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Planning Optimum Logging Operations through Precision Forestry Approaches

Nese Gulci [1*], Abdullah E. Akay[2], Orhan Erdas[1], Michael G. Wing[3], John Sessions[3]

[1] Kahramanmaraş Sütçü Imam University, Faculty of Forestry, 46100 Kahramanmaraş, Turkey

[2] Bursa Technical University, Faculty of Forestry, 16330 Bursa, Turkey

[3] Oregon State University, College of Forestry, 97331 Corvallis, Oregon, USA

Abstract

In this study, it was aimed to determine optimum logging operations by using Geographical Information System (GIS) techniques as one of the effective tools of a precision forestry approach. In the first stage of the application process, a high resolution Digital Elevation Model (DEM) of the study area was produced by using Real Time Kinematic GPS in the field. Then, the DEM was used to classify the area into slope classes specified by the International Union of Forest Research Organizations (IUFRO). A map for the optimum logging operations was generated for two scenarios (i.e. maximum productivity and minimum residual stand damage) considering current terrain conditions. Four different logging methods were evaluated: ground skidding logs using a portable winch integrated with skidding cone, winching logs by using a farm tractor, downhill sliding of logs by chute system with gravity, and controlled sliding of logs downhill by chute system integrated with portable winch. During the assessment of logging methods, the results from the previous empirical studies conducted in similar stand characteristics and topographical conditions were used. For both scenarios, results indicated that skidding by portable winch integrated with skidding cone was the optimum logging method for more than half of the study area, followed by downhill sliding by chute system and controlled sliding by chute system integrated with portable winch.

Keywords: Logging operations, Precision forestry, GIS, RTK-GPS

1. Introduction

The extraction of wood based products is performed by three main harvesting systems; cut-to-length, tree-length, and full-tree (Uusitalo, 2010). Cut-to-length (CTL) is the most common system in which trees are felled, delimbed, and bucked directly at the stump. Even though CTL is the primary system, full-tree and tree-length systems are also implemented in some parts of the world.

Based on terrain conditions and availability of mechanization, felled logs are transported from stump to landing areas by using various logging methods. The logging methods should be carefully selected since they closely affect the cost of harvesting operations (Akay and Sessions, 2004). The logging methods are also the most important factors that can cause serious damage on forest stand if they are not planned properly (Seablom and Reed, 2005; Akay et al., 2006; Akay et al., 2007).

The forest resource should be managed according to principles of precision forestry which aim to provide optimum productivity from forest resources and to minimize environmental damage. These objectives are met by modern analytical and measurement techniques so support economic, environmental, and sustainable decisions in forestry activities (Gulci, 2014). Therefore, the optimum logging method should be selected to ensure sustainable management of forest resources (Eroglu, 2012).

The logging method is evaluated based mainly on physical properties of the terrain, and in particular the ground slope of the terrain is considered as one of the primary properties. The ground slope classes suggested by the IUFRO for logging operations include gentle slope (0-10%), low slope (11-20%), medium slope (21-33%), high slope (34-50%), and steep slope (>51%) (Gulci et al., 2015).

Fully mechanized harvesting systems combined with harvester, feller-buncher, forwarder, and other machinery are used in North America and Europe during forest operations. In Turkey, most of these machines are not currently applied in forest operations due to high purchase prices, high operating cost correlated with fuel price, topographic conditions, and

[*]Corresponding author: Tel: +90 3442801731 E-mail: nesegulci@gmail.com

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negative effects on workforce (Akay and Sessions, 2004). On flat and gentle slope terrains in Turkey, farm tractors and small size skidders are usually used to skid logs on the ground. The logs are pulled by a winch system mounted on farm tractors or skidded by skidders on medium slope terrains. Since road construction is a very difficult and costly operation on high slope, skidders are used to pull logs from stump to road sides by cable (Gulci, 2014). In addition, chute and cable logging systems are also preferred to extract woods on forested areas with high ground slope. On steep slope terrain, forest road construction can be economically infeasible and environmentally detrimental, thus, logs are only transported by cable logging systems.

Given that ground slope is the main factor in determining the optimum logging method, accurate slope maps should be generated based on high resolution DEMs. The modern and technological tools of precision forestry approach can be employed to produce accurate slope maps (Figure 1).

In this study, the optimum logging operation is determined based on productivity of logging methods, stand damage and topographical conditions. GIS techniques and ground survey measurements, as effective tools of precision forestry approach, were implemented on a sample study area to generate a map for the optimum logging operations. The ground slope map was classified based on slope classes designated by IUFRO. Then, two scenarios were evaluated; maximum productivity and minimum residual stand damage.

2. Materials and Methods

2.1. Study Area

The study area was selected from Bahçe Forest Enterprise Chief of Osmaniye Forest Enterprise Directorate at Adana Forest Regional Directorate in Turkey (Figure 2). The study area comprised 67 hectares with 57 hectares covered by forest with the dominant tree species being Brutian pine (*Pinus brutia* Ten.). The average ground slope and elevation was 32.73% and 683 m, respectively.

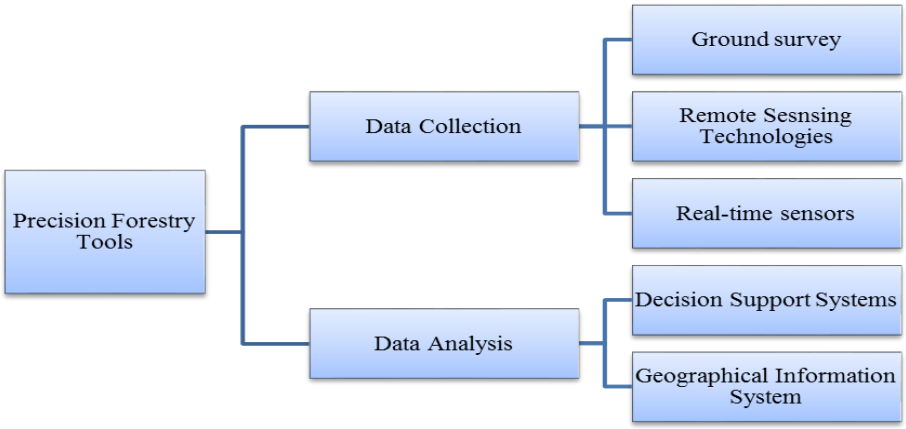

Figure 1. The tools of precision forestry approach (Taylor et al., 2002)

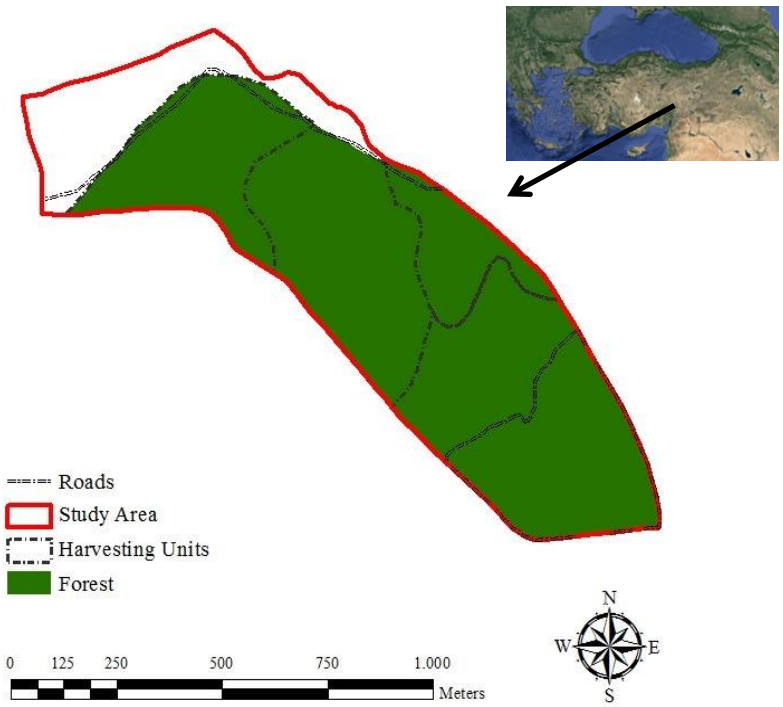

Figure 2. Study area map

2.2. Slope classes

The high resolution DEM was generated for the study area through measurements collected by using a Real Time Kinematic (RTK)-GPS system. A South S82-V model RTK-GPS with a data logger was used in the field to collect elevation data points. Then, the DEM was used to produce a slope map by using the 3D Analyst tool within ArcGIS 9.3. The slope classes were determined based on IUFRO slope classification suggestions for logging operations (Gulci, 2014). Due to available logging methods considering in this study, gentle and low slope classes were combined under into a single slope class (0-20%). Therefore, the study area was divided into four slope classes (Table 1).

2.3. Optimum Logging Methods

In the study, four different logging methods were evaluated: ground skidding logs using a portable winch integrated with skidding cone, winching logs by using a farm tractor, downhill sliding of logs by chute system with gravity, and controlled sliding of logs downhill by chute system integrated with portable winch. The map for the optimum logging operations was generated for two scenarios considering current terrain conditions. For the first scenario, logging methods with maximum productivity were considered, while the methods with minimum residual stand damage were evaluated for the second scenario. Results from the previous studies, conducted in a region with a similar stand type and topographical properties, were used during the solution process (Gulci, 2014; Sert, 2014; Akay et al., 2014). Table 2 indicates the average productivity and stand damage results from these studies.

Table 1. Slope classes

Slope Classes	Ground Slope (%)
Gentle and low	0–20
Medium	21–33
High	34–50
Steep	> 50

Table 2. Productivity and stand damage values of logging methods from previous studies (Gulci, 2014; Sert, 2014; Akay et al., 2014)

Logging Methods	Average Productivity (m^3/hour)				Number of Average Residual Stand Damage			
	Gentle and Low Slope	Medium Slope	High Slope	Steep Slope	Gentle and Low Slope	Medium Slope	High Slope	Steep Slope
Ground skidding logs using portable winch integrated with skidding cone (PW)	5.76	4.97	4.51	-	2.30	3.33	4.33	-
Winching logs using farm tractor (TW)	-	-	4.67	4.14	-	-	15.50	29.00
Downhill sliding of logs by chute system with gravity (CS)	-	4.24	5.84	-	-	3.00	5.00	-
Controlled sliding of logs downhill with chute system and portable winch (CCS)	-	-	-	7.83	-	-	-	4.00

3. Results and Discussion

The high resolution DEM of the study area was generated based on X, Y, and Z coordinates from data collected by a RTK-GPS system in the field. A map of the slope classes was produced based on the DEM. The results indicated that 36.9% of the study area was on high slope terrain, while 34.1% and 17.8% were on medium slope and gentle and low slope terrains, respectively (Table 3 and Figure 3). The rest of the field (11.2%) was on steep slope terrain.

After generating slope characteristic, optimum logging methods were chosen from among the alternative methods based on terrain conditions. Besides, logging methods were evaluated for each slope class considering two scenarios seeking either maximum productivity or minimal stand damage.

For the first scenario (maximum productivity), ground skidding logs using a portable winch integrated with skidding cone was the optimum method on medium slope and on flat and low slope terrain. A downhill sliding chute system was selected for the high slope terrain. A controlled downhill sliding chute system with portable winch was selected as the optimum logging method for maximum productivity on steep slope terrain. Table 4 indicates areal distribution of the logging methods.

It was found that ground skidding logs using a portable winch integrated with skidding cone was the optimum logging method for 51.9% of the study area, followed by downhill sliding chute system (36.9%) and controlled downhill chute system with portable winch (11.2%). The results indicated that productivity decreases as ground slope increases for winching timbers by farm tractors and portable winch (Gulci, 2014). On the other hand, productivity tends to increase on high slope terrains for downhill chute systems (Cankal, 2013). Figure 4 indicates the map of the optimum logging methods for the first scenario.

Table 3. Areal distribution of slope classes

Slope Classes	Area (ha)
Flat and low slope (%0-20)	11.97
Medium slope (%21-33)	22.99
High slope (%34-50)	24.86
Steep slope (>%50)	7.52

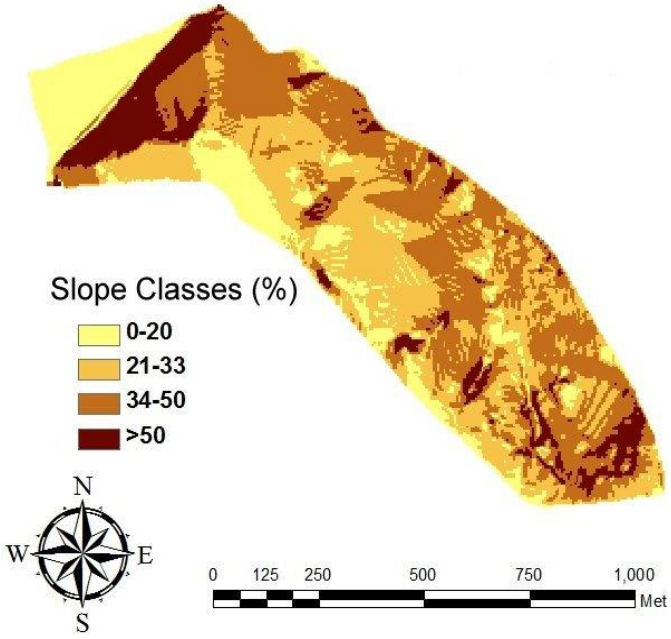

Figure 3. Slope classes map

Table 4. Areal distribution of logging methods for Scenario I

Logging Methods	Area (ha)
Ground skidding logs using a portable winch integrated with skidding cone (PW)	34.96
Downhill sliding of logs by chute system with gravity (CS)	24.86
Controlled sliding of logs downhill by chute system integrated with portable winch (CCS)	7.52

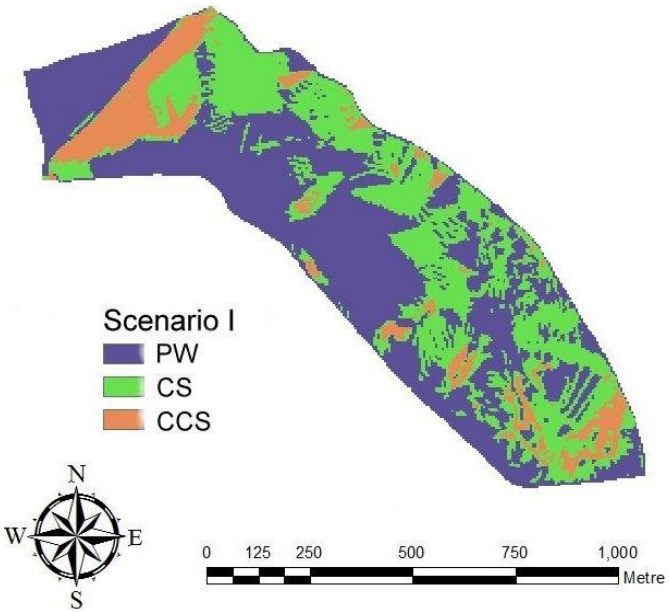

Figure 4. A map of optimum logging method for Scenario I

For the second scenario (minimal stand damage), ground skidding logs using a portable winch integrated with skidding cone was the optimum method on high slope and on flat and low slope terrain. A downhill sliding chute system was selected for the medium slope terrain. A controlled downhill sliding chute system with portable winch was selected as the optimum logging method for minimal stand damage on steep slope terrain. Table 5 indicates areal distribution of the logging methods.

Table 5. Areal distribution of logging methods for Scenario II

Logging Methods	Area (ha)
Ground skidding logs using a portable winch integrated with skidding cone (PW)	54.7
Downhill sliding of logs by chute system with gravity (CS)	34.1
Controlled sliding of logs downhill by chute system integrated with portable winch (CCS)	11.2

It was found that ground skidding logs using a portable winch integrated with skidding cone was the optimum logging method for 54.7% of the study area, followed by downhill sliding logs chute system (34.1%) and controlled downhill sliding logs chute system with portable winch (11.2%).

The results also indicated that winching logs by farm tractors may result in the highest residual stand damage (Gulci, 2014). Besides, stand damage increases as ground slope increases for winching by farm tractors and portable winch. Figure 5 indicates the map of the optimum logging methods for the second scenario. Thus, skidding by portable winch integrated with skidding cone was the optimum logging method for more than half of the study area for both scenarios.

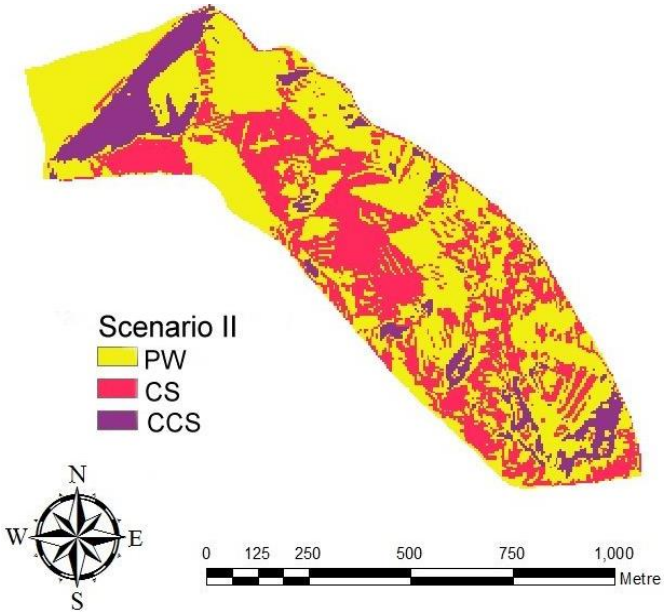

Figure 5. A map of optimum logging method for Scenario II

4. Conclusion

Within the concept of precision forestry, the optimum logging methods were evaluated based on GIS techniques and field survey data considering productivity, stand damage, and terrain characteristics. The results from the previous empirical studies, conducted in a region with a similar stand type and topographical properties, were used during the analysis. If a variety of logging equipment and machines are available, ground slope is the most important factor in determining the optimal logging method in most cases. Thus, precise ground slope data is critical in the success of forest operations planning.

In this study, high resolution DEMs generated based on RTK-GPS data were used to provide accurate digital maps displaying slope classes of the study area. Maps for the optimum logging method were generated for two scenarios considering four different potential logging methods. For the first scenario, logging methods with maximum productivity as a goal were evaluated, while the methods with minimum residual stand damage were considered as a goal for the second scenario.

The results indicated that ground skidding logs using a portable winch integrated with skidding cone was the optimum logging method for over 50% of the study area for both scenarios. It can be concluded that using a portable winch system during logging operations provides cost efficient and environmentally friendly alternative for logging. Using a skidding cone decreases the risk of hanging logs on residual trees, stumps, and other obstacles, which also leads to positive effects on skidding time and therefore productivity. The results also indicated that downhill sliding logs chute systems are the second most favored effective logging method for both scenarios. In chute systems, logs slide fast within the plastic pipes downhill which reduces travel time and prevents logs from damaging residual stands and other surrounding landscape features.

The sample applications presented in this study indicated that implementing modern precision forestry tools during planning of logging methods may provide important outcomes such as protection of forest resources, maximizing productivity of logging operations, and extracting high value and quality products. Thus, managing forest resources through precision forestry approaches may be beneficial in meeting current and future resource needs.

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