PRECISION FORESTRY IN THE SOUTHEAST U.S.

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Abstract
The U.S. forest products industry has undergone significant changes in recent years. Changes in workforce levels and ownership patterns have both had major influences on the implementation of precision forestry (PF). This paper defines precision forestry and describes the development of precision forestry in the southeast U.S. Early PF activities quantified impacts from harvesting operations and measured productivity of harvesting machines. Today, primary uses of PF techniques have started to focus on silvicultural operations and emphasize site-specific mechanical and manual herbicide and fertilizer application techniques. These are areas where PF can have an economic impact for landowners' providing spatial feedback to ensure services were performed correctly while providing environmental and worker assurance documentation. New technology is being developed for mapping yields in tree-length harvesting systems for site-specific feedback about production. Future developments in PF are also discussed.

Keywords: GPS, machine productivity, yield mapping, planting, herbicide.
INTRODUCTION

“Precision forestry” (PF) is a relatively new phrase that has become part of the vocabulary of the forest engineering - forest operations community. This term is similar to those frequently used in agricultural production circles, i.e. “precision agriculture,” “precision farming,” or “site-specific agriculture.” Over the last 20 years, the concepts of precision agriculture have been refined into a definition that most people will accept. That is, precision agriculture can be defined as managing crop inputs, such as fertilizer, herbicide, etc. on a site-specific basis to reduce waste, increase profits, and maintain the quality of the environment.

Initially, one would think that the term “precision forestry” should have a very similar meaning to the frequently used “precision agriculture” term. Yet, as several international symposia and technical sessions at international meetings have attempted to synthesize, based on the current body of knowledge on PF, it is evident that the term PF has many different meanings depending on who uses the term (Becker, 2001; Dyck, 2003; Farnum, 2001). While many of the aspects of precision agriculture can be applied to forest management, the considerable differences between the two industries require a different, broader definition for precision forestry. Therefore, the objectives of this paper are to:

1. Discuss and define the term precision forestry in the context of forest operations, and
2. Discuss the development of precision forestry in the southeast U.S.

PRECISION AGRICULTURE CONCEPTS

Precision or site-specific agriculture techniques are centered on a database of geospatial information including soil fertility, soil variables, crop yield, in some cases crop quality, and different geospatial information on cropland. Many harvesting machines now have yield monitors that collect continuous geospatial data on the amount of the crop being harvested as a function of location in the field. When yield maps are combined with soil fertility and other soil type maps, management units within a field can be defined called management zones. Then, each management zone can have its own prescribed rates of fertilizer, herbicide, pesticide, and more recently, irrigation. Using variable-rate technology (VRT), the rates at which these inputs are applied can be changed as the applicator moves across the field based upon the rates assigned to these management zones. The ability to change fertilizer, herbicide, and irrigation application rates to suit the needs of each management zone leads to a more efficient use of these inputs, thereby possibly reducing production costs, reducing environmental impacts, or maximizing production in each zone.

PRECISION FORESTRY DEFINED

Since there are several differences between the forest products industry and the agricultural sector, all of the concepts of precision agriculture are not directly applicable to forest production systems. Moreover, there are different applications in forest management that can be considered part of PF. We choose to define PF as follows:
Precision Forestry - planning and conducting site-specific forest management activities and operations to improve wood product quality and utilization, reduce waste, and increase profits, and maintain the quality of the environment.

Further, we separate PF into three main categories:

1. Using geospatial-information to assist forest management and planning;
2. Site-specific silvicultural operations; and
3. Advanced site-specific technology to meet market demands for higher valued products.

The common thread in all three of these areas of PF is the emphasis on site-specific practices and geospatial technologies. Rather than conducting operations at the stand level, operations and activities are conducted in smaller management units or zones within the timber stand. The following text briefly defines each of these three PF categories.

**FOREST MANAGEMENT AND PLANNING**

This area of precision forestry encompasses a wide variety of activities that use geospatial information to assist in the site-specific management of forests and planning of future operations. This actually encompasses many current management and planning activities since many industrial and private landowners use geospatial tools to manage their land bases. Traditional examples would include using geographic information systems (GIS) to help develop management plans for forested areas; however, what makes these activities fit under the PF umbrella would be an emphasis on site-specific management.

New examples of this type of precision forestry include the use of information technology to optimize the transportation routes of wood products from the forest to their most appropriate processing location. Advances in wireless communication are at the point where much of this information can be shared from the harvesting machine directly to transportation dispatching services and to the manufacturing facilities. Another example of site-specific management and planning is the use of something similar to an agricultural yield map for collecting site-specific performance on a timber tract and using this information to develop site-specific management plans. Recent developments in forest yield mapping are discussed in the latter part of this paper.

**SITE-SPECIFIC SILVICULTURAL OPERATIONS**

Site-specific silvicultural operations involve the use of geospatial technologies, such as the global positioning system (GPS) and GIS, to improve operational efficiency and reduce the cost of wood fiber. This involves using much of the technology developed for precision agriculture. Example technology includes using GPS and variable-rate technology (VRT) to improve the efficiency of herbicide spraying or fertilizer application. Control systems and field computers are available to give real-time guidance information to the machine operator so they minimize areas of overspray and areas where they fail to spray along with
assisting operators when navigating during operations. This technology is readily available and is currently being used in forest operations in the U.S.

Other examples of new technologies include radio frequency identification (RFID) and GPS-based steering systems have great potential for use in silvicultural operations. Temperature recording RFID tags can be used to track the conditions in which tree seedlings are lifted, processed, transported and stored before planting. This temperature data can be combined with information on who planted the tree, when it was planted, and where it was planted (using GPS data) to help landowners better understand tree seedling survivability. GPS-based steering systems are being used frequently for guidance for agricultural tractors. However, these systems also have the potential to provide guidance for forestry site preparation operations (both tillage and herbicide or fertilizer application). Rows can be more precisely established to minimize erosion and to maximize the number of trees planted on the site.

Site specific silvicultural operations will continue to expand because the development of precision agriculture technology continues to progress at a rapid pace and most of this technology can be readily adapted to silvicultural operations. Also, forest industry trends of consolidation and workforce reduction are encouraging more automation and data collection for verification of services.

ADVANCED SITE-SPECIFIC TECHNOLOGY TO MEET MARKET DEMANDS

Two of the largest components of the cost of wood when it is delivered to the mill are harvesting and transportation. These high costs directly impact forest landowners’ bottom line by reducing the income they receive. Significant transportation costs and energy savings to the industry can be realized if a coordinated geospatial-technology-based harvesting and transportation approach is used. In such a system, it is possible to collect data on location and volume of trees as they are felled during the harvest. These data can be shared through the entire procurement and manufacturing chain to improve efficiencies. Example uses include optimizing the skidding or forwarding process using the product type and location data of logs on the ground, and optimizing trucking scheduling by knowing the inventory and location of logs harvested.

Also, most current production systems are very inefficient in the methods employed to evaluate raw materials for future production. “Tree-length” harvesting systems, which are the most common in the southern U.S., cut trees and transport tree-length logs to mills, where logs are processed; however, this may not be the ideal location for any given log or part of it. The end result is multiple sorting and transportation steps before the final product is made (and even then, it may not have been the optimal use of the log). New sensors can be used in the woods or at the time of harvest to evaluate the quality of trees or logs and then determine the best use of that tree or log (Wang et al., 2003 and Murphy, 2003). After sensing the quality of a tree or log and determining its best future use, GPS and other information systems can monitor its location and schedule shipping directly to the best manufacturing plant. This type of system will eliminate unnecessary transportation steps, saving costs and energy while potentially maximizing profits for timber stands. For example, this type of system can identify higher value
products, like veneer logs or high-stiffness lumber, in a given timber stand, so they can be segregated from other lower value logs to increase the return on the landowner’s investment.

DISCUSSION

There are several key components in these three categories. The primary component that is common to all forms of precision forestry is the use of geospatial technologies such as GPS, GIS, remote sensing, LiDAR, etc. as tools to assist in site-specific forest management, planning, or silvicultural operations.

A second component in precision forestry is the development and use of an extensive information base to help make management and operational decisions. This information base could include data on product growth and yield, product quality, and environmental conditions as a function of location and time. A critical part of this use of information is the feedback mechanism that is possible. In other words, it is possible to take the geospatially attributed data on yield and product quality and use it to validate and refine growth and yield models so that future management strategies can increase return on investment for the landowner.

A final concept in precision forestry is that of defining the most appropriate management unit. As a start, this would involve examining stand maps, terrain information, soil maps, and soil fertility maps along with other information such as wildlife habitat, etc. Eventually, this should incorporate the development of yield maps but with additional information on product quality. Once the size or number of management units is determined, more focused management and operational decisions can be made on site-specific bases.

One of the primary goals of precision forestry is the gathering of site-specific information for various users. These users include forest landowners, forestry consultants, and forestry contractors. This information can be used ultimately by the landowner for verification of services provided by contractors, improving management decisions, and for certification purposes for programs like the Sustainable Forestry Initiative. Industry trends in the southeast U.S. that have influenced this need for more verification data include consolidation of the industry into fewer industrial landowners and the concomitant reduction in staffing levels. With fewer employees, these landowners are relying more and more on contractors to provide electronic data that verifies that the work was performed in a specific location and specific time.

Precision forestry should not mean that every operation is computerized or automated. Many site-specific silvicultural operations can be conducted in a cost effective manner without being automated. What it should mean is that the management process or operational activity is focused on making decisions for the smallest practical management unit area or number of management units within a given tract or management area. For example, this could determine how much fertilizer or which herbicide is applied at a particular location on a tract.

Using many of these concepts, we can envision that these geospatial technologies can help the forest products industry adopt scenarios similar to the following:
1. Develop yield maps during harvesting operations. From the yield maps, begin to quantify variability in wood quality and wood fiber production rates as a function of location.

2. Once variability is quantified, identify site conditions that contribute to that variability (e.g., soil type, soil fertility, moisture conditions, etc.).

3. Track the types and dates of operational practices and prescriptions that are carried out during the rotation (fertilization, herbicide application, seedling quality, planting methods, etc.). It may be possible to track tree growth during the rotation using remote sensing data or other methods on the ground.

4. With a record of these data, begin to conduct comprehensive analyses to determine what contributes to spatial and temporal variability in seedling survival rates, wood fiber growth rates, and final wood quality.

5. Using these conclusions, determine the most appropriate management unit size or number of management units for the operations.

6. Using these management units and the previously collected data, plan future silvicultural operations for the same rotation or the subsequent rotations. Fertilizer and herbicide application rates, planting density, etc. can be varied as a function of location depending on the site conditions.

7. At the time of the next harvest, product type and quality can be recorded and even used in determining the optimal use for the product as well as the optimal destination for further processing of the product.

**PRECISION FORESTRY IN THE SOUTHEAST U.S.**

The evolution of precision forestry techniques in the southeast U.S. began with the rapid use of GPS and other geospatial technologies in forestry in the early 1990’s. Industry consolidation and increasing foreign competition since 2000 have forced the industry to reduce workforce levels and reduce other operational costs. These efforts at cost reduction have led to a greater reliance on contractors to provide mapping and GIS services and operational services for silvicultural operations such as site preparation, planting, etc. To provide verification of these services, the industrial landowners are relying more and more on electronic geospatial data supplied by the contractor. These data provide verification of the time at which the services were provided, location at which they were done, workers who conducted the work, chemicals applied at each location, and weather data during the operation at the site. These needs for data have led to increased development of precision forestry technologies in the southeast U.S. The following text describes initial work in using GPS for quantifying machine productivity, performance, and environmental impacts; implementation of precision technologies for herbicide and fertilizer application; and developing techniques for mapping growth and yield on a site-specific basis.

**QUANTIFYING PRODUCTIVITY AND PERFORMANCE OF FOREST MACHINE SYSTEMS**

**Estimating Harvesting Impacts from GPS Machine Tracking**

In the early 1990’s, forest industry practitioners and researchers began to use the Global Positioning System (GPS) for forestry mapping activities. Early studies postulated that GPS could be used to track forest machines to help automate
machine productivity determination. McDonald et al. (1998a) presented a method to use GPS tracking data to determine the area impacted by a machine as it traveled over a site. The method, which was similar to one presented by McMahon (1997), used pairs of x,y position data to represent sampled locations of a machine, then assumed that machinery moved linearly between adjacent location samples. These data were transformed into a map showing how many times the machine passed a given location. Final output of the transformation was a raster map, with cells in the raster having a value equal to the number of times the object, or machine, passed over a particular location in a rectangular region.

The model was tested initially by using data collected from a rubber-tired skidder working in part of a clear-cut harvest. Several features of the harvesting operation were discernable from the mapped paths: the deck or landing, the deliming area, the main skid trail, and the return skid trails. Although they did not conduct any detailed position error determination, they concluded that overall the calculated travel patterns matched the true machine movements closely enough for stand-level assessments of operational productivity.

In a later study, McDonald et al. (1998b) and Carter et al. (2000a) used identical methods to map the travel paths of feller bunchers and skidders over an entire harvest tract. The output from this study was a traffic map of cumulative totals of traffic intensities and their distribution in the tract. Figure 1 shows the traffic intensity map resulting from this study. They found that 25 percent of the stand received no traffic, 25 percent received more than five tire passes, and 50 percent received one to five tire passes. When visual disturbance assessment methods were compared with GPS estimated traffic intensities, the visual methods overestimated the presence of heavily trafficked areas. They noted that the GPS-based method was superior to the traditional methods because it was less time consuming and presumably more accurate.

![Traffic Intensity Map](image)

**Figure 1.** Harvest traffic intensities (number of machine passes indicated by different colors) as monitored by a GPS data logger during a clear-cut harvest of a loblolly pine plantation (adapted from Carter et al., 2000a).
Carter et al. (1999, 2000a, 2000b) presented detailed results of the soil physical responses measured during the study introduced by McDonald et al. (1998b). They assessed the impact of traffic intensity on spatial variability of soil physical properties by measuring changes in the properties at select points that corresponded to estimated traffic intensities within the harvest tract. They found that bulk density and cone index responded to increased traffic intensities and achieved peak values after a limited number of passes. This ability to compare detailed data on traffic intensities with soil strength properties would not have been possible without integration of GPS into the impact assessment process.

**HARVESTING MACHINE TRACKING – AUTOMATED TIME STUDY**

The machine tracking work begun by McDonald et al. (1998a, 1998b, 1998c) was extended to facilitate time and productivity study of harvesting machines by McDonald (1999), McDonald et al. (2000a, 2000b), and McDonald and Fulton (2005). The system to develop time study data solely from GPS position information was implemented using two components: 1) a feature extraction sub-system to identify characteristics of a machine path, given some site-level information, independent of the type of machine being tracked, and 2) an event processor that applied machine-specific knowledge to combine characteristic movements and sub-events into operational functions. The intention was to develop a system that was useful to analyze the functional performance of any type of machine where movement and position were important factors in its operation.

McDonald et al. (2000a) conducted further research using GPS for unattended time study of grapple skidders. The GPS data were reduced to movement-defined events, then movement events were combined into machine functions, and elemental times (travel loaded/empty, delimbing, positioning and grappling) were determined. For gross time study measurements, the data acquisition system performed well, recognizing over 90 percent of the time elements. These methods also have been applied to automating time study of wheeled feller bunchers (McDonald et al., 2000b). In addition to collecting GPS position data, a field computer in the machine monitored the states of two switches that indicated feller buncher activity: 1) cutting a tree as indicated by micro switches on the foot pedals that controlled the felling head grabbing arm, and 2) felling head tipping as indicated by a set of magnetic switches mounted on the felling head linkage. Figure 2 shows a map of feller buncher movements across a study plot as well as the locations of tree cut and head dump events as indicated by the data acquisition system. The system performed well in a gross time study, and for individual felling cycles the automated system agreed well with traditional time study methods. With more accurate information on the location of cut trees and with an additional system to measure tree size, it will be possible to measure yield across the site.
New GPS-based data collecting systems have since been developed for use in the forest products industry. Turcotte (2003) described the use of the MultiDAT system for determining harvesting machine utilization. This commercially-available data collection system is able to collect data similar to that described in the early studies by McDonald et al. but it has more flexibility and software tools than those used in the early machine tracking studies. These commercial systems will continue to develop and increase in functionality and geospatial accuracy and robustness.

SITE-SPECIFIC SILVICULTURAL OPERATIONS

Currently, most operational precision forestry activities in the southeast U.S. are in site-specific silvicultural operations. These silvicultural operations include site preparation, planting, fertilization, herbicide and insecticide application, thinning, pruning, and final harvest. This section will describe ground-based machines that are being used for herbicide and fertilizer application. Another paper being presented by McDonald et al. in this same proceedings, describes in detail new developments in GPS-assisted manual spraying and planting systems. These manual systems are proving extremely valuable in the certification of services conducted by the forestry contractor.

Regional Herbicide Applicator Trends

Site-specific application of herbicides and fertilizers is the most frequently used precision forestry technique. Noteworthy developments include more efficient ground-based machines for herbicide and fertilizer application, “smart” systems for aerial spraying, and “smart” backpack spraying systems. Informal surveys of forestry herbicide application contractors in the southeast U.S. indicate that there are approximately 400 contractors in the region that stretches from Virginia to Texas. Of these contractors, approximately 30 use ground based machines equipped with GPS-based guidance systems. Three contractors have implemented advanced GPS-based guidance and control systems for their equipment. Across the region, there are approximately 35 contractors who use...
aerial systems for chemical application. All aerial applicators use some form of GPS-based guidance system for their aircraft today.

**Precision Ground-Based Spraying Machine Systems**

One innovative silvicultural contractor in the southeast U.S., Woodlands Specialists Inc. has developed several ground-based machines that use GPS guidance and variable-rate controllers. Taylor et al. (2002) described one such machine that was configured for post-planting herbicide and fertilizer application. The machine, referred to as the WS Sprayer, is shown in Figure 3 and is constructed on the same chassis used for a wheeled feller buncher. Herbicides are not tank mixed; rather the machine contains one main 500 gallon water tank with chemicals injected at the nozzles. This design allows many different chemicals to be placed on the machine and used only when determined by the operator or the spray controller. Variable-rate pumps are used to deliver chemicals to the spray nozzles. An additional 250 gallon tank is mounted on the rear of the machine. This tank allows liquid fertilizer to be applied. When not in use for fertilizer, the tank can hold additional water for herbicide spraying.

![Figure 3. Photograph of WS sprayer configured for banded spraying. Inset shows the field computer and spray control equipment mounted in the cab.](image)

A MidTech TASC spray controller, coupled to a field computer, was used to control chemical injection and monitor navigation of the machine. The controller uses GPS to determine machine location and speed. The controller also monitors water flow rate, band width, and herbicide application rate. Using these inputs, the control system can maintain the desired application rates by properly adjusting the amount of injected chemical based on ground speed fluctuations. This type of variable-rate control is critical to maintain efficient chemical usage as the ground speed of forestry sprayers can be highly variable.

Herbicides are injected in their original concentration from the manufacturer, except for dry flowable formulations such as Oust, Oustar, and Velpar by this control system. Using the injection system means that there is no measuring or mixing required of a chemical, which minimizes operator exposure to herbicides. Also, there is no leftover tank mix solution to dispose of at the completion of the tract; only the amount of product needed on the tract is applied. In its current configuration, the sprayer can inject three different products simultaneously;
however, up to six injection pumps can be used on the machine. Spraying prescriptions can be easily changed using the control console.

The spray control system provides a field computer display and a light bar so the operator can observe where they have sprayed and where they need to steer the machine. By comparing this real-time map to maps provided by the customer, the operator can insure that all designated areas are treated. There is also the capability to download a digital tract map from the customer to the field computer before beginning the tract. Finally, an “as-applied” map is stored in the controller that can be downloaded and provided to the customer for incorporation into a GIS database. A typical “as-applied” map is illustrated in Figure 4. This map shows the machine path as it is spraying and it indicates areas that were not sprayed.

![Figure 4. Typical “as-applied” map illustrating sprayer transverse (blue lines) when spraying was activated. Light gray regions depict areas not sprayed.](image)

<table>
<thead>
<tr>
<th>Acres</th>
<th>Owner GIS</th>
<th>Herbicide</th>
<th>Tractor GPS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>82</td>
<td>79</td>
<td>77</td>
</tr>
</tbody>
</table>

The machine has been configured for two types of operation: 1) broadcast spraying and 2) banded spraying. In broadcast spraying, two Radiarc nozzles are mounted on the upper rear portion of the machine so that a 50-ft-wide strip can be sprayed during chemical site preparation or during understory release spraying. The Radiarc nozzles provide a uniform spray pattern and uniform droplets of large diameter to reduce drift. In banded spraying, booms with six TeeJet® spray nozzles on a common manifold are mounted on the front of the machine. These nozzles are shielded, positioned close to the ground, and operated at low pressures to also reduce drift when conducting a spraying operation. The booms are configured to spray a band of herbicide directly over three rows during a single pass by the sprayer. Also, liquid fertilizer can be applied along the row using the same booms.
By applying the herbicides and fertilizer in a band over the row, only those areas close to the trees are treated, thereby reducing approximately 2/3 of the total herbicide and fertilizer applied to a tract. Studies have shown that by applying the herbicide in a 4-ft-wide band around the tree, the growth response is the same as in broadcast herbicide applications. Also, by applying the fertilizer in a band, it is left in a concentrated area a few inches from the tree, providing a more effective burn down. In addition, by applying the fertilizer in a band, the total amount of fertilizer applied to the tract is much less than needed compared to the traditional broadcast application. The effect of this fertilization method on seedling growth rates has not been quantified.

Cost data for this new machine indicated that it can apply herbicide at a rate nearly half of that of aerial application methods. By performing a more site-specific application of herbicides and fertilizers, and by combining operations to limit machine passes, the cost of herbaceous weed control can be reduced significantly. Perhaps just as important as reducing cost, the use of herbicides and fertilizers can be reduced by two-thirds in this when implementing this type of management scheme.

An additional benefit of this type of operation is that the locations of the rows are established by the GPS track of the sprayer. This map can serve as the beginning of the complete geospatial history for a tract. In fact, the machine is capable of using a dye to mark the potential tree seedlings planting locations and geospatially document these sites for future mapping or analyses. This ability to mark the recommended tree location is important for manual tree planting operations since during winter planting operations, it is often difficult to distinguish the location of the herbicide treated rows, since all the surrounding vegetation is dead as well.

A second generation machine, constructed in 2003, was designed to apply banded both herbicides and liquid fertilizers simultaneously before planting seedlings. This sprayer (Figure 5) was constructed on a typical wheeled skidder carrier with water tanks mounted behind the cab and spray booms located at the rear of the machine. Since the sprayer is designed to apply herbicide in a band over the row before planting (i.e., the sprayer defines where the rows of trees will be planted in subsequent operations), additional equipment was installed on the sprayer to apply paint markings on the ground to identify row location. This row delineation indicates to manual or mechanical planting operators where the trees should be planted in order to take advantage of the herbicide and fertilizer. A GPS-based spray control system and field computer is used. As discussed earlier, the “as-applied” map provides a valuable product geospatially illustrating an activity completed. Since many industrial forest landowners have reduced staffing levels, the “as-applied map” produced by the contractor reduces the landowner’s need to send personnel to the tract to ensure that the job was completed within contract specifications.
CONCEPTS IN FOREST YIELD MAPPING

Yield maps and the associated soil, fertility, and terrain maps are fundamental elements in site-specific or precision agricultural practices. The data available in these maps can assist the land manager identify sources of yield variation, which in turn help formulate strategies to improve yield and ultimately profit. The concept of a timber yield map is not quite as simple as in agricultural crops since the crop rotation length is much longer in forestry. Typically, agricultural producers can collect yield maps yearly for cropland; in some cases two per year in double-cropping situations. Additionally, forest management could conduct multiple thinning operations coupled with the impact of environmental and other management events over the life of the rotation can influence growth and the final yield of a timber tract. However, a yield map can provide valuable information to the management of a timber production system.

Many researchers and practitioners have investigated methods to use LiDAR and other remote sensing techniques to quantify timber stand volumes and growth (Andersen et al., 2001 and Andersen et al., 2003). Research at Auburn University has been focusing on developing yield mapping techniques based on using information collected by the harvesting machine at the time of felling and tree processing. Current work is centered on the platform of the feller buncher since tree length harvesting systems are the most common harvesting system in the southeastern U.S.

Research by McDonald and Fulton at Auburn University has been developing and testing various sensors that can be placed on the felling head to determine the diameter of the tree as it is severed from the stump. While the optimal sensing system has yet to be determined, an optical sensor device attached to the felling head has been tested in the laboratory and in the field and appears to be the most promising method. To validate these sensors and to help develop concepts of yield mapping in forestry, test sites have been established where detailed tree measurements have been made using traditional manual techniques combined
with high accuracy GPS for geospatial location. Example results, from one test site, are illustrated in Figures 6 through 9. This particular test site, which has a total area of 3.6 Ha, has a stand density of 599 stems/Ha, a mean DBH of 14.0 cm, and mean tree height of 17.8 m.

**Figure 6.** Tree diameter (DBH) map for the 3.6 ha test site.

**Figure 7.** Generated digital elevation model for test site.
Figure 8. Proposed management zones for test site.

Figure 9. Generated value map (US dollars) overlaid onto the proposed management zone layer.
Figure 6 depicts the basic map of tree size and tree location. This map is indicative of what would be collected during a final harvest using a feller buncher equipped with a diameter sensing systems in a cut-to-length system. Figure 7 is a plot of the digital elevation model (DEM) generated for the site. The DEM shows how the terrain slopes downward when panning from left to right on the map. Along the right edge of the tract, the area starts to level out into a flood plane where a stream exists several meters away from the tract boundary. One can tell that the tree DHBs significantly differ within this area (Figure 6) and it could be considered as a unique zone to manage differently from other areas of the tract. Examination of the “yield map” in Figure 6 shows that other zones exist where tree size and density is distinctly different while these regions also vary with elevation changes. These differences in tree size and density may be related to soil fertility and soil moisture variability when moving down the slope. The map also reveals evidence of a previous fifth row thinning. After examining the yield map, one could segregate the tract into four different management zones based on the characteristics of the timber in each zone (Figure 8). Future decisions on thinning or final harvest may be varied now based on these management zones. More importantly, if this was information collected at the final harvest, it could be combined with other soil type and fertility maps to plan for the subsequent stand establishment which could be enhanced having this type of spatial data available at one’s finger tips. One of the final output products of such a map is a value map (Figure 9). This map depicts how tree value varied across the tract. It also indicated that the overall total value of the stand is estimated at $28 034 USD. Table 1 provides details of area, density, basal area, and total value per zone for this tract. Providing site-specific data like these can assist landowners make more informed site-specific management decisions to help maximize profit and achieve long term stand goals.

<table>
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<th>Zone Area (ha)</th>
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**SUMMARY**

Precision forestry is a rapidly developing field finding many applications in the forest products industry. We define precision forestry as planning and conducting site-specific forest management activities and operations to improve wood product quality and utilization, reduce waste, increase profits, and maintain environmental quality. Precision forestry can be categorized into three main areas: 1) using geospatial-information to help make forest management and planning decisions; 2) conducting site-specific silvicultural operations; and 3) advanced site-specific technology to meet market demands for higher valued products.

Researchers and practitioners in the southeast U.S. are applying these geospatial based technologies in many different areas. Early work used GPS-based systems
to study the performance and productivity of harvesting and site preparation machines. Currently, the most common use of precision forestry is in site-specific silvicultural operations such as herbicide spraying and fertilizer application. New systems for GPS-assisted manual spraying and planting are increasingly being used for certification of services provided by contractors and compliance with environmental and labor regulations. Finally researchers are developing the concepts of yield mapping to help land managers make more site-specific management decisions to improve growth, yield, and ultimately profit. We see precision forestry continuing to advance in the southeast U.S. providing technologies and management systems to improve the productivity and efficiency of the forest products industry.

REFERENCES


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