sustainability

Article

Investigating Forest Cover Change Using Historical GIS Technologies: A Case Study with an Example of Jurbarkas District of the Republic of Lithuania

Ruta Puziene

Department of Geodesy and Cadastre, Faculty of Environmental Engineering, Vilnius Gediminas Technical University, Sauletekio av. 11, LT-10223 Vilnius, Lithuania; ruta.puziene@vilniustech.lt; Tel.: +370-52730629

Abstract: Effective forest management systems based on comprehensive tools need to be developed for the analysis and assessment of forest cover change. This requires a wide range of data, starting from old maps, which allow the reconstruction of spatially referenced information on past forest areas, to recently collected data. The research methodology proposed in this paper involves a combined analysis of data from different sources, using statistical, comparative, and visual analysis methods. The case study is Jurbarkas District of the Republic of Lithuania characterized by a high land productivity score. The research found that the highest forest cover areas were in the 19th century and the lowest in the 20th century. It can be seen that during the period under research, forest areas 'migrated' from an area favorable for agricultural activities to a less favorable area with higher slopes. Permanent forest cover areas and the age of the dominant trees have been identified. The age of the trees in the forest areas has allowed for the identification of the periods when the most intensive logging took place. The rate of forest cover change made it possible to predict the total disappearance of the forest areas provided that the factors influencing forest cover change at that time remained unchanged. If the trends in forest change in Jurbarkas District had been maintained in the period between the 19th and 20th centuries, the forest would have disappeared in 2006.

Keywords: historical GIS; forest cover dynamics; military topographic maps; CORINE Land Cover; rate of change in forest cover area; permanent forest areas; spatial and statistical analysis

check for updates

Citation: Puziene, R. Investigating Forest Cover Change Using Historical GIS Technologies: A Case Study with an Example of Jurbarkas District of the Republic of Lithuania. *Sustainability* **2024**, *16*, 4825. https://doi.org/10.3390/su16114825

Academic Editor: Sharif Ahmed Mukul

Received: 25 April 2024
Revised: 29 May 2024
Accepted: 30 May 2024
Published: 5 June 2024

1. Introduction

Changes in vegetation affect climate due to biogeophysical effects such as changes in albedo and heat fluxes [1,2]. Ongoing large-scale changes in the Earth's surface affect large-scale atmospheric circulation. The more forested the area is, the greater the positive effect and vice versa. Uncontrolled deforestation on a large scale negatively affects microclimate and climate change [3]. The analysis of the changes in the cover makes it possible to evaluate trends in the carbon accumulated in the biomass and changes in biodiversity [4]. Due to the current climate change process, it is important to understand the past forest coverage of the territory as accurately as possible. This is useful for studying the impact of surface cover change on the environment, creating models for predicting possible future processes and planning actions for the purpose of reducing climate change.

Currently, the cutting of forests growing in middle latitudes is not very significant, except for the territory of Russia [5]. The largest diminishing in forest areas occurs in tropical forests [6]. Forests in the middle latitudes have already experienced the main wave of destructive anthropogenic impact and their areas have stabilized [7]. Large areas of agricultural land have already been deforested for agriculture and other purposes in most European countries; meanwhile, these processes are still ongoing in tropical forests [8,9]. By studying the processes of anthropogenic deforestation in Europe and their consequences, it is possible to predict the consequences of tropical deforestation and the likely future ratio of forest and non-forest areas. It also allows us to better understand the processes of forest diminishing that occurred due to anthropogenic impacts, control these processes, and plan forest restoration.

Forest areas in Europe have been affected by many factors for a long time [10]. The most important of these factors, given that the climate has remained relatively constant for 4500 years, has been an anthropogenic effect. The current structure of forests, the occupied areas, the configuration of the areas, and the distribution of tree species reflect the result of the effects of deforestation, spontaneous regrowth, and replanting that have taken place over the years [11–14]. As the human population grew, the need for wood to meet various needs, such as fuel, construction, tar production, etc., increased [13,15]. Forest cover occupied land areas needed for agriculture. The first more intensive efforts to reduce forest areas began to meet the needs of agriculture when there was a need to convert the land occupied by the forest into land areas used for agriculture [16]. The change in forest areas did not take place in isolation from the increase in the areas needed for animal husbandry and agriculture; it was tightly connected with the change in the scale of these activities. However, as long as the human population was relatively small, the effect on the area forest coverage was not very significant and increased proportionally to the increase in the human population [13].

Population growth and the impact on forest areas are not the same in all European countries and have been predetermined by various reasons [13,17–19]. The biggest jump in population growth during the industrial period occurred due to the progress of science, leading to the development of industry, the development of urbanized territories, and the application of more advanced tools and methods in agriculture.

Most states did not have a targeted legal base that would apply the legal regulation to felling and the protection of forest areas, taking into account ecological indicators and the aspiration of maintaining a certain percentage of the forest coverage of the country's territory until the 20th century. As a result, forests in Western Europe were cut down in most areas in the pre-industrial period; in some countries, the forest coverage of the territory has become small because forests have given way to areas of arable land and pastures [13]. Forest coverage depends on the amount of land suitable for agriculture in the territory of the country. In Norway where there are many mountainous areas, the lands suitable for agriculture were utilized, while the unsuitable ones remained overgrown with forest. Since there was not much land suitable for agriculture, the territory of the country remained forested [13].

Dynamics of forest cover were different in different countries over time, determined by historical and socioeconomic reasons [13,20,21]; therefore, in order to get a complete picture of the change, it should be examined in more local areas, without generalization of regions. The forest coverage was quite high in the territory of the Republic of Lithuania compared with Western Europe, although the area was suitable for the development of pastures and agricultural activities. In the study of Kaplan et al. [13], the territory of the Republic of Lithuania is studied as a single research unit together with the republics of Latvia and Estonia. It was determined that there are 35.1% of land suitable for agriculture in this territory. There was 93% of forest areas on the land suitable for farming in 1000 BC, 91.8% in 500 BC, 84.4% in 1 AD, 77.9% in 500 AD, 71.7% in 1000 AD, 37.2% in 1350 (plague pandemic period), 43.9% in 1400 AD, and 6.1% in 1850 AD. This study reveals the general trends of forest cover loss on this territory; however, it is a generalized study that covers three states as a single unit and does not reflect the situation in Lithuania. In order to learn the processes that took place more thoroughly and understand their trends, the study should use local territories and more accurate and less generalized data that can be obtained from contemporary studies, statistical data, and cartographic material. After the examination of the statistical data and the contemporary studies, it can be said that there were much more forests in the territory of Lithuania [15,22].

Scientists use different methods to study forest change: they study lake sediment, pollen deposits, historical data, statistics, historical military topographic maps, etc. [23–28]. Topographic maps are great sources of information as they are a unique image of the area mapped out at a given time. They capture spatially oriented information; examining the old military topographic maps makes it possible to look at the surface cover that existed at that time [29–39]. Comparison of the information in the maps compiled chronologically, it is possible to monitor changes over time. Various scientists use this material as a source of information to study landscape changes, cover changes, urbanization development, etc. [39–47]. Remote monitoring data can be used in a complex way. The use of historical GIS technology allows us to spatially orient all data obtained from different sources according to a unified system, unify the data format, and perform modelling, spatial, and statistical analyses. This helps better understand the processes, dynamics, and trends that took place.

In order to plan forest areas and implement their regulation, it is important to know and understand trends of their change, understand which forest areas have remained unchanged over the centuries and how many areas have been cut down/replanted. In different regions, the trends of forest cover area change are different [27,48–54]. This study can help understand the importance of the application of historical GIS technology to studying the extent of forest cover change and the factors influencing it in Eastern European countries. These countries are related by similar historical and environmental conditions. Estonia, Latvia, Lithuania, and Poland are in the same climate zone, have similar areas of land suitable for farming, and have a similar history. They were all part of the Russian Empire since the 19th century. Exploitation and maintenance of forests were influenced by the same legal base and the same state interests. So there were very similar factors at work here as the same policies were applied to forests at the same time, except for the short period between the two world wars.

The aim of the study is to improve the methodology of assessing the dynamics of real forest cover, applying historical GIS technologies, using various data sources and data of different origins in a complex way.

The novelty of the paper is that it proposes a methodology for the analysis of forest cover change, using data from different sources: old topographic maps, CORINE Land Cover dataset, and forest cadastral database. The methodology uses identification of areas favorable for agricultural activities according to the geomorphological parameters of the territory; analysis of changes in the forest cover; analysis of the age distribution of trees growing in the forest, which allows for the identification of the periods of intensity of logging; identification of the correlation between the geomorphological parameters of the territory and forest cover; the rate of forest cover change in areas of different slopes (during the periods studied); the rate of forest cover change and the forecast of the disappearance/doubling of forest areas without changes in the factors that have influenced the dynamics of these areas; the identification of areas of stable forest cover; and the analysis of the age of the trees that grow in them. This methodology, involving the integrated use of data from different sources and the application of different research methods, is new and has not been applied in the work of other researchers.

Military topographic maps from different years, forest cadastral database, LIDAR data, Corine Land Cover dataset, and orthophoto images were used in the study.

Jurbarkas District of the Republic of Lithuania was chosen for the case study as the land there has a high productivity score; part of it belonged to two different states in the course of its history. The latter factor allows us to compare the impact of different forest management guidelines on forest cover dynamics in the course of history. The use of historical GIS helps us understand the configuration and dynamics of the forest cover, as well as establish links with the geomorphology of the territories.

2. Materials and Methods

2.1. Field of the Research

The aim of this study was to carry out monitoring of forest cover change and its trends over the longest possible period of time with the use of different data sources; application of historical GIS technologies; and spatial, statistical, and analysis methods, including the analysis of data of different origins in a combined manner. In most cases, only one type of data source is used for studies of the forest area change. It can be maps, cadastral data, pollen remains, and other things depending on the research methodology. Also, the past and present forest cover of the territory is often assessed separately. This narrows the scope of the results and prevents researchers from obtaining a complete picture of changes in forest cover and the identification of change trends. This article, through the application of the methods of historical GIS analysis, proposes to apply a complex methodology of data use, including former forest coverage that was present over a period of 158 years, forest coverage that is currently declared, and an actual one are estimated by combining different data sources. The areas of permanent forest cover were determined and the age of the trees was analyzed. This proposed research methodology makes it possible to evaluate past and present situations comprehensively and perform an analysis of changes in forest cover over a period of a couple of hundred years or more. The research period is limited only by the availability of data.

The research area was selected using the case analysis and taking the administrative unit of the Republic of Lithuania in order to demonstrate the proposed methodology for the assessment of changes in forest cover. First, the decision was based on the choice of administrative division of the territory since it has changed several times in the last 200 years. In order to make the territory chosen for the study more suitable to the modern user, the current administrative division of the territory was chosen for the case analysis (Figure 1). The current Republic of Lithuania is divided into 60 administrative units—district municipalities (Figure 1). Jurbarkas District, located in the middle part of Lithuania, was chosen for the case analysis through the application of the criteria listed below.

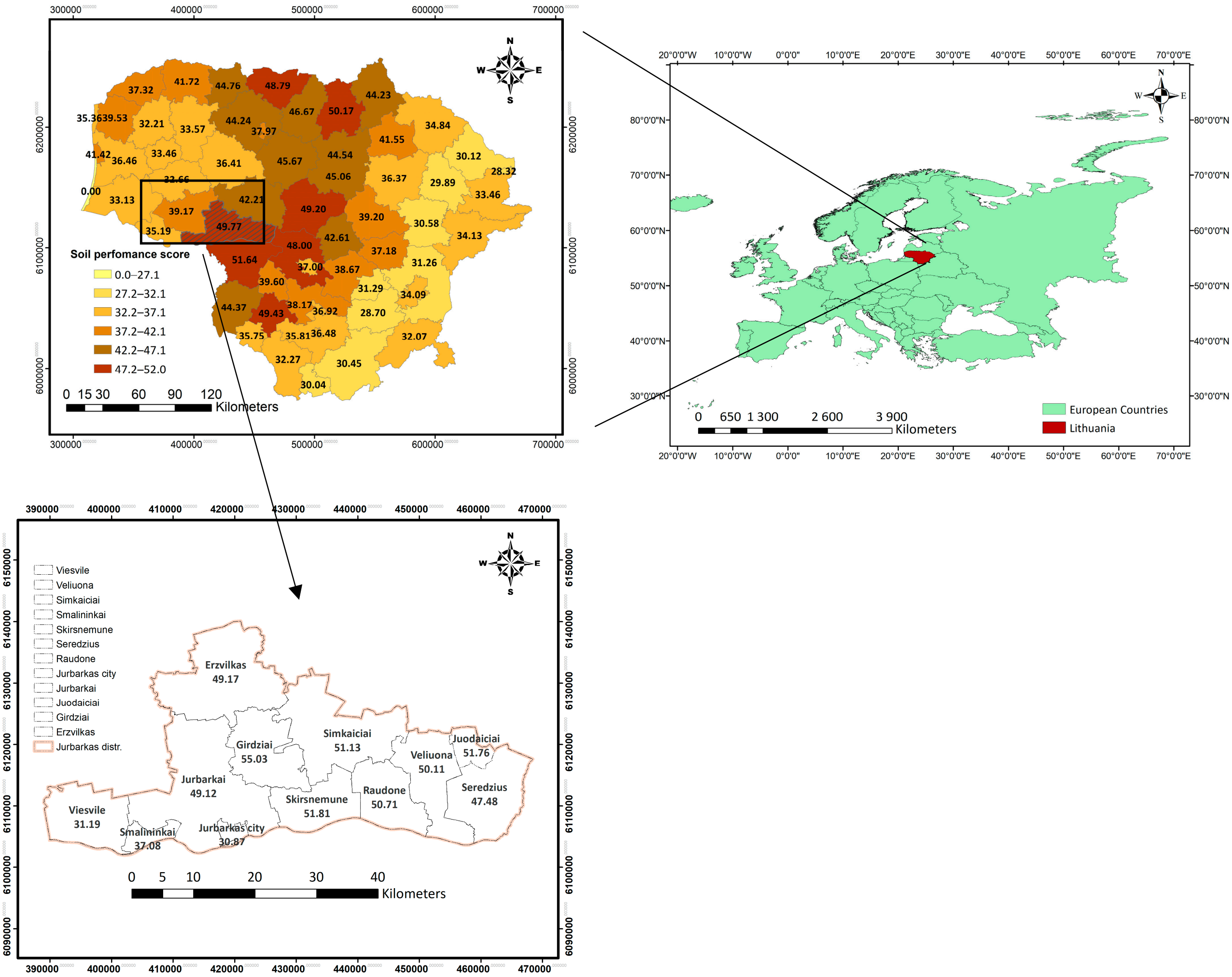


Figure 1. Administrative division of the Republic of Lithuania and Jurbarkas District (with land productivity scores in them).

Jurbarkas District occupies an area of 1507 km^2, population density is 17 people/km^2. There is Karšuva forest in the western part, since ancient times. Viešvilė State Nature Reserve has been established there. The forest itself is included in the network of Natura 2000 sites. Economic activity has been suspended in some of the state-owned forest plots.

The following criteria were applied when choosing the location of the case study, in order to select the most optimal region:

Criterion I. After reviewing the studies published by other researchers about the shrinking of forests in Europe, it can be seen that in research papers [10,13,36,38,45,47,54], the shrinking of forests is associated with anthropogenic activities and the size of areas suitable for agricultural activities. In order to investigate the extent to which the productivity score influenced the change in forested areas, the land productivity score was taken into account when choosing the research area; therefore, an analysis of the districts was carried out according to the size of the prevailing land productivity score. The land productivity score in Lithuania is from 27.16 to 55.27 (in elderships) (https://www.geoportal.lt/map/#, accessed on 3 March 2022). There are no data for one eldership (Figure 1). The aggregated productivity score in the district municipalities ranges from 28.32 to 51.64. The study grouped productivity scores in 5-point increments starting at 27.1. Five groups were obtained (hereinafter—gr.):

I. 27.1–32
II. 32.1–37
III. 37.1–42
IV. 42.1–47
V. 47.1–52

The grouping of districts according to these groups is presented in Figure 2.

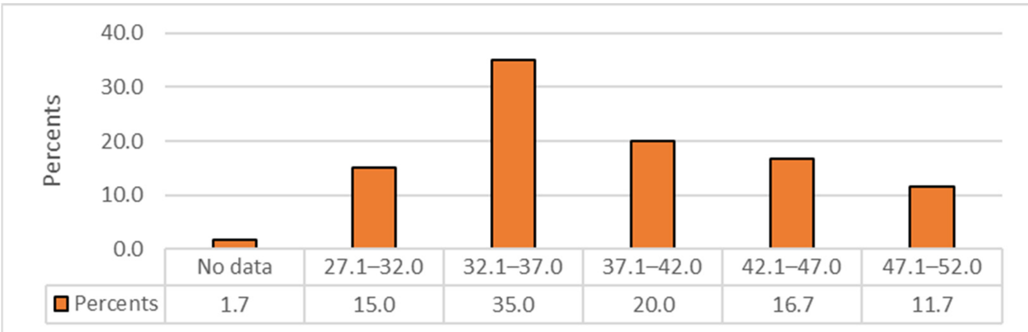


Figure 2. Percentage distribution of municipalities according to soil productivity score.

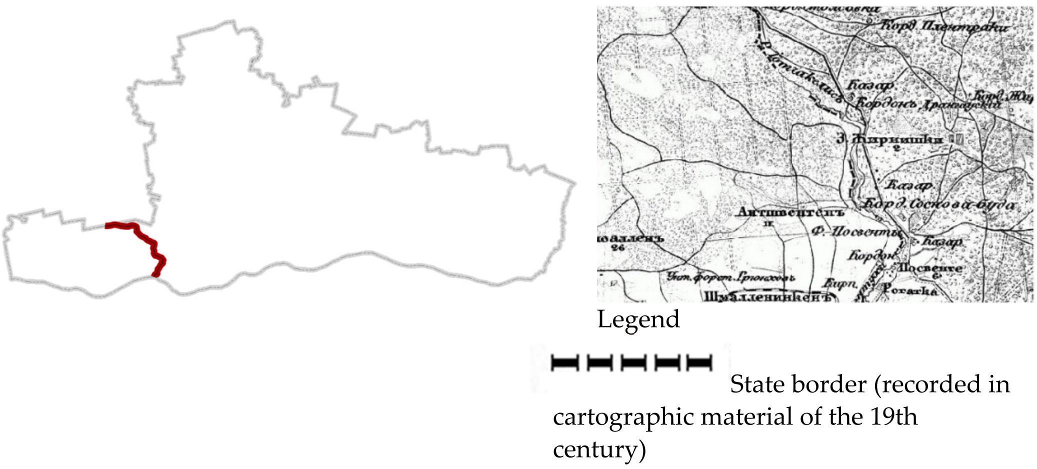
Out of all 60 municipalities, only 11.7% (7) fall into the group with the highest productivity (47.1–52) scores. It can be seen on the map (Figure 1) that the eastern part of the Republic of Lithuania has the most infertile lands (Group I–II), while the middle of the country has the most fertile ones (Group IV–V). Therefore, one of these municipalities, specifically Jurbarkas District, was chosen for the study. It is in Group V according to the productivity score as it is an extremely attractive criterion for the development of agricultural activities.

Variation of productivity scores in neighboring administrative units—from groups V to I.

Criterion II. The aim was to choose an administrative unit within which the productivity score would vary from low to high so that the study would be carried out in geographically very close areas but with different attractiveness for the development of agricultural activity. The territory of Jurbarkas District meets this criterion. It is divided into 12 elderships: Viešvilė, Smalininkai, Jurbarkas City, Jurbarkai, Eržvilkas, Girdžiai, Šimkaičiai, Raudonė, Veliuona, Skirsnemunė, Juodaičiai, and Seredžius. Nine elderships (75%) have extremely fertile soils (Group V), and three elderships fall into the group of not very fertile (16%) or medium fertility (8%) soils (Viešvilė, Jurbarkas City—Group I, Smalininkai—Group III) (Figure 1).

Criterion III. The priority was given to areas of forest cover that have survived since ancient times when choosing a research case so that it would be possible to study the changes in the area of forest massifs that have existed since ancient times under the influence of different policies of forest management. Forest areas, in an ideal case, have historically belonged to different states with different concepts of forest management. These are precisely the conditions in the selected district.

There is the Karšuva forest that has existed for more than 600 years in the western part of Jurbarkas District (in the elderships of Viešvilė, Smalininkai, Jurbarkai, and Eržvilkas). It is the fourth largest forest massif in Lithuania, located in Jurbarkas District and the neighboring Tauragė District. These locations have been unfavorable for agriculture since ancient times—barren, swampy soil. These were almost uninhabited areas throughout the historical period, serving as a dividing line between tribes and, therefore, little affected by anthropogenic activities. This forest was mentioned in written sources in 1422 during the demarcation of the state border that separated the Teutonic Order from the Grand Duchy of Lithuania [55]. This border passes through Smalininkai Eldership (Figure 3a). The parts of the forest found in different states were used very differently. Cultivation of the historic E. Prussia side started earlier, and it was much more intense. The Lithuanian side was used much less, with the first larger settlements appearing only in the 17th–18th centuries. Planned management of the forest began here only after 1863. In Figure 3b, differences in the use of the forest can be seen on both sides of the border—clearings were cut on the German side, and no signs of methodical forest management can be seen on the Lithuanian side. This should be a very important aspect during research as it would allow for the comparison of the change in forest areas with different use.



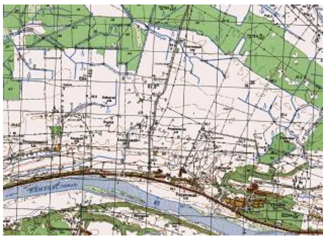
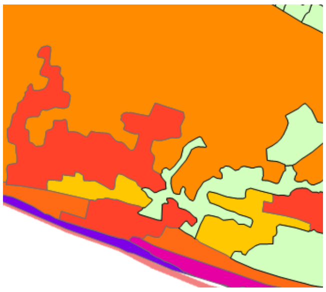
(**a**) (**b**)

Figure 3. Karšuva forest: (**a**) the location of the former interstate border in Jurbarkas District, (**b**) a fragment of the Karšuva forest, separated by the interstate border.

2.2. Data Sources

The following data sources were used for the research: old military topographic maps, Corine Land Cover dataset, forest cadastral database, orthophotos, and LIDAR data (Table 1, Supplementary Materials). These data cover a period of 158 years.

Table 1. Data sources of forest areas from the 1st half of the 19th century to the 1st half of the 21st century.

No.	Data	Example	Data Source
1	Old topographic maps, 1860. Updated in 1865		https://www.maps4u.lt/lt/maps.php?cat=20 (accessed on 1 January 2021)
2	Old topographic maps, 1933–1940. Updated in 1938		https://www.geoportal.lt/map/ (accessed on 1 January 2021)
3	Old topographic maps, 1988. Updated in 1983		https://www.geoportal.lt/map/ (accessed on 1 January 2021)
4	CORINE Land Cover 2018, (CLC18_LT)		https://www.geoportal.lt/geoportal/naujienos/-/asset_publisher/sUiF20Ur705t/content/2018-metu-corine-zemes-dangos-duomenu-rinkinys-jau-geoportal-lt (accessed on 1 February 2021)
5	State forest cadastral data, 2021		https://www.geoportal.lt/geoportal/valstybine-misku-tarnyba#savedSearchId=%7B5CA476B2-E876-4B39-A16B-C10FDF4009B9%7D&collapsed=true (accessed on 1 January 2021)
6	Orthophoto maps, 2021		ArcGIS Desktop (10.8.1, ESRI, Redlands, CA, USA) Basemap (Maps.lt orthophoto LKS)

This paper uses maps from different periods, scales, and authors. It is therefore recommended to carry out a map uncertainty study prior to the research. Uncertainty analysis is difficult for maps from the 19th and the 1st half of the 20th century. Fixed points, by which it would be possible to measure deviations in the representation of objects on maps, are questionable (surviving objects were selected for the orientation of the maps; however, for that reason, these points are no longer suitable for the study). The great socioeconomic changes that took place after the occupation radically changed the image of the area. There were large-scale deportations, collectivization, land reclamation, and people were moved from homesteads to settlements, homesteads vanished, and settlements were rebuilt. If a homestead survived, the wooden huts were likely rebuilt due to wear and tear, possibly elsewhere. River beds were straightened in most cases. Roads changed their location in many places, some disappeared, and others were built anew, by laying asphalt or gravel surfaces, in places convenient for logistics. In order to carry out a high-quality analysis of the uncertainty of such maps, it is necessary to carry out a study of the history of individual places, verifying the material in the archives and interviewing older local residents about the geography of the preserved old objects of the area. The data on the map from the 2nd half of the 20th century are more reliable as most of the objects have survived. This topic is worthy of a separate study as it has been little researched. This is a problem for Eastern Europe because the Soviet occupation changed the pre-Soviet landscape considerably.

The old military topographical maps are probably the data source that provides the most information about the objects of the area that existed before. The creation of military topographic maps began in the territory of Lithuania in the 19th century after the installation of triangulation networks [56]. Later, the territory was mapped out several more times, including during the 1st and 2nd halves of the 20th century. The outlines of the depicted forest areas are generalized due to map generalization and area mapping methods, but the generalization process does not lead to significant losses of the mapped-out forest areas. Therefore, it can be stated that micro-changes in the outlines of forest areas do not significantly affect the results of the study, and the main processes of forest changes are sufficiently accurate and informative.

Different data sources with different accuracy of data collection were used, but the results of the study will not be affected by a small difference in the accuracy of the data, since large areas of forests are studied.

Description of data sources used:

1. Old maps:

(a) Topographic maps of the European part of the Empire of the 2nd half of the 19th century created by the Military Topography Department, edition of 1860–1915. Scale—3 miles are equal to 1 English inch, which corresponds to a scale of 1:126,000. The map page is rectangular, 58 × 42 cm; it corresponds to an area of 73 × 53 km at the location. During the maps' creation, the works in the military topographic photo were completed around 1845, the area was reconnoitred, and the data were updated in 1865 (mainly names of villages and settlements).

(b) Maps of the Lithuanian Military Topography Department of the 1st half of the 20th century, 1933–1940 edition, scale 1:100,000. The maps map out the territory of the country of that time; the map sheet size is 47 × 45 cm. They were created using available material (aerial photographs, other maps), without fieldwork.

(c) Topographic maps of the 2nd half of the 20th century, scale 1:50,000, 1988 edition. Maps with a 1:50,000 scale were made after the updating of mapping data in 1956–1957. Aerial photos and area survey data were used for the update.

2. CORINE Land Cover database of 2018 (CHA18_LT) (https://www.geoportal.lt/geoportal/duomenu-paieska#queryText=corine). It was created by automatically merging databases CLC12_LT and CHA18_LT and interpreting the IRS satellite imagery of 2012–2013 and Sentinel-2 satellite imagery of 2017. The smallest mapped area object is 25 ha; the smallest mapped area object in the database of changes CHA18_LT is 5 ha (https://www.

geoportal.lt/geoportal/duomenu-paieska#queryText=corine). This is a vector land cover dataset divided into 44 classes. There are 30 classes according to the type of land cover and purpose of use in the territory of Lithuania.

The following covers (marked with codes) were used for the study: deciduous forests (311), coniferous forests (312), and mixed forests (313). During the study, these covers were treated as forest cover.

3. State forest cadastral data. The forest cadaster of the Republic of Lithuania collects data on all Lithuanian forests regardless of their ownership form and protection regime. The cadastral object is a forest land valuation plot. The vector dataset was downloaded from (https://www.geoportal.lt/geoportal/); data on tree species, age, and land plot areas were used in the research.

4. Orthophoto images oriented in the LKS 94 coordinate system. Freely available to all ArcGIS Desktop users; used for the correction of cadastral data.

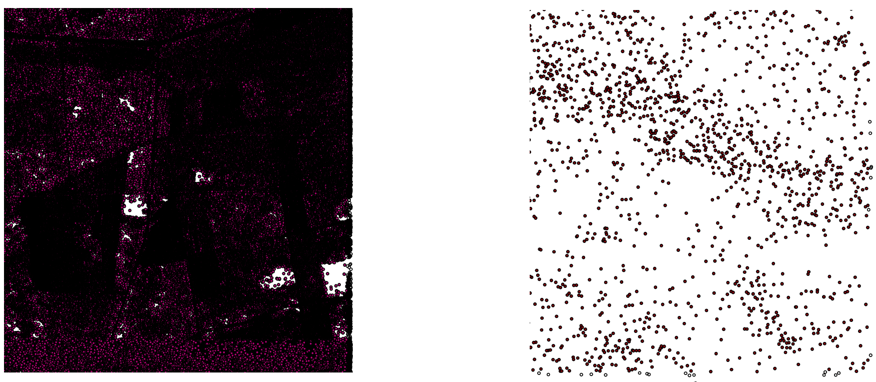
5. LIDAR data—digital spatial laser scanning point data of the land surface of the Republic of Lithuania (years 2009–2010); obtained from the National Geoportal (https://www.geoportal.lt/leip-gpp-web/gpp/client-orderGeoproduct?geoProductId=ef755c95-e879-4776-92b4-06fe538e243a). LIDAR point clouds are provided for individual areas of the territory divided into squares. Point density—several points per square meter.

Forest cover areas were recorded in the old topographic maps in 1865 (2nd half of the 19th century), 1938 (1st half of the 20th century), and 1983 (2nd half of the 20th century). Data from the Corine Land Surface database were obtained in 2018 (1st half of the 21st century).

2.3. Land Surface Modelling

The research area is large. Combining all the downloaded LIDAR point clouds into a single point cloud resulted in a point cloud of about 13 points, occupying 3 GB. The processing of this data requires very high technical capacity. At the same time, it can be noted that the study does not need such a high density of points; the study of terrain features with the accuracy of a square meter with respect to Jurbarkas District is too fine and pointless. Such features of the microrelief of the land surface do not have any significant influence on the research results. The program code for point thinning is written in the Python (3.8.10) programming language to solve the problem. Point thinning is performed for individual squares.

By thinning the points using Python code (Supplementary Materials), only every thousandth point was added to the newly created point cloud. The point cloud visualized in the GIS (ArcMap 10.8.1) program before thinning and after thinning is presented in Figure 4.



(**a**) (**b**)

Figure 4. LIDAR point cloud: (**a**) before thinning, (**b**) after thinning.

The clouds after point thinning are "cropped" according to the territory of Jurbarkas District and merged into one point cloud with the help of a GIS program. The final score was 726,402 points.

2.4. Research Object

The term "forest" differs in different countries and may differ even within the same country, depending on the change in the legal base, the consideration by the society, and the understanding of the linguistic term. When applying the term "forest", the forest areas identified during the study can differ quite significantly. Therefore, the research needs to define term "forest".

Legally, the concept of a forest in the Republic of Lithuania is defined by the law on forests—the cadastral database includes data consistent with this interpretation. Currently, the forest is legally defined in the Republic of Lithuania as follows: "land area of at least 0.1 hectare covered with trees with a density of at least 0.3 and the height of which in the natural habitat at maturity reaches at least 5 m, including other forest vegetation, as well as an area of land of at least 0.1 hectare where the stands have thinned or there are temporarily no trees due to human activity or natural factors (forest sites to be planted, clearings, dead stands). Groups of trees located in fields, roadsides, near water bodies, residential areas and cemeteries, greenery planted on road lanes, trees and bushes growing on non-forestry land plots managed by the public railway infrastructure manager under the right of trust, narrow strips of trees up to 10 m wide, hedges, single trees and bushes, as well as greenery planted on non-forestry land in cities and rural areas are not considered forests" [57]. As can be seen, the legal term "forest" includes areas of land where there are no trees, including clear cuttings.

Forest areas represented by the customary symbol "forest" on old maps are simply tree-covered areas suitable for mapping, depending on the degree of generalization. We have the same data in the CORINE database in the sense of the term. Orthophoto images also show tree-covered areas and it is practically impossible to identify areas considered as "forest" under the law on forests.

Different interpretations of the term "forest" can lead to accounting for different forest areas; therefore the terms "forest" and "forested areas" will be treated as forest cover areas in this work and this term will be applied to all data sources used herein.

2.5. Research Methods

The use of historical GIS allows us to study and analyze the data obtained from different sources, make them available for research, comprehensively examine both mapped forest cover areas and those obtained from other sources, model surfaces based on LIDAR data, and perform complex data analysis; it also allows for the data to be converted into a unified coordinate system.

A schematic representation of the methodological approach is illustrated in Figure 5 below.

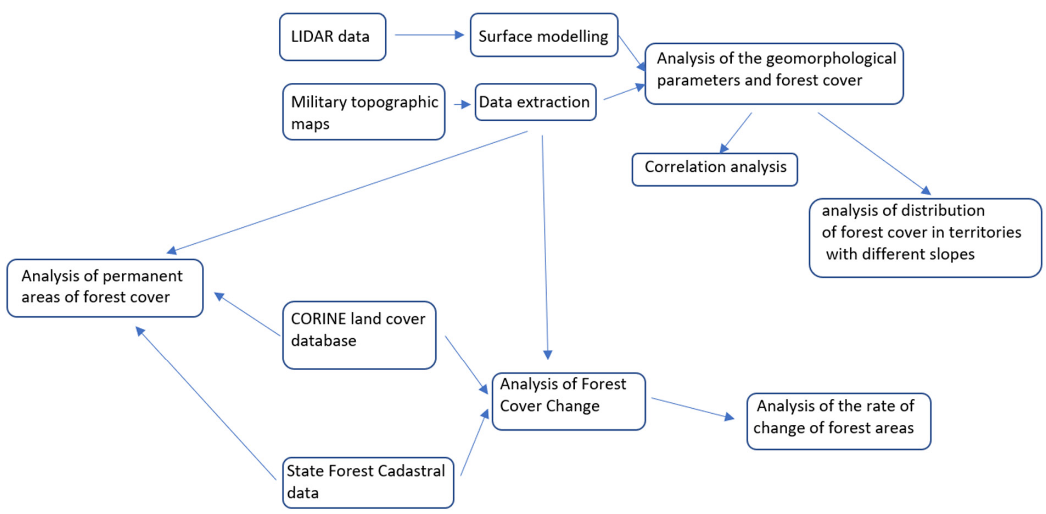


Figure 5. Overall methodology adopted in this study.

ArcGIS Desktop software was used for the study. Cartographic and thematic layers installed in ArcMap are as follows: digital copies of old maps, CORINE land covers, forest cadastral databases, and LIDAR data. A problem was encountered after uploading digital technology maps of the 2nd half of the 19th century and the 1st half of the 20th century—they are not oriented in space. Old, unchanged objects in the area are visually identified for orientation—churches, railway junctions, etc. The history of these objects has been studied. After the spatial constancy of the objects was verified (there were objects burned during the war or moved to other structures; they were eliminated from the list of objects suitable for orientation), their coordinates were determined and the coordination of map sheets was carried out according to these objects in the GIS program. Maps of the 2nd half of the 20th century were downloaded and coordinated in the LKS 94 coordinate system.

After installing the layers of cartographic material, a geodatabase of forest cover areas was created. The polygon vectorization method was used for this. The maps were vectorized manually due to the poor quality of the cartographic material and to avoid the influence of automatic vectorization errors. This is especially relevant for maps of the 19th century (Table 1). They are black and white, the image resolution of the available copies is not good, the borders of the objects are partially blurred, and the forests are represented by circles of different sizes filled with conventional signs. The terrain in these maps is represented by a criss-crossed pattern, drawn on the conventional forest marks. The combination of all these factors makes the application of automatic digitization methods very complicated.

The cadastral database has been adjusted. Forest cadastral data were uploaded into the GIS program as a layer, and after uploading the orthophoto image layer, a visual analysis of the cadastral plots divided into ranges according to the age of the trees was performed. It was established that a relatively large share of the data does not correspond to the actual situation.

In order to conduct a more accurate study (a number of land plots were identified where the forest had already been cut down and the data had not been updated), a visual inspection of all 41,289 land plots was performed to compare them with the image seen in the orthophoto. It was impossible to visually estimate the age of the replanted forest with an accuracy of one year from the orthophoto images, but it can be seen that it consists of seedlings no older than 5 years. The age of the trees indicated in the cadastral database has been adjusted to 1 year for all such land plots. These land plots fall into range I according to the age of the trees (see below) where there is no forest cover or the age of the trees is no older than 5 years.

The land plots are divided into 9 groups according to the age of the dominant trees. Parentheses contain the years in which the trees started to grow/were planted:

I. 0–5 years (2017/2022),
II. 6–9 years (2013/2016),
III. 10–19 years (2003/2012),
IV. 20–39 years (1983/2002),
V. 40–59 years (1963/1982),
VI. 60–79 years (1943/1962),
VII. 80–99 years (1923/1942),
VIII. 100–120 years (1922/1902),
IX. 125 years old and more (1897 and more).

All studied groups cover an interval of 20 years. Only groups I, II, III, and IX are distinguished: I and II—6 and 4, III—9-year intervals. The first two reflect the logging trends of the last year. Group I was singled out due to the discrepancy between the cadastral data and the orthophoto image when the database contains data on mature trees, and the orthophoto image shows clear cuts or areas planted with seedlings of up to 5 years old. This group makes it possible to obtain areas where there is no actual forest cover. Trees from the 19th century grow on land plots belonging to group IX.

The analysis of these groups was carried out with the help of historical GIS, using selection methods according to attributive queries, to determine the areas occupied by them.

The geomorphological parameters of the territory were modelled and their comparative analysis was carried out using spatial analysis methods. The heights and slopes of the territory and slopes in relation to the cardinal directions were determined. A correlation analysis of forest cover areas and various parameters was performed, *p*-values were determined, and the reliability of the analysis of the obtained correlation coefficients was evaluated.

The rate of change in forest cover areas was calculated after determining the forest cover areas in the periods in question (1):

$$v_f = (S_{t2} - S_{t1})/(t_2 - t_1) \quad (1)$$

where v_f—forest cover change rate, t_1, t_2—year, S_{t1}, S_{t2}—forest cover areas (ha) in years t_1 and t_2.

Permanent forest areas were discerned with the help of the GIS-integrated Clip function, and the places where the forest grew during the entire studied period were determined. These are places where no activity of anthropogenic origin has ever been carried out and which have not been affected by factors of other origin that led to the shrinking of forest areas.

3. Results

3.1. Analysis of the Geomorphological Parameters of the Area

In order to better understand the evolution of the forest area change and its dependence on the features of the land surface, a study of the links with the topographical and geomorphological parameters of the area was conducted. This helps answer the "where" question when studying the expansion/diminishing of forest areas. It also helps determine the links between these topographic parameters, which determine the attractiveness of the territory for agricultural activities and, historically, had the greatest influence on the change in forest areas, and the changes in the area of forest cover. By applying GIS software, using the cloud of LIDAR points and the IDW modelling algorithm, a raster model of the altitudes of the land's surface was created (digital terrain model—DTM). Its spatial resolution is 3.14×3.14.

A model of surface slopes (in degrees) was created from this model. Next, the slope was reclassified according to the orientation in relation to the cardinal directions (directions: north, northeast, east, southeast, south, southwest, west, northwest). The obtained geomorphological parameters were reclassified and converted into tables. A statistical analysis was performed using the obtained data. All quantitative land surface parameters processed with GIS software and expressed by raster maps are presented in Figure 6.

It can be seen in Figure 6a,b that the altitudes in Jurbarkas District change from 8 m to 92 m, from east to west. The altitudes vary quite evenly, with the lowest points in the eastern part and along the Nemunas River and the highest points in the western part of the district.

It can be seen from Figure 6c that, bigger slopes of the territories are concentrated on the banks of the rivers; the biggest slopes are on the banks of the Nemunas River, in the southern part of the district. Figure 6d shows that the majority of the area is occupied by areas with a very low slope, respectively:

$0°–0.78° \approx 58\%$
$0.78°–2.59° \approx 31\%$
$2.59°–5.18° \approx 6\%$
$5.18°–8.55° \approx 2\%$

Determination of the slope of the land surface favorable for agricultural activity (small and moderate) of the entire area (as a percentage) was carried out. Areas with a low and moderate slope of 0°–13° are assigned to a single interval (a slope gradient of up to 13 degrees can be considered suitable for farming). The remaining slope, which is not particularly favorable for agricultural activities, is divided into intervals. The intervals have been chosen based on the difficulty of cultivating the land and the tendency for erosion (Figure 6g).

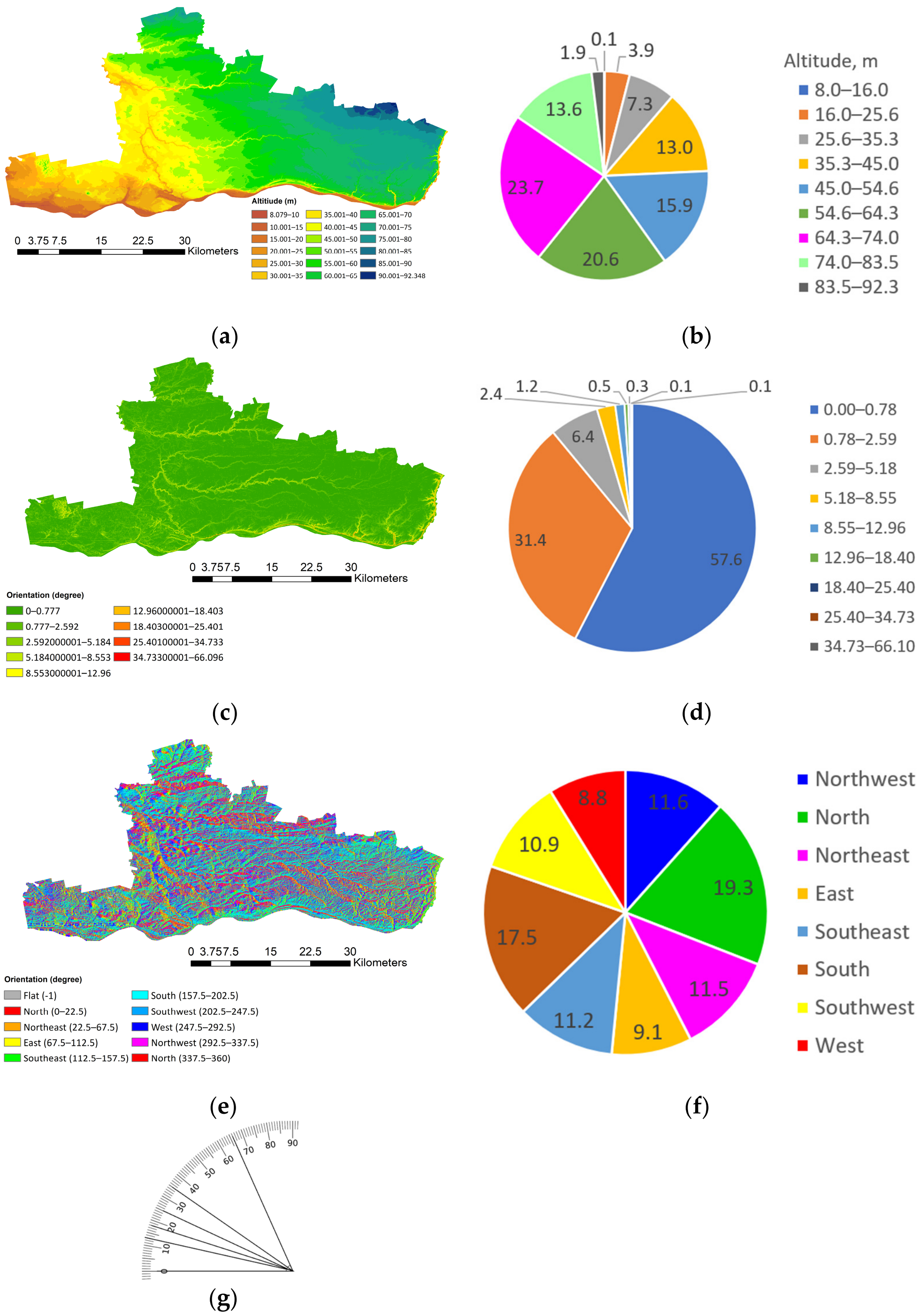


Figure 6. Geomorphological parameters of Jurbarkas District: (**a**) distribution of altitudes of the land surface, expressed in meters; (**b**) shares of the land surface slopes, divided into intervals, of the territory of the entire district (intervals of the slopes are given in the legend of the chart; the ratio of the area occupied by the slopes to the area of the entire district is presented as a percentage); (**c**) distribution of slopes of the land surface (intervals of slopes are given in the legend); (**d**) shares of the slopes of the land surface, divided into intervals, of the territory of the entire district (intervals of slopes are given in the legend of the chart; the ratio of the area occupied by the slopes to the area of the entire district is presented as a percentage); (**e**) aspect of the earth surface; (**f**) shares of slopes with respect to the cardinal directions of the total area of the district; (**g**) expression of the slope of the area in degrees.

The calculations are presented in Table 2.

Table 2. Distribution of land surface slope in Jurbarkas District.

Slope, Degree	Of the Total Area of the District, %
0–13	99.0
13–18	0.5
18–25	0.3
25–35	0.15
35–66	0.05

Areas with a small and slight angle of 0°–13° are assigned to one interval (a slope angle up to 13 degrees can be considered convenient for agriculture), and the rest of the angles are divided into intervals (according to Figure 6) and calculations are performed (Table 2).

It can be seen from the data presented in Table 2, that 99% of the territory (in terms of angles) is favorable for agriculture. The remaining 1% is only partially unfavorable for agricultural activities. A steeper angle is observed in only 0.05% of the territory and it is mostly river banks.

The slope of the territory in relation to the cardinal directions and the size of the sloped territory as a percentage of the total area occupied are presented in Figure 6d,e. Slopes are distributed more or less evenly, mostly in the south and north directions.

Jurbarkas District is divided into 12 elderships. The slopes are bigger and the altitude is lower in the southern elderships bordering the Nemunas River compared with the northern ones (Figure 6). Therefore, in order to research it more thoroughly, an analysis of the slopes in individual elderships of Jurbarkas District was carried out. These parameters allow us to determine the correlations between the geomorphological properties of the land surface and changes in forest areas.

Slope and aspect models were created for each eldership using GIS modelling capabilities. These models are reclassified by rearranging the range boundaries assigned by default. Calculated geometric dimensions (areas) of each slope zone are converted into tables, and these are converted into tables in Microsoft Excel.

The slopes of the land surface in Jurbarkas District elderships are presented in Figure 7.

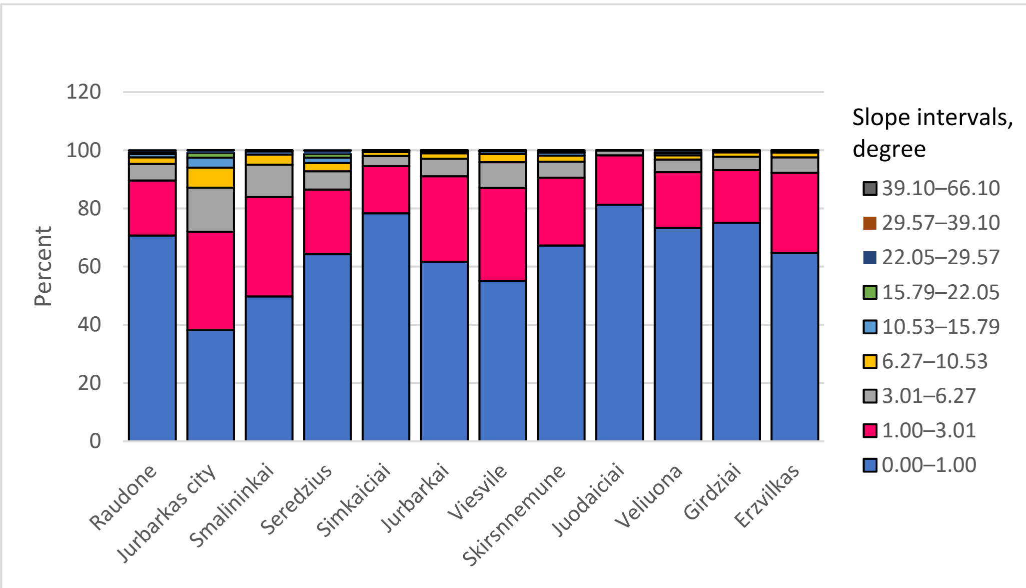


Figure 7. Distribution of slopes in the elderships, % (of the total area of the elderships).

Angles of 0° to 3° exceed 80% of the eldership area in all elderships, except for the urbanized area, i.e., the City of Jurbarkas. The slope suitable for agriculture comprises as much as 98–100% of the total area of the eldership in nine out of twelve districts. There are between 94 and 98% of such areas in the remaining three elderships. There are only 0–0.1% of areas unattractive and unsuitable for agriculture where the slope is 39–66 degrees.

The slope of the surface in relation to the cardinal directions in Jurbarkas District and its elderships are presented in Table 3 and Figure 8. The slope of the land surface in Jurbarkas District in relation to the cardinal directions is mainly oriented toward the south and less toward the east.

Table 3. Distribution of land surface aspect in Jurbarkas District.

Distribution of Land Surface Slope in Relation to the Cardinal Directions	Of the Total Area of the District, %
Š (315°–44.9°)	20.1
R (45°–134.9°)	10.9
P (135°–224.9°)	43.2
V (225°–314.9°)	25.8

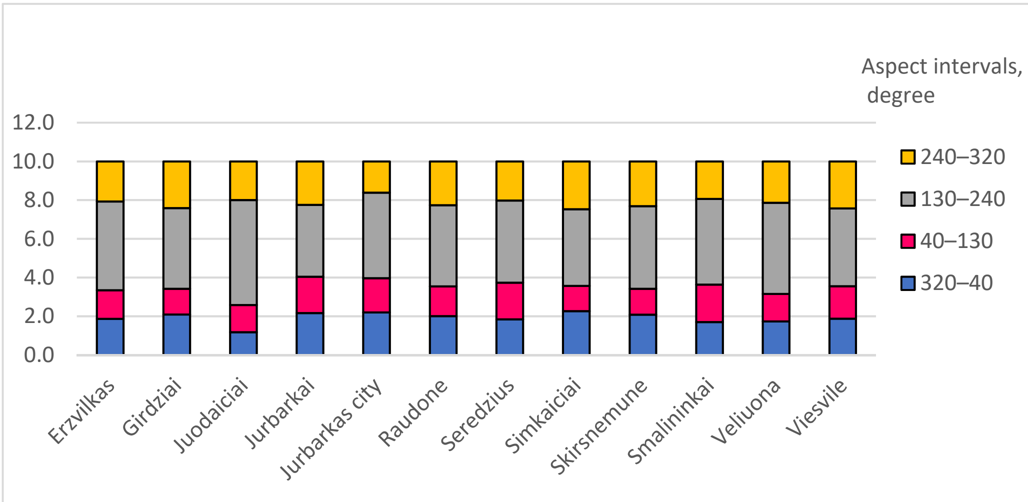


Figure 8. Distribution of slopes in the elderships, % (of the total area of the elderships) in relation to the cardinal directions.

The angle of the land surface in relation to the cardinal directions is distributed more or less similarly in all twelve elderships of Jurbarkas District, except for the southern direction: in the northern direction, 11.8–22.6%; in the eastern direction, 13.1–19.0%; in the southern direction, 37.1–54.2%; and in the western direction, 16.1–24.7% (Figure 8). This figure shows the slopes in each sub-district and Table 2 shows the data for the entire Jurbarkas District.

The territory of Lithuania is in the middle latitudes; therefore, the slope of the land surface to the south is favorable for agriculture—the soil warms up earlier, and plants receive more solar radiation. It can be seen that the studied territory is quite attractive for agricultural activities in this regard.

Next, the analysis of the distribution of the altitudes of the land surface was carried out. Table 4 shows the distribution of heights in Jurbarkas District. The largest part of the territory is occupied by areas with a height of 40–70 m (64.8%). However, these are not mountainous areas (Figure 6), and the altitudes change gradually. Again, these are not low, swampy areas, which increases the attractiveness of the area for agricultural activities.

Table 4. Distribution of land surface altitudes in Jurbarkas District.

Land Surface Altitudes, m	Of the Total Area of the District, %
0–10	0.5
10–20	2.9
20–30	6.2
30–40	6.5
40–50	15.4
50–60	29.2
60–70	23.8
70–80	13.6
80–90	1.9
90–100	0.0

The distribution of the altitudes of the land surface in individual elderships is presented in Figure 9. Unlike the distribution of slope and aspect values in the elderships where, perhaps, similar results were observed, in this case, we have a quite different picture.

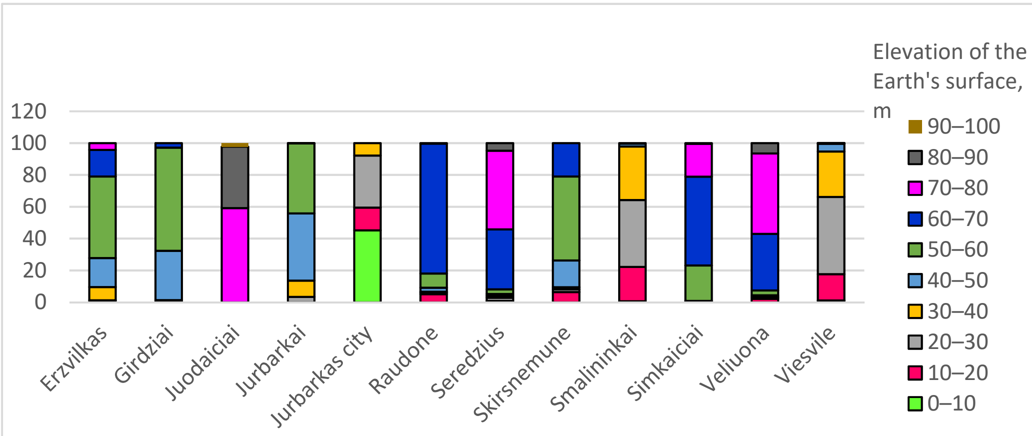


Figure 9. Distribution of land surface altitudes in the municipalities of Jurbarkas District.

Lowlands prevail in Viešvilė eldership, located in the eastern part of the district, and higher places prevail in the elderships of Juodaičiai, Seredžius, Šimkaičiai, and Veliuona.

This study of the topographical and geomorphological parameters of the territory helps us identify areas favorable for agricultural activities. As this activity is one of the main factors influencing the decline of forest areas, the results of the analysis will be used in further analysis to investigate the correlation between them and the forest cover area.

3.2. Forest Cover Dynamics Determined from Old Topographic Maps

The use of cartographic material in historical GIS allows us to observe not only the areas of forest cover but also the logging of forests during mapping, and we can determine the results of this anthropogenic impact documented in a certain period—the areas of forest logging; we can also get a picture of the forest areas that existed before logging, the intensity of logging, and the remaining forest coverage after logging.

The forest coverage of Jurbarkas District elderships was analyzed separately in each eldership because they differ in various geomorphological parameters that can affect forest coverage.

A study of forest cover areas that existed in the 19th century was conducted in the first place using cartographic material. Data about forest areas present in the 19th century and their logging areas were obtained using historical GIS (Table 5). Maps of forest cover in the 19th century for administrative units are presented in Figures 10 and 11. The obtained data were analyzed, and the forest area before logging, areas of logging, and forest remaining after logging in the 19th century were determined. This makes it possible to study the change in forest cover areas recorded in the cartographic material as a result of an anthropogenic impact.

Table 5. Areas of forest cover in the elderships during the period of the 2nd half of the 19th century as a percentage of the area of the elderships.

Elderships	Area of Forest before Logging, %	Area of Forest after Logging, %	Area of Logging from the Forest Area, %	Area of Logging from the Eldership Area, %
2nd Half of the 19th Century				
Eržvilkas	58.2	57.9	0.6	0.3
Girdžiai	67.4	63.4	5.9	4.0
Juodaičiai	51.1	49.8	2.6	1.3
Jurbarkai	69.0	60.6	12.2	8.4
Jurbarkas city	8.0	8.0	0.0	0.0
Raudonė	54.1	51.1	5.5	3.0
Seredžius	44.9	44.4	1.2	0.5
Skirsnemunė	46.8	46.3	1.2	0.6
Smalininkai	14.2	14.2	<0.1	0.0
Šimkaičiai	66.2	63.9	3.5	2.3
Veliuona	62.7	61.9	1.4	0.9
Viešvilė	67.4	67.4	0.0	0.0
Jurbarkas Distr.	59.9	56.6	4.6	2.7
1st half of the 20th century				
Eržvilkas	16.7	16.6	0.7	0.1
Girdžiai	28.9	27.9	3.5	1.0
Juodaičiai	3.8	3.8	-	-
Jurbarkai	45.7	45.7	-	-
Jurbarkas city	12.3	12.3	-	-
Raudonė	15.9	15.9	-	-
Seredžius	17.1	17.1	-	-
Skirsnemunė	17.5	17.5	-	-
Smalininkai	22.4	22.4	-	-
Šimkaičiai	21.2	21.2	-	-
Veliuona	25.9	25.9	-	-
Viešvilė	70.5	70.5	-	-
Jurbarkas Distr.	28.8	28.7	0.4	0.1
2nd half of the 20th century				
Eržvilkas	22.3	22.3	-	-
Girdžiai	29.5	29.5	-	-
Juodaičiai	17.6	17.6	-	-
Jurbarkai	51.1	51.0	0.2	0.1
Jurbarkas city	16.8	16.8	-	-
Raudonė	23.4	23.4	-	-
Seredžius	31.5	31.5	-	-
Skirsnemunė	19.0	19.0	-	-
Smalininkai	33.8	33.5	0.7	0.3
Šimkaičiai	25.7	25.7	-	-
Veliuona	33.2	33.2	-	-
Viešvilė	76.4	76.3	0.1	0.1
Jurbarkas Distr.	35.0	34.9	0.1	<0.1

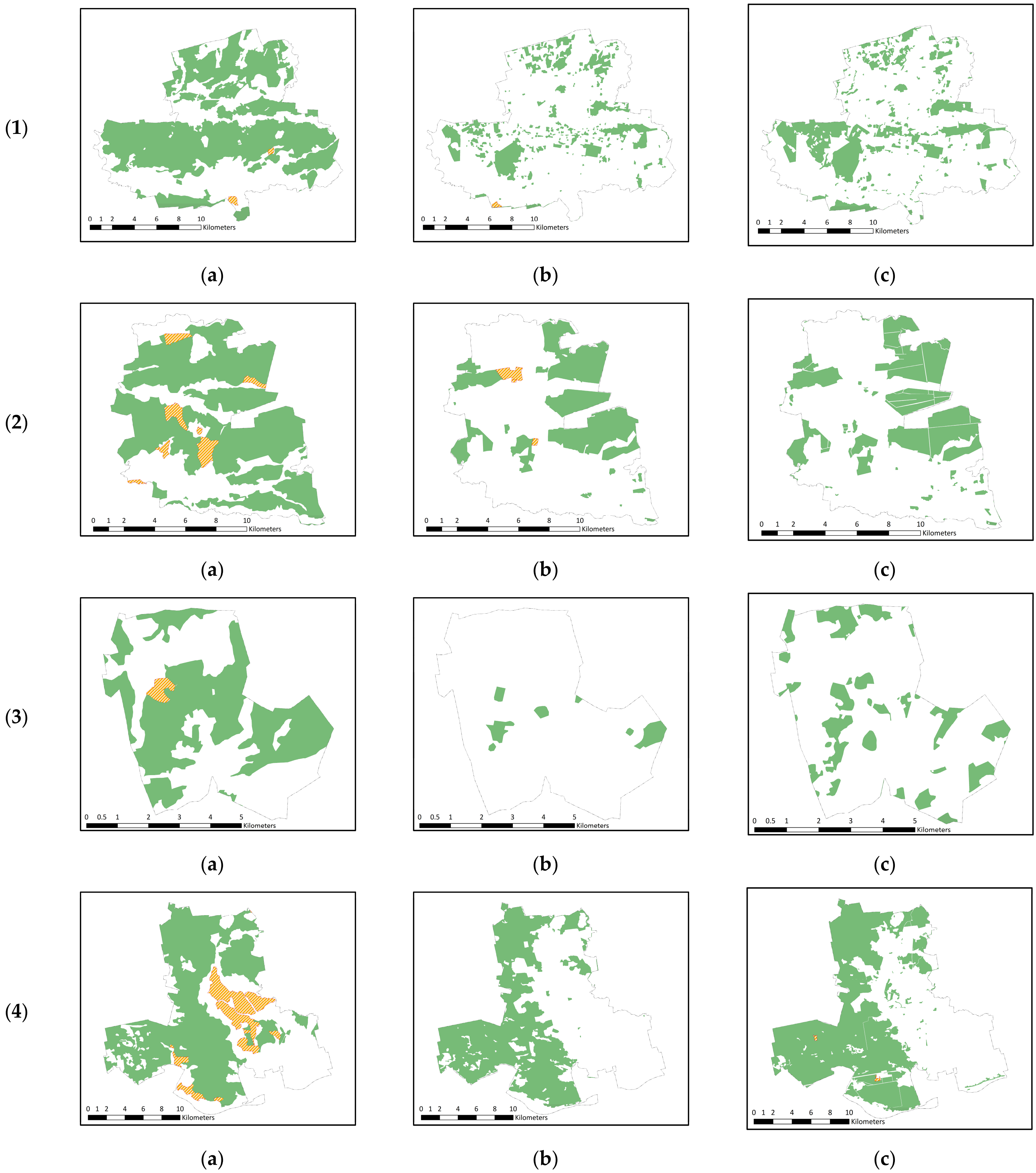


Figure 10. *Cont.*

Figure 10. *Cont.*

Figure 10. Forest cover maps with visible logging areas for elderships: (**1**) Eržvilkas, (**2**) Girdžiai, (**3**) Juodaičiai, (**4**) Jurbarkai, (**5**) Jurbarkas City, (**6**) Raudonė, (**7**) Seredžius, (**8**) Šimkaičiai, (**9**) Skirsnemunė, (**10**) Smalininkai (**11**) Veliuona, and (**12**) Viešvilė; period: (**a**) 19th century, (**b**) 1st half of the 20th century, (**c**) 2nd half of the 20th century.

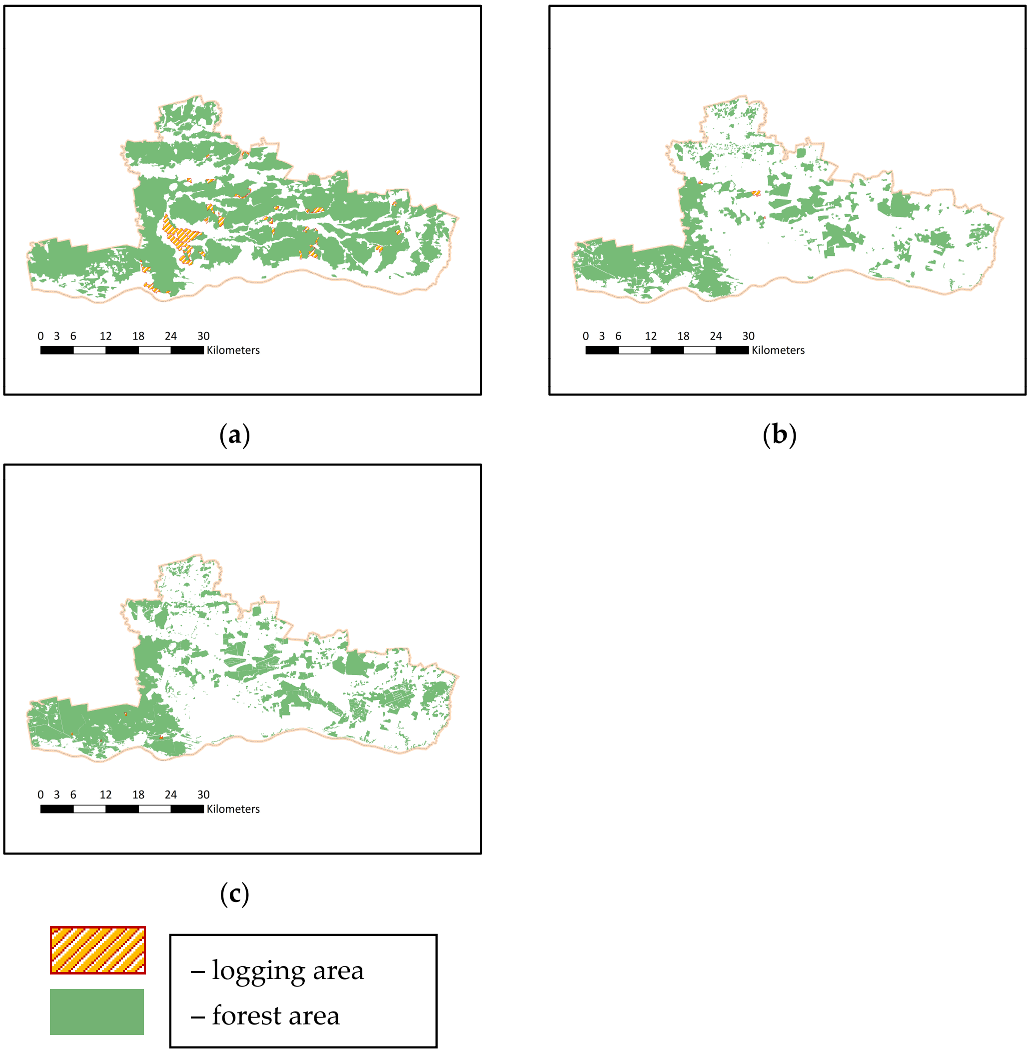


Figure 11. Forest coverage of Jurbarkas District with visible logging areas: (**a**) 19th century, (**b**) 1st half of the 20th century, (**c**) 2nd half of the 20th century.

It can be seen from the results of the study presented in Table 5 that the forest areas in 10 municipalities occupied 44.9% to 69.0% of their area in the 19th century, before logging. The forest occupied more than 50% of the area of an eldership in eight out of twelve elderships with similar forest cover. The area occupied by forest was smaller than in most elderships only in two elderships: 8.0% in the City of Jurbarkas, 14.2% in the Smalininkai Eldership. The City of Jurbarkas is an urbanized area, which can explain the small forest coverage. The area of Smalininkai Eldership was part of the Kingdom of Prussia in the 19th century. These lands were associated with quite actively developed anthropogenic activities from the 15th century onward—there was a border control point, a port, etc. [58]—which can be attributed to the lower forest coverage of this area. The average area of forest cover in the elderships is 50.9% of the area of the elderships. Forest area exceeds 30% in ten elderships out of twelve.

The total forest coverage of Jurbarkas District was 89,551.6 ha at that time, i.e., as much as 59.9% of the total area (Table 5, Figure 6a), which is a very good indicator if you look at it in terms of the objectives of climate change management.

The maps of the 19th century recorded tree logging during the mapping out period as well. No logging was recorded in only two elderships: Jurbarkas City and Viešvilė. The logging area was less than 0.1% of the eldership of Smalininkai. The largest forest losses of the total forest area were in the elderships of Jurbarkai (12.2%) and Girdžiai (5.9%). In the remaining elderships, they ranged from 0.6% to 5.5%.

During the mapping period in the 19th century, 4292.1 ha of forest area was lost throughout the District of Jurbarkas; that is 4.6% of the total forest area. It would be 2.7% of the area of the district. The cleared forest areas are presented in Figures 11 and 12. After visual analysis of Figures 3, 6b and 11, it can be seen that the soil productivity score does not have a significant influence yet. The largest logging areas are along the state border near the port of Smalininkai.

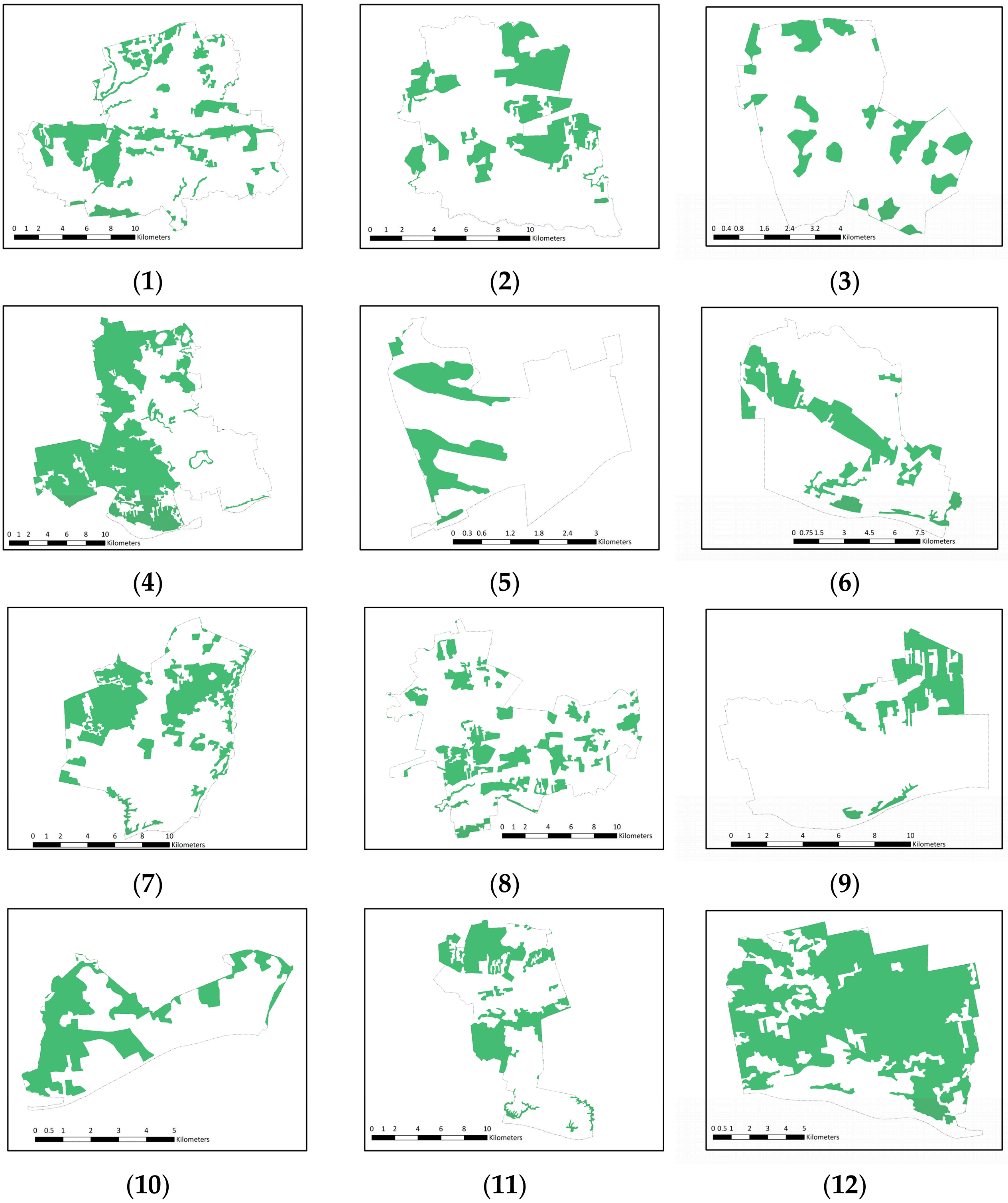


Figure 12. Maps of forest cover recorded in the CORINE Land Cover database for elderships: (**1**) Eržvilkas, (**2**) Girdžiai, (**3**) Juodaičiai, (**4**) Jurbarkai, (**5**) Jurbarkas City, (**6**) Raudonė, (**7**) Seredžius, (**8**) Šimkaičiai, (**9**) Skirsnemunė, (**10**) Smalininkai (**11**) Veliuona, and (**12**) Viešvilė.

Bearing in mind that the soil productivity score in this area is one of the best in the Republic of Lithuania, agricultural activities in this area did not have a significant impact on the reduction in forest areas in the 19th century. Examining the distribution of forest areas in elderships in the 19th century allows us to tie the size of the area of forest more closely to urbanized, densely populated areas where anthropogenic activities are more active.

The forest cover areas shown in the maps created in the 1st half of the 20th century were identified using historical GIS. Analysis of the data obtained shows forest areas that are much smaller than those in the 1st half of the 19th century (Table 5). Maps of forest cover of elderships and Jurbarkas District in the 1st half of the 20th century are presented in Figures 10 and 11.

A significant shrinking in forest areas is visible in the interwar period—the forest areas that existed before logging in 10 municipalities occupied 3.8% to 28.9% of their area. The forest covered an average of 15.9% in eight out of twelve municipalities with similar forest cover. The area occupied by the forest was significantly larger in two elderships than in most elderships: 70.5% in Viešvilė Eldership and 45.7% in Jurbarkai Eldership. The smallest area of forest cover in Juodaičiai Eldership was only 3.8%. The forest area did not differ in size from other elderships in the City of Jurbarkas (in the urbanized area). The average forest cover area for all elderships was 24.8%. The forest area exceeded 30% of the area of elderships in only two elderships.

The total forest cover in Jurbarkas District was 43,228.9 ha—28.7% of the total area (Table 5, Figure 6b), not even reaching 30%.

Forest cuttings, identified from the maps from the 1st half of the 20th century during the period being mapped, are insignificant and are present only in two elderships—Eržvilkas (0.7%) and Girdžiai (3.5%).

A forest area of 153.7 ha, i.e., 0.4% of the total forest area, was lost throughout Jurbarkas District in the 1st half of the 20th century during the mapping period. It would be 0.1% of the area of the district. The cleared forest areas are presented in Figures 10 and 11. After visual analysis of Figures 3, 6 and 13, it can be seen that the forest cover is diminishing sharply in areas favorable for agriculture.

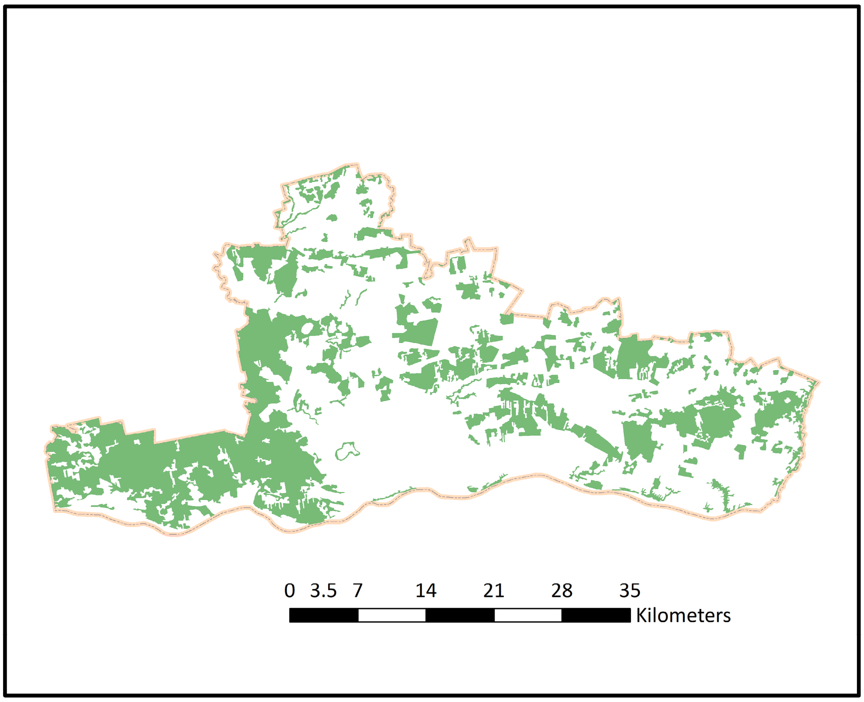


Figure 13. Maps of forest cover recorded in the CORINE Land Cover database for Jurbarkas District.

After identifying and analyzing the forest cover data recorded on the maps of the 2nd half of the 20th century, the forest cover areas of the administrative units were calculated as percentages and are presented in Table 5. Maps of forest cover in the 2nd half of the 20th century for elderships and Jurbarkas District are presented in Figures 10 and 11.

An increase in forest areas was observed in the 2nd half of the 20th century compared with the 1st half of the 20th century, i.e., forest areas before logging in 10 municipalities occupied 15.4% to 33.6% of their area. After the cuts, they diminished from 15.4% to 33.4%, respectively. The forest covered an average of 25.1% in ten out of twelve municipalities with similar forest cover. The area occupied by forest was significantly larger in two elderships than in other elderships: 70.5% (Viešvilė) and 45.7% (Jurbarkai), respectively. The smallest area of forest cover in Juodaičiai Eldership was only 3.8%. The average forest cover area for all elderships was 31.6%. The forest area exceeded 30% of the area of elderships in only five of twelve elderships.

The total forest coverage in Jurbarkas District was 52,601.3 ha, i.e., 34.9% of the total area (Table 3, Figure 11).

Forest cuttings, identified in the maps of the 2nd half of the 20th century during the period being mapped, are insignificant and are present only in three elderships—Jurbarkai (0.2%), Smalininkai (0.7%), and Viešvilė (0.1%).

A forest area of 50.1 ha, i.e., 0.1% of the total forest area, was cut down throughout Jurbarkas District in the 2nd half of the 20th century during the mapping period. It would be less than 0.1% of the area of the district. Cleared forest areas are presented in Figure 11a.

3.3. CORINE Land Surface Cover Database

The data in the CORINE Land Cover database are recorded in the 1st half of the 21st century. The CORINE database was uploaded into the ArcGIS software package, and then, data processing and analysis were performed. CORINE forest cover was compared with data obtained from old topographic maps. Three classes were used in the study—"deciduous forests", "coniferous forests", and "mixed forest", which were combined into one class "forest cover". Attribute data were selected according to the codes defining the forest by applying the analysis methods integrated into the GIS program, and exported to separate shapefiles. The data format was unified with other available data formats and data analysis was performed. Forest covers and areas for each eldership and Jurbarkas District have been determined. The area occupied by forest cover was calculated from the areas of administrative units, as a percentage (Table 6).

Table 6. Areas of forest cover in the 1st half of the 21st century as a percentage of the area of the elderships.

Elderships	The Area of Forest Cover, %
Eržvilkas	24.1
Girdžiai	26.9
Juodaičiai	17.5
Jurbarkai	50.6
Jurbarkas city	15.3
Raudonė	22.0
Seredžius	33.6
Skirsnemunė	14.4
Smalininkai	39.2
Šimkaičiai	24.3
Veliuona	33.5
Viešvilė	67.6
Jurbarkas Distr.	33.9

The area of forest cover in the elderships is 17.5–67.6% of the areas of the elderships in the 1st half of the 21st century. The average is 30.7%.

The forest covers more than 30% of the territory in five out of twelve elderships. The forest covers only 17.5–26.9% of the area of the elderships in the remaining eight elderships.

Forest coverage in Jurbarkas District is up to 33.9%. Forest coverage exceeding 30% is achieved only thanks to two elderships—Jurbarkas and Viešvilė. The average forest coverage of the studied territory in the remaining elderships without said two elderships, would be only 25.7%.

The created forest cover maps are presented in Figure 12 for the elderships and in Figure 13 for Jurbarkas District.

3.4. Forest Cadastral Data

In the next stage of the study, forest cadastral data were used to monitor forest cover change in the long term. The downloaded forest cadastral data were uploaded into the ArcGIS software package and data analysis and comparison with previously conducted research was performed. The following attribute data were used in this study: forest area and age. The areas of forest plots in the municipalities of Jurbarkas District and in the district itself were determined during the research. Analysis of these data aimed to determine the current officially declared forest area, which does not necessarily coincide with the forest cover areas and the distribution of forest areas according to the age of the trees growing in them.

Table 7 presents the area occupied by forest land valuation plots as a percentage of the municipal areas.

Table 7. Forest areas according to the data from the Forest Cadastre as a percentage of the area of the elderships.

Elderships	Area of Forest, %
Eržvilkas	26.4
Girdžiai	33.2
Juodaičiai	18.9
Jurbarkai	56.2
Jurbarkas city	18.8
Raudonė	25.7
Seredžius	35.4
Skirsnemunė	20.5
Smalininkai	40.9
Šimkaičiai	29.1
Veliuona	36.4
Viešvilė	82.8
Jurbarkas Distr.	38.9

Table 7 shows that according to the forest cadastral data provided, the area of forest valuation plots in the elderships is 18.8–82.8% of the area of the elderships. The size of the forest areas in Viešvilė and Jurbarkas elderships stands out from other elderships—82.8% and 56.2%, respectively. The forest area covers more than 30% in six out of twelve elderships. The average forest area in the municipalities is 35.4%.

The forest area reaches 38.9% in Jurbarkas District.

Additional research was carried out with the help of historical GIS methods. After dividing the data into groups according to the age of the dominant trees in the plots, an analysis of the dominating forest areas according to age was carried out. Age intervals are every 19 years, ranging from 10 to 225 years. In order to distinguish clear cuttings and newly planted areas, the first ten years are divided into periods of 0–5 and 6–9 years. After determining the polygons falling into the relevant age ranges, the percentage of the total area of the polygon of the forest located in the elderships (Table 8) was calculated.

Table 8. Forest areas of different ages of the total forest area (percentage).

Age of Trees, in Years	Eržvilkas	Girdžiai	Juodaičiai	Jurbarkai	Jurbarkas City	Raudonė	Seredžius	Skirsnemunė	Smalininkai	Šimkaičiai	Veliuona	Viešvilė	Jurbarkas Distr.
0–5	9.3	7.6	14.5	12.2	4.2	13.0	13.7	12.9	17.9	13.5	12.6	8.8	11.4
6–9	1.8	5.0	2.4	3.3	0.1	4.1	3.3	3.1	5.7	4.4	2.8	3.3	3.4
10–19	10.2	14.8	13.2	8.4	0.6	12.7	11.0	12.7	10.2	16.3	11.1	5.4	10.2
20–39	14.3	26.8	22.0	20.1	5.8	17.3	13.7	28.0	20.8	20.0	21.1	11.1	18
40–59	15.8	13.5	15.6	13.4	12.2	17.4	15.6	19.0	8.3	10.1	19.5	12.9	14.2
60–79	25.6	14.5	19.2	21.2	19.7	19.9	21.0	15.0	12.9	15.1	17.8	30.8	21.5
80–99	18.3	13.3	12.5	20.6	17.9	11.2	17.8	6.4	11.8	17.3	13.9	11.7	15.9
100–119	3.8	3.8	0.4	0.4	19.0	2.6	3.5	1.9	8.8	3.1	0.7	11.0	3.9
120–139	0.7	0.4	0.2	0.1	20.5	1.2	0.4	0.8	3.3	0.1	0.2	3.5	1.0
140–159	0.2	<0.1	-	0.3	-	0.6	-	0.2	0.1	0.1	0.3	1.0	0.4
160–179	-	0.1	-	-	-	-	-	-	0.2	-	-	0.5	0.1
180–199	-	0.1	-	-	-	-	-	-	-	-	-	0.05	<0.1
200 and more	-	-	-	-	-	-	-	-	-	-	-	<0.01	<0.01

Jurbarkas District elderships and Jurbarkas District are dominated by forest areas comprising trees from 0 to 99 years of age. Forest areas with trees of 100 years of age and older are few and insignificant. Areas (in eleven out of twelve elderships), when examined according to the age of growing trees, decrease significantly after reaching the age of trees of 100 years or more and make up only 0.4–8.8% of the area of elderships. Considerable areas occupied by 100–139-year-old trees have remained only in the urbanized area, i.e., in the City of Jurbarkas.

Only three of the twelve municipalities have forest areas with trees older than 160 years. One eldership stands out—Viešvilė—where we can see even small areas with trees over 200 years old.

The distribution of trees by species in the plots (dominated by trees older than 160 years) is as follows:

1. From 160 to 179 years old: 50% of pines, 16.7% of spruces, 33.3 of oak trees;
2. From 180 to 199 years old: 71.4 % of pines, 28.6 % of oak trees;
3. 200 years and older: 95.7 % of pines, 4.3 % of spruces trees.

The data visualized by the forest cadastre on the maps are presented in Figures 14 and 15.

Figure 14. Forest cadastral data maps for elderships: (**1**) Eržvilkas, (**2**) Girdžiai, (**3**) Juodaičiai, (**4**) Jurbarkai, (**5**) Jurbarkas City, (**6**) Raudonė, (**7**) Seredžius, (**8**) Šimkaičiai, (**9**) Skirsnemunė, (**10**) Smalininkai, (**11**) Veliuona, and (**12**) Viešvilė.

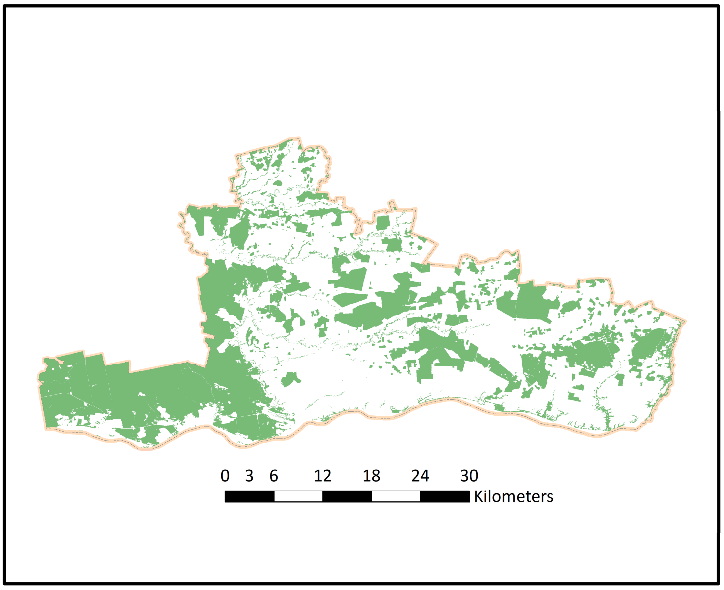


Figure 15. Forest cadastral data map of Jurbarkas District.

3.5. Dynamics of Forest Cover

The table below (Table 9) shows in detail the dynamics of forest cover over different periods. The areas of forest cover after felling, documented in the cartographic material, were used. Forest areas of the administrative units were calculated as percentages, and the differences between them were also calculated. It can be seen that, depending on the forest management policy in different countries, the dynamics of the forest cover areas changed quite significantly and there was no expansion/diminishing observed uniformly. It is also possible to single out an urbanized territory—the City of Jurbarkas—where the dynamics of the forest cover were affected by factors other than those affecting nonurbanized territories.

Table 9. The forest cover change as a percentage of the area of the elderships.

Elderships	2nd Half of the 19th Century–1st Half of the 20th Century	2nd Half of the 19th Century–2nd Half of the 20th Century	2nd Half of the 19th Century–1st Half of the 21st Century	1st Half of the 20th Century–2nd Half of the 20th Century	1st Half of the 20th Century–1st Half of the 21st Century	2nd Half of the 20th Century–1st Half of the 21st Century
Eržvilkas	−41.3	−35.6	−33.8	5.7	7.5	1.8
Girdžiai	−35.5	−33.9	−36.5	1.6	−1	−2.6
Juodaičiai	−46	−32.2	−32.3	13.8	13.7	−0.1
Jurbarkai	−14.9	−9.6	−10.0	5.3	4.9	−0.4
Jurbarkas city	4.3	8.8	7.3	4.5	3	−1.5
Raudonė	−35.2	−27.7	−29.1	7.5	6.1	−1.4
Seredžius	−27.3	−12.9	−10.8	14.4	16.5	2.1
Skirsnemunė	−28.8	−27.3	−31.9	1.5	−3.1	−4.6
Smalininkai	8.2	19.3	25	11.1	16.8	5.7
Šimkaičiai	−42.7	−38.2	−39.6	4.5	3.1	−1.4
Veliuona	−36	−28.7	−28.4	7.3	7.6	0.3
Viešvilė	3.1	8.9	0.2	5.8	−2.9	−8.7
Jurbarkas Distr.	−27.9	−21.7	−22.7	6.2	5.2	−1.0

Forest areas diminished very significantly in nine out of twelve elderships from the 2nd half of the 19th century to the 1st half of the 20th century. The difference in forest areas is as follows: −23.1–−47.3%. The area of the total forest cover in elderships decreased by 24.3% on average. Juodaičiai eldership stands out due to the changes in its forest cover where only 3.8% of the territory's forest coverage remains from 51.1% in the period from the 19th century to the 1st half of the 20th century. Forest areas of three municipalities (Viešvilė, Smalininkai, Jurbarkas City, Lithuania) avoided destruction processes and there was even a slight increase—from 3.1% to 8.2%. Abandoned areas appeared in the City of Jurbarkas as a result of the impact of World War I. Thanks to the abandoned areas, the forest spread on its own. The areas occupied by Viešvilė and Smalininkai elderships were part of the Kingdom of Prussia, and they managed to avoid long-term military operations and the destruction of forest areas that took place during World War I.

The forest cover has decreased by more than 20% in Jurbarkas District since the 19th century.

The areas of forest cover expanded from the 1st half of the 20th century to the 2nd half of the 20th century. This trend was observed in all Eastern European countries that were occupied by Soviet Russia. The most important factors in the dynamics of such forest cover were collectivization and deportations, which significantly reduced agricultural land [59]. An increase of more than 10% was observed in three elderships and from 1.5% to 7.5% in the remaining ones.

The increase in Jurbarkas District was 6.2%. This increase did not compensate for the results of forest cover diminishing in previous periods.

The area of forest cover has decreased to 8.7% in most of the elderships from the 2nd half of the 20th century to the 21st century. The change of cover area in Jurbarkas District is −1%.

By following the dynamics of the forest cover chronologically, it can be seen that forest areas were diminishing in most of the elderships from the 2nd half of the 19th century to the 1st half of the 20th century. These results match the results of the study by Potapov et al. in 2015 [60] where the diminishing of forest areas in Eastern Europe due to the collapse was observed from the 2nd half of the 20th century, mainly due to logging operations. This can also be seen in Table 8 where the percentage of trees of the age corresponding to that period is one of the highest in the elderships.

This analysis made it possible to see the change in forest cover areas in relation to the area of administrative units (elderships and Jurbarkas District), but the question arises as to how much of forest cover area has been lost/acquired in relation to the former forest cover areas (Table 10).

Table 10. The increase in forest area from the forest area.

Elderships	2nd Half of the 19th Century–1st Half of the 20th Century	2nd Half of the 19th Century–2nd Half of the 20th Century	2nd Half of the 19th Century–1st Half of the 21st Century	1st Half of the 20th Century–2nd Half of the 20th Century	1st Half of the 20th Century–1st Half of the 21st Century	2nd Half of the 20th Century–1st Half of the 21st Century
Eržvilkas	−71.4	−61.5	−58.4	34.6	45.4	8.1
Girdžiai	−56.0	−53.5	−57.6	5.8	−3.6	−8.8
Juodaičiai	−92.3	−64.7	−64.9	359.4	356.7	−0.6
Jurbarkai	−24.5	−15.2	−16.4	12.3	10.7	−1.5
Jurbarkas city	55.0	93.7	95.4	25.0	26.1	0.9
Raudonė	−69.0	−54.3	−57.0	47.2	38.6	−5.9
Seredžius	−61.5	−29.1	−24.3	84.3	96.9	6.9
Skirsnemunė	−62.2	−59.0	−69.0	8.4	−17.9	−24.3
Smalininkai	57.5	135.0	176.3	49.1	75.3	17.6
Šimkaičiai	−66.9	−59.8	−62.0	21.3	14.7	−5.5
Veliuona	−58.2	−46.4	−45.9	28.4	29.4	0.8
Viešvilė	4.6	13.2	0.4	8.3	−4.0	−11.4
Jurbarkas Distr.	−49.5	−38.6	−40.4	21.7	18.0	−3.0

The reference points are the forest areas that existed in different periods: 2nd half of the 19th century (Table 10, columns II, II, IV) and 1st half of the 20th century (Table 10, columns V, VI, VII). The percentage increase/decrease in forest cover in these periods was calculated: 2nd half of the 19th century–1st half of the 20th century, 2nd half of the 19th century–2nd half of the 20th century, 2nd half of the 19th century–1st half of the 21st century, 1st half of the 20th century–2nd half of the 20th century, 1st half of the 20th century–1st half of the 21st century, 2nd half of the 20th century–1st half of the 21st century.

In this eldership, the increase in forest area from the forest area in the first half of the 20th century is the highest of all the elderships—over 35%.

During the analysis of the change of the forest area from the area of the forest cover itself, we see much more dynamic processes than when analyzing the areas of the municipalities. Forest areas diminished in nine out of twelve elderships—Eržvilkas, Girdžiai, Juodaičiai, Jurbarkai, Raudonė, Seredžius, Skirsnemunė, Šimkaičiai, Veliuona—quite drastically, from 24.5 to 92.3% from the 19th century to the 1st half of the 20th century. The forest area diminished by 62.4% on average in these elderships. There is practically no forest left in Juodaičiai eldership—only 7.7% of the former area remains. The dynamics of forest areas were moving in a positive direction from the 1st half of the 20th century to the 2nd half of the 20th century—an increase in forest areas from 5.8% in Girdžiai eldership to 359.4% in Juodaičiai eldership was observed. In this eldership, the increase in forest area from the first half of the 20th century is the highest of all the elderships—over 350%.

3.6. Rate of Change in Forest Cover Area

Knowing the rate of change in forest areas, it is possible to monitor the long-term dynamics of forest areas and forecast the size of future forest areas in the time ahead if the same factors affecting the change in forest areas are maintained. The rate of forest cover change shows the expansion/diminishing of forest areas per year. Knowing this rate allows us to predict the size of forest cover areas during the chosen period. Since the increase/decrease in forest areas these days is mainly determined by legal regulation in this area, it is possible to predict future sizes of forest areas during the chosen period if the conditions are unchanged.

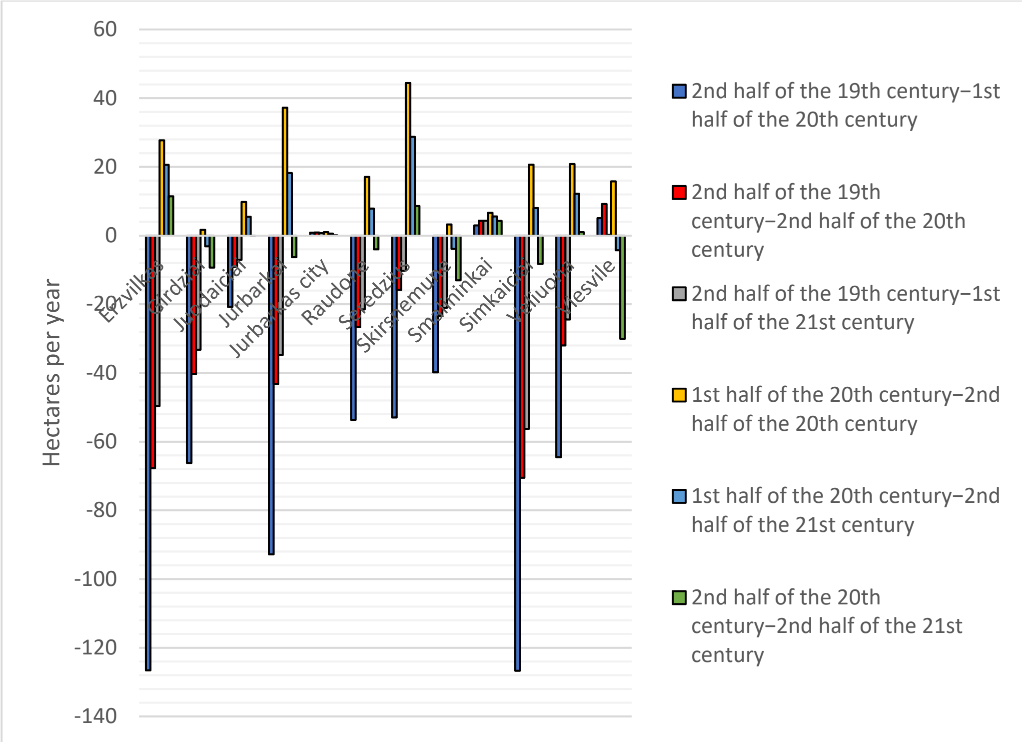
During the research, the rate of change in forest cover areas was calculated by analyzing data on forest cover areas over different periods. Of course, the rate of forest area decline was not uniform as the factors affecting the expansion/diminishing of forest cover areas changed repeatedly over the course of 158 years. However, after evaluating these factors, it is possible to see generalized trends of expansion/diminishing of forest areas and the influence thereof on forest areas and to model possible future covers after adding or eliminating certain factors.

Periods between data sources were identified (Table 11):

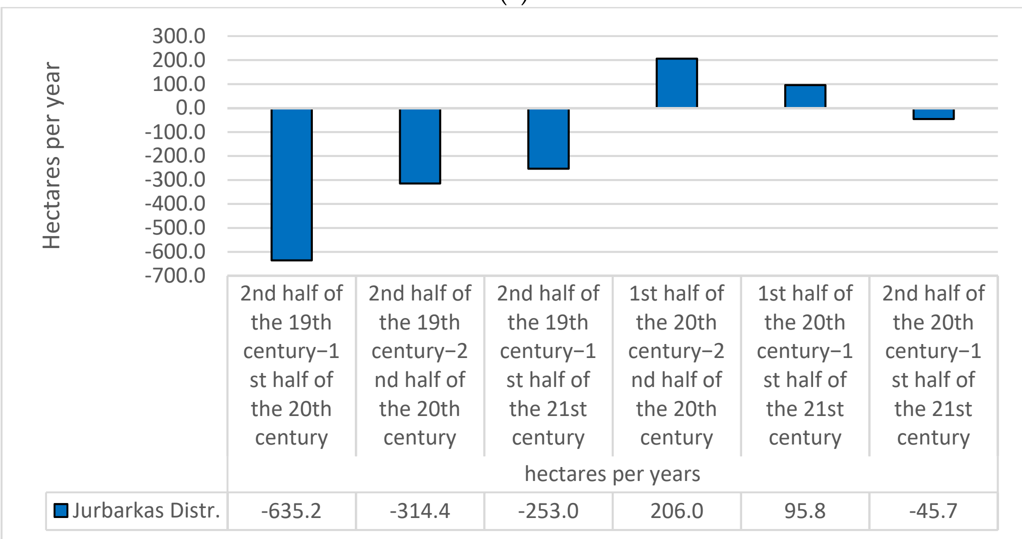
Table 11. Periods between years in which forest areas are recorded.

Period	2nd Half of the 19th Century	1st Half of the 20th Century	2nd Half of the 20th Century
2nd half of the 19th century	-	-	-
1st half of the 20th century	73 years	-	-
2nd half of the 20th century	118 years	45 years	-
1st half of the 21st century	158 years	80 years	35 years

Having the data presented in Table 11 and the forest cover areas determined with the help of GIS software, the rate of change in forest areas in the elderships and Jurbarkas District was calculated, in hectares per year (Figure 16).



(**a**)



(**b**)

Figure 16. The rate of change in forest areas in (**a**) elderships and (**b**) Jurbarkas District.

Figure 16 shows that the highest rate of diminishing of forest areas was in the 19th century–the 1st half of the 20th century. The forest cover area diminished at a rate of 20.8 ha/year—126.7 ha/year in all elderships, except for the urbanized territory, i.e., the City of Jurbarkas and the elderships of Smalininkai and Viešvilė. There was an extremely slight increase in three elderships, at a rate of 5.1–0.9 ha/year. Forest cover has diminished at a rate of 635.2 ha/year in Jurbarkas District from the 19th century to the 1st half of the 20th century.

The highest rate of increase in forest areas was from the 1st half of the 20th century to the 2nd half of the 20th century. The areas of forest cover increased in all elderships. They increased quite slightly in four out of the twelve at a rate of 1–6.6 ha/year and from 9.8 ha/year up to 44.4 ha/year in the rest. The area of forest cover expanded at a rate of 206 ha/year in Jurbarkas District during this period.

Studying the rates of forest cover change during these periods shows how great the influence of certain factors affecting forest cover areas is. Quite different rates of change were obtained during different periods. If we take a period of the 2nd half of the 19th century—1st half of the 20th century, an extremely high rate of loss of forest areas is observed. Extending the period to the 2nd half of the 20th century results in lower rates of change—forest growth during the 1st half of the 20th century–the 2nd half of the 20th century reduced the negative rate of change. During this period, the largest growth of forest areas is observed.

The study of individual shorter periods allows for monitoring the influence of factors affecting forest cover areas, while large generalized periods show the cumulative effect of those factors and trends in the change in forest areas.

Compiling a chronological time scale that covers the entire research period allowed us to determine the number of years (after maintaining the forest management guidelines that existed in certain periods and the rate of change in forest areas determined by them) during which forests in Jurbarkas District would have vanished (−)/had their areas doubled (+) (Table 12).

Table 12. Number of years in which forest cover areas would have disappeared/doubled.

Elderships	If the Effects of Factors of 2nd Half of the 19th Century–1st Half of the 20th Century Were Maintained	If the Effects of Factors of 1st Half of the 20th Century–2nd Half of the 20th Century Were Maintained	If the Effects of Factors of 2nd Half of the 20th Century–1st Half of the 21st Century Were Maintained
Eržvilkas	−102	+134	+469
Girdžiai	−128	+2165	−575
Juodaičiai	−79	+12	−58,333
Jurbarkai	−216	+357	−853
Jurbarkas city	+133	+180	+100,078
Raudonė	−103	+95	−1338
Seredžius	−118	+53	+626
Skirsnemunė	−116	+536	−412
Smalininkai	+127	+90	+1258
Šimkaičiai	−107	+211	−650
Veliuona	−124	+159	+5479
Viešvilė	+1593	+536	−178
Jurbarkas Distr.	−141	+211	−117

If the effects of factors of the 19th century—the 1st half of the 20th century were maintained at the rates presented in Figure 16, the forest cover areas would vanish:

(a) At the rate of the 19th century—the 1st half of the 20th century period: after ≈141 years, i.e., around 2006;
(b) At the rate of the 2nd half of the 20th century—the 1st half of the 21st century period: after ≈117 years, i.e., around 2100.

The area of forest cover in this district would double by 2149 if the growth rate of forest cover areas of the 2nd half of the 20th century—the 2nd half of the 20th century period would remain.

3.7. Spatial and Statistical Analysis

Spatial and statistical analysis provides an opportunity to determine the links between geomorphological and spatial parameters of the territory and changes in forest areas, as well as to analyze the possible influence of topographical and geomorphological factors on changes in forest cover areas. Since the land productivity score, the land surface altitudes, and the slopes create favorable/unfavorable conditions for agricultural activities that gradually replace forests, complex factor analysis allows for highlighting and identification of these links.

A correlation analysis was performed between changes in forest cover determined using historical GIS and land productivity scores in the elderships while analyzing links between changes in forest cover areas and land productivity scores (Table 13). The following periods were selected: the 19th century–the 1st half of the 20th century, the 1st half of the 20th century–the 2nd half of the 20th century, the 2nd half of the 20th century–the 21st century.

Indicators of correlation analysis:

i—change in forest cover areas in a certain period, m^2;
j—the land productivity score.

Table 13. Results of correlation analysis between land productivity scores and forest cover areas.

	If the Effects of Factors of 2nd Half of the 19th Century-1st Half of the 20th Century Were Maintained		If the Effects of Factors of 1st Half of the 20th Century-2nd Half of the 20th Century Were Maintained		If the Effects of Factors of 2nd Half of the 20th Century-1st Half of the 21st Century Were Maintained	
	r_{ij}	*p*-Value	r_{ij}	*p*-Value	r_{ij}	*p*-Value
Land productivity scores	−0.92	0.00	−0.11	0.25	0.16	0.52

It can be seen from the results of the analysis that there is a statistically significant strong negative correlation between the diminishing of forest cover areas and the productivity score in the first period. In other periods, there are no statistically significant correlations.

During the analysis of the dependence of the change in forest cover areas on the slopes of the land surface in relation to the cardinal directions, the slopes of individual elderships were determined with the help of historical GIS, their reclassification was performed, the data with the slope areas were converted into a table, and a correlation analysis was performed (Table 14).

Indicators of correlation analysis:

i—change in forest cover areas in the corresponding period, m^2;
j—areas of slopes of the land surface in relation to the cardinal directions, m^2.

Table 14. Results of correlation analysis between aspect and changes in forest cover areas.

Aspect, Degree	If the Effects of Factors of 2nd Half of the 19th Century–1st Half of the 20th Century Were Maintained		If the Effects of Factors of 2nd Half of the 19th Century–2nd Half of the 20th Century Were Maintained		If the Effects of Factors of 2nd Half of the 19th Century–1st Half of the 21st Century Were Maintained	
	r_{ij}	*p*-Value	r_{ij}	*p*-Value	r_{ij}	*p*-Value
320–40	−0.35	0.57	−0.38	0.46	−0.42	0.39
40–130	0.40	0.08	0.51	0.04	0.55	0.02
130–240	0.26	0.25	0.23	0.31	0.29	0.22
240–320	−0.42	0.34	−0.43	0.29	−0.52	0.17

The results of the correlation analysis presented in Table 14 show that correlation coefficients of moderate significance were obtained between slopes in the east ($|0.40| \leq r_{ij} \leq |0.55|$) and west (($|0.42| \leq r_{ij} \leq |0.52|$) directions. However, only the correlation coefficients between the change in forest cover areas and the slope of the land surface in the eastern direction have statistical significance ($0.02 \leq p$-value ≤ 0.08).

Jurbarkas District: The angle is 30.8° in the north direction, 18.4% in the south direction, and more or less the same in the west and east directions—20.4% and 20.3% respectively.

The slopes are distributed more or less evenly throughout the district, but the links to them are not the same. GIS visualization of the hydrographic network (Figure 17) shows that it is oriented in the east–west direction. A visual analysis of the old military topographic maps shows that in the 2nd half of the 19th century, it is mostly absent along river banks. Later, this trend is not observed. It can be assumed that the changes in the surface that took place from the 19th century to the 1st half of the 20th century are so great that they overshadow the influence of changes in later years.

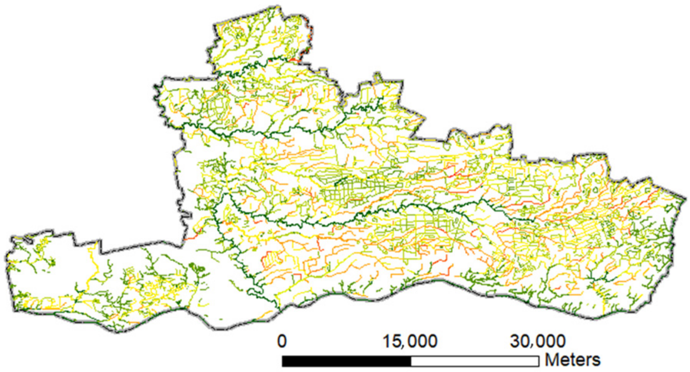


Figure 17. Hydrographic network of Jurbarkas District.

A correlation analysis was performed when analyzing the dependence of the change in forest cover on the altitudes of the land surface (Table 15).

Indicators of correlation analysis:

i—change in forest cover areas in the corresponding period, m^2;

j—areas of altitudes of the land surface, m^2.

Table 15. Results of correlation analysis between altitudes of land surface and changes in forest cover areas.

Elevation of the Earth's Surface	If the Effects of Factors of 2nd Half of the 19th Century–1st Half of the 20th Century Were Maintained		If the Effects of Factors of 2nd Half of the 19th Century–2nd Half of the 20th Century Were Maintained		If the Effects of Factors of 2nd Half of the 19th Century–1st Half of the 21st Century Were Maintained	
	r_{ij}	*p*-Value	r_{ij}	*p*-Value	r_{ij}	*p*-Value
0–10	0.46	<0.01	0.43	<0.01	0.43	<0.01
10–20	0.57	<0.01	0.58	<0.01	0.50	<0.01
20–30	0.44	<0.01	0.48	<0.01	0.40	<0.01
30–40	0.00	0.01	0.06	0.02	0.01	0.02
40–50	−0.44	0.01	−0.40	0.03	−0.42	0.02
50–60	−0.72	0.05	−0.72	0.13	−0.73	0.08
60–70	−0.59	0.05	−0.58	0.11	−0.57	0.08
70–80	−0.29	0.02	−0.21	0.04	−0.17	0.02
80–90	0.11	0.005	0.16	0.01	0.20	0.01
90–100	0.22	<0.01	0.21	0.01	0.22	<0.01

The results of the correlation analysis presented in Table 15 show that correlation coefficients of moderate significance were obtained between the following altitudes of the land surface: 0–30, 40–70 m ($|0.40| \leq r_{ij} \leq |0.73|$) toward directions. However, only the correlation coefficients between the change in forest cover areas and the slope of the land surface in the eastern direction have statistical significance ($0.02 \leq p$-value ≤ 0.08).

Figure 18 shows the map of altitudes of Jurbarkas District correlating/non-correlating with changes in forest cover in the 19th–21st centuries. Areas where weak correlations are observed are marked in blue, and areas where strong correlations are observed are marked in yellow.

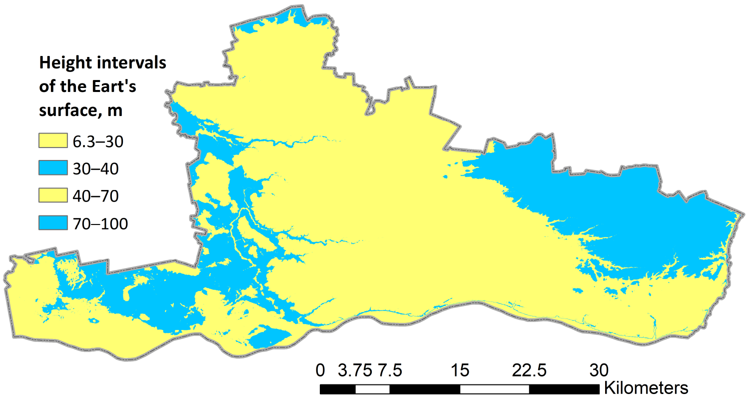


Figure 18. Visualization of correlation analysis of altitudes in Jurbarkas District with forest cover change.

It can be assumed that the altitudes in the eastern part of Jurbarkas District did not have a significant influence on the dynamics of forest areas because wetlands and marshy places that are unattractive for agricultural activities have been there since ancient times; thus, the links of forest cover change are insignificant. Since the reclamation works of national importance were started only in the 2nd half of the 20th century, when there was already a legal framework regulating the use of forest resources, land drainage did not have a significant impact on the reduction in forest areas but increased the areas devoted to agricultural activities. There may be an additional factor in the western part of the district, which can be revealed by additional research.

The slope of the land surface, depending on its size, makes the territory attractive/unattractive for agricultural activities; therefore, a correlation analysis of the dependence of change in forest cover areas on the land slopes was performed (Table 16).

Indicators of correlation analysis:

i—change in forest cover areas in the corresponding period, m^2;
j—areas of slopes of the land surface, m^2.

Table 16. Results of correlation analysis between slopes of land surface and changes in forest cover areas.

Slope Intervals	If the Effects of Factors of 2nd Half of the 19th Century–1st Half of the 20th Century Were Maintained		If the Effects of Factors of 2nd Half of the 19th Century–2nd Half of the 20th Century Were Maintained		If the Effects of Factors of 2nd Half of the 19th Century–1st Half of the 21st Century Were Maintained	
	r_{ij}	*p*-Value	r_{ij}	*p*-Value	r_{ij}	*p*-Value
0–1.00	–0.90	0.04	–0.85	0.02	–0.87	0.03
1.00–3.01	–0.63	0.17	–0.55	0.08	–0.57	0.11
3.01–6.27	–0.53	0.05	–0.44	0.02	–0.47	0.03
6.27–10.53	–0.54	0.03	–0.43	0.01	–0.45	0.02
10.53–15.79	–0.40	0.04	–0.27	0.02	–0.26	0.02
15.79–22.05	–0.16	0.11	–0.02	0.05	0.01	0.05
22.05–29.57	–0.07	0.19	0.06	0.10	0.10	0.09
29.57–39.10	–0.05	0.22	0.06	0.12	0.11	0.11
39.10–66.1	–0.03	0.24	0.08	0.15	0.11	0.14

Correlation analysis revealed that there is a strong inverse relationship between the angle of 0°–1° and the dynamics of forest areas ($|0.85| \leq r_{ij} \leq |0.90|$). This link is statistically significant ($0.02 \leq p\text{-value} \leq 0.04$). The average statistically significant relation is between forest area change and angles of 1°–10.53° ($|0.43| \leq r_{ij} \leq |0.63|$). There is a weak statistically significant relation between the angle of 10.53°–15.79° and the dynamics of forest areas. Larger slopes and forest area change are linked by very weak correlations. It can be assumed that the forest areas decreased in the plains quite significantly, and with an angle steeper than 15.79°, the links between the change in forest areas and the angles are very weak because such territories are not favorable for agricultural activities.

A map is created for the visualization of correlation links with the help of GIS: territories with a small angle (0°–10.53°) that have strong and medium correlations with the dynamics of forest area change are marked in green, those that have weak correlations are marked in yellow, and very weak ones in red (Figure 19). We can see that these are river banks with steep slopes, which make these areas unattractive for agricultural activities.

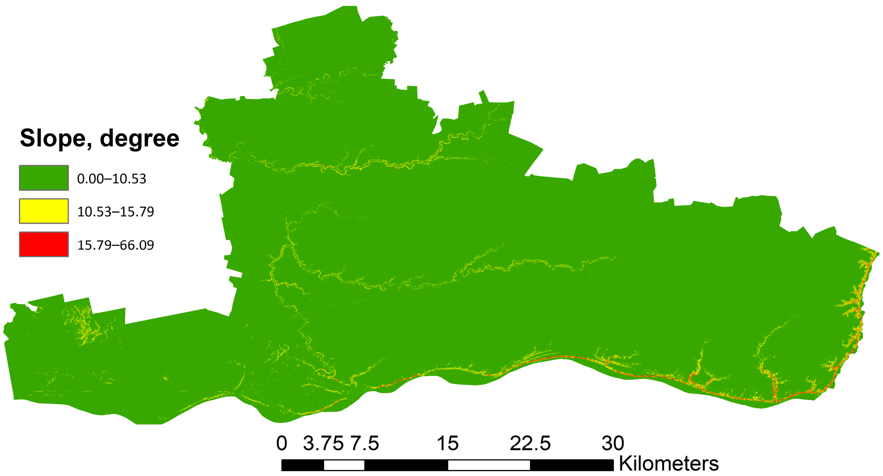


Figure 19. Map of slopes of Jurbarkas District correlating/non-correlating with changes in forest cover in the 19th–21st centuries.

As the study continued, the slopes of the land surface where there is forest cover, were identified using functions of the GIS program. The data were converted into Microsoft Excel tables. Calculations of what percentage of the forest area was made up of certain slopes of land surface in individual administrative units were performed. A correlation analysis was performed as the study of statistical links between slopes and changes in forest areas continued (Table 17). Indicators:

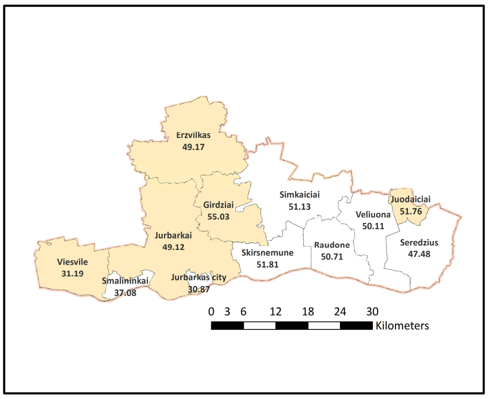
i—share of the area occupied by the forest cover (as a percentage) in the areas with the respective slope;

j—slope of the land surface.

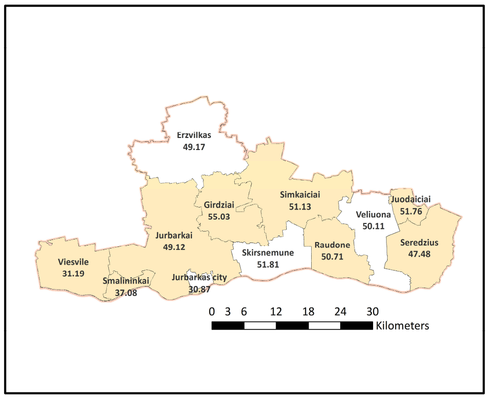
Table 17. Correlation analysis results between slope and forest cover areas.

Elderships	2nd Half of the 19th Century		1st Half of the 20th Century		2nd Half of the 20th Century	
	r_{ij}	*p*-Value	r_{ij}	*p*-Value	r_{ij}	*p*-Value
Eržvilkas	−0.72	0.03	−0.56	0.11	−0.66	0.05
Girdžiai	−0.75	0.02	−0.66	0.05	−0.19	0.63
Juodaičiai	−0.86	0.03	−0.85	0.03	−0.76	0.08
Jurbarkai	−0.91	0.00	−0.92	0.00	0.51	0.16
Jurbarkas city	−0.66	0.05	0.27	0.48	0.05	0.90
Raudonė	−0.59	0.09	0.90	0.00	0.91	0.00
Seredžius	−0.62	0.08	0.69	0.04	0.69	0.04
Skirsnemunė	−0.59	0.09	−0.40	0.29	0.72	0.06
Smalininkai	−0.62	0.08	−0.81	0.01	−0.91	0.00
Šimkaičiai	0.24	0.54	−0.70	0.04	−0.70	0.04
Veliuona	−0.58	0.10	0.22	0.58	0.28	0.47
Viešvilė	0.90	0.00	0.84	0.00	−0.54	0.13
Jurbarkas Distr.	−0.82	0.01	0.02	0.95	0.82	0.01

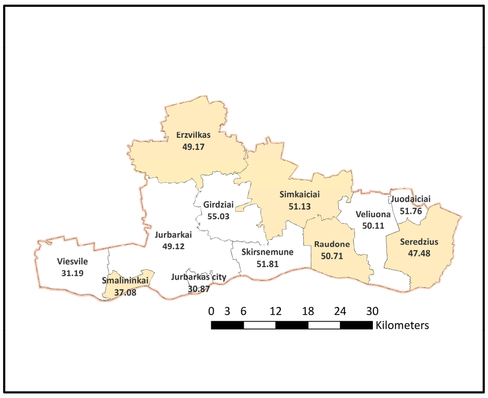
In order to visualize the results of the research, a map of the correlation analysis results was created using the GIS program (Figure 20). It shows the elderships of Jurbarkas District and their soil productivity scores. Elderships with very strong, strong, and moderate correlations and p-values ≤ 0.05 are marked in yellow.



(**a**)



(**b**)



(**c**)

Figure 20. Elderships with very strong, strong, and moderate statistically significant correlations (marked in yellow): (**a**) the 19th century, (**b**) 1st half of the 20th century, (**c**) 2nd half of the 20th century.

Quite different results were obtained when researching the links between forest areas and surface slopes. No statistically significant correlations between indicators were found in the eastern part of Jurbarkas District in the 19th century (Table 17). Figure 20 shows that there are quite strong correlations between the areas of forest cover and the land surface slopes in the elderships located in the western part. Forests grow on plains in almost all of them (with the exception of Viešvilė eldership) because as the slope increases, forest areas decrease. Figure 11 shows that forest cover is mostly absent along the rivers. Viešvilė eldership is unique—a positive correlation is observed in it—the forest areas increase with the increase in the slope of the territory. This eldership is located in another state where a completely different forest management and land management strategy is implemented.

Five elderships balance on the limit of statistical significance ($0.08 \leq p$-value ≤ 0.10), and the correlation coefficients in them vary $|0.58| \leq r_{ij} \leq |0.62|$. Šimkaičiai eldership stands out, with p-value = 0.24.

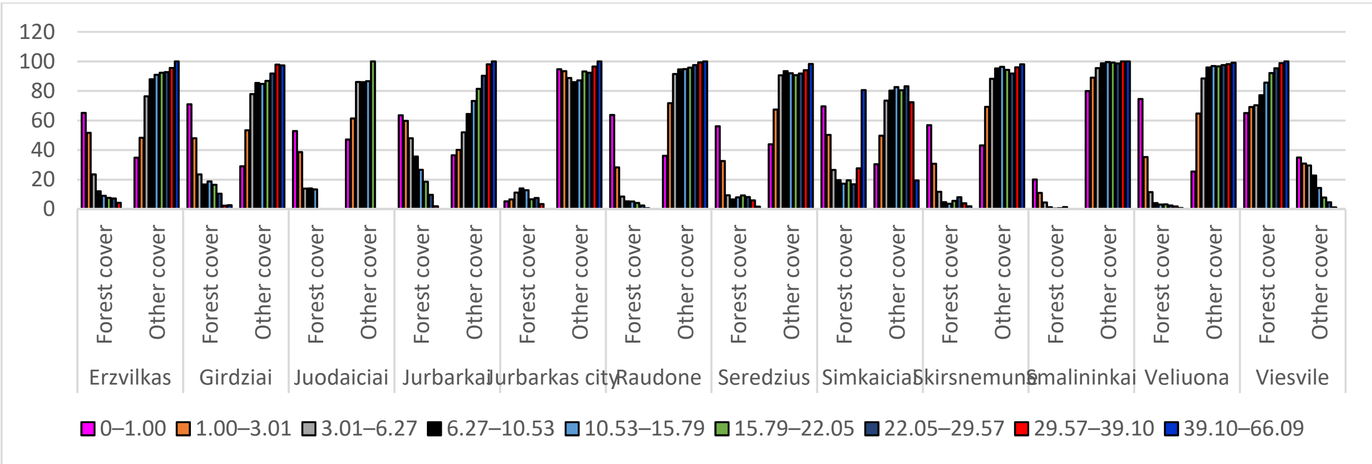
Taking the entire Jurbarkas District for the study, we get r = −0.82, p-value = 0.01. No positive correlation coefficients between forest areas and slopes of the territory were found in the 19th century (except for one eldership, which was in another state). From this, it can be concluded that at that time, agricultural activities did not have a significant impact on the diminishing of forest areas and displacement to territories unsuitable or not very attractive for agricultural activities.

We see a completely different situation in the 1st half of the 20th century (Table 17, Figure 20b). Statistically significant results were obtained in eight out of the twelve elderships: $|0.66| \leq r_{ij} \leq |0.92|$. In three of them, we see positive correlation coefficients. A study of Jurbarkas District shows a correlation of only 0.02 and p-value of 0.95. At that time, the forest change was affected by the deforestation processes that occurred during World War I, which were not focused on agricultural activities; therefore, taking the entire district in general, no links with places favorable for farming and forest cover areas were found. A more detailed examination of individual administrative units (smaller areas of the territory affected by local conditions) revealed links in individual elderships.

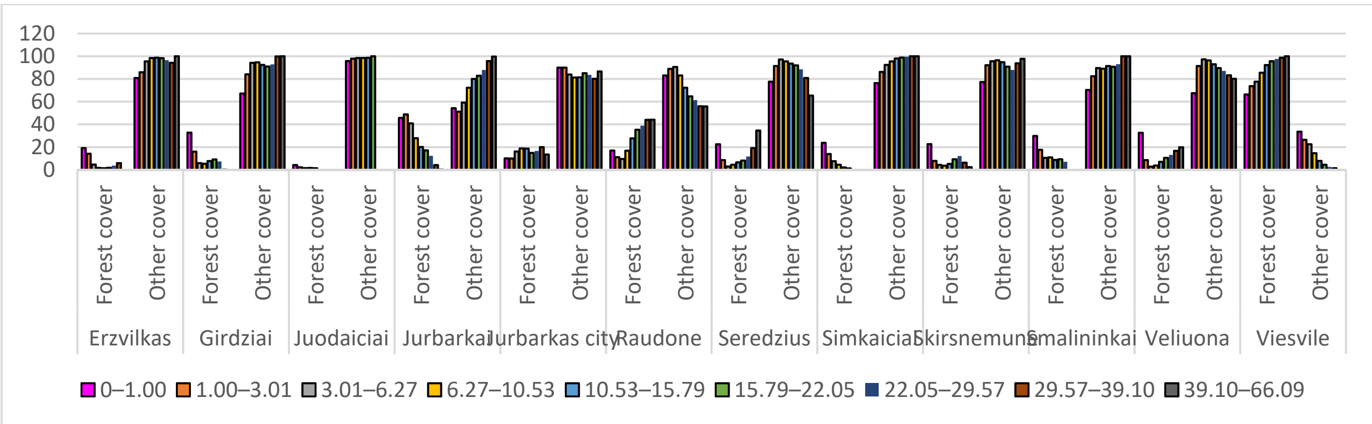
Statistically significant links were established in Jurbarkas District and only in five of the twelve elderships in the 2nd half of the 20th century (Table 17, Figure 20c). Two elderships balanced on the edge of statistical significance ($0.06 \leq p$-value ≤ 0.08). The situation in Jurbarkas District, $r_{ij} = 0.82$, p-value = 0.01, was the complete opposite of that in the 19th century. Taking all elderships as a whole, the area of forest cover increased as the slope of the territory increased.

If we compare the change in the sign of the correlation coefficients, it can be seen that they changed in the 19th–20th centuries—forest areas were affected by the expropriation of lands more favorable for farming, displacing forest areas to areas less favorable for farming. However, with the advent of legal state regulation, forest areas were recorded and their arbitrary cutting and conversion to agricultural land ended.

The distribution of forest cover and non-forest cover in territories with different slopes in the elderships of Jurbarkas District is shown in Figure 21, and the distribution of these covers in the entire Jurbarkas District is presented in Figure 22.

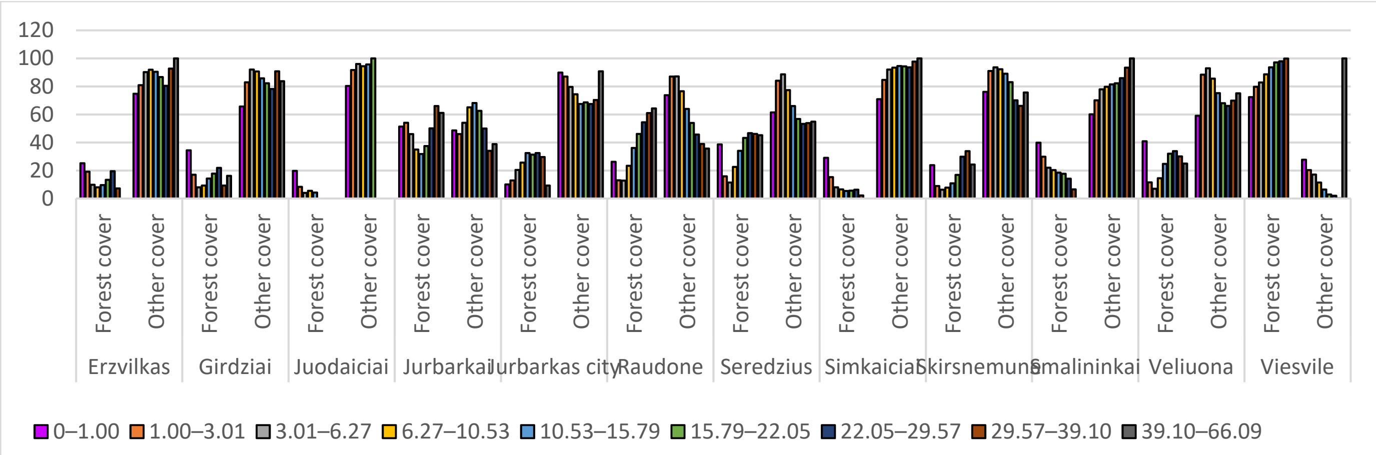


(**a**)



(**b**)

Figure 21. *Cont.*



(**c**)

Figure 21. The ratio of forest cover/non-forest cover in slope ranges in elderships of Jurbarkas District: (**a**) 2nd half of the 19th century, (**b**) 1st half of the 20th century, (**c**) 2nd half of the 20th century.

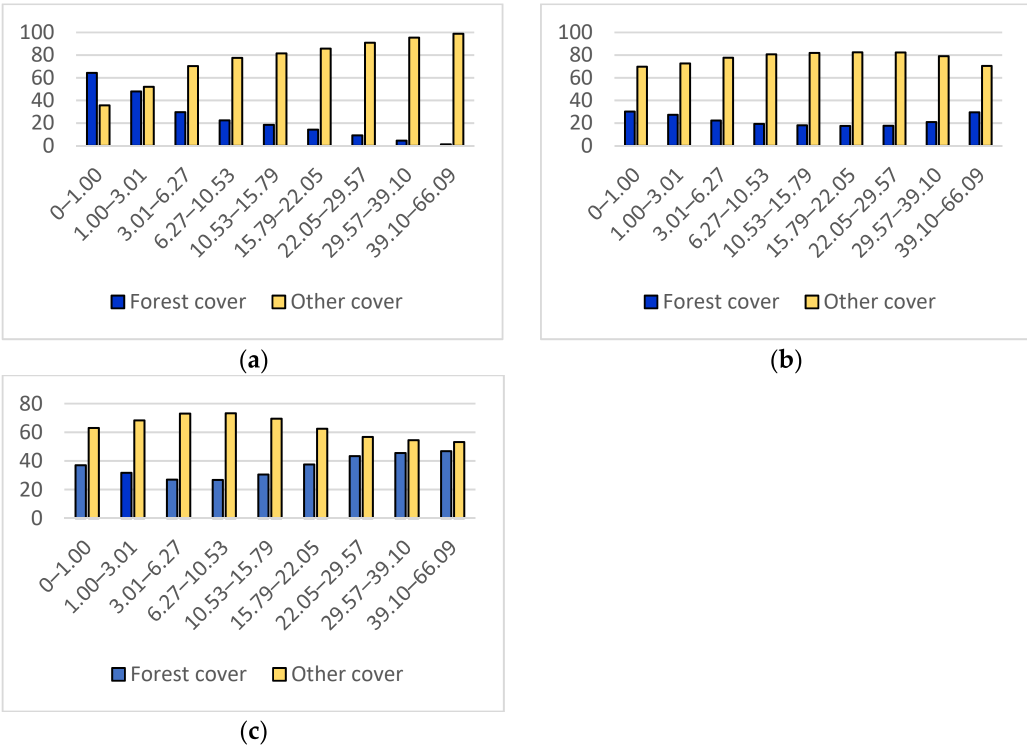


Figure 22. Distribution of forest cover/non-forest cover in Jurbarkas District: (**a**) 2nd half of the 19th century, (**b**) 1st half of the 20th century, (**c**) 2nd half of the 20th century.

3.8. Isolation of Permanent Forest Areas

During the comparison of forest cover areas that were present at different times in GIS program, constant forest cover areas were determined where a forest cover was without any interruptions during the period of 19th–21st centuries. This means that no economic-anthropogenic activity was ever carried out in those areas, and tree massifs grew there throughout the period. Layers of forest cover present at different time periods were uploaded into the ArcGIS software package and permanent forest areas were isolated using the polygon overlay method. The sizes of permanent areas of the area of the eldership (as percentages) are presented in Table 18.

Table 18. Permanent forest areas.

Elderships	Area of Forest, %
Eržvilkas	11.5
Girdžiai	23.1
Juodaičiai	2.2
Jurbarkai	36.6
Jurbarkas city	3.8
Raudonė	11.0
Seredžius	12.2
Skirsnemunė	16.0
Smalininkai	8.9
Šimkaičiai	16.1
Veliuona	23.0
Viešvilė	57.6
Jurbarkas Distr.	22.6

The permanent forest areas in the elderships make up 2.2–57.6% of the area of these elderships. Viešvilės eldership has the largest area—57.6%, and the area in the rest of the elderships ranges from 2.2% to 23.1%. The average is 18.5%.

Permanent forest areas make up 22.6% of the area throughout Jurbarkas District.

The layer of permanent forest areas is divided into polygons according to the attribute data, the age of the trees, by overlaying the cadastral data layer with the use of the ArcGIS program. The applicable age ranges are the same as in Section 2.4. The area of these polygons was calculated (as a percentage) of the total area of permanent growth areas in the elderships (Table 19).

Table 19. Percentages of polygons with corresponding tree age of the total permanent forest cover area.

Age of Trees, in Years	Eržvilkas	Girdžiai	Juodaičiai	Jurbarkai	Jurbarkas City	Raudonė	Seredžius	Skirsnemunė	Smalininkai	Šimkaičiai	Veliuona	Viešvilė	Jurbarkas Distr.
0–5	11.2	7.4	18.1	8.9	3.8	12.3	16.5	12.5	7.9	14	11.8	4.4	9.4
6–9	2.7	5.5	3.8	3	0.2	4.5	4.5	3.0	5.5	5.4	3.9	3	3.6
10–19	15	15.9	11.1	7.5	0	17.6	16.5	13.1	13.4	17.9	11.8	3.8	10.5
20–39	20.4	31.2	19.7	19.7	0	24	16.1	32.2	27.4	22.2	23.2	10.4	20.0
40–59	5.3	14.3	9.6	9.4	1.2	15	8.1	19.5	9.5	7.9	20.5	15	12.0
60–79	17.4	15.7	13	16.2	6.6	13.8	15.5	11.5	14.4	14.3	14.8	34.8	19.4
80–99	22.5	5.7	23.7	19.5	18.7	9.8	18.8	6.1	8.1	15.6	12.7	12.6	15.2
100–119	4.7	3.9	1.1	11.5	30.8	2.3	3.2	1.7	10.5	2.7	0.6	10.4	7.2
120–139	0.7	0.2	-	3.4	1.8	0.6	0.8	0.3	2.7	-	0.1	4	2.1
140–159	-	-	-	0.6	36.9	-	-	-	0.1	-	0.5	1.1	0.5
160–179	-	0.1	-	0.2	-	-	-	-	0.4	-	-	0.4	0.2
180 and more	-	0.1	-	-	-	-	-	-	-	-	-	-	-

Analysis of the obtained data shows that an urbanized area—the City of Jurbarkas—stands out in the obtained results. It is dominated by areas of trees older than 80 years old in its permanent growth areas. This can be explained by the fact that mature trees were preserved in the city, but new areas were not planted, using city areas for other purposes. A fairly clear process of felling/planting of forest trees can be seen in the non-urbanized areas—trees 0–5 years old account for as much as 4.4–18.1% of the total area of growth areas. Bearing in mind that such changes took place over a period of 5 years, it can be said that quite intensive deforestation is taking place. If Viešvilė eldership is eliminated from the research results, which, like the urbanized territory of the City of Jurbarkas, stands out from the general trends, the deforestation in the permanent growth areas over the last 5 years amounts to 7.4–18.1%. It is interesting that in the age group of 6–9 years, no such large areas of former logging were observed. The area of trees of this age is only 0.2–5.5%.

Further examination of the distribution of forest areas according to the age of the trees growing in them shows that the largest areas of permanent forest cover are in age groups of 10–99 years. The areas of planted/grown trees make up 0–27.4% of the total forest cover area during these periods. If you eliminate the City of Jurbarkas, as an urbanized area that was influenced by factors other than those affecting nonurbanized areas, this percentage is 5.3–27.4%. Forest areas of the remaining age groups are much smaller, and the areas of older trees account for 0.1–11.5% (after eliminating the urbanized area).

The identified areas of permanent forest cover in the elderships are 4.3–85.5% of the forest areas that were present in the 19th century (Table 20).

Table 20. The area of permanent forest cover of forest areas of the 19th century, %.

Elderships	The Area of Permanent Forest Cover, %
Eržvilkas	19.7
Girdžiai	34.3
Juodaičiai	4.3
Jurbarkai	53.6
Jurbarkas city	43.7
Raudonė	20.3
Seredžius	27.2
Skirsnemunė	34.1
Smalininkai	62.8
Šimkaičiai	24.4
Veliuona	36.7
Viešvilė	85.5
Jurbarkas Distr.	38.1

There is quite a clear difference between the elderships that were previously in different states. The largest areas of permanent forest cover have remained in the elderships of Smalininkai and Viešvilė. Also, a considerable permanent cover area remained in the urbanized area (City of Jurbarkas). The average area of this cover is 28.3% in the rest of the elderships. Juodaičiai eldership, where the biggest diminishing in the area of forest cover took place during the studied period, stands out.

The visualization of permanent forest areas in the elderships and Jurbarkas District is presented in Figures 23 and 24.

Figure 23. Permanent areas of forest cover in elderships of Jurbarkas District: (**1**) Eržvilkas, (**2**) Girdžiai, (**3**) Juodaičiai, (**4**) Jurbarkai, (**5**) Jurbarkas City, (**6**) Raudonė, (**7**) Seredžius, (**8**) Šimkaičiai, (**9**) Skirsnemunė, (**10**) Smalininkai, (**11**) Veliuona, and (**12**) Viešvilė.

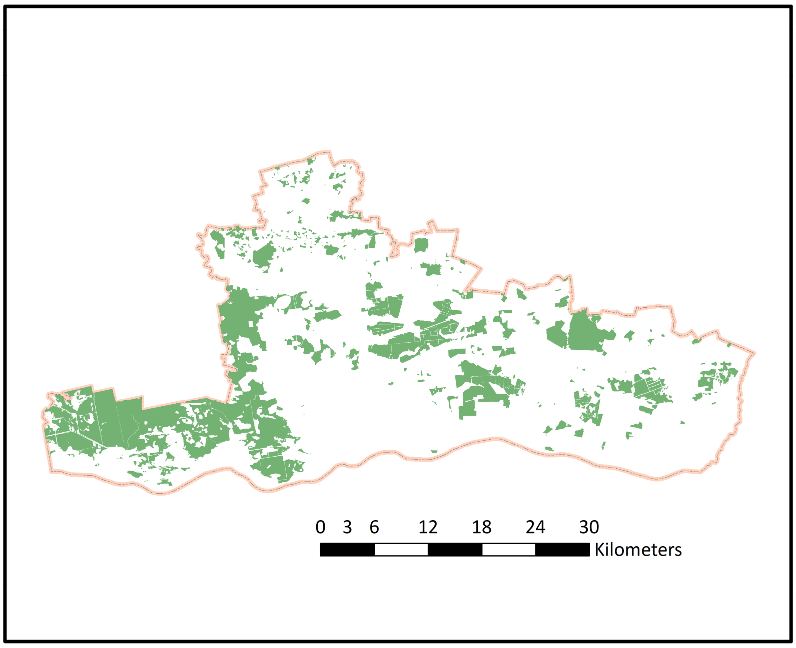


Figure 24. Permanent areas of forest cover in Jurbarkas District.

4. Discussion

4.1. Dynamics of Forest Cover

The dynamics of the forest cover in individual elderships during the studied period from the 2nd half of the 19th century to the 21st century were similar in size and direction, which means that the change in forest cover everywhere was influenced by the same factors that were determined by the period. There is a clear difference between the dynamics of forest cover in elderships from different states. Since the time these elderships were included in the composition of one state (1st half of the 20th century), this difference has disappeared and the direction and extent of forest cover changes are similar in all elderships of Jurbarkas District. However, the changes that took place from the 19th century to the 1st half of the 20th century were so great that when studying the change in forest cover not over separate periods arranged in chronological order but over longer, generalized intervals of time, these changes were not compensated by the reverse change in forest cover that took place later.

Forest areas (as a percentage of the area of elderships) and the decrease/increase in forest areas during the periods in question (Figure 25) present fairly uniform trends in forest cover loss until the 1st half of the 20th century; however, quite different are trends of the increase in forest cover from the 1st half of the 20th century to the 2nd half of the 20th century.

Three elderships stand out when analyzing the change in forest cover (as a percentage of the former forest cover area): Jurbarkas, Smalininkai, and Viešvilė. The City of Jurbarkas is an urbanized area, and the land areas there are affected by different processes than lands suitable for agriculture. The elderships of Smalininkai and Viešvilė are distinguished by the increase in forest areas. It can be assumed that they were affected by different processes than the rest of the elderships due to their geographical location and topographical and geomorphological factors. These two elderships have the lowest land productivity score, and they belonged to another state with a different forest management policy. Also, they were behind the front line for most of the time during World War I. This statement can be proven with the help of historical GIS, by uploading all the data, performing a complex statistical analysis, and analyzing the results. After visually analyzing the geographically oriented areas of forest cover presented in GIS, it can be seen that former forest areas could be maintained only in the territory belonging to the Kingdom of Prussia and on its border, while elsewhere, they were diminishing drastically.

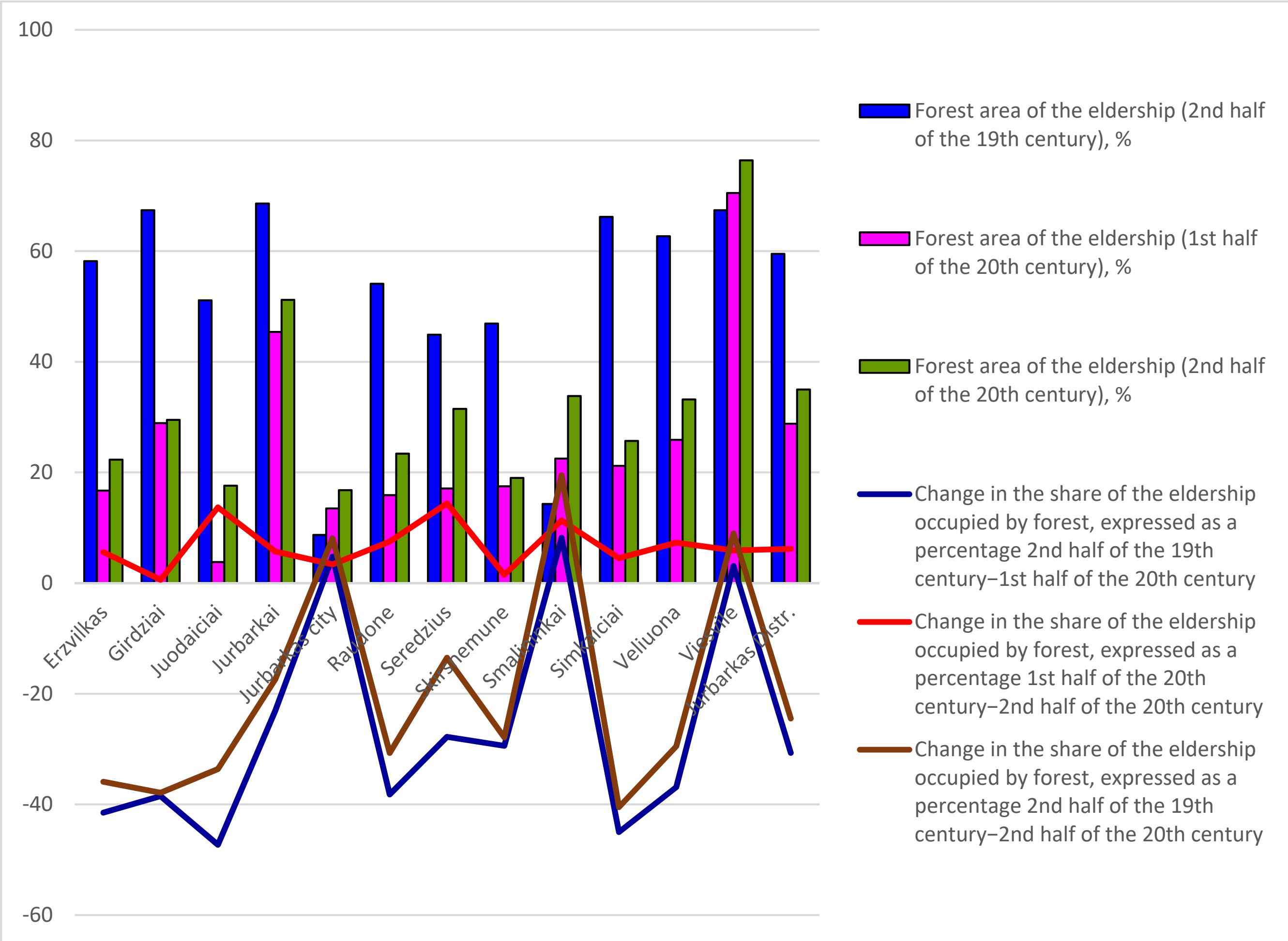


Figure 25. Forest areas present during the 19th–20th centuries.

In Jurbarkas District, 49.6% of forest areas were lost from the 19th century to the 1st half of the 20th century, but the forest cover area increased by 21.7% from the 1st half of the 20th century to the 2nd half of the 20th century. However, from the 2nd half of the 20th century to the 21st century, it diminished by 3%. Taking the 19th–21st centuries as a whole, the area of forest cover decreased by 40.4%; therefore, it can be concluded that from the 1st half of the 20th century to the 2nd half of the 20th century, the increase in forest cover did not compensate for the shrinking that had taken place until then, and part of it was irretrievably lost. A very optimistic scenario is observed in some elderships when analyzing the change in forest cover from the former forest area (Table 10) when the forest cover increased by more than 350%; in others, it is pessimistic because it decreased by more than 60%. However, the results must be viewed in a complex way, by analyzing the dynamics of the cover area of the cover and administrative areas together (Tables 9 and 10) and by evaluating GIS-created maps visually (Figures 10 and 12). The change in forest cover from the forest area, when analyzed separately, does not reflect the size of forest areas, only their dynamics in relation to it. This is valuable information, but it can be quite misleading if other factors are not taken into account. Figure 26 shows the substantiation of this statement with the example of Juodaičiai eldership.

It can be seen that the forest area was quite large in the 19th century and occupied 49.8% (over 1500 ha) of the area of the eldership. The estimated 92.3% of the total forest area was lost by the 1st half of the 20th century and the forest occupied 3.8% of the eldership area. The area of the forest increased by as much as 359.4% from the former area (it reached over 500 ha) from the 1st half of the 20th century to the 2nd half of the 20th century, and the forest cover made up 17.6% of the area of the eldership. Thus, with an increase in forest cover by more than 300% with respect to the forest area, this seemingly large increase is not significant with respect to the eldership area.

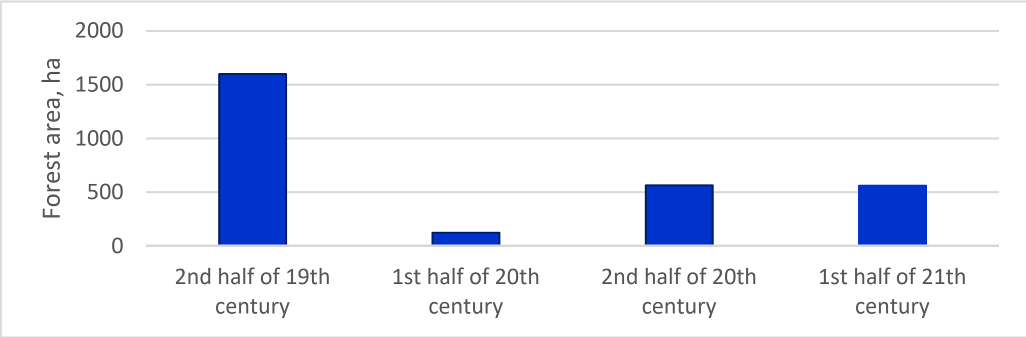


Figure 26. Dynamics of the forest cover area in the 19th–21st centuries.

Analysis of the 19th-century maps shows that the boundaries of forests are natural, not limited by the outlines of geometric shapes. The boundaries of the forests acquired rather strict outlines in the 1st and 2nd halves of the 20th century; the increasing influence of anthropogenic impact on forest areas and the outlines of their boundaries can be seen.

The areas of felling are recorded in the maps only during a certain time, and as can be seen from the analysis of the expansion/diminishing of forest areas, they do not reflect the entire trend of forest area change. This is especially evident when forest areas diminished in a very short period of time (during World War I). However, this information makes it possible to observe the trends of forest destruction/planting over the period being documented—a general analysis of the change in forest areas and studying forest areas documented at a certain moment allows us to see how much they have expanded or diminished. The areas of forest felling documented at a certain time allow us to observe the felling that took place at that time and to draw conclusions as to whether the forests were intensively felled at that time. A complex analysis of forest trees by age can also help understand these trends. The forest areas determined from the maps and their dynamics allow us to say that there would not have been any forest left in Jurbarkas District around 2006 if felling had continued at the same pace as in the 19th century–1st half of the 20th century.

Lithuania was affected by factors of external origin, which led to the fact that at a certain point in the 1st half of the 20th century, the rate of destruction of forest cover areas increased sharply, and the largest increase in forest areas occurred in the middle of the 20th century, not in the 21st century, when the EU took measures to manage climate change processes. No changes in legislation or green course-oriented policy guidelines for the 21st century led to such a large increase in forest areas as turmoil, population decline, and abandonment of areas previously used for agriculture that took place in the middle of the 20th century. These trends are characteristic of Eastern European countries, which were affected by the same political processes [50,59]. After analyzing the data and maps, it can be concluded that the current forest areas with minor changes were inherited from the 2nd half of the 20th century.

Eastern Europe also experienced a series of social, economic, and institutional upheavals in the 20th century, including revolutions, wars, and the rise and fall of the Soviet Union, all of which led to major changes in land use. Therefore, the factors influencing the change in forest cover in the region, due to the major political, and socioeconomic changes that have taken place in the region, are somewhat different in their impact from those in Western Europe [61]:

1. The main factor of forest cover change in ancient times was the activities of anthropogenic origin and attractive areas for agriculture. The decline of forests is associated with the volume of areas suitable for agricultural activities [10,13,36,38,45,47,48,54,62].

2. Social changes (the decrease in the number of inhabitants due to the ongoing repressions was one of the factors that led to the increase in forest areas after the Soviet occupation) [59].

3. Geographical position (in the case of East Europe, short distances to paper and timber factories in Scandinavia and Poland).

4. Economic policy of the country (e.g., trade liberalization after joining the European Union) [63].

5. Political system (for example, expropriation of land, land restitution, market opening, etc.) [63].

6. Demand for wood [60].

7. Environmental and forest protection policy implemented by the state. Restrictions focused on the preservation of forest areas, i.e., logging restrictions in the country preserve forest areas but create a higher demand for forest imports.

8. In Eastern Europe, forest areas are also affected by the pace of forest privatization [63].

Forecasts are more demonstrative in nature when analyzing the speed of forest cover area dynamics. However, in the case of uniform planned or illegal deforestation, in the absence of state control or in the presence of a certain state policy, this methodology allows us to predict the diminishing of forest areas without changing the influencing factors, and it also allows us to carry out future-oriented monitoring of changes in forest areas. It is possible to predict forest cover areas in the future under the influence of one or another factor that leads to a certain predictable increase/decrease in the cover as the European Union is engaged in the policy focused on managing climate change. This forecasting can also be carried out in territories where there is a problem of mass deforestation—such monitoring can be carried out by conducting the study and forecasts of the change in tropical forest areas.

To sum up the change in forest cover, it can be said that the lands freed from forest cover were occupied by agricultural lands. This factor allows us to assume that the former forest areas will not be restored if the situation does not change.

4.2. Features of the Combined Application of Historical GIS and Statistical Methods for Monitoring, Planning, and Preservation of Forest Cover Dynamics

The use of historical GIS allows us to obtain geographically oriented data about objects and phenomena that are recorded in time and cartographic material. It helps create an image of the past situation, collect data, and analyze them both by applying various analysis methods and visually. Combined application of different analysis methods, using various data, fully reveals the dynamics of the phenomenon, its trends, and links between various processes and geomorphological, topographic, and other parameters. Historical GIS allows us to compare past processes with current ones, monitor changes, and visualize possible forecasts.

It is important to take into account possible topographical measurements, cartographic errors, scales, and degrees of generalization, which may cause differences in data accuracy when using cartographic material. However, it should be borne in mind that micro-changes do not have a significant impact on the study when examining large areas [50]. The old maps provide an indicative picture of the forests at that time and allow for a general assessment of the former forest cover areas in the region [36,38].

The application of historical GIS provides an opportunity to compare the impact of different forest management policies on the development of forest cover areas. According to the results of the analysis, the forest protection policy or absence of it, even a century and a half ago, and its change over time have an influence on what forest areas we have today. It can be seen that in this case, long-term factors have a greater impact than short-term ones.

Historical GIS makes it possible to understand the "migration" of forest areas in space and its links to the geomorphological indicators of the territory and to distinguish places where no economic anthropogenic activity was carried out over time and where forest cover was always present. Only 38% of the forest cover was permanent and did not "migrate" in

Jurbarkas District. About 62% of the forest cover grows in different places than it did in the 19th century or was cut during that time; agricultural activities were carried out in those lands and the forest cover recovered/was restored there only under certain circumstances.

It would be useful to study larger areas, highlighting the factors affecting forest cover through the use of historical GIS methods and combining them with spatial and statistical analysis. However, this analysis is often complicated by the difficulty of determining the initial data due to the lack of cartographic material—i.e., in certain cases, it is difficult to determine the initial data in terms of time and resources as only low-quality cartographic material, which complicates automatic vectorization, remains.

5. Conclusions

The area of forest cover depends on various factors, but over recent centuries, it has been most influenced by anthropogenic activities. In order to understand the extent of this impact, monitoring of cover change is required. The use of old maps is the only possibility to obtain spatially oriented data on the land covers, which have changed irreversibly over the years. The integration of historical GIS into the research provides an opportunity to comprehensively use data sources created at different times and in different coordinate systems: cartographic material, remote survey results, and databases. This provides an opportunity to model the geomorphological parameters of the surface, perform the analysis of created vector and raster models, and apply statistical analysis. This complex approach allows us to see the interdependencies and trends in forest cover change.

Geomorphological parameters in Jurbarkas District are favorable for agricultural activities. The land productivity score of this district is one of the highest in the Republic of Lithuania. Only two of the twelve elderships fall into the group of medium or not very fertile soils. The change in the altitude of the land surface occurs evenly, and the values of the altitudes vary within the range of 8–92 m. Sudden changes in altitudes are recorded only on the banks of rivers. A total of 99% of the area is favorable for agricultural activities in terms of angles. Almost 42% of the angles is in the south direction. It can be seen that the selected territory is favorable for agricultural activities, which, based on the results of research by other authors, is directly related to the diminishing of forest areas. However, the territory is crossed by the border between two states, with large areas of forest since the old times on both sides of it and conditions that are not very favorable for agricultural activities.

The areas of forest cover in the 19th century were the largest during the entire studied period. They occupied about 60% of the entire territory in Jurbarkas District. The research results show that the most intensive processes of the diminishing of forest cover areas took place in the 19th century–1st half of the 20th century when the forest cover was lost at a rate of 635 ha/year. It occupied 28.7% of the entire area of the district in the 1st half of the 20th century. An increase in forest cover at a rate of 206 ha/year was observed as a result of the great socioeconomic changes that took place after World War II when there was an increase in uncultivated lands. Forest cover accounted for 34.9% of the area of the district in the 2nd half of the 20th century. Since then, its area practically remained the same—it decreased slightly, at a rate of 45.7 ha/year. It occupied 33.9% of the area of the district in the 1st half of the 21st century. The drastic diminishing of forest cover that took place in the 1st half of the 20th century was not compensated for by the growth of this cover that took place in the 2nd half of the 20th century. Currently, the existing forest cover areas actually coincide with the forest cover areas present during the 1st half of the 20th century.

Studying the areas of forest cover present in different states in the past and establishing links with the geomorphological indicators of the territory show that these factors have influence—the area change in different states and territories with different geomorphological factors took different directions and happened at different rates. After the territory was included in the composition of one state and the impact of the same socioeconomic changes began, the trends of forest area change became similar.

Jurbarkas District is dominated by forest areas comprising trees from 0 to 99 years of age. Forest areas with 100-year-old and older trees are insignificant and make up only 5.4% of the forest area. Permanent forest areas where tree cover grew during the entire studied period reach 22.6% in Jurbarkas District. They have forest areas with trees older than 100 years, making up 10% of the area.

The use of historical GIS technology has made it possible to work with data from different sources in a single coordinate system. It allowed for analysis, visualization of results, and data extraction for further research in a non-GIS environment. The results obtained show that the highest forest cover was in the 19th century and the lowest in the first half of the 20th century. The rate of change in forest cover allowed for a prediction of the complete disappearance/doubling of the forest cover provided that the factors influencing it remained unchanged. Over time, a 'crowding out' of the forest into areas less favorable to agricultural activity and with a higher slope has been observed.

Further research, involving more factors, could be carried out to investigate the influence of the following factors: past policies on forest management, population, agriculture, etc. on the upward/downward trends in forest cover. Studies can also be carried out on the amount of CO_2 accumulated in former forests: how much would be accumulated if the former forest areas were preserved or if the smallest forest areas identified in the research were preserved.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16114825/s1. A list of all software and packages used.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The datasets used or analyzed during the current study are available from the corresponding author upon reasonable request.

Acknowledgments: The author of this article would like to thank the Department of Geodesy and Cadaster, Vilnius Gediminas Technical University, for their support.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Strandberg, G.; Kjellström, E. Climate Impacts from Afforestation and Deforestation in Europe. *Earth Interact.* **2019**, *23*, 1–27. [CrossRef]
2. Gorte, R.W.; Sheikh, P.A. *Deforestation and Climate Change. CRS Report for Congress*; Congressional Research Service: Washington, DC, USA, 2010; pp. 1–41. Available online: https://www.nationalaglawcenter.org/wp-content/uploads/assets/crs/R41144.pdf (accessed on 28 March 2024).
3. Lawrence, D.; Vandecar, K. Effects of tropical deforestation on climate and agriculture. *Nat. Clim. Chang.* **2015**, *5*, 27–36. [CrossRef]
4. Kaima, D.; Kozak, J.; Kolecka, N.; Ziółkowska, E.; Ostafin, K.; Ostapowicz, K.; Gimmi, U.; Munteanu, C.; Radeloffc, V.C. Broad scale forest cover reconstruction from historical topographic maps. *Appl. Geogr.* **2016**, *67*, 39–48. [CrossRef]
5. Vandergert, P.; Newell, J. Illegal logging in the Russian Far East and Siberia. *Int. For. Rev.* **2003**, *5*, 303–306. [CrossRef]
6. Achard, F.; Eva, H.D.; Stibig, H.-J.; Mayaux, P.; Gallego, J.; Richards, T.; Malingreau, J.-P. Determination of Deforestation Rates of the World's Humid Tropical Forests. *Science* **2002**, *297*, 999–1002. [CrossRef] [PubMed]
7. Keenan, J.; Reams, G.A.; Achard, F.; de Freitas, J.V.; Grainger, A.; Lindquist, E. Dynamics of global forest area: Results from the FAO Global Forest Resources Assessment 2015. *For. Ecol. Manag.* **2015**, *352*, 9–20. [CrossRef]
8. Lewis, S.L.; Edwards, D.P.; Galbraith, D. Increasing human dominance of tropical forests. *Science* **2015**, *349*, 827–832. [CrossRef] [PubMed]
9. Hansen, M.C.; Wang, L.; Song, X.-P.; Tyukavina, A.; Turubanova, S.; Potapov, P.V.; Stehman, S.V. The fate of tropical forest fragments. *Sci. Adv.* **2020**, *6*, 1–9. [CrossRef] [PubMed]
10. Zgłobicki, W.; Gawrysiak, L.; Baran-Zgłobicka, B.; Telecka, M. Long-term Forest cover changes, within an agricultural region, in relation to environmental variables, Lubelskie province, Eastern Poland. *Environ. Earth Sci.* **2016**, *75*, 1373. [CrossRef]
11. Fuchs, R.; Herold, M.; Verburg, P.H.; Clevers, J.G.P.W. A high-resolution and harmonized model approach for reconstructing and analysing historic land changes in Europe. *Biogeosciences* **2013**, *10*, 1543–1559. [CrossRef]

12. Johann, E. Forest History in Europe. In *Biological Resources and Migration*; Werner, D., Ed.; Springer: Berlin/Heidelberg, Germany, 2004.
13. Kaplan, J.O.; Krumhardt, K.M.; Zimmermann, N. The prehistoric and preindustrial deforestation of Europe. *Quat. Sci. Rev.* **2009**, *28*, 3016–3034. [CrossRef]
14. Kalyakin, V.N.; Smirnova, O.V.; Bobrovskii, M.V.; Turubanova, S.A.; Potapov, P.V.; Yaroshenko, A.Y. History of the Eastern European forest cover. *For. East. Eur.* **2004**, *15*, 515–536.
15. Cvetkov, M.A. *Change in Forest Cover in European Russia from the End of the 17th Century to 1914*; USSR Academy of Sciences Publishing House: Moscow, Russia, 1957; p. 212. (In Russian)
16. Oprsal, Z.; Šarapatka, B.; Kladivo, P. Land-use changes and their relationships to selected landscape parameters in the cadastral areas in Moravia (Czech Republic). *Morav. Geogr. Rep.* **2013**, *21*, 41–50. [CrossRef]
17. Galloway, P.R. Secular changes in the short-term preventive, positive, and temperature checks to population growth in Europe, 1460 to 1909. *Clim. Chang.* **1994**, *26*, 3–63. [CrossRef] [PubMed]
18. McKeown, T.; Brown, R.G.; Record, R.G. An interpretation of the modern rise of population in Europe. *J. Demogr.* **2011**, *26*, 345–382. [CrossRef]
19. Kaplan, J.O.; Krumhardt, K.M.; Gaillard, M.-J.; Sugita, S.; Trondman, A.-K.; Fyfe, R.; Marquer, L.; Mazier, F.; Nielsen, A.B. Constraining the Deforestation History of Europe: Evaluation of Historical Land Use Scenarios with Pollen-Based Land Cover Reconstructions. *Land* **2017**, *6*, 91. [CrossRef]
20. Brouwer, F.M.; Thomas, A.J.; Chadwick, M.J. *Land Use Changes in Europe: Processes of Change, Environmental Transformations and Future Patterns*; Springer Science and Business Media: Berlin/Heidelberg, Germany, 2012; p. 529.
21. Fuchs, R.; Herold, M.; Verburg, P.H.; Clevers, J.G.P.W.; Eberle, J. Gross changes in reconstructions of historic land cover/use for Europe between 1900–2010. *Glob. Chang. Biol.* **2014**, *21*, 299–313. [CrossRef]
22. Lithuanian Foresters' Union. *Southern Lithuania in the Description of Gregorian Valavičius' 1599 Lithuanian Woods*; Lithuanian Foresters' Union in the Diaspora: Chicago, IL, USA, 1964; p. 62. (In Lithuanian)
23. Gaillard, M.-J.; Sugita, S.; Mazier, F.; Trondman, A.-K.; Brostrom, A.; Hickler, T.; Kaplan, J.O.; Kjellstrom, E.; Kokfelt, U.; Kuneš, P.; et al. Holocene land-cover reconstructions for studies on land cover-climate feedbacks. *Clim. Past* **2010**, *6*, 483–499. [CrossRef]
24. Tinganelli, L.; Erlendsson, E.; Eddudóttir, S.D.; Gísladóttir, G. Impacts of climate, tephra and land use upon Holocene landscape stability in Northwest Iceland. *Geomorphology* **2018**, *322*, 117–131. [CrossRef]
25. West, R.G. Pleistocene Forest history in East Anglia. *New Phytol.* **1980**, *85*, 571–622. [CrossRef]
26. Fyfe, R.M.; Woodbridge, J.; Roberts, N. From forest to farmland: Pollen-inferred land cover change across Europe using the pseudobiomization approach. *Glob. Chang. Biol.* **2014**, *21*, 1197–1212. [CrossRef] [PubMed]
27. He, F.; Ge, Q.; Dai, J.; Rao, Y. Forest change of China in recent 300 years. *J. Geogr. Sci.* **2008**, *18*, 59–72. [CrossRef]
28. Čarni, A.; Jarnjak, M.; Oštir-Sedej, K. Past and present forest vegetation in NE Slovenia derived from old maps. *Appl. Veg. Sci.* **1998**, *1*, 253–258. [CrossRef]
29. Jaworek-Jakubska, J.; Filipiak, M.; Michalski, A.; Napierała-Filipiak, A. Spatio-Temporal Changes of Urban Forests and Planning Evolution in a Highly Dynamical Urban Area: The Case Study of Wrocław, Poland. *Forests* **2020**, *11*, 17. [CrossRef]
30. Loran, C.; Ginzler, C.; Bürgi, M. Evaluating Forest transition based on a multi-scale approach: Forest area dynamics in Switzerland 1850–2000. *Reg. Environ. Chang.* **2016**, *16*, 1807–1818. [CrossRef]
31. Marull, J.; Tello, E.; Wilcox, P.T.; Coll, F.; Pons, M.; Warde, P.; Valldeperas, N.; Oll, A. Recovering the landscape history behind a Mediterranean edge environment (The Congost Valley, Catalonia, 1854–2005): The importance of agroforestry systems in biological conservation. *Appl. Geogr.* **2014**, *54*, 1–17. [CrossRef]
32. Ostafin, K.; Iwanowski, M.; Kozak, J.; Cacko, A.; Gimmi, U.; Kaim, D.; Psomas, A.; Ginzler, C.; Ostapowicz, K. Forest cover mask from historical topographic maps based on image processing. *Geosci. Data J.* **2017**, *4*, 29–39. [CrossRef]
33. Popelkova, R. Changes in woodland cover in the Karvina district from the second half of the 18th century to the beginning of the 21st century. *Ekologia* **2018**, *37*, 134–151. [CrossRef]
34. Raet, J.; Sepp, K.; Kaasik, A. Assessment of changes in forest coverage based on historical maps. *For. Stud. Metsanduslikud Uurim.* **2008**, *48*, 67–78. [CrossRef]
35. Shen, D.; Dong, S. Transition of Urban Morphology in the Mountainous Areas Since Early-Modern Times from the Perspective of Urban Historic Landscape—A GIS Tools and Historical Map Translation Approach. *Sustainability* **2022**, *14*, 12896. [CrossRef]
36. Šantrůčková, M.; Dostálek, J.; Demková, K. Assessing long-term spatial changes of natural habitats using old maps and archival sources: A case study from Central Europe. *Biodivers. Conserv.* **2015**, *24*, 1899–1916. [CrossRef]
37. Skokanová, H.; Havlíček, M.; Borovec, R.; Demek, J.; Eremiášová, R.; Chrudina, Z.; Mackovčin, P.; Rysková, R.; Slavík, P.; Stránská, T.; et al. Development of land use and main land use change processes in the period 1836–2006: Case study in the Czech Republic. *J. Maps* **2012**, *8*, 88–96. [CrossRef]
38. Stanga, I.C.; Niacsu, L. Using old maps and soil properties to reconstruct the forest spatial pattern in the late 18th century. *Environ. Eng. Manag. J.* **2016**, *15*, 1–21.
39. Godet, L.; Thomas, A. Three centuries of land cover changes in the largest French Atlantic wetland provide new insights for wetland conservation. *Appl. Geogr.* **2013**, *42*, 133–139. [CrossRef]
40. Gosheva, S.; Walthert, L.; Niklaus, P.A.; Zimmermann, S.; Gimmi, U.; Hagedorn, F. Reconstruction of Historic Forest Cover Changes Indicates Minor Effects on Carbon Stocks in Swiss Forest Soils. *Ecosystems* **2017**, *20*, 1512–1528. [CrossRef]

41. Bicik, I.; Jeleček, L. Land use and landscape changes in Czechia during the period of transition 1990–2007. *Geography. J. Czeh Geogr. Soc.* **2009**, *114*, 263–281.
42. González-Puente, M.; Campos, M.; McCall, M.K.; Muñoz-Rojas, J. Places beyond maps; integrating spatial map analysis and perception studies to unravel landscape change in a Mediterranean mountain area (NE Spain). *Appl. Geogr.* **2014**, *52*, 182–190. [CrossRef]
43. Jawarneh, R.N.; Julian, J.P. Development of an accurate fine-resolution land cover timeline: Little Rock, Arkansas, USA (1857–2006). *Appl. Geogr.* **2012**, *35*, 104–113. [CrossRef]
44. Orczewska, A. Age and Origin of Forests in South-western Poland and their Importance for Ecological Studies in Man-dominated Landscapes. *Landsc. Res.* **2009**, *34*, 599–617. [CrossRef]
45. Skaloš, J.; Engstová, B. Methodology for mapping non-forest wood elements using historic cadastral maps and aerial photographs as a basis for management. *J. Environ. Manag.* **2010**, *91*, 831–843. [CrossRef]
46. Skaloš, J.; Weber, M.; Lipský, Z.; Trpáková, I.; Šantrůčková, M.; Uhlířová, L.; Kukla, P. Using old military survey maps and orthophotograph maps to analyse long-term land cover changes—Case study (Czech Republic). *Appl. Geogr.* **2011**, *31*, 426–438. [CrossRef]
47. Wulf, M.; Sommer, M.; Schmidt, R. Forest cover changes in the Prignitz region (NE Germany) between 1790 and 1960 in relation to soils and other driving forces. *Landsc. Ecol.* **2010**, *25*, 299–313. [CrossRef]
48. He, F.; Li, S.; Zhang, X. A spatially explicit reconstruction of forest cover in China over 1700–2000. *Glob. Planet. Chang.* **2015**, *131*, 73–81. [CrossRef]
49. Cillis, G.; Statuto, D.; Picuno, P. Historical GIS as a Tool for Monitoring, Preserving and Planning Forest Landscape: A Case Study in a Mediterranean Region. *Land* **2021**, *10*, 851. [CrossRef]
50. Affek, A. Landscape continuity versus landscape transformation: A case study in the Wiar River catchment, Polish Carpathians (1780–2000). *Probl. Landsc. Ecol.* **2011**, *30*, 147–155.
51. Bičiík, I.; Jeleček, L.; Štěpánek, V. Land-use changes and their social driving forces in Czechia in the 19th and 20th centuries. *Land Use Policy* **2001**, *18*, 65–73. [CrossRef]
52. Hamre, L.N.; Domaas, S.T.; Austad, I.; Rydgren, K. Land-cover and structural changes in a western Norwegian cultural landscape since 1865, based on an old cadastral map and a field survey. *Landsc. Ecol.* **2007**, *22*, 1563–1574. [CrossRef]
53. Feranec, J.; Jaffrain, G.; Soukup, T.; Hazeu, G. Determining changes and flows in European landscapes 1990–2000 using CORINE land cover data. *Appl. Geogr.* **2010**, *30*, 19–35. [CrossRef]
54. Hellstrom, K. Agricultural Reforms and Policies Reflected in the Farming Landscapes of Hiiumaa from 1850 to 2000. Ph.D. Thesis, Department of Landscape Planning, Swedish University of Agricultural Sciences, Alnarp, Sweden, 2002.
55. Karšuvas Giria Is a Cultural Heritage. Available online: http://jkgg.lt/karsuvos-giria-kulturos-paveldas/ (accessed on 28 March 2024). (In Lithuanian).
56. Puziene, R. The Struve Geodetic Arc: The development of the triangulation, technical possibilities, and the initiation of the project. *Hist. Geo- Space. Sci.* **2019**, *10*, 269–277. [CrossRef]
57. Law of the Republic of Lithuania on Forests, 1994 November 22 No. I-671, Vilnius. Available online: https://e-seimas.lrs.lt/portal/legalAct/lt/TAD/TAIS.6036/asr (accessed on 5 April 2024). (In Lithuanian).
58. History. Available online: http://smalininkai.lt/apie-mus/istorija/ (accessed on 25 February 2024). (In Lithuanian).
59. Mander, Ü.; Palang, H. Changes of landscape structure in Estonia during the Soviet period. *GeoJournal* **1994**, *33*, 45–54. [CrossRef]
60. Potapov, P.V.; Turubanova, S.A.; Tyukavina, A.; Krylov, A.M.; McCarty, J.L.; Radeloff, V.C.; Hansen, M.C. Eastern Europe's forest cover dynamics from 1985 to 2012 quantified from the full Landsat archive. *Remote Sens. Environ.* **2015**, *159*, 28–43. [CrossRef]
61. Kuemmerle, T.; Kaplan, J.O.; Prishchepov, A.V.; Rylsky, I.; Chaskovskyy, O.; Tikunov, V.S.; Müller, D. Forest transitions in Eastern Europe and their effects on carbon budgets. *Glob. Chang. Biol.* **2015**, *21*, 3049–3061. [CrossRef] [PubMed]
62. Yeloff, D.; Van Geel, B. Abandonment of farmland and vegetation succession following the Eurasian plague pandemic of AD 1347–1352. *J. Biogeogr.* **2007**, *34*, 575–582. [CrossRef]
63. Alix-Garcia, J.; Munteanu, C.; Zhao, N.; Potapov, P.V.; Prishchepov, A.V.; Radeloff, V.C.; Krylov, A.; Bragina, E. Drivers of forest cover change in Eastern Europe and European Russia, 1985–2012. *Land Use Policy* **2016**, *59*, 284–297. [CrossRef]