INVENTORY OF PRIMARY AND SECONDARY FOREST COMMUNICATIONS BY THE USE OF GPS IN CROATIAN MOUNTAINOUS FOREST

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Abstract: *The non-existence of a cadastre of primary (forest roads) and secondary (strip roads and skid trails) forest communications represents a great problem in planning forest communications in economic forests of the Republic of Croatia. It is also almost impossible to carry out intensive, rational management of forest ecosystems based on principles of continuity and bio diversity, if we do not have a good insight into an existing forest traffic infrastructure. This paper suggests contemporary methods of surveying forest roads by the use of GPS device Trimble GeoExplorer 3 and so-called return survey method with the differential correction and its mapping by a programme package ArcGis on previously established GIS of the researched area. The forest communication categorization system has also been suggested. Researches were carried out in the area of Forest administration Buzet, Forest office Opatija, Management unit Veprinačke šume, while strip roads were surveyed in 14 departments (on the area of 537.63 ha). The classical and relative openness of the researched area by forest roads and strip roads has been determined. Advantages of the existence of cadastre of forest communications and GIS of the researched area has been emphasised, both for forest opening and planning of works in forestry, as well as for multi-disciplinary, comprehensive integral forestry.*

1. Introduction

By development of forestry, mechanization of forest works and more intensive forest management, there is an increasing need for forest communications (primary and secondary) without which the rational management of the forest ecosystem is impossible. Many forest areas have not been quality or sufficiently opened or they have not been opened at all. If we want to manage forests successfully and efficiently, the only possible solution is building new communications. In this, we have to know the quantity and distribution of the existing communications for which we need a cadastre of forest communications which we do not have or it does not include all the communications, so this cadastre is incomplete and cannot be used.

Due to all the mentioned, we started the inventory of forest communications on the researched area and the results of the research should be used as guidelines in doing the same job in other areas (management units, forest offfices, forest administrations). By the inventory of forest communications we want to get the insight into previously built communications, their condition, distribution, quantity and purpose, which should enable us to continue with efficient and quality forest opening.

2. The aim and the purpose of the paper

The basic aims of this paper are defined as follows:

- ⇒ making the full cadastre of primary forest roads and their drawing into forest-economic maps in a digital form, for a Management unit Veprinačke šume, Forest office Opatija, Forest Administration Buzet,
- ⇒ making the full cadastre of secondary forest roads and their drawing into forest-economic maps in a digital form, for chosen departments of the Management unit Veprinačke šume, Forest office Opatija, Forest Administration Buzet,
- ⇒ determining the categorization criteria of a certain forest road category and their categorization,
- ⇒ the analysis of secondary openness of chosen departments of the management unit Veprinačke šume,
- ⇒ suggestion of the methodology of making a cadastre of forest communications.

In surveying forest roads we have used GPS device - Trimble GPS Pathfinder Pro XRS and GPS device Trimble, GeoExplorer 3. The obtained data were processed in a programme package GPS Pathfinder Office 2.80. then corrected by measurements of base stations at the Cadastre of the city of Zagreb in order to eliminate the mistake and increase the preciseness of data, and drawn into previously scanned maps. Forest roads were surveyed by an external antenna put on a vehicle with the interval of surveying points of 5 seconds while points of separating forests from public roads were surveyed by GPS device - Trimble GPS Pathfinder Pro XRS.

Strip roads were surveyed by GPS device Trimble, GeoExplorer 3 which, unlike surveying forest roads was not in the vehicle, but we walked along each tractor road. For strip roads we also made a correction of a differential mistake using the results of continuing survey of base stations at the Cadastre of the city of Zagreb.

Both primary and secondary forest communications were surveyed by so-called return method (recording was carried in both directions) during the vegetation resting stage, according to the previously determined almanac (satellite position above the research area at a various time of the day).

3. The research area

The research was carried out in the area of the Management unit Veprinačke šume which is within the Forestry Opatija, i.e. the Forest Administration Buzet. This management unit where we can find selective, uneven-aged forests comprises the total area of 1950.87 ha and is a part of the mountain massif Ćićarija. The highest peak is Makljen with 1144 m of height above sea-level and the lowest point is on 760 m of height above sea-level. The management unit Veprinačke šume is in the mountainous area intersect with numerous ridges and depressions and with karst valleys on plateaux. The average slope is 5-30°.

The Management unit Veprinačke šume is situated in the forest zone of seaside beech (*Seslerio Fagetum*), stretches on the area of 1761.77 ha (92.76 %). In a ten-year period 89685 m^3 of gross harvesting volume (98.94 %) is realized, out of which the beech total harvesting volume is 87877 m^3 (97.98 %). These are mostly pure beech stands with a mixture of hornbeam, plane-tree maple, spruce and black pine. The growing stock is 274.5 m^3/ha, with the annual increment of 6.62 m^3/ha.

In felling and proceesing half tree-length method is used. Cable skidders type LKT 80, LKT 81 and Timberjack 240C are used in timber skidding. Such a method of work demands good secondary openness. Due to the configuration of terrain and developed orography, strip roads have to be built. Basic features in opening and forest exploitation are steep and indented mountainous terrain, the richness of karst relief phenomena, shallow grounds, rocky base and heavy building material categories. The total surface area of the management unit Veprinačke šume is 1950.87 ha and the total quantity of forest roads is 17707.25 m, so the openness is 9.08 m/ha, i.e. 17.28 m/ha if we include in this openness the old Italian public road with the superstructure of broken stone.

4. Problems of the research

4.1 Forest communications

Forest communications are structures on which traffic is carried out and regarding their purpose, location in a stand, technical characteristics, etc. there are many definitions and divisions according to various criteria.

Forest roads (FR) belong to primary forest communications. These are permanent structures which enable constant traffic of motor vehicles for carrying out tasks envisaged by management plan (timber transport, hunting, forest protection, silviculture). They are built of superstructure and substructure with all technical characteristics of the road and permanently take a fertile ground from the forest (for a road width).

Secondary forest communications are structures which are used from time to time for tasks envisaged by a management plan. They are primarily intended for tractor skidding. They include strip roads (SR) and skid trails (ST). Strip roads are structures where ground works are present, which means that they consist only of a substructure. They are just drawn into maps and are not designed. Skid trails are temporary structures which are obtained by cutting through a forest and continuous passage of tractor along the same trace. After completing its purpose, a forest takes them over again.

4.2 Global position system (GPS)

The Ministry of Defence of the USA has established “Global Position System”, which should make navigation easy and the system itself accessible to everyone. The system is based on the “constellation” of 24 satellites which continuously circle in the orbit around the Earth on the height of 20 000 km above the atmospheric envelope and therefore cannot meet ground systems.

Since it was primarily intended for military purposes, it uses a very developed computer technology by which it can precisely determine the position of any point on the Earth 24 hours a day, it is fast and offers many possibilities and has numerous systems for protection from failures, overload, disturbances and any other undesired problems. Signals sent by satellites are received by receivers which are practical with their dimensions and design, so we can carry them everywhere, they can be hand held or put in the pocket. With them, we can know at any moment our position, where we are going to, etc. In that system each point on the Earth has its unique address.

The basis of the system are 24 satellites which circle around the Earth along their orbits and send coded signals while we move on the ground with receivers which receive those signals and according to the length of the signal path calculate their length from the satellite. By signals from several satellites we can determine our geographical latitude and longitude, height above sea-level, direction and speed of movement. Measurements are faster than one in a second with a precision of several tenths of a meter to only a few millimetres.

4.3 Geographic information system (GIS)

By classical procedures it has become almost impossible to comprise, maintain, interpret and analyse necessary data quantity which refer to the condition, quantity and distribution of phenomena and structures in the forestry. Finding a way to avoid such a tiresome work and wasting time on routine jobs resulted in establishing GIS technology. That technology enables:

- ⇒ automatic cartography supported by electronic computers,
- ⇒ acceptance, storage, searching, maintaining, renewal, analysis, statistical analysis and printout in various forms of a huge number of various data,
- ⇒ collection and storage of spatial information in numerous form, which enables objective analysis of spatial data,
- ⇒ obtaining new cartographic contents by various ways of overlapping or statistical processing of numerous and descriptive data.

GIS proved as technology which connects data according to all kinds of criteria, enables continuous following of changes in a forest ecosystem and planning and timely decision making (Martinić, 1993). The established system consists of geocoded cartographic bases and relation databases integrated in the geographic information system (GIS), then of algorithms by which we manage these data and from procedures for fast and economic establishment of changes that have arisen, which is particularly important in following the dynamics of changes in forestry.

Geographic information system (GIS) is the organized group of equipment, programme and spatially determined data which enables fast and quality handling, managing, processing and creating new information necessary for decision making in all human activities (Kušan, 1993), therefore, in forestry, as well. It enable fast and selective obtaining of data on the location and availability of natural resources as the basis for their management.

Geographic information system consists of the electronic equipment, programme support and data.

Geographic information system consists of specialized databases in which a spatial and time location of all the elements included in them is ensured. The computer technology enables the use of data from bases in which each data about the space is connected with the location (geographical coordinates) where it was surveyed and when the changes occurred. GIS in fact represents a serial of layers of different contents (topographic, thematic, numerical) for a certain area (section, department, management unit, forest administration, branch…).

5. Results of the research

5.1 Inventory and categorization of forest roads of the management unit Veprinačke šume

Table 1: Lengths of forest roads of the management unit determined by a contemporary method (GPS)

Forest road, no.	1	2	3	4	5	6	7	8	9	10	11	12	13	**Total**
Forest road length, m	676.84	1020.43	5015.56	1310.17	311.31	912.35	865.08	589.02	957.41	295.29	1473.14	1975.92	2304.19	**17707.25**

We have categorized the primary forest traffic infrastructure in the researched area in the following way:

- ⇒ public roads – all the public roads which can be used in works in forestry and as such represent a consisting part of the primary forest road infrastructure,
- ⇒ forest roads of the 1st order – these are all forest roads whose building and maintenance are financed by "Hrvatske šume" Ltd. Zagreb and are separated from public roads,
- ⇒ forest roads of the 2nd order – these are all forest roads whose building and maintenance are financed by "Hrvatske šume" Ltd. Zagreb and are separated from forest roads of the 1st order,
- ⇒ forest roads of the 3rd order -– these are all forest roads whose building and maintenance are financed by "Hrvatske šume" Ltd. Zagreb and are separated from forest roads of the 4th order.

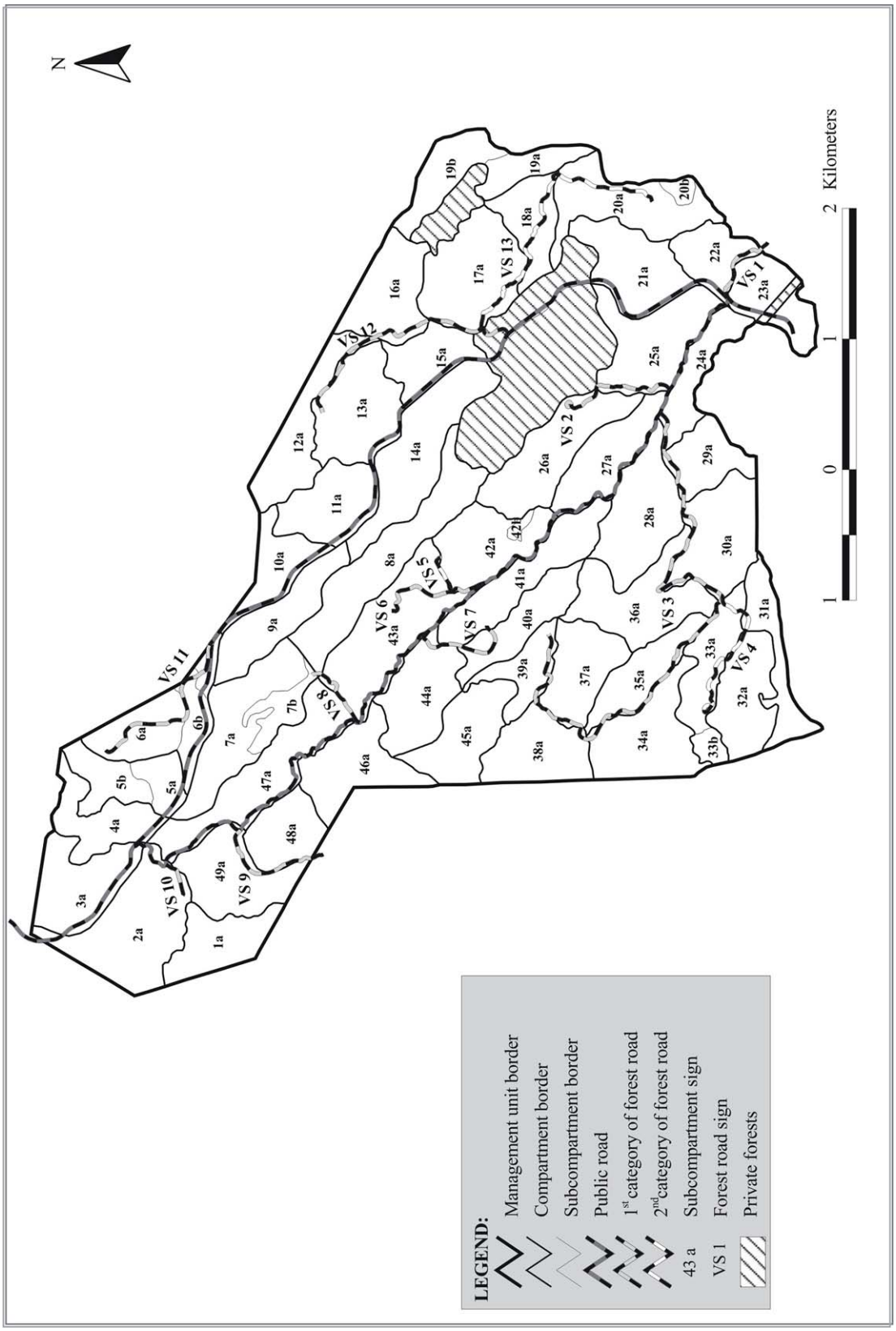

Figure 1: The cadastre of the primary forest traffic infrastructure of the management unit Veprinacke sume

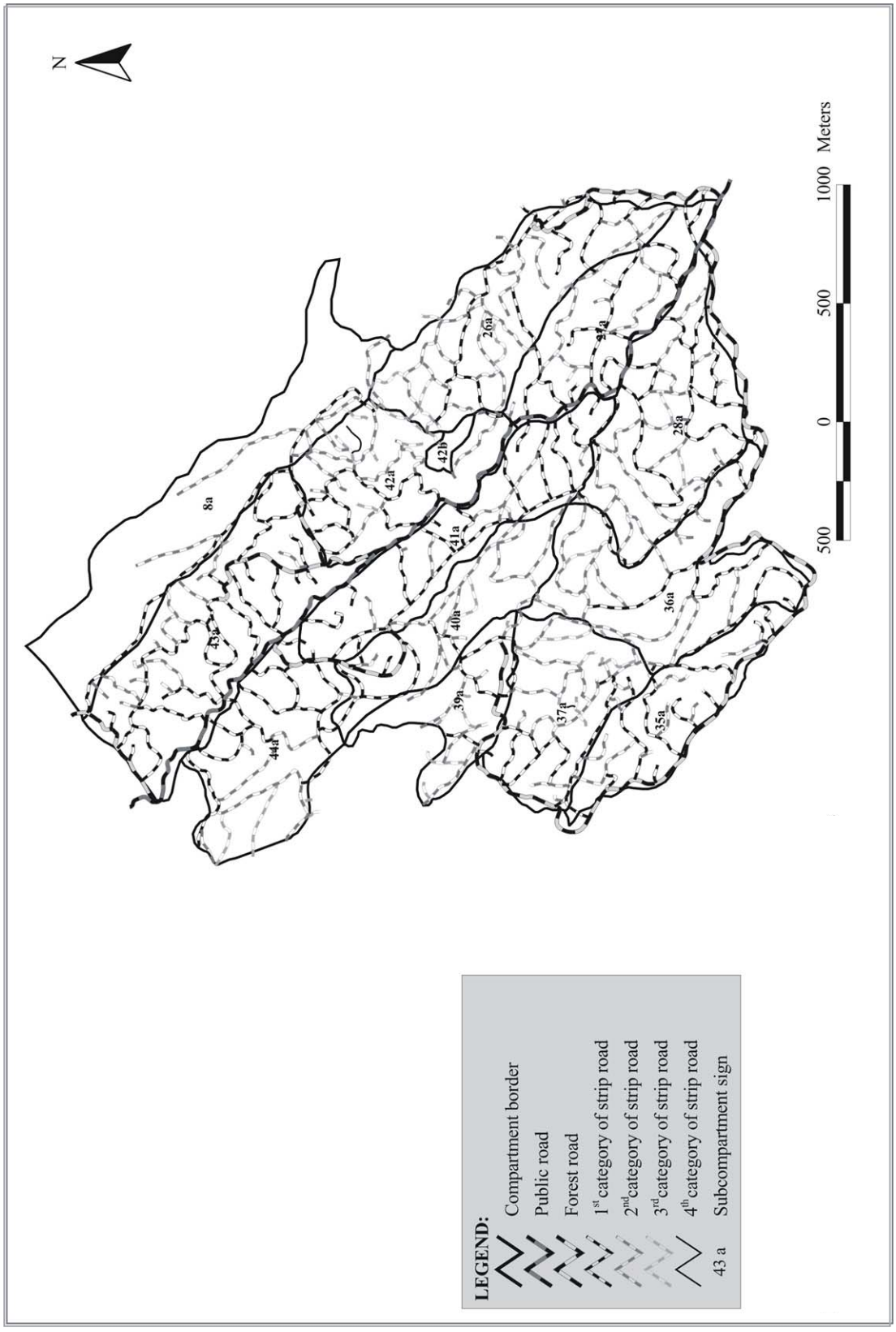

Figure 2: Situational drawing of strip roads in chosen departments of the management unit Veprinacke sume

5.2 Inventory and categorization of strip roads of chosen departments of the management unit Veprinačke šume

The cadastre of strip roads of fourteen chosen departments of the Management unit Veprinačke šume was carried out by GPS receiver Trimble GeoExplorer 3 by so-called return method (strip roads were surveyed in two directions: from the point A to the point B and the point B to the point A, in order to increase the preciseness and decrease the possibility of appearance of so-called dead zones – the area where we did not have satellite signals of sufficient quality) of continuous survey on foot with the interval of recording points of 5 seconds.

The cadastre of strip roads of fourteen chosen departments of the management unit Veprinačke šume was carried out by GPS receiver Trimble GeoExplorer 3 by so-called return method (strip roads were surveyed in two directions: from the point A to the point B and the point B to the point A, in order to increase the preciseness and decrease the possibility of appearance of so-called dead zones – the area where we did not have satellite signals of sufficient quality) of continuous survey on foot with the interval of recording points of 5 seconds.

We marked standing trees in the stand, by a marking spray the beginning and the end of each strip road in order to avoid "double" measurement. Coding of strip roads in making the cadastre of secondary forest roads was carried out by three marks: SR x y z. The mark x represents the ordinal number of the strip road within the research area. The mark y denotes the department in which a strip road starts, while the mark z was used to show the category of the strip road.

Strip roads were categorized in the similar way like forest roads; 1st category represents those strip roads which are separated from public or forest roads, the 2nd category includes strip roads which are separated from tractor roads of the 1st category, etc.

Table 2: Summarized data of the inventory of strip roads of the researched area

Strip road category	Number of recorded strip roads	Length	
	no	m	%
I	101	35408.54	51.72
II	120	28026.49	40.94
III	39	4829.21	7.05
IV	2	200.41	0.29
Total	**262**	**68464.65**	**100.00**

The research included the total of 537.63 ha of the forest area (of the total of 1950.87 ha). 262 tractor roads were surveyed, mapped and categorized by GPS of the total length 68464.65 m. The highest number is of tractor road of 1st category (51.72 %), then tractor roads of the 2nd category (40.94 %) and tractor roads of the 3rd category (7.05 %). The least number was of the tractor roads of the lowest , 4th category (0.29 %).

5.3 The analysis of the secondary openness of the researched area

The analysis of the secondary openness has been carried out by the method of bordered areas (Pentek, 2002). In the analysis, apart from the strip roads, we have taken the primary forest road infrastructure since from this category of forest roads it is also possible to roundwood.

Skidders type LKT 80, LKT 81 and Timberjack 240C equipped with winches with steel wire cables of 60 m of useful length are used in wood skidding. Due to the configuration of ground (big slopes and many karst forms) and other stand factors, we took 45 m as the distance which can be covered in winching round wood on both sides of a forest road and strip road.

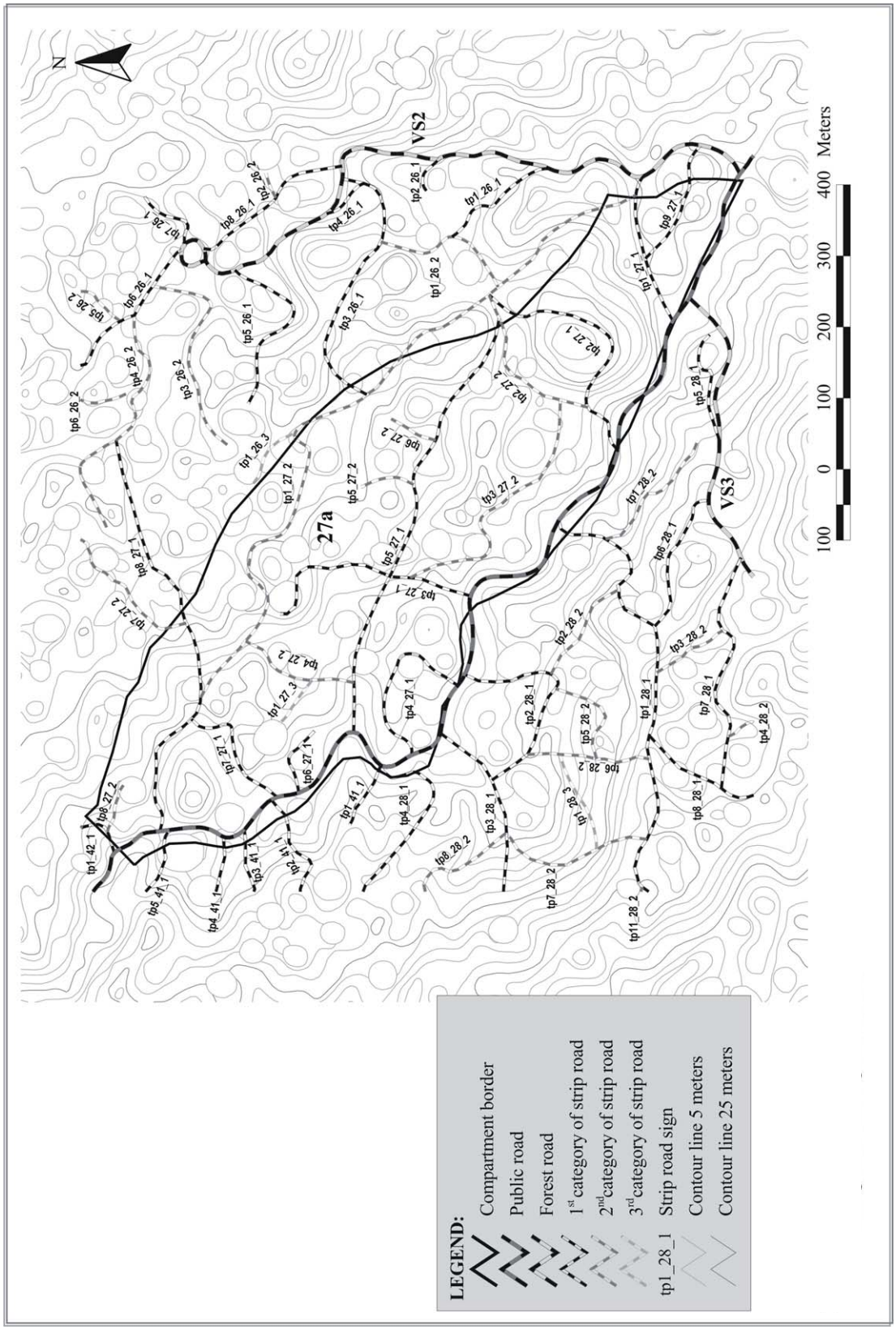

Figure 3: Secondary forest roads of the department 27a of the management unit Veprinacke sume

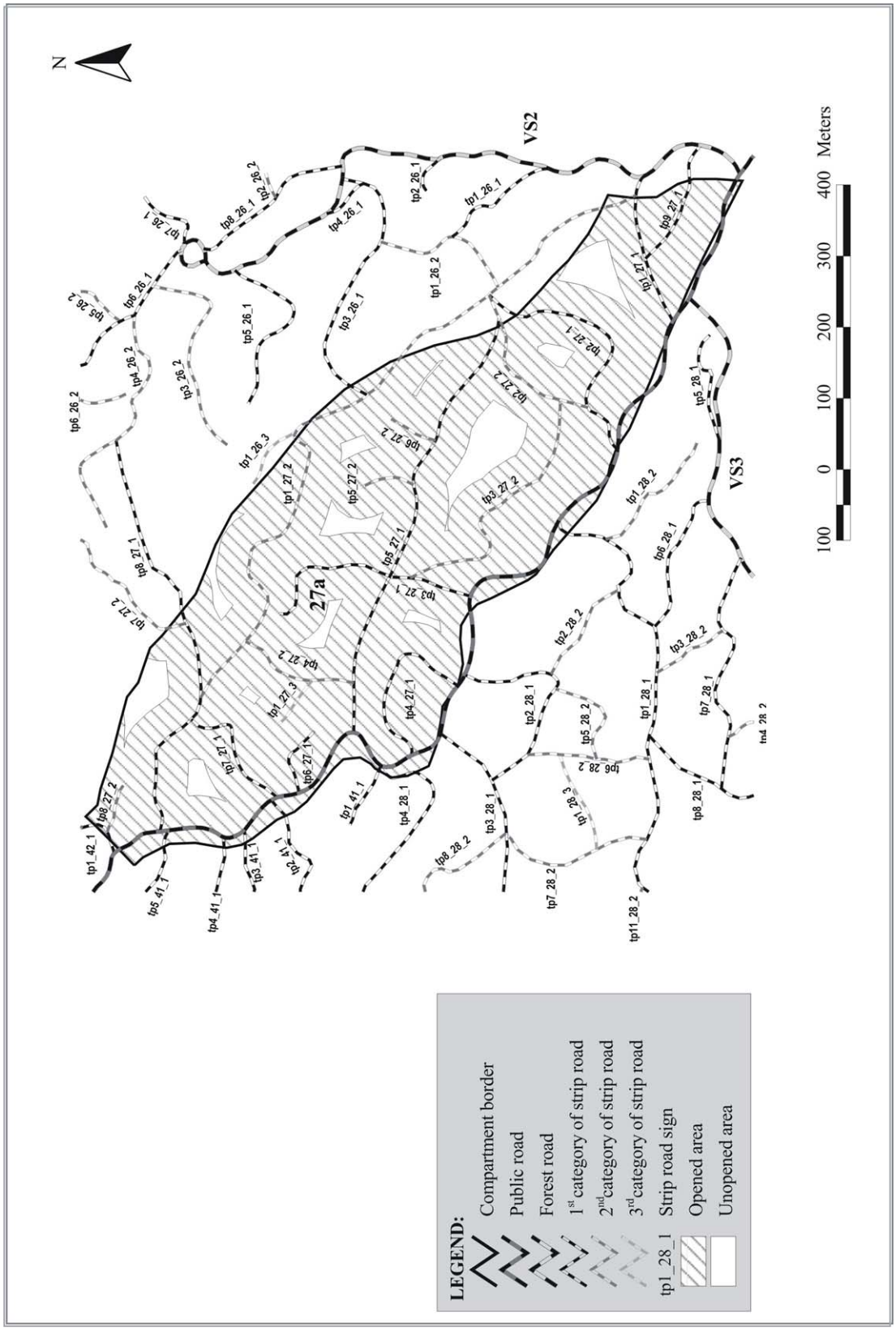

Figure 4: The analysis of the openness of the department 27a of the management unit Veprinacke sume for the length of the rope of the winch of 60 m (45 m)

In the evaluation and the comment of the relative openness we will use a bit changed system for the estimate of the primary openness (Pentek, 2002). The new evaluation system of appearance looks as it follows: till 60 % – insufficient openness (1), from 60 to 70 % – poor openness (2), from 70 to 80 % – barely good openness (3), from 80 to 90 % – very good openness (4) and over 90 % – excellent openness (5).

Table 3: The results of the analysis of relative openness according to departments

Department	Total area	Open area	Relative openness	
	ha	ha	%	Evaluation
8a	61.63	24.15	**39.18**	insufficient (1)
43a	62.41	58.63	**93.94**	excellent (5)
44a	39.36	34.66	**88.06**	very good (4)
42a	37.46	35.42	**94.55**	excellent (5)
41a	41.41	37.70	**91.03**	excellent (5)
40a	30.35	26.59	**87.62**	very good (4)
39a	20.87	17.46	**83.69**	very good (4)
26a	48.48	44.71	**92.21**	excellent (5)
42b	2.13	1.19	**55.93**	insufficient (1)
37a	34.65	33.23	**95.90**	excellent (5)
27a	34.21	31.61	**92.41**	excellent (5)
36a	48.31	43.51	**90.05**	excellent (5)
35a	28.10	27.18	**96.70**	excellent (5)
28a	48.26	45.73	**94.75**	excellent (5)
Total:	**537.63**	**461.75**	**85.89**	**very good (4)**

In departments 8a and 42b the insufficient openness has been established, while in departments 39a, 40a and 44a the very good openness has been calculated, while in other departments the openness is excellent and there is no need for further building of strip roads. For the whole researched area we have determined very good (4) relative openness (85.89 %). The classical openness of the researched area by strip roads (secondary openness) is 127.35 m/ha.

6. Conclusions

The inventory of forest communications of the researched area carried out by the use of GPS-a Trimble GeoExplorer 3, data processing by the programme package Pathfinder Office 2.80 and mapping by software ArcGIS on previously scanned and geocoded maps of the scale 1:5000 gave very precise data.

The situational entering of forest communications into maps of big scales requires surveying on the terrain by so-called return method, i.e. surveying the route of a forest communication in two directions in order to reduce those sections of forest communications on which we have no surveyed data or were not sufficiently quality surveyed to the least possible extent, and fitting in of a differential correction into original terrain databases.

Once established cadastre of primary and secondary forest communications enables us:

- ⇒ a precise and detailed insight into existing resources of the certain forest area,
- ⇒ the analysis of the existing condition of primary and secondary forest openness,
- ⇒ noticing potential needs, failures and inadequacies regarding traffic infrastructure,
- ⇒ planning and control of costs of maintaining forest roads and repairs of strip roads,
- ⇒ making the working site study in harvesting certain forest areas, etc.

The method of bordered area in combination with relative openness for which a system of quality evaluation has been made, represent exceptionally efficient mean in the analysis of the existing network of primary and secondary forest communications, separating unopened areas and their further opening.

The relative openness together with the data on the quantity of forest communications gives us also data about the quality of their spatial distribution.

In making studies of opening forest areas, it is necessary to define categories of forest roads since forest roads of higher categories will be built with higher building standards and quality while, their building standards will decrease in accordance with the decrease of forest road category. This is due to the fact that roads of higher order are exposed to higher traffic volume and higher traffic frequency, so the quality of their performance must be higher than of forest roads which are less frequently used. Technical features of a certain forest road category must be in accordance with their use value.

It is similar with their maintenance; forest roads of higher order will be maintained more frequently with more works, while forest roads of lower order will be periodically maintained in longer time intervals and less intensity. Due to the rationalization of building and maintaining costs, it is necessary to carry out the analysis of intensity (traffic volume) and frequency of traffic on certain forest road sections.

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