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Soil and Vegetation Cover and Biodiversity Transformation of Postagrogenic Soils of the Volga-Oka Interstream Area

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Abstract: Based on the actual material, the state of the land, previously (more than 15 years ago) placed under cultivation and "neglected" to date, was assessed. Control sites within different landscape provinces of the Volga-Oka interstream area were compared by the state of soil cover and vegetative cover, as well as the type of anthropogenic transformation. The study identified three types of transformation of post-agrogenic lands characteristic of the initial and intermediate overgrowth stages of pre-climax communities: field overgrowth associated with a change in land use; field overgrowth with nearby forest; and field overgrowth without nearby forest. The soil cover state was assessed by acidity, pH, and humus content, and it generally corresponds to the area's characteristics. Deterioration of these characteristics was noted on sod-podzolic soils overgrown with forest vegetation, as evidenced by low humus content of 0.96–1.46%. The results of research using statistical methods reliably showed that the overgrowth of most sites with herbaceous vegetation within different landscapes followed common successions, even on different soils (sod-podzolic and gray forest). With the leveling of landscape features of areas, there were similar plant species and communities. It was shown that as a result of agricultural overgrowing, the species richness of plant communities was sharply reduced. For example, the maximum value of the Shannon index on overgrown lands is 3.6, which is lower than the reference natural community, where this indicator is 4.1. The remediation of biodiversity in the foreseeable future is very problematic. Although post-agrogenic phytocenoses can gradually restore their productive potential to the level of natural phytocenoses (the maximum value of phytomass in overgrown lands is 10.2 mt/ha, for comparison, natural phytocenoses accumulate 6.3 mt/ha at reference sites), their productivity is provided by a different species composition of herbaceous plants with poor biodiversity. In order to preserve biodiversity, it seems advisable to intersperse croplands with uncultivated plots of sufficiently large size which can serve as a kind of natural ecosystem preservation bank.

Keywords: agricultural lands; anthropogenic transformation; types of overgrowth; biodiversity; phytomass

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1. Introduction

Biodiversity is considered one of the most important criteria for assessing the condition of the landscape; it is an important factor in maintaining the stability of flora and fauna habitats and providing ecosystem services. To restore and maintain biodiversity in ecosystems, it is important to preserve pollinators and seed dispersers [1,2].

Problems of optimal landscape territorial organization are insufficiently studied. Various options for the conservation of natural plant communities and their biodiversity under active territory development are being considered and proposed [3–5]. For example, conversion of low-productive arable land to hayfields and pastures or conversion of disused lands to the protected ecosystem [6].

Post-agrogenic transformation is determined by a variety of factors and depends largely on the landscape features of the territory, so studies confined to different regions are necessary. Agrocenoses are replaced by disused lands with vegetation that differs sharply from natural cenoses [7].

Successions arising on such lands are being actively studied. In particular, the role of phytocenosis, seedbank, soil properties, and climate change in secondary successions is investigated, and the complexity of constructing chronological series of successions due to the breadth of time intervals is indicated [8–10].

Such areas are spontaneously overgrown with ruderal vegetation and later with shrubs and woody plants; there is a change in soil properties [11–15]. Overgrowth of deposits occurs in stages. The species composition of phytocenoses depends on a number of factors, and as a result, various ecological consequences are possible, including changes in climatic characteristics and carbon balance, which require further study [16–19]. For example, in the middle taiga zone, overgrown meadows are replaced by pine and birch plantations. The ratio of species changes over time, and the intensity depends on the distance to the forest and the degree of meadow plant stand development [11,20]. It has been shown that the composition of the forming young forest stands depends on many factors, including the soil type and other properties [21].

At present, putting disused lands into agriculture is topical; therefore, it is necessary to analyze soil cover changes in the process of overgrowing, which often leads to the loss of the positive properties of cultivated soils [22–26]. The processes of restoration of the original properties of post-agrogenic lands occur at different rates depending on the territory use; haying, grazing, grass burning, etc., and can have a restraining effect. [27,28]. An increase in soil fertility can be observed on clean leas [29,30].

Post-agrogenic transformation affects soil carbon emission, and the processes of soil respiration recovery over time and its relationship with the recovery of phytomass and soil organic carbon in different landscapes are actively studied [31,32].

The vast majority of studies are devoted to the study of post-agrogenic lands with forest vegetation. The studies, as a rule, are applicable, practical in nature, and aimed at identifying economic losses when lands are withdrawn from agriculture.

The issues of herbaceous vegetation renewal and its species composition and productivity, i.e., studies of biodiversity reproduction, remain practically poorly investigated.

The purpose of the work was to typify the post-agrogenic transformation of the soil and vegetation cover of landscapes of the Volga-Oka interstream area, which are in a disused state, taking into account the indicators of biodiversity and phytoproductivity using field studies and methods of mathematical statistics.

2. Materials and Methods

The study was conducted within the Volga-Oka interstream area, which rises in the west and northwest by the forested Smolensk-Moscow upland to 300 m above sea level and in the south by the Srednerusskaya upland dissected by ravines and gullies, with broad-leaved groves predominantly in the river valleys, gradually flattening out in northwestern and south-western directions to the east, forming the flat forested-marshy Meshchera lowland and Balakhna (Frolischev) valley bottom at 70–90 m above sea level (Figure 1). The Klyazma River basin is almost at the center of the interstream area, and it is represented by diverse natural areas in the landscape.

The study sites are located in four provinces: Klin-Dmitrov, Volga-Klyazma, Meshchera, and Oka-Tsna.

The soil cover of the studied area is mainly sod-podzolic and gray forest soils. The climate is moderately continental with warm summers, moderately cold winters, and stable snow cover. The average monthly temperature in July is +17 °C, while it is −11 °C in January. The average annual precipitation is 550 mm.

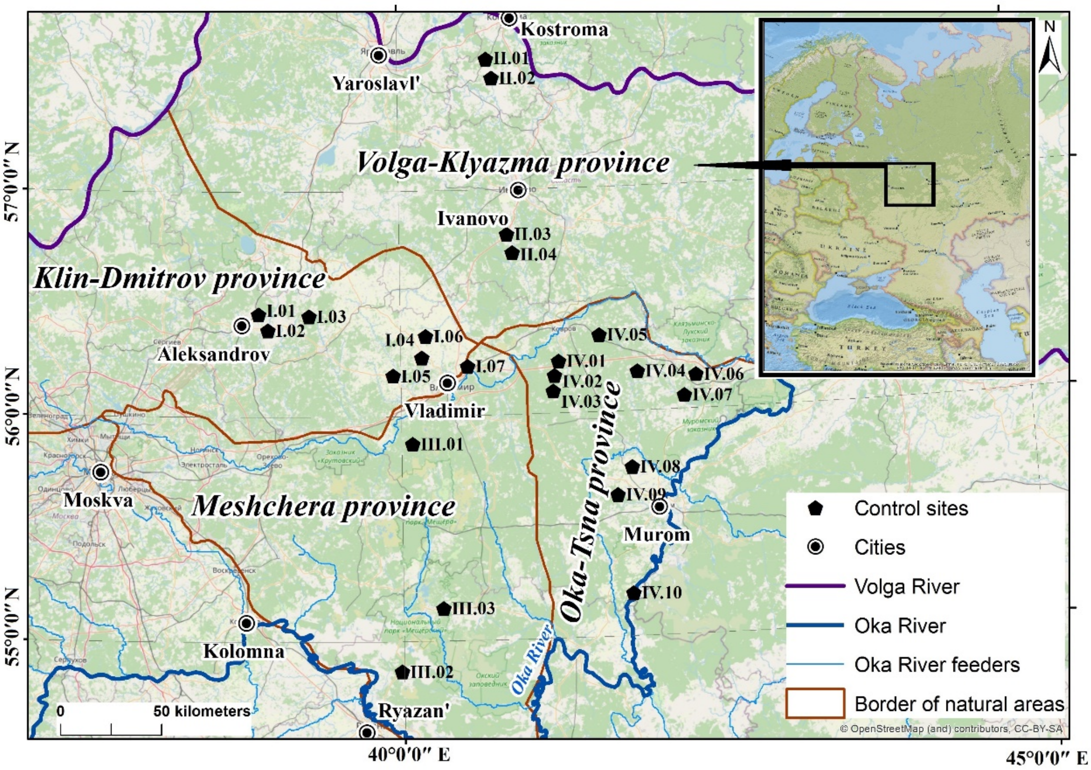

Figure 1. Location of key sites. The Open Street Map substrate (map scale of 1:1,500,000) was used as the topographic base for the raster map of key sites. Control sites are marked with a pentagon; cities are marked with a circle; the Oka River is marked with a light blue line; the Volga River is marked with a dark blue line; tributaries of the Oka River are marked with a thin light blue line; and the border of natural areas is marked with a light brown line.

Methods and approaches. The methodological basis for identifying the leading mechanisms of landscape transformation caused by various anthropogenic impacts, in particular changes in land use, is based on the study of changes in soil properties and their fertility, characteristics of phytoproductivity, and biodiversity.

The research was conducted from 2017 to 2021 and the following methods were used.

Field studies include defining control sites (key areas), laying soil sections, and sampling soil and vegetation. The sites were located on post-agrogenic lands and within initial (natural) phytocenoses (Figure 1 and Table 1).

Table 1. Characteristics of control sites (sections) of the Volga-Oka interstream area.

Landscapes	No. of the Site	Cropland Name
I. Klin-Dmitrov Province		
Klin-Dmitrov Ridge	I.01	Overgrown lea
Vladimir High Plain	I.02	Field planted with clover and alfalfa
Plane interfluve area occupied by fields and leas,	I.03	Forb-grass meadow
Vladimir High Plain	I.04	Overgrown lea
Territory of the Rpen river basin	I.05	Overgrown lea

	I.06	Overgrown lea
Vladimir High Plain Bogolyubov Meadow	I.07	Forb-grass meadow
II. Volga-Klyazma province		
Pless-Galich upland	II.01	Lea
Nerlya-Klyazma lowland	II.02	Mixed forest
	II.03	Lea
	II.04	Dry meadow
III. Meshchera Province		
Meshchera Plain	III.01	Herb meadow
	III.02	Renewing pine forest on the sands within the burned area in 2010.
	III.03	Herb mesophytic meadow
IV. Oka-Tsna Province		
Oka-Tsna Bar	IV.01	Mixed forest
	IV.02	Overgrown lea
Kovrov-Kasimov Plateau	IV.03	Herb meadow
	IV.04	Grass-forb meadow
	IV.05	Mixed forest
Gorokhovets spur	IV.06	Motley grass-grasses meadow
Murom High Plain	IV.07	Grass lea
	IV.08	Agricultural lands
	IV.09	Lea
Dmitrievogorsk Landscape Area	IV.10	Lea

A total of 24 control sites characterized by post-agrogenic areas and specific phytocenoses that are not used in agricultural activities were laid. The selection of these sites was based on the remote and cartographic analysis of the territory and their belonging to different landscape areas and provinces.

The following studies were conducted at the study sites:

(A) The type and intensity of anthropogenic impact were determined;

(B) The state of the vegetation was evaluated through geobotanical descriptions of the vegetation cover; the stocks of herbaceous phytomass (crude) sampled with a standard frame were determined by weighing accurately to within about 1 g. A quantitative assessment of phytomass was carried out during the maximum vegetative mass development (early July).

The state of the soil cover was evaluated according to the content of humus (Tyurin method modified by Nikitin), pH of H_2O, and pH of KI (potentiometric method) were determined.

Statistical analysis was performed by MANOVA, which is used when more than one observation unit is measured per character and observation units are obtained from independent populations.

The classic assumption of ANOVA is that the initial vectors (1):

$$x_{ij}(p \cdot 1) \tag{1}$$

are generated based on model (2):

$$x_{ij} = \mu_i + £_{ij} \tag{2}$$

where (3) is the location center for the *i*-th sample (population):

$$\mu_i = (\mu_{i1}\mu_{i2} \cdots \_\mu_{ip})^T \tag{3}$$

and (4) are random errors that are independent and equally distributed:

$$£_{ij} = (£_{ij1}£_{ij2} \dots \_£_{ijp})^T \quad (4)$$

from a multivariate normal distribution (5):

$$N_p(0, \sum) \quad (5)$$

This paper applies the classic T2 Hotelling's test to a single sample.

Ward's cluster analysis was performed to group the key sites according to the characteristics of soil and vegetation cover. The scheme of the cluster analysis is shown in Figure 2. The following characteristics were taken into account in the calculation: post-agrogenic arable land overgrowth type, phytomass determined in the field, Shannon index, and humus content (%).

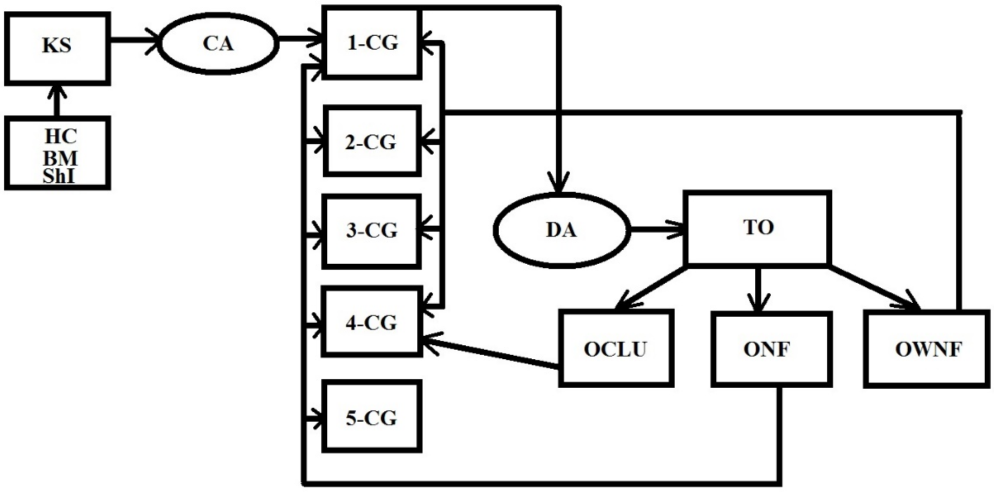

Figure 2. Schematic of cluster analysis of key sites. The direction of the object clustering algorithm corresponds to arrows; square-shaped blocks—input and output results; oval-shaped blocks—data analysis operations; Alphabetic notations in the diagram: ShI. Shannon Index; BM—Herbaceous Plant Biomass, t/ha; HC. Humus Content, %; KS. Key Sites; CA. Cluster Analysis; 1-CG. 1st Cluster Group; 2-CG. 2nd Cluster Group; 3-CG. 3rd Cluster Group; 4-CG. 4th Cluster Group; 5-CG. 5th Cluster Group; DA. Dimensional Analysis; TO. Type of Overgrowth; OCLU. Overgrowth Associated with A Change in Land Use; ONF. Overgrowth Associated with Nearby Forest; OWNF. Overgrowth without Nearby Forest.

The cluster analysis of control sites was carried out according to the following characteristics: phytomass determined in the field, Shannon index, and humus content (%).

In the narrative assessment of the resulting cluster groups, the average values of the characteristics by which the clusters are separated from each other are reduced to certain scales. The humus gradation according to Orlov and Grishina was used [33]. By phytomass and the Shannon index, their own scales were created that divide the studied dataset on overgrown territories into equal intervals. Thus, the following scale for the Shannon index is proposed for post-agrogenic areas:

1. From 2.0 to 2.50—Poor biodiversity;
2. From 2.51 to 3.0—Average biodiversity;
3. From 3.01 to 3.5—High biodiversity.

For phytomass (t/ha), gradation was applied:

1 From1,0 to 5.0—low phytomass;

2 From 5.01 to 7.0—high phytomass.

For humus (%):

1. <2—very low;
2. From 2 to 4—low;
3. From 4 to 6—medium.

A MANOVA analysis was performed (Statistical 10 software, Creator StatSoft, Inc. (2011). STATISTICA (data analysis software system), USA, Texas).

GIS dimensional analysis of landscape components. Visualization of the study results and the creation of a database of soil and vegetation characteristics of the Volga-Oka interstream area were implemented in the ArcGis 10.7 geoinformation environment.

3. Results and Discussion

3.1. Allocation of Control Sites on the Territory of the Volga-Oka Interstream Area

The analysis of cartographic and remote data, as well as the route territory survey, resulted in the selection and laying of control sites characterized by different landscapes of the Volga-Oka interstream area (Figure 1).

The areas of the selected sites reflect the most significant features of the post-agrogenic transformation of different landscapes of the Volga-Oka interstream area (Table 1). They permit determining both the presence of patterns common to the Volga-Oka interstream area and the features characteristic of certain landscapes. It turned out to be appropriate to lay several control sites in landscapes characterized by a wide range of conditions and features of post-agrogenic transformation in order to conduct more accurate analytical assessments.

3.2. Assessment of the Soil Conditions of the Control Sites

The humus content, salt extract acidity and pH in the studied natural soils correspond to the values typical of the zone (Table 2), in which these characteristics are presented both for postagrogenic territories and, for comparison, natural phytocenoses and agricultural lands. Typical agricultural lands are represented by sites I.02 and IV.08. They are characterized by a high humus content of 2.88 and 4.05%, respectively, and a neutral pH. On all sod-podzolic soils under the deposit, overgrown with forest vegetation, a low humus content of 0.96–1.46% is observed. For example, at control sites with sod-podzolic soils, where as a result of overgrowth, forb and grass-forb meadows are formed, most often the acidity of the soils is close to neutral, and the provision of humus is high (up to 4.6%), but areas covered with humus with high acidity, for example, site III.01 (the environment is highly acidic, the humus content is 0.7%) can be found as well [30].

Table 2. Condition of the soil cover of the control sites.

No. of the Site	Acidity of Salt Extract, pH	Humus, %	Cultural States [34]
Sod-podzolic soils under natural forest vegetation			
II.02	5.59 (medium acid)	3.05	-
IV.02	5.75 (medium acid)	2.70	-
IV.05	4.35 (strongly acid)	3.49	-
Sod-podzolic soils under natural meadow vegetation			
I.07	6.59 (neutral)	3.85	highly cultivated
Sod-podzolic soils under forage crops			
I.02	6.18 (neutral)	2.88	cultivated
Disused sod-podzolic soils with established herb meadow and grass-forb meadow			
I.03	6.09 (neutral)	3.01	highly cultivated
II.01	6.61 (neutral)	4.32	highly cultivated
IV.03	6.55 (neutral)	3.33	highly cultivated
IV.04	5.44 (slightly acid)	4.60	highly cultivated

IV.06	6.48 (neutral)	3.64	highly cultivated
IV.07	5.06 (slightly acid)	3.52	highly cultivated
IV.01	5.75 (close to neutral)	2.70	cultivated
IV.10	6.42 (neutral)	3.41	highly cultivated
III.01	3.9 (strongly acid)	0.70	degraded
III.03	5.3 (slightly acid)	1.33	degraded
Sod-podzolic soils under leas overgrown with woody vegetation			
I.01	5.89 (close to neutral)	0.96	degraded
II.03	5.83 (close to neutral)	1.18	degraded
II.04	5.71 (close to neutral)	1.46	degraded
III.02	5.21 (slightly acid)	1.25	degraded
Gray forest soils under long-fallow vegetation			
I.04	6.15 (neutral)	2.98	highly cultivated
I.05	5.81 (close to neutral)	2.55	cultivated
I.06	5.71 (close to neutral)	2.68	cultivated
IV.09	5.99 (close to neutral)	3.74	highly cultivated
Gray forests under forage crops			
IV.08	6.95 (neutral)	4.05	highly cultivated

3.3. Evaluating Transformation Types of Post-Agrogenic Areas

The zone of mixed forests (subtaiga) is characterized by the predominant development of forest communities, which are restored in place of neglected agricultural lands [21]. In the first stage, an herbaceous community emerges, which is replaced by woody vegetation at varying rates. This paper examines the types of post-agrogenic succession characteristics of the initial and intermediate stages of pre-climax community overgrowth.

Three types of transformation of post-agrogenic lands were identified, which differ in the characteristics of the phytocenoses formed on the overgrown lands and the phytoproductivity:

- overgrowth associated with a change in land use;
- overgrowth with nearby forest;
- overgrowth without nearby forest.

There were also three areas with characteristic vegetation of forest communities (II.02, IV.01, and IV.05) and two areas occupied by agricultural land in active development (I.02 and IV.08).

For comparison, a site (I.07) with minimal anthropogenic impact on the Specially Protected Natural Territories "Bogolyubovsky meadow," which in the foreseeable past was maintained in a natural state by cattle grazing and haying, was identified as a natural-meadow association. It is believed that the phytodiversity characteristic of the region is maximally represented in this area [35,36]. This site was the reference for comparative analysis of phytoproductivity and biodiversity of different types of post-agrogenic transformation.

The key sites representing the selected overgrowth types are confined to different landscapes and systematized (Table 3 and Figure 1). Table 3 provides qualitative and quantitative characteristics of key sites, which are grouped by type of overgrowth, and sites belonging to typical forest and meadow communities. Phytomass, Shannon index, the number of species, and the dominant plant species are listed for all sites. Based on the presented data, an analysis of the types of overgrowth and cluster analysis is carried out.

Table 3. Post-agrogenic system transformation types (based on 2018–2019 field studies).

TO	No.	SV		Ph	ShI	NS
		SU	ShG			
Overgrowth associated with a change in land use. Almost complete absence of woody vegetation; well-developed sod; and abundant development of herbaceous vegetation (with a predominance of cereals). Used as a hay-field or pasture. The stock of phytomass is close to natural.	IV.03	-	*Dactylis glomerata* *Anthriscus sylvestris* *Lupinus perennis*	7.8	3.4	19
	IV.04	-	*Festuca pratensis* *Phleum pratense* *Agrostis capillaris* *Ranunculus acris* *Trifolium pratense*	3.2	3.1	17
Overgrowth with nearby forest. Intensive overgrowth with woody vegetation of indigenous forest species prevails, especially along the forest wall. Sod that is not sufficiently developed; low species diversity of herbaceous vegetation (with a predominance of herbs); and medium to high phytomass stocks.	IV.02	*Pinus sylvestris* *Betula pendula*	*Lupinus perennis* *Dactylis glomerata* *Phleum pratense* *Epilobium angustifolium* *Stellaria graminea*	6.4	3.0	13
	IV.06	-	*Cichorium intybus* *Erigeron annuus* *Phleum pratense* *Dactylis glomerata* *Senecio jacobaea*	6.1	3.4	18
	IV.07	*Populus tremula* *Salix caprea* *Betula pendula*	*Calamagrostis epigejos* *Equisetum arvense* *Tanacetum vulgare*	5.1	2.4	9
	III.02	*Pinus sylvestris*	*Calamagrostis epigejos* *Chamaenerion angustifolium* *Pulsatilla vernalis*	4.2	2.1	8
	III.01	*Pinus sylvestris* *Betula pendula*	*Lupinus perennis* *Erigeron annuus* *Pilosella officinarum* *Rumex acetosa* *Phleum pratense*	3.5	3.4	16
	II.01	*Betula pendula* *Pinus sylvestris* *Picea abies* *Salix caprea*	*Dactylis glomerata* *Galium boreale* *Centaurea jacea* *Trifolium pratense* *Campanula patula*	10.2	3.5	23
Overgrowth without nearby forest.	I. 01	*Salix caprea* *Betula pendula* *Pyrus communis*	*Equisetum arvense* *Lupinus perennis* *Vicia cracca*	3.84	3.64	19

Overgrowth by woody vegetation occurs at a later date, mainly by species whose seeds are well dispersed by the wind. Average overgrowth: poor species composition and dominated by grasses and herbs (in the initial stages of overgrowth, and ruderal vegetation predominates). Stage changes in phytomass stocks and phytocenosis species composition.			*Calamagrostis epigejos* *Phleum pratense*			
	II.03	*Pinus sylvestris* *Betula pendula*	*Erigeron annuus* *Rumex acetosa* *Equisetum arvense* *Chenopodium album*	4.3	2.0	7
	II.04	*Salix caprea* *Betula pendula*	*Dactylis glomerata* *Centaurea jacea* *Medicago falcata* *Agrostis capillaris*	5.0	3.2	17
	I.03	-	*Anthríscus sylvestris* *Festuca pratensis* *Phleum pratense* *Carex leporina* *Centaurea jacea*	5.2	2.6	17
	I.04	*Salix aurita*	*Calamagrostis epigejos* *Solidago canadensis* *Poa pratensis*	6.0	3.0	13
	I.05	*Pinus sylvestris* *Betula pendula* *Salix caprea* *Picea abies*	*Calamagrostis epigejos* *Solidago canadensis* *Erigeron annuus*	3.9	2.6	11
	I.06	*Sorbus aucuparia*	*Calamagrostis epigejos* *Aegopodium podagraria* *Tussilágo fárfara*	4.3	2.7	11
	IV.10	*Betula pendula*	*Elytrigia repens* *Erigeron annuus* *Rumex acetosa* *Tanacetum vulgare*	7.5	2.6	12
	IV.09	*Pinus sylvestris* *Betula pendula*	*Erigeron annuus* *Rumex acetosa* *Pilosella officinarum* *Potentilla argentea*	5.9	3.1	15
	III.03	*Betula pendula*	*Calamagrostis epigejos* *Dactylis glomerata* *Phleum pratense* *Chamaenerion angustifolium*	4.6	2.2	12
Characteristic vegetation of forest communities. Mixed forests with forest plant species typical to the area.	IV.01	*Pinus sylvestris* *Betula pendula* *Picea abies*	*Pyrola minor* *Rubus saxatilis* *Melampyrum nemorosum* *Veronica officinalis* *Geum urbanum*	1.2	2.3	10

	IV.05	*Pinus sylvestris* *Betula pendula* *Picea abies*	*Fragaria vesca* *Melampyrum nemorosum* *Melampyrum pratense* *Geum urbanum* *Asarum europaeum*	4.6	3.4	19
	II.02	*Picea abies* *Betula pendula* *Populus tremula*	*Rubus saxatilis* *Vaccinium myrtillus* *Fragaria vesca* *Ajuga reptans* *Convallaria majalis* *Dryopteris fílix-mas*	8.0	2.5	10
Characteristic vegetation of meadow communities. Forb-grass community Bogolyubov meadow.	I.07	-	*Centaurea jacea* *Pinélla saxífraga* *Alopecurus pratensis L.* *Trifolium praténse* *Phleum pratense* *Poa pratensis* *Stellaria graminea L.* *Silene vulgaris* *Ranunculus repens L.* *Capsella bursa-pastoris* *Medicago falcata* *Geránium praténse*	6.3	4.1	28

Note: TO. Type of Overgrowth (or Transformation) and its Characteristics; No. of the site; SV. Surrounding Vegetation; SU. Forest Stand and Understorey; ShG. Predominant Shrub-grass Cover; Ph. Phytomass (herbaceous plants), t/ha; ShI. Shannon Index; NS. Number of Species on the Geobotanical Site. Table does not include sites used as agricultural lands.

3.4. Analysis of Successional Processes on Post-Agrogenic Lands and the Main Types of Overgrowth

Type of lea overgrowth: Overgrowth with nearby forest. This type of overgrowth is represented by six control sites.

The overgrowth of territories with a nearby forest is shown in (Figure 3).

Analysis of the three types of overgrowth is performed by examples of key sites located in different landscapes (Table 3 and Figure 4).

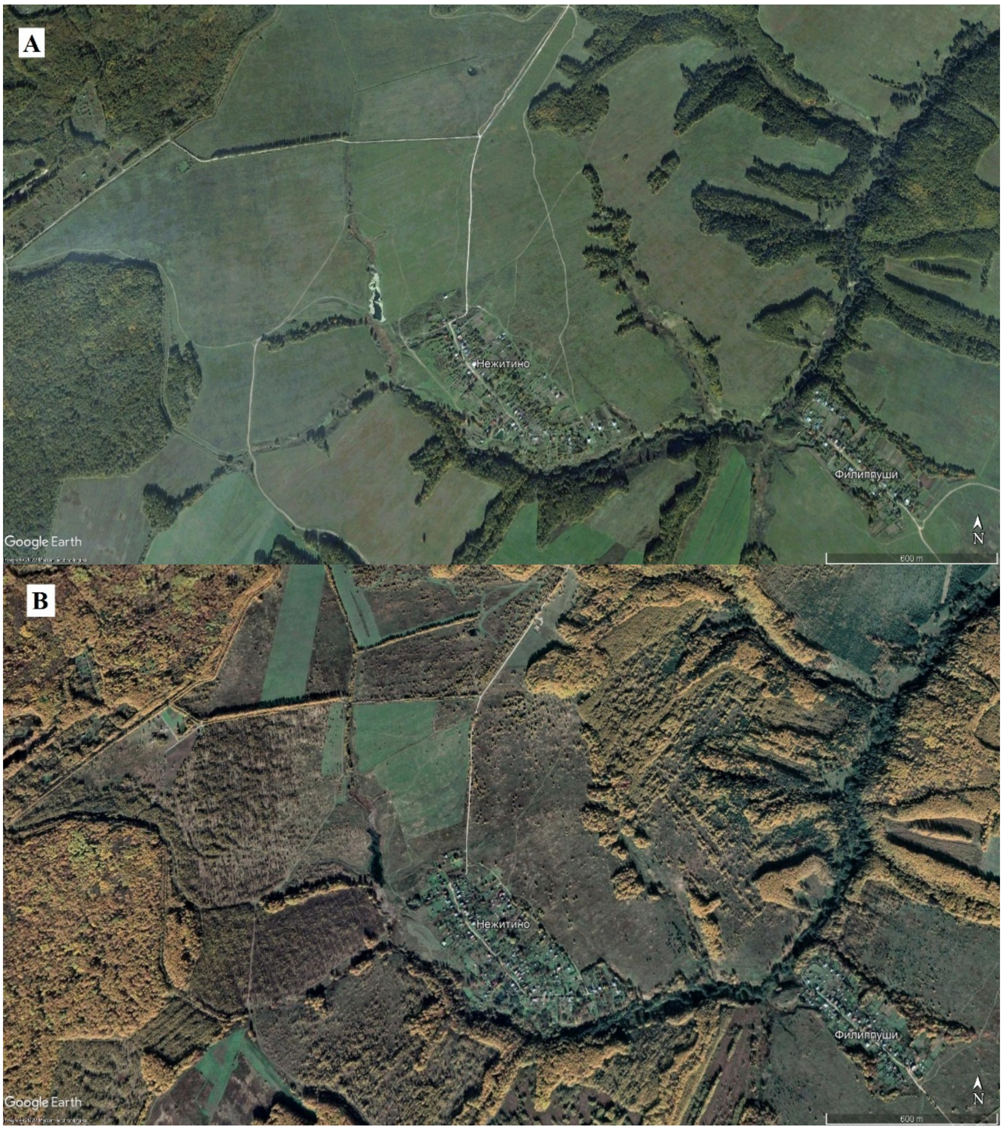

Figure 3. Examples of overgrowth nearby (space images of the Earth's surface, Google Earth Pro V. 7.3.4.): (**A**) -2006, (**B**) -2018.

The most typical processes are observed on plot IV.02 with disused soils near the Oka-Tsna bar, which was withdrawn from agriculture about 30 years ago and is located next to a mixed forest (site IV.01).

This area is intensively overgrown with pine and birch, which is due to the predominance of these species in the adjacent forest area. Their projective coverage is already more than 50%, and the crown density does not occur. The prevailing herbaceous vegetation is presented in Table 3. Despite the sufficient amount of woody vegetation, intensive overgrowth with typical herbaceous forest plants has not yet occurred, and its species composition is significantly different from the nearby forest area (site IV.01). For example, there is no *Geum urban, Pyrola minor*, etc., and meadow grasses grow (*Phleum pratense, Dactylis glomerata*, etc.). A community has formed in which under woody vegetation there are species more typical of meadow areas, because initially, there was overgrowth without a forest stand and at this stage, conditions for the settlement of forest herbaceous vegetation have not been formed. A well-formed sod layer and insufficient projective cover of woody vegetation prevent this dispersal. The herbaceous vegetation of the formed phytocenosis is characterized by significantly greater phytomass and a little greater species diversity compared to the forest; and it is significantly inferior in species richness and number to meadow associations with minimal anthropogenic impact (control site I.07 "Bogolyubovsky meadow"), approaching them only in phytomass.

Among the sites belonging to the type of overgrowth with adjacent forest, it is necessary to note the site located within the Volga-Klyazma Province (II.01) in the territory of the Pless-Galich upland. It is also characterized by the renewal of tree species typical of the neighboring forest (reference site II.02). However, the vegetation cover transformation is characterized by being maximum among all the sites, including reference sites, the stock of herbaceous phytomass (10.2 t/ha) and, in addition, the largest number of species among post-agrogenic areas (23 species). However, the biodiversity (by the Shannon index) is also well below the control site.

The type of overgrowth: Overgrowth with a change in land use. This type of overgrowth is represented by two key sites (IV.03 and IV.04) which differ in the anthropogenic impact affecting the accumulation of phytomass by plant communities.

The disused land site within the Oka-Tsna bar (IV.03) is located near the forest, but for a long time after leaving the category of arable land, was used for hayfields, which created good conditions for sod layer formation, so the overgrowth by woody vegetation does not occur here. The total stock of phytomass of above-ground herbaceous vegetation is 7.79 t/ha, which is higher than the values for natural mesophytic meadow phytocenoses. At the second site (IV.04 Kovrov-Kasimov Plateau), a grass-forb phytocenosis was formed, which is used not only for haying but also for cattle grazing. The phytomass of this area is quite low (3.2 t/ha) due to intensive grazing.

What both sites have in common is that their species composition differs from the reference site and has poorer biodiversity compared to it.

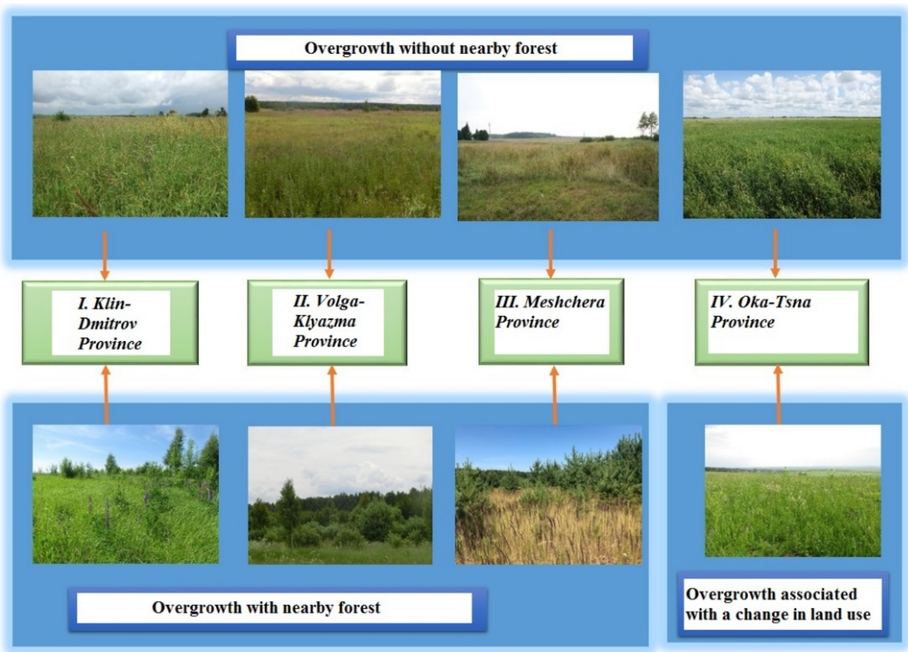

Figure 4. Examples of overgrowth in post-agrogenic areas.

The type of overgrowth: Overgrowth without nearby forest. Overgrowth without nearby forest is represented by 10 sites, which, regardless of landscape affiliation, compared to the reference meadow site (I.07), are characterized by a lower Shannon index, fewer species of herbaceous plants, and almost all sites have lower phytomass.

Thus, the analysis of the types of post-agrogenic transformation of arable lands revealed the following patterns specific to the initial and intermediate stages of preclimax communities' overgrowth.

First, the type of overgrowth does not depend on the landscape affiliation of the overgrowth area. The main trend throughout the area is the restoration of forest vegetation, which is going at varying speeds. It is determined mainly by the location of the area next to the forest or at a considerable distance from it, as well as by the anthropogenic activities on neglected arable land.

Second, the results of the research showed that the overgrowth of most areas within different landscapes followed common successions, even on different soils (sod-podzolic and gray forest), the leveling of landscape features of areas, and there were similar plant species and communities. The most typical of which are: cereals—*Phleum pratense*, *Dactylis glomerata, Calamagrostis epigejos, Festuca pratensis*; legumes—*Lupinus perennis* and *Vicia cracca*; herbs—*Tanacetum vulgare, Artemisia vulgaris, Agrimonia eupatoria, Achillea millefolium, Galium boreale, Hypericum perforatum, Erigeron annuus, Equisetum arvense, Tartxacum officinale*, and *Centaurea jacea*. In the post-agrogenic territories of these areas, there is an increase in the number of species that do not have special requirements for soil fertility and moisture (*Erigeron annuus, Senecio jacobaea, Hieracium pilosella, Artemisia vulgaris*, and *Artemísia absínthium*), which indicates the low productivity of post-agrogenic soils, the loss of many valuable agrochemical properties associated with the cessation of land use, and the appearance in the mass of such plants-edificators such as *Equisetum arvense*. Various *Rumex* species indicates intensive soil acidification.

Third, as a result of post-agrogenic transformation, the phytoproductivity of herbaceous plants decreases in the first stages; then it usually increases and can reach values typical of reference forb-grass communities or even, in rare cases, exceed these values. A similar situation was observed in vegetation restoration after soil contamination by technogenic pollutants [37,38].

Fourth, when compared to the characteristics of the reference vegetable forb-grass communities represented by the site I.07, herbaceous plant biodiversity and the number of species (species richness) decrease at all control sites, regardless of landscape affiliation, type, or time of overgrowth. The same productivity of phytocenoses is ensured by the different species composition of communities.

3.5. Analysis of Factors Affecting Successional Processes in Overgrown Areas Using Cluster and Factor Analysis

A statistical analysis of the results based on cluster and factor analyses was carried out to verify the conclusions obtained about the factors affecting successional processes (Tables 4 and 5).

As a result, all sites are grouped into five clusters (Figure 5 and Table 4).

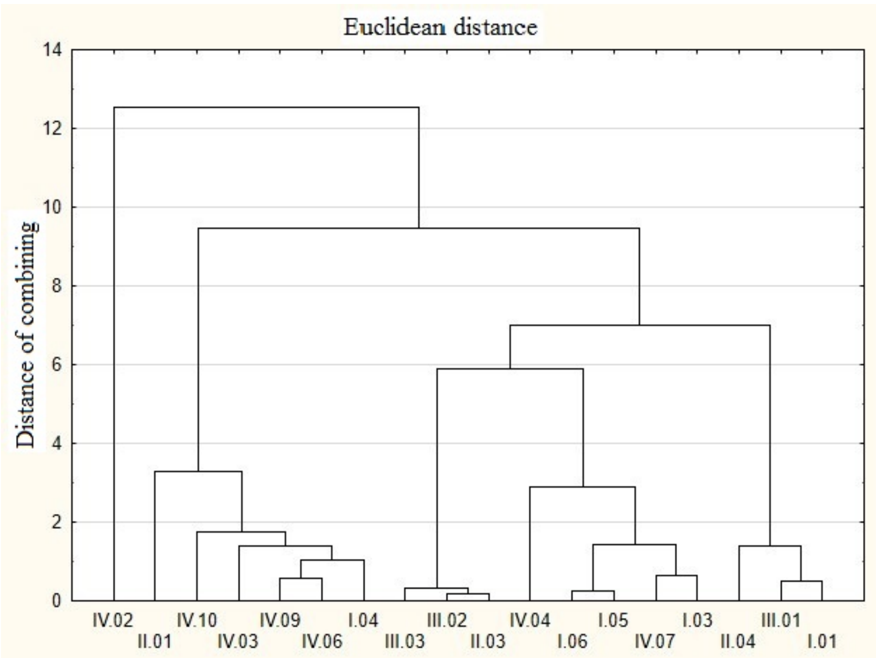

Figure 5. Key site clustering tree. The abscissa axis corresponds to the key sites and the ordinate axis corresponds to the distance of combining objects into groups (Euclidean distance). Ward's method was used as the method of association.

Table 4. Results of clustering of the Volga-Oka interstream area control sites.

Cl	CS	LP	Means			Estimate
			ShI	Ph	HC	
		1st cluster group				
1	I.01—Klin-Dmitrov Ridge III.01—Meshchera II.04—Nerlya-Klyazma lowland	Klin-Dmitrov Province Meshchera Province Volga-Klyazma Province	3.43	4.13	1.04	High biodiversity, low phytomass, and very low humus.
2	I.03, I.05, I.06—Vladimir High Plain IV.07—Gorokhovets spur	Klin-Dmitrov Province Oka-Tsna Province	2.51	4.64	2.93	Average biodiversity, low phytomass, and low humus.
3	II.03—Nerlya-Klyazma lowland III.02, III.03—Meshchera	Volga-Klyazma Province Meshchera Province	2.14	4.39	1.25	Low biodiversity, low phytomass, and very low humus.
		2nd cluster group				
4	I.04—Vladimir High Plain II.01- Pless-Galich upland IV.03—Oka-Tsna Bar IV.04—Kovrov-Kasimov Plateau IV.06—Gorokhovets spur IV.09—Murom High Plain IV.10—Dmitrievogorsk Landscape Area	Klin-Dmitrov Province Volga-Klyazma Province Oka-Tsna Province	3.14	6.59	4.06	High biodiversity, high phytomass, and average humus.
		3rd cluster group				
5	IV.02—Oka-Tsna Bar	Oka-Tsna Province	2.95	6.43	2.70	Average biodiversity, high phytomass, and low humus.

Note: Cl. Cluster; CS. Control Sites; LP. Landscape Province; Ph. Phytomass (herbaceous plants), t/ha; ShI. Shannon Index; HC. Humus Content, %.

Table 5. Results of factor analysis for the biodiversity of herbaceous vegetation in post-agrogenic areas.

Effects (Factors)	Degree of Freedom	SS	MS	F	$p < 0.05$
Type of overgrowth	2	0.26	0.13	0.49	0.62
Humus content	2	0.20	0.10	0.39	0.69
Phytomass	1	0.13	0.13	0.50	0.49

Note: SS. Sum of Squares; MS. Mean Square; F. Fisher Criterion (calculated); *p*. Significance Levels (significant effects are highlighted in red).

Sites similar in such characteristics as herbaceous plant phytomass, Shannon index, and soil humus in different landscapes are grouped into one cluster. Combinations of these characteristics are not related to the landscape affiliation of the site.

The first cluster included three sites belonging to three different provinces with high herbaceous plant biodiversity, with low phytomass and very low soil humus.

The second cluster, according to the given parameters, includes four areas of the Klin-Dmitrov and Oka-Tsna provinces, which are characterized by average biodiversity of herbaceous plants and low phytomass with low soil humus.

The third cluster consists of three sites confined to the Volga-Klyazma and Meshchera provinces characterized by poor biodiversity in combination with low phytomass and very low soil humus.

The fourth cluster is the most numerous (seven sites); it demonstrates the most typical combination of overgrown areas characteristics within the Klyazma basin, which are confined to the Klin-Dmitrov, Volga-Klyazma, and Oka-Tsna provinces. This cluster is characterized by sites with the highest biodiversity among the overgrown lands, but it is lower than this characteristic in natural phytocenoses. The cluster is also characterized by a large phytomass, approaching the phytomass of natural meadow communities and the average content of soil humus.

The fifth cluster included one site located within the Oka-Tsna province and recorded the average biodiversity of herbaceous plants combined with high phytomass and low soil humus.

Thus, the same cluster combines sites similar in biodiversity, phytomass stock of herbaceous plants, and humus content, but they may be located in different natural areas and landscape provinces within the Volga-Oka interstream area. This analysis demonstrates the diversity of variants of post-agrogenic transformation of arable lands, which does not depend on the landscape affiliation of the site but is determined by the local conditions of territory location and use.

Factor analysis was used to assess the impact on the biodiversity of herbaceous vegetation of overgrown cropland, which was characterized by the Shannon index, such factors as the content of humus in the soil, the stock of phytomass of herbaceous plants, and the type of overgrowth (the three types of overgrowth described above were taken into account: overgrowth associated with a change in land use, overgrowth with nearby forest, and overgrowth without nearby forest).

Each factor is considered in the following gradations: humus content is evaluated as very low, low, and average; phytomass as low and high; and overgrowth type as related to land use change, as well as related to the forest, and not related to the forest. The results are presented in Table 5.

Factor analysis demonstrates the lack of influence on the value of biodiversity of each of three factors: humus content, phytomass stock, and overgrowth type. No significant effects were observed at $p < 0.05$.

Consequently, restoration of plant cenoses on all neglected croplands in the conditions of the considered territory takes place ignoring their aboreal composition.

4. Conclusions

Thus, the analysis of post-agrogenic phytocenoses typical of the initial and intermediate stages of overgrowth of preclimax communities showed that they could gradually restore the productive potential of natural phytocenoses and, in some cases, surpass it. For example, the maximum value of phytomass in overgrown lands is 10.2 mt/ha. For comparison, natural phytocenoses accumulate 6.3 mt/ha at reference sites.

As a result of the overgrowing of agricultural lands, the biodiversity of communities decreases because overgrowing in different landscapes with different soil covers follows common succession. It is confirmed by the fact that in postagrogenic territories, the highest value of the Shannon index is 3.6, which is lower than the reference natural community, where this indicator is 4.1.

There is a leveling of landscape features of phytocenoses, and there are similar species of plants and communities. Restoring biodiversity for the foreseeable future is very problematic. Later, these results can be used to create a database of the state of overgrown land according to a set of indicators (Shannon index, phytomass, and humus), as well as for further monitoring of their condition, biodiversity conservation, and management decision-making.

In order to preserve and subsequently restore biodiversity, it seems advisable to intersperse croplands with uncultivated plots of sufficiently large size, which can serve as a kind of seed bank of aborealvegetation to preserve phytodiversity when plowing the territories. In addition, it is obvious that the nearby large areas of arable land deprive natural biotopes of insect pollinators, which also negatively affects the conservation and maintenance of natural landscapes and ecosystem biodiversity.

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