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## SPACE-TIME ANALYSIS OF STRONGHOLDS IN THE SOUTHERN SECTION OF THE POLISH-RUTHENIAN BORDERLAND WITH PARTICULAR EMPHASIS ON CARPATHIAN CENTERS, RESEARCH USING GIS TOOLS

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### Abstract

The article contains the findings of geoarchaeological research conducted by means of geoinformatics, related to various aspects of territory occupied in early Middle Ages by the so-called Cherven Towns. The issues presented in the publication concern the complex aspect of the borderland between Poland and the Rurik Rus during the formation of these two monarchies. The main objectives include: presenting the diverse time of strongholds' use over the centuries within the early medieval borderland of south-eastern Poland, demonstrating the relationships between them, as well as visualizing the research findings by means of geoinformatics tools, based on geoarchaeological data. The article presents maps and visualizations that can help understand how medieval societies functioned. These maps and visualizations have been developed by means of GIS and graphical software. Data was verified by means of field research carried out in 2021 directly on the selected fortified settlements. The result comprises a variety of maps and models. The main outcome of the research is a mapped diversification of the termination of existence of the discussed defensive structures, for example, in the Wiar river catchment, which took place from the 11th century, near Sanok, until the 13th/14th century. This indicates a change in the defense strategy of these areas within the quoted territory of influence of medieval Poland and Rus, including within the range of the Carpathian arch.

**Keywords:** Polish-Ruthenian borderland, space time cube, geoarchaeology, Kernel Density, strongholds

## CZASOPRZESTRZENNA ANALIZA FUNKCJONOWANIA GRODÓW NA POŁUDNIOWYM ODCINKU POLSKO-RUSKIEGO POGRANICZA, ZE SZCZEGÓLNYM UWZGLĘDNIENIEM OŚRODKÓW KARPACIKICH, BADANIA Z WYKORZYSTANIEM NARZĘDZI GIS

### Abstrakt

Artykuł zawiera rezultaty badań geoarcheologicznych prowadzonych metodami geoinformatycznymi, dotyczących szeroko rozumianego terytorium zajmowanego przez tzw. Grody Czerwieńskie we wczesnym średniowieczu. Publikacja dotyczy złożonego aspektu pogranicza Polski i Rusi Rurykowiczów w trakcie tworzenia się tych dwóch monarchii. Głównymi celami opracowania są: ukazanie zróżnicowania czasu korzystania z ośrodków grodowych na przestrzeni wieków na obszarze

wczesnośredniowiecznego pogranicza południowo-wschodniej Polski, przedstawienie relacji jakie zachodziły pomiędzy nimi oraz zwizualizowanie otrzymanych wyników badań za pomocą narzędzi geoinformatycznych, na podstawie danych geoarcheologicznych. W opracowaniu przedstawiono mapy i wizualizacje, które mogą pomóc zrozumieć, jak funkcjonowały społeczności wieków średnich. Do ich opracowania zastosowano narzędzia GIS i programy graficzne. W celu weryfikacji danych, w 2021 r. przeprowadzono badania terenowe bezpośrednio na wybranych grodziskach. W rezultacie opracowano szereg map i modeli. Głównym wynikiem przeprowadzonych badań jest wskazanie zróżnicowania czasu zakończenia istnienia omawianych obiektów obronnych – przykładowo w zlewni rzeki Wiar miało to miejsce do XI wieku, nieopodal Sanoka do XIII/XIV wieku. Świadczy to o zmianie strategii obrony danych terenów w obrębie przytoczonego terytorium wpływu średniowiecznej Polski i Rusi, w tym w zasięgu łuku Karpat.

**Słowa kluczowe:** pogranicze polsko-ruskie, kostka czasoprzestrzenna, geoarcheologia, Kernel Density, grody

## 1. INTRODUCTION

Fortified settlements are a testament to the passing of old cultures and societies. Some have been transformed into cities or castles, while others have been hidden among farmlands or overgrown with dense forest [1]. Still, all are connected by Slavic archaeological (cultural) heritage [2] and a recording of the early medieval past. Each stronghold had the same origin – it began with piling up ramparts. At the final stage, which is especially critical to further analyses described in the article, the transformation stemmed from the continued use of the stronghold (or abandonment thereof). This reflects a shift in the defensive and residential tactic supervised by a given central authority, and has strategic and administrative implications. The formation of Central European countries in the Middle Ages led to the creation of buffer territories. Between Poland and Rus, such an area was influenced by the so-called *Chevrén Towns* [3]. The often controversial term *Chevrén Towns* [4] is associated with the belt that lies within today's Podkarpacie, Lublin Province, and western Ukraine. The notion appears in *The Tale of Bygone Years* by Nestor, but it is difficult to find other written sources from that time. In this article, the concept of *Chevrén Towns* has been assigned to locations from the vicinity of Przemyśl to the region of Chełm, mainly during the reign of the first king of Poland, Bolesław the Brave and his father, Mieszko I [5]. Frontier defense structures inside the area were of vital strategic importance, stretching from the Bieszczady Mountains in the south to Polesie in the north, it became the subject of research (Fig. 1). Probably due to hypsometry, the area constituted an administrative challenge for a given ruler. It is difficult to reconcile extremely mountainous settlement conditions in the south with lowland ones towards

the rivers Wieprz and Bug. Figure 1 demonstrates the lack of developed settlement in Roztocze. This was related to the water divide that runs here, which was reflected in the complex history of the examined settlements [6].

The main purpose of the study is to demonstrate the differences in the usage time of strongholds over the centuries within the early medieval borderland of south-eastern Poland, to indicate the relationships between them, and to visualize the research findings by means of geoinformatics tools, based on geoarchaeological data. The time frame was specified between the 9th and 14th century. A major aspect of the study was also to highlight the importance of the researched territory in shaping the powers of Central Europe. The findings were assigned analyses related to the border between Poland and Hungary (Slovakia). The visualizations refer to the location of checked and unchecked strongholds, which additionally demonstrates the essence of using traditional archaeological and geographical research and new technologies in learning about the past.

## 2. MATERIALS AND METHODS

The data collected for the purpose of analysis origin from diverse academic publications as well as geospatial databases. The extent of the impact of the studied strongholds was obtained from the historical atlas [5]. However, the exact locations of the strongholds had to be determined from the interactive atlas [7] and a catalog of strongholds [8]. Nevertheless, the exact location of the strongholds was confronted with an online virtual map (National Institute of Cultural Heritage) [9]. The Digital Elevation Model was taken from transformed SRTM (Shuttle Radar Topography Mission) data [10]. In the process of creating the database, there was a dif-



**Fig. 1.** Map of the terrain with marked area of the Cherven Towns. Border of the area based on [5]. Black indicates the names of geographical regions. Digital Elevation Model [25] based on SRTM data [10]

**Ryc. 1.** Mapa rzeźby z zaznaczonym obszarem Grodów Czerwieńskich. Granica obszaru na podstawie [5]. Na czarno uwzględniono nazwy krain geograficznych. Numeryczny Model Terenu [25] na podstawie danych SRTM [10]

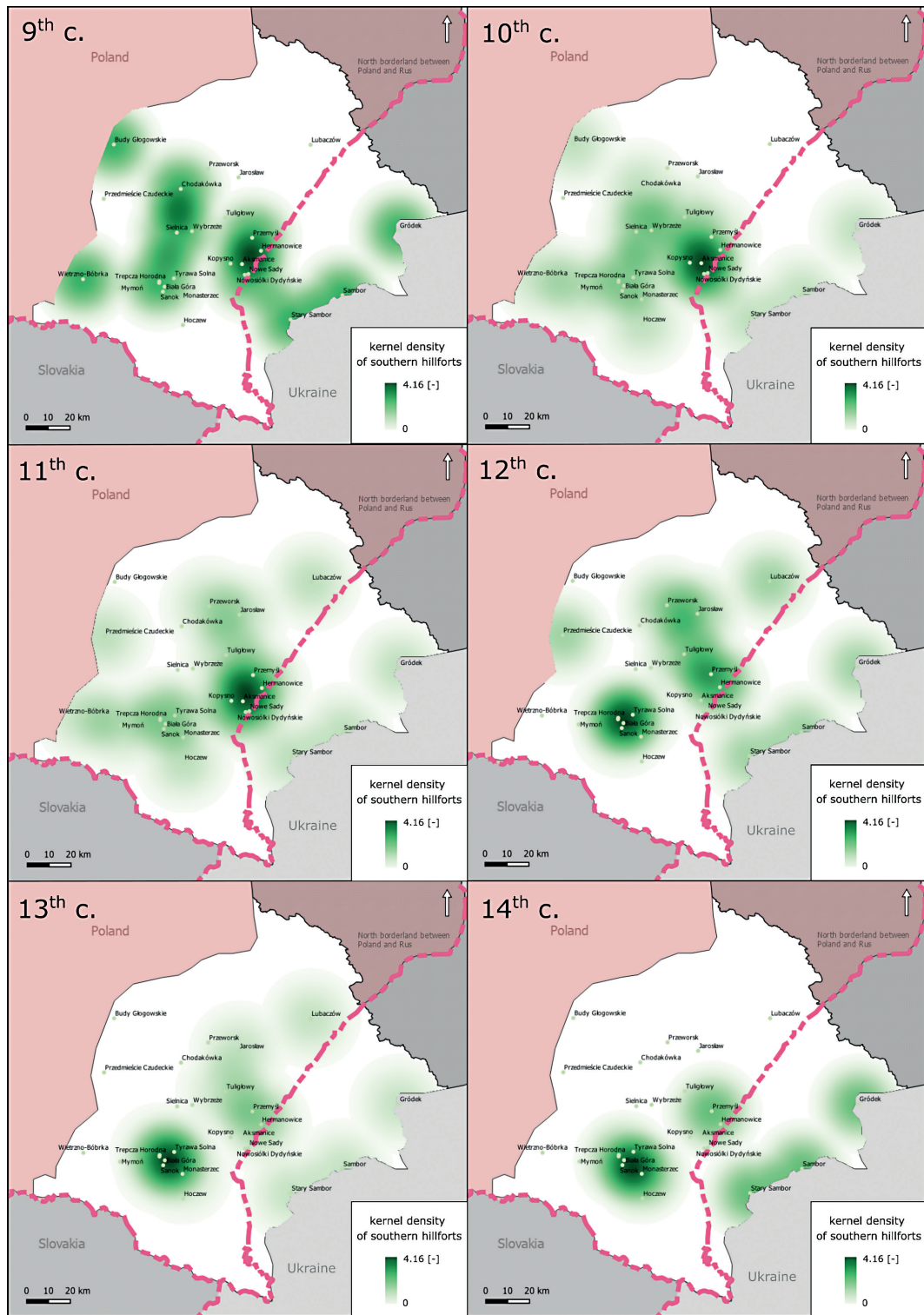
difficulty with the fortresses in Ukraine, and therefore the database was supplemented partly on the basis of Janeczek's maps [11].

Maps of the historical atlas were scanned in the form of raster data and georeferenced in the QGIS software. This operation was the starting point for vectorization, giving the result layers the shp (ESRI Shapefile) format, covering the historical and modern administrative borders of countries and regions. The location of individual strongholds was determined based on their localization in the interactive atlas and the catalog of strongholds, creating independent points also in the cited vector format [12]. The difficulty was in the fact that it was impossible to obtain the data directly from the website. The precise placement of geoarchaeological objects in space is the basis for Kernel Density and Space Time Cube analyses. The downloaded Digital Elevation Mod-

els in GeoTIFF format were mosaicked appropriately in the ArcGIS Pro software. Next, the resulting raster was trimmed to the desired size.

The methods used to analyze the data presented in the article are divided into geoarchaeological and geoinformatics. This publication is less concerned with the former, which mainly includes geomorphological field research [13]. In 2021, there were three field trips carried out to selected settlements: Tuligłowy, Trepcza, Biła Góra, Aksmanice, Nowosiółki Dydyńskie, Hoczew, Manasterzec, Nowe Sady, Wybrzeże, and additionally the mound in Sólca. The locations have been placed on the map (Fig. 1). The second group of methods (geoinformatics) forms the backbone of this publication, and therefore they will be briefly described below.

The maps were drawn up using the method of density estimation by means of non-parametric kernel density



**Fig. 2.** Map showing the periods of operation of settlements and their density in space, based on geoarchaeological data in the catalog by Marszałek (1993) and the atlas [7]

**Ryc. 2.** Mapa ukazująca okresy funkcjonowania grodów i ich zagęszczenie w przestrzeni na podstawie danych geoarcheologicznych w katalogu Marszałka (1993) i atlasu [7]

estimators, also known as Kernel Density. Kernel Density consists in obtaining interpolated, continuous geographical information in order to portray changes in the intensity of the studied phenomenon [14]).

To generate the Kernel Density map, the following steps were listed [15]:

- creating a grid of squares with a specific, selected area,
- determining a circle of a given radius around individual squares,
- calculating the number of points within each circle,
- determining the value by dividing the number of points by the area of the drawn circle,
- assigning this value to each square, which is then weighted,
- aggregating the determined weights and dividing the obtained value by the area of the circle.

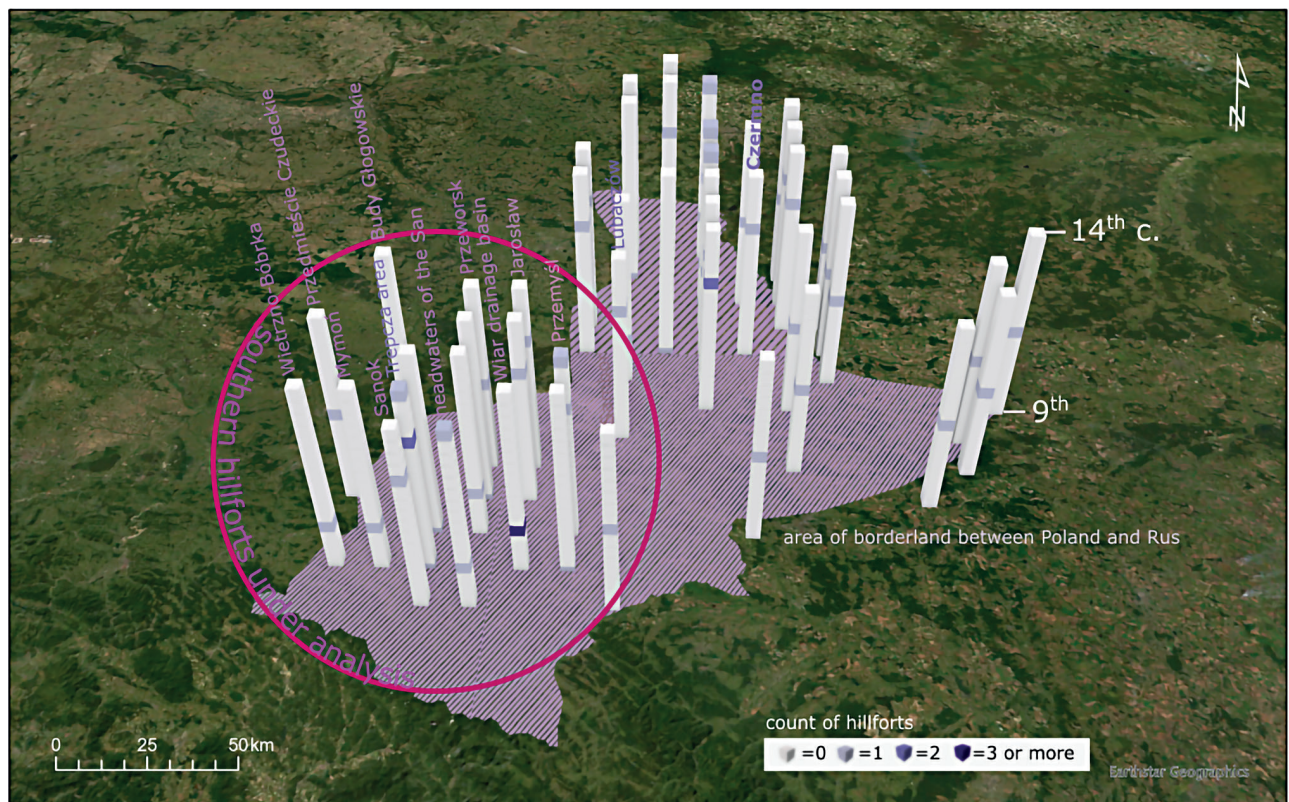
For the purpose of estimation developed in Figure 2, we assumed a radius of 35 km, and 10 km in Figure 5,

since a larger radius was taken into account for a smaller number of strongholds in a given area.

In addition, we used weights (for strongholds, for example, the size of the defensive layout), which were defined for the parameters of the Heatmap (Kernel Density Estimation) tool in the QGIS software, while assuming that the rank of each stronghold was equal in the analysis. This concept originates from the approach that the most important element in the study is to identify areas of the largest concentrations of strongholds based on their location alone, rather than an additional hierarchy (for example, taking into account the division into more important – larger, and the less important – smaller strongholds).

The next visualization involves the use of the space-time cube generation method in ArcGIS Pro (Fig. 3).

It consists in providing a graphic presentation of both time (in this case age) and space in the sense of the range within which individual points are located [16]. The distribution of points was used as the basis to



**Fig. 3.** Space Time Cube of the early medieval borderland between Poland and Ruthenia based on geoarchaeological data in Marszałek's catalog (1993) and the atlas [7]

**Ryc. 3.** Space Time Cube wczesnośredniowiecznego pogranicza Polski i Rusi na podstawie danych geoarcheologicznych w katalogu Marszałka (1993) i atlasu [7]

determine the height in the cuboid (time) and the base of the cuboid (space). The format that allows to save multi-dimensional data is netCDF [17]. For this to be possible, we had to add attributes to the probable age of the end of prosperity of strongholds. Each resulting pole in the study was divided into Time Step Intervals of 25 years (this was also performed for the period from the 9th to the 14th century). Sixty point objects were introduced based on which we determined the intensity of occurrence of strongholds in space (with a specific distance interval and amounting to 25 km). This method can be successfully extended for the purposes of archaeological research with the analysis of hot and cold spots [18]. Nevertheless, the purpose of the selected procedure is merely to visualize the dependence of time and space based on point data (strongholds).

### 3. DATA ANALYSIS

For the purpose of accurate location of settlements on maps, it was first essential to locate the strongholds on the basis of Poland's interactive atlas of strongholds [7]. Unfortunately, the atlas did not include several important towns (for example, Sobień Mountain, where the present ruins of the castle are located), which was supplemented on the basis of a catalog by Marszałek (1993).

Figure 1 shows the location of strongholds across the borderlands of Poland and Ruthenia in the early Middle Ages. The number of geoarchaeological objects covers the entire surveyed period, which makes it possible to trace regularities within the entire borderline of the two monarchies. The former comprises a division into two fundamental groups in the north and in the south (with a clear division in Roztocze). The second is the effect on terrain profile and watercourses on the location of strongholds (mountain strongholds are significantly dependent on rivers, the northern ones a bit less). There are two significant concentrations thereof north of Huczwa, which are not situated in the vicinity of major rivers – around Majdan Nowy (six strongholds) and around Busówno (six strongholds). In the Carpathian part, the San River is the axis of the border between the country of the Piast dynasty and the rule of the Rurykowicz family, where one of the most important strongholds, i.e., Przemyśl, was built.

Figure 2 demonstrates the probable dynamics of the existence and prosperity of strongholds in the Car-

pathian portion of the border between Poland and Ruthenia. The map that refers to the 9th century depicts the use and construction of defensive structures around Przemyśl and to the south (forts on the river Wiar), presenting the most intensive area in the region. Further to the west, there is a linear strip of objects from Chodakówka to Trepcza. Budy Głogowskie and Wietrzno-Bóbrka could already thrive in the west. Another map from the 10th century shows a different trend. To the west of Przemyśl, the intensity of the estimation gently fades. The strongholds over Wiar and Przemyśl exaggerate the result. The occurrence of the Tuligłowy and Wybrzeże sites also affects the color intensity in this period. The map related to the 11th century slightly deviates from the previous one. Next, we can clearly see the dominance of the Przemyśl area. There is increased intensity north of the Tuligłowy stronghold (Jarosław and Przeworsk) and less in Lubaczów and Przedmieście Czudeckie. The 12th century brought major changes. The region of Sanok is very heavily fortified, as evidenced by the exceptional, almost maximum density value on the map. There is also a belt stretching from Przeworsk to Przemyśl. The high importance of the towns of the Sanok region continues in the 13th century. That is the probable time when Biała Góra and Manasterec are formed, additionally strengthening the defense of the San River Valley. The intensity around Przemyśl declines. In the 14th century, there are only two significant centers – around Przemyśl and around Sanok.

The three-dimensional visualization of the Space Time Cube (Fig. 3) alludes to the dependencies described in the previous paragraph. The ending of the functioning of strongholds occurs the earliest in the catchment area of the Wiar River, which is indicated by their location in the lower part of the cube. There is also a noticeable significant number of such strongholds (according to the additional scale in the figure – more than three). It is clearly shown from the model for this area that cessation of use of the objects can be estimated at the 10th century. This occurred the latest for Przemyśl, the region of Sanok and for the strongholds in the upper course of the San, and dates back to the 14th century. Suburb Czudeckie, Przeworsk and Jarosław are located in the middle part of the cube. In order to compare the Carpathian strongholds with the hillforts located further the north, within today's Lublin Province, there is also a signed Czeremno, which

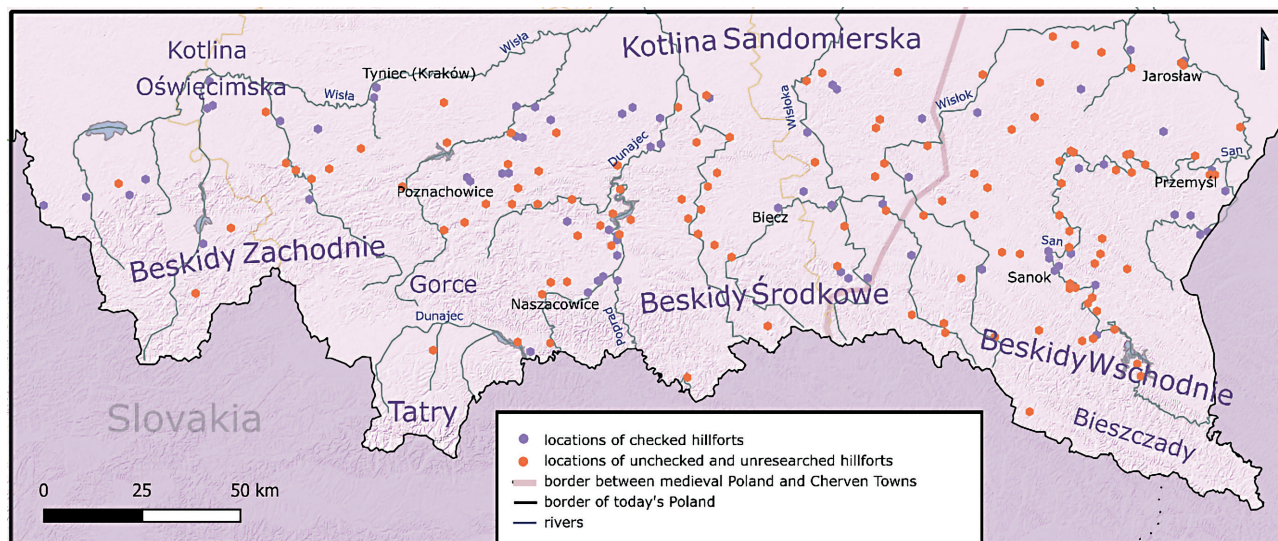


Fig. 4. Distribution of early medieval settlements in the Polish Carpathians based on Marszałek (1993)

Ryc. 4. Rozmieszczenie grodów wczesnośredniowiecznych w polskich Karpatach. na podstawie Marszałek (1993)

probably represents the mysterious Cherven [19]. However, having cherry-picked data from the area within the borders of today's Ukraine, it is difficult to pinpoint whether the dependencies are fully present during the late end of the functioning of defense structures in the east of the studied area.

The distribution of the studied strongholds in the early Middle Ages throughout the Carpathian Mountains is also not completely homogeneous. At that time, the Polish-Hungarian borderland was characterized by different natural conditions than their lowland counterparts (mostly mountainous scenery). There are more strongholds in the east than in the west. Overall, it has to be concluded that that these hillforts are concentrated along significant watercourses. They are presented on the map in Figure 4, primarily for comparability purposes. An unprecedented number of fortified settlements can be seen on the Dunajec River, in relation to the western part of the Polish Carpathians and on the San River.

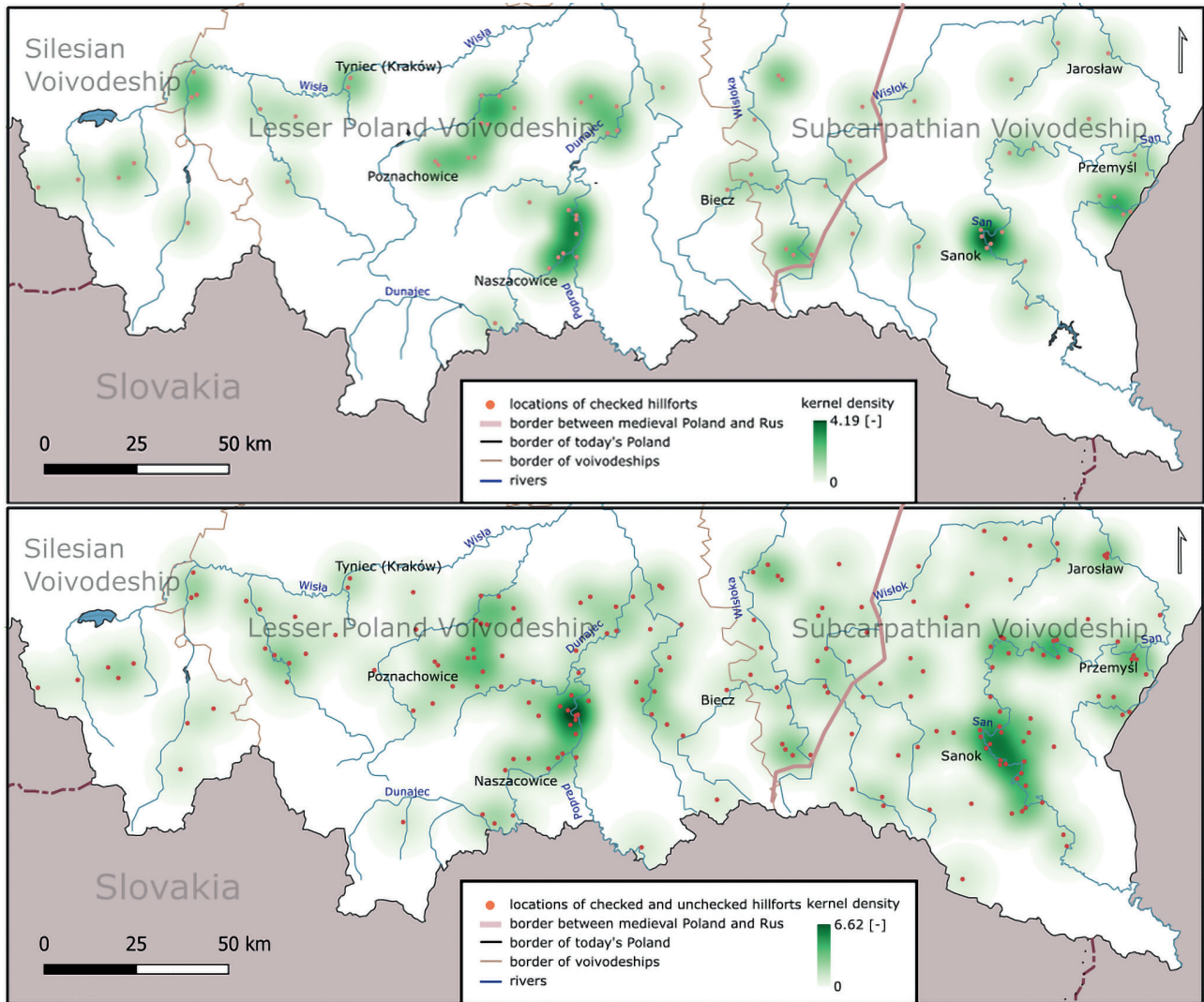
On the other hand, Figure 5 demonstrates one estimation of the performed interpolation (kernel density) for checked settlements and another one for all strongholds from the catalog, both checked and unchecked.

The periods of their operation have not been demarcated, since the purpose of the figure is to indicate the preferred areas for the construction of early medieval fortifications. The first map reveals that the highest

value of the estimator in the Polish Carpathians is found in the towns near Sanok. Moreover, the middle course of the Dunajec, in the vicinity of the mouth of the Poprad, as well as in the valley of the Raba, encompasses a large number of strongholds. Areas south of Przemyśl and north-east of the current Lake Rożnów are also important from the perspective of the region's fortification. On the second map we can see a dominance of the areas around today's Nowy Sącz and Sanok, in terms of intensity of the number of strongholds. Observable is also a greater density of settlements in eastern Lesser Poland and Podkarpacie, excluding the Bieszczady Mountains, in relation to western Lesser Poland and Podhale, and in the upper reaches of the Vistula.

#### 4. RESULTS

The developed maps featuring the location of fortresses on the territory of the Polish-Ruthenian borderland confirm the possible dualism in the regional administration. In its southern part, there are 16 settlements used only over the course of two centuries. The Przemyśl stronghold was used almost entirely throughout the time frame adopted in the article, that is from the beginning of the 9th to the end of the 14th century. Another area where early medieval settlements were used for a relatively long time is Tyrawa Solna and in its vicinity Tuligłowy (dated over the centuries, i.e., approx.



**Fig. 5.** Maps of the density of the number of settlements within the Polish Carpathians. From the top, only for checked strongholds. At the bottom, for all in Marszałek's catalog (1993)

**Ryc. 5.** Mapy zagęszczenia ilości grodów w przestrzeni polskich Karpat. Od góry jedynie dla grodów pewnych (checked). Na dole dla wszystkich w katalogu Marszałka (1993)

10th–13th century). Visualization of data in the form of a space-time cube has shed light on where the settlements have stood the test of time. It turns out that these are: the vicinity of Huczwa, at the San River (area around Sanok and Przemyśl), and the eastern part of the studied area. The same cannot be said about the territories in the basin of the Wiar. The site in Przemyśl was characterized by exceptional continuity throughout the early Middle Ages. The three main areas within the borderland in question were not covered with cuboids to any extent, i.e., Roztocze, Bieszczady and Górne Po-

buże. The achieved result can be associated with the presence of watersheds and the lack of sufficient location data for settlements in Ukraine. The estimation maps in Figure 5 confirm that rivers have been the most important communication routes for centuries. The last one clearly illustrates the two main centers, Ruthenian and Polish. The border, which was added merely for the sake of comparison, confirms this regularity. However, this map applies to all strongholds, including those not explored to the full, so one should be careful with such an interpretation of this result.



## 5. CONCLUSIONS AND DISCUSSION

The core purpose of this article was to shed light on the diversified timeframe of using stronghold centers over the centuries within the early medieval borderland of south-eastern Poland, to indicate the relationships between them, and to visualize the findings by means of geoinformatics tools, based on geoarchaeological data. This was achieved by analyzing the results of dating settlements, which were included in catalogs and atlases. We used various methods of cartographic presentation to develop the explored relationships. The longest-running defensive structures (up to the 14th century) were mostly transformed into towns or castles. The changing authorities had diverse approaches and ideas for organizing strategic concepts of the defense, which is why some strongholds were abandoned. In addition, the weakness of these settlements was the human factor, migrations, and the depletion of raw materials as well as food. At certain periods, this region was ruled by Polish princes or kings, in others – by princes from Kiev, Halych or Volhynia [20]. Over time, various military and demographic concepts were established, following the plan to build new settlements. Initial projects of strengthening Przemyśl, and in the following centuries – Sanok, are the most noticeable. This was due to economic (raw materials) and geopolitical reasons (defense of important sites on the map of the Polish and Ruthenian monarchies). The catchment area of the river Wiar was probably used for extracting brine, and from it – salt, for hundreds of years [21]. This raw material was extremely valuable in the early Middle Ages; hence it is possible that such settlements as Aksamnice, Nowe Sady, Kopyšno, and Nowosiółki Dydyńskie were supposed to protect these areas already so early (the monarchy of the first Piast dynasty). Przemyśl and Sanok were of vital strategic importance, especially for the descendants of the Rurikowicz family. The first of the aforementioned settlements even became the capital of the principality and a major center of the principality of Halych. In the latter case, the context of the so-called “Hungarian Gates” is important [22].

Also analyzed are the relations between settlements on the basis of maps illustrating the use of kernel density estimation. The created models show space in 2D (two-dimensional maps) and in perspective (3D visualization). It is also vital to highlight the importance

of the territory of the Cherven Towns in shaping the powers of Central Europe. A large number of settlements (more than 40 within the entire strip of land; it is difficult to assess the number of settlements in Ukraine and how many objects are just waiting to be explored) confirms the significance of this region. The findings were also supplemented with the preliminary results of the analysis related to the borderland: Poland and Hungary (Slovakia), which forms the basis for further research on historical and archaeological geospatial issues in the Carpathians. The result portraying the two key construction areas of defensive architecture of these mountains in the early Middle Ages only confirms the past existence of two main political entities. The method of visualization was selected in such a way that there were no exponential ranges of the tested density [23]. The result is more transparent. In the case of the maps included in this study, we can see even the smallest intensity values of a given phenomenon, and more specifically, the occurrence of given settlements in time and space – as for example Lubaczów in the 11th century (Fig. 2). The Space Time Cube also proved to be successful in visualizing the paper’s topic area (Fig. 3). Certainly, a great advantage is the lack of the need to present several maps in concrete centuries (Fig. 2). It only takes one visualization generated in ArcGIS Pro, as for example in the image [24].

The presented analyses merely represent the initial phase of interdisciplinary research in the field of geography, history, archeology (including geoarchaeology) and geoinformatics for this subject matter. The findings could be valuable for further analysis in exploring the beginnings of Polish statehood, especially in the border area. New archaeological excavations and accurate dating of settlements (including by means of the latest techniques) could help in accurately determining the functioning of settlements in a given age. The above visualizations bring near the general tendencies and regularities in the strategy of defending the former monarchies in the present areas of south-eastern Poland.

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