OPTIMIZATION OF TIMBER HARVESTING USING GIS-BASED SYSTEM

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Modern GIS software allows users to create cartographic models and to make specific spatial analysis for different application fields, such as forest operation sector.
In the present study, a spatial analysis was carried out to analyze the territorial constraints (slope, hydrographic network and hydrogeological risk) of a forest that do not allow the transit of workers and machines during forest harvesting operations. Moreover, a forest road network analysis was made to quantify density per hectare of forest roads (m/ha), and to identify the accessibility of forests, flat land 20-25 (m/ha) and steep terrain 30-35 (m/ha).
The results showed that the spatial (spatial constraints) and infrastructure analysis (forest road network) were useful to create thematic maps that allowed forest company to choose the proper mechanization and harvesting systems in terms of productivity and profitability.

Keywords: GIS, spatial analyst, timber harvest, forest planning.
Parole chiave: GIS, analisi spaziale, raccolta legno, pianificazione forestale.

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1. Introduction

In forest operation planning, several factors shall be considered for determining forest machinery and working systems to be used. Existing forest road network, operator's skills, available equipments for timber harvesting are factors that may be modified over time, while other conditions, such as cutting intensity, log size, and terrain features (slope and ground condition) are rather rigid or not modifiable (Civitarese *et al.*, 2006).
For ground features and for quantification of the road network assessment, it may be convenient to use high-tech systems such as GIS (Geographic Information System)
The spatial analysis on the forest through GIS soft ware along with field and machinery characteristics survey may be used to optimize the work in forest.
There are many experiences within forestry sciences based on the management of digital territorial data through GIS software (Pira and De Natale, 1999) used to access road infrastructure network in the forest (Scrinzi *et al*., 1999), not lacking experiences of three-dimensional visualization of the landscape (Civitarese and Pignatti, 2005), or forest exploitation (Cavalli and Lobello, 2005).
The basic requisite for correct management of a timber harvesting site in a forest area is the knowledge of suitability of the machine to be used in the various operations (Curro and Verani, 1990).
The time consumption of timber harvesting is studied for various reasons. The most typical task is to investigate the main factors affecting work productivity and to establish a base for cost calculations. Researchers may also have other reasons to conduct time studies. Accurate models may be utilized in different kinds of simulations that aim to plan appropriate harvesting operation for optimizing machinery usage (Nurminen *et al.*, 2006).
The aim of this study was to combine previous spatial analysis with field survey to identify a suitable and efficient (in terms of time consumption, productivity and cost) harvesting system for timber extraction in mountainous forest.

2. Materials and Methods

2.1 Study site
The study site (Rifreddo forest) is a regional forest located in Basilicata region, South of Italy, between 40°36'1" N and 40°34'29" N latitudes and 15°47'50" E and 15°49'45" E longitudes. The elevation ranges from 760 to 1.200 m above sea level.
The natural vegetation is a deciduous forest with dominant species of turkey oak (*Quercus cerris* L.)

2.2 Spatial analysis
In this analysis, the following parameters were analyzed: forest accessibility (network road system) and road density (m/ha), slope of ground, hydrographic network (river presence) and hydrogeological risk.
The roads and the rivers were survived by Garmin GPS Montana 650 T and reported on GIS to be elaborated.
The presence/absence of rivers was scored (1/0) and each river was classified according to its length. Short (0-200 m), medium (201-400 m), and high (> 400 m) classes of length were defined.
The forest accessibility or/ and inaccessibility analysis was made by using Path Distance tool.
This analysis was carried out by relating the slope analysis and network road system analysis. Following

Hippoliti (1994), a buffer of 100 m was used as spatial parameter to identify the forest accessibility along both road sides. According to the author, a forest can be considered as accessible if served by roads to a height difference (hd) of 100 m. In the present study, this value was used to classify forest areas into three different classes: low - (66 m≤hd<100 m), medium - (34 m <hd≤ 65 m), and high-accessible (hd ≤ 33 m) forest areas.
The slope analysis was performed by using the DEM (Digital Elevation Model) at a 20 m resolution, which was processed by using the Spatial Analyst Tool "Slope", and reclassified according to Hippoliti's classification (1994): 0-20%,21-40%, 41-60%, > 60%.
The hydrogeological risk analysis was conducted by using a reference layer downloaded from the website of Watershed Authority of Basilicata Region:
http://www.adb.basilicata.it/adb/pStralcio/download.asp.
The presence/absence of hydrogeological risk was scored (1/0), and each risk type was classified according to Watershed Authority classification, R1, R2, R3, and R4 (AUTORITÀ DI BACINO REGIONE BASILICATA, 2014).
Finally, all these analysis were used to identify suitability areas (Area 1, 2, 3 and 4) of forest machinery by using the Weighted Overlay tool, as showed in Figure 1.

2.3 Dendrometric analysis
The dendrometric data analysis was carried out to complete the forest utilization planning, in particular the choice of forest machineries, labor instruments and optimal work systems (harvesting systems).
A pilot inventory was done considering 6 sampling plots (radius 40 m), which confirmed the timber data from forest management plan. This forest was subjected to low cutting intensity (low thinning), which provided a timber extraction about 30 cubic meters per hectare for each extraction cycle, for firewood production.

2.4 Harvesting machinery choice and field survey
The spatial analysis was carried out to choice the most suitable machinery for each forest area. Among the machineries in supplied of forest company the following ones were chosen in according to their characteristics of use.
For Area 1 and 2 a wheeled tractor equipped with front and back three-pronged attack (Landini 7880 DT, 55 Kw) was used, on medium slope with one cage, on low slope with two cages. A crawler tractor with one cage on steep slope (Fiat 605 C, 45 Kw) was used for Area 3.
The time consumption, productivity and cost of harvesting was calculated for each forest area.
The machinery costs (€/h) were directly collected through interviews to forestry owner to calculate the total cost of timber harvesting (€). The harvesting element times included empty travel, timber loading, load travel, unload travel, timber unloading and technical delay. For each travel, were measured the distance (m) and time (min) of harvesting from timber concentration point to the storage square, and machinery productivity (t/h). Finally, it was calculated the effect of harvesting distance on harvesting time.

2.5 Statistical analysis
A linear regression analysis was used to describe the relationship between distance and time harvesting for each forest area.

3. Results and discussions

3.1 Spatial analysis
The analysis showed that the road density of flat land was 68.8 m/ha, and 64.3 m/ha for steep land, and whole forest was divided in 4 areas, A1 (Area 1, 32 ha, 19%), A2 (Area 2, 109 ha, 64.6%), A3 (Area 3. 28 ha, 16.3%), A4 (Area 4, 0.24 ha, 0.1%), the fourth wooded area, although small, resulted totally impracticable, as showed in Figure 1.

3.2 Field analysis
The field analysis confirmed that, for low thinning, the harvesting cost was very high (44,072 €), as showed in Table 1. For this reason, a preventive spatial analysis may allow the forestry owner to know the real territorial conditions before starting the forest work in order to optimize the time consumption, forest mechanization and economic competitiveness of forest utilization, still "weak link" of supply chain forest (Baldini *et al*., 2006). The daily productivity for all the machinery was 46.5 t/d, whereas the total number of days needed to harvest the timber in whole forest was 502.62. The machinery productivity is usually influenced by empty travel and loaded travel that dominate the time cycle of forest operations (Gilanipoor *et al.*, 2012). The effect of harvesting distance on harvesting time for each forest area are shown in Figures 1, 2, and 3. For all the areas, there was a positive relationship between the variables. However, the A3 was characterized by the lowest R square value (0.62). This result may be due to time of dumping and load timber, as well as to a significant presence of natural obstacles.

4. Conclusions

Our results indicate that a preliminary spatial analysis could provide forest companies with effective guidelines for improving mechanization of forest harvesting. In particular, the analysis may be useful in helping forest companies to choice the most suitable systems in relation to different territorial conditions. Ultimately, GIS tools combined by field survey may lead to optimize the work in forest (woodcutter work).

Table 1. Total cost estimation for timber harvesting for each area.
Tabella 1. Stima del costo totale per l'esbosco per ogni area.

Forest area		*Harvesting machinery*		*Biomass analysis*				*Cost analysis*		
Code	*Surface (ha)*	*Type*	*Power (Kw)*	*Yield per hour (t/h)*	*Yield per day (t/d)*	*Total day (d)*	*Total biomass (t)*	*Cost per hour (€/h)*	*Cost per day (€/d)*	*Total cost (€)*
A 1	32	Crawler tractor with 1 cage	45	1.3	9.7	91.7	95.4	12.5	94	89,44
A 2	109	Tractor with 2 cages	55	3.5	26.3	116.2	325.2	11.5	86	28,049
A 3	28	Tractor with 1 cage	55	1.4	10.5	73.3	82.1	11.5	86	7,079
Total	*169*	-	-	*6.2*	*46.5*	*281.2*	*502.7*	*35.5*	*266*	*44072*

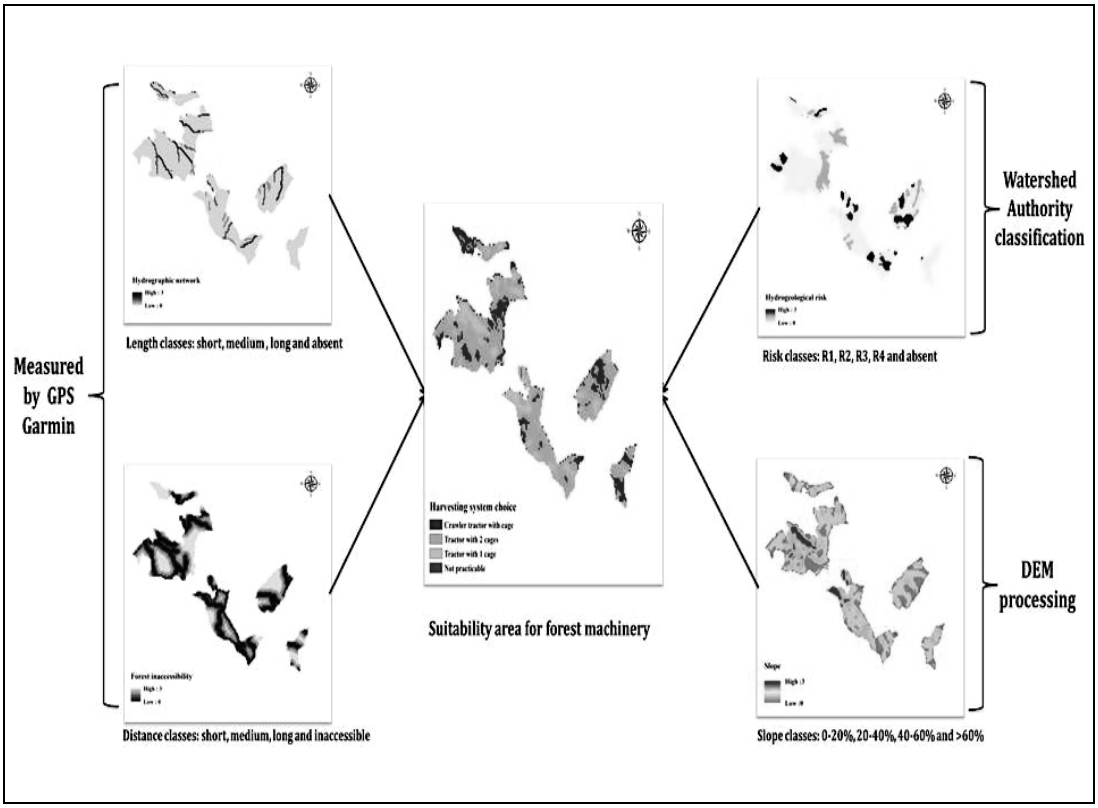
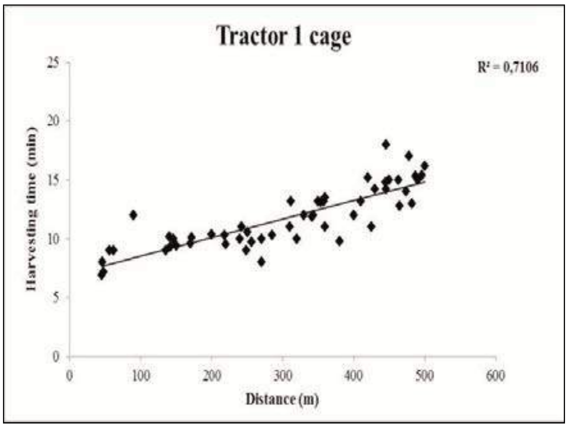
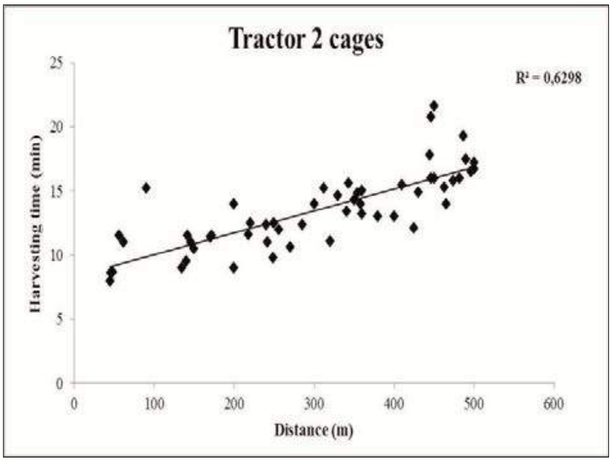


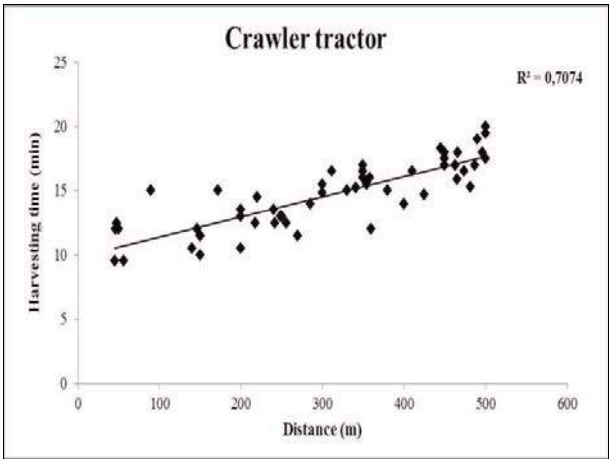
Figure 1. Suitability area for forest machinery.
Figura 1. Zona d'idoneità per le macchine forestali.



Graph 1. Effect of distance on harvesting time, tractor 1 cage.
Grafico 1. Effetto della distanza sul tempo di raccolta, trattore 1 gabbia.



Graph 2. Effect of distance on harvesting time, tractor 2 cage.
Grafico 2. Effetto della distanza sul tempo di raccolta, trattore 2 gabbie.



Graph 3. Effect of distance on harvesting time, crawler tractor.
Grafico 3. Effetto della distanza sul tempo di raccolta, trattore cingolato.

RIASSUNTO

Ottimizzazione della raccolta di legname mediante GIS

I moderni software (GIS) usati per creare cartografie permettono di effettuare analisi territoriali ben specifiche in differenti campi di applicazione, come quello forestale in particolare nel comparto delle utilizzazioni forestali.
Nel presente lavoro è stata effettuata un analisi spaziale per analizzare i vincoli territoriali (pendenza, reticolo idrografico e rischio idrogeologico) di una foresta che non permettono il transito degli operatori e delle macchine forestali durante le operazioni di raccolta del legname. Inoltre, è stata analizzata la viabilità forestale per quantificare la densità per ettaro delle strade forestali ad ettaro (m/ha) e per identificare l'accessibilità delle foreste, per terreno pianeggiante 20-25 (m/ha) mentre per terreno ripido 30-35 (m/ha).
I risultati hanno mostrato che l'analisi spaziale (vincoli spaziali) e analisi delle infrastrutture (rete viaria forestale) sono state utili per creare mappe tematiche che hanno permesso alla impresa forestale la meccanizzazione appropriata e i sistemi di esbosco in termini di produttività e di redditività.

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