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Spatiotemporal Dynamics of *Betula pendula* Crown Cover on Abandoned Arable Land in a Broad-Leaved Forest Zone of Bashkir Cis-Ural

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Abstract: Silver birch (Betula pendula Roth) is one of the fast-growing tree species that often colonize abandoned agricultural lands in Europe and the European part of Russia. The purpose of this article is to analyze the spatiotemporal dynamics of *Betula pendula* crown cover on abandoned arable lands in a zone of broad-leaved forests of the Bashkir Cis-Ural (Russia, Republic of Bashkortostan). The assessment of current and retrospective values of crown cover was carried out using a regression model of the dependence of crown cover on the values of red channel brightness in early-spring images from Landsat 5–8 and Sentinel-2 satellites from 2012–2022. To estimate the number and height of trees, a survey was carried out using a LiDAR camera mounted on a UAV. After calculating the crown cover in grid squares and their distance from the seed source in QGIS, variance analysis was carried out to assess the influence of the factor of distance from the seed source on the crown cover. The influence of the factor of distance from the seed source on the crown cover was higher at earlier stages of overgrowth of abandoned agricultural lands. An exception to this dependence was only one sample plot where the prevailing wind direction was opposite to the direction of seed dispersal. The leading factors affecting the distribution of birch on abandoned agricultural lands were wind direction, height of seed trees, and grazing. In the parts of the sample plots that were furthest away from seed sources, the trees were 1–3 years younger or the same age, and stand density was lower than in sites located closer to the seed trees. In general, the results of the present study indicate two opposite relationships between seedling survival and distance to seed trees: (1) seed fall and seedling density decrease with increasing distance from the seed tree, and (2) the probability of seed/seedling survival increases due to decreased competition.

Keywords: *Betula pendula*; abandoned croplands; crown cover; seed dispersal

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Citation: Fedorov, N.; Tuktamyshev, I.; Bikbaev, I.; Shirokikh, P.; Zhigunova, S.; Baisheva, E.; Martynenko, V. Spatiotemporal Dynamics of *Betula pendula* Crown Cover on Abandoned Arable Land in a Broad-Leaved Forest Zone of Bashkir Cis-Ural. *Forests* **2024**, *15*, 34. https://doi.org/10.3390/f15010034

Academic Editors: Mingyang Zhang, Huiyu Liu and Timothy A. Martin

Received: 8 November 2023
Revised: 6 December 2023
Accepted: 21 December 2023
Published: 22 December 2023

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1. Introduction

The silver birch (*Betula pendula* Roth) is a species with a wide natural range in the Eurasian continent, extending from the Atlantic coasts to the Far East. Although the silver birch is found almost all over Europe, the richest birch wood resources are found in the boreal and temperate forests of Northern Europe. In Baltic and Nordic countries, the share of birch in the total volume of the forest stand ranges from 11% to 28% [1]. The birch is tolerant of various soil conditions, so seeds can germinate and establish on sites with soil pH from 3.5 to 7.8 [2]. The number of seeds per square meter in a birch grove can reach hundreds of thousands [3]. In the temperate forests of Central Europe, a single silver birch tree can produce from 0.3 to 6.5 million seeds [4]. Birch seeds are 1.5–2.0 mm in size [5] weigh 0.12–0.25 mg [2], and are dispersed mainly from June to November [6]. In the climatic conditions of Central and Northern Russia, birch seeds ripen in the second half of July, and most of them are dispersed in August–September [7]. Seed productivity and dispersal are influenced by habitat conditions (e.g., wind, temperature, precipitation, light availability, etc.) and the structure of the stands [8,9]. Heavy fruiting in the silver birch is observed with different frequency depending on the conditions. Under favorable conditions, the silver birch usually has a productive year every 2–3 years, when seed viability increases [10]. In the semi-arid conditions of the forest steppes of the European part of Russia, high seed productivity is observed 1–2 times in 10 years and cannot be predicted in advance [11]. Seeds usually germinate in spring, when the snow melts and the temperature rises to positive values [2,6,12]. Seeds may not germinate simultaneously and can survive in the soil from 5 to more than 13 years [4,13,14].

In the Republic of Bashkortostan, the share of birch groves is 20.4% of the total forest area. The silver birch is one of the fast-growing species that often colonize abandoned agricultural land [1], including in the Bashkir Cis-Ural. The colonization of abandoned arable lands by the birch is associated not only with its high seed productivity, but also with the peculiarities of seed dispersal by wind. Although the average distance of wind dispersal for birch seeds varies from 40 to 360–400 m [15,16], seeds from trees with tall crowns are dispersed further, especially in stronger winds [17–19]. Winds with higher speeds are always turbulent, which increases seed dispersion due to both horizontal wind speed and seed fall speed [8,20–23]. Seeds that fall to the ground may undergo secondary dispersal—be carried further by wind or water flows that exceed the frictional force of the ground [8,24,25]. In order to understand how the colonization of abandoned lands contributing to the natural restoration of ecosystems occurs, it is necessary to determine what the main biotic and abiotic constraints are for this process and at what spatial scales they operate [26]. Thus, the colonization of abandoned lands by the birch can be influenced to a certain extent by the frequency of intensive fruiting, the height and number of seed-bearing trees, as well as the direction and speed of the wind [6,27–29].

The success of natural regeneration depends on complex interactions in the structure of forest stands and on natural processes of seed dispersal and seedling development. In particular, the spatial pattern of seed dispersal, the formation and growth of seedlings, as well as microenvironmental factors, are closely interconnected, thus determining the results of natural regeneration [29]. For a retrospective analysis of the spatial patterns of tree species formation and growth on abandoned agricultural lands, long-term ground observations or multispectral images from different years with a resolution that allows for the visualization of small tree seedlings are required. Currently, LiDAR images are widely used. They were not available in the early 21st century due to their high cost. LiDAR sounding is a good solution to explore the vegetation dynamics of abandoned agricultural lands. Three-dimensional laser scanning allows for the determination of stand parameters such as volume, crown area, and stand height, which are closely related to the stages of reforestation [30–32]. However, some information about the formation of tree stands on abandoned arable lands can be obtained using the dynamics of changes in crown cover—the vertical projection area of the tree crown edge (the outermost perimeter of the natural spread of the foliage, which includes within-crown gaps) per unit of the horizontal ground surface area, which includes within-crown gaps [33]. Globally, changes in the tree canopy cover (TCC) of trees higher than 5 m were analyzed during the periods 2000–2012 and 2012–2022, and changes in forest canopy cover were calculated based on the regression relationship between TCC and NDVI [34]. With the expansion of forests on fallow arable lands, an increase in canopy cover correlates with stand age, and, thus, reflects the stages of reforestation succession [35]. Despite numerous publications on the dynamics of overgrowing of abandoned agricultural lands, questions are raised about the mechanism of forest stand mosaic formation on fallow lands. The purpose of this article is to analyze the spatiotemporal dynamics of crown cover of *Betula pendula* on abandoned arable lands in a broad-leaved forest zone of the Bashkir Cis-Ural.

2. Materials and Methods

The study area is located in a broad-leaved forest zone of the Bashkir Cis-Ural (Russia, Republic of Bashkortostan) (Figure 1). The climate in the study area is moderately continental, warm, and slightly arid [36]. The average annual air temperature and annual precipitation are 3.5 °C (−12.6–19.5 °C) and 600 mm, respectively. The soil type is represented mainly by gray forest soils, less often by dark gray forest soils, and both soil types are classified as Luvic Greyzemic Phaeozems in the WRB classification [37].

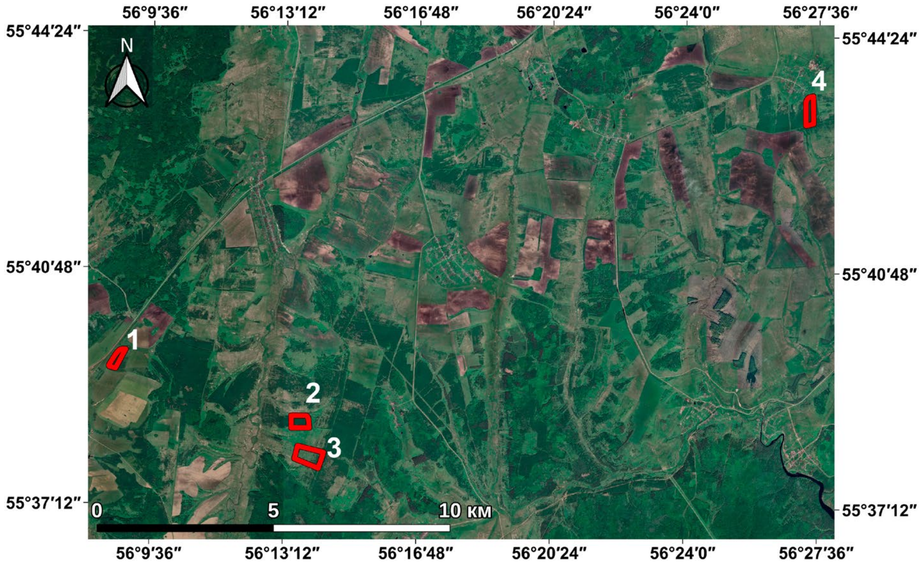

Figure 1. Location of sample plots in abandoned arable lands overgrown with silver birch (*Betula pendula*) within the study area in the zone of broad-leaved forests of the Bashkir Cis-Ural (Republic of Bashkortostan).

The native forest vegetation of the study area is represented by secondary mixed broad-leaved forests with *Tilia cordata* Mill., *Ulmus glabra* Huds., *Acer platanoides* L., *Quercus robur* L., and less often by birch groves with a predominance of *Betula pendula*. Plant communities representing different successional stages of forest restoration on abandoned arable lands are also common in the study area [35]. Abandoned arable lands are overgrown mainly by the silver birch, less often by the aspen (*Populus tremula* L.) or the goat willow (*Salix caprea* L.). Areas located near pine woods may also be overgrown by the pine (*Pinus sylvestris* L.).

This study was carried out on four sample plots within the study model area (Figures 1 and 2).

Despite the proximity of abandoned arable lands to broad-leaved forests, no regeneration of the lime, maple, elm, or oak was observed.

The distance from the seed sources to the opposite edge of the sample plots ranged from 391 to 776 m (Table 1). In the remote part of Sample Plot 3, a few isolated *Pinus sylvestris* trees were found. During the period of mass dispersal of birch seeds (July–October), northwest winds prevailed. The direction of seed dispersal did not coincide with the prevailing wind direction. The seed sources on Sample Plots 1, 3, and 4 were birch stands. On Sample Plot 2, the seed source was a narrow strip of birch groves in a land depression. The elevation difference between the depression and the near and far edges of the sample plot was 10 and 23 m, respectively.

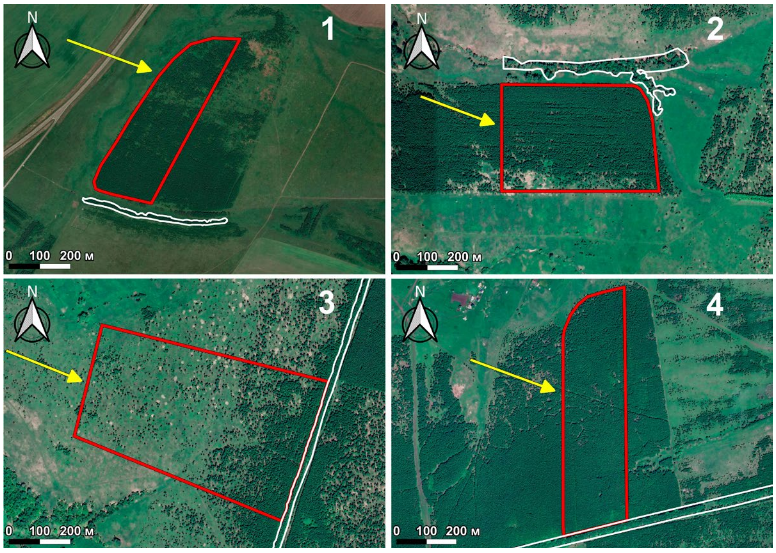

Figure 2. Prevailing wind direction and location of seed sources on sample plots overgrown with silver birch (*Betula pendula*) on abandoned arable land in a broad-leaved forest zone of the Bashkir Cis-Ural (Republic of Bashkortostan). Notes: Yellow arrows show the prevailing wind direction, and white lines indicate sites with mature birch trees that are the sources of seeds dispersed to the sample plots.

Table 1. Characteristics of sample plots in a broad-leaved forest zone of the Bashkir Cis-Ural (Mishkinsky District, Republic of Bashkortostan).

No. of Sample Plot	Coordinates of Center of Sample Plot	Surface Topography	Sample Plot Size		Distance between Seed Source and Opposite Edge of Sample Plot	Seed Dispersal Direction on Sample Plot	Elevation, m above Sea Level
			Length, m	Area, ha			
1	N55°39′24″, E56°8′41″	Flat surface	604	9.37	640	NE	176
2	N55°38′28″, E56°13′39″	NW slope, 3.6°	345	16.03	391	S	202
3	N55°37′57″, E56°13′54″	W slope, 2.0°	756	32.15	756	NW	231
4	N55°43′17″, E56°27′21″	Flat surface	776	15.04	776	N	204

To assess the current and retrospective values of the crown cover (CC) of tree stands in overgrown areas of abandoned arable land, grid mapping with a square size of 30 × 30 m was used [38], which coincides with the size of pixels in Landsat satellite images and the SRTM-2 digital elevation model, which are freely available through the USGS Earth explorer electronic resource [39]. The age of the tree stands was determined by counting annual rings. Wood samples (cores) were taken from the lower part of the trunks at the lowest possible height (15–40 cm above the ground) using a Haglöf age auger (Långsele, Sweden). Measurements of the width of annual layers of wood were performed using a stereo microscope MBS (Micromed, Moscow, Russia) with the TSAP-WinTM V. 4.89 software package of the Lintab measurement platform [40].

As a preliminary step, a polygonal grid layer with polygons sized 30 × 30 m was created in QGIS to build the regression model. This grid layer was used to select sample plots with differences in crown density and tree stand age on the Google satellite map. At least 10 sample plots were selected for each class of projective tree cover (up to 1%, 1%–5%, 5%–15%, 15%–25%, 25%–50%, 50%–75%, 75%–100%). In July, during the period of maximum crown development, sample plots sized 30 × 30 m, the centers of which coincided with the centers of the selected polygons on the grid map, were laid. In total, data on crown density, stand composition, and tree height were obtained from 189 sample plots.

After this, several regression equations were calculated for the dependence of the CC on red channel brightness values from Landsat 8 and Sentinel-2 images for different dates in winter and early spring of 2021. To estimate the CC of birch stands on overgrowing arable lands, a regression model was used, based on an inverse correlation between the intensity of sunlight reflected in the snow in the inter-trunk spaces in the red spectrum and the CC measured in the summer (Figure 3). The software "Statgraphics Centurion 19" was applied for regression analysis, and the algorithm "Comparison of Alternative Models" was used to select the optimal regression model. The most optimal equation was calculated using an early spring image for 8 April 2021 [38]:

$$CC = (12.9157 - 17.4905 \times RED)^2$$

where RED—brightness values of the red channel, CC—birch crown cover.

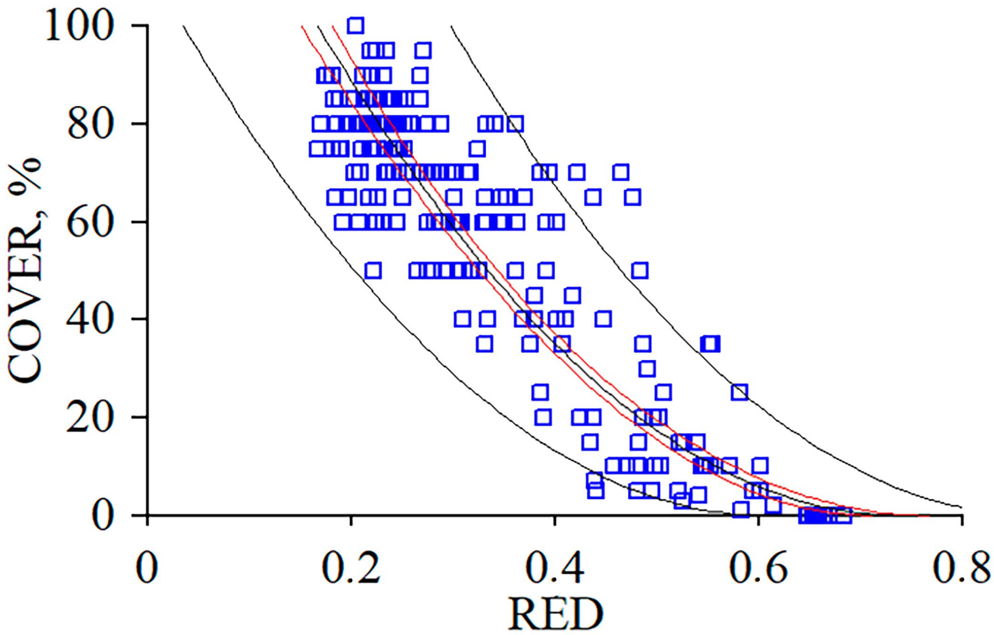

Figure 3. Regression model of dependence of birch stand crown cover on red channel brightness values.

The equation has a correlation coefficient R = −0.90 and a determination coefficient R^2 = 0.81 [38]. Early spring images (late March–early April) were used to build the regression model. At this time, the average thickness of the snow cover was 20 cm and the grass layer was still buried under the snow. The model allows for the identification of birch seedlings with a height of 1.5–2.0 m, and the minimum value is only 10%, which is unattainable when using satellite images taken during the growing season. At the same time, the accuracy of the assessment increases as the CC increases [38].

A retrospective assessment of birch stand CC within the sample plots was carried out using the obtained regression model of the dependence of the CC on the brightness values of the red channel in early spring satellite images from Landsat 5, Landsat 7, Landsat 8, and Sentinel-2 [38]. To analyze the CC dynamics of birch stands on the sample plots, Satellite images from 8 April or the closest possible date from 2009 to 2022 were used. There were no earlier cloudless images available for the required period of time. Brightness values in grid polygons were calculated from the red channels of retrospective images in the Zonal Statistics module of QGIS 3.22 software. To estimate the distance from the seed source to the centers of the grid map squares (centroids), the "NNJoin" module of the QGIS 3.22 software was used [41]. After calculating the CC in the grid squares and their distance from the seed source, an analysis of variance on the effect of the distance from seed source on CC was carried out in the Statgraphics Centurion 19 program using the one-factor analysis of variance (ANOVA) tool [42].

In June 2023, to assess the current state of the forest stand (number of trees and their CC) in different parts of the sample plots, a survey of the forest stand was carried out from a height of 50 m using a Zenmuse L1 LiDAR camera installed on a DJI Matrice 300 RTK UAV (Shenzhen, China). The resulting images were imported into the DJI Terra program and automatically stitched together. As a result, a single cloud of imaging points was formed in LAS format with a density of 300 to 950 imaging points per m^2 [43]. Post-processing of the scanning results was performed in the Lidar360 Version 4.5 program (Green Valley International Ltd., Hornchurch, UK). Next, using the ASL Forest module of the Lidar 360 program, the number of trees, their geometric coordinates on the image, and the height of the trees were calculated.

3. Results

As can be seen from Table 2, in 2023, the age of the tree stands at the sample plot edges adjacent to the seed trees ranged from 21 to 24 years. The age of the tree stands in the part opposite from the seed sources was equal to that of the tree stands near the seed sources or lower by 1–4 years. Thus, the main settlement of these abandoned arable land areas with birches took place in 1999–2002. Unlike in 2003, when there was a spring–summer drought (the amount of precipitation for the year, including winter, was half the average), the amount of precipitation was favorable during the years of birch expansion [44]. Currently, in the parts of the sample plots adjacent to the seed trees, tree stand density (number of trees, pcs/ha) was 2–3 times higher than at their opposite ends on Sample Plots 1–3 and only 30% higher in Sample Plot 4. At the same time, on Sample Plot 4, the CC at the edge of the plot adjacent to the seed trees was lower than at the opposite part.

Table 2. Characteristics of *Betula pendula* stands in parts of sample plots located near and far from seed sources.

No. of Sample Plot	Average Height of Seed Trees, m	Age Range of Tree Stand, years		Number of Trees in 2022, pcs/ha		Average Height of Trees in Sample Plots, m	
		Near Seed Source	Far from Seed Source	Near Seed Source	Far from Seed Source	Near Seed Source	Far from Seed Source
1	19.4 ± 0.1	21–22	20–21	1568	740	14.2 ± 0.1	12.2 ± 0.2
2	22.4 ± 0.1	21–22	21–22	1548	504	14.8 ± 0.1	12.1 ± 0.2
3	21.2 ± 0.1	22–24	19–22	476	256	14.1 ± 0.1	9.2 ± 0.2
4	24.0 ± 0.2	22–24	20	1068	720	11.9 ± 0.1	11.5 ± 0.1

As can be seen from Figure 4, on Sample Plot 1 in 2009, the CC of birch trees 8–9 years of age and 1.5–2 m in height was on average close to 24% at a distance of up to 100 m from the seed source and no more than 5% at a distance of 200–600 m. Therefore, CC distribution is consistent with the inverse power function, as maximum overgrowth occurs at a distance of up to 100 m from the plot edge adjacent to the seed trees. The strength of factor influence (the ratio of intergroup to total variance) of the distance from seed source was 0.76 in 2009, and in 2022, it decreased to 0.18 (Table 3). By the time birch trees reach 21–22 years of age, a closed tree stand is formed throughout the entire sample plot along the entire gradient of distance from the seed source.

Table 3. Changes in the strength of factor influence (distance from seed source trees) on the crown cover of *Betula pendula* during tree stand formation on abandoned arable lands.

Sample Plot Number	Strength of Factor Influence η2 *					
	2009	2012	2014	2016	2017	2021
1	0.76	0.57	0.53	0.49	0.45	0.24
2	0.61	0.70	0.69	0.64	0.67	0.63
3	0.40	0.72	0.64	0.69	0.68	0.76
4	0.90	0.86	0.74	0.47	0.35	0.40

* η2—ratio of intergroup to total variance.

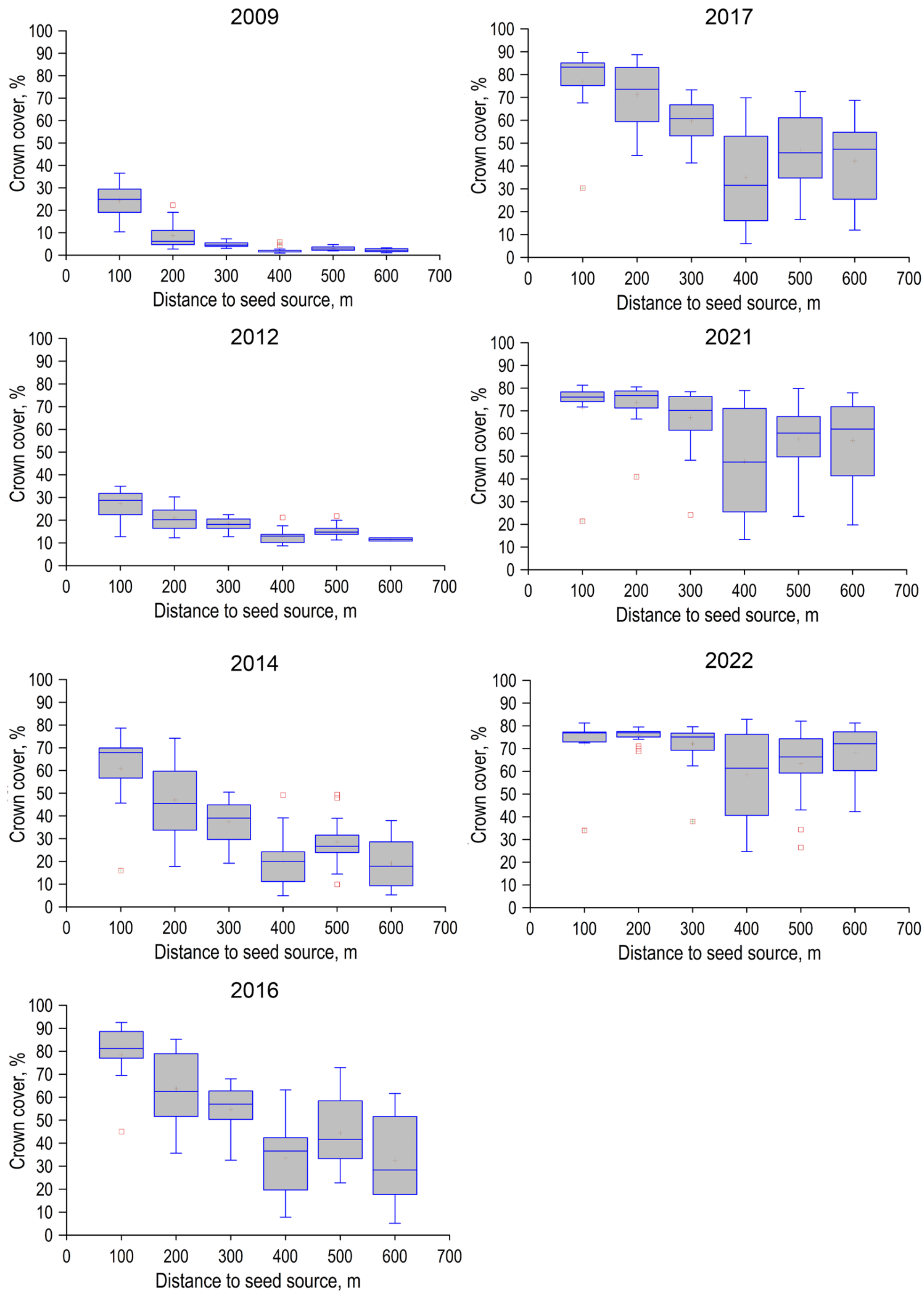

Figure 4. Influence of distance from seed source on the crown cover of *Betula pendula* during the overgrowth of abandoned arable land on Sample Plot 1; seed source—forest belt; prevailing wind direction does not coincide with direction of seed dispersal. Red squares indicate the values outside the confidence interval.

Sample Plot 2 was different from the others both in terms of size—its length was shorter by 250 m compared to the other plots—and in terms of the location of the seed trees. The latter were growing in a 10-meter-deep land depression, but were taller than the seed trees of other plots by 3 m. As a result, on Sample Plot 2, tree height was 7 m shorter in relation to the plot edge than, for example, on Sample Plot 1 (Table 2).

In 2009, on Sample Plot 2, the CC of growing birch trees was, on average, 25% at a distance of up to 100 m from the seed source, but here, the difference between the CC at a distances of up to 100 and 200 m was smaller than in Sample Plot 1 (Figure 5). The strength of influence of the "distance from the seed source" factor on the CC was smaller and amounted to 0.61. Five years later, in 2014, the differences in CC along the gradient of distance from seed source on Sample Plot 2 became more apparent and, in contrast to Sample Plot 1, the strength of influence of this factor on the CC did not decrease, but rather increased to 0.69. In subsequent years, the strength of influence of this factor on the CC slightly decreased. In 2021–2022, the CC of 21–22-year-old birch trees leveled out at a distance of up to 300 m from the seed source and reached 80% on average, while an open forest formed at the opposite edge of the plot.

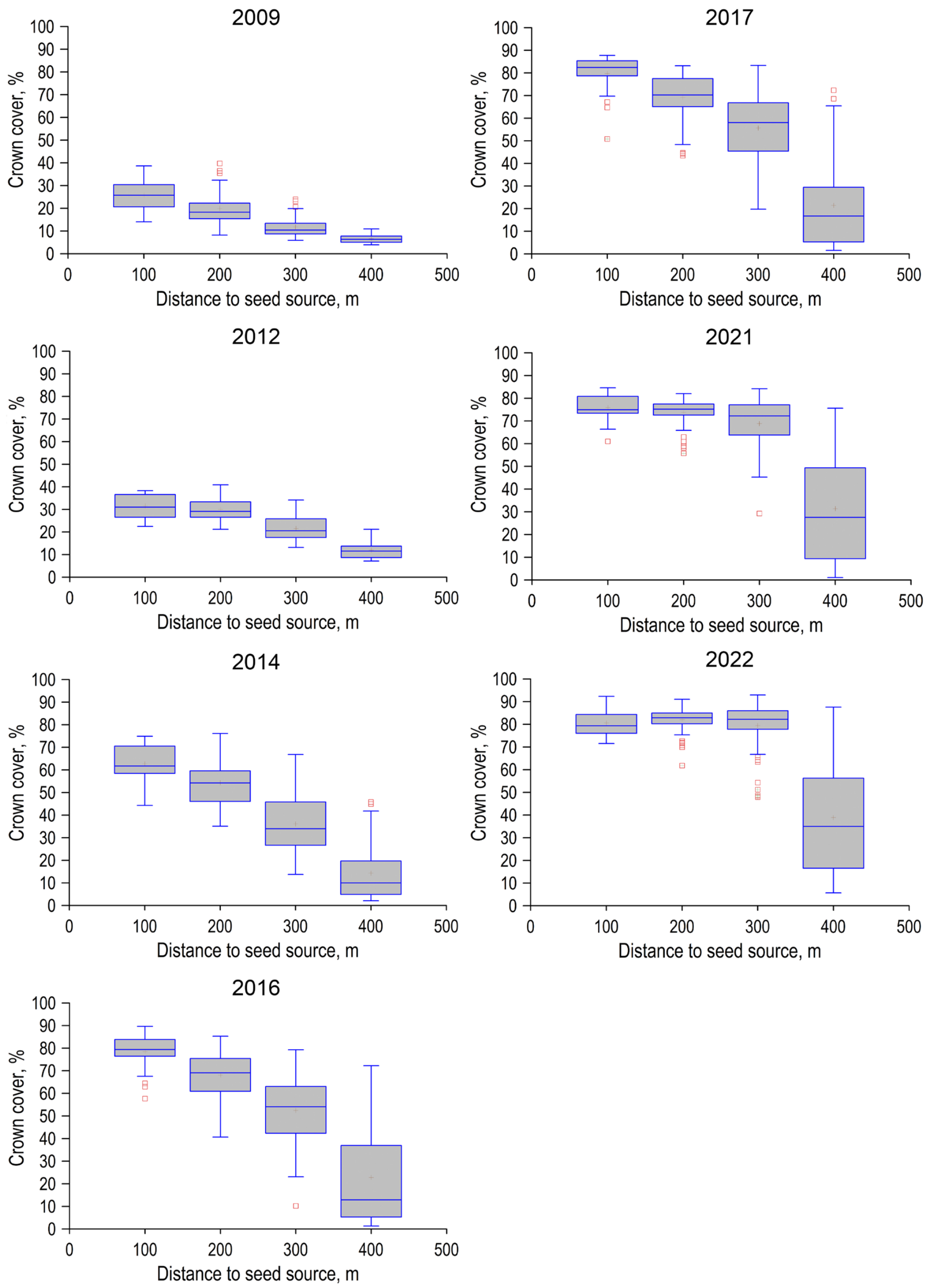

Figure 5. Influence of distance from seed source on the crown cover of *Betula pendula* during the overgrowth of abandoned arable land on Sample Plot 2; seed source—birch grove in land depression; prevailing wind direction does not coincide with direction of seed dispersal.

The source of seeds for Sample Plot 3 was a strip of birch forest. Unlike Sample Plots 1 and 2, here, the prevailing wind direction was opposite to the direction of seed dispersal and the CC was less than 5% throughout the entire distance between 100 and 800 m, and in 2009, the differences were not statistically significant (Figure 6). The strength of influence of the "distance from the seed source" factor on the CC amounted only to 0.40. Within the distance of 100 m from the seed source, the average CC was only 16% in 2014, and over the next 200–800 m, it was less than 5%. A clear tendency was formed for the CC to decrease with increasing distance from seed source. As a result, the strength of influence of the "distance from the seed source" factor increased to 0.65. This trend continued to intensify, and in 2022, at the tree age of 20–22 years, the average CC at a distance of up to 100 m increased to 65%, but at a distance of 200 m, it was 45%, and the strength of this factor's influence increased to 0.78. Thus, the complete mismatch between the direction of seed dispersal and the direction of prevailing winds reduced the density of seed dispersal but did not affect the distance of their dispersal.

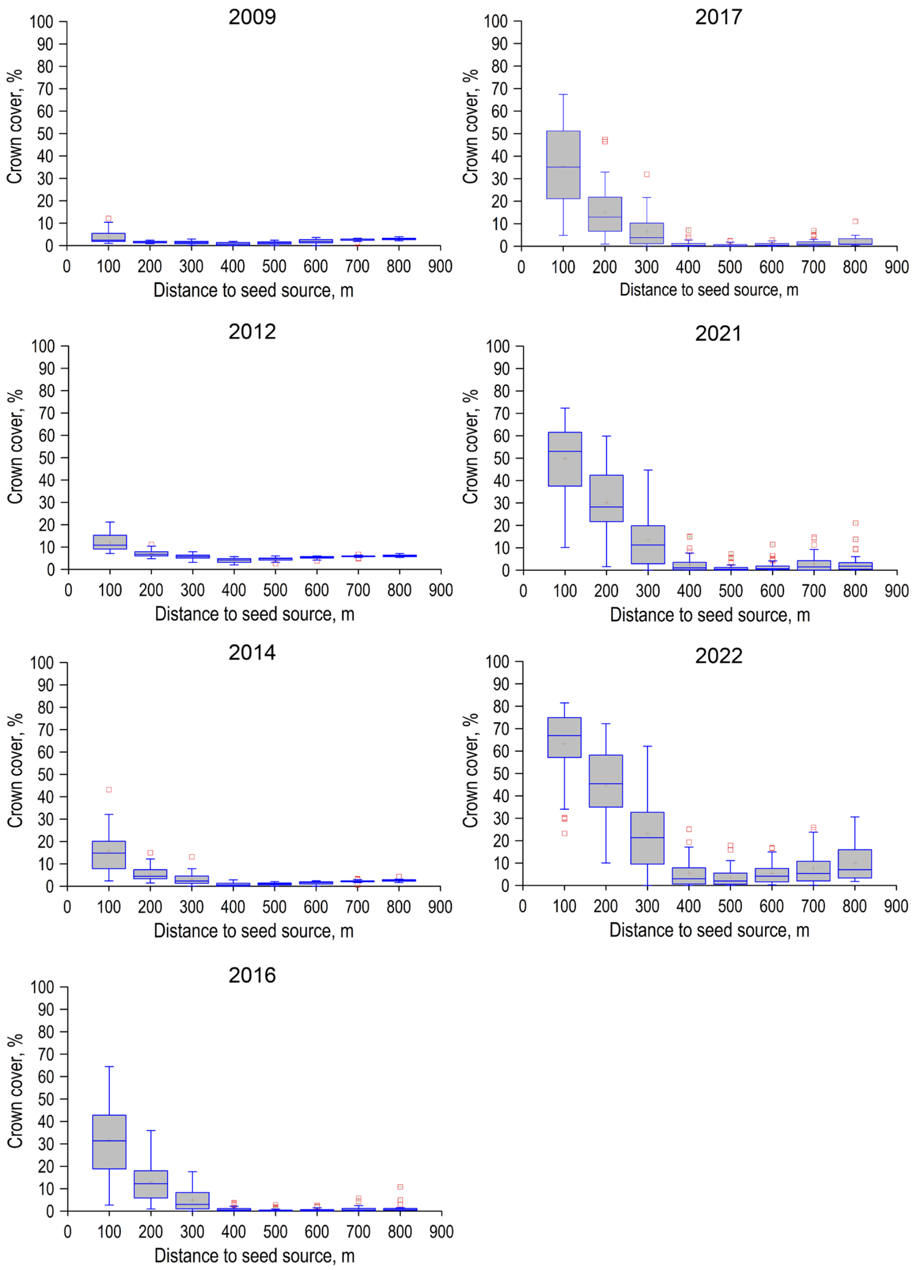

Figure 6. Influence of distance from seed source on the crown cover of *Betula pendula* during the overgrowth of abandoned arable land on Sample Plot 3; seed source—forest belt; prevailing wind direction is opposite to direction of seed dispersal.

The source of seeds for Sample Plot 4 was a birch grove. On the opposite side, the sample plot was adjacent to a village, and thus, at the time the abandoned arable land began to be overgrown with birches, grazing became an additional factor. As can be seen from Figure 7, at a distance of 100 m from the seed source, the CC in 2009 was higher than on other sample plots and amounted to 52%, but at a distance of 600–800 m, it decreased sharply. The strength of influence of the "distance from the seed source" factor was the highest in 2009 and amounted to 0.90. In 2014, at a distance from seed source of up to 400 m, the CC was already more than 70%, and by 2017, a closed forest stand had formed along the entire distance gradient. At the same time, the strength of this factor's influence decreased to 0.35. In 2022, the strength of this factor's influence increased to 0.45, while the CC of the tree stand became the highest at a distance of 600–800 m from the seed source.

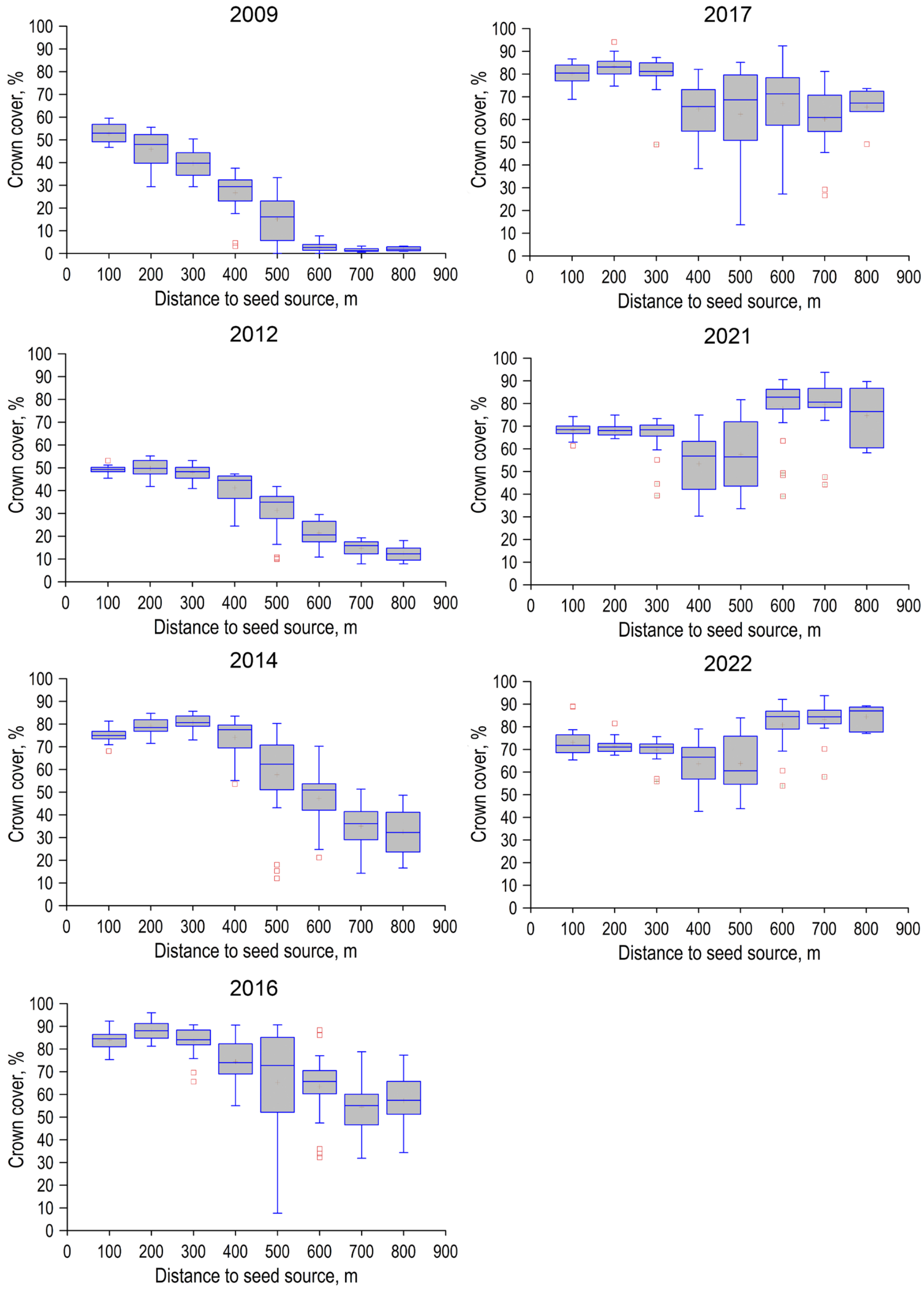

Figure 7. Influence of distance from seed source on the crown cover of *Betula pendula* during the overgrowth of abandoned arable land on Sample Plot 4, near a village; seed source—birch grove; prevailing wind direction does not coincide with direction of seed dispersal.

4. Discussion

Detailed knowledge of the spatial distribution of animal and plant species is essential for the development of a deep understanding of many branches of ecology [45]. Spatial point pattern analysis of developing forest stands on abandoned arable lands is a complex, multifactorial task, defined by seed productivity, primary and secondary seed dispersal, the soil seed bank [4,13,14], habitat conditions (e.g., wind, temperature, precipitation, illumination), and stand structure [8,9], all of which affect the growth of woody plants. The studied sample plots were located on relatively flat areas at a short distance from each other and, therefore, did not differ in temperature and precipitation. The start dates of overgrowth were close to one another (2000–2002), which indicates an almost simultaneous cessation of their use as arable land. At the initial stages of birch overgrowth of the sample plots, the CC was low. This finding highlights the patterns of seed dispersal, which are generally in agreement with the literature data [46–48]. Therefore, the influence of the "distance from the seed source" factor on the CC was higher at earlier stages of overgrowth. The exception is Sample Plot 3, where the direction of prevailing winds is opposite to the direction of seed dispersal. Thus, despite the fact that during the dispersal of birch seeds in the study area, winds with a speed of up to 3.3 m/s predominate (winds with a speed of 3.4–5.4 m/s are less prevalent, and moderate winds with a speed of 5.5–7.9 m/s are quite rare), their influence is quite significant (Figure 8). This is due to the fact that instantaneous wind speed profiles never correspond to their average values. Average wind speed values are an extremely complex integral of systematic and turbulent flows on many temporal and spatial scales [20]. In addition, the elevation in the area of Sample Plot 3 is 30–60 m higher than the other sample plots (Table 1). In this regard, wind speed on this sample plot is enhanced by its topographic position. In 2009, birch overgrowth in this area was characterized by less than 10% of CC. Since 1948, the Food and Agriculture Organization of the United Nations (FAO) has defined forests as having a canopy cover higher than this value [49], i.e., "Land with trees more than 5 m tall and a canopy cover of more than 10%" [50]. Therefore, the developing tree stand was not yet a forest at this stage. On Sample Plot 3, even over 23 years after the start of overgrowth, a closed forest stand formed only at a distance of up to 100 m from the birch grove, and the density of the living tree stand was 2–3 times lower than on other sample plots. However, single trees were found at a distance of up to 800 m from the seed source. Thus, wind direction was one of the leading factors in the dispersal of birch seeds on abandoned arable lands.

The height of seed source trees relative to the overgrown area also had a significant impact. On Sample Plot 2, trees growing in a 10-meter land depression were 7 m shorter than those growing at the edge of the overgrown field on Sample Plot 1. Therefore, the distance of effective seed dispersal, which ensured the formation of a closed forest stand by the age of 20, on Sample Plot 2 was 300 m less than on Sample Plot 1. Such a strong difference is apparently due to the fact that seeds can "rise" above their release height in very strong winds due to air turbulence, and then steadily glide down from this higher point (assuming they are not picked up by subsequent turbulence) [51]. This is consistent with the literature data, which indicate that the stronger the wind and the taller the tree, the longer and farther the seeds will fly [52]. The formation of a closed forest stand at a distance of 600 m from the seed source on Sample Plot 1 over 20 years after the start of overgrowth indicates that fully developed seeds were dispersed to this distance. This is consistent with the literature data, which indicate that the transition of seeds into the long-distance dispersal phase depends more on the characteristics of the prevailing winds than on internal differences between seeds [17,18,53,54].

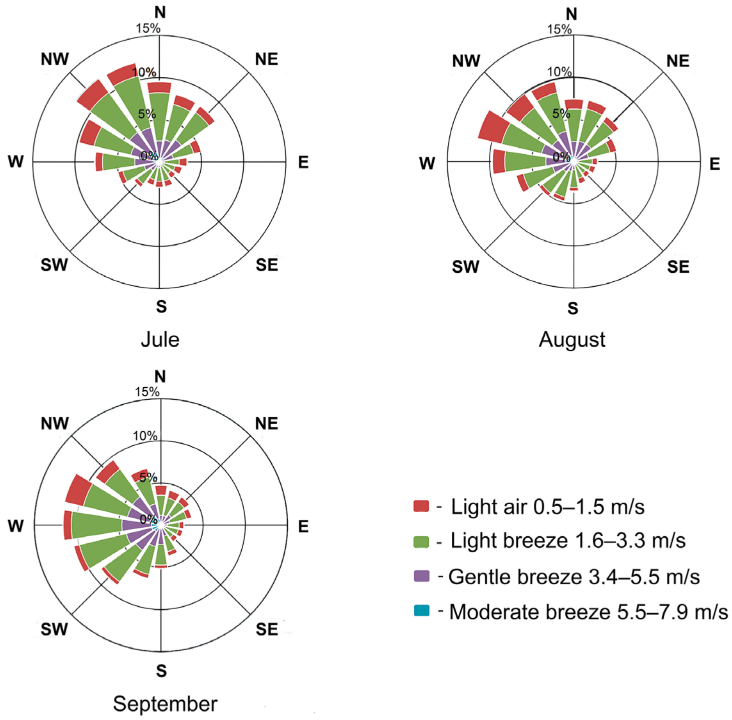

Figure 8. Wind rose diagram during the period of main seed dispersal in the study area (https://ru.meteocast.in/, accessed on 23 November 2023).

The most intensive birch growth occurred on Sample Plot 4, which was due to its proximity to a pasture on the outskirts of a village and to grazing of livestock after it ceased to be used as a field. Grazing of livestock suppressed herbaceous vegetation, and the disturbance of the grass turf contributed to the dispersal of the birch. On hot summer days, livestock entered the emerging birch groves from the side adjacent to the village, which contributed to the enrichment of the soil with animal waste products. This contributed to the growth of birch groves and to an increase in CC value to higher values than at the edge of the sample plot near the seed sources.

In the parts of the sample plots most distant from the seed source, the trees were 1–3 years younger or the same age (on Sample Plot 3), and the tree stands were sparser than in the parts of the sample plots located near the seed sources. Tree density at the sites farthest from the seed source was less than 800 trees/ha, that is, less than the tree density required for the greatest productivity of the stand at this age [55]. Accordingly, the trees grew in more favorable conditions. In 2022, on Sample Plots 1 and 4, the CC values of sites located near and far from the seed sources were practically indistinguishable. In general, the results of this study indicate two opposite dependencies of seedling survival on distance from seed trees: (1) seed fall and seedling density decrease with increasing distance from seed source, while (2) the probability of survival of seeds/seedlings increases due to decreased competition.

The ecological and biological characteristics of the silver birch allow it to play an important role in the processes of forest restoration after disturbances. In Russia, as in Western Europe, the birch is an underestimated native species for forestry, but has great potential [56]. Knowledge about birch seed productivity and seed dispersal is necessary to predict the probability of birch regeneration on abandoned arable lands. This helps to clarify whether the regeneration of birch forests in disturbed areas is limited by the number of seed sources or by dispersal distance. Considering the important role of the birch in the reforestation of abandoned agricultural lands, it is necessary to study the spatial patterns of the formation of birch stands in various climatic conditions. The heterogeneity of stand CC affects the diversity of the herb layer and the possibility of other tree species penetrating into the forest community. Analyzing the growth rate of the birch at sites with different tree stand densities can be useful for estimating the optimal tree stand density when using birch groves on abandoned arable lands as a source of timber. Because of the rapid growth of the birch, these groves are effective for carbon sequestration. Determining the dependence of greenhouse gases on the CC and density of tree stands may help to optimize the structure of birch forests to create carbon farms. Carbon accumulation in the forests can be increased through active forest management measures, such as pruning and thinning, which improve stand growth on these recovering lands [57].

5. Conclusions

This study showed that forest restoration on abandoned arable lands in the forest steppe zone of the Cis-Ural is influenced by several environmental variables: wind direction, tree height, and livestock grazing. This study did not allow us to assess the contribution of seed banks to the formation of the stands, which may have had their own impact, as well as of secondary seed transfer. The results obtained explain the occurrence of a mosaic of density and projective cover of birch forests on abandoned arable lands. They allow us to predict birch overgrowth in new areas of abandoned agricultural lands. In addition, they provide a basis for studying the course of reforestation succession depending on the distance from seed sources and abiotic habitat factors. The methodology used for the retrospective analysis of birch overgrowth in abandoned arable lands can be used to analyze the formation of the spatial structure of other tree species with different seed dispersion and seed productivity. Our method has some limitations and it is primarily applicable to monodominant stands with unexpressed vertical structures. Due to the fact that stands with *Pinus sylvestris* may also be found to overgrow abandoned agricultural lands, it is necessary to further improve the methods of retrospective analysis of stand formation.

Author Contributions: Conceptualization, N.F. and V.M.; methodology, N.F., I.B., V.M. and P.S.; software, N.F., I.B. and P.S.; validation, N.F., P.S. and S.Z.; formal analysis, I.B., I.T. and P.S.; investigation, N.F., P.S., I.B., I.T. and E.B.; data curation, N.F. and P.S.; writing—original draft preparation, N.F., I.B., S.Z. and V.M.; writing—review and editing, N.F., I.B., S.Z., V.M., E.B. and P.S.; visualization, I.T. and S.Z.; project administration, N.F. and P.S. All authors have read and agreed to the published version of the manuscript.

Funding: The study was supported by a grant of the Russian Science Foundation No. 22-24-00186, https://rscf.ru/en/project/22-24-00186/, accessed on 23 November 2023.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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

References

1. Uri, V.; Varik, M.; Aosaar, J.; Kanal, A.; Kukumägi, M.; Lõhmus, K. Biomass production and carbon sequestration in a fertile silver birch (*Betula pendula* Roth) forest chronosequence. *For. Ecol. Manag.* **2012**, *267*, 117–126. [CrossRef]
2. Atkinson, M.D. *Betula pendula* Roth (*B. verrucosa* Ehrh.) and *B. pubescens* Ehrh. *Russ. J. Ecol.* **1992**, *80*, 37–870. [CrossRef]
3. Koski, V.; Rousi, M. A review of the promises and constraints of breeding silver birch (*Betula pendula* Roth) in Finland. *Forestry* **2005**, *78*, 187–198. [CrossRef]
4. Tiebel, K.; Huth, F.; Wagner, S. Is there an effect of storage depth on the persistence of silver birch (*Betula pendula* Roth) and rowan (*Sorbus aucuparia* L.) seeds? A seed burial experiment. *Iforest-Biogeosciences For.* **2021**, *14*, 224–230. [CrossRef]
5. Brouwer, W.; Stählin, A. *Seed Manual of Agriculture, Horticulture and Forestry [Handbuch der Samenkunde für Landwirtschaft, Gartenbau und Forstwirtschaft]*; DLG-Verlags-GmbH: Frankfurt am Main, Germany, 1975; 655p.
6. Perala, D.A.; Alm, A.A. Reproductive ecology of birch: A review. *For. Ecol. Manag.* **1990**, *32*, 1–38. [CrossRef]
7. Chizhov, B.E.; Ivanova, R.I.; Shtol, V.A.; Kulyasova, O.A. The features of silver birch *Betula verrucosa* Ehrh. and downy birch *Betula pubescens* Ehrh. seed regeneration in subtaiga and forest-steppe of Western Siberia. *Sibirskij Lesnoj Zurnal* **2016**, *6*, 49–59. [CrossRef]
8. Minami, S.; Azuma, A. Various flying modes of wind-dispersal seeds. *J. Theor. Biol.* **2003**, *225*, 1–14. [CrossRef]
9. Kohler, M.; Pyttel, P.; Kuehne, C.; Modrow, T.; Bauhus, J. On the knowns and unknowns of natural regeneration of silviculturally managed sessile oak (*Quercus petraea* (Matt.) Liebl.) forests—A literature review. *Ann. For. Sci.* **2020**, *77*, 101. [CrossRef]

10. Sarvas, R. A research on the regeneration of birch in Southern Finland. *Commun. Inst. For. Fenn.* **1948**, *35*, 1–91. (In Finnish (English Summary)).
11. Krasnobaeva, K.V.; Singatullin, I.K. *Recommendations on Management in Birch Forests of Mixed Forests and Forest-Steppe Subzone (on the Example of the Republic of Tatarstan)*; GUP PIK Idel-Press: Kazan, Russia, 2002; 32p.
12. Midmore, E.K.; McCartan, S.A.; Jinks, R.L.; Cahalan, C.M. Using thermal time models to predict germination of five provenances of silver birch (*Betula pendula* Roth) in southern England. *Silva Fenn.* **2015**, *49*, 1266. [CrossRef]
13. Granström, A. Seed viability of fourteen species during five years of storage in a forest soil. *J. Ecol.* **1987**, *75*, 321–331. [CrossRef]
14. Skoglund, J.; Verwijst, T. Age structure of woody species populations in relation to seed rain, germination and establishment along the river Dalälven, Sweden. *Vegetatio* **1989**, *82*, 25–34. [CrossRef]
15. Huth, F. Studies on the Regeneration Ecology of the Sand Birch (Betula pendula Roth) [Untersuchungen zur Verjüngungsökologie der Sand–Birke (Betula pendula Roth)]. 2009. Available online: https://tud.qucosa.de/landing-page/?tx_dlf[id]=https://tud.qucosa.de/api/qucosa%253A25272/mets (accessed on 5 November 2023).
16. Tiebel, K.; Huth, F.; Frischbier, N.; Wagner, S. Restrictions on natural regeneration of storm–felled spruce sites by silver birch (*Betula pendula* Roth) through limitations in fructification and seed dispersal. *Eur. J. For. Res.* **2020**, *139*, 731–745. [CrossRef]
17. Greene, D.F.; Johnson, E.A. Fruit abscission in *Acer saccharinum* with reference to seed dispersal. *Can. J. Bot.* **1992**, *70*, 2277–2283. [CrossRef]
18. Greene, D.F.; Johnson, E.A. Particulate diffusion models and the dispersal of seeds by the wind. *Trends Ecol. Evol.* **1989**, *4*, 191–192. [CrossRef]
19. Nathan, R.; Safriel, U.N.; Noy-Meir, I.; Schiller, G. Seed release without fire in *Pinus halepensis*, a Mediterranean serotinous wind-dispersed tree. *J. Ecol.* **1999**, *87*, 659–669. [CrossRef]
20. Horn, H.S.; Nathan, R.A.N.; Kaplan, S.R. Long–distance dispersal of tree seeds by wind. *Ecol. Res.* **2001**, *16*, 877–885. [CrossRef]
21. Tackenberg, O.; Poschlod, P.; Kahmen, S. Dandelion seed dispersal: The horizontal wind speed does not matter for long-distance dispersal-it is updraft! *Plant Biol.* **2003**, *5*, 451–454. [CrossRef]
22. Tackenberg, O. Modeling long distance dispersal of plant diaspores by wind. *Ecol. Monogr.* **2003**, *73*, 173–189. [CrossRef]
23. Lentink, D.; Dickson, W.B.; Van Leeuwen, J.L.; Dickinson, M.H. Leading-edge vortices elevate lift of autorotating plant seeds. *Science* **2009**, *324*, 1438–1440. [CrossRef]
24. Kaproth, M.A.; McGraw, J.B. Seed viability and dispersal of the wind-dispersed invasive *Ailanthus altissima* in aqueous environments. *For. Sci.* **2008**, *54*, 490–496.
25. Zhu, J.; Liu, M.; Xin, Z.; Liu, Z.; Schurr, F.M. A trade-off between primary and secondary seed dispersal by wind. *Plant Ecol.* **2019**, *220*, 541–552. [CrossRef]
26. Pías, B.; Escribano-Avila, G.; Virgós, E.; Sanz-Pérez, V.; Escudero, A.; Valladares, F. The colonization of abandoned land by Spanish juniper: Linking biotic and abiotic factors at different spatial scales. *For. Ecol. Manag.* **2014**, *329*, 186–194. [CrossRef]
27. Gómez-Aparicio, L.; Gómez, J.M.; Zamora, R. Microhabitats shift rank in suitability for seedling establishment depending on habitat type and climate. *J. Ecol.* **2005**, *93*, 1194–1202. [CrossRef]
28. Dey, D.C.; Knapp, B.O.; Battaglia, M.A.; Deal, R.L.; Hart, J.L.; O'Hara, K.L.; Schuler, T.M. Barriers to natural regeneration in temperate forests across the USA. *New For.* **2019**, *50*, 11–40. [CrossRef]
29. Im, C.; Chung, J.; Kim, H.S.; Chung, S.; Yoon, T.K. Are seed dispersal and seedling establishment distance–and/or density–dependent in naturally regenerating larch patches? A within–patch scale analysis using an eigenvector spatial filtering approach. *For. Ecol. Manag.* **2023**, *531*, 120763. [CrossRef]
30. Janus, J.; Piotr, B.; Bartosz, M.; Taszakowski, J.; Doroż, A. Long-term forest cover and height changes on abandoned agricultural land: An assessment based on historical stereometric images and airborne laser scanning data. *Ecol. Indic.* **2021**, *120*, 106904. [CrossRef]
31. Sačkov, I.; Barka, I.; Bucha, T. Mapping aboveground woody biomass on abandoned agricultural land based on airborne laser scanning data. *Remote Sens.* **2020**, *12*, 4189. [CrossRef]
32. Bozek, P.; Janus, J.; Taszakowski, J.; Glowacka, A. The use of lidar data and cadastral databases in the identification of land abandonment. *Int. Multidiscip. Sci. GeoConference SGEM* **2017**, *17*, 705–712. [CrossRef]
33. Li, L.; Mu, X.; Jiang, H.; Chianucci, F.; Hu, R.; Song, W.; Qi, J.; Liu, S.; Zhou, J.; Chen, L.; et al. Review of ground and aerial methods for vegetation cover fraction (fCover) and related quantities estimation: Definitions, advances, challenges, and future perspectives. *ISPRS J. Photogramm. Remote Sens.* **2023**, *199*, 133–156. [CrossRef]
34. Hansen, M.C.; Potapov, P.V.; Moore, R.; Hancher, M.; Turubanova, S.A.; Tyukavina, A.; Thau, D.; Stehman, S.V.; Goetz, S.J.; Loveland, T.R.; et al. High-resolution global maps of 21st-century forest cover change. *Science* **2013**, *342*, 850. [CrossRef]
35. Fedorov, N.; Shirokikh, P.; Zhigunova, S.; Baisheva, E.; Tuktamyshev, I.; Bikbaev, I.; Komissarov, M.; Zaitsev, G.; Giniyatullin, R.; Gabbasova, I.; et al. Dynamics of biomass and carbon stocks during reforestation on abandoned agricultural lands in Southern Ural region. *Agriculture* **2023**, *13*, 1427. [CrossRef]
36. Wiki02. Encyclopaedia of Bashkortostan. Mishkinskiy District. Available online: http://wiki02.ru/encyclopedia/Mishkinskiy_rayon/t/9004 (accessed on 5 November 2023).

37. IUSS Working Group WRB. World Reference Base for Soil Resources 2014, Update 2015. In *International Soil Classification System for Naming Soils and Creating Legends for Soil Maps*; World Soil Resources Reports № 106; FAO: Rome, Italy, 2015. Available online: https://www.scirp.org/(S(czeh2tfqyw2orz553k1w0r45))/reference/ReferencesPapers.aspx?ReferenceID=1960251 (accessed on 5 November 2023).
38. Fedorov, N.I.; Tuktamyshev, I.R.; Shirokikh, P.S.; Martynenko, V.B.; Naumova, L.G. Application of the winter and early-spring satellite images for assessment of the birch forest coverage on the abandoned agricultural lands. *Bull. Tomsk. State Univ. Biol.* **2022**, *59*, 110–127. [CrossRef]
39. USGS Earth Explorer. Available online: https://earthexplorer.usgs.gov (accessed on 5 November 2023).
40. Rinn, F. *TSAP V 3.6 Reference Manual: Computer Program for Tree-Ring Analysis and Presentation*; Rinntech: Heidelberg, Germany, 1996; 263p.
41. QGIS Development Team. QGIS Geographic Information System. Open-Source Geospatial Foundation Project. 2022. Available online: http://qgis.osgeo.org (accessed on 5 November 2023).
42. Statgraphics Technologies. Statgraphics 19 Centurion. Software. 2020. Available online: https://www.statgraphics.com/ (accessed on 5 November 2023).
43. Durrant-Whyte, H.; Bailey, T. Simultaneous Localization and Mapping: Part I. *IEEE Rob. Autom. Mag.* **2006**, *13*, 99–110. [CrossRef]
44. RP5.ru. World Weather. Available online: https://rp5.ru/%D0%9F%D0%BE%D0%B3%D0%BE%D0%B4%D0%B0_%D0%B2_%D0%BC%D0%B8%D1%80%D0%B5 (accessed on 5 November 2023).
45. Velázquez, E.; Martínez, I.; Getzin, S.; Moloney, K.A.; Wiegand, T. An evaluation of the state of spatial point pattern analysis in ecology. *Ecography* **2016**, *39*, 1042–1055. [CrossRef]
46. Niemistö, P. Influence of initial spacing and row-to-row distance on the growth and yield of silver birch (*Betula pendula*). *Scand. J. For. Res.* **1995**, *10*, 245–255. [CrossRef]
47. Niemistö, P. Effect of growing density on biomass and stem volume growth of downy birch stands on peatland in Western and Northern Finland. *Silva Fenn.* **2013**, *47*, 1–24. [CrossRef]
48. Liu, Z.; Evans, M. Effect of Tree Density on Seed Production and Dispersal of Birch (*Betula pendula* Roth and *Betula pubescens* Ehrhs). *Forests* **2021**, *12*, 929. [CrossRef]
49. Chazdon, R.L.; Brancalion, P.H.; Laestadius, L.; Bennett-Curry, A.; Buckingham, K.; Kumar, C.; Moll-Rocek, J.; Guimarães Vieira, I.C.; Wilson, S.J. When is a forest a forest? Forest concepts and definitions in the era of forest and landscape restoration. *Ambio* **2016**, *45*, 538–550. [CrossRef]
50. FAO. Global Forest Resources Assessment 2020: Terms and Definitions. 2020. Available online: https://www.fao.org/forest-resources-assessment/2020/en/ (accessed on 5 November 2023).
51. Whitcomb, R.F.; Robbins, C.S.; Lynch, J.F.; Whitcomb, B.L.; Klimiewica, M.K.; Bystrak, D.; Sharpe, D.M. Forest island dynamics in a man dominated landscape. In *Ecological Studies: Analysis and Synthesis*; Springer: New York, NY, USA, 1981; Volume 41, pp. 125–205.
52. Kim, M.; Lee, S.; Lee, S.; Yi, K.; Kim, H.-S.; Chung, S.; Chung, J.; Kim, H.S.; Yoon, T.K. Seed Dispersal Models for Natural Regeneration: A Review and Prospects. *Forestry* **2022**, *13*, 659. [CrossRef]
53. Augspurger, C.K.; Franson, S.E. Wind dispersal of artificial fruits varying in mass, area, and morphology. *Ecology* **1987**, *68*, 27–42. [CrossRef]
54. Nathan, R.; Horn, H.S.; Levin, S.A.; Pacala, S.W.; Katul, G.G.; Avissar, R.; Walko, R.L.; Thomas, S.M. Long-distance dispersal of tree seeds by wind: The role of vertical wind updrafts [abstract]. In *Symposium Abstracts of the 86 Annual Meeting of the Ecological Society of America*; Ecological Society of America: Washington, DC, USA, 2001; pp. 28–29.
55. Oikarinen, M. Growth and yield models for silver birch (*Betula pendula*) plantations in southern Finland. *Commun. Instituti For. Fenn.* **1983**, *113*, 1–75.
56. Dubois, H.; Verkasalo, E.; Claessens, H. Potential of birch (*Betula pendula* Roth and *B. pubescens* Ehrh.) for forestry and forest-based industry sector within the changing climatic and socio-economic context of Western Europe. *Forests* **2020**, *11*, 336. [CrossRef]
57. Aldea, J.; Bravo, F.; Bravo-Oviedo, A.; Ruiz-Peinado, R.; Rodríguez, F.; Del Río, M. Thinning enhances the species-specific radial incremen response to drought in Mediterranean pine-oak stands. *Agric. For. Meteorol.* **2017**, *237*, 371–383. [CrossRef]

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