PRECISION FOREST HARVESTING: WOOD EXTRACTION PLANNING AND VALIDATION OF GIS MODELS

Latterini F.[1*], Stefanoni W[1]., Pari R[2]., Lazar S.[1], Venanzi R[3]., Tocci D[3]., Picchio R[3].
[1]Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria, Unità di ricerca per l'ingegneria agraria - Monterotondo (Rome-Italy) francesco.latterini@crea.gov.it; walter.stefanoni@crea.gov.it; sandu.lazar@crea.gov.it
[2]Roma Tre University, Faculty of Law, Via Ostiense, 163, 00154 Roma RM, rob.pari@stud.uniroma3.it
[3]Tuscia University, DAFNE Department, venanzi@unitus.it; toccidamiano91@gmail.com; r.picchio@unitus.it
[*]Correspondance: francesco.latterini@crea.gov.it

ABSTRACT: Proper planning of forest operations is crucial to get sustainable forest management. Considering that forest sector is one of the major producers of biomass, this aspect has a strong influence on the overall sustainability of biomass supply chain. In the last years the shift towards the precision forestry has been recognized as a powerful tool to allow sustainable forest operations. In particular, GIS approach can be suitable for the development of *ad-hoc* planning of forest logging, ensuring the respect of the three pillars of sustainability. However, precision forestry needs clear input data. Taking into account what written above, the present study aimed to demonstrate the reliability of three different Digital Terrain Models (DTMs) for the planning of forest operations in mountainous areas of Central Italy, through the Real Distance Buffer Method (RDBM) model. The obtained results showed that the LiDAR based DTM with 1 m resolution had the best performance in the prediction of the accessible areas for extraction operation. Subsequently, a simulation of intervention planning was carried out considering the appliance of two different extraction systems, i.e. cable skidder and cable yarder. The simulation revealed that 17.33% of the intervention area was accessible to cable skidder, while for the remaining surface, cable yarder is needed to ensure the extraction of the overall biomass.
Keywords: cable skidder, cable yarder, sustainable forest operation, QGIS, DTM

1 INTRODUCTION

In the last decades there has been a growing interest to sustainable forest management [1–3]. In particular, the concept of sustainable forest operation is crucial to ensure a forest management meeting the goals of all the three pillars of sustainability [4–6]. One of the most powerful instruments to pursue this important and challenging aim, is the application of precision forest harvesting, with particular reference to GNSS (Global Navigation Satellite System) and GIS (Geographic Information System) technologies [7,8]. GIS approach is indeed able to allow the forest managers to obtain a proper logging planning, by optimizing work productivity, reducing environmental impacts and ensuring safety for the operators [9–12]. The issue of sustainable forest operations becomes even more important when dealing with biomass supply chain for bioenergy purposes. Indeed, reducing impacts and optimizing the harvesting logistic is fundamental to achieve a final positive environmental, and economic, balance[13–18]. On the other hand, GIS is a powerful tool, but it needs to have solid input data to be more reliable [19]. Taking into account what written above, the present study presents a comparison between the performance of three different DTMs for the planning of extraction operation, in a mixed beech-black pine high stand, through the application of the RDBM method. After assessing the best DTM to be used for the proper evaluation, an example of extraction planning was performed considering both ground-based extraction (cable skidder) and aerial extraction (cable yarder).

2 MATERIALS AND METHODS

2.1 Study area

Study area was located in Montebello di Bertona (Abruzzo, Italy). The studied forest stand was an even-aged high stand of beech (*Fagus sylvatica* L.) and black pine (*Pinus nigra* Arn.). The overall surface of the sub-compartment was 41.29 ha, but the net intervention surface was 37.79 ha, considering a portion in which the presence of a vertical rocky part did not allow forest operations. Main features of the stand and sub-compartments are given in Table I.

Table I: main characteristics of the studied sub-compartment.

	Surface (ha)	Slope (%)		
		Prevalent	Minimum	Maximum
Sub-compartment	41.29	40	11	Vertical
Intervention	37.79	40	11	>100%
Beech area	13.55	42	11	Vertical
Black pine area	27.74	40	20	>100%

Regarding forest road network, the current presence of roads and skid trails is showed in Figure 1.

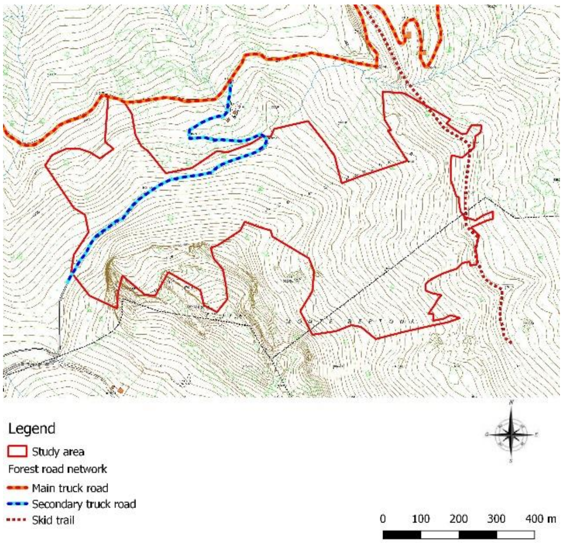

Figure 1: Forest road network in the study area.

2.2 GIS procedure and field survey

Three different DTMs were used for GIS elaborations and tested by field survey. In particular: a 10 m resolution DEM available for Italian territory (DTM_Ita) [20,21], a 10 m resolution DTM developed from Abruzzo region (DTM_Abr) [22] and a 1 m DTM derived from LiDAR data available only for some zones of Italy (DTM_LiDAR) [23]. These DTMs were used as input for the calculation of topographic distance from roads, according to the RDBM method described by Picchio [9,10]. The simulation of topographic distance from roads of RDMB model, with the three different DTMs as input, was field tested through field survey. In particular, 57 ground control points (GCPs) were randomly identified within the sub-compartment and their distance from the roads were measured through a metrical tape, after identifying the GCPs on the field through a Trimble Juno handheld GNSS receiver [24].

2.3 Statistical analysis

After checking for normality and homoscedasticity with Shapiro-Willk and Levene test, paired samples T-test was performed with Statistica 7.0 software [25], in order to check the presence of statistically significant differences ($p < 0.05$) between the distance from roads of the GCPs and the distance calculated by RDBM model with the three different DTMs as input.

2.4 Extraction operation planning

Once identified the DTM which showed the highest reliability in the prediction of the topographic distance from road (hence of the area accessible for extraction), a simulation of a thinning intervention planning was carried out. Extraction systems taken into consideration were cable skidder and medium gravity cable yarder. Regarding cable skidder, considering the characteristics of the stand, authors considered a maximum working distance of 100 m from the existing road network in uphill extraction, and 40 m for downhill one. For cable yarder instead, a 600 m working distance was considered for both downhill and uphill bunching-extraction.

3 RESULTS AND DISCUSSIONS

Results of the paired samples T-test are given in Table II.

Table II: Results of the paired samples T-test for the different DTMs in comparison to the results of the field survey with GCPs.

	Orographic distance from road network (m)		
	Average	St.Dev	P-value
GCPs	38.01	20.78	
DTM_Ita	35.71	21.76	0.01022
DTM_Abr	36.17	20.95	0.05280
DTM_LiDAR	38.64	22.81	0.41483

As it is possible to notice, the only DTM which showed statistically significant difference with the GCPs was DTM_Ita, while DTM_Abr and DTM_LiDAR did not show any significant difference. In particular, the prediction of DTM_LiDAR was the closest to the GCPs, showing how the higher resolution of this, as expected, led to higher precision in the prediction. Unfortunately, this DTM at 1 m resolution is not available for the all Italian territory. Thus, in order to improve the prediction reliability of GIS model for forest operation planning, there is a need to make high resolution data available on large scale, and also to improve the skills of forest managers and engineers regarding precision forestry, allowing them, for example, to obtain by themselves a high-resolution DTM through LiDAR-based UAV (Unmanned Aerial Vehicle) survey [26–29]. Regarding the results of the extraction planning, GIS revealed to be a suitable and powerful instrument, as already stated in several previous works [8,11,30,31]. According to the extraction plan, 6.55 ha (17.33%) of the study area are accessible to a cable skidder, while the biomass from the remaining surface needs to be extracted by a medium gravity cable yarder (Figure 2).

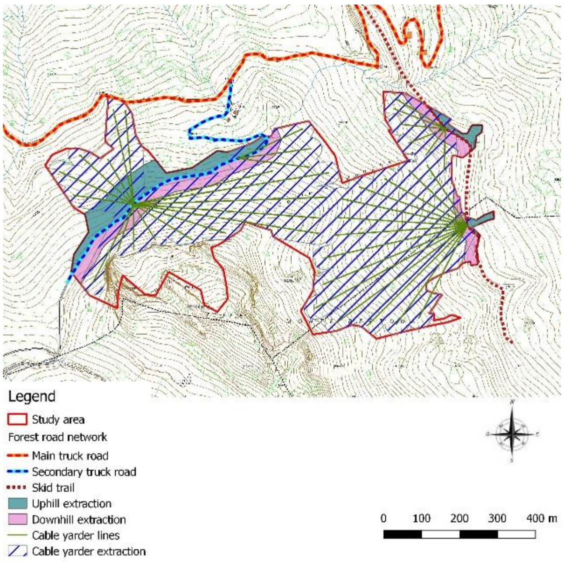

Figure 2: Accessible areas.

Details of the cable yarder lines are showed in Table III.

Table III: Characteristics of the cable yarder lines.

Number of lines needed for extraction	40
Number of the positions of the cable yarder tower	4
Min cartographic length (m)	87
Avg cartographic length (m)	264
Max cartographic length (m)	520
Min orographic length (m)	98
Avg orographic length (m)	283
Max orographic length (m)	554
Min slope (%)	6.37
Avg slope (%)	40.63
Max slope (%)	145.00

The need of aerial extraction system is a consequence of the scarce road density and of the steep slope of the sub-compartment. This situation is often present in Central Italy, so even in this case, a training action is fundamental to allow local forest operators to work with these systems, which are not widely spread in this zone of the Country at present, therefore getting a proper forest management.

4 CONCLUSIONS

Precision forest harvesting is for sure a powerful instrument to reach the objectives of sustainable forest operations. This study highlighted how the resolution of input data is fundamental to ensure higher reliability of the GIS models. Future interactions between forest stakeholders should therefore being addressed to make high resolution data available on large scale.

5 REFERENCES

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6 ACKNOWLEDGEMENTS

The work was performed in the framework of the project Suscace ("Supporto Scientifico alla Conversione Agricola verso le Colture Energetiche").