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Article

Fields in Forest Roman Land Division Between Siscia and Andautonia Through LIDAR Data Analysis

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Abstract: This study investigates the Roman land division system, centuriation, using LIDAR data and historical data to understand the landscape during the Roman period, in this case between Roman cities such as Siscia and Andautonia. LIDAR data analysis provided evidence of the preservation of Roman centuriation system in present day forest Turopoljski lug. The azimuth suggests that the centuriation aligns with Siscia's ager, while the precise territorial limits between the two agers remain unclear. Additionally, the orientation of Siscia's streets and the alignment of modern roads like Zagrebačka street suggest continuity of Roman road systems. The research also sheds light on the agricultural nature of the region, challenging traditional views of Turopolje as a swampy, forested area. The presence of Roman-era drainage systems and the re-evaluation of the historical landscape indicate that the region was actively cultivated. The study also discusses the abandonment of the centuriation system after the Roman period and its subsequent transformation into forested land. Future research should focus on the exact borders between the agers of Siscia and Andautonia, and the ongoing influence of Roman land divisions on later historical landscapes. This is the first time that centuriation grid was discovered in the continental part of Croatia.

Keywords: Roman centuriation; remote sensing; LIDAR; historical records

1. Introduction

Centuriation, or land division in equal plots is an essential feature of global impact of the Ancient Roman world to the landscape. It was formed above ground (walls) or cut into the ground (ditches). Ancient authors such as Frontinus and Hyginus Gromaticus illustrate important aspects of the work of land division by dividing balks and roadways (limites) in squares or rectangles (*centuriae*), which could then be subdivided to provide allotments for settlers was done by surveyors (mensores, agrimensores or gromatici) as described in the *Corpus Agrimensorum Romanorum* [1]. The drawing of maps to record land division was due to surveyors as it kept on part of map in *teritori Lacimurgenses* (Spain) [2].

Roman colony Siscia was founded on strategical intersection near the border of the Roman provinces Pannonia and Dalmatia [3]. Numerous documented roads were intersected in this area.

The area between Roman towns Andautonia (Šćitarjevo) and Siscia (Sisak) is long recognized as the important archaeological landscape, primarily because of the location of Roman roads between Emona, Poetovio, Andautonia and Siscia [4]. Large part of this area is now covered in forest, known as Turopoljski lug [5,6]. At the end of 20th century size of the forest was 4,337,46 ha [8]. In the late 19th century the size of the forest was almost two times smaller [9] which is important for the understanding of the present level of preservation of archaeological features (Figure 1).

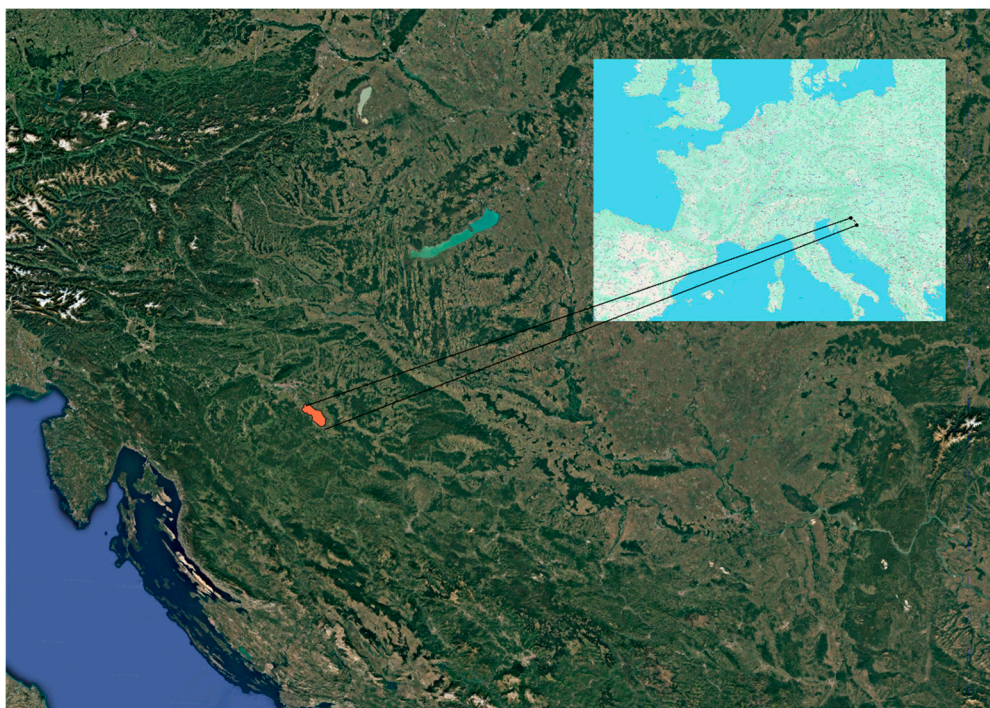


Figure 1. Position of the Turopoljski lug forest on the map of Europe.

Centuriation was part of the formal process of colonization, where land was conquered and divided into rectangular units, often for agricultural purposes. Most common division is in 20 by 20 actus (regular squares 710x710 m), especially in the Augustan era [21], but could be also of other measurements such as 12x12 Forum Iulii, 21x20 Cremona, 25x16 Beneventum, or other measurements as indicated by ancient authors [21]. The 20x20 actus produced area of 200 iugera [22] by intersecting *limites*. *Limites* could be built as walls or dug up as ditches in marshy lowlands when they served also for reclamation. The remains of Roman centuriations are, as generally, so on the territory of Croatia better documented on the stone rich environment where it was marked by (dry) walls. At present, remains of centuriation are detected on the Istrian peninsula, with azimuth of 18° [10,11], Zadar (Iadera), island Ugljan, Salona, Epidaurum, Tragurium, Parentium, Pola, Pharos, Cissa [12–18], all along the Adriatic coast. LIDAR data analysis and visualization confirm the presence of Roman land division and its remains as elevations and drywalls e.g., [19, 20].

The area in focus of our research is forests between Roman towns of Siscia and Andautonia in the Roman province of Pannonia Superior. Siscia is Roman town since August (from 35 BC), colony status gets probably from 71. AD [23], in same time Andautonia become municipium [24] in Flavian urbanization of Roman province Pannonia [25,26]. Siscia was of vital importance since it was the starting point of the Roman colonization of the Carpathian Basin and formation of province Pannonia. It was also strategic point in the emperor Traian's Dacian wars.

The remains of centuriation in Turopoljski lug presents first observation of Roman land division in continental Croatia, which is, unlike the coastal part, formed by ditches and henges. This observation led to important research question whether it is part of territory of the colony of Siscia or municipium Andautonia. Question of the boundaries between two territories are in constant interest of the researches of this period in the last 100 years.

In the centuriated territory there are clusters of Noric-Pannonian tumuli as well as traces of Roman road connecting Siscia and Andautonia that were previously documented.

2. Materials and Methods

We developed a comprehensive and methodologically rigorous approach, which encompassed the visualization and analysis of LIDAR data, the examination of historical records and maps, the

interpretation of aerial and orthophoto imagery, as well as a detailed review of relevant archaeological publications. This multifaceted methodology was designed to ensure the inclusion of all available data pertaining to the landscape under study.

For the observation and interpretation of tumuli and land division, we used the LIDAR dataset provided by the Croatian Geodetic Administration through the project Multisensory Aerial Survey of the Republic of Croatia for Natural Disaster Risk Assessment and Reduction. This dataset had a resolution of at least 4 points per square meter [27]. To aid in visualization, we used the Digital Model of Relief (DMR) generated by the Croatian Geodetic Administration, which was proved to be of highly adequate quality to support both detailed observation and accurate visualization of the terrain. For these visualizations, we employed the Relief Visualization Toolbox [28–30], which offered a variety of tools for enhancing and interpreting the data. Initially, we applied a vertical exaggeration factor of 8 to facilitate the identification of subtle topographic features. After the initial observation, the vertical exaggeration was reduced to a factor of 1 for a more realistic representation of the landscape.

Among the available visualization methods, several proved particularly effective in revealing key features. These included the Hillshade model with a 35° zenith angle and a 315° azimuth, the Multi-directional Hillshade (with 16 directions and a 20° sun elevation), the Simple Local Relief Model with a 20-meter search radius, and the slope model. These techniques provided valuable insights into the underlying topography, and were therefore selected as the most efficient for analysis. The research area spanned a significant region between Andautonia and Siscia, covering a total area of approximately 850 square kilometers. Notably, the region currently occupied by the Turopoljski lug forest extends over 4500 hectares [31].

The study began with the observation of tumuli that had been previously published in archaeological publications on LIDAR data visualisations. During this phase, we also noted the presence of regular lines, which led to the expansion of the initial area of focus. This expansion allowed for the discovery of additional tumuli and remains of the centuriation grid. The identification of these features was crucial for understanding the land division patterns in the area. Historical maps were also instrumental in tracing the evolution of the landscape, enabling us to track changes to the area under forest cover over the last four centuries. These maps, sourced from maps.arcanum.com and Geoportal.dgu.hr, provided valuable context for understanding the shifting toponymy of the region over time, offering further insight into how the area had been used and developed throughout history.

This multi-disciplinary approach, integrating advanced LIDAR data analysis with historical cartographic research, allowed for a comprehensive interpretation of the tumuli, land division patterns, and other archaeological features present in the landscape. It also provided a better understanding of how the region has transformed over the centuries, aiding in the reconstruction of its ancient spatial organization.

3. Results

In this analysis we detected and/or confirmed 3 important elements of Roman landscape on LIDAR data visualisations: tumuli, roads and centuriation division. Some of them are previously documented and researched, while some of them are observed for the first time. The most documented are the remains of Roman roads, then tumuli, while the remains of centuriation were completely unknown until now.

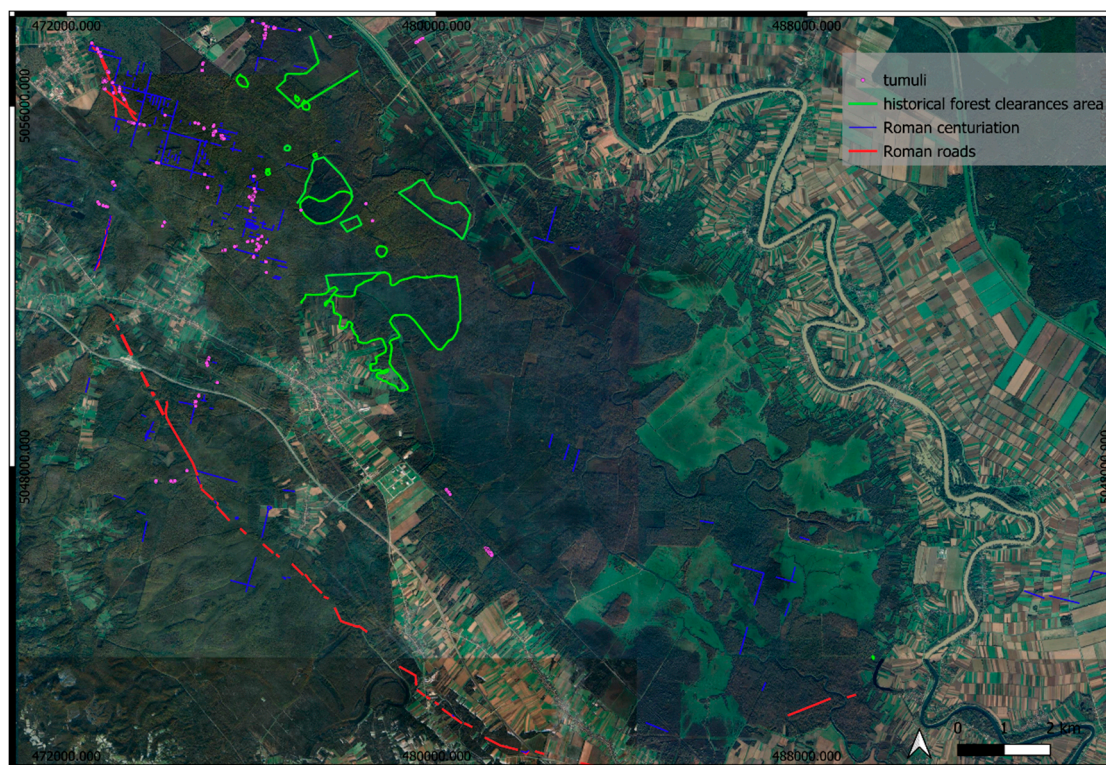


Figure 2. The marked positions of Roman tumuli, roads and centuriation, and documented historical forest clearances area.

3.1. Tumuli

In Turopoljski lug 10 areas with concentration of tumuli was discovered almost 50 years ago, with the total of 104 tumuli. Concentration of tumuli is from 1 to 23 in a group [5–7]. Six of those tumuli were excavated and all confirmed to the Roman period, from late 1st till the beginning of 3rd century AD [5]. The tumuli represent specific group known by the name of Norricum-Pannonian tumuli.

The areas with preserved tumuli is confirmed on LIDAR data and field survey, while some new areas with tumuli were detected (Figure 3-5).

Z. Gregl [6] noted the regular concertation of tumuli group VI in parallel lines and mentions the possibility that they were aligned alongside the road, but that could not be confirmed (Figure 4a). The space between groups he observed is line of the centuriation (Figure 4b). On LIDAR data we recognized 389 tumuli in 32 zones (Table 1), (Figure 5).

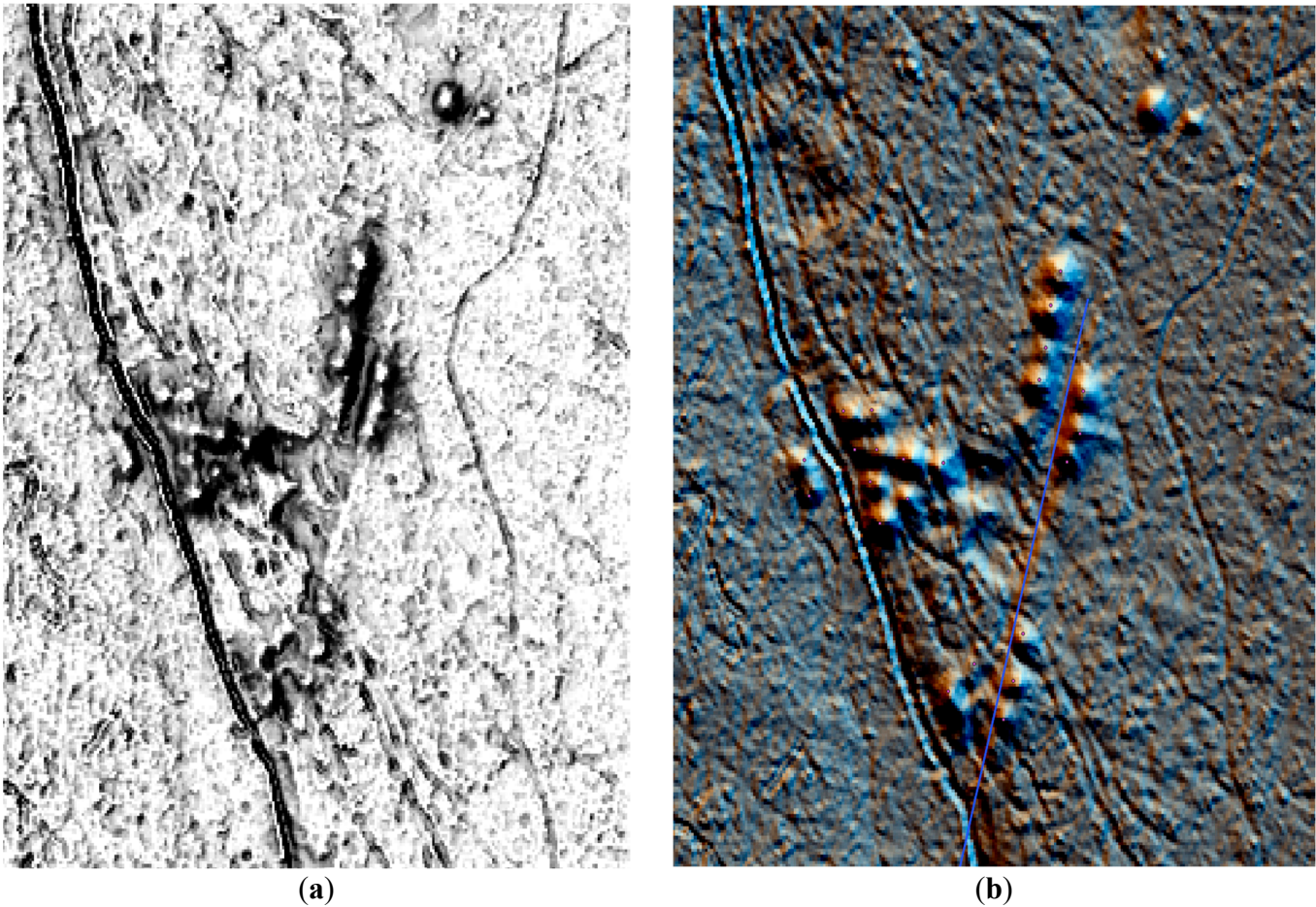


Figure 3. Archaeological (VAT) general terrain RWT visualisation (a) and Multi-direction hillshade (number of directions:16, sun elevation: 20) of tumuli group VI according to [6]. The horizontal and vertical limites are visible between tumuli.

Table 1. Number of tumuli in Turopoljski lug.

reference	number of tumuli	number of areas with tumuli
Koščević Makjanić 1986	49	4
Gregl 1990	104	10
LIDAR data 2024	389	32

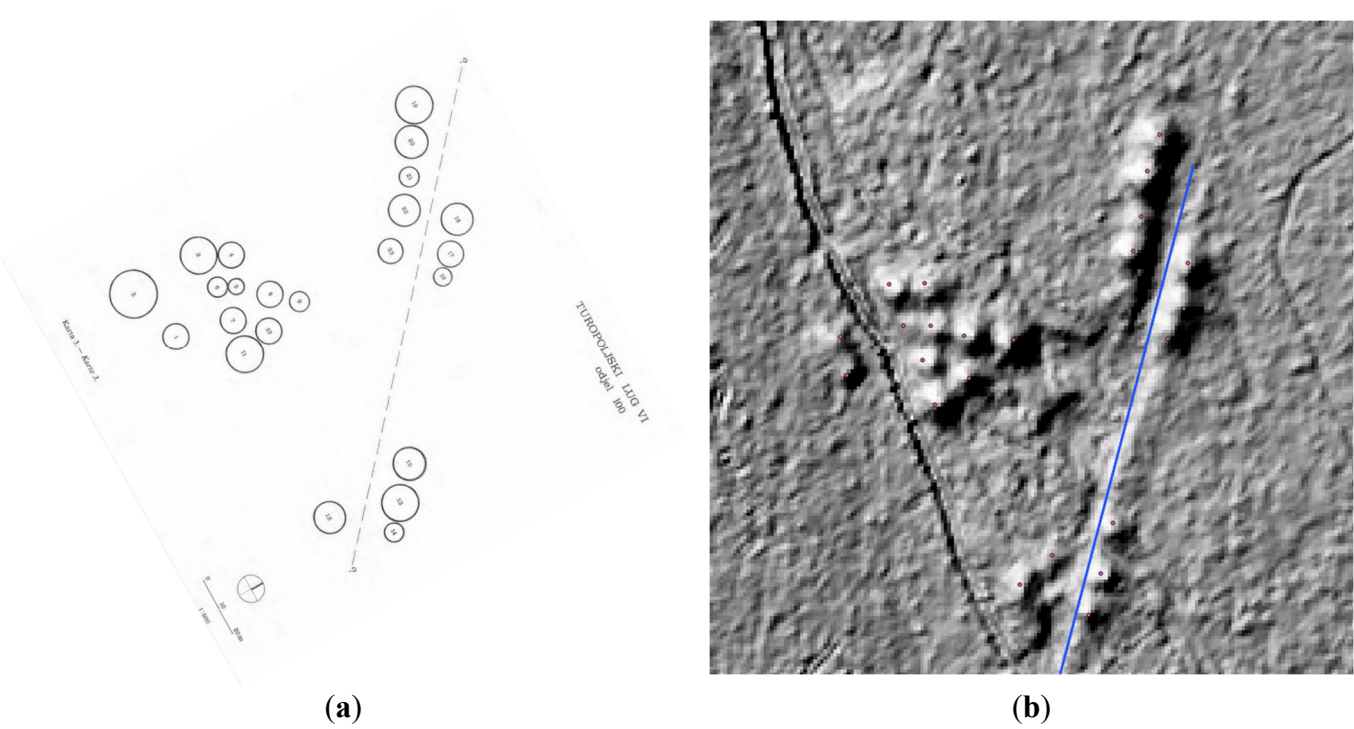


Figure 4. Tumuli and centuriation in Turopoljski lug a) sketch by Gregl [6]; (b) Hillshade visualisation (35° zenith angle, 315° azimuth).



Figure 5. Previously undocumented tumuli in Turopoljski lug discovered by LIDAR data analysis and confirmed by field survey.

3.2. Centuriation

Beside main division in squares Main squares are 710x710 m. The remains of 11 squares well preserved is marked in Turopoljski lug. On some, internal division is preserved 8x8 parts what is not traditional inner measures.

The division identified on LIDAR visualization presents a typical Roman centuriated landscape. Limites are formed by drains or ditches, frequently flanked by trees and henges [32], Figure 1 in that text. That is why the edges of ditches are usually elevated. Both ditches and hedges were visible on LIDAR data visualisations (Figure 3). The inner grid are was also made by ditches and hedges as documented elsewhere e.g., [33] and observed in this analysis (Figure 3, Figure 4).

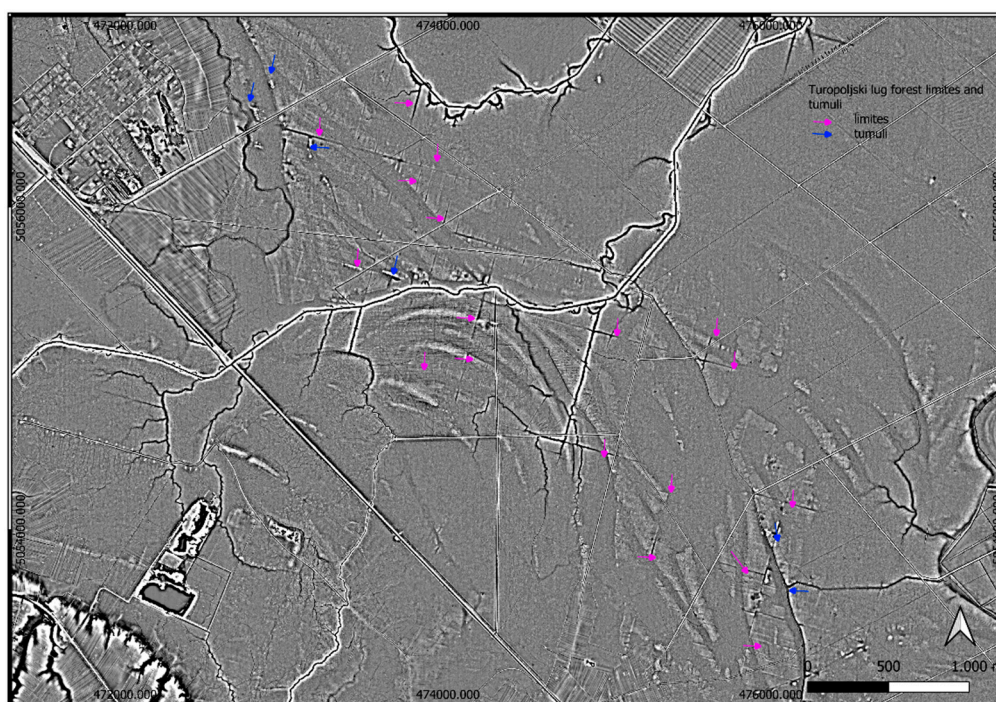


Figure 6. The are with biggest concentration with centuriation grid and tumuli in Turopoljski lug. Visualisation Simple local relief model. Search radius 20 m.

During the 18th century exhaustive forest clearing was undertaken and transformed into arable land which is documented by written records, plans and topographical names. The biggest one happened in second half of 18th century when organized deforestation took place and the new land was equally divided among Turopolje nobility [34]. It lasted from 1776. in 1779. and as a remembrance to this big event, memorial gate was erected – *Vrata od krča* (Deforestation gates). The gates were destroyed and restored several times and are now protected monument [9]. The area that were cleared frequently are recognizable by the toponim KRČ (Croatian word for clearing forest/bush to transform into arable land same Krčevina or Kerč/ć bed noted by historical map). Historical maps prove that the areas where centuriation lines are not visible were areas where deliberate deforestation and clearances took place (Figure 2, 7). Some are near modern villages like Buševac, Lekenik on east Krči; Poljan on east Krčevina; west from Suša Kerči, Kerčinci all on Habsburg Empire - Cadastral maps (XIX. century) (Figure 7a). On First Military Survey (1783–1784) Provinz Kroatien west from Veleševac is toponym Kerchevina [Mapire] (Figure 7b). on modern map Krči Geoportal same toponym is in vicinity village Ogulinec [Geoportal].

In 1876 government approved sale of forest Kozjak [35]. It is later mentioned as meadow, as well as big cleared areas of Krči and Vratovo [36] which are toponyms on the areas where there are no remains of centuriation. We can conclude that the lack of centuriation remains is the result of subsequent forest clearance activities and preparation for agricultural activities. Here it is not

documented, as elsewhere that the limites ditches were used in later periods, probably because for a period of time the entire area was abandoned.



Figure 7. (a) Lekenik Turopoljski, Habsburg Empire - Cadastral maps (XIX. century) Arcanum with toponimy Stari Krč and Novi Krč; (b) First Military Survey (1783–1784) Arcanum – toponimy Novi Krč.

The azimuth of centuriation is 15 degrees. It is worth mentioning that the streets of present day Sisak in its northern part (Zeleni brijeg), outside of the Roman town perimeter have the same inclination, while the street raster in the part of the town that was Roman Siscia have different orientation. We can conclude than that this block of land division finished at the northern entrance to Roman Siscia. The existing Zagrebačka cesta entering Sisak from the west Siscia follows that azimuth as well as Zeleni brijeg part of the town (Figure 8). On LIDAR visualization there are some features visible that could present remains of limites since are not part of present streets and blocks.

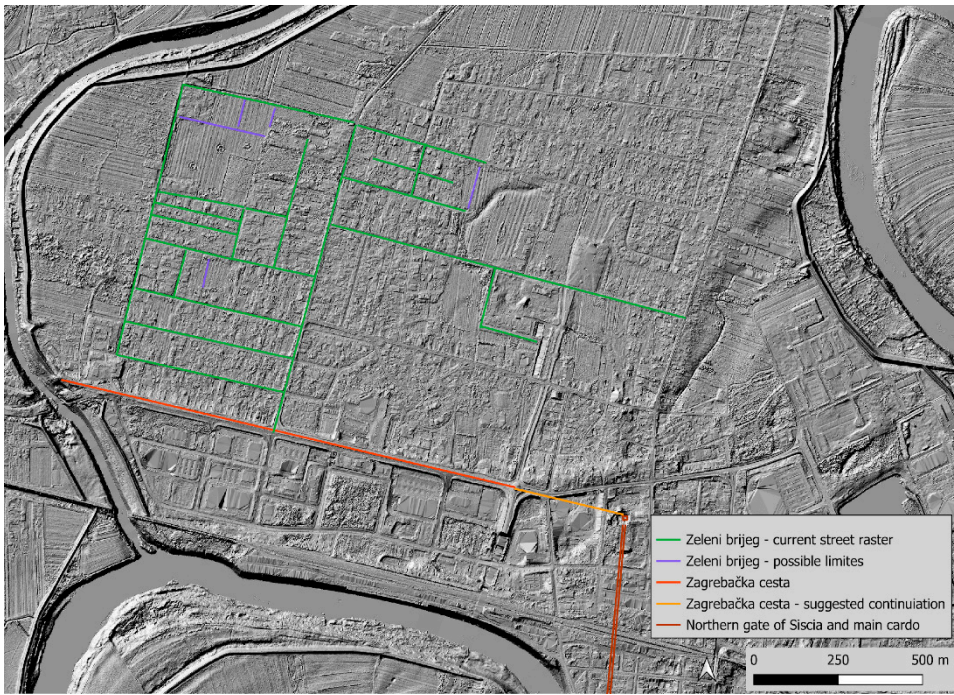


Figure 8. The street raster of Northern part of Siscia.

3.2.1. Main Grid

The main grid is formed as regular rectangles dimension 710 x 710 m (most typical centuriation grid). It was formed by digging channels 4 to 10 meters wide for the main grid. On the both sides of the channels, there are remains of the elevations, so we can conclude that the henges were formed on the edges of the channels, thus forming the most typical centuriation features for the lowlands, especially marshy areas which Turpoljski lug most certainly is. A total of 425 horizontal of vertical grid lines (both main and internal) were documented in this research (Figure 9,10).



Figure 9. Visible traces of ditch and hinge of main *limites* in Turopoljski lug.

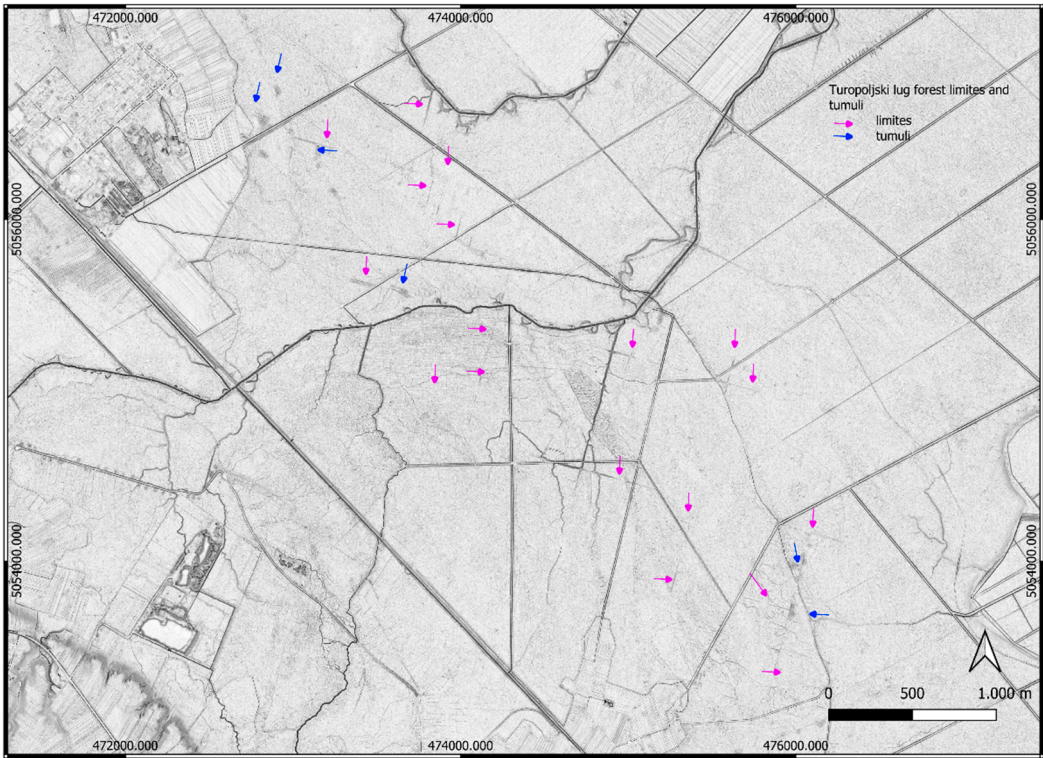


Figure 10. Tumuli and centuriation grid. Visualisation Sky-View Factor. R20 D 23 A270. 20 m search radius in 23 directions with 270° azimuth.

3.2.2. Internal Division

The internal division is visible within several main divisions. The width of the channel is 3-5 meters. It is not so well preserved in all areas, but in the central area with most finds of tumuli and main grid, there are also numerous remains of the internal division. The internal division was formed similar to main one, with channels and henges, but much more narrow (Figure 11-13).

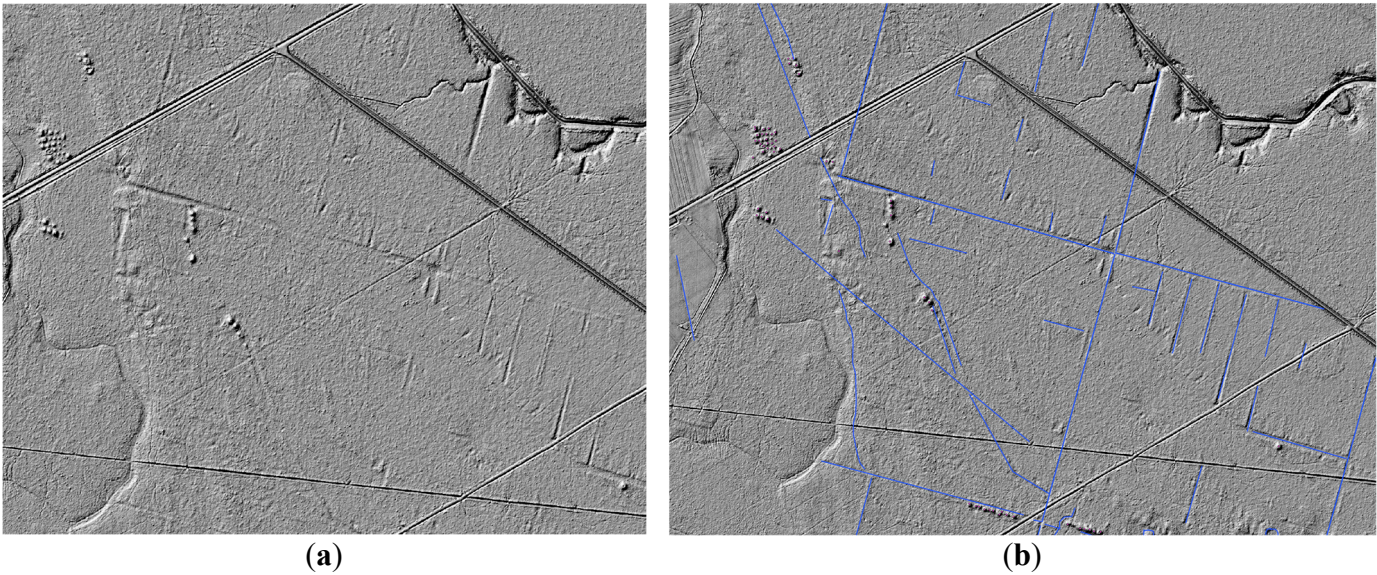


Figure 11. Turopoljski lug the best preserved part of centuriation, (a) Hillshade visualisation (35° zenith angle, 315° azimuth); (b) plotted main limits, internal divisions and auxiliary roads.

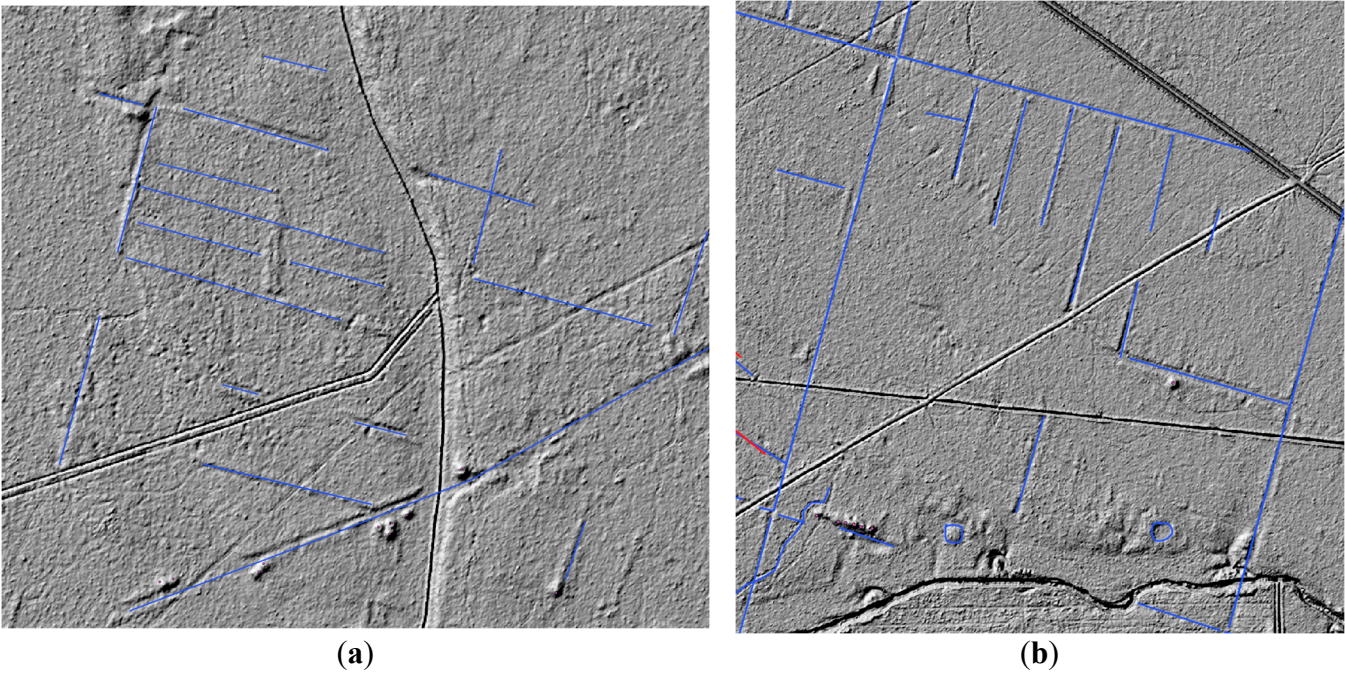


Figure 12. Turopoljski lug the best preserved part of centuriation, Hillshade visualisation (35° zenith angle, 315° azimuth); (a) plotted main limits, internal horizontal divisions and auxiliary road (b) plotted main limits, internal vertical divisions.



Figure 13. Turopoljski lug the best preserved part of centuriation, Hillshade visualisation (35° zenith angle, 315° azimuth, with remains of tumuli, main centuriation limites (on left side probably with original depth), inner division and the auxiliary road.

3.3. Roads

Matija Petar Katančić in late 18th century described the route of the Roman road from Andautonia to Siscia [37]. In modern village of Buševac road split in two branches – one towards the west, and the other towards the southeast, in the direction of Siscia [38]. The road was still visible in 18th century and was called “Roman path”. Field surveys confirmed those conclusions [38]. The branch from Buševac is visible on LIDAR visualisations, almost in continuity, till village Sela (Figure 14), from where it is covered by the modern road till Siscia (Sisak), but the archaeological excavations preceding the reconstruction of the aforementioned road confirmed presence of Roman road [39].

This main Roman road route is on the Western side of the best preserved part of the land division, but there are also remains (though much less numerous) to the west from this road.

Auxiliary roads – they were not made of pebbles and cobbles. In the vicinity, remains of such road were excavated [40].



Figure 14. Position of the Roman road Andautonia – Siscia on Archaeological map from Klemenc 1938.

Traces of possible small auxiliary Roman roads are visible in the area. Remains of Roman auxiliary road were discovered during the rescue excavation in Donji Vukojevac, on the route of the motorway Zagre-Sisak, as well as remains of Roman rural settlement [40]. Remains of such type of roads were also found during the excavations for the same motorway more towards the North [41]. Elevated narrow features visible on LIDAR visualisations are therefore interpreted also as remains of auxiliary roads.

The remains of the road entering Siscia at the Northern Gate were discovered along the present day Zagrebačka cesta, confirming the direction suggested from 18th century. This road has the same orientation as centuriation (Figure 8). This road crosses the Odra river, close the confluence with Kupa river. In 1968, remains of the Roman bridge were discovered nearby [42], and interpreted as bridge connecting the road leading to Andautonia [42]. The remains of the road in the direction of N-E was found in the area of Zeleni brijeg on two places [42] also following 15 degrees azimuth, in Roman period as today.

4. Discussion

The analysis of LIDAR datasets and historical data provide concrete evidence for interpretation of the Roman land division, centuriation. The areas where centuriation is not preserved mostly coincides with the areas that were deforested during the historical periods. as seen on historical images. LIDAR offers significant advantages in detecting and analyzing Roman *centuriation*, including non-invasive surveying, high-resolution data, and the ability to access hard-to-reach areas, its limitations—such as difficulties with subtle features, environmental factors, and historical changes—must be considered. Complementing LIDAR with other archaeological techniques and historical records will help overcome these limitations and provide a more comprehensive understanding of ancient land divisions. At the moment, the potential of application of LIDAR data analysis in archaeology highly overcomes potential limitations. It will take time until we reach those limitations.

This is especially clear in the research of forested and marshy areas where archaeological remains are difficult to observe using traditional methods but on the other hand, better preserved because of environmental factors. With LIDAR we can now reach areas that were out of modern infrastructure impact as well as archaeological methodology.

The land is, even though marshy, suitable for agriculture which is confirmed through use in historical and recent periods.

Area now covered in forest known as Turopoljski lug between Siscia and Andautonia are considered as Siscia territory [42]. Some authors [43 <https://www.amz.hr/media/et3hcdx4/polo%C5%BEaj-i-pretpostavljena-veli%C4%8Dina-teritorija-andautonijskog-municipija.jpg>] consider Turopoljski lug as a part of Andautonia ager. Kadi suggests, based on analysis of historical maps and modern infrastructure that the azimuth of Andautonia centuriation was 22,5 degrees [43]. One of the roads from Šćitarjevo towards the south-east which was confirmed by geophysical research also has azimuth of 22,5 degrees, suggesting the possibility of the centuriation with the same azimuth. (<https://www.amz.hr/media/threp3d2/gradsko-i-prigradsko-podru%C4%8Dje-andautonije-s-prilaznim-cestama-s-engl.jpg>). Street raster of Roman Andautonia in its first phase are aligned with the main cardo, oriented towards the north [44]. In the second phase the azimuth of the streets and buildings is 60 degrees [44]. It is interesting to note that the most northern street of Andautonia discovered by the geophysical research has azimuth of 15 degrees [44, Figure 8], but that could be in connection with the local topography or some other factors.

If we accept the northern raster of present day Zeleni Brijeg area of Sisak and Zagrebačka street as remains of orientation from the Roman period we could suggest that the Siscia ager starting point was at the northern city walls of Siscia. Present day Zagrebačka street ends at the roundabout and the following road in the direction toward the East (Ferde Hefelea street) changes orientation. This roundabout is around 300 meters from the Northern gate to Siscia. This Northern Gate were confirmed by archaeological excavations [45]. If we continue to follow direction of Zagrebačka street

it ends precisely at the location of the Northern Gate. [45]. The existence of the Roman road was confirmed in 2013 during archaeological rescue excavation preceding reconstruction of Zagrebačka street (39). This road today crosses the bridge across Odra river. Along the road there were finds of graves on various places (Koprivnjak 2014). Zagrebačka street is the continuation of the modern road which partly follows the route of the Roman road Andautonia-Siscia which was recognized in the early Modern Period [37], and confirmed in 19th and 20th century [4,38] (Figure 15).

The azimuth of our centuriation does not follow neither Andautonia [] or Siscia azimuth []The azimuth of street raster of municipium Siscia is 5 degrees.

The orientation of the town and its ager does not have to be (or usually is not) the same. [46]. Both cities and land are planned according to specific characteristics of the city structure demands or local topography, relations with surrounding areas and also astronomical aspects. [46]. Around some towns are even several different orientations of land. It is common practice that the orientation of the city does not match orientation of the *ager*. [46]. Also, orientation of centuriation of two different towns is usually different. One of the rare opposite examples, where there are the same is between Parentium and Pola on Istrian peninsula [11].

The suggested area of Andautonia ager stretches up to village of Lekenik, in the area where LIDAR data confirmed presence of centuriation with 15 degrees azimuth [43]. This research was concentrated on the area south of Sava river, and confirms for that area that the azimuth was different (15 degrees as mentioned here). Considering all this data we can suggest that the border between Siscia and Andautonia ager is somewhere to the north of the suggested line. Since there are no undisputable traces detected so far of 15 degrees centuriation north of village Ribnica, it is too early to hypothesize whether the ager of Andautonia started only north of the city perimeter. Kadi places eastern edge of the Andautonia ager at the village Orli [43], but the western edge is deep in 15 degrees azimuth, in our opinion, Siscia ager and should be placed at least 6 km in the direction of NW concerning current data (Figure 15). The eastern edge of the Siscia ager is yet to be determined since the traces of centuriation reach at least village Osekovo which is the distance of 18 km from Siscia.

The practice of detecting centuriation through analysis of modern infrastructure was proven efficient and in use e.g., [47–51]. Therefore we accept Kadi suggestion of 22,5 azimuth of Andautonia centuriation, especially since partly confirmed by geophysical research and archaeological excavation [43,44]. The focus on future research should be to find the border zone between two agers.

This research could also have implications for some of the traditional general knowledge about the area, for example the famous cattle breed bears the name of the Turopolje (tur) and is traditionally regarded as remains of aurochs. The fact that this area was cultivated land during Roman period calls for re-evaluation of this knowledge, since this data clearly shows that the area was not covered in forest in all periods..

Turopolje is often mentioned as very swampy densely forested area until the melioration in 19th century, while the elevated Roman roads were the only passable areas [52]. It is clear now that during the Roman period the area was agricultural land, and numerous ditches forming inner and main divisions were probably part of complex water regulation system because of the topographical characteristics of the area. First mention of Turopolje forest as a forest dates from 1217 [35].

In this case, centuriation system, with all its advantages as efficient drainage system was not later in use. Floods were frequent and the area is “famous” for it. There are numerous documented cases where Roman centuriation system was later in use and constantly maintained, especially in the marshy environment [50,53], but not in this case. Current forest division visible on aerial and satellite photos does not follow Roman land division.

After Roman period the land division is abandoned. The excavated tumuli are dated from late 1st century till early 3rd century [5]. Most of the tumuli respect the centuriation limits. Only some of them are in the inner part. This could mean that these parts were used specifically for burial areas or that the land could have been gradually abandoned and its function replaced. The Turopolje after Roman period became densely forested space and in tradition those forests are called “Prehistoric forests”. The kind of isolation reflects in the fact that the forests were regarded as a possible refugia

for late remaining aurochs between Roman period and Middle Ages. Archaeogenetical analysis in the future should conclude whether there were aurochs in historical periods in the region. Abandoned forested places that were only again cleared up for agriculture in the Early modern period could reflect the special relations later inhabitants had with these visible burials in the environment – area of the dead. Slav toponyms Trebarjevo and Veleševac (from Veles, in Slavic mythology god of the could support that interpretation.

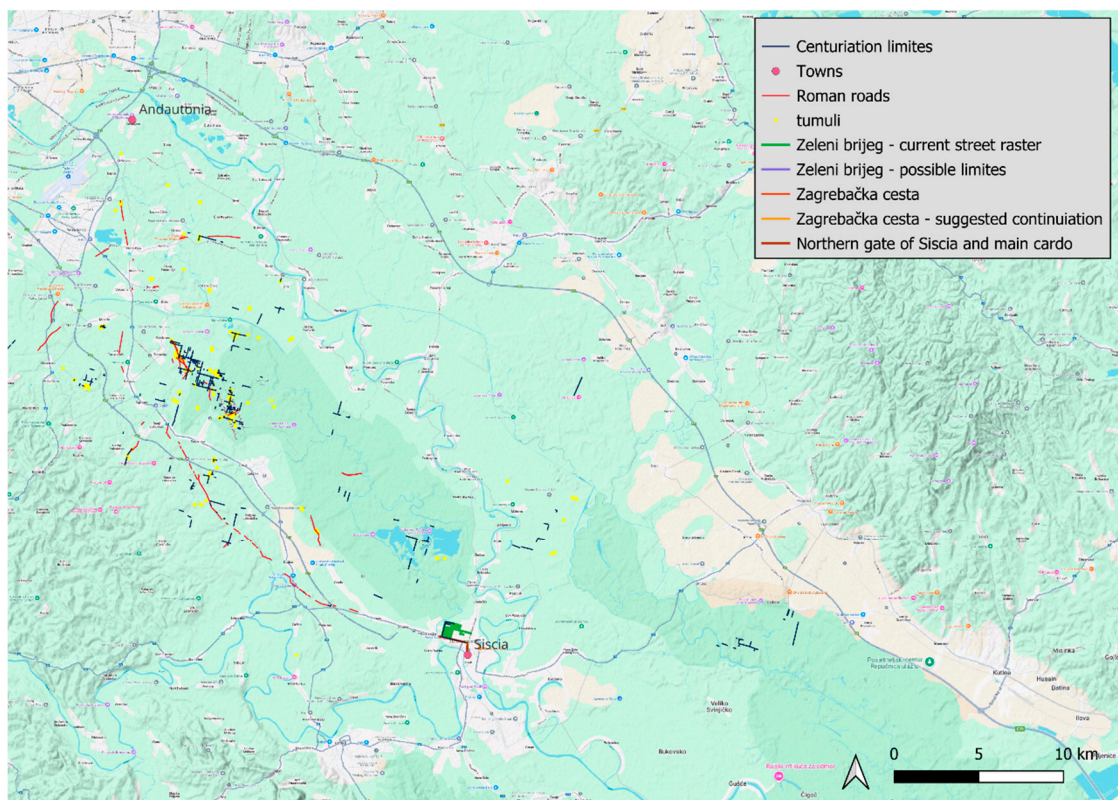


Figure 15. The marked positions of Turopoljski lug forest (1), Andautonia, Siscia, Roman roads (red), centuriation (blue) tumuli (yellow).

5. Conclusions

Based on the analysis of LIDAR data, it is evident that the centuriation discovered in the Turopoljski lug forest is linked to the land division of Roman colony Siscia. Our preliminary findings suggest that the remains of the centuriation, combined with the current street layout and orientation in Sisak, point to the land division of Siscia. The centuriation pattern detected in the forest of Turopoljski lug is most likely part of the larger colonial land division structure of Siscia. The alignment of the visible remnants of centuriation, when considered alongside the modern street grid, strongly supports the idea that they belong to Siscia's ancient land division. The position and alignment of the current centuriation remains observed in Sisak further confirm its association with the Roman colony of Siscia. Considering Siscia's role as a Roman colony, its high-ranking status among provincial authorities helps explain the sophisticated land divisions, such as the centuriation found in Turopoljski lug. LIDAR data analysis is proven as highly powerful tool for observation and analysis of Roman landscapes as well as better understanding of relations between towns.

Supplementary Materials: All materials are presented in the text.

Author Contributions: Conceptualization, H.K., B.Š. and R.Š.K.; methodology, B.Š., H.K. and R.Š.K.; investigation, R.Š.K., B.Š. and H.K.; resources, R.Š.K., B.Š. and H.K.; writing—original draft preparation, R.Š.K., B.Š. and H.K.; writing—review and editing, H.K., B.Š. and R.Š.K.; funding acquisition, R.Š.K., H.K. and B.Š. All

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