Conference Paper

Effects of Grass Fires on the Trajectory of Vegetation Dynamics in Abandoned Agricultural Lands: A 30-year Retrospective Based on Remote Sensing Data (A Study of an Area South of the Moscow Region)

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Abstract

The authors propose that the spatial structure of woody vegetation on former arable lands can be used as a diagnostic feature that indicates the occurrence or absence of grass fires after land abandonment. Based on the analysis of a series of Landsat satellite images from 1985 to 2016 for an area of 256.5 km^2 located in Central European Russia, the authors have reconstructed the history of spring fire events. They found correlations between the frequency of fire events and the density and spatial structure of woody vegetation on abandoned arable lands. Without fires, areas with homogeneous woody vegetation are formed: individuals of pioneer tree species (*Betula pendula, B. pubescens* and *Salix caprea*) are evenly distributed and exist in high densities over the entire area. Affected by fires, trees become unevenly distributed over the area: pioneer trees grow in groups or as separate individuals depending on the intensity and frequency of grass fires. With frequent fires, the vegetation remains in a weedy stage for decades.

Keywords: abandoned agricultural lands (old-fields), Earth remote sensing data, Landsat, grass fire, spatial structure of woody vegetation

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1. Introduction

Presently, the world is experiencing a growing abandonment process of previously intensively managed land. In Russia alone, about 70 million hectares of land were taken out of agricultural usage in the twentieth century: two thirds of this figure were removed during the social and economic crisis of the 1980s and 1990s [1, 2]. In Europe,

this issue is relevant due to the socio-economic changes of the second half of the twentieth century and the introduction of the Common Agricultural Policy. A large number of studies have been devoted to the dynamics of ecosystems on abandoned lands. Changes in soil properties during overgrowing and the dynamics in biodiversity and in carbon and nitrogen budgets, etc., have been studied [3–7]. The spatial structure of developing vegetation and the possible trajectories of vegetation dynamics have also been discussed earlier [8–10 and others]. However, factors which determine successional processes have not been studied in detail, even though they provide effective methods for the sustainable ecosystem management of such lands [11].

We earlier investigated vegetation restoration on former arable lands and pastures located within the Kaluzhskie Zaseki State Nature Reserve, where lands are overgrowing without fires, and on former fields located near the Reserve which were affected by fire [12, 13]. We preliminarily concluded that features of vegetation restoration on abandoned lands are mainly determined by (i) the specifics of the preceding impacts (the type of agricultural use, whether it was arable land or pasture) and (ii) the presence and intensity of spring grass fires. We have also proposed distinguishing plant communities developing on abandoned arable lands that were either affected or not affected by fire based on the structural and taxonomic features of the vegetation. Our hypothesis is as follows: the spatial structure of tree populations developing on abandoned ploughed fields depends on the occurrence of grass fires, and that structure can be used as a diagnostic feature of the fire history of the vegetation: vegetation developing in the form of a closed tree stand of a pioneer species testifies that it was an abandoned arable field that recovered without fire events, while in burnt areas the occurrence and severity of the fires is also reflected in the vegetation structure. The aim of our article was to check this hypothesis by using the available archive of remote sensing data from different points in time. The concrete objectives of our study were to select a study area with abandoned agricultural lands, to estimate the frequency of spring fire events in the area with remote sensing archival data and to analyze the relationship between the fire frequency and the degree to which abandoned lands are overgrown by trees.

2. Methods

The prerequisites of our study were the following: (i) the spatial structure of young woody vegetation is clearly visible in high-resolution satellite images, which make it possible to map the vegetation on abandoned lands according to their structure; (ii)

grass fires are also clearly visible in spring via medium-resolution satellite images; and (iii) there is a freely available archive of Landsat imagery that allows us to reconstruct the history of fire events in the selected area.

We took a study area in the north of the nemoral forest region [14], on the right bank of the Oka River in the Serpukhov district of the Moscow Region; its total size is about 25650 ha (coordinates 54.71778° – 54.88310° N and 37.26959° – 37.78316° E).

Based on the analysis of topographic maps, high-resolution satellite imagery and field observations (Figure 1(a)–(d)), we developed a map of the lands in the study area which included the following categories: (i) settlements; (ii) water bodies; (iii) forest; (iv) arable land; (v) overgrowing arable land: (a) without trees, (b) with a small number of single trees; (c) with a tree undergrowth of medium density, (d) with a dense undergrowth but in separate spots; (e) with a uniform structure of tree growth; (vi) meadows outside valleys of small rivers and streams; (vii) meadows and shrubs along valleys of small rivers and streams; (viii) meadows and shrubs in the floodplain of the Oka River; and (ix) other (quarries, shoals, other outcrops, areas near roads, etc.) (Figure 2 in [12]).

Aiming to evaluate areas with fire events and their spatial distribution, we have analyzed Landsat imagery: images with low cloud covers from 1985 to 2016 were taken: of these, the photographs of periods in which grass fires are most likely (from March to June) were reviewed and selected. Finally, 37 images were selected for detailed analysis. The contours of fires (Figure 1(e) & (f)) were manually digitized: we did this sequentially from the photographs of different years, keeping the topology given in the layer with the boundaries of different land categories. As a result, a new layer was obtained in the GIS; for each polygon of this layer, the attribute table contained information on the current type of land and the presence/absence of fire in each analyzed year. The number of fires for each polygon was calculated: analyses of the distribution of fire areas and the proportions of areas with different numbers of fire events by land category were also carried out.

3. Results

Forty percent of the analyzed area was abandoned arable land, but only 1.8% of these were former arable lands with a uniform overgrowth of trees. There were no fires registered within the study area in the Landsat images of 1985, 1987, 1989, 1991, 1998 and 2005 while fire events were shown in neighboring areas in those years. We concluded that there were no fire events in those years in the study area, or the area

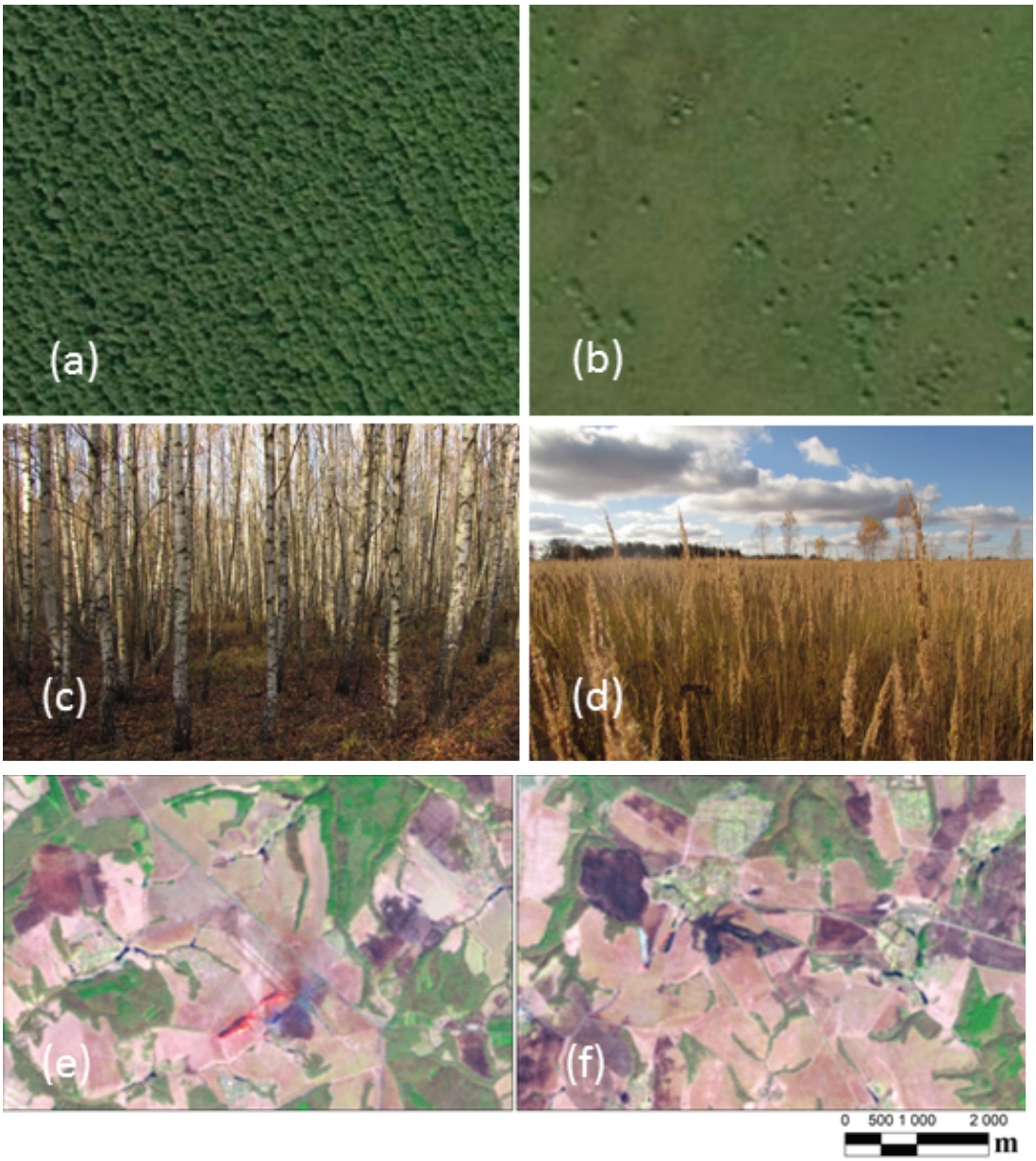

Figure 1: Satellite images and results of field-based observations that were used for mapping. Abandoned arable fields in high-resolution satellite images (a, b) and field photographs (c, d): uniformly overgrown by trees (a, c) and overgrown by single trees (b, d). (e) and (f) show examples of analyzed Landsat images: green polygons – forest, pink – arable land, black and purple – burnt area, red strip – edge of grass fire. (a, b [15]; c, d author's photos, e, f [16]).

affected by fire was small. Fire events within the study area were registered in the satellite images of 1986, 2000, 2001, 2006, 2009–2012 and 2014. In these nine years, fires affected 58% of the area. The maximum areas of grass fires were in 2009 and 2010; the burned areas amounted to 21% of the analyzed territory in 2010 (Figure 2).

Most of the area unaffected by fire was represented by settlements, current arable lands or forests. As regards the distribution of areas affected by fires of different frequency over the different land type categories (Figure 3), the lowest frequency of

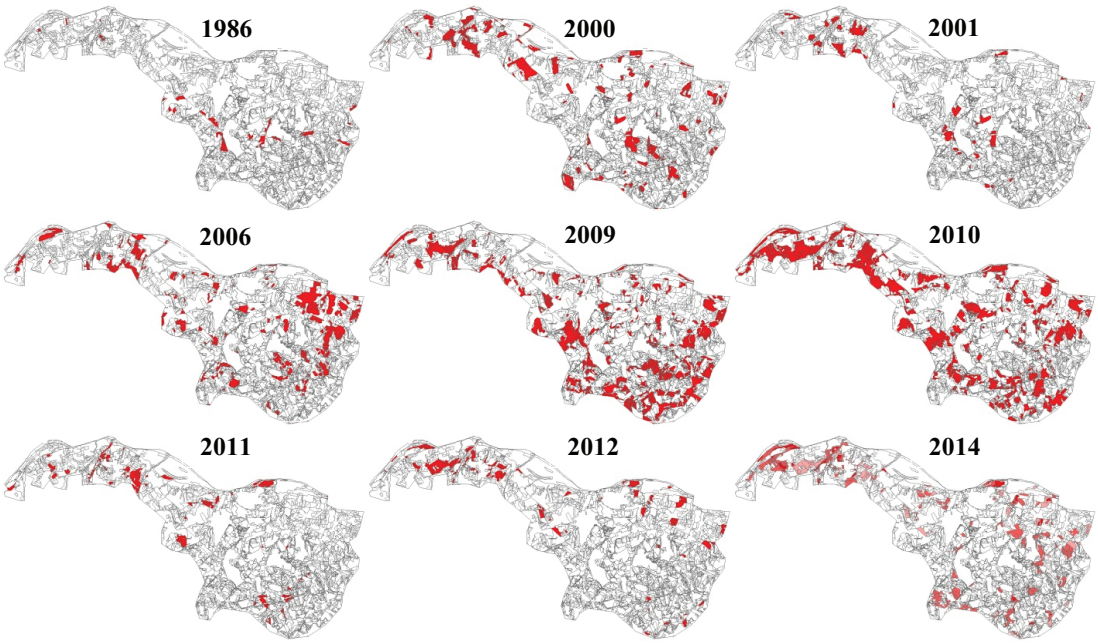

Figure 2: Grass fires registered in different years in the study area in the south of the Moscow Region. Sites affected by fire are marked in red. **Source:** Authors' own work.

fires was registered for forests and meadows/shrubs located in the floodplain of the Oka River. The highest number of fires per polygon was found for meadows located outside the valleys of rivers and streams. Meadows and shrub thickets located in the floodplains of small rivers and streams also scored high frequencies of fires: on several spring photographs available for a certain year, we could see that a fire starting in a vegetation near water bodies often caused grass fires in the surrounding areas. In the former arable lands with uniform tree overgrowth, fires were absent for the entire period of observation (Figure 3, category 8). The largest proportion of polygons that burned more than once were polygons that in the end were unevenly overgrown by woody vegetation and they usually occurred adjacent to areas with high fire frequencies. For such unevenly overgrowing areas (categories from 4 to 7 in Figure 3), there was a negative correlation between the frequency of fire events and the density of woody vegetation: the frequency of fire events and the proportion of burned areas decreased when moving from formerly ploughed lands without woody vegetation to former arable lands with dense undergrowth. The area affected by fires on abandoned agricultural land (together with lands which were abandoned and then re-ploughed) amounted to 84% of the total area affected by grass fires.

Thus, the lower the intensity of fire impacts on the abandoned arable lands, the higher the density of pioneer trees in their undergrowth. An abandoned ploughed field initially is bare land on which the pioneer tree species *Betula* spp. and *Salix caprea* easily

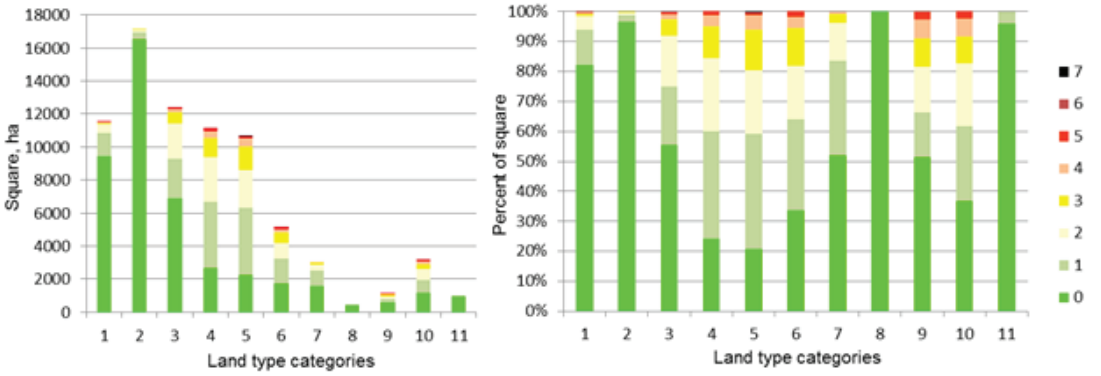

Figure 3: Distribution of areas and proportions of burnt areas with different numbers of fire events (from 0 to 7) in the following categories of land types: 1 settlements; 2 forest; 3 arable lands; 4–8 abandoned arable lands: 4 without trees, 5 with single trees, 6 with tree undergrowth of medium density, 7 with dense tree undergrowth in spots and 8 with a uniform tree cover; 9 meadows outside valleys of small rivers and streams; 10 meadows and shrubs along valleys of small rivers and streams; and 11 meadows and shrubs in the floodplain of the Oka River. **Source:** Authors' own work.

establish themselves since they successfully compete with other species due to the large numbers of seeds and high growth rates. As a result, these tree species occupy the entire area of the former arable land, forming a uniform spatial structure of woody vegetation. Grass fires destroy the tree undergrowth and promote the establishment and persistence of grasses, especially *Calamagrostis epigeios*, and other meadow-edge species, such as the weeds *Tanacetum vulgare, Artemisia vulgaris, Cirsium arvense,* etc., whose tussocks and sods then prevent recolonization with trees. In this way, a mosaic of wooded and meadow (weedy) sites is formed. With a high frequency and intensity of fires, even after decades of abandoning the ploughed fields, the vegetation remains a grassland dominated by *Calamagrostis epigeios* and weeds, and there is no restoration of the woody vegetation.

4. Conclusion

Based on the analysis of a series of satellite images, we reconstructed the 30-year history of fire events in the study area and showed that the variation regrowth of the vegetation on former arable lands differs strongly in terms of the spatial structure of woody vegetation: this directly depends on the presence/frequency of grass fires. We have shown that the succession dynamics of re-growing vegetation on former arable land without fires lead to a uniform woody vegetation cover: pioneer tree species (birch and willow goat) are distributed evenly over the entire area. Affected by grass fires, trees in the re-growing vegetation become unevenly distributed over the area: depending on the intensity and frequency of the grass fires, woody vegetation occurs

in groups or as single individuals of pioneer tree species, and the remaining area is occupied by a grassy vegetation dominated by *Calamagrostis epigeios* and weeds.

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