

Article

# Recent Afforestation in the Iowa River and Vorskla River Basins: A Comparative Trends Analysis

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**Abstract:** Afforestation trends were compared between two continentally-distinct, yet similar ecoregions to characterize similarities or differences in forest advancement due to natural and anthropogenic forcings. Temporal changes in forest cover were analyzed using high resolution aerial and satellite photographs for Southeast Iowa, USA, and satellite photographs for the western Belgorod Oblast, Russia. An increase in forested area was shown to occur over a 44-year period from 1970–2014 in Iowa where afforestation was reflected by the aggregation of smaller forest units. In the Belgorod region the opposite occurred in that there was an increase in the number of smaller forested units. The rate of forest expansion into open grassland areas, previously used as haying lands and pastures, was 14 m decade<sup>-1</sup> and 8 m decade<sup>-1</sup> in Iowa and the Belgorod Oblast, respectively. Based on current trends, predicted times for complete forest coverage in the study areas was estimated to be 80 years in Iowa and 300 years in the Belgorod Oblast. In both the Iowa and Belgorod Oblast, there was an increase in annual precipitation at the end of the 20th and the beginning of the 21st centuries, thus providing a contributing mechanism to forest advancement in the study regions and implications for future management practices.

**Keywords:** afforestation; climate change; Iowa River Basin; Vorskla River Basin; remote sensing

## 1. Introduction

Investigations of the forested extent of the biosphere and anthropogenic impacts on forest ecosystems are greatly needed given the implications for forest ecosystem and natural resource management, conservation and policy [1]. Widespread deforestation is often implicated as a contributing factor of global climate change [2,3]. However, recent studies of afforestation indicate both anthropogenic and natural process drivers represent a combined focus that integrates contemporary issues of climate change [4–8].

Previous studies showed that natural vegetation communities have reacted strongly to changes in climate during the last 10 thousand years (KY) (the Holocene). For example, dry climatic conditions during the Middle Holocene (8–4 KY before present (BP)) in the USA, the Eurasian East European

Plain and Western Siberia were reflected by the development of widespread grasslands. Later, during the Late Holocene (the most recent 4 KY BP), forest advancement into grasslands occurred in many locations due to climatic cooling and an increase in precipitation [9–13]. More recently, the climate of the Midwestern States of the USA (e.g., Iowa, Missouri, Kansas) has become warmer and moister since the early 1980s [14,15]. These conditions would seem to favor increased tree growth in the Midwest, as studies have shown that tree growth is positively correlated with precipitation in the mid-latitudes [16,17], but not always in the tropics [18]. It was shown that in the Northern Hemisphere during the atmosphere circulation epoch of 1890–1920s, the annual amount of precipitation exceeded the long-term climatic norm [19]. Thus, from the 1920s to the mid-1950s, a new atmospheric regime became established during which global temperatures increased and precipitation decreased, which caused more frequent droughts in the steppe and dry-steppe regions of East Europe. From the mid-1950s to the decade encompassing the turn of the century (the mid-1990s to the mid-2000s), the climate became wetter over the central USA and southwest Russia. With an increase in precipitation over southwestern Russia, many ecosystem processes significantly changed, for example the ground water level increased, and the composition of natural vegetation communities changed sharply. Hygrophilous forms of plants appeared, and the activity of wind-erosion processes decreased [19]. Conceivably, these ecosystem-level changes may alter expected climate change trajectories. It is therefore important to investigate the extent of these changes, particularly in forested ecosystems, as forests can disproportionately affect global climates relative to many other vegetated ecosystems.

An accepted method for studying ecosystem dynamics is via comparative analysis of archived remote sensing data. Remote sensing technology has been shown to be useful in examining the impact of natural and anthropogenic changes on land cover spatially and temporally [20–28]. Aerial photography has a longer history of use for monitoring the environment and is often used in concert with satellite information [20,29,30]. The usefulness of satellite information in this regard was recognized shortly after the launch of the first satellites [31]. While aerial and satellite information is available at various resolutions, medium resolution imagery (e.g., 30 m) may underestimate the extent of forest cover as demonstrated in an urban environment of upstate New York, USA [26]. A study of a rainforest biome in Africa [32], however, indicated such a resolution is adequate for examining changes in forest cover. During the last decade, a number of authors have utilized very fine resolution imagery, whether it was acquired from aerial photographs or satellites [25,30], including the use of visual analyses [32,33]. Many of these studies included an analysis of regional and local-scale changes for the purpose of monitoring the local environment [30,33–35]. Ultimately, the use of layered maps and high resolution imagery has become a common way to estimate changes in forest cover area regionally and globally [25,30,36].

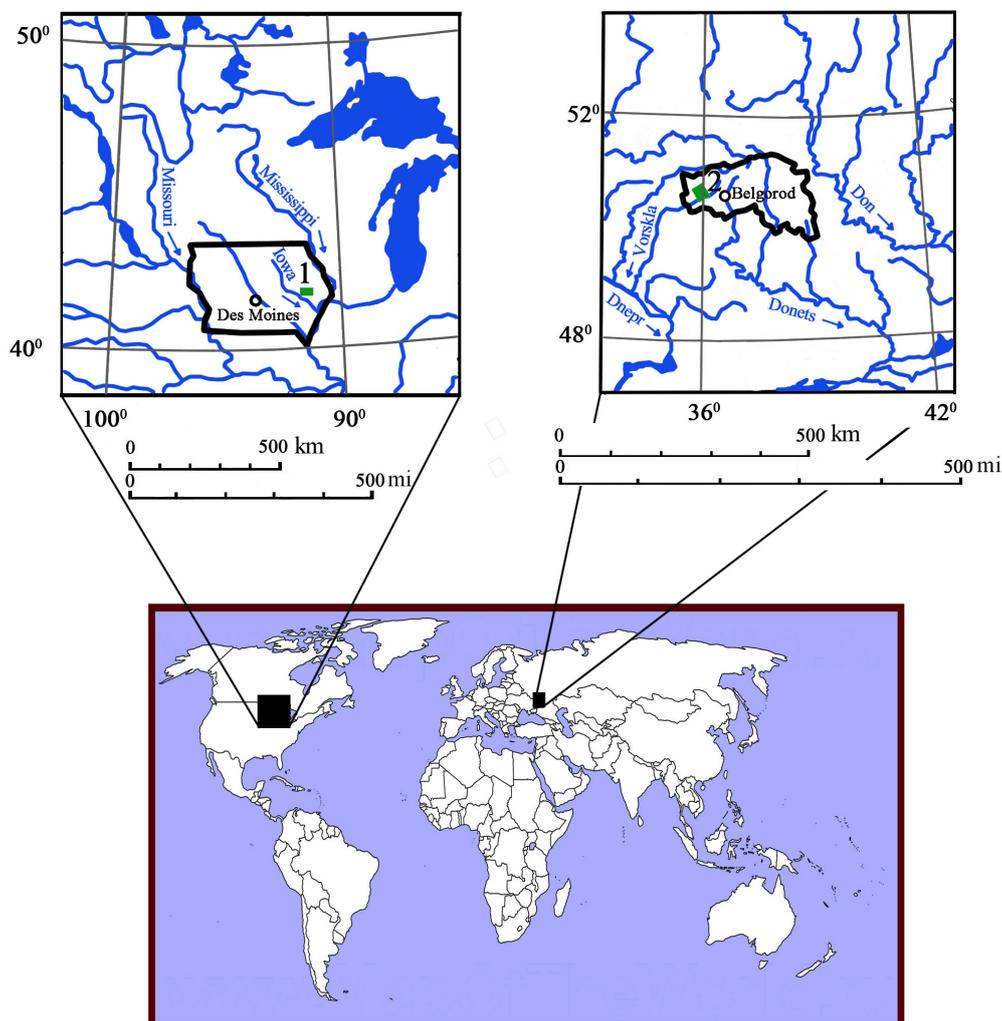
As local regional and/or global studies dedicated to the investigation of recent afforestation are not plentiful, addressing this lack of information by investigating differences in forest advancement due to natural and anthropogenic forcings using a time series aerial photographic, a GIS approach, was the primary objective of this study. Sub-objectives included (a) estimating the rate of afforestation during the later 20th century and into the 21st century in Iowa, USA, and the Belgorod Oblast in Russia and (b) identifying physical and geographic drivers of afforestation in those regions. Conceivably, afforestation in a warmer and wetter climate may help mitigate future climate warming, and such information could inform regional land use and policy decisions.

## 2. Materials and Methods

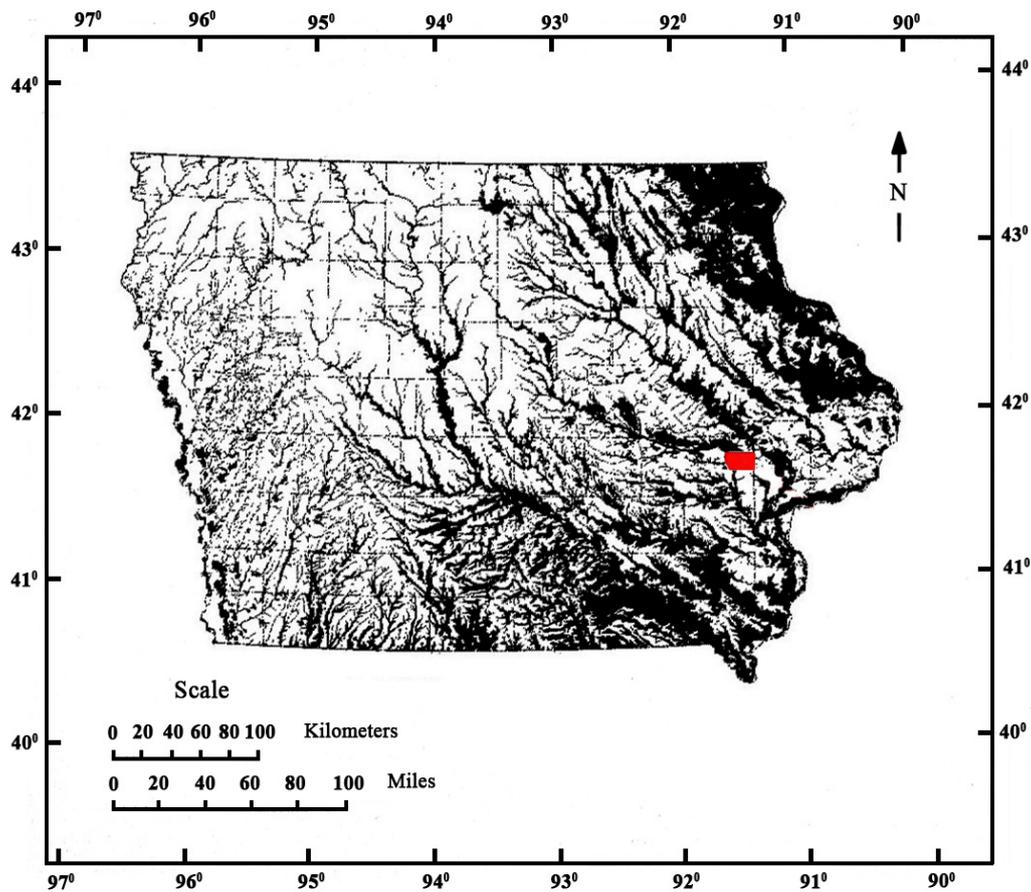
### 2.1. Study Regions

Study regions included Johnson County, Iowa, USA, and the Borisovka District in the Belgorod Oblast of southwest Russia (Figure 1). These regions are situated in different continents, but have similar ecoregion characteristics given that they are mid-latitude forest regions with similar long cool seasons and warm humid summers, are both located in transitional zones between forests and

grasslands in moderate climates and were opportunistic research activities for the authors. The Iowa, USA, study area was located east of Coralville Lake reservoir in Newport and Graham Townships. Prior to 1840, the area was a typical oak-hickory broad-leaf forest land that stretched for hundreds of miles along the main rivers of the state (Figure 2). In 1870, the western half of the study area (within Newport Township) was almost completely covered with timber [37], and the eastern region was a combination of prairie, timber and agricultural lands [37,38]. The western and the eastern regions were described in 1870 as follows [37] (pp. 15–16): “Newport Township is located on the east bank of the river, just above Iowa City . . . It is nearly all covered with timber, and although it is not quite so good as an agricultural Township, its timber makes it of full as great a value to the County at large as most any Township in the County”. The authors continue; “Graham Township is one of the finest in the County, being mostly all prairie, with a few fine places which give considerable timber for fuel and building purposes”.

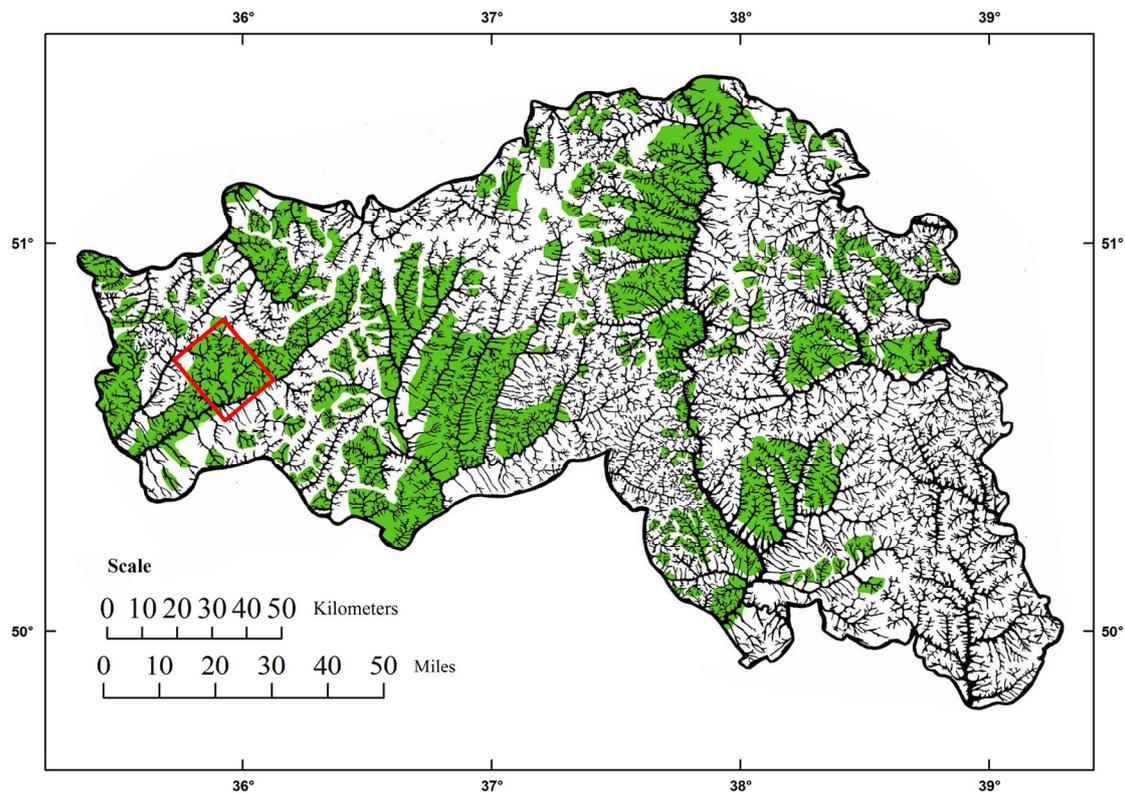


**Figure 1.** Study areas in the USA and Russia: (1) Iowa River Basin; (2) Vorskla River Basin.



**Figure 2.** Pre-settlement forest cover (shown in black) in the State of Iowa [39]. The study area is marked by the red box.

In Russia, the study area was located in Belgorod Oblast in the southwest region of European Russia. The area is situated north of the Vorskla River, a branch of the Dnieper River, and mainly corresponds to the border of the Belgorod Oblast District, the Borisovka District. As in the Iowa study, the study area in the Belgorod Oblast was almost completely covered by broadleaf forest before the arrival of intensive human activity (before 1600). The area is thus an approximate Russian environmental equivalent of the natural forests in Iowa (Figure 3). The native forests of the study area here were represented by predominantly by English oak (*Quercus robur* L., 1753) with a mixture of ash (*Fraxinus excelsior* L., 1753), maple (*Acer platanoides*, *Acer tataricum* L., 1753) and linden (*Tilia cordata* Miller, 1768) [40]. The areal extent of study regions within the Iowa and Belgorod was approximately 166 km<sup>2</sup> and 420 km<sup>2</sup>, respectively.



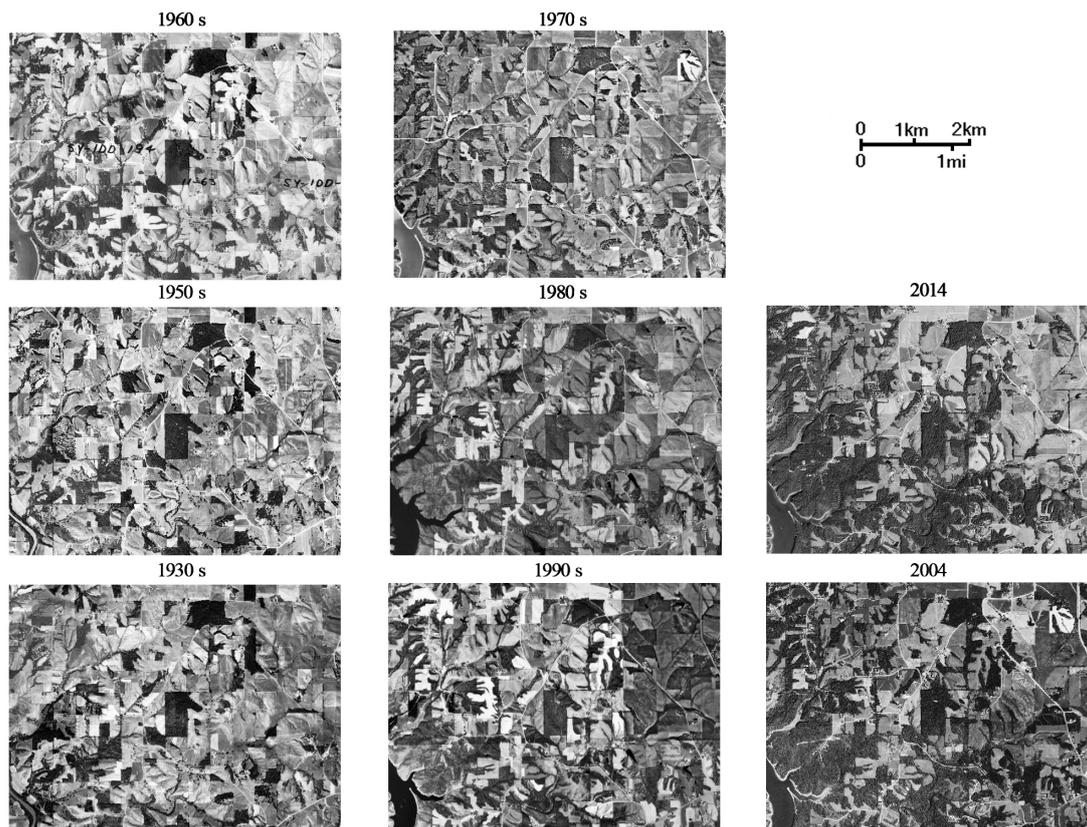
**Figure 3.** Pre-settlement forest cover (shown in green) in the Belgorod Oblast [41]. The study area is marked by the red rectangle.

## 2.2. Orthophotographs

For the Iowa study area, orthophotographs from aerial surveys, as well as satellites were obtained from the Iowa Geographic Map Server [42]. The collection on the server includes black-white aerial photos (from the 1930s to the 1990s) and colored satellite images (since approximately 2000). The highest resolution for all photos is one square meter per pixel. For the current investigation, a resolution of two square meters per pixel was used. Using the aerial photos from the U.S. Department of Agriculture from May 1967–October 1974 (Figure 4), it was shown that afforestation began in the study area in the 1970s [42]. Thus, for the purposes of comparison to current forest cover, we used data starting at 1970. For context, Figure 4 shows the time series of orthophotographs that was used to make this determination.

In order to characterize a trend of afforestation in the Iowa study area, orthophotographs for three years (1970, 1992 and 2014) were studied. Lacking other information, changes were assumed to be approximately linear between these periods. For the Belgorod Oblast study area, data from satellite images were available for only two periods in 1970 [43] and 2014 [44] due to the limited availability of satellite imagery during the 1980s and 1990s for public use. The resolution of satellite images for Belgorod Oblast area for both study dates was 1.8 m per pixel. No horizontal shift was observed. Thus, for both the Iowa and Belgorod study areas, the same time period was used for the investigation of change in forest cover (1970–2014). In both areas, the analyzed orthophotographs were measured manually (i.e., digital interrogation was not possible given available information for each site) for the propagation of woodland. The authors recognize that manual interpretations can introduce subjectivity; however, great care was taken to use the same methods, by the same individual between all sites, thereby maximizing consistency and quality control. Distances were calculated using pixel counts while accounting for the sloping terrain using topographic maps. These results served as the basis for forested area change estimations and maps created by overlaying geographic information

systems (GIS) layers over orthophotographs. In addition, maps of drainage networks were created for each study area and used for the identification of forested watershed and ravine types and the calculation of linear rates of forest advancement or retreat relative to those features. Soil maps at the 1:15,800 scale (cm to m) were constructed using aerial photographs [38]. Topographic maps from [42] were used to create a drainage network map for the Iowa study area. The map of the drainage network for the Belgorod study area was created using topographic maps at a scale of 1:10,000 (cm to m). This region's topography was the opposite of the dense drainage network in the Iowa study area as evidenced by the absence of vast and relatively flat (less than 2 degrees of change) watershed regions.



**Figure 4.** Series of aerial (before 2000) and satellite (after the 2000s) orthophotographs in a fragment of the study area east of Corallville Lake Iowa, USA.

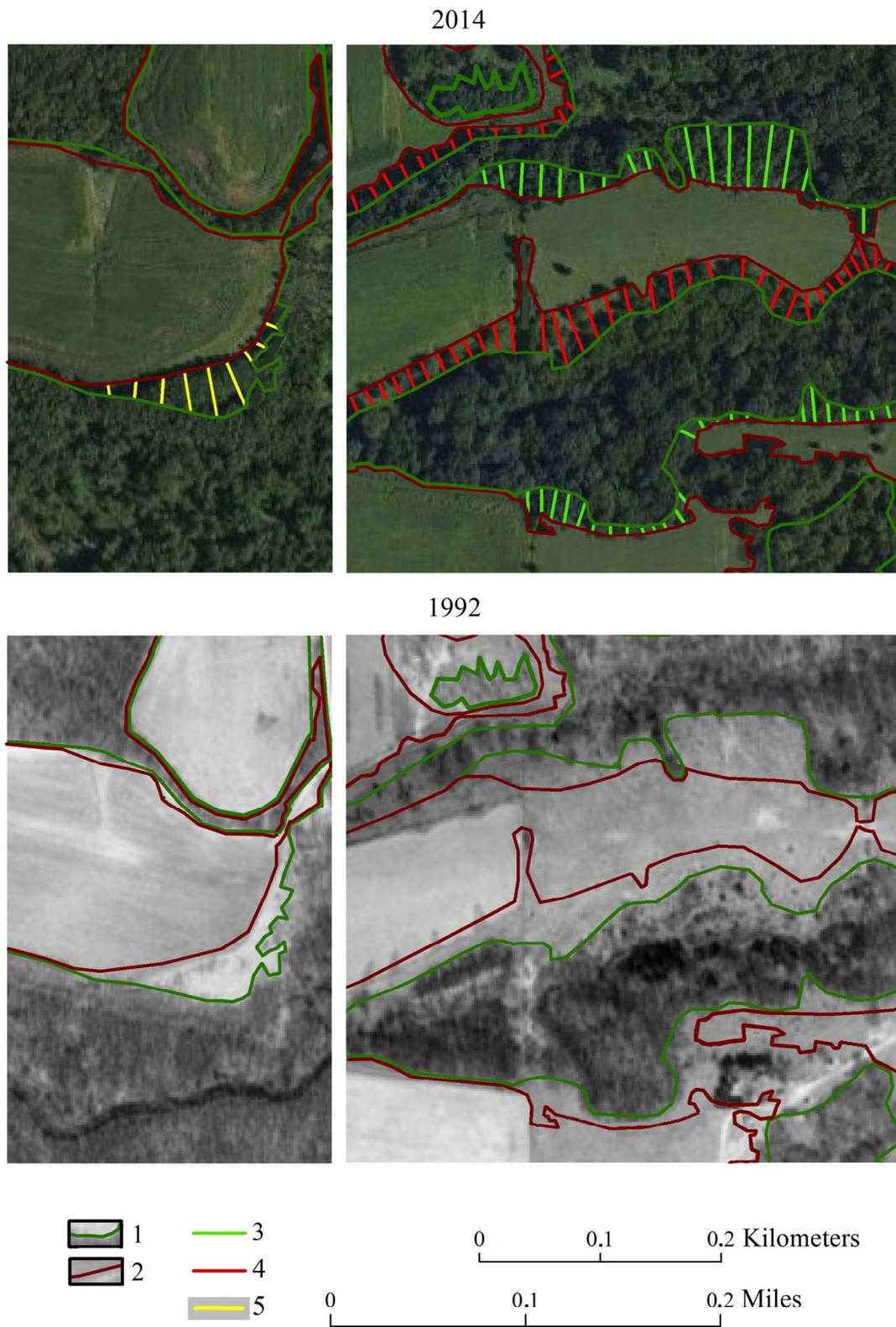
The developed forest area change maps were used to predict the time needed for complete forest coverage of the study areas (i.e., the amount of change, per unit time between orthophotographs). These maps served as the primary map's layers for the forest area photographs and were also used to calculate linear forest advancement. It is acknowledged that the time for complete coverage of both areas by forest is hypothetical since land use and climate changes may influence those rates. Nonetheless, the estimation based on current rates of advancement is of use to land managers and policy makers wishing to make informed future planning decisions.

### 2.3. Data Analysis

For the Iowa study area, aerial photographs and satellite imagery (1970, 1992 and 2014) were projected into the North American Datum (NAD) 1983 coordinate system (Projection UTM, Zone 15N). Satellite images for the Belgorod study area were similarly geographically referenced, but into the WGS 84 reference system (Projection UTM, Zone 36N). Geo-referencing and geometric correction were performed using the software package ERDAS IMAGINE, wherein geospatial data are combined and quickly organized for geocorrection, analysis, visualization and map output. The study areas

of Iowa and Belgorod Oblast were delineated in the software package ArcGIS 10.1, resulting in an integrated archive of aerial photographs, satellite images and vectored layers of data (for each study period and location) for wooded lands at the 1: 9000 scale, which enabled the assessment of linear change at the one meter level. This allowed for an unbiased and accurate quantitative assessment of forested area and the rates of deforestation or afforestation [42–44]. Precipitation data (mm) for Iowa were compiled from daily rainfall observations at several locations, archived and subsequently made available via the National Climate Data Center in Asheville, North Carolina, USA, or available from the Midwest Regional Climate Center at the University of Illinois [45]. Precipitation (mm) and temperature (°C) data used for the Belgorod region were obtained from the All Russia Research Institute of Hydrometeorological Information-World Data Centre [46]. Data supplied descriptive statistics and were used to support observed results and future projections.

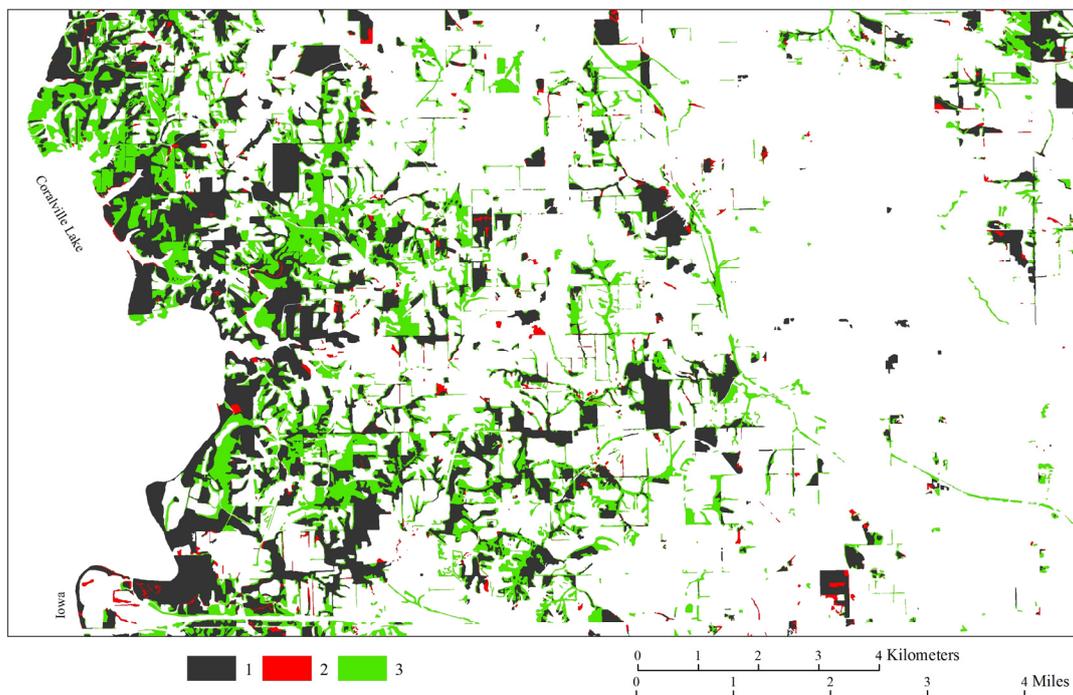
The rate of forests edge advancement (m/year) was estimated in places where open areas remained in the form of corridors or glades with meadow-steppe vegetation between sprawling forests. These are areas where forests have not yet fully occupied open areas during the study period (1970–2014), but may in the future. The analysis of a subset of sites within slopes of ravines and river valleys for northern and southern exposures was also performed. Selection criteria for those sites included (a) confirmed slope exposure as per the digital model of relief and aerial and/or satellite images analysis and (b) the area of the forested slope could not be dissected by roads or railways, settlements or agricultural land, especially croplands, and must have grassland connectivity. This latter condition was complicated given that forests in both Iowa and the Belgorod Oblast study areas were, in many places, situated among agricultural lands. Nevertheless, it was possible to choose a representative number of forest test plots for which the measurements were conducted, except for the Belgorod Oblast, where all forested areas bordered cultivated land. Forest advancement estimates were performed in GIS by measuring the distance between forest borders in the Iowa study area during the periods 1970–1992 and 1992–2014 and in Belgorod Oblast study area for the period 1970–2014. The distance between adjacent linear measurements of forest edge increments ranged from 15–30 m. Examples of measuring distance between forests boundaries for different years of surveys for ravine slopes of southern and northern exposures, as well as in the watershed for the Iowa study area are shown in Figure 5.



**Figure 5.** Measurement of forests edges' frontal advancement (e.g., Iowa study area, 1992–2014). Legend: (1) borders of forest in the orthophotograph from 1992; (2) borders of forest in the orthophotograph of 2014; (3) increments of the forest edge on northern slopes; (4) increments of the forest edge on southern slopes; (5) increments of the forest edge on the watershed.

### 3. Results

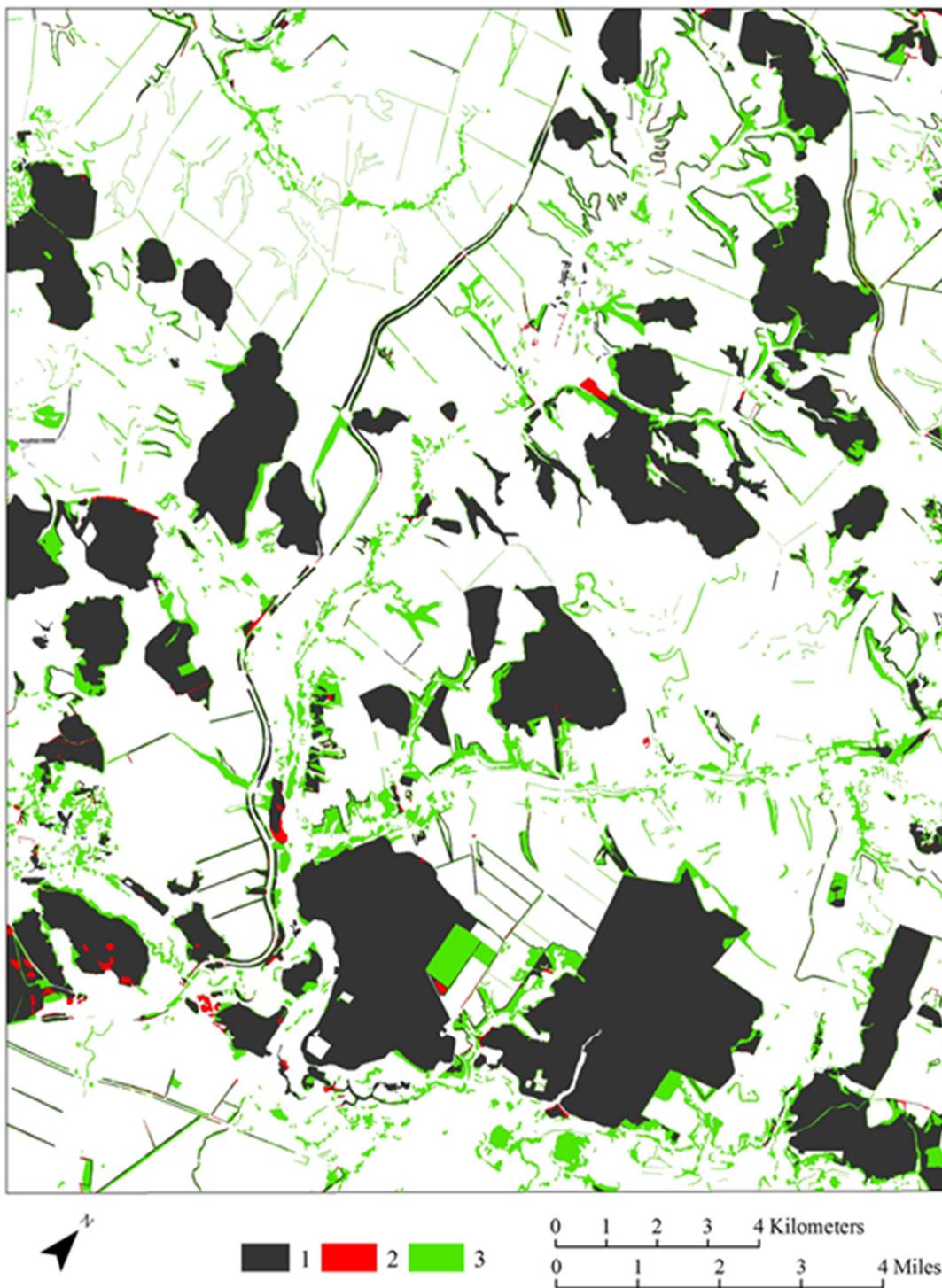
Analysis indicated relatively heterogeneous forest stand and cover dynamics from 1970–2014 (Figures 6 and 7). There was an overall increase in forest area within the Iowa and Belgorod Oblast study areas (Figures 6 and 7). Forest advancement in the Iowa study area during the periods 1970–1992 and 1992–2014 occurred at a uniform rate (Table 1). During the earlier period of analysis (1970–1992), the total forested area increased (on average) from approximately 14.8%–19.8% of the total area, and for 1992–2014, the increase was from 19.8%–24.8%. Results also indicated a decrease in the number of distinct forest blocks, as smaller blocks combined to form larger forest blocks in the Iowa region (Table 1). In the Belgorod Oblast study area during the same period, the same tendency for forest growth was observed (Table 2). However, unlike the Iowa site, there was an increase in the number of smaller area forest blocks in the Belgorod Oblast. Overall, the increase from 1970–2014 in forest cover in the Belgorod Oblast study area was 36.6%, while in Iowa, this increase was 67.5% (Table 1). In the Belgorod Oblast, in spite of the large increase in square area, forest growth appeared to be primarily in ravines, which were previous grasslands (pastures or hayfields) (Figures 6 and 7). This accounted for the doubling of the number of forest blocks in Belgorod, each with a smaller footprint (Table 1).



**Figure 6.** Dynamics of forest cover for the period 1970–2014 (Iowa study area). Shaded area: (1) forests in 1970–2014; (2) forest loss; (3) forest expansion.

**Table 1.** Changes in forest characteristics during the period between 1970 and 2014 in the Iowa and Belgorod Oblast study areas (based on aerial and satellite orthophotographs). Data presented as Iowa/Belgorod Oblast.

Year	Forest Cover (km <sup>2</sup> )	Number of Forest Blocks	Mean Block Area (ha)	Total Forested Area (%)
1970	24.6/91.0	1109/667	2.2/13.7	14.8/21.0
1992	32.9	702	4.7	19.8
2014	41.1/121.0	663/1439	6.2/8.4	24.8/28.1



**Figure 7.** Dynamics of forest cover for the period 1970–2014 (Belgorod Oblast study area). Shaded area: (1) forests in 1970–2014; (2) forest loss; (3) forest expansion.

Figure 8 shows land cover in 1970 versus 2014 within the Iowa and Belgorod Oblast study areas. To obtain a subset of information in addition to the earlier articulated methods, land types were divided into three physiographic groups depending on landscape position (Figure 8) as follows: (a) included areas situated on undulating surfaces in the watersheds or on watershed slopes. The typical tendency for this land type was the formation of denser forests replacing sparse forest or individual groups of trees. Group (b) contained plots within the gentler slopes of relatively vast river valleys and big ravines.

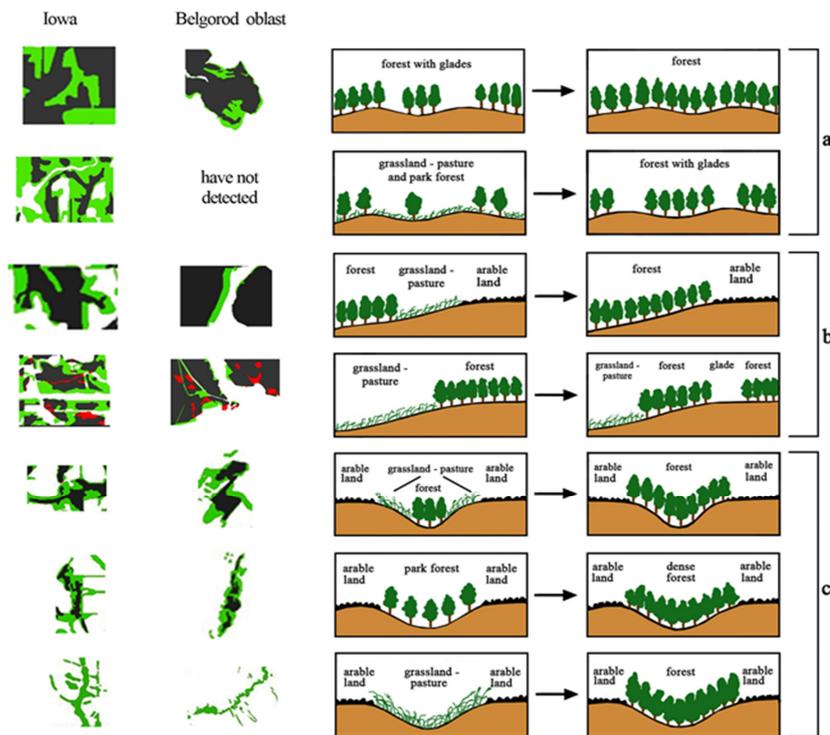
In this land type, areas of forest advanced in two ways: (1) gradual encroachment upward along slopes (when forest was situated earlier in the floodplain or ravine bottoms); or (2) downward along slopes (when forests contacted underlying along-slope grasslands). In Group (b), haying lands and pastures (grasslands), which in 1970 were transitional zones between forest and arable land areas, were, in the majority of cases, completely afforested by 2014. In these areas, simplified spatial combinations of land management occurred (e.g., previously forest, pasture, arable land or forest, haying, arable land became forest, arable land). However, in some cases, forested area was replaced by hay or pasture lands or the appearance of glades or other open areas (Figure 8b). Group (c) consisted of watershed slopes, combined with relatively small ravines. In these areas, haying lands and pastures within ravines were replaced by forests or dense forests advanced into sparse park-type forests (Figure 8c).

**Table 2.** Results of the statistical analysis for forest advancement (m) in different geomorphological positions of the Iowa study area during the periods 1970–1992 and 1992–2014 for Iowa.

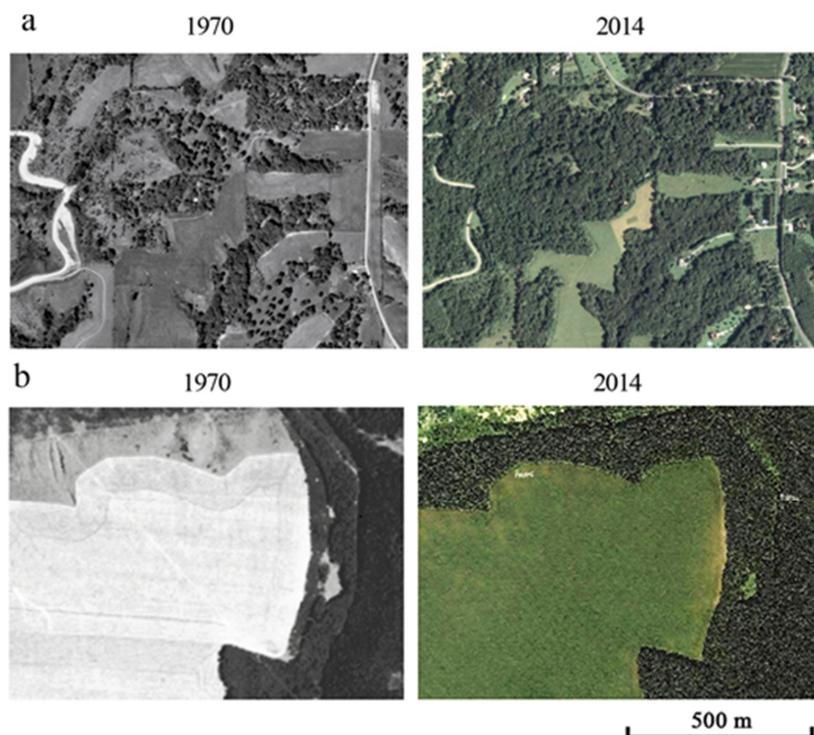
Position in Relief	N	Min	Max	Max-min	$\bar{X} \pm \delta_x$	$\delta$	Mean Rate of Advancement, (m/Year)
1970–1992							
Flat watersheds and gentle watershed slopes	36	12	64	52	$27.3 \pm 1.9$	11.2	1.37
Slopes of ravines (northern exposure)	65	10	112	102	$32.6 \pm 2.9$	23.9	1.48
Slopes of ravines (southern exposure)	96	10	132	122	$41.2 \pm 3.0$	29.3	1.87
1992–2014							
Flat watersheds and gentle watershed slopes	44	10	54	44	$25.1 \pm 1.8$	11.9	1.14
Slopes of ravines (northern exposure)	120	10	92	83	$31.1 \pm 1.7$	19.1	1.41
Slopes of ravines (southern exposure)	193	10	94	84	$31.1 \pm 1.4$	20.0	1.41

Results confirmed that field cultivation at the forest edge restrained forest advancement. This was clearly demonstrated by forest fragments visible in the 1970 and 2014 surveys of aerial photographs (1970) and satellite images (2014) presented in Figure 9. In particular, the south central area in Figure 9a and central area in Figure 9b were arable lands for the entire period 1970–2014. Conversely, in the absence of cultivation, some tree species spread into formerly cultivated areas, presumably at least in part due to wind-induced seed distribution [47,48]. Thus, in areas without plowing and other anthropogenic activities, afforestation was apparent. For example, hay and pasturelands present in 1970 were replaced by forests by 2014 (Figure 9). Afforestation in the Belgorod Oblast was shown to begin within two years of abandonment. This trend was visible by manual inspection near the edge of the forest in contact with the abandoned field. Next to the *Acer negundo* (box elder) plantation of the windbreak and among the grasses and weeds in the abandoned field, many one- and two-year-old trees were observed at a distances of up to 20–25 m from the forest edges.

Forest edge advancement within the Iowa study region was investigated from different relief positions (northern and southern slopes of ravines, watersheds and watershed slopes) during the periods 1970–1992 and 1992–2014. There was a tendency toward a decreased rate of afforestation during the second part of the study period (Table 2), and the forest advancement rate between watersheds and ravine slopes was not statistically significant (CI = 0.05). For example, rates of forest advancement on ravine slopes during both study periods were higher than lesser sloped areas (Table 2). The mean rate of the forest edge advancement in the Iowa study area for the period 1970–2014 was  $1.3 \text{ m year}^{-1}$  in watersheds;  $1.4 \text{ m year}^{-1}$  in ravines with a northern exposure; and  $1.6 \text{ m year}^{-1}$  in ravines with a southern exposure (Table 2). The mean rate of forest advancement in the Iowa study area was  $1.4 \text{ m year}^{-1}$ . The Belgorod Oblast study area was characterized by slower rates of forest edge advancement or about 50% less than that found in Iowa (Table 3). The mean rates of forest advancements for ravine slopes of northern and southern exposures were approximately equal, about  $0.8 \text{ m year}^{-1}$  (Table 3).



**Figure 8.** Physiographic types of afforestation process: (a) on watershed summits and slopes; (b) on slopes of river valleys, large ravines; (c) in ravine systems. Left: examples of afforestation according to fragments of the maps of forestland cover dynamics in Iowa and Belgorod Oblast. Map indices: symbols of forests dynamics are the same as in Figure 7.



**Figure 9.** Orthophotographs fragments of surveys from different periods, 1970 (left) and 2014 (right) [42–44]; (a) Iowa study area; (b) Belgorod Oblast study area. The appearance of forests took place mostly in ravines and slopes. Outlines of plowed lands remain largely unchanged.

**Table 3.** As in Table 2, except for the Belgorod Oblast study area during the period between 1970 and 2014.

Position in Relief	<i>n</i>	Min	Max	Max-Min	$X \pm \delta_x$	$\delta$	Mean Rate of Advancement, (m/Year)
Slopes of ravines (northern exposure)	175	10	90	80	$33.1 \pm 1.4$	18.2	0.75
Slopes of ravines (southern exposure)	137	10	132	122	$35.9 \pm 2.3$	27.4	0.82

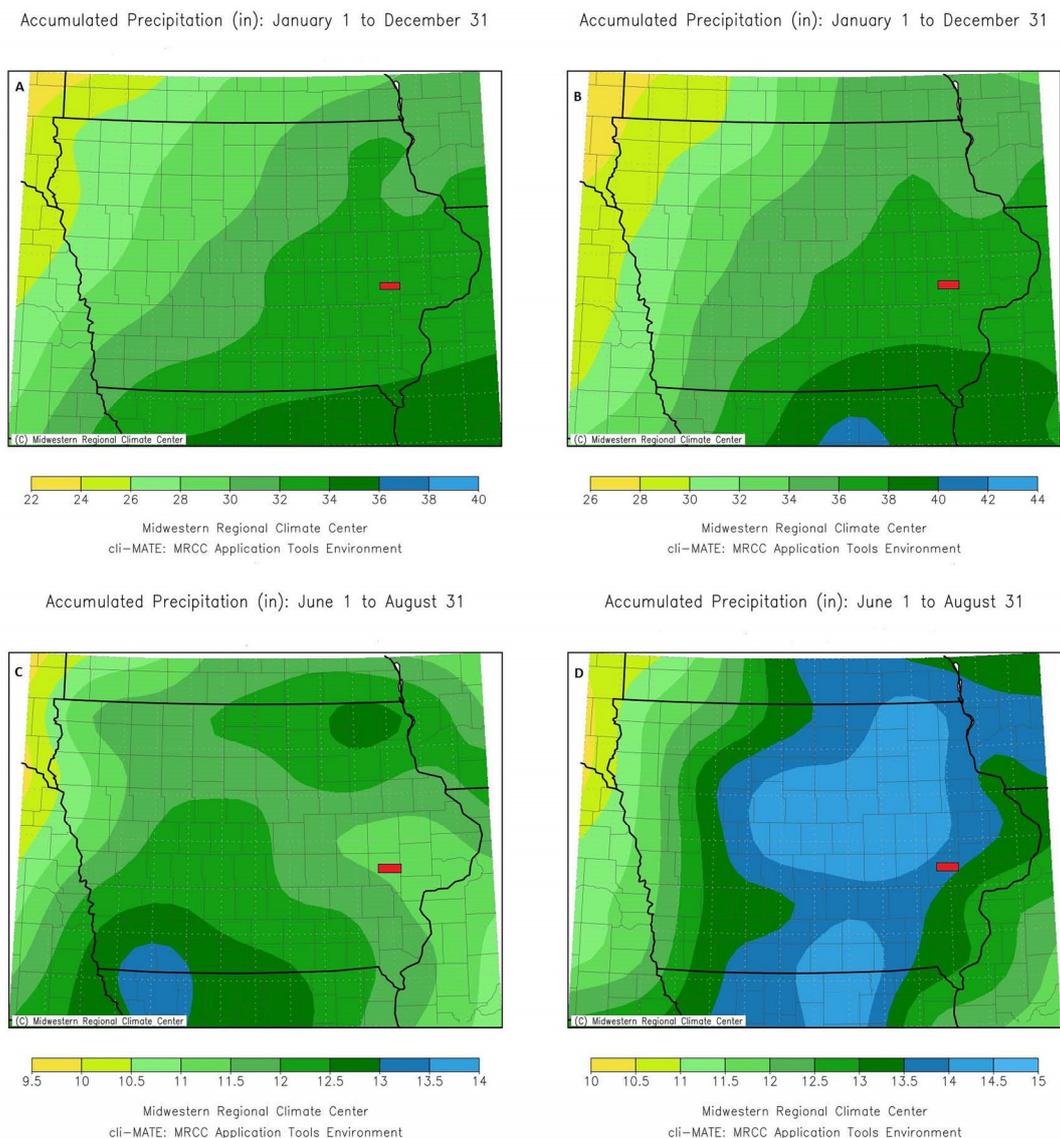
#### 4. Discussion

An analysis of aerial photographs, coupled with available information in the literature provided the basis for some explanations pertaining to the relative influence of anthropogenic and natural factors for the increase in forest land cover within the study areas. In some locations, forest-plantations were established, which on the photographs were identified clearly by visible rows of planted trees. The reason for the appearance of forest-plantations and/or abandoned agricultural lands (mainly on slopes) may at least in part be attributed to depletion of soil fertility as a result of erosion on slopes [49]. In some areas, there were changes in the number of forested pixels apparently due to residential construction and/or the planting of trees near new development. This process resulted in a net loss of forested area (see red areas in Figures 6 and 7). In Iowa, the development of a recreation facility on former farm lands in the area of study also resulted in afforestation. An increase in forest land cover near the Coralville Lake shore, after the creation of a reservoir in 1958, was a direct effect of changes in land management (Figure 4). Land was retired from agricultural use and converted into recreational zones, namely the Coralville Lake Wildlife Area [50]. Aerial photography from 1970 showed many open areas that were covered with young trees. At that time, forests covered about 40% of the area within two kilometers of the lake shore just 12 years after the reservoir was created. Forty-four years later (2014), forests covered 80% of that same part of the lake's shoreline (Figure 6). In the absence of forest plantations in the photography from 1970 and 2014, it is possible to conclude that the change in forest cover was largely due to natural expansion by forest vegetation near the shoreline of the Coralville Lake reservoir (as measured by changes in the number of forested pixels). In Iowa, the process of natural forest expansion into the prairie is confirmed by examining the properties of soils that have clear signs of meadow-steppe soil formation, which at present are situated in forested lands [38]. In a number of locations in Iowa, there are current areas of prairie that were formerly forested during the period of intensive settlement during the second-half of the 19th century [37,51].

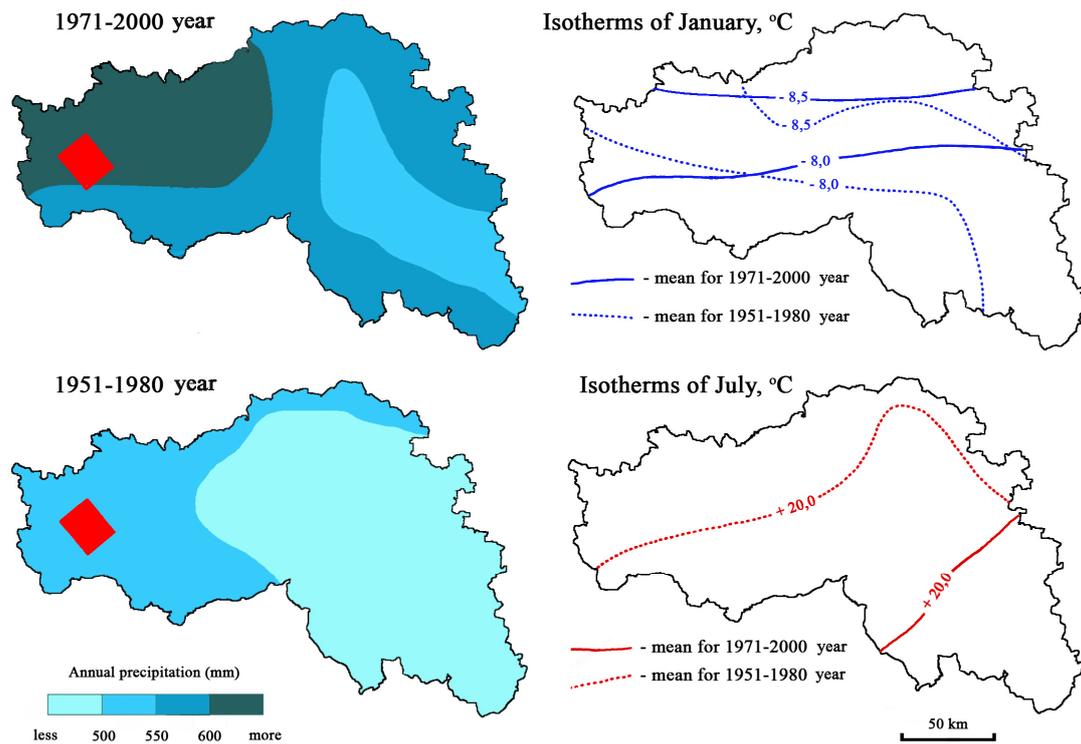
It is of interest to note that the forest advancement shown in the current work is also favored by the climatic trends that have existed for about 800–900 years associated with the completion of a climatic episode that was warmer and more arid at the end of the first and the beginning of the second millenniums A.D. [9,52,53]. There is also significant discussion in the literature regarding pre-settlement conditions in Iowa, USA. The pre-settlement conditions of the forest and prairie were regulated largely by periodic fires [54–56]. The authors of one of the oldest publications on the geography of Iowa reported that if not for the occurrence of frequent prairie fires into the 19th century, it is possible that the entire area within a few decades would have been covered by forest [51].

In the Belgorod Oblast, the same patterns noted in Iowa, USA, of natural afforestation during the Late Holocene were observed. In a number of places currently forested, grassland soils or chernozems (Russian equivalent of Mollisols in USA soil taxonomy) were found buried under prehistoric mounds from the bronze epoch [12]. Applying the paleosoils for the reconstruction of natural environments within Belgorod Oblast and combining this with modern trends for forest area growth and replacement of these by human activity (grasslands), it is inferred that the characteristics of the environmental succession were very close to those of Iowa for the last 700–800 years. Natural afforestation was especially rapid during the so-called Little Ice Age Period (15th–19th centuries) [57].

During recent decades in Iowa and the Belgorod Oblast, quantifiable changes in climate (e.g., increased precipitation) have been observed. The comparison of annual and summer season (June–August) only precipitation in Iowa during two periods (1931–1960 and 1981–2010) indicates that by the second-half of the 20th century, the climate of Iowa was more humid, particularly in the summer season. This observation is consistent with many published investigations [15,58–60]. In particular, within the study area, the annual precipitation increased by approximately 100 mm (four inches); more than half of this amount during the summer season (Figure 10). Similar climate change was confirmed for the Belgorod Oblast (Figure 11). The comparison of climate maps, which reflect average temperature and precipitation during 1971–2000, with maps of the same variables during the previous thirty-year period (1951–1980), showed that, for the last quarter of the 20th century, there were distinct increases in the annual amount of precipitation. This was reflected by the shift to the north of the January isotherms and to the south of the July isotherms (Figure 11).

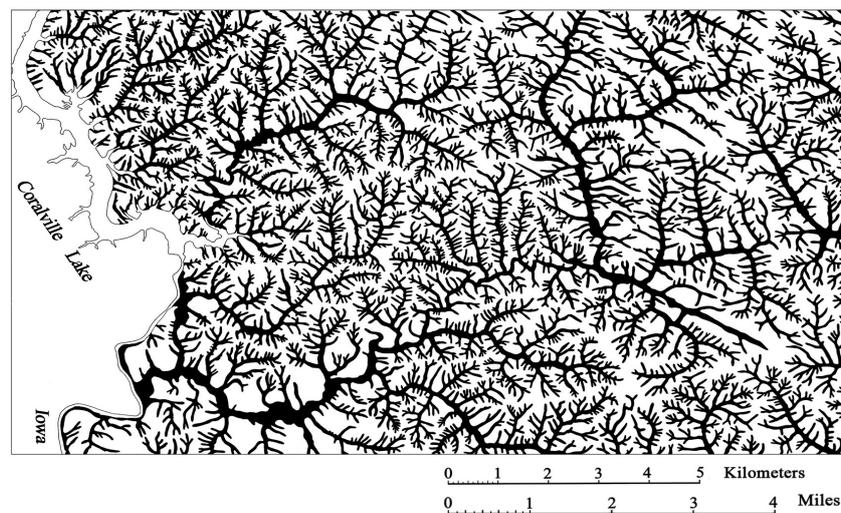


**Figure 10.** Average values of annual and summer precipitation (in inches) in Iowa during two periods: (A,C) 1931–1960; (B,D) 1981–2010 [45]. The study area is shown by the red rectangle.

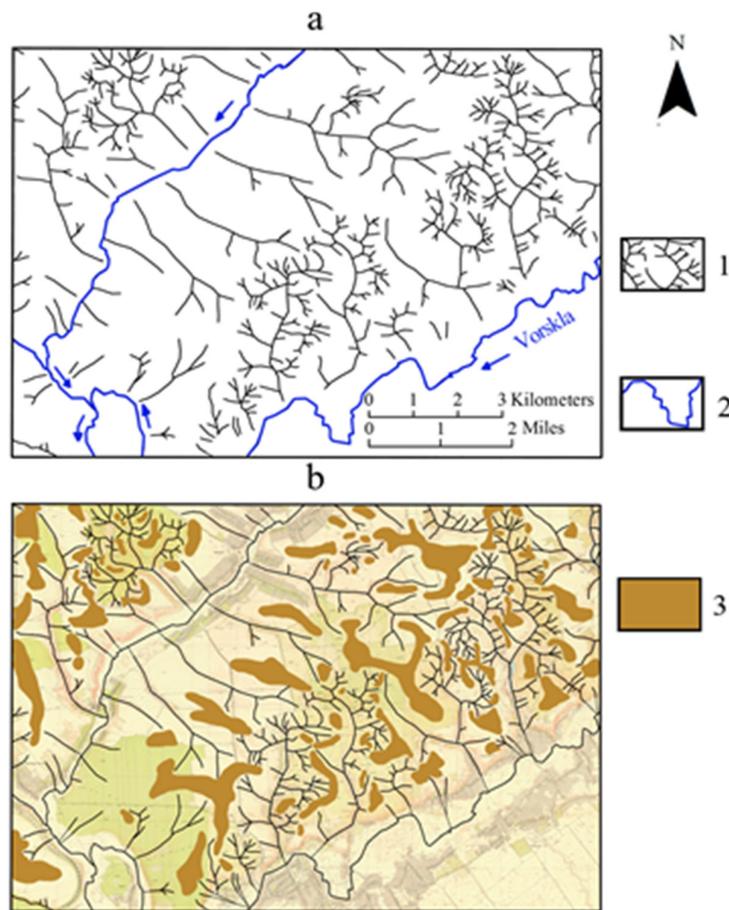


**Figure 11.** Climatic mean precipitation (left) and temperatures (right) for the Belgorod Oblast during the periods 1951–1980 and 1971–2000 (adapted from [61,62]). The study area is shown by the red rectangle.

In addition, and in response to climatic changes, natural factors favoring the modern increase in forest cover for Iowa (but also the Belgorod Oblast) include evolving hydrologic erosion networks [8,63,64] with coupled shallow groundwater supplies that are known to support dense riparian forests [61]. Similarly, an additional explanation for forest cover increase is the strongly dissected relief within dense drainage networks, the density of which in some places reaches 5–6 km/km<sup>2</sup> in Iowa (Figure 12) and 2–3 km/km<sup>2</sup> in Belgorod Oblast (Figure 13). In effect, the slope sections, which obtain additional moisture with surface and subsurface soil drainage, create land forms that are favorable for forest expansion.



**Figure 12.** Drainage network (contours of ravines and river floodplains) in the Iowa study area.

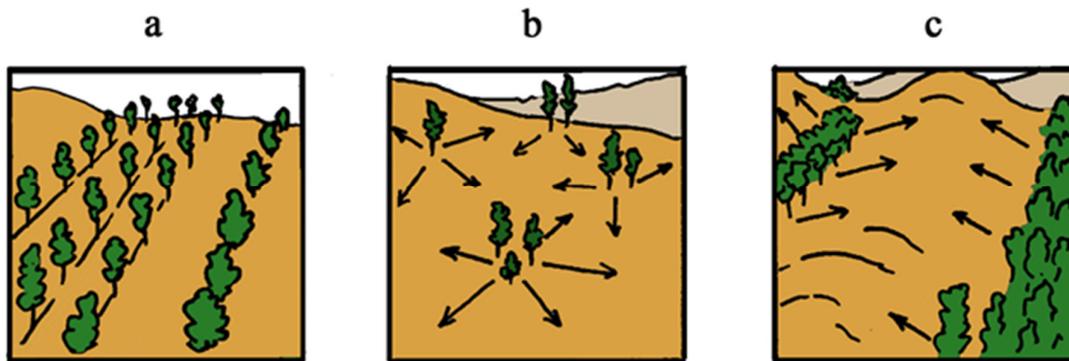


**Figure 13.** Drainage network in the Belgorod Oblast study area (southern fragment) (a) and flat watersheds distribution (b). Map indexes: (1) bottoms of ravines; (2) rivers; (3) flat watersheds (steepness of surface less than  $2^\circ$ ).

The comparative analysis of plant cover distributions in the orthophotographs from 1970 and 2014 (Figures 6 and 7) made it possible to identify the three modes of forest cover increase presented earlier (Figure 14). Anthropogenic forest regeneration was characterized by the simultaneous appearance of woody vegetation (mainly windbreaks) (Figure 14a). Natural forest regeneration was determined by identifying particular forest segments or patches in the 1970 photos and then locating them within forested stands in the 2014 photos. In places where there were sparse forests or separate trees, forest advancement could proceed in all directions from each group of trees or isolated trees (Figure 14b). It was thus assumed based on Figures 5 and 9a that this is the manner by which the largest blocks of forests in the Iowa study area were formed. In the case of the forest expanding outward from the boundaries of dense forest present at the start of the study period, frontal advances of forest boundaries took place (Figure 14c).

It is of use for land management purposes to estimate the time to complete forest cover represented by this 44-year period analysis. It is acknowledged that such calculations are somewhat speculative since future changes in climate or anthropogenic activity may accelerate or decelerate these rates. Regardless, based on current results, considering that (a) the average linear rate of forests growth during the period between 1970 and 2014 (14 m per decade) and assuming forests existed originally at the lowest elevations only (ravine bottoms and flooded parts of river valleys), as well as that (b) the average distance between the bottoms of the drainage network depressions and the central parts of the divided uplands (110 m), it was estimated that the time for the total areal forest coverage in the western part of the study Iowa study area would be approximately 80 years. This estimate would be

considerably less if it included forest cover in the bottoms of the erosion network, as well as on slopes and summits between ravines, as well as projections of future climate, which is expected to be warmer and wetter during the growing season [3,60]. For the Belgorod study area, the same calculations and assumptions indicated that the average distance between the bottoms of the drainage network equaled 233 m (Table 4), and the estimated time for the total areal forest coverage would be approximately 300 years.



**Figure 14.** Processes of increases in forest cover within study areas in Iowa and Belgorod Oblast during the period from 1970–2014: (a) artificial forest-plantations; (b) growth of forest from many centers; (c) frontal growth from boundaries of forests.

**Table 4.** Results of the statistical analysis of the distance between the bottom of ravines or border parts of river floodplains and divided watersheds.

Index	<i>n</i>	Min	Max	Max-Min	$\bar{X} \pm \delta_X$	$\delta$
<b>Iowa Study Area</b>						
Distance Between Ravine Bottoms or Borders of Rivers Flooded Plains and Central Parts of Watersheds	245	50	298	248	$110 \pm 3$	39
<b>Belgorod Oblast Study Area</b>						
Distance Between Ravine Bottoms or Borders of Rivers Flooded Plains and Central Parts of Watersheds	310	30	1022	992	$233 \pm 8$	149
Distance Between Ravine Bottoms or Borders of Rivers Flooded Plains and Edges of Nearest Flat Watersheds	121	30	296	266	$89 \pm 7$	72

The main characteristic of the natural environment for the forest-steppe zone of European Russia is the presence of forests and grasslands in relatively flat watersheds [65]. Therefore, there is interest by land managers and policy makers in estimations of the time needed for the formation of forest-steppe from a former steppe environment. In the Belgorod study area, the mean distance from the ravine bottoms or river flood plain borders to the nearest flat watersheds was about 90 m (Table 4). Thus, considering the calculated mean rate of forest advancements to grasslands of 0.8 m year<sup>-1</sup>, the estimated time of forest-steppe advancement from a previous steppe environment may be as little as 110–115 years.

Climatic conditions favorable for the formation of a “climax prairie” in the Midwest, USA, including Iowa, were optimal during the so-called “Thermal Maximum of Holocene” or the interval between 6.0 and 4.0 KY BP [9,11,50]. For the Central Chernozem Region of Russia, including Belgorod Oblast, this period is associated with the interval from 4.3–4.0 KY BP [12,66]. This was a period of time when forests within the study areas were located mainly in the bottoms of the drainage network. Later, more humid climatic conditions prompted the successional conversion of prairie-grassland into forest

in many places. Conceivably, in places with dense drainage networks (such as the study areas here), the formation of large forested areas as a result of forest expansion from ravines and valley confluences could have occurred during a relatively short period time during the transition from Middle to Late Holocene. The calculations made here substantiate this observation.

In the future, the study regions and adjacent regions in much of Iowa and the Belgorod Oblast are expected to be subjected to warmer and wetter climatic conditions. The results of this study may suggest that improved conditions for forest growth in warmer climates could be advantageous in efforts to mitigate climate change [2,3,67]. This is due to the fact that forest ecosystems (biomass and soils) are highly productive in terms of carbon sequestration processes [3,68,69]. In addition, planting trees has long been used as a strategy to mitigate urban heat island effects [70] by multiple mechanisms, including decreased albedo [71].

## 5. Conclusions

From 1970–2014, a large increase in forest cover occurred in Johnson County, Iowa, to the east of Coralville Lake reservoir in Iowa, USA, and in Borisovka District of Belgorod Oblast, to the north of Vorskla River, Russia. Forest cover increased in the Belgorod Oblast by 36.6% during the study period, while in Iowa, the increase in forest cover was 67.5%. Several factors supporting these findings include (but are not limited to): the development of a recreational area adjacent to river areas (in Iowa), changes to conservation practices, a change in priorities of farmer landownership, the warming and moistening climate and the dense drainage network. Three mechanisms of forest advancement were investigated including: (a) the simultaneous appearance of forest as a result of the artificial planting of trees; (b) the growth of forest from groups or isolated trees; and (c) forest edge advancement. The average linear rate of forest growth, which in the context of mainly natural factors occupying meadow and steppe areas (pastures and haying lands), was approximately 14 m (Iowa study area) and 8 m (Belgorod study area) per decade, respectively.

Based on the 44-year study period, it was projected that the entire study area could be forested in about 80 years in Iowa and in approximately 300 years in Belgorod Oblast. The time period may be reduced given projections for a warmer and wetter future climate (assumes no further anthropogenic impacts). Rapid forest advancement similar to that shown in the current work may also have occurred during previous epochs when greater precipitation may have been observed, such as the Middle to Late Holocene or after 1000 A.D. It could thus be inferred from this work that the forests are “returning” to their historic, pre-human settlement, positions on the landscape in Iowa and Belgorod Oblast. Therefore, afforestation rates in association with a warmer and wetter climate may encourage afforestation, which may be advantageous for climate change mitigation.

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