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Composition and structure of regrowth forests on abandoned agricultural land

Irina N. Volkova[1]*, *Alexander Solodunov*[2], *Larisa N. Kondratenko*[3]

[1]*Department of Social and Economic Geography, Institute of Geography RAS, Moscow, Russian Federation*
[2]*Department of Geodesy, Kuban State Agrarian University, Krasnodar, Russian Federation*
[3]*Department of Advanced Mathematics, Kuban State Agrarian University I. T. Trubilin, Krasnodar, Russian Federation*

**Corresponding author: volkovairin@yahoo.com, volin511@yandex.ru*

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Abstract: Overgrowing of agricultural land by forest in Russia is a large-scale process. This study aims to examine the composition and structure of forests that took over abandoned agricultural lands in Belorechensky district, Krasnodar Krai (Russia). The research on 4 farmland plots was carried out in 2018. At the time of observation agricultural land has been abandoned for 7 to 8 years. Research methodology was developed to determine parameters such as tree and shrub density per ha, height and age at 50 m and up to 100 m from the forest. Two study sites were dominated by mesophytes, whilst the other two sites were invaded by xerophytes. Xerophytic landscapes were co-dominated by downy oaks and dog roses. The stand density of examined plants was 1.7 times lower at 51 to 100 m than near the forest ($P \leq 0.05$). There were 3.3 times as many dog roses as downy oaks. The stand density of common ash stand at 51 to 100 m from the forest edge was 10 times lower than that of dog rose ($P \leq 0.01$). Mesophytic landscapes were co-dominated by black poplars and crack willows. Black poplar was 4.3 times more frequent than dog rose ($P \leq 0.002$) and 130 times more common than elm ($P \leq 0.0001$). Natural overgrowth or succession can affect vast areas of land. It was established that dog roses and downy oaks regenerate xerophytic fields within 6 to 7 years, whereas mesophytic fields become dominated by black poplars and crack willows within 5 to 7 years.

Keywords: abandoned agricultural land; black poplar; downy oak; overgrowth; regeneration

The total area of agricultural land has decreased over the past few decades. Besides the global economic crisis (Suleymanov et al. 2020), there were other reasons for this. In Eastern Europe and Russia, farmland withdrawal from agricultural use was caused by reforms carried out in the 90s (Komissarov, Gabbasova 2017). Many areas of agricultural land became abandoned. Of these, most were areas of arable land and hayfields. It is estimated that agricultural land overgrown with forests covers around 30–70 million ha, yet these are only approximate estimates (Pisarenko 2016). According to several researchers, there are long-abandoned sites that have already been overgrown with well-structured secondary forest (Abolina, Luzadis 2015; Medvedev et al. 2020).

One-quarter of agricultural land in Russia is cultivated occasionally, usually in the autumn to remove weeds (Mohnachev et al. 2018). Furthermore, ploughing activities may be documented but they

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need not be done in reality. If the pasture has not been grazed or hay harvesting is no longer done, the land area is likely to start overgrowing with trees and shrubs (Shirokikh et al. 2017). The composition of newly grown vegetation is dependent upon many factors ranging from location to landscape dimensions. Obviously, factors such as types of land use, soil characteristics, and proximity of forest are also important (Swedish Forest Agency 2014). The spread of seeds from forest areas to unoccupied land will eventually result in natural regrowth or regeneration.

The extent of overgrowth varies from country to country (Segura et al. 2020). According to available data, the percentage of man-made forests in Russia fell from 27.0% (263 million ha) in 2000 to 18.9% (172 million ha) in 2018, whereas the percentage of naturally regenerated lands rose from 73.0% (710 million ha) to 81.1% (768 million ha) during that period (Russian Statistical Yearbook 2019). Over the past 28 years, the pace of natural regeneration in Russia was twice slower than it should be to fully compensate for the area loss. Nevertheless, these data relate only to the Russian Forest Fund.

In 1990, the percentage of abandoned agricultural land in Poland was 14%, in Belarus 13%, in Latvia around 42%, in Lithuania 28%, and in Russia 31% (Nijnik et al. 2014, Abolina and Luzadis 2015, Medvedev et al. 2020). Considering the size difference between these countries, the most significant rate of land abandonment was observed in Russia. That is, nearly half of agricultural land was overgrown with forest. If abandoned lands are located within forest or forest-steppe biome, the overgrowth can reach 80%. Therefore, there is a need to monitor these areas (Arevalo et al. 2017). This issue is crucial to forest management and forestry.

There are evidences that succession from abandoned farmlands to forests occurs in a broad range of biomes (Baude et al. 2019). It was established that in the southern parts of the taiga biome, the abandoned land becomes overgrown with birch trees within 10 to 14 years after abandonment (Glushenkov 2015).

The early birch forest grows into a mixed birch-spruce forest and finally turns into *a spruce*-dominated forest. Note that this happens because the surrounding landscape is normally taken over by the dominant tree species of the nearby forest. In the northern forest-steppe biome, it takes 12 years for birch trees to regenerate (Beck et al. 2018). Since birch and aspen trees are able to spread by seed, new seedlings can emerge at a considerable distance from the parent plant. Hence, the type of regrowth forest is heavily dependent upon soil moisture, wind direction, and the presence of seeds (Feng et al. 2018).

Normally, natural regeneration of forests is associated with the transfer of seeds to areas without woody vegetation. Mature tree stands are able to annually produce seeds in quantities sufficient for maintaining this process. For example, pine (*Pinus sylvestris* L.) trees generate approximately 1 million seeds per ha during the harvest period. Yet, only few seeds will eventually grow into trees, since nearly 40% have insufficient germination capacity, around 10% are carried away by wind, and most are eaten by birds and rodents (Mohnachev et al. 2018). Besides, it is known that different trees shed their seeds at various intervals (Fern et al. 2018). From the aspect of economic efficiency, overgrowth is a natural and thus cost-effective process as it does not require human involvement.

Furthermore, abandoned lands are typically infertile areas, so farmers will lose little if they overgrow (Funes et al. 2019). Nevertheless, if soils are not suitable for crops, they may be favourable for growing oligotrophic plants such as birch and aspen trees. From the ecological aspect, overgrowth refers to natural succession (Gradinaru et al. 2019).

The large-scale overgrowth can significantly affect the economy. Regrowth forests can provide raw materials needed to meet consumer demands. The total area of agricultural land overgrown with forest in Russia is 50 million hectares. Its annual output is about 3.9 billion tons or 18% of the world's lumber consumption (Rodin, Rodin 2009). Germany and other EU member countries put a lot of efforts to create new forests.

For this, landowners are provided with subsidies covering around 80% of reforestation costs (Swedish Forest Agency 2014). The Russian government, on the contrary, does not have any similar initiatives due to the abandonment of agricultural lands where forests regrow on their own. Yet, there is a need for monitoring and protecting non-registered forest units (Low et al. 2015). An important issues is the regrowth of abandoned agricultural lands in different climatic zones and biomes (Morano and Tajani 2018). Particularly, little is known about the status of abandoned agricultural lands in the Krasnodar Krai (Southern Russia).

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This study aims to examine the composition and structure of forests that have regrown on abandoned agricultural lands in Belorechensky district, Krasnodar Krai. The research objectives are: (*i*) to identify the key plant species involved in regeneration; (*ii*) to determine and characterize the distribution area of regenerative communities; (*iii*) to assess stand age and density. Note that the studied forest-steppe area may be overgrown to a lesser extent than northern regions.

MATERIAL AND METHODS

Research design and intervention. The study was conducted in 2018 in Belorechensky district, Krasnodar Krai (Russian Federation). The forest area of Krasnodar Krai is equal to 1.5 million hectares, accounting for 22% of the total area. Most forests (85%) are hardwood forest ecosystems, one-third of which are old-growth fo*rests.*

The studied area was dominated by oak forests composed of common oak (*Quercus robur*) and downy oak (*Quercus pubescens*) trees. In drier mesophytic areas, forests are dominated by black poplar (*Populus nigra*). The total area of agricultural land in Belorechensky district is around 60%, 25% of which is abandoned (up to 25%) and prone to overgrowth.

Study sites were chosen using the compass method. Selected sites were at 10 to 50 and 51 to 100 m from the nearest forest. Study sites were included in the study based on whether or not they had successive seedlings (Shvidenko 2018). Each plot was decided to have at least 100 young trees. Consequently, the size of land varied from plot to plot. The number of trees within the plot, their age and height were determined.

A total of four study sites (or 8 plots) were selected. Of these, two sites comprising 23 ha and 37 ha of abandoned pasture land were located near the oak forest, whereas the other two sites covering 3 ha and 7 ha of abandoned pasture were standing near the black poplar forest. The first study site has been abandoned for 8 years and the other sites have not been cultivated for 7 years.

Forest near the first study site is composed of common oak trees and common ash (*Fraxinus excelsior*) trees. Its age is 60 years. The forest edge is dominated by downy oaks (55%) and dog roses (*Rosa canina*, 45%). All plots are occupied by alluvial sandy sod-podzolic soils. Forest near the second study site is similar to that near the first site. The forest edge is dominated by downy oaks (75%) and dog roses (25%). Forest near the third study site consists of black poplar and elms (*Ulmus sp.*). The forest edge is occupied by dog roses. The site has not been used for 7 years. Forest near the fourth study site is similar to that near the third site, yet it also includes crack willows (*Salix fragilis*). There are no shrubs along the forest edge.

Statistical analysis. Statistical data processing was performed using Statistica v. 6.0 (StatSoft Inc., Tulsa, USA). As data followed normal distribution, the parametric analysis was used. The arithmetic mean and standard deviation were found. Two-sample *t*-test was employed to find out whether a difference between variables (tree height, tree age, and stand density per unit area) was reliable. Differences were considered significant at $P \leq 0.05$.

RESULTS

In spite of the one-year difference in land abandonment, the overgrowth of study sites was found to have fundamentally different scenarios. The overgrowth scenario stems from the forest composition. For instance, the overgrowth of land near the oak-dominated forest (first study site) occurred at 100 m or so from the forest edge (Table 1). At the same time, common oak demonstrated the

Table 1. Density, height and age of tree and shrub seedlings at various distances from tree seed sources (data obtained for the 1st study site)

Distance from forest	Density per unit area (thousand plants per ha)				Average age (years)				Average height (cm)			
	CO	DO	CA	DR	CO	DO	CA	DR	CO	DO	CA	DR
< 50 m	0.01	0.5	0.7	1.2	4.0	5.0	5.0	7.0	65.0 ± 4.0	56.0 ± 3.7	61.0 ± 5.3	45.0 ± 2.9
51–100 m	0	0.3	0.1	1.0	–	4.0	4.0	6.0	–	45.0 ± 4.1	57.0 ± 3.9	36.0 ± 3.1

CO – common oak (*Quercus robur*); DO – downy oak (*Quercus pubescens*); CA – common ash (*Fraxinus excelsior*); DR – dog rose (*Rosa canina*)

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Table 2. Density, height and age of tree and shrub seedlings at various distances from tree seed sources (data obtained for the 2nd study site)

Distance from forest	Density per unit area (thousand plants per ha)				Average age (years)				Average height (cm)			
	CO	DO	CA	DR	CO	DO	CA	DR	CO	DO	CA	DR
< 50 m	0	0.8	0.6	1.5	–	4.0	4.0	6.0	–	52.0 ± 2.9	58.0 ± 4.6	41.0 ± 2.2
51–100 m	0	0.3	0.2	1.2	–	3.0	3.0	5.0	–	39.0 ± 3.4	53.0 ± 2.8	34.0 ± 2.8

CO – common oak (*Quercus robur*); DO – downy oak (*Quercus pubescens*); CA – common ash (*Fraxinus excelsior*); DR – dog rose (*Rose canina*)

lowest rate of overgrowth (the ratio of land area overgrown with certain tree species to the total abondened land area) compared to the other tree species. Single oak trees were found closely to the forest, that is at 50 m from the forest edge. Other tree and shrub species showed a greater potential for spreading. For instance, the stand density of downy oak stand found at 50 m from the forest edge is 50 times higher than that of common oak ($P \leq 0.0001$). However, it is 1.4 times lower than that of common ash ($P \leq 0.05$) and 2.4 times lower than that of dog rose ($P \leq 0.01$). The number of common ash trees and dog roses at 50 m from the forest edge is 70 times ($P \leq 0.0001$) and 120 times ($P \leq 0.0001$) higher than that of common oak, respectively.

The average stand density of examined stands at 51 to 100 m from the forest edge is 1.7 times lower than that of vegetation near the forest ($P \leq 0.05$). Shrubs continue to prevail. The stand density of dog roses is 3.3 times higher than that of downy oaks and 10 times higher compared to common ash ($P \leq 0.01$). Therefore, dog rose has the maximum potential for uniformly spreading over 100-m distances, followed by downy oak. Common ash has the maximum potential for spreading over shorter (up to 50 m) distances. There were no significant age differences between trees. All subjects began growing 2 to 3 years after land abandonment. Dog roses, however, appeared much earlier, around 1 year after abandonment ($P \leq 0.05$). This can explain the dominance and high density of dog roses in the studied area. There was no significant difference in average height between trees, except for the common oak aged 5-4 years ($P \leq 0.05$), and between shrubs ($P \leq 0.05$).

Similar results were obtained for the second study site. Dog roses dominated over other plants at all distances. In close proximity to the forest, dog roses were 2.5 times and 1.8 times more frequent than common ash ($P \leq 0.01$) and downy oak trees ($P \leq 0.05$), respectively. At 100 m from the forest edge, their stand density was 4 times higher than that of downy oak stand and 6 times higher as compared to common ash ($P \leq 0.001$) (Table 2).

The second study site had no common oak seedlings outside the forest. Downy oak trees aged 4 years were higher than those aged 3 years ($P \leq 0.05$). There was no similar trend among the common ash trees, although they were higher compared to downy oaks ($P \leq 0.05$). Shrubs (dog roses) were two years older than trees, yet smaller ($P \leq 0.05$).

The third and fourth study sites were located near the black poplar forest. The black poplar seedlings have the greatest potential for self-regenerating and spreading, as evidenced by their dominance over other plants at all studied distances (Table 3).

In close proximity to the forest, there were 2.2 times as many black poplar seedlings as dog rose seedlings ($P \leq 0.01$). Furthermore, there were

Table 3. Density, height and age of tree and shrub seedlings at various distances from tree seed sources (data obtained for the 3rd study site)

Distance from forest	Density per unit area (thousand plants per ha)			Average age (years)			Average height (cm)		
	BP	E	DR	BP	E	DR	BP	E	DR
< 50 m	1.8	0.4	0.8	5.0	2.0	6.0	71.0 ± 3.3	27.0 ± 2.3	48.0 ± 3.1
51–100 m	1.3	0.01	0.3	4.0	1.0	4.0	57.0 ± 4.5	13.0 ± 2.9	39.0 ± 4.4

BP – black poplar (*Populus nigra*); E – elm (*Ulmus sp.*); DR – dog rose (*Rose canina*)

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Table 4. Density, height and age of tree and shrub seedlings at various distances from tree seed sources (data obtained for the 4th study site)

Distance from forest	Density per unit area (thousand plants per ha)			Average age (years)			Average height (cm)		
	BP	E	CW	BP	E	CW	BP	E	CW
< 50 m	1.3	0.2	2.1	5.0	5.0	5.0	73.0 ± 3.2	58.0 ± 3.9	55.0 ± 4.7
51–100 m	0.6	0.01	1.5	4.0	3.0	4.0	66.3 ± 3.4	36.0 ± 3.4	37.0 ± 4.1

BP – black poplar (*Populus nigra*); E – elm (*Ulmus sp.*); CW – crack willow (*Salix fragilis*)

4.5 times more black poplar seedlings than elm seedlings ($P \leq 0.001$). At 100 m from the forest, black poplar seedlings continue to dominate over dog rose and elm seedlings. There were 4.3 times more black poplar seedlings than dog rose seedlings ($P \leq 0.002$). There were 130 times as many black poplar seedlings as elm seedlings ($P \leq 0.0001$). Thus, elm has the lowest potential to dominate in succession: the density of elm seedlings at 51 to 100 m from the forest dropped by 97.5% ($P \leq 0.0001$). For comparison, the stand density of dog rose seedlings decreased by 62.5% ($P \leq 0.05$). At the same time, black poplar seedlings showed no significant difference in stand density between the studied distances ($P \leq 0.05$). Elm seedlings were twice as young as other two species ($P \leq 0.05$). Black poplar seedlings were 1.5 to 2.5 times higher than elm and dog rose seedlings.

The fourth study site is characterized by the absence of dog roses and by the presence of crack willow trees (Table 4). The crack willow seedlings dominated over other plants. The stand density of crack willow seedlings at 50 m from the forest was 1.6 times higher than that of the black poplar stand ($P \leq 0.05$) and 10.5 times higher compared to elm seedlings ($P \leq 0.001$). At 100 m from the forest edge, it was greater by 2.5 ($P \leq 0.01$) and 150 times ($P \leq 0.001$), respectively. The stand density of all studied plants decreased with distance: crack willow 1.4 times, elm 20 times, and black poplar 2.1 times ($P \leq 0.01$).

Thus, crack willow has the biggest potential to take over the abandoned land in comparison with black poplar and elm. There was practically no significant difference in age between plants. The exception is the elm tree species at 51 to 100 m from the forest, which began spreading later than other plants and were lower in density. Crack willows were 1.3 to 1.5 times lower in height than other plants ($P \leq 0.05$).

Results suggest that spatial distribution patterns of plants in the forest-steppe region of *Krasnodar Krai* depend on their soil moisture preferences. For instance, downy oaks and dog roses dominate in xerophytic areas, whilst crack willows, black poplars, and, to a lesser extent, dog roses dominate in mesophytic areas at 100 m from the forest.

DISCUSSION

The study revealed specific characteristics of forest regeneration on abandoned agricultural land in the forest-steppe region. In contrast to similar works carried out in forest and taiga zones in Russia, Europe, and China (Raiesi, Salek-Gilani 2018; St-Denis et al. 2018; Rodrigo-Comino et al. 2018; Shang et al. 2019), this study shows the co-dominance of downy oaks, crack willows, and dog roses. At the same time, birches, aspens, grey alders, and conifers dominate the forest biome (Shi et al. 2018). The overgrowth of agricultural land by forest will progress faster in the forest zone (Song et al. 2019).

Thus, a dense birch forest takes 11 to 14 years to take over the abandoned land, whereas in the northern forest-steppe zone, this will take 12 years (Zethof et al. 2019). This study shows that dense stands of downy oak and dog rose can grow in 5 to 7 years. Dog roses are the first plants to invade abondoned xerophytic land areas, whilst crack willows and black poplars are the pioneer species in mesophytic landscapes.

The conversion of meadow or steppe areas into forest results in the change of microclimatic conditions. For instance, dog roses attract invertebrate animals that are native to forests, such as ants, whereas steppe animals are not common in a dog rose-dominated area (Stukalyuk, Radchenko 2011). This happens because woody plants are a main source of food for invertebrate animals (Stukalyuk et al. 2019a).

The presence of invasive species in plant communities can have a negative effect on the species diversity of invertebrates (Stukalyuk et al. 2019b).

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There were no invasive plants found in the studied forests and overgrown pasture lands, so this factor was not considered. The present case of overgrowth refers to the natural succession process (Valle et al. 2019) that does not require any financial investments (this does not include spending on sanitary felling). The state financial support for farmland restoration in the Moscow region had a small but noticeable positive effect on their return to circulation (Volkova 2018). However, these events are not yet conducted on a large scale. Hence, the bulk of abandoned farmland in Russia goes through different stages of succession.

Natural regeneration in Sweden represents only 18% of the area (Swedish Forest Agency 2014). Other areas were restored by sowing seeds or planting seedlings. Note that over the past 10 years, the area of natural regeneration in Sweden decreased by 50%. Meanwhile, the felling volume remained unchanged. In Russia, felling activities and natural regeneration events are not controlled by the government. Therefore, it is necessary to assess the extent of natural regeneration, including abandoned agricultural lands not only in Russia but also in other countries.

CONCLUSION

The key finding of this study is that the spread of plants within the forest-steppe biome of Krasnodar *Krai* depends on their soil moisture preferences. Over 6 to 7 years, open-field xerophytic sites up to 100 m from the tree seed sources have accomplished succession to early forest with two co-dominant plant species: dog rose and downy oak. Mesophytic landscapes were characterized by the dominance of crack willows and black poplars, which spread across the area over the period of 5 to 7 years after abandonment.

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