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Cable Yarding Practices in Romania: An Analysis of Corridor Geometry Based on Aerial Imagery and GIS Techniques

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HIGHLIGHTS

- 589 cable yarding corridors are taken into study.
- Length, width and terrain slope on the corridors varied widely.
- Mean length was of 800 m and mean width was of 13 m. Slope averaged 28%.
- Most corridors were opened in broadleaved - resinous mixed forests.

GRAPHICAL ABSTRACT

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ABSTRACT

Cable yarding is one of the most common options used in steep terrain harvesting. In Romania, sledge yarders are used to extract timber in steep terrain due to many factors such as the current situation in which the road network is still poorly developed. Nevertheless, there is a lack of national statistics in regard to the cable yarding use and on the practices typically implemented in such operations. This study analyses the geometry of cable yarding corridors based on their features identified on aerial imagery. Analysis was implemented in QGis software to manually extract the needed parameters and to build a reference database containing the identified cable yarder corridors. Based on a sample that accounted for a number of 589 corridors, the main findings are as follows: the average length of the corridor was of approximately 800 m, and the average corridor width was of approximately 13 m. Longitudinal slope of the corridors averaged approximately 28% but it was characterized by a wide variation between approximately 5 and 90%. The results in terms of both, statistics and developed database, may be of help as a starting point for more detailed statistics and analyses.

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1. INTRODUCTION

Cable-based timber harvesting has been the prevailing technology in steep-terrain harvesting in many mountainous regions of the world [1], having a long development tradition in the Central European Alps where the sledge-yarding technology has been replaced by mobile tower yarders since the 1970s [2]. Eastern European countries, on the other hand, shared some economic and technical commonalities that resulted in rather a scarce use of cable-based timber harvesting [3]. In particular, the Romanian practice has indicated that the use cable yarding technology is limited nowadays [4] compared to the socialist period. This outcome may be related to a decline in the investment potential of most of the logging contractors established lately, that are, in their majority, small to medium enterprises, as well as to the lack of training facilities on cable yarding operations and the lack of trained personnel in harvesting operations [5]. These facts gave a significant momentum to the use of ground-based extraction systems [3] which are currently dominated by skidders that, in many ways, are more easily to learn, operate and maintain. Their predominance in use was also supported by the local manufacturers who developed and sell affordable machines. Meanwhile, the forest accessibility is still poor, with only 6,5 meters of forest road per hectare [6], a fact that constitutes a technical limitation in the use of short-distance mobile cable yarding technology [7] and restricts the harvesting options, in many cases, to that using skidders. Such an option, however, often contradicts the legal provisions, especially in steep terrain harvesting, where the development of skidding roads is currently restricted to slopes less than 25 degrees.

Nevertheless, recent studies carried out in Romania have shown that the use of sledge yarding, as a harvesting option is steep terrain, may result in acceptable productivities and costs [8-9]. In addition, this kind of equipment is positively regarded by forestry professionals [10], therefore a reorientation to this technology could bring benefits on the short-medium term. At the same time, many textbooks classify the cable systems in terms of operational distance [*e.g.* 11-13] but few studies addressed the actual design of cable systems (*i.e.* the arrangements and patters of cable systems) [14], their spatial distribution and geometrical characteristics; such information can bring evidence and reflects on how the practice approaches or approached the problem related to the geometrical design and layout of cable systems, feeding also, in many ways, the science. While it is likely that the location and geometric layout of cable systems to be mapped in some countries, in our knowledge, this kind of data is unavailable in Romania, from the main sources such as the maps or documentation of forest management plans, making it impossible to evaluate the patters used in cable yarding.

The aim of this study was to characterize the practice of cable yarding systems layout in Romania from a geometrical point of view, based on the freely available aerial imagery and contour maps. The focus was, in particular, on (i) the corridor geometry that was characterized by length and width, to be able to classify the practices mainly based on the corridor length, (ii) terrain slope on the corridors' path, to be able to see what was the dominant slope on which cable yarding operations were carried out in the past, and (iii) altitudinal (vegetation) strata in which the cable yarding corridors were opened, to be able to see where this kind of technology was dominantly used. Since this study was based on the latest Google imagery data, the authors acknowledge here that the results may reflect, mostly, the situation from the past, but they include also the latest features related to the cable yarding operations.

2. MATERIALS AND METHODS

The study was carried out in several steps with the support of QGis software [https://qgis.org/en/site/], using the aerial data layers of Google® and a contour layer (10 m) available for the Romanian territory. A first step consisted of a detailed examination of aerial data at country level to identify those areas in which cable-yarding operations were carried out. This was supported by the visual identification of cable yarding corridors on the aerial imagery, that was followed by the identification of those counties in which this kind of features were most frequent. Based on this examination, a block of four counties were selected (**Figure 1**) based on the frequency of cable yarding corridors visually identified in their area.

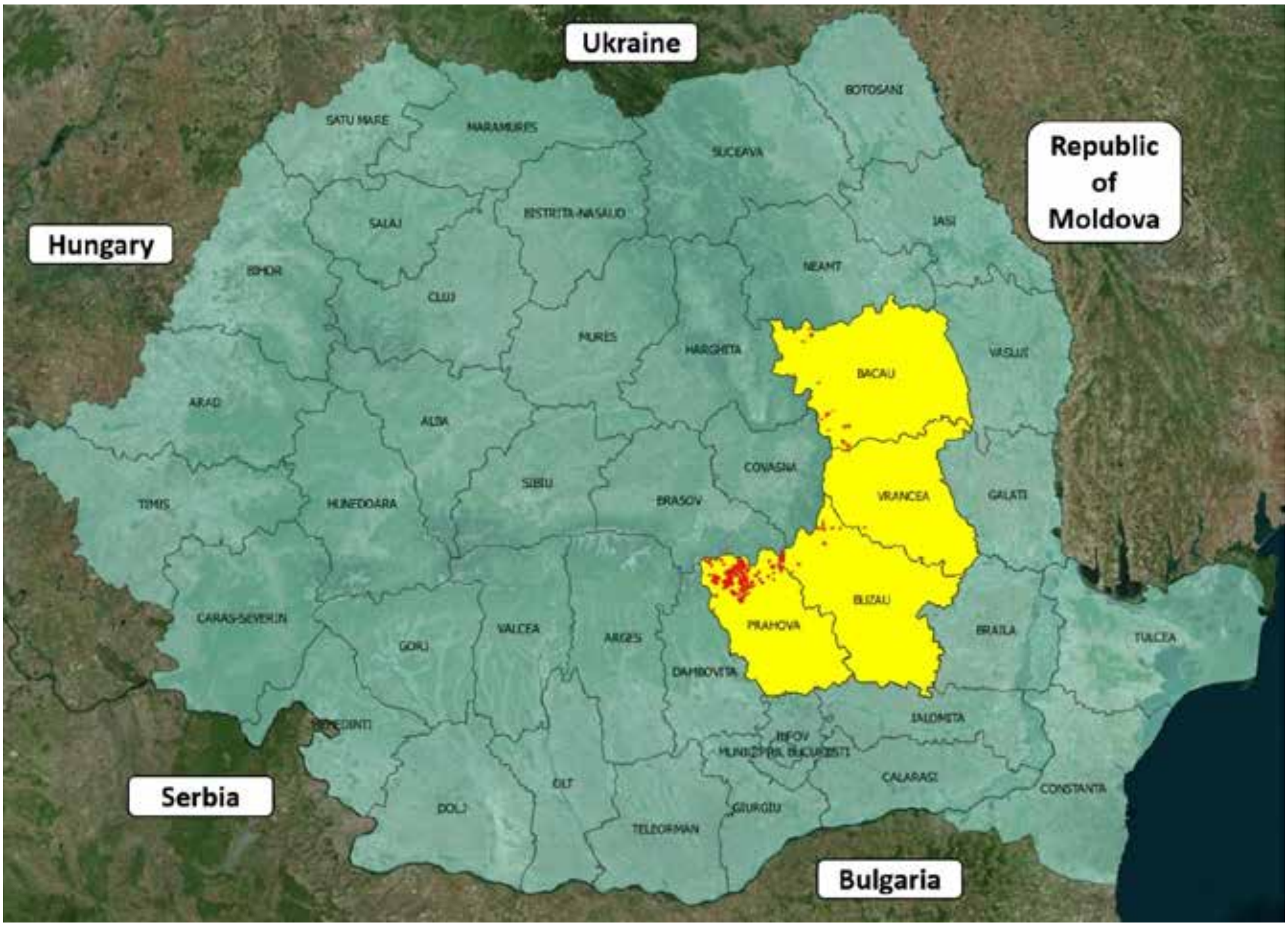

Figure 1. Map of Romania showing the selected counties and location of the identified cable yarding corridors. Legend: yellow - counties taken into study, red - corridors taken into study.

All of the counties taken into study share the characteristic of having forests distributed in mountainous regions of the Romanian Carpathians. The identified and analyzed cable yarding corridors were considered based on a set of three criteria. First of all, a detailed examination of each identified corridor was carried out to see if it was a cable yarding corridor or it belonged to other types of land uses or infrastructure. Based on the outcome of this criteria, the following selection was based on those corridors that were clearly visible on the aerial images (*i.e.* exclusion of those covered partially by clouds or shaded). A third criterion was that of considering only those corridors for which detailed data was visible on the contour maps.

Finally, this subset of corridors was taken into analysis to determine, using the functionalities of QGis, the following geometrical features:

- The sloped length of each corridor (***L***, m), based on the length extracted from the map (run, L_0, m) and elevation difference between the endpoints (rise, ***ΔH***, m), where the elevation difference was calculated using the elevations at endpoints extracted from the contour map;
- Corridor width (***CW***, m), based on the average of three width samples (two collected at the endpoints and one collected at the midpoint of the corridor) measured between the crowns' centers of marginal trees;
- Corridor slope (***S***, %), calculated based on the run and rise of each length feature characterizing an analyzed corridor;

In addition, a classification of altitudinal (vegetation) stratum to which the identified corridors belonged was made based on the elevations determined at the three points of each corridor and the provision of related literature [15], resulting in three strata: spruce forests (1300 - 1700 m), broadleaved-resinous mixed forests (700 - 1300 m) and broadleaved mixed forests (200 - 700 m).

Procedurally, a layer was built in QGis to store linear features, then the supporting layers (aerial imagery and contour map) were uploaded to facilitate the construction of new linear features standing for the corridors. To ease the database building procedure, a polygon layer was used to cover the area already evaluated as the work progressed. The approach used to identify, analyze, build linear features and to extract the corridor widths and the elevations needed in computations (**Figure 2**) was based on the analysis at elementary watershed level. Features of interest were either directly populated in the database or manually extracted and included in the layer designed to store the data (**Figure 2**).

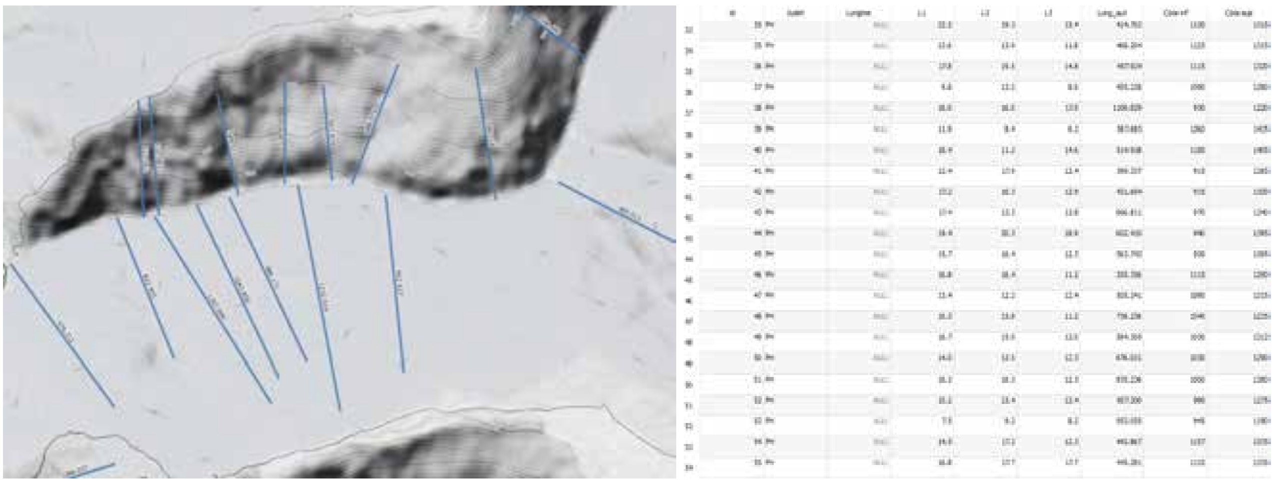

Figure 2. An example of corridors taken into study (left) and the associated database (right).

The associated database included attribute columns such as the identification number, county abbreviation, length of the corridor (L_0), sampled widths of the corridor and the elevations sampled at the endpoints (**Figure 2**).

Once the database building was finished, all the stored data was exported to a Microsoft® Excel® file that was used to compute the needed parameters as well as to carry on the statistical analysis. To this end, statistical analysis consisted of building a set of descriptive statistics as well as of a frequency analysis for several features taken into study. Descriptive statistics were built for all the geometrical and location parameters considered in this study while the frequency analysis was carried on only for those most important for the characterization objectives of the study.

3. RESULTS AND DISCUSSIONS

In total, 589 cable yarding corridors were identified and taken into study, as shown in **Table 1.** However, most of them were identified in the Prahova county (cca. 84%), reflecting the past and present practice in the area. Taking into consideration the altitudinal (vegetation) strata, the distribution of the identified cable yarding corridors is given in **Figure 3**.

Table 1. Number and share of analyzed corridors per county and at the sample level.

County	Number of identified and analyzed cable yarding corridors	Share
Bacău	38	6.5
Buzău	56	9.5
Prahova	493	83.7
Vrancea	2	0.3
Total	**589**	**100**

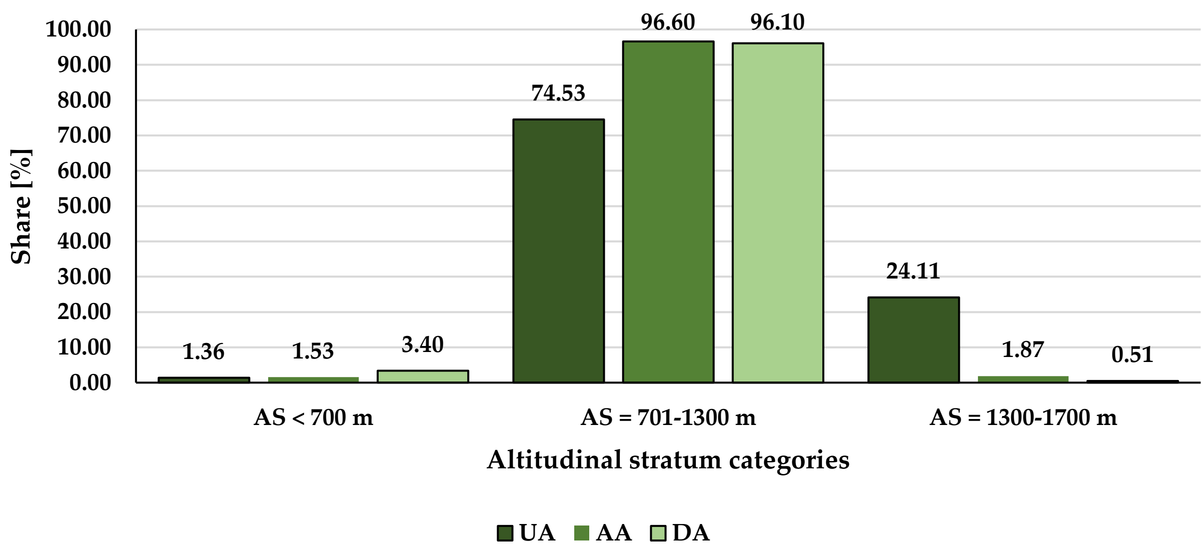

Figure 3. Distribution (share) of the identified cable yarding corridors on altitudinal strata (AS) based on the downhill endpoint elevation (*DA*, m), average elevation (*AA*, m) and uphill endpoint elevation (*UA*, m).

Irrespective of the elevation variable taken into consideration to characterize the altitudinal strata in which the cable yarding corridors were identified, as shown, their majority was found between 1300 and 1700 m. By considering the average elevation, roughly 97% of the cases were identified to be distributed in the broadleaved-resinous altitudinal stratum and only to a minor extent in the rest. However, in more than 24% of the cases these corridors reached by their uphill endpoint the spruce altitudinal stratum. Therefore, the main use of cable yarding could be attributed to the extraction of wood from mixed forests located at altitudes higher than 700 m.

The main descriptive statistics of the variables used to characterize the geometry and terrain slope on which the corridors were identified are given in **Table 2**. As this study builds up on a relative high sample of corridors, worth mentioning that the cumulated length of the identified corridors was more than 470 km (**Table 2**). The sloped length (*i.e.* the real length of the corridor) varied widely between approximately 190 and 1900 m, averaging approximately 800 m. Also, the corridor width at the three sampling points varied quite widely, averaging approximately 11 to 13 m and, as an aggregate mean value, approximately 13 m.

Table 2. Descriptive statistics characterizing the layout of cable yarding corridors.

Parameter (abbreviation)	Minimum value	Maximum value	Range	Mean ± Standard Deviation	Median value	Sum
Map length (L_0, m)	185.10	1862.13	1677.03	771.57±296.41	726.76	454455.58
Sloped length (L, m)	193.10	1913.41	1720.30	803.78±301.16	761.62	473424.97
Corridor width at the downhill endpoint (CWD, m)	5.30	24.50	19.20	13.88±3.48	13.20	-
Corridor width at the midpoint (CWM, m)	5.20	24.90	19.70	13.28±3.07	12.80	-
Corridor width at the uphill endpoint (CWU, m)	4.00	23.90	19.90	11.72±3.04	11.10	-
Elevation at the downhill endpoint (DA, m)	450.00	1400.00	950.00	982.18±136.47	998.00	-
Average elevation (AA, m)	520.00	1485.00	965.00	1088.83±137.40	1110.00	-
Elevation at the uphill endpoint (UA, m)	580.00	1570.00	990.00	1195.48±152.22	1220.00	-
Rise (R, m)	40.00	490.00	450.00	213.30±89.89	205.00	-
Mean corridor width (CW, m)	5.43	23.47	18.03	12.96±2.89	12.53	-
Corridor slope (S, %)	5.06	93.82	88.76	28.99±11.00	27.73	-

Note: Data shown in the table failed the normality check.

Terrain slope, as a characteristic of the corridors, was found to vary between 5 and 94%, averaging, at the sample level, approximately 28%. This (probably) indicates the fact that in some cases the technology used was not based on gravity, as the minimum slope required in such cases should be more than 15% [*e.g.* 2, 13].

A breakdown of the identified corridors per categories of distances is given in **Figure 4**, somehow to a finer scale compared to the Romanian textbooks [*i.e.* 11, 13], indicating that more than 60% of the analyzed corridors belonged to the category of medium distance cable yarders. Since it was not clear which were the criteria used by the Romanian textbooks to categorize the cable yarders as a function of their setup length, and if one considers three categories of length (less than 500, 500 - 1000 and more than 1000 m), then approximately 16% of the corridors would belong to the first category, 60% to the second and 24% to the last, with approximately 3% of them being identified as having lengths of more than 1500 m.

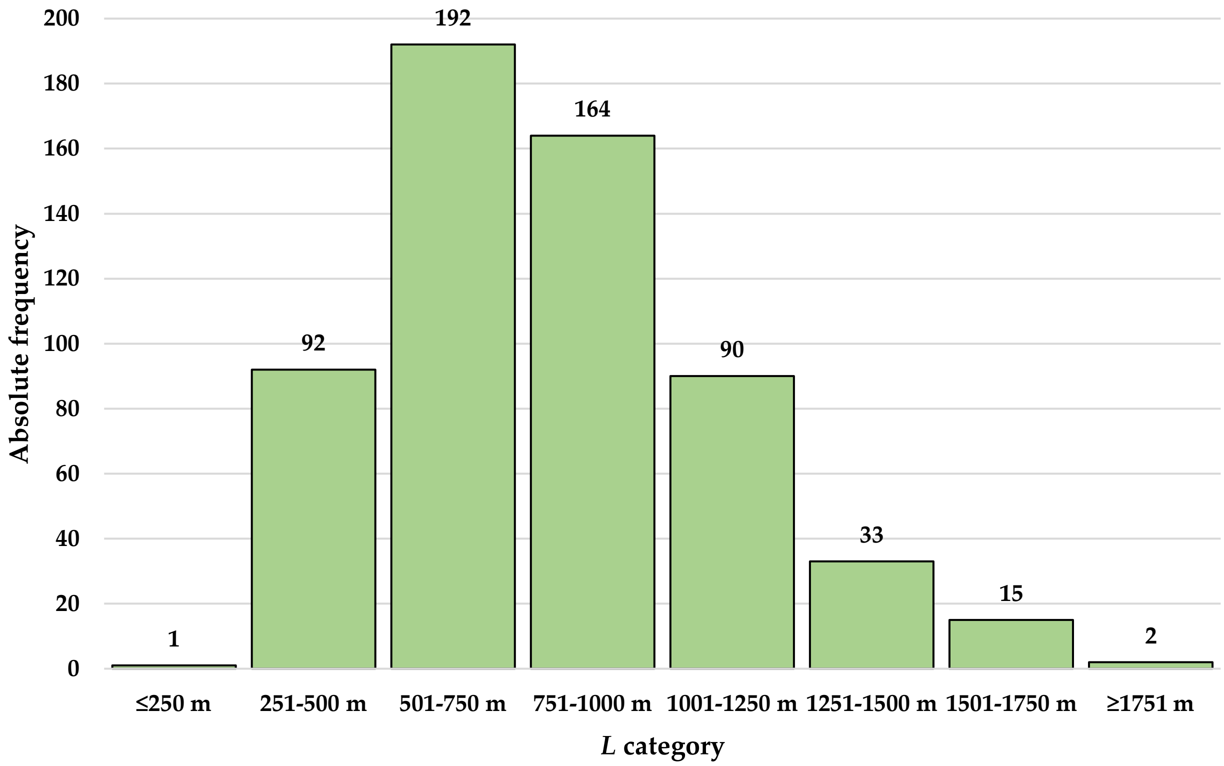

Figure 4. Absolute frequency of the corridors per categories of distances.

A distribution on average corridor width categories is given in **Figure 5**. Acknowledging the methodological limitations of this study, it is showing an interesting trend, placing most of the identified corridors in categories of width greater than 10 m. However, data on the past practices of cable yarding is scarce with little information on the length and volume of payloads. Most probably these widths were related to the practices in the past and should be interpreted with caution since a precise delimitation and determination of these features was not possible by the approach of this study. In this regard, a field check could clarify the exact numbers. Nevertheless, it seems that the corridor width was related to its length, being wider in case of longer lengths (**Figure 6**). Probably this could be associated with the functions that those cable yarders fulfilled, knowing the fact that long distance cable yarders were often rigged to fulfill only extraction functions while the bunching functions (operations) were carried out by other means [16], an option that is still used today [*e.g.* 9]; therefore, such corridors were probably designed to provide more space depending on the length of payloads as resulted from the equipment operating upstream in the process and the level of technology integrated in both of them. Also, the width of the corridors could be affected by the space between the trees, especially those used to rig the cable yarders, and by the silvicultural system used, with different distributions in case of mature forests compared to the young ones.

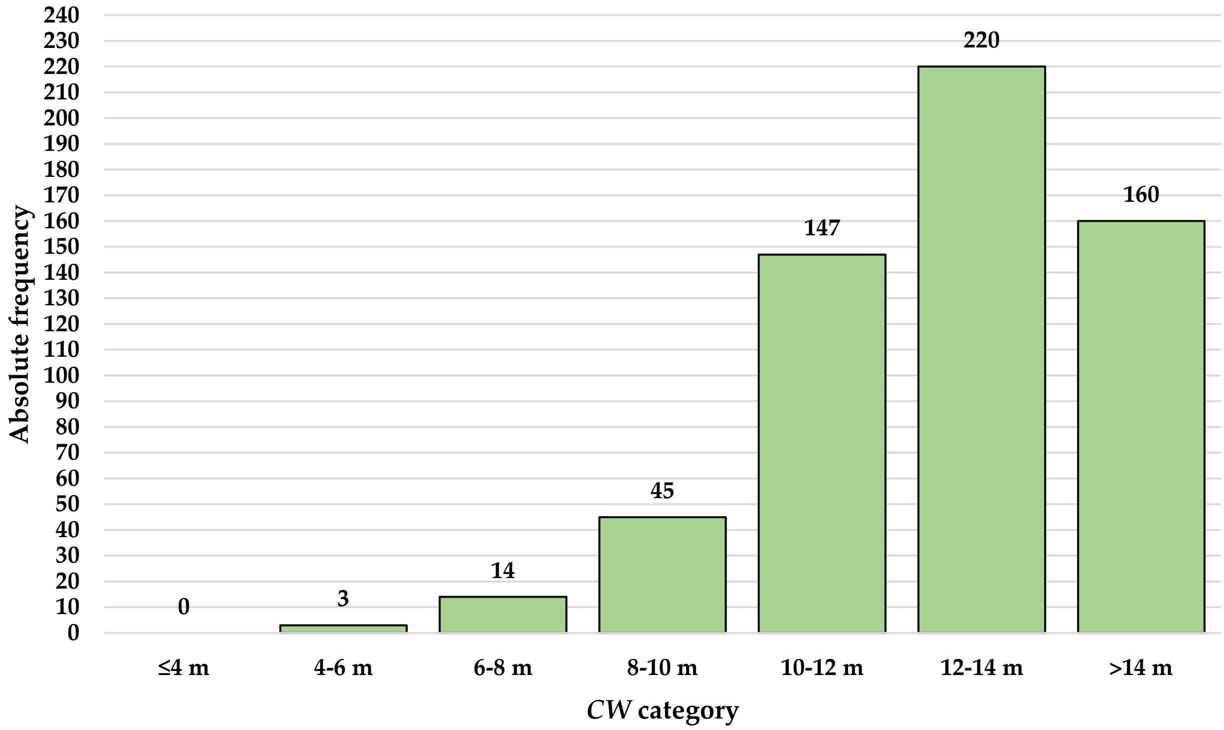

Figure 5. Distribution (share) of the identified cable yarding corridors on corridor width categories (*CW*, m).

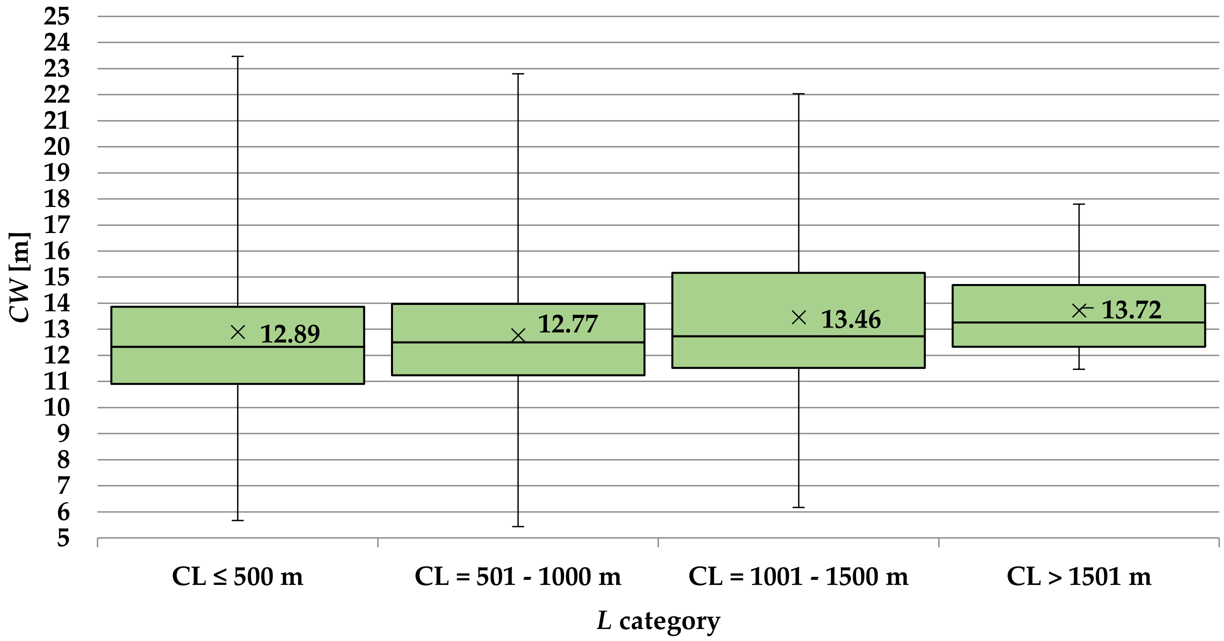

Figure 6. Distribution of corridor width values in relation to the corridor length. Legend: "x" denotes the mean value, error bars denote the range, center line in the boxes stands for the median value, external lines in the boxes stand for the 2nd and 3rd quartiles.

In what regards the distribution of corridors per categories of slopes, **Figure 7** shows a breakdown of the sampled data on main descriptive statistics characterizing the terrain slope along the yarding corridors by considering the same categories of distances, while **Figure 8** shows a breakdown of the analyzed corridors on slope categories. As shown, those corridors that served to rig short-medium distance cable yarders [as defined in *e.g.* 11, 13], were characterized by a greater longitudinal slope compared to the rest. Approximately 6% of the corridors were found to belong to a slope category of less than 15%, therefore indicating, in the resolution limits of the used contour map, that the operations were not carried out by the use of gravity (**Figure 8**).

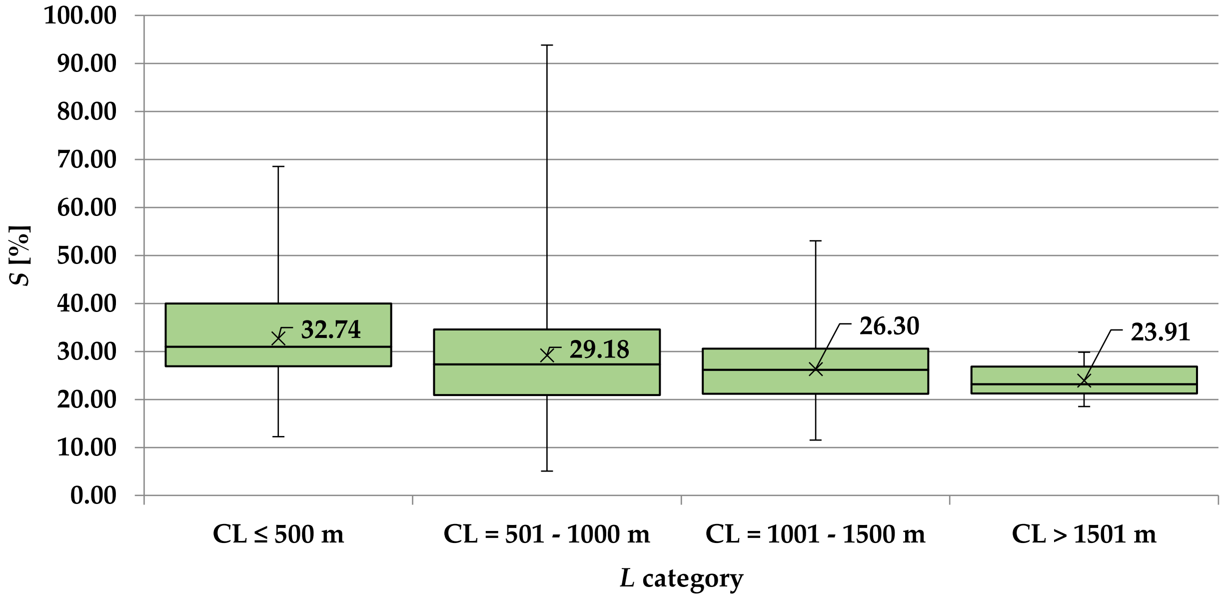

Figure 7. Distribution of longitudinal slope values in relation to the corridor length. Legend: "x" denotes the mean value, error bars denote the range, center line in the boxes stands for the median value, external lines in the boxes stand for the 2nd and 3rd quartiles.

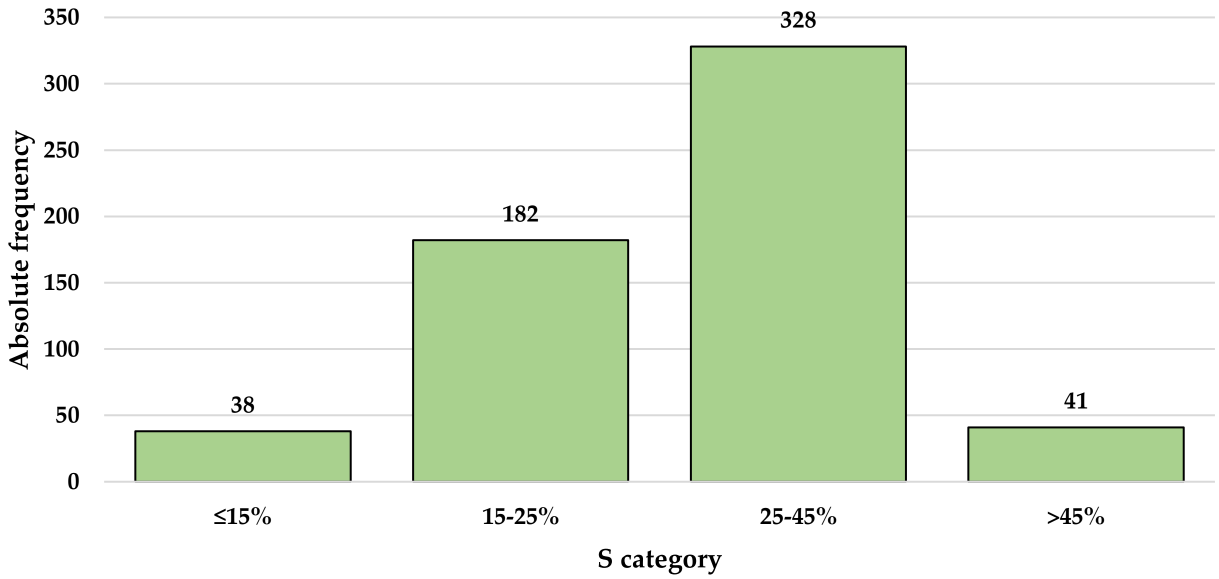

Figure 8. Absolute frequency of slope values on categories.

At the same time, approximately 30% of the corridors were found in the slope category of 15-25%, more than half of the corridors were found in the slope category of 25-45% and approximately 7% in the category of slope of more than 45%. Therefore, the practice indicates a predominant use of cable yarding on corridors sloped in between 15 and 45%, with a dominance in between 25 and 45%.

4. CONCLUSIONS

To summarize based on the above presented data, the following may be concluded:

1. Based on the sample of yarding corridors taken into study, the practices used in the past were characterized by a wide variation in terms of length and width of the corridors as well as in terms of terrain slope on the corridors on which cable yarders were operated;
2. In average, the length of the corridors was of approximately 800 m. Therefore, according to the Romanian textbooks on forest operations and cable yarding, the data indicated the use of mostly medium to long distance cable yarders. Also, the corridor width was highly variable, averaging approximately 13 m, but this data should be interpreted with caution given the limitations of the method used to determine it. The average terrain slope on the corridor was found to be of approximately 28%, but it also varied between approximately 5 to 89%;
3. This study aimed to characterize the geometric layout of the cable yarding practices accounting, mostly for those used in the past. Nevertheless, the reported figures, as well as the developed database may be used as a starting point for other kind of studies or to develop and enhance the statistics related to such issues.

SUPPLEMENTARY MATERIALS

Not the case. The developed database is available at the Department of Forest Engineering, Forest Management Planning and Terrestrial Measurements, Faculty of Silviculture and Forest Engineering, Brasov.

FINANCING

Not the case.

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CONFLICT OF INTEREST

Not the case.

APPENDIX

Not the case.

EXTENDED ABSTRACT - REZUMAT EXTINS

Titlu în română: *Analiza principalelor elemente geometrice ale culoarelor de funicular prin utilizarea imaginilor aeriene şi a tehnicilor GIS*

Introducere: *Funicularele forestiere au servit şi încă servesc pentru colectarea lemnului în teren predominant accidentat unde, de multe ori, utilizarea altor mijloace nu este posibilă. În condițiile forestiere româneşti, în care accesibilitatea fondului forestier este încă redusă, din categoria funicularelor se folosesc majoritar cele de distanță lungă, echipate cu grupuri de acționare montate pe sănii. Cu toate acestea, există un corp de informații limitat atât cu privire la numărul de utilaje de acest tip cât şi la practicile tipice implementate în amplasarea culoarelor de funicular atât în condițiile forestiere româneşti cât şi în cazul celor internaționale. Prezentul studiu analizează caracteristicile geometrice ale culoarelor de funicular pe baza unui eşantion considerat a fi reprezentativ.*

Materiale şi metode: *Culoarele de funicular luate în studiu s-au identificat pe baza imaginilor aeriene recente produse de Google® care au fost importate şi analizate în programul QGis. Pe baza examinării vizuale a întregii suprafețe a României, s-au ales patru județe în care s-a constatat o frecvență mai mare a culoarelor de funicular, apoi s-a recurs la utilizarea unui set de criterii pentru alegerea celor de analizat. Eşantionul final, constând dintr-un număr de 589 de culoare analizate s-a structurat pe baza vizibilității pe imaginile aeriene şi pe un strat de curbe de nivel precum şi prin identificarea clară a faptului că acestea au fost culoare de funicular şi nu alte tipuri de infrastructură sau folosință a terenului. Pentru fiecare culoar luat în studiu, s-au derivat, manual sau automat, parametrii necesari pentru caracterizarea lungimii reale, a lățimii şi a declivității terenului pe traseul respectiv. Pe baza acestor informații s-au estimat statisticile descriptive necesare pentru caracterizarea geometrică precum şi cele legate de declivitatea terenului pe traseele respective şi încadrarea lor în straturi altitudinale de vegetație.*

Rezultate şi discuții: *În general, datele cu privire la lungimea reală, lățimea culoarelor şi declivitatea terenului pe traseele respective au fost foarte eterogene, indicând un mare grad de variabilitate. În medie, lungimea culoarelor a fost estimată la circa 800 m, lățimea la circa 13 m iar declivitatea traseelor la circa 28%. În mare majoritate, astfel de trasee au fost identificate în etajul de vegetație al amestecurilor de foioase cu răşinoase şi numai într-o mică măsură în etajul molidişurilor deşi capetele superioare a circa 24% dintre culoare au fost identificate în acest etaj.*

Concluzii: *Deşi prezentul studiu este bazat pe un eşantion, rezultatele prezentate pot fi considerate ca fiind acoperitoare pentru condițiile româneşti dat fiind faptul că eşantionul surprinde o mare parte din realitatea din teren vizibilă pe imagini aeriene. Atât rezultatele prezentate sub formă de statistici descriptive cât şi baza de date dezvoltată pot servi ca puncte de plecare pentru generarea unor studii de amploare mai mare sau pentru analizarea (reanalizarea) mai detaliată a culoarelor de funicular, inclusiv în relație cu alte domenii de interes relaționate cu ştiința forestieră.*

REFERENCES

1. Bont L., Heinimann H.R, 2012: Optimum geometric layout of a single cable road. European Journal of Forest Research, 131, 1439-1448, DOI 10.1007/s10342-012-0612-y.

2. Heinimann H.R., Stampfer K., Loschek J., Caminada L., 2001: Perspectives on Central European cable yarding systems. In: International Mountain Logging and 11th Pacific Northwest Skyline Symposium. December 10-12, 2001, Seattle, Washington, USA, 268-279.

3. Moskalik T., Borz S.A., Dvorak J., Ferencik M., Glushkov S., Muiste P., Lazdins A., Styranivsky O, 2017: Timber harvesting methods in Eastern European countries: a review. Croatian Journal of Forest Engineering, 38(2), 231-241.

4. Sbera I, 2007: Forest resources and market potential in Romania. Meridiane Forestiere, 2, 3-7.

5. Rauch O., Wolfsmayr U.J., Borz S.A., Triplat M., Krajnc N., Kolck M., Oberwimmer R., Ketikidis C., Vasiljevic A., Stauder M., Muehlberg C., Derczeni R., Oravec M., Krissakova I., Handlos M, 2015: SWOT analysis and strategy development for forest fuel supply chains in South East Europe. Forest Policy and Economics, 61, 87-94, DOI: 10.1016/j.forpol.2015.09.003.

6. Enescu A.H., 2011: Research on the usefulness and economic efficiency of developing the forest transportation network in mountainous areas by low volume roads and their characteristics [Cercetări privind utilitatea și eficiența economică a dezvoltării rețelelor forestiere de transport, din zona montană, cu drumuri sumar amenajate și caracteristicile acestora]. PhD Thesis, Transilvania University of Brasov, Brasov.

7. Borz S.A., Birda M., Ignea G., Popa B., Campu V.R., Iordache E., Derczeni R.A, 2014: Efficiency of a Woody 60 processor attached to a Mounty 4100 tower yarder when processing coniferous timber from thinning operations. Annals of Forest Research, 57(2), 333-345.

8. Munteanu C., Yoshida M., Iordache E., Borz S.A., Ignea G, 2019: Performance and cost of downhill cable yarding operations in a group shelterwood system. Journal of Forest Research, 24(3), 125-130, DOI: 10.1080/13416979.2019.1603577.

9. Munteanu C., Ignea G., Akay A.E., Borz S.A, 2017: Yarding pre-bunched stems in thinning operations: estimates on time consumption. Bulletin of the Transilvania University of Brasov, Series II, Forestry-Wood Industry-Agricultural Food Engineering, 10(59)1, 43-54.

10. Munteanu C., Borz S.A, 2018: Perception of Romanian state forest managers on the use of different timber harvesting systems. Bulletin of the Transilvania University of Brasov, Series II. Forestry-Wood Industry-Agricultural Food Engineering, 11(60)1, 53-68.

11. Drăgan I.C., Bora L., Cherchez G., Comănescu A., Stan I., 1971: Cable yarders [Funiculare forestiere], Ceres Publishing House, Bucharest, Romania.

12. Ionaşcu G., Antonoaie N., Ignea G., 1982: Cable yarders [Instalaţii cu cablu], Ceres Publishing House, Bucharest, Romania.

13. Oprea I., 2008: Timber harvesting technology [Tehnologia exploatării lemnului], Transilvania University Press, Brasov, Romania.

14. Cavalli R., 2012: Prospects of research on cable logging in forest engineering community. Croatian Journal of Forest Engineering, 33(2), 339-356.

15. Florescu I., Nicolescu N., 1996: Silviculture, Vol. I. Study of forest [Silvicultură Vol. I Studiul Pădurii]. Lux Libris Publishing House, Brasov, Romania.

16. Oprea I., Sbera I., 2004: Timber harvesting technology [Tehnologia exploatării lemnului], Tridona Publishing House, Oltenița, Romania.