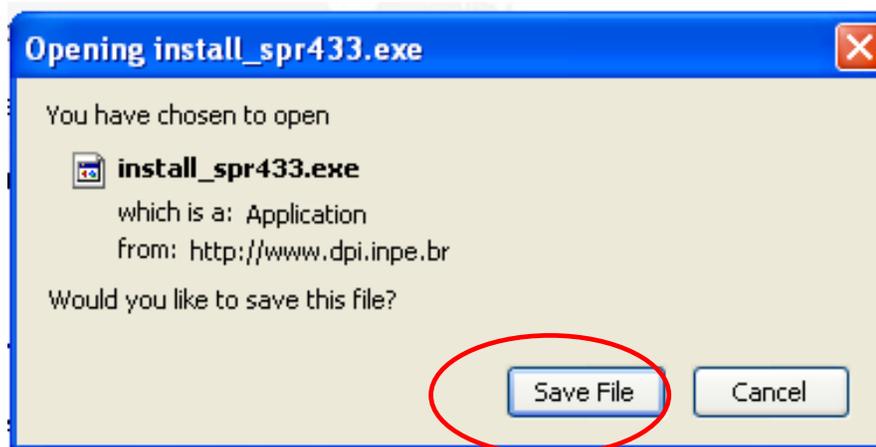
- **Spring** contains Geoprocessing and Image Processing functions.
- **Scarta** is used for interactive map production in IPL format.
- **Impima** is used for reading satellite images in different formats (LTWG, SPOT IMAGE, ERS-1, INPE) from CD-ROM, 8mm and 4 mm tapes besides converting TIFF, RAW e Sitim formats to GRIB.
- **Iplot** developed by TECGRAF - PUC Rio, is useful for reading IPL formatted files and generating output in Postscript format or to send maps to printers and plots.

→ Check the improvements of this new version at [News](#).

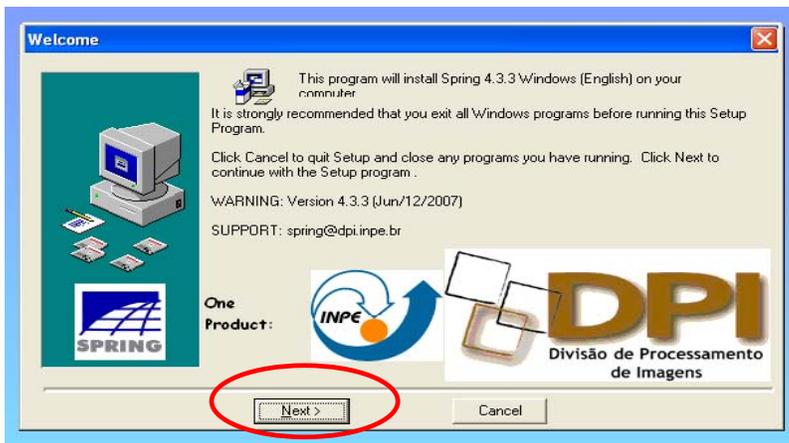
Choose the Site for downloading

4.3.3 - WINDOWS			
Fonte	Português	Espanhol	Inglês
DPI - INPE - Brasil	LEIAME 4.3.3	LEAME 4.3.3	README 4.3.3
	Instala Completo (27.3 MBytes) Opção 1	Instalacion Completo (30.8 MBytes) Opção 1	Install complete (30.8 MBytes) Opção 1

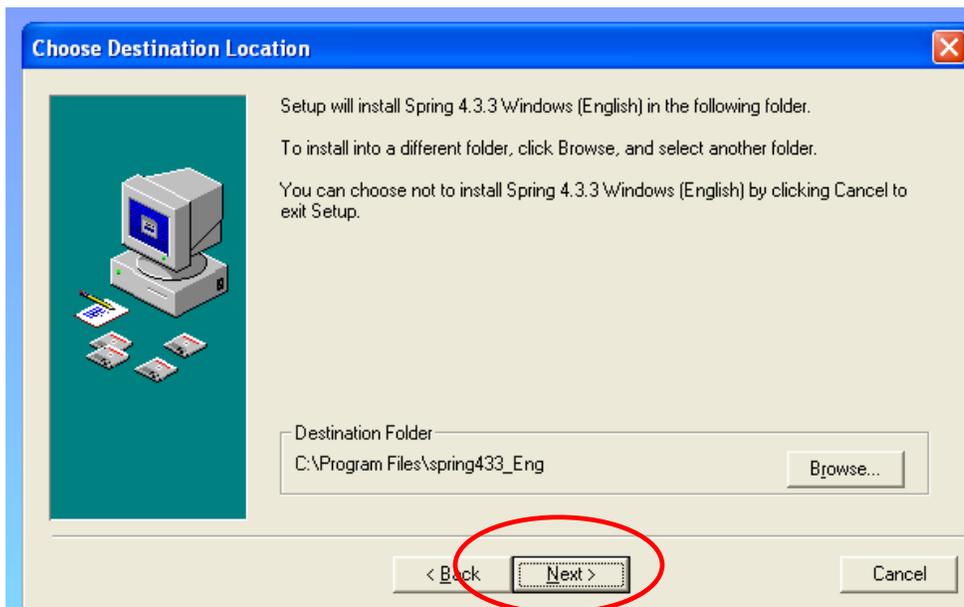
6. Choose to “Save File” and specify where to save the install_spr433.exe file to.



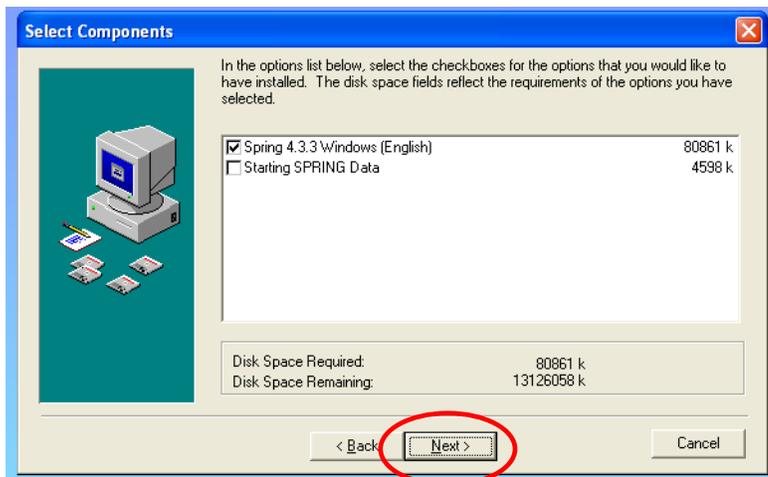
7. Once the file has downloaded, run the install_spr433.exe from the directory where it was saved. Click “Next” to start the install.



8. Click “Next” to accept the license agreement.
9. Choose the directory where you would like to install SPRING, and click “Next” to start the install.



10. Choose to only install the SPRING program, and click “Next.”



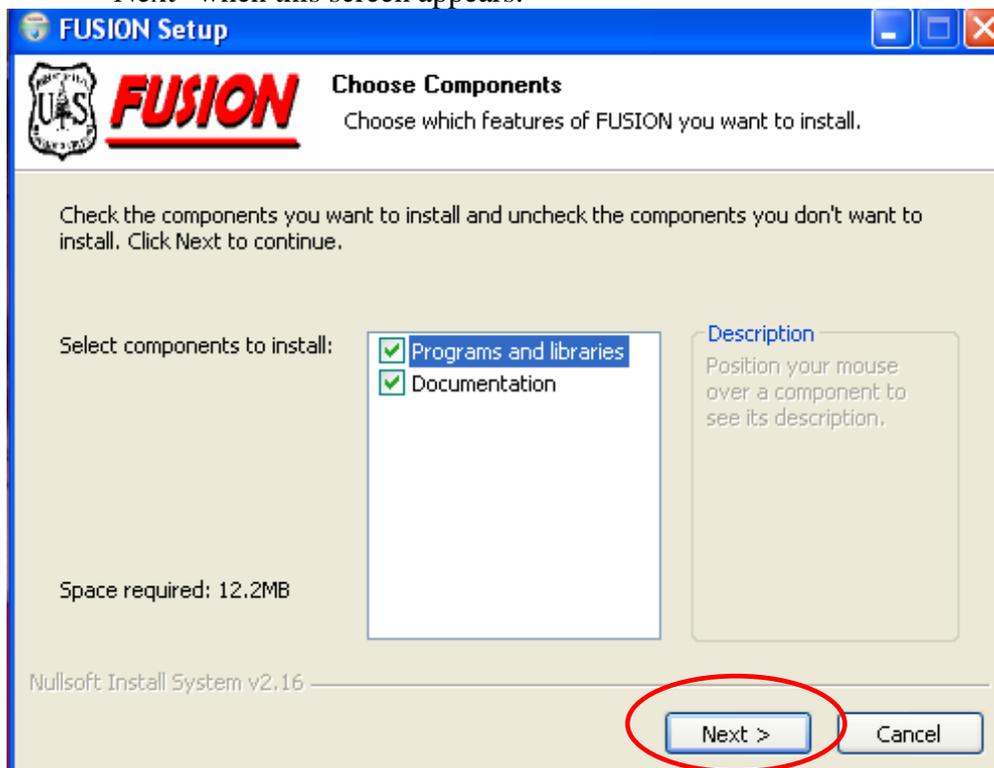
11. Click “Next” on the following screen and the install will begin. Once the install is complete, click on the “Finish” button and you will exit the install wizard. The SPRING program has a desktop shortcut or can be accessed through the Start->All Programs->SPRING.
12. You have now completed the installation of SPRING.

1.2 FUSION- FUSION was developed by Robert McGaughey at theUSFS Pacific Northwest Research Station. This program is primarily a viewing tool for LIDAR data, but also provides basic analysis that is important to the foundation of this project. The current version of FUSION can be found at:

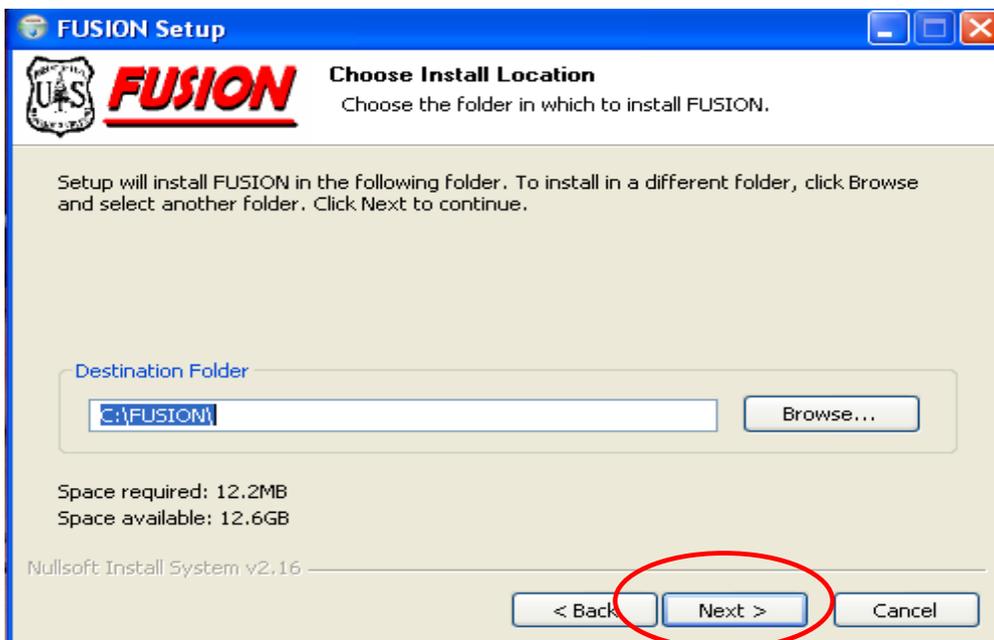
<http://forsys.cfr.washington.edu/fusion/fusionlatest.html> this website is updated by the developers of FUSION and will contain the latest public release of FUSION.

1. From the webpage above, click on the “Install.exe” at the bottom of the page.

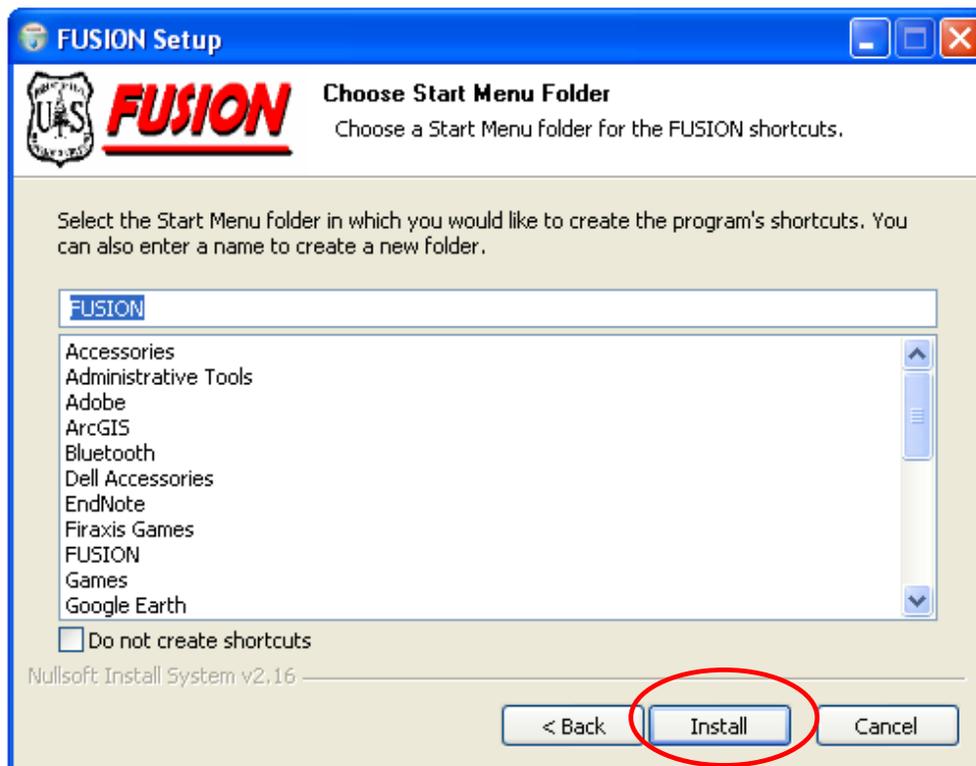
2. Choose to save the file and choose the destination directory.
3. Run the FUSION_Install.exe from the directory in which it was saved. Click on “Next” when this screen appears.



4. Choose the directory you would like FUSION installed (Recommended to use defaults). Click “Next.”



5. Choose the Start menu folder you would like the FUSION shortcut to reside in, then click "Install"



6. This will start the install process, this may take several minutes. When it is finished, click “Finish” to exit the installation.
 7. You have now completed the install of FUSION.
-

Hawth’s Tools- This program is a set of ecology analysis tools that are packaged as an extension for use in ArcMap. The software is free and can be downloaded at <http://www.spatial ecology.com/htools/download.php> . This extension will be used later in the tutorial for accuracy assessment.

To set up this extension:

1. Go to the link above and click on “Download Hawth’s Tools.” Follow the installation instructions below.

Installation Instructions: (From website)

1. Download Hawth's Tools using the link below. Save the WinZip file to your hard drive (anywhere), and unzip it. (If you do not have a copy of WinZip, you can download it from <http://www.winzip.com>.)
2. Run the program called htools_setup.exe. (Note that this program can also be used to uninstall the software).

Hawth's Analysis Tools for ArcGIS SpatialEcology.Com

OVERVIEW | TOOLS DESCRIPTION & HELP | DOWNLOAD | VERSION HISTORY | FAQ | SERVICES

You are here: [Home](#) - [Hawth's Tools](#) - [Download](#)

Download Hawth's Tools

Hawth's Tools is an extension for ArcGIS (ArcMap). You must have a licensed copy of ArcGIS for this extension to work. (Visit the [ESRI website](#) for further details.)

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Although you may distribute this software, I ask that you refer other interested users directly to this web site to ensure they have acquired the latest version.

Implicit in the use of this product is the understanding that:

- No technical support is offered for this product.
- The product is provided AS-IS, without warranty of any kind.
- YOU are responsible for ensuring that the output of these tools is accurate, relevant, consistent, and otherwise error-free.
- The author assumes no responsibility for any suffering you may experience as a result of the use (or misuse) of this software.
- The author does not warrant that this software is bug free.

INSTALLATION INSTRUCTIONS

1. Download Hawth's Tools using the link below. Save the WinZip file to your hard drive (anywhere), and unzip it. (If you do not have a copy of WinZip, you can download it from <http://www.winzip.com>.)
2. Run the program called htools_setup.exe. (Note that this program can also be used to uninstall the software).

If you have a previous version of Hawth'sTools, it is highly recommended that you skim the brief [Version History](#) notes to check for fundamental changes in the tools you commonly use before you download the newer version.

The current version of the tools is for ArcGIS 9.x only:

[DOWNLOAD HAWTH'S TOOLS \(v3.27\) FOR ARCGIS 9.x](#)

NOTE: some people receive an "invalid archive" message when they try to unzip the above file. This may be related to slow download speeds, firewalls, and/or realtime virus protection. If you receive this message, please try downloading the file a few more times until you acquire a valid copy.

A [very old](#) archived version of the tools for ArcGIS 8.x is also available. This version is not maintained, and contains only a subset of the tools that are available in the current version (for ArcGIS9):

[DOWNLOAD THE ARCHIVED HAWTH'S TOOLS \(v2.10\) FOR ARCGIS 8.x](#)

Please email bug reports to: hawthorne@spatialecology.com.

09/08/07

Home | Articles | Services | Hawth's Tools: Overview | Description | Download | FAQ

Click here to
Start download.

Part II- Generation of Raster Data

This portion of the manual is comprised of two sections. The first will lead you through the process of dealing with the raw LIDAR products and work within FUSION. The second section will focus on the analysis within ArcMap. The final products of this section will be three raster datasets that will then be used in SPRING.

Section 1- Working with FUSION command lines

Software needed:

- FUSION (see downloads section)

Data Required:

- Ground Model (demo_4800K_UTM.dtm)
- LIDAR points (demo_4800K_UTM.la)
- Aerial Photograph (demo_4800K_UTM.jpg and demo_4800K_UTM.jpgw)

Data for this section:

1. Download the example data from <http://forsys.cfr.washington.edu/fusion/fusionlatest.html> which is the same page where you downloaded the FUSION software. Click on example data. **Make sure to download the UTM example data!**

FUSION
Providing fast, efficient, and flexible access to LIDAR, IFSAR and terrain datasets

FOREST SERVICE
U.S.
DEPARTMENT OF AGRICULTURE

Robert J. McGaughey
Pacific Northwest Research Station

"The Latest Version"
Version 2.51 is the latest version of FUSION.

If you have an earlier version of FUSION, you should upgrade to take advantage of several new features and bug fixes.

To upgrade from previous version, first remove the old version using the "Add/remove programs" option in the Windows control panel. Then simply install the new version into the same folder as the previous version. Existing project and data files should not be affected.

[Release notes describing changes to FUSION](#)

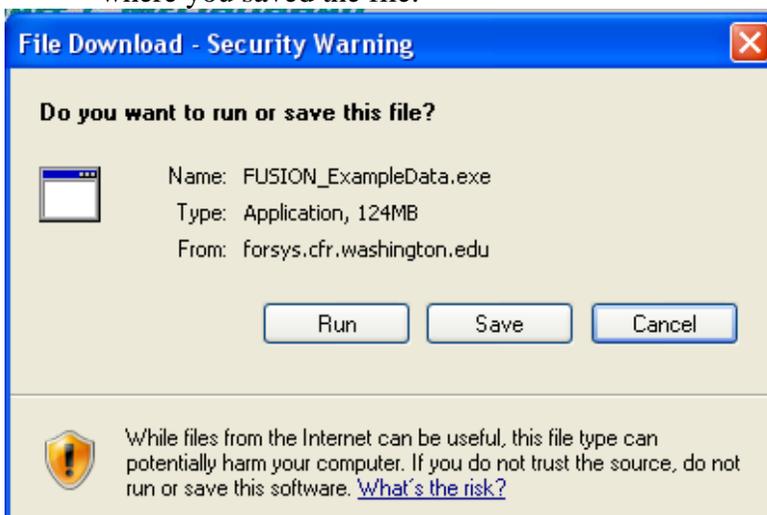
[Manual describing FUSION/LDV and the LIDAR Toolkit \(LTK\) \(2.1 Mb\)](#)

You can download FUSION from the following locations:

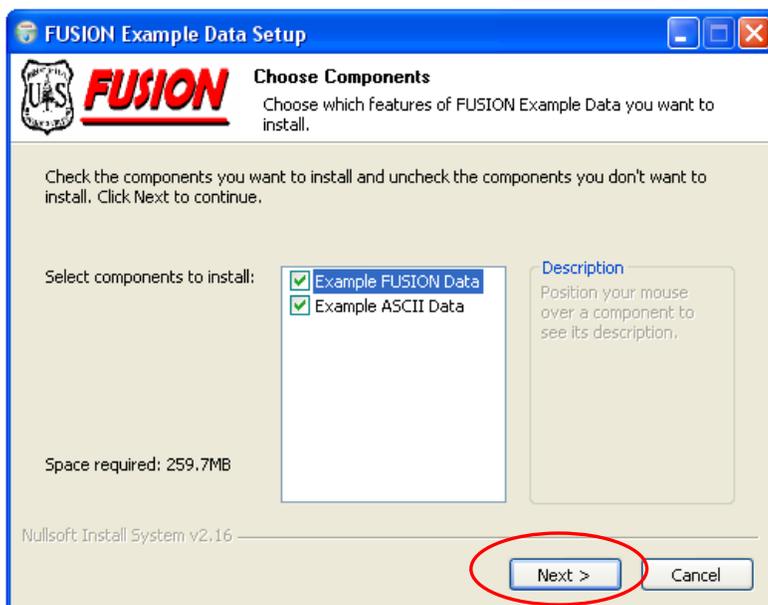
- [Install file \(163 Mb\)](#)
- [Example data \(124 Mb\)](#)
- [General information regarding FUSION](#)

Example data download

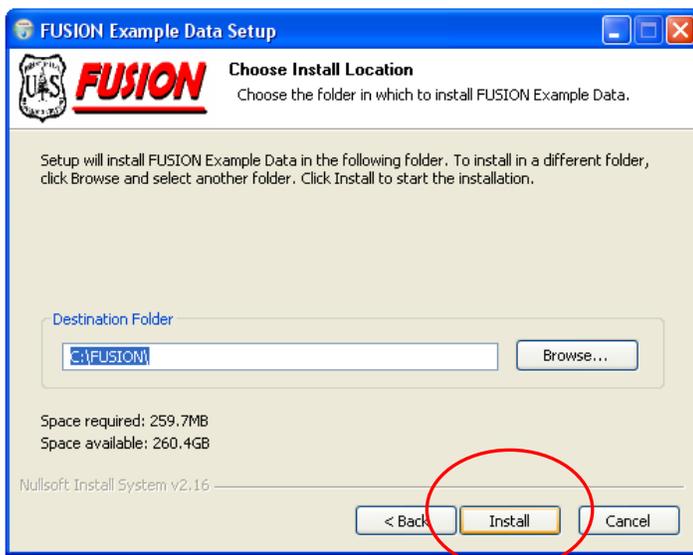
2. Choose "Run" or "Save" from the pop up menu, if you chose to save it, remember where you saved the file.



3. Choose to download both components, and click “Next.” (maybe change this when Bob updates webpage)



4. Choose the directory to install the example data. Then click “install.”

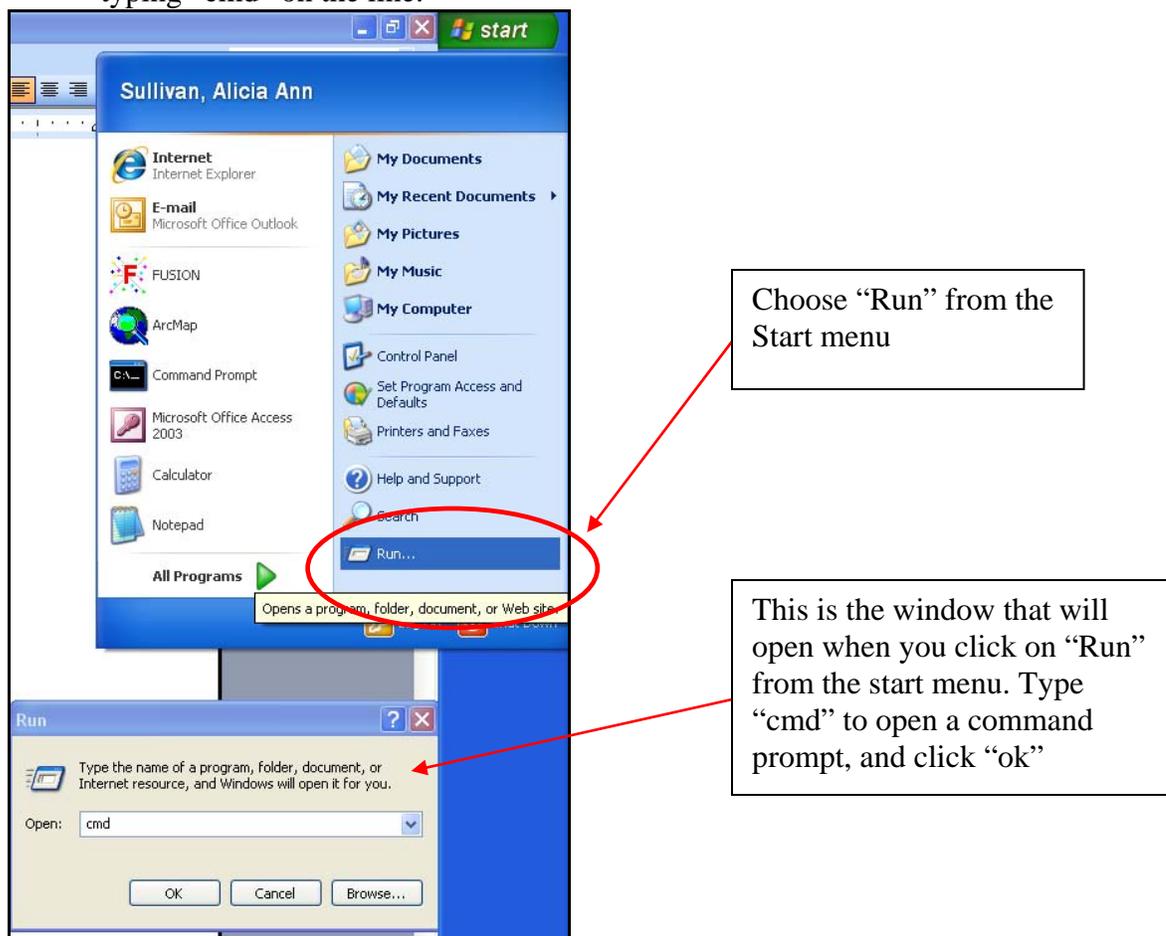


5. The install will run and when it is finished, click “finish” and you now have successfully downloaded the example data. The next portion of this section will be working with raw LIDAR points.

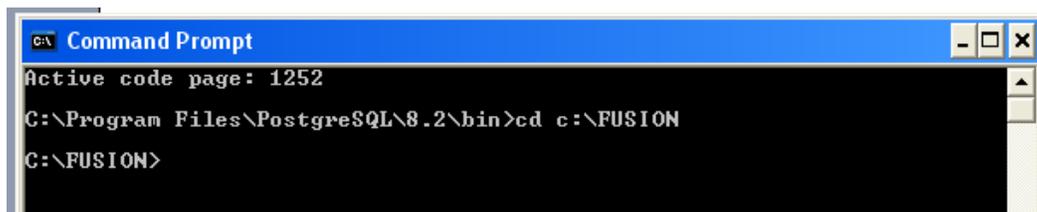
Working with the FUSION batch files:

This portion of the process will involve the use of command prompts and batch files. All of the batch programs are located in the C:\FUSION directory of the computer, unless otherwise specified during download. The default will be to run these programs out of the C:\FUSION directory, which will require all of the data that is called by the batch file to be in that directory, the outputs will also be put there. It is also possible to set the environmental variables on the machine to allow for data processing in other directories, this manual does not cover how to do this. The FUSION manual has detailed descriptions of each tool and the variables available. This manual will focus on the tools needed for this process. Make sure that the example dataset being used is in the UTM projection, this will cause problems later in the tutorial if using the incorrect datasets. All UTM datasets will have “UTM” somewhere in the file name.

1. Open a command prompt window from the Start menu, by selecting “Run” and typing “cmd” on the line.



2. The command prompt window will open. At the prompt, type “cd c:\FUSION” and press “enter” to change the directory to the location of the batch programs.



```

C:\ Command Prompt
Active code page: 1252
C:\Program Files\PostgreSQL\8.2\bin>cd c:\FUSION
C:\FUSION>

```

- Now we are ready to work with the batch files in FUSION. The files that will be used in this step are the raw LIDAR points (**demo_4800K_UTM.lda**) and the bare ground model (**demo_4800K_UTM.dtm**). Make sure that these files are in the C:\FUSION directory on your computer.

FUSION batch file tools:

The tools need for this tutorial are described in the following section. The FUSION user's manual gives a more complete description of the tool and the available switches. The tools are presented in chronological order for this method.

1. Percent Cover Calculation:

The first step is to use the Cover batch program in FUSION to create a percent cover estimation for the study area. The description from the FUSION user's manual is: "*Cover* computes estimates of canopy closure using a grid. Output values for cover estimates range from 0.0 to 100.0 percent. Canopy closure is defined as the number of returns over a specified height threshold divided by the total number of returns within each cell. In addition, *Cover* can compute the proportion of pulses that are close to a bare-ground surface model to help assess canopy penetration by the laser scanner. With the addition of an upper height limit, *Cover* can compute the proportion of returns falling within specific height ranges providing estimates of relative vegetation density for various height strata." (McGaughey, R.J., 2007).

General syntax:

```
Cover [switches] groundfile coverfile heightbreak cellsize xyunits zunits coordsys zone
horizdatum vertdatum datafile1
```

The syntax that will be used for this data set:

```
Cover demo_4800K_UTM.dtm demo_cover_89916m_utm.dtm 2 8.9916 m m 1 10 2 2
demo_4800K_UTM.lda
```

Explanation of Syntax: The cell size of this analysis is based on 1/50 acre. 8.9916m by 8.9916m is approximately 1/50th of an acre and a common area used in forest inventory. The data is in meters and projected in UTM NAD 1983 NAVD88 zone 10 north, which explains the rest of the syntax (see FUSION user's manual for more information).

1. Copy and paste the syntax give above into the command prompt window and press “enter”. This will start the batch program, and may take a while to run depending on your computer. Status information will be displayed as the program runs.

```

C:\Program Files\PostgreSQL\8.2\bin>cd c:\fusion
C:\FUSION>Cover demo_4800K_UTM.dtm demo_cover_89916m_utm.dtm 2 8.9916 m m 1 10 2 2 demo_4800K_UTM.l
da
Cover v1.30 <FUSION v2.60> <Built on Dec 4 2007 09:19:40>
Command line: Cover demo_4800K_UTM.dtm demo_cover_89916m_utm.dtm 2 8.9916 m m 1 10 2 2 demo_4800K_U
TM.lda
Run started: Wed Apr 02 13:54:13 2008
Using 1 data files:
    demo_4800K_UTM.lda: 4859996 points
Canopy cover layer file produced:
    demo_cover_89916m_utm.dtm Apr 2, 2008 @ 1:54 PM
Run finished: Wed Apr 02 13:54:16 2008 <elapsed time: 3 seconds>
Done
C:\FUSION>

```

DTM2TIF Tool:

The second step for the percent cover dtm will be to create a geo tiff file from the dtm. This will create the final product to be used in SPRING and will allow for the percent cover image to be viewed in ArcMap. This step will use the DTM2TIFF tool in FUSION. This tool will also be used to create the stem density and average height geo tiff files later in the tutorial.

General syntax:

DTM2TIF [switches] inputfile [outputfile]

The syntax that will be used for this data set is:

DTM2TIF demo_cover_89916m_utm.dtm demo_cover_89916m_utm.tif

1. Copy and paste the syntax give above into the command prompt window and press “enter”. This will start the batch program, and may take a while to run depending on your computer. Status information will be displayed as the program runs.

```

C:\FUSION>DTM2TIF demo_cover_89916m_utm.dtm demo_cover_89916m_utm.tif
DTM2TIF v1.00 <FUSION v2.60> <Built on Dec 4 2007 09:18:09>
Command line: DTM2TIF demo_cover_89916m_utm.dtm demo_cover_89916m_utm.tif
Run started: Wed Apr 02 14:14:59 2008
TIF image file produced:
    demo_cover_89916m_utm.tif Apr 2, 2008 @ 2:14 PM
TIF world file produced:
    demo_cover_89916m_utm.tfw Apr 2, 2008 @ 2:14 PM
Run finished: Wed Apr 02 14:14:59 2008 <elapsed time: 0 seconds>
Done
C:\FUSION>

```

Explanation of Output: This generates a geo tiff file from the demo_cover_89916m_utm.dtm that was created in the previous step. There are two files output from this process, a tiff image file (.tif extension) and a world file (.tfw extension). Both files will have the same name but be distinguished by the extensions, any changes to the file name must be made on both files or the geo tiff will not function correctly. It is

important to note that **BOTH** of these files must be moved when moving this file around in order to preserve the functionality of the geo tiff.

2. Canopy Maxima- Generation of the canopy maxima points is a two step process that requires the use of the Canopy Model tool and the Canopy Maxima tool in FUSION.

Canopy Model Tool-

The second program that will be used in this process is the Canopy model tool. This tool uses the raw LIDAR points (**demo_4800K_UTM.lda**) and the ground surface model (**demo_4800K_UTM.dtm**) to create a model of the surface of the canopy. The ground model is used to “subtract the ground elevations from the return elevations to produce a canopy height model” (McGaughey, R.J., 2007). The canopy height model is an intermediate step to producing the canopy maxima points.

General Syntax:

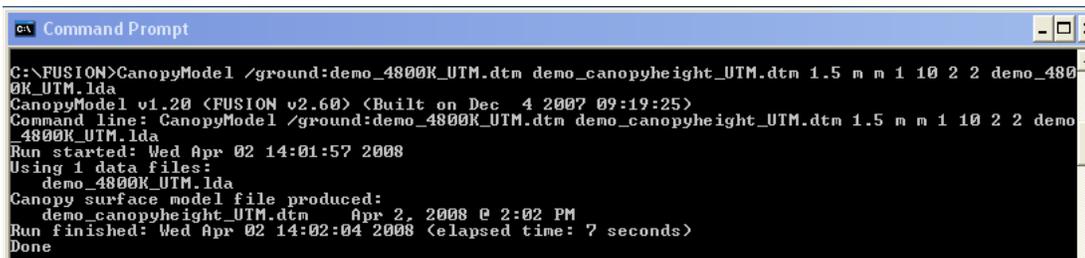
CanopyModel [switches] surfacefile cellsize xyunits zunits coordsys zone horizdatum vertdatum datafile1

The syntax that will be used for this data set:

```
CanopyModel /ground:demo_4800K_UTM.dtm demo_canopyheight_UTM.dtm 1.5 m m
1 10 2 2 demo_4800K_UTM.lda
```

Explanation of Syntax: The ground switch is needed to create a canopy height model. The cell size is 1.5 meters, which is approximately 5 feet. The data is in meters and projected in UTM NAD 1983 NAVD88 zone 10 north, which explains the rest of the syntax (see FUSION user’s manual for more information).

1. Copy and paste the syntax give above into the command prompt window and press “enter”. This will start the batch program, and may take a while to run depending on your computer. Status information will be displayed as the program runs.



```

C:\FUSION>CanopyModel /ground:demo_4800K_UTM.dtm demo_canopyheight_UTM.dtm 1.5 m m 1 10 2 2 demo_4800K_UTM.lda
CanopyModel v1.20 (FUSION v2.60) (Built on Dec 4 2007 09:19:25)
Command line: CanopyModel /ground:demo_4800K_UTM.dtm demo_canopyheight_UTM.dtm 1.5 m m 1 10 2 2 demo_4800K_UTM.lda
Run started: Wed Apr 02 14:01:57 2008
Using 1 data files:
demo_4800K_UTM.lda
Canopy surface model file produced:
demo_canopyheight_UTM.dtm Apr 2, 2008 @ 2:02 PM
Run finished: Wed Apr 02 14:02:04 2008 (elapsed time: 7 seconds)
Done

```

Canopy Maxima Tool-

The next step in FUSION is to generate the canopy maxima points using the Canopy Maxima tool. This tool uses a variable analysis window to identify local maxima points as well as information about crown height and width. The output of this process is a

comma separated value file (.csv) that will need to be manipulated in the FUSION GUI program before returning to the command line analysis. This process will be covered in subsequent sections. This tool uses the Canopy Height Model produced in the previous step.

*** Note about Canopy Maxima***

Methods for finding canopy maxima with LIDAR is a relatively new and changing process. The user should be aware that at the time of this manual being written, there are several tools that are available to find canopy maxima and depending on the purpose of the project, this tool may not be the best. The FUSION canopy maxima tool was chosen for this project and manual due to the availability of the tool and its ability to process large areas. However, this choice was made with the awareness that the canopy maxima tool underestimates the true maxima in forest stands. Currently, this tool will work well for either young stands or mature stands based on the parameters that are set. Mixed forest areas such as the example data pose a problem in that it will provide very good stem density information for one stand type and not the others. For more information about the methodology used in the Canopy Maxima tool see:

Kini, A.U. & Popescu, S.C. (2004, September, 16). *Treevaw: A versatile tool for analyzing forest canopy LIDAR data- A preview with an eye towards the future.*

Paper presented at the 2004 ASPRS Images to Decisions: Remote sensing for GIS applications conference, Kansas City, MO.

With that said, this project is interested in creating a density layer that represents the densities of stands relative to one another, not an absolute count of trees per acre. The information generated about stem density in this method will not accurately represent the conditions on the ground, but will provide a data layer that will act as a relative measure of density between stands for the image segmentation in SPRING.

General Syntax:

CanopyMaxima [switches] inputfile outputfile

The syntax that will be used for this data set:

CanopyMaxima /mult:0.5 /threshold:2 demo_canopyheight_UTM.dtm
demo_canopymaxima_utm.csv

Explanation of Syntax: The choice of these switches and the values here are specific for this dataset. It is likely that for each data acquisition, there will need to be adjustments made to these values. The values were chosen for this dataset because it produced the best results for comparison of densities between stands (see note above).

1. Copy and paste the syntax give above into the command prompt window and press “enter”. This will start the batch program, and may take a while to run depending on your computer. Status information will be displayed as the program runs.

```

C:\FUSION>canopymaxima /mult:0.5 /threshold:2 demo_canopyheight_UTM.dtm demo_canopymaxima_utm.csv
CanopyMaxima v1.10 (FUSION v2.60) (Built on Nov 16 2007 10:41:16) DEBUG
Command line: CanopyMaxima /mult:0.5 /threshold:2 demo_canopyheight_UTM.dtm demo_canopymaxima_utm.csv
Run started: Tue Apr 08 15:06:11 2008
Identified 12447 local maxima
Run finished: Tue Apr 08 15:06:16 2008 (elapsed time: 5 seconds)
Done
C:\FUSION>

```

2. A file called demo_canopymaxima_UTM.csv will be located the C:/FUSION directory. This file contains the information for each canopy maxima pint. This file will be used in the next section to produce the stem density and average height data layers.

Section 2- Working with FUSION GUI

This section will be a brief departure from the FUSION command line interface used in the previous section. Once the needed files are created, the command lines will be used again to produce the final two data layers, stem density and average height.

Software needed:

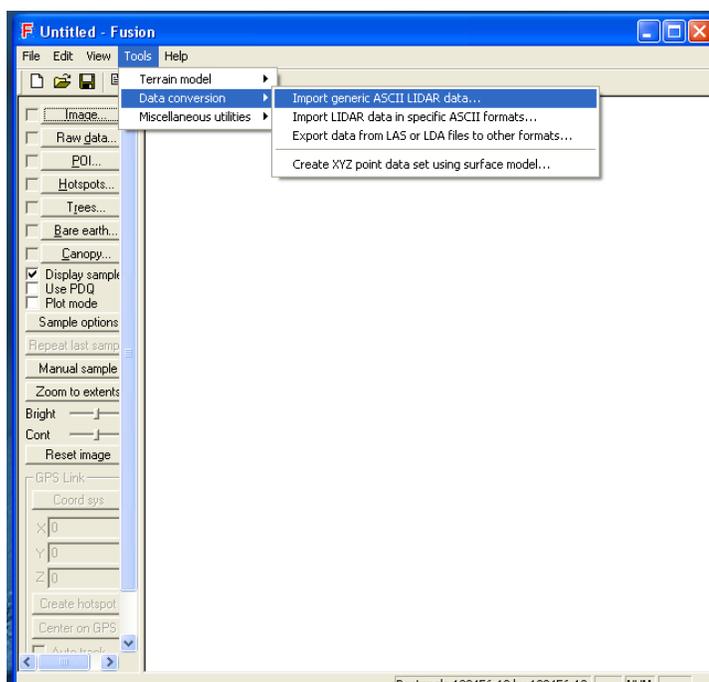
- FUSION (see downloads section)

Data Required:

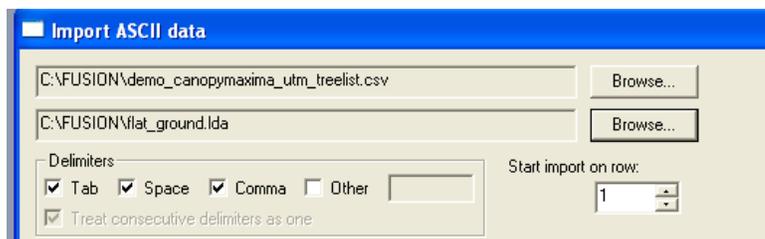
- Canopy maxima file from previous section (demo_canopymaxima_utm.csv)

1. Open the FUSION GUI in Start -> Programs -> FUSION.

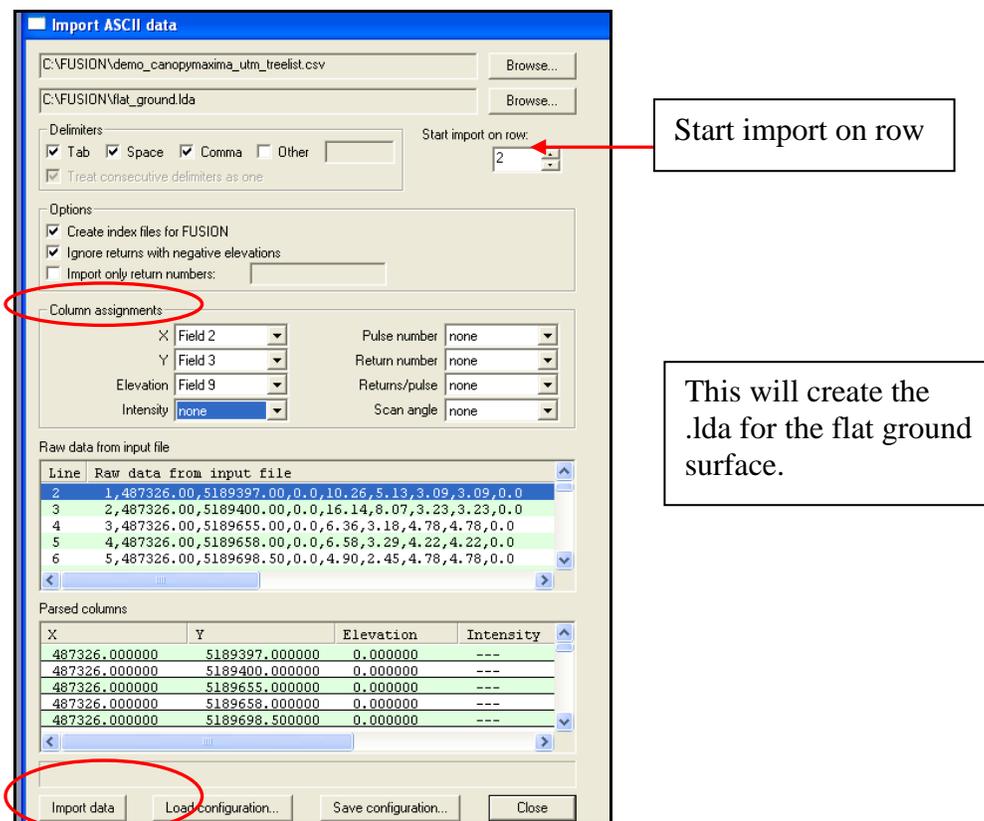
When the program opens go to the top menu bar and open Tools -> Data Conversion -> Import generic ASCII LIDAR data.



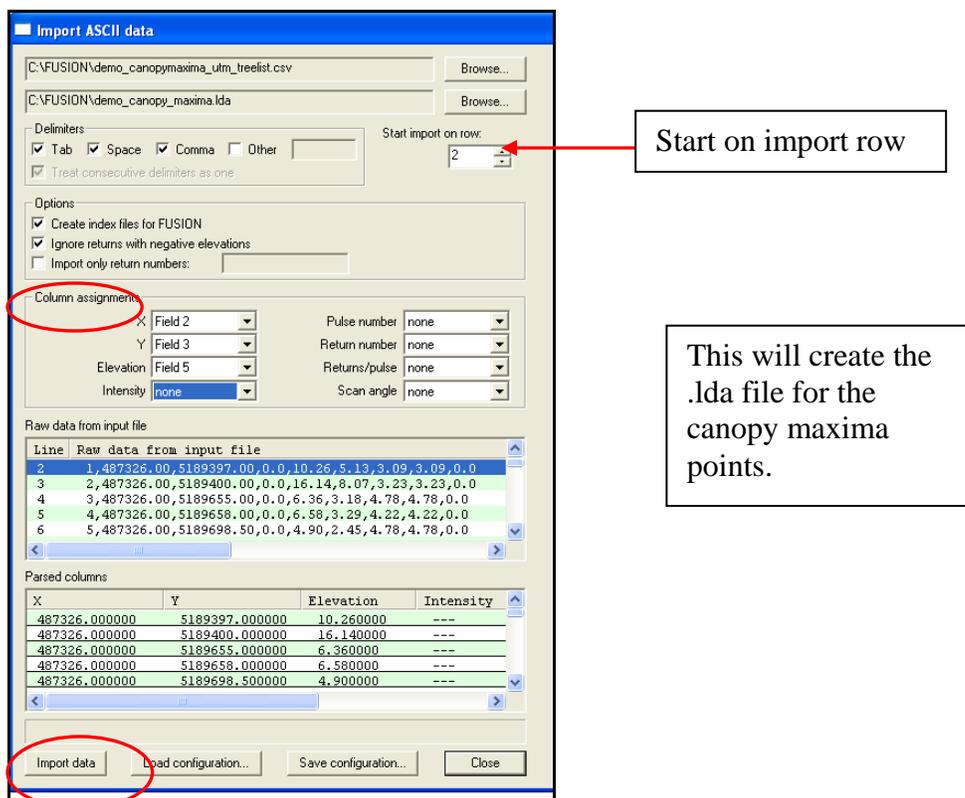
2. This will open a dialogue box for importing ASCII and CSV files. This tool will be used to create “point clouds” from the canopy maxima file that represent a flat ground model and the canopy maxima points. To do this, the canopy maxima .csv file must be converted into two .lda files.
3. To create the flat ground model, click on the first “Browse” button and navigate to the demo_canopymaxima_utm.csv file. Click on the second “Browse” button and give the output file a name of “demo_flat_ground.lda” in the C:\ FUSION directory.



4. The next step is to set the parameters for the import of the data. In the “Start on import row” type 2. This will start the data below the column headers. In the “Column assignments” dialogue box Set X to “field 2”, Y to “field 3” and Elevation to “field 9” the remaining fields should be set to “none”. (Setting the elevation to field 9, or 0 will create a flat surface when taken through the future steps.) Click on “Import data” and then close when the import is complete.



- Repeat this process for the canopy maxima points to create an .lda file for the canopy points. Open Tools -> Data Conversion -> Import generic ASCII LIDAR data.
- Click on the first "Browse" button and navigate to the demo_canopymaxima_utm.csv file. Click on the second "Browse" button and give the output file a name of "demo_canopy_maxima.lda" in the C:\ FUSION directory.
- The next step is to set the parameters for the import of the data. In the "Start on import row" type 2. This will start the data below the column headers. In the "Column assignments" dialogue box Set X to "field 2", Y to "field 3" and Elevation to "field 5" the remaining fields should be set to "none". (Setting the elevation to field 5, uses the height of the canopy maxima points) Click on "Import data" and then close when the import is complete.



8. The demo_flat_ground.lda and demo_canopy_maxima.lda files will now be used in the command line interface of FUSION for the final analysis.
9. Open a command line as described in the previous section, and change the directory to C:\FUSION to start the next portion.

1. Grid Surface Create:

This tool will be used to produce the flat ground surface from the demo_flat_ground.lda file just created. The importance of this flat ground model relates to the next tool that will be used called Grid Metrics. Grid Metrics is generally used on raw LIDAR datasets and uses the ground model to normalize the data. Since the data has already been normalized through the production of the Canopy Height model, this is not necessary and the flat ground model is used as a trick to make the Grid Metrics tool work properly for this application.

General Syntax:

GridSurfaceCreate [switches] surfacefile cellsize xyunits zunits coordsys zone
horizdatum vertdatum datafile1

The syntax that will be used for this data set:

GridSurfaceCreate demo_flat_ground.dtm 8.9916 m m 1 10 2 2 demo_flat_ground.lda

Explanation of Syntax: The data is in meters and projected in UTM NAD 1983 NAVD88 zone 10 north, (see FUSION user's manual for more information).

1. Copy and paste the syntax give above into the command prompt window and press "enter". This will start the batch program, and may take a while to run depending on your computer. Status information will be displayed as the program runs.

```

C:\FUSION>gridsurfacecreate demo_flat_ground.dtm 8.9916 m m 1 10 2 2 demo_flat_ground.lda
GridSurfaceCreate v1.60 (FUSION v2.63) (Built on Apr 1 2008 13:23:04) DEBUG
Command line: GridSurfaceCreate demo_flat_ground.dtm 8.9916 m m 1 10 2 2 demo_flat_ground.lda
Run started: Wed Apr 02 15:09:20 2008
Using 1 data files:
demo_flat_ground.lda: 9679 pts
Surface model file produced:
demo_flat_ground.dtm Apr 2, 2008 @ 3:09 PM
Run finished: Wed Apr 02 15:09:20 2008 (elapsed time: 0 seconds)
Done
C:\FUSION>

```

2. Grid Metrics:

This tool will create the two final data layers; stem density per pixel and average height per pixel using the points from the demo_canopy_maxima.lda. This tool has several other functionalities that are detailed in the FUSION manual. For this exercise, the min points, and raster switches will be used. The final output will be two .dtm layers for mean and count that will be converted to geo tiff files using the DTM2TIF tool.

General Syntax:

GridMetrics [switches] groundfile heightbreak cellsize outputfile datafile1

The syntax that will be used for this data set is:

```
GridMetrics /minpts:1 /raster:count,mean demo_flat_ground.dtm 2 8.9916
demo_gridmetrics demo_canopy_maxima.lda
```

Explanation of Syntax:

The /minpts switch controls the minimum number of points that have to be in a cell to have metrics computed, this sets it to a minimum of 1. The /raster switch creates .dtm files for the count of points in a cell (stem density) and the average value for the points in the cell (in this case, height). The heightbreak is set to 2 and the cell size is set to the standard 8.9916 for the output cell size.

1. Copy and paste the syntax give above into the command prompt window and press "enter". This will start the batch program, and may take a while to run depending on your computer. Status information will be displayed as the program runs.

```

C:\FUSION>GridMetrics /minpts:1 /raster:count,mean demo_flat_ground.dtm 2 8.9916 demo_gridmetrics de
mo_canopy_maxima.lda
GridMetrics v1.90 (FUSION v2.63) (Built on Apr 2 2008 10:43:52)
Command line: GridMetrics /minpts:1 /raster:count,mean demo_flat_ground.dtm 2 8.9916 demo_gridmetric
s demo_canopy_maxima.lda
Run started: Wed Apr 02 15:56:48 2008
demo_canopy_maxima.lda: 9679 points
Total first returns used for cover calculation: 9679 points

Grid metrics file produced:
demo_gridmetrics_first_returns_density_only_elevation_stats.csv Apr 2, 2008 @ 3:56 PM
ASCII raster grid header file produced:
demo_gridmetrics_first_returns_density_only_elevation_stats_ascii_header.txt Apr 2, 2008 @ 3:5
6 PM
Point count file produced:
demo_gridmetrics_first_returns_density_only_elevation_count.dtm Apr 2, 2008 @ 3:56 PM
Mean value file produced:
demo_gridmetrics_first_returns_density_only_elevation_mean.dtm Apr 2, 2008 @ 3:56 PM
Run finished: Wed Apr 02 15:56:49 2008 (elapsed time: 1 seconds)
Done
C:\FUSION>

```

DTM2TIF Tool:

This tool has been described in the earlier section of this manual, so only the syntax needed for this section will be provided. This tool converts dtm files to geo tiff files with the associate world file.

General Syntax:

DTM2TIF [switches] inputfile [outputfile]

The syntax that will be used for this data set:

Stem density:

DTM2tif demo_gridmetrics_first_returns_density_only_elevation_count.dtm
demo_stem_density.tif

Average Height:

DTM2tif demo_gridmetrics_first_returns_density_only_elevation_mean.dtm
demo_avg_height.tif

```

C:\FUSION>DTM2tif demo_gridmetrics_first_returns_density_only_elevation_count.dtm demo_stem_density.
tif
DTM2TIF v1.00 (FUSION v2.60) (Built on Dec 4 2007 09:18:09)
Command line: DTM2TIF demo_gridmetrics_first_returns_density_only_elevation_count.dtm demo_stem_dens
ity.tif
Run started: Wed Apr 02 16:05:40 2008
TIF image file produced:
demo_stem_density.tif Apr 2, 2008 @ 4:05 PM
TIF world file produced:
demo_stem_density.tfw Apr 2, 2008 @ 4:05 PM
Run finished: Wed Apr 02 16:05:40 2008 (elapsed time: 0 seconds)
Done
C:\FUSION>DTM2tif demo_gridmetrics_first_returns_density_only_elevation_mean.dtm demo_avg_height.tif
DTM2TIF v1.00 (FUSION v2.60) (Built on Dec 4 2007 09:18:09)
Command line: DTM2TIF demo_gridmetrics_first_returns_density_only_elevation_mean.dtm demo_avg_height
.tif
Run started: Wed Apr 02 16:05:50 2008
TIF image file produced:
demo_avg_height.tif Apr 2, 2008 @ 4:05 PM
TIF world file produced:
demo_avg_height.tfw Apr 2, 2008 @ 4:05 PM
Run finished: Wed Apr 02 16:05:50 2008 (elapsed time: 0 seconds)
Done
C:\FUSION>_

```

Congratulations! You are now finished with the data generation portion of this tutorial. The next step will be image segmentation and classification with SPRING.

The files that were generated in this part will be located in the C:\FUSION directory and will be needed for the next section.

Part III- Segmentation and Classification with SPRING

This portion of the tutorial will deviate from the step by step nature of the previous sections. Image classification is a process that is dependant on the individual analyst and there are multiple ways to segment, train and classify the same image. This section will use a tutorial developed by the US Fish and Wildlife Service in their remote sensing lab in Albuquerque, New Mexico.

Software needed:

- SPRING (see downloads section)

Data Required:

- Percent cover (demo_cover_89916m.tif)
- Stem density (stem_density.tif)
- Average height (avg_height.tif)

Other Downloads

- USFWS tutorial: <http://www.fws.gov/data/documents/SPRING%20Manual%20022306.pdf>
-

Download for this section:

For this section a tutorial developed by the U.S. Fish and Wildlife Service will be used. This tutorial was chosen to be used in this manual because it covers the basic functionalities of SPRING and image classification. The tutorial is also basis for the method used in this project. The primary focus of this section of the manual will be as a guide through the USFWS tutorial and explanation of known problems with SPRING. The information in this section is intentionally vague. The parameters for segmentation, classes and training sites are subjective and will vary greatly depending on the goals and skill of the analyst. This section is meant to be a rough guide to object orientated classification using SPRING.

1. Download the USFWS SPRING tutorial from:
<http://www.fws.gov/data/documents/SPRING%20Manual%20022306.pdf>
 2. Print or save the USFWS tutorial for use in the next section.
-

Section I: Guide through the USFWS SPRING tutorial:

This section will go through each part of the USFWS tutorial, numbers correspond to the tutorial sections.

- 2.1 Download and install SPRING-** See download section of this manual
- 2.2 Acquire and Install ERDAS ViewFinder-** Not necessary for this project.

2.3 Reproject and Resample Imagery with ERDAS ViewFinder- Not necessary, projections set in ArcMap

2.4 Create Database, Project Category and Import Image- Follow these instructions as is. Name the database and project relevant to the data. Set the bounds to the extent of the geo tiff images created in FUSION. Set the projection to UTM WGS84 zone 10 north. See note below about importing images into SPRING.

***Note about importing images-**

SPRING is very particular about the format of the files it will import. Geo tiff files with associated world files are necessary. In addition, the size of the geo tiff files and origin in the world file must match EXACTLY. Depending on the outputs that are generated from the FUSION analysis, there may need to be some adjustment to the size or origin information listed in the world file. There are several programs that manipulate the size of images, so this process will not be covered in this manual. To edit world files, simply open the .fw files associated with the geo tiff files and edit them accordingly in notepad. It is also important that the geo tiff images have the projection defined before bringing them into SPRING. This can easily be done through ArcMap in the data management -> projections ->define projection tool in the toolbox.

SPRING as released in the version for this manual will only accept geo tiff images. The functionalities shown in the File menu on the main SPRING menu do not work. There is no documentation as to why this occurs.*

2.5 Create Segmentation- Follow these instructions as is. The values for similarity and area will vary depending on the purpose of the classification. Try several combinations to see the difference. For this dataset a similarity of 5 and area of 10 produce decent results.

2.6 Create Classes for Classification, Training Samples Collection- Again this section can be followed as is. Create class names that reflect the type of classification that is desired. The training sites will be dependant on the classes that are chosen. The aerial photograph of the study site (demo_4800K_UTM.jpg) may be helpful to determine classes and location of training sites.

2.7 Run Training Sample Analysis, Classification and Output Map- Follow instructions as is. If classification is not satisfactory, return to the previous section and edit the training or segmentation and re-run the classification.

2.8 Create Vector- Follow instructions as is. Save the shapefile to a directory relevant to the tutorial.

2.9 Export Thematic Map- The view the output shapefile, open ArcMap and add in the shapefile to a project with the demo_4800K_UTM.jpg image already loaded.

***Note about shapefiles-** SPRING has a defect that adds 10,000,000 units to the Y coordinates of the output shapefile. This can be corrected by using the “Move” tool in the editor of ArcMap. Subtract 10,000,000 units from the Y axis and the shapefile for the classification should line up. *

2.10 Add Projection, Reproject, Load into GIS- Projection will need to be defined for the shapefile in ArcMap in the data management -> projections ->define

projection tool in the toolbox. The projection should be set to UTM NAD 1983 NADV 88 zone 10 north.

Part IV: Accuracy Assessment of Classified Images

This is the final section of the tutorial and briefly describes how to perform an accuracy assessment on classified images using a confusion matrix. For a full description of the theory and methods please see:

Congalton, R.G and K. Green (1999). Assessing the Accuracy of Remotely Sensed Data: Principles and Practices. Boca Raton, FL, Lewis Publishers.

Software needed:

- Hawth's Tools (see downloads section)
- ArcMap 9.2

Data Required:

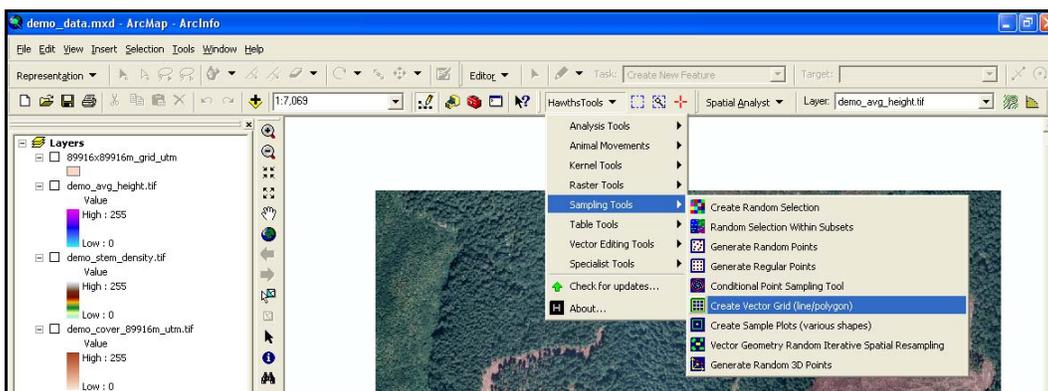
- Output of SPRING classification (shapefile)
 - Aerial Photograph (demo_4800K_UTM.jpg and demo_4800K_UTM.jpgw)
-

Section I: Setting up a sampling grid and points

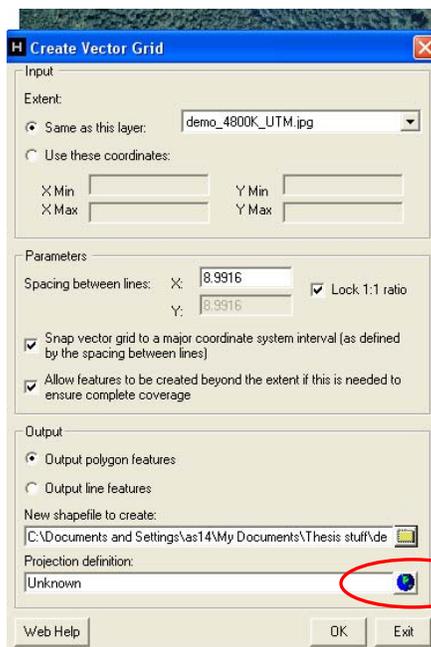
As mentioned in the introduction to this part, only the set up for the accuracy assessment will be covered. This is primarily because this is only one method of accuracy assessment for classifications and is also described in detail in Congalton and Green's book.

Create a Grid: In order to see the individual pixels, a grid must be created to distinguish pixels.

1. Open ArcMap with and navigate to the project used for the tutorial.
2. Open the extensions menu and turn on the toolbar for Hawth's Tools
3. Open Hawth's tools and navigate to Sampling tools-> Create Vector Grid

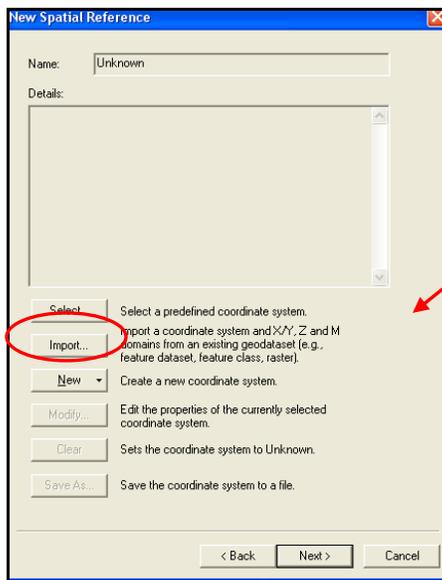


4. In the dialogue box that pops up, set the extent to the "Same as Layer" and choose the demo_4800K_UTM.jpg from the drop down menu. Under the "Parameters" section, set the spacing between lines to 8.9916, and uncheck the two boxes. Under "Output", choose the destination and name of the output grid. In this example it is called 89916_grid.shp. Click the button next to the "Projection Definition" to set the projection (see next step).

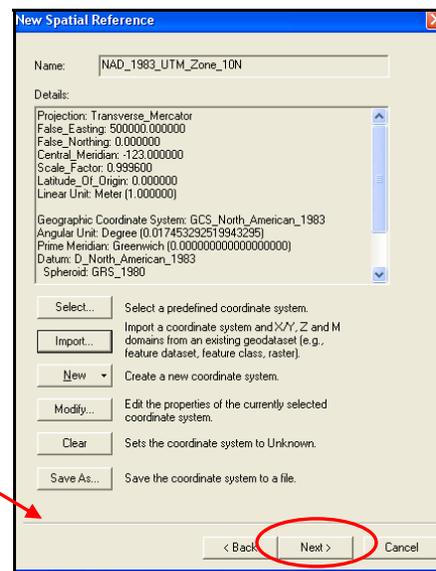


Click here to define the projection.

- When the dialogue box below appears, choose “Import” and navigate to the folder where the demo_4800K_UTM.jpg file is on your computer. Select this file and click “add” the menu on the right will appear showing that the projection has been set to NAD_1983_UTM_Zone_10N. Click “Next” and then “Finish” on the next screen.

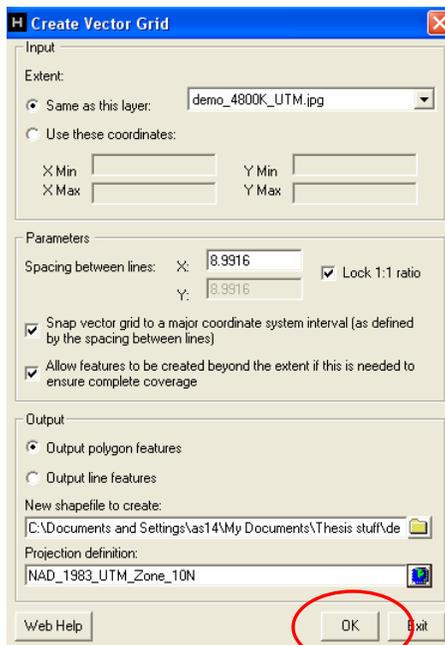


First dialogue box

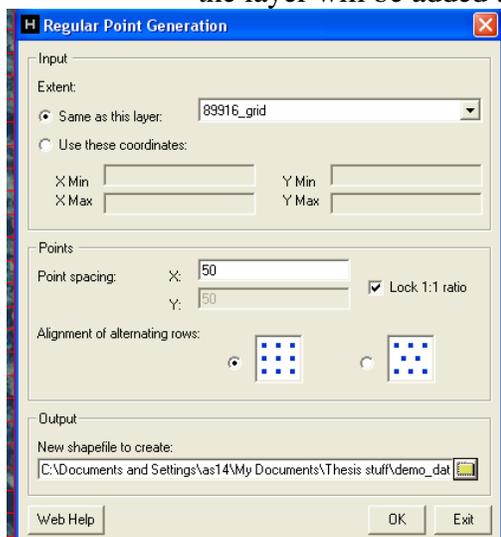


Second dialogue box

- Once the projection is set, click “ok” from the Create Vector Grid menu to run the program. When the processing is finished, the layer will be added to the project.



7. To view the grid, double click on the grid layer and set the fill to “hollow”, the line color to red and the outline width to 1.
8. To create the point layer that will be used to as the sampling grid for the accuracy assessment, open the Hawth’s tools extension and navigate to Sampling tools -> Create a regular grid to open the tool.
9. In the “Input” section choose the Extent to be Same as the 89916_grid.shp layer from the drop down menu. In the “Points” section enter 50 for the point spacing. Choose the alignment of rows as follows and name the output file 50m_points.shp and click “ok”. When processing is finished, the layer will be added to the project.



Section II – Accuracy Assessment

Now that the analysis grid and sample point layers have been created, the accuracy assessment can be performed on the classification. This process is dependant on the preferences of the analyst and data that is available. In the case of this tutorial, sample point spacing was chosen to give approximately 100 samples per class with extra points included to account for pixels that have multiple classes.

The basic concept of this accuracy assessment method is to compare the classification of the pixels that contain a sample point to the aerial photograph to determine if the classification is correct. The accuracy of this method is highly dependant on the analyst's ability to determine classes from aerial photographs. Each of the sample point pixels will then build the error matrix that will be the basis for calculating the user's accuracy, producer's accuracy, overall accuracy and KHAT (Congalton and Green, 1999).

Appendix 2: Command lines for processing

Clip data: clip raw data to ground model

clipdata /shape:0 all_utm.lda br_99_clip_data_utm 486240 5188650 489360 5190330

Canopy height model:

1999-

CanopyModel /ground:lidar99_grd_surfer7_may9_UTM.dtm

br_99_canopyheight_1.5_UTM.dtm 1.5 m m 1 10 2 2 br_99_clip_data_utm.lda

2003-

CanopyModel /ground:lidar99_grd_surfer7_may9_UTM.dtm

br_03_canopyheight_1.5_UTM.dtm 1.5 m m 1 10 2 2 br_clip_data_utm.lda

Cover:

1999-

cover lidar99_grd_surfer7_may9_UTM.dtm br_99_cover_89916m.dtm 2 8.9916 m m 1

10 2 2 br_99_clip_data_utm.lda

2003-

cover lidar99_grd_surfer7_may9_UTM.dtm br_03_cover_89916m.dtm 2 8.9916 m m 1

10 2 2 br_03_clip_data_utm.lda

Canopy maxima:

1999-

canopymaxima /wse:4.996,.05988,.001302,.000004327

br_99_canopyheight_1.5_UTM.dtm br_99_canopymaxima_tests_bob_UTM.csv

2003-

canopymaxima /mult:0.5 /threshold:4.5 br_03_canopyheight_1.5_UTM.dtm

br_03_canopymaxima_4.5_UTM.csv

These were trials used to determine the best combination of parameters:

Canopymaxima /mult:0.5 br_99_canopyheight_1.5_UTM.dtm

br_99_canopymaxima_tests_pt5_UTM.csv

canopymaxima /threshold:2.0 br_99_canopyheight_1.5_UTM.dtm

br_99_canopymaxima_tests_thres20UTM.csv

canopymaxima /mult:0.5 /threshold:3.04 br_99_canopyheight_1.5_UTM.dtm

br_99_canopymaxima_tests_combo_UTM.csv

DTM to Tiff:

This tool needs to be run for all of the final outputs to create a raster file for processing.