Patterns of afforestation on abandoned agriculture land in Latvia

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Abstract Abandonment of agriculture land and subsequent natural afforestation have been common features of the contemporary Latvian rural landscape, particularly in the period since 1990. This process affects the structure, ecology and visual qualities of the landscape. The study examines spatial characteristics of afforestation in relation to various environmental factors. The study was conducted in the central part of Latvia, where there is abundant abandoned agriculture land and a great variety of spatial afforestation patterns. The most typical patterns in this area were linear, mosaic, and continuous afforestation, as well as development of afforestation from the forest edge. The results of the study show that the spatial patterns of natural afforestation of abandoned agriculture fields can be very diverse, and do not follow the classical secondary succession model. Afforestation can be delayed by a dense cover of herbaceous vegetation for a period of up to 20 years. There are many interacting factors that affect succession and development of afforestation patterns, such as soil properties, size and configuration of fields, previous land use and also the random nature of plant colonization by seed. Further studies on afforestation patterns would help to understand better their ecological, economic and social effects as well as to determine optimal solutions for the use of abandoned agriculture land.

Keywords Abandonment · Afforestation · Secondary succession · Environmental factors

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Introduction

Land abandonment and natural afforestation have become common processes of the contemporary landscape in marginal areas of Europe (Sirami et al. 2007; Sitzia et al. 2010) and most probably this trend will continue in the future. Models of land use change in Europe in the period up to 2030 predict a decline of agricultural land, which will be one of the major factors influencing the European landscape in the future (Stoate et al. 2009). In Latvia, afforestation has occurred from the beginning of the last century, resulting from frequent changes in the political and economic conditions. Between 1935 and 2008 the forest area increased from 27 to 50% (Ministry of

Agriculture 2009) due to state afforestation policy in the 1930s, natural afforestation on farmland abandoned after II World War and establishment of Soviet collective farms in the 1950–60s. During the Soviet period large drained agriculture fields were established around countryside settlements, while more distant fields were abandoned (Peneze et al. 2009). Extensive land abandonment and subsequent natural afforestation occurred after regaining of independence from the Soviet Union in 1991. This land use change was due to collapse of the collective farming system, urbanization and land reform, when a big share of the agriculture land was retrieved by the former land owners who lived in cities and had no interest in farming (Bell et al. 2009; Nikodemus et al. 2005).

In recent years land abandonment has been studied regarding the socio-economic and political factors driving the marginalization process, impacts on the landscape structure and on biodiversity, and the potential of abandoned land for use of natural resources or restoration of habitats (Bürgi et al. 2004; Jongman 2002; Mander et al. 2004; Antrop 2005, Nikodemus et al. 2005; Kristensen 1999, Kristensen et al. 2004; Łowicki 2008; Palang et al. 2005, 2006; Romero-Calcerrada and Perry 2004). Several authors (Hietel et al. 2004; Łowicki 2008; Mander et al. 2004) argue that socio-economic factors are the main drivers of land abandonment. Little is known about the impact of environmental factors on secondary succession and the associated changes in landscape spatial structure, but clearly major land cover change is related with the physical attributes of land (Hietel et al. 2004).

When land has been abandoned, the secondary successions that ensue are affected by environmental factors, as these determine which of the species arriving by seed can potentially participate in the successions (Gleason 1926). The course of natural afforestation, the spatial character and species composition in successions depend on factors such as physical and chemical properties and moisture conditions of soil, topography, initial cover of herbaceous vegetation, proximity to forest, as well as former land use (Egler 1954; Connell and Slatyer 1977; Tilman 1987; Prach et al. 2001a, b; Bartha et al. 2003; Alard et al. 2005; Daugaviete 2009; Kopecký and Vojta 2009; Rosenthal 2010). Depending on the interactions between these factors, secondary succession creates a suite of heterogenic spatial patterns. Several studies in Europe have examined soil property changes in relation to secondary succession (Alriksson and Olsson 1995; Merilä et al. 2002; Mund et al. 2002; Nierop et al. 2001; Ritter et al. 2003; Smal and Olszewska 2008; Wall and Hytönen 2005) and land abandonment (Armolaitis et al. 2007; Falkengren-Grerup et al. 2006; Hagen-Thorn et al. 2004; Tullus et al. 2007; Vesterdal et al. 2002; Wall and Heiskanen 2003). The initial and subsequent soil properties also affect the dynamics of secondary succession (Tilman 1987), resulting in a feedback mechanism.

Afforestation of abandoned landscape affects the structure and ecological functions of the landscape (Reger et al. 2007; Stoate et al. 2009). At the initial stage of afforestation, habitat and species diversity can increase, but in the long-term period the landscape becomes more homogenous, thereby reducing biological diversity (Fjellstad and Dramstad 1999; Gutko et al. 2001; Hietel et al. 2004; Nikodemus et al. 2005; Sirami et al. 2007; Sitzia et al. 2010). Abandonment of agricultural land causes fragmentation of suitable habitat for resting, feeding and breeding of bird species that require an open landscape (Sirami et al. 2007). However, secondary succession can be viewed as a process that can be used also for restoration of natural habitats required for typical woodland animal species (Prach et al. 2001a; Stoate et al. 2009). Land abandonment also influences the scenic quality of landscape and its identity, which might psychologically affect inhabitants, causing feelings of e.g. isolation, poverty, shame etc. (Bürgi et al. 2004; Palang et al. 2006; Benjamin et al. 2007). A better understanding of the role of environmental factors in the process of natural afforestation would help to predict the course of its development and to make optimal choices for the future use of the abandoned land.

The aim of the study was to determine the spatial character and paths of secondary succession in selected abandoned agriculture areas, in relation to environmental factors (former land use, soil fertility, initial species composition of herbaceous vegetation, tree species composition of neighbouring forest stands, as well as size and configuration of the field). We hypothesized that natural afforestation processes differ in spatial character and species composition among different types of former agriculture land.
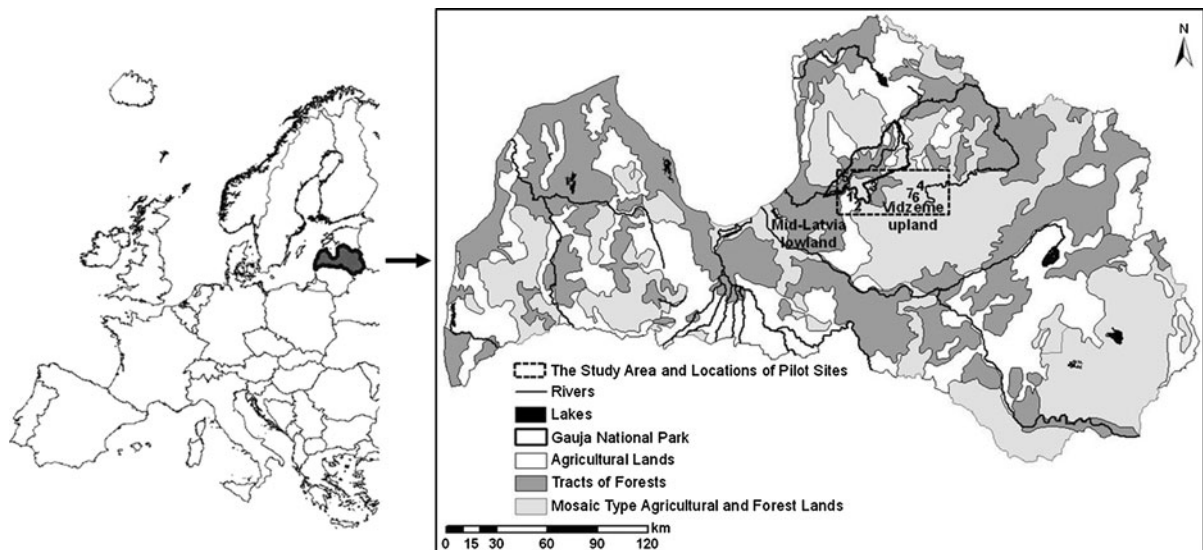
Fig. 1 Location of the study area within Europe and Latvia

Materials and methods

Study area

The study was conducted in the central part of Latvia, encompassing part of the Vidzeme upland of Latvia (Fig. 1), which has slightly undulated topography (ca. 200–300 m above the sea level), and part of the Mid-Latvia lowland. The climate is moderate. Annual precipitation is 750–850 mm of which about 500 mm falls in the warm period. The average temperature is 16.5°C during the warmest month, and −6°C in the coldest month. This area is located in the hemiboreal region, where the predominant coniferous tree species (*Pinus sylvestris* and *Picea abies*) are mixed with deciduous species (mainly *Betula pendula, Populus tremula, Alnus glutinosa* and *Alnus incana*), while broad-leaved tree species such as *Quercus robur* and *Fraxinus excelsior* are less abundant (Hytteborn et al. 2005). The most common tree species participating in secondary succession on abandoned agriculture land are *Salix* spp., *A. incana* and *B. pendula* (Korotkov et al. 2001). In the area, Arenosols, Podzols, Cambisols, Albeluvisols, Luvisols, Stagnosols and Gleysols have developed on glacial till, glaciofluvial and glaciolacustrine deposits (loamy sand, sandy clay, loam, clay, gravel, sand) and Fluvisols on alluvial deposits (sand) (Nikodemus et al. 2008).

The study area is characterized by a typical rural landscape formed by a mosaic of forest patches and agriculture fields and farmsteads. About half of the area is classified as agriculture land, of which 25–35% is currently not used as such (Peneze 2009). The high proportion of non-used agriculture land in the Vidzeme upland has been caused by marginalization processes and unfavourable natural conditions for agricultural development. In the part of the study area located within the Mid-Latvia lowland the afforestation process is driven by suburbanization and transformation of agriculture land into built-up areas, which due to the economic crises are not used.

Methods

Seven fields of different size (5–56 ha) and configuration were chosen within the study area to cover the range of variability in the patterns of natural afforestation (Table 1). Selection of the fields was based on visual analysis of colour orthophoto maps (scale 1:10,000; resolution of 0.5 m) from the Latvian Geospatial Information Agency, produced from airborne remote sensing images taken in 2007.[1] Four of the selected fields were located in the Mid-Vidzeme lowland. Of these, fields 1 and 2, which were the largest and had rather strait boundaries, were located in a big agriculture land matrix with plain topography.

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[1] Remote sensing images produced using digital camera Vexcel "UltraCamX" (216 megapixels), at the flight height of 7,000 m.

Table 1 Characteristics of studied fields and their patterns of afforestation

No. of field	Pattern of afforestation	Land use before afforestation	Year since abandonment	Area of the field (ha)	Area covered by afforestation patches		Soil type	Soil texture
					ha	% of the field		
1	Linear	Arable land	1996	56	2	3.6	Stagnosols	Sandy loam, loam
							Luvisols	Silt loam
2	Linear	Arable land	1991	53	4	7.6	Stagnosols	Loam
							Gleysols	Silt loam
3	Mosaic	Meadow	1992	24	4	16.7	Stagnosols	Sandy loam
							Cambisols	Sandy loam
							Podzols	Sandy loam
							Arenosols	Sandy loam
							Luvisols	Sandy loam
4	Mosaic	Meadow	1995	9	2	22.2	Stagnosols	Sandy loam
							Luvisols	Silt loam
5 (1)	Continuous	Meadow	2000	3	1.1	36.7	Arenosols	Sand
5 (2)	From forest edge and mosaic	Meadow	1991	11.7	0.9	7.7	Arenosols	Sand
6	Mosaic	Meadow	1991	12	1	8.3	Stagnosols	Loamy sand
							Luvisols	Loamy sand, loam
							Arenosols	Medium sand
7 (1)	Continuous	Arable land	1988	1.4	1.2	85.7	Stagnosols	Loamy sand
							Luvisols	Loamy sand, loam
							Arenosols	Medium sand
7(2)	Mosaic	Meadow	1993	4.1	0.5	12.2	Stagnosols	Loamy sand
							Luvisols	Loamy sand, loam
							Arenosols	Sand

The other two fields (field 3 and 5) on the lowland were smaller and had more complex shapes. Fields 1, 2 and 3 were located in an open landscape area along major traffic roads, and field 5 was located between the Gauja river valley and the strict protection zone of the national park. Three fields (fields 4, 6 and 7) were selected in the Vidzeme upland. All of these were small (<15 ha) and had irregular shapes typical for the mosaic landscape of the upland.

The studied fields represented four spatial patterns of afforestation: linear, mosaic, continuous and from the forest edge (Table 1). The linear pattern was distinguished by afforestation proceeding along linear structures in the landscape (e.g. ditches, roads etc.). In the selected sites, the linear shapes of afforestation patches followed the former ploughing direction. The

mosaic pattern was formed by scattered afforestation patches of different size and shape in the fields. In the continuous pattern, afforestation occurred simultaneously over entire fields. The fourth pattern represented the case when afforestation started from forest edges and which could develop into a mosaic or linear pattern.

The boundaries of the afforestation patches were mapped using the global positioning system (GPS).[2] In each field, sampling plots (10 m × 10 m) were established in almost all patches of shrub and tree cover. Their number, which depended on size of the study site and complexity of the afforestation pattern,

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[2] GPS—*Magellan.*

ranged from 8 to 27 per field (20 in field 1, 24 in field 2, 27 in field 3, 14 in field 4; 15 in field 5, 8 in field 6 and 10 in field 7). In the plots, the numbers of individuals of woody species were counted, and mean and maximum tree heights of each species were estimated. Ages of the trees were determined in the field by counting tree rings of tree discs removed by saw at base of the trees. Data collected in the plots on trees were used to estimate afforestation characteristics for the fields. Floristic description of the plant species on a habitat level was carried out in the herbaceous layer of the plots and in the open area between patches. The dominant plant species were recorded, adopting the approach of cover estimation by eye (Kent and Coker 1992)—in open areas the species covering more than 25% of the projective cover were noted, while within the afforestation patches, where the herbaceous layer covered only 1–2% of the projective cover, the most abundant species were indicated. The spatial distribution of the dominant species in plots was then examined to provide descriptive information in context of the afforestation patterns. Information on the relative dominance of tree species in the overstorey of forests surrounding the fields (up to 40 m from the forest edge) was obtained from forest inventory data in the State Forest Register, made available in digital format from the State Forest Service (data for 2011).

The soil types in all studied fields were determined on a crude scale using a digitised version of soil maps obtained from the State Land Service of the Republic of Latvia for the inventory period 1980–1987. The detailed spatial distribution of the soil types was determined in the field by sampling with a soil auger. Soil types were identified following the international FAO WRB classification system (IUSS Working Group 2007). In addition, 13 soil profiles were unearthed in fields 1, 2 and 3, which had the most representative afforestation patterns. These soil profiles were also described as above. Thickness of the plough horizon (Ap) was measured. In the soil profiles, a total of 57 soil samples were collected from soil profile diagnostic horizons for detailed physical and chemical analyses: soil texture, total nitrogen, total phosphorus, potassium, and soil pH_{KCl}. The analyses were conducted in the laboratory according to standard methods used in *ICP*[3] Forest monitoring (Forest Soil Co-ordinating Centre 2006).

The obtained data were analysed spatially using geographical information systems (GIS) software.[4]

Distribution of the afforested patches was evaluated in relation to the configuration, size and soil type.

Information on the former land use and the year of abandonment were obtained from local residents by direct interviews at the sites. The dynamics of the afforestation process were determined by comparing orthophoto maps produced in 1997–1998, 2003–2004 and 2007.

Relationships between various environmental factors e.g. soil physical and chemical properties in the plough (Ap) horizon; topography; age of secondary succession development and tree density were determined using principal component analysis (PCA)[5] A Monte Carlo test was used to test significance of the PCA axes. Samples represented soil profiles (13) and the patches where they were located. As the fields were very heterogenous in soil types, and since we did not use replicates within fields to test for differences between fields, we can consider the soil profiles samples within a field to be independent samples and not pseudoreplicates. Pearson correlation coefficients were determined between environmental factors and PCA scores for samples.

Results

Spatial character and tree species composition in natural afforestation patches in relation to former land use, size and configuration of the field

Most of the fields were used as arable land for crop cultivation during the period of collective farms (until the beginning of the 1990s), while others had meadow (hay collection) or pasture (cattle grazing) use, or mixed arable land and meadow use (Table 1). Crop cultivation was stopped in all fields since liquidation of the collective farms in the period from 1991 to 1995, while hay collection was continued for a few years in fields 2, 4 and 5. By 2000, all regular farming activities had ended in the selected fields, except in field 2, part of which was ploughed in 2005, then again abandoned.

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[3] ICP—International Cooperation Programme.

[4] GIS softwere *ESRI Arc Map 9.2.*

[5] PCA softwere *PC ORD 5.10.*

Fields 1 and 2 (Fig. 2a, b) represent comparatively large and homogenous units, which were drained and used for crop production until 1995, when the land was divided among several new land owners. A linear afforestation pattern developed in both fields, but the dominant tree species in the afforested patches differed. In field 1 the dominant tree species was *B. pendula* mixed with *Salix* spp. (Table 2), forming mostly sparse stands (up to 50 trees per 100 m^2), but in places forming dense patches (up to 126 trees per 100 m^2). Based on ages of trees (12 years for *B. pendula)* development of woody patches here started around the year 1999 (4 years after abandonment) and height of trees in the stands in 2010 reached a maximum of 8 m. Dominant tree species in surrounding forests were *P. abies, A. incana* and *B. pendula.* The main soil types were Stagnosols (soil texture characterised by sandy loam and loam) and Luvisols (silt loam). In field 2, the part that had not been used already from 1991 was colonized by *B. pendula* mixed with *Salix* spp. and some *A. incana* and *P. abies.* Height of the trees reached 11 m for both *B. pendula* and *Salix* spp. (Table 2). Age of *B. pendula* in 2011 reached 19 years, showing that colonisation of the field by this species started immediately after abandonment. The other part of the field, which was ploughed in 2005, was invaded by *Salix* spp., which had reached 6 m height and formed visually dense stands, although the number of trees was less than 100 trees per 100 m^2. The most common soil type in that field was Stagnosols formed on loam.

Field 3 (Fig. 2c), which was previously used for crop production, was later split into three land properties, of which none had been used for agriculture production since liquidation of the collective farm in 1992. Topography of this field was slightly undulated. Soil cover was rather complex, and the main soil types were Stagnosols (soil texture—sandy loam and loam) and Luvisols (silt loam). Dominant tree species in surrounding forests were *B. pendula*, *P. abies*, *P. tremula* and *A. incana.* A mosaic pattern of afforestation had developed in the field, characterized by patches of different size, shape and species composition. The stands were mainly sparse. The most common tree species were *B. pendula*, reaching 11 m height*,* and *P. abies* (Table 2), which formed a few patches reaching up to 6 m in height. Age of *B. pendula* reached 19 years, indicating that this species

invaded immediately after abandonment of the field, while maximum age of *P. abies* was 12 years.

Field 4 (Fig. 2d) was located on the slope of a hillock. Soil types were Stagnosols (on sandy loam) and Luvisols (on silt loam). Dominant tree species in surrounding forests were *P. tremula*, *P. abies*, *A. incana* and *B. pendula.* Until the beginning of the 1990s the field was partly used as arable land. After 1990, due to loss of function of the drainage system, it was converted into grassland, and left to natural afforestation in 1995. Woody patches formed a mosaic pattern, dominated by *P. abies* mixed with *Salix* spp., *B. pendula* and *A. incana* (Table 2). Maximum height of trees was 9 m and age of the trees reached 12–13 years, indicating that colonization of the field started ca. 3 years after abandonment.

Field 5 had a very complex shape and included different patterns of afforestation. The topography was plain and the dominant soil types were Luvisols, Stagnosols, Gleysols and Arenosols, formed on sand. Surrounding forests were dominated by *B. pendula*, *P. sylvestris* and *A. incana.* Part of the field—5 (1) formed a narrow belt along a river (Fig. 2e). This part was previously used as arable land, later as a meadow, and abandoned around 2000. Now, continuous afforestation has entirely taken over this part of the field, forming a rather dense stand (up to 150 trees per 100 m^2) dominated by birch up to 3 m height (age of the trees was around 4 years). The remaining part of the field—5 (2) (Fig. 2f) was abandoned in 1991 and gradually overgrew with a mosaic pattern of woody patches starting from the forest edge at the eastern part of the field. The dominant tree species there were *B. pendula* mixed with numerous *P. abies* (age 12 years) and *P. sylvestris* (age 6 years) (Table 2). Thus, invasion of the tree species in this part of the field started ca. 8 years after abandonment. The tallest trees reached 8 m. In this area most tree stands were dense (over 50 trees per 100 m^2).

Field 6 (Fig. 2g) was used as meadow and pasture before being abandoned in 1991. Also here colonization of the field by tree species has been rather slow, starting 8 years after abandonment and forming a mosaic afforestation pattern. A few sparse patches of *P. abies* (up to 4.5 m with age 12 years) developed in the elevated part of the field, while *Salix* spp. formed patches in the lower part (up to 5 m high), although the surrounding forest was dominated by *A. incana*, *B.*

Fig. 2 Patterns of afforestation in the studied fields: **a** field 1—linear afforestation pattern, **b** field 2—linear afforestation pattern, **c** field 3—mosaic afforestation pattern, **d** field 4—mosaic afforestation pattern, **e** field 5 (1)—continuous afforestation pattern, **f** field 5 (2)—afforestation from the forest edge and mosaic pattern, **g** field 6—mosaic afforestation pattern, **h** field 7 (1)—continuous afforestation pattern, **i** field 7 (2)—mosaic afforestation pattern
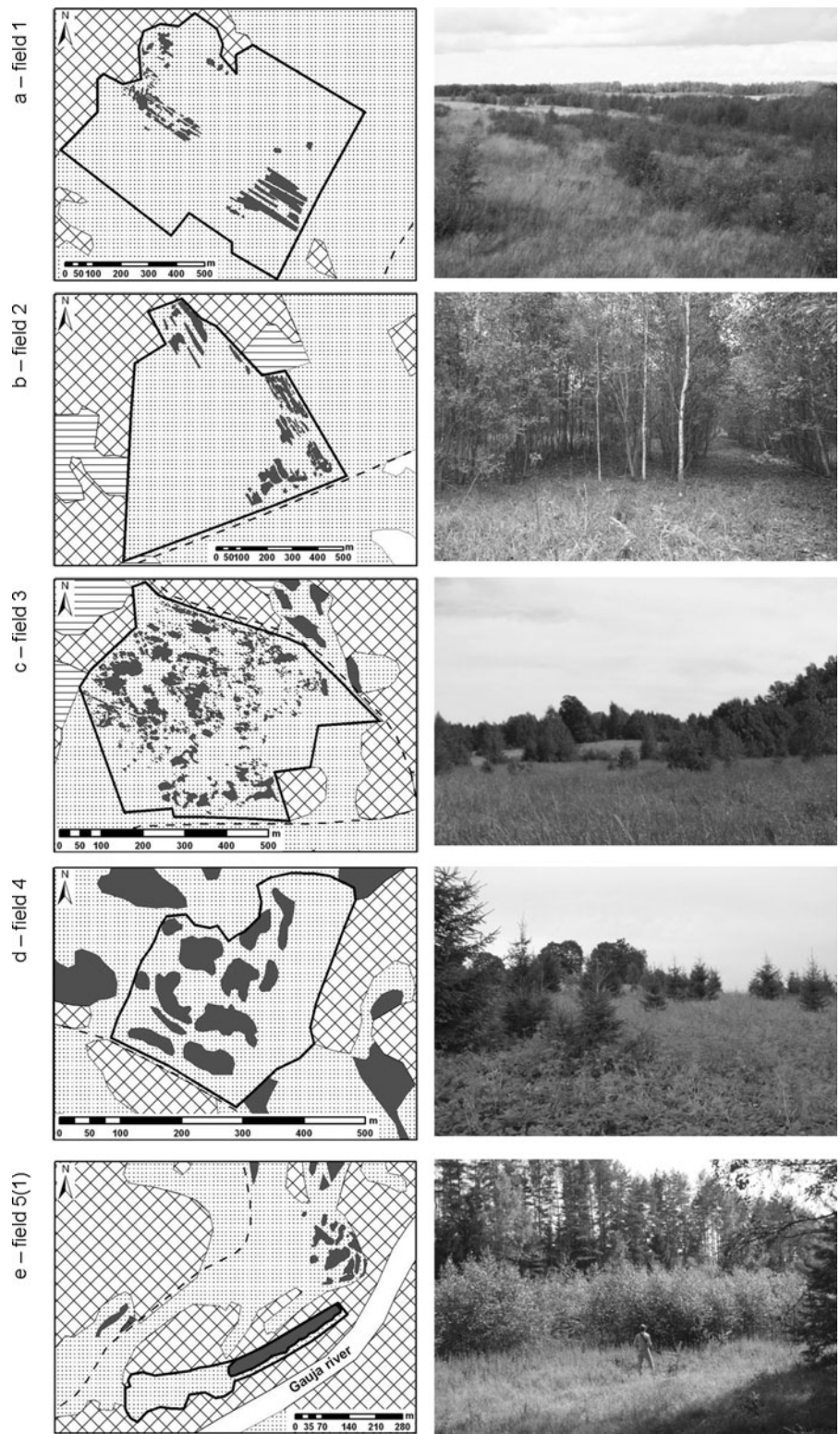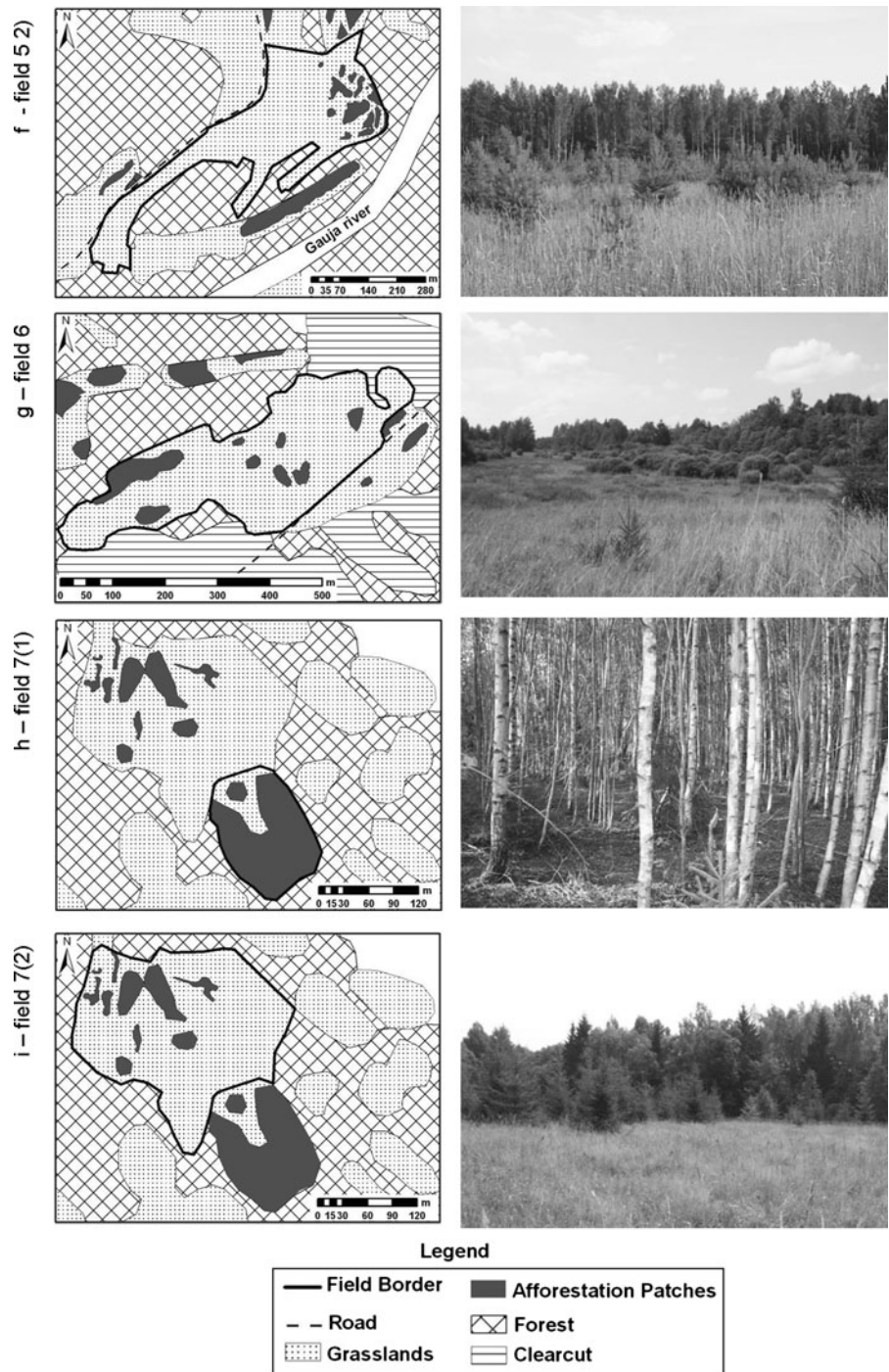
Fig. 2 continued

Legend

— Field Border   ■ Afforestation Patches

– – Road   ⬚ Forest

⬚ Grasslands   ⬚ Clearcut

pendula and *P. tremula*. Soil types were Stagnosols and Luvisols, formed on loamy sand and loam.

Field 7 (1) (Fig. 2h) was ploughed before abandonment around 1988. This part in 2010 was overgrown by a rather dense stand of *B. pendula* and

A. incana (Table 2) up to 12 m height and age 19 years, indicating that afforestation began right after the abandonment. In the other part—field 7 (2) (Fig. 2i), which was used formerly as a meadow, invasion of *P. abies* began around 1997 and forming a

Table 2 Proportion (%) of stems and maximum age and height (m) of tree species in the afforested patches in fields in 2011

Tree species	Field 1	Field 2	Field 3	Field 4	Field 5 (1)	Field 5 (2)	Field 6	Field 7 (1)	Field 7 (2)
B. pendula									
%	64.9	28.6	74.0	14.3	77.7	58.9	–	60.7	–
Age	12	19	19	12	3	12		19	
m	8	11	11	9	3.5	8		12	
P. abies									
%	–	0.1	18.0	56.1	10.9	25.3	90.0	19.6	84.4
Age		2	12	12	3	12	12	12	12
m		0.5	6	8	2	6	5	7	6
P. sylvestris									
%	–	–	5.4	0.2	4.7	13.7	–		–
Age			12	12	3	6			
m			6.5	8	2	6			
A. incana									
%	–	0.1	–	5.1	–	0.6	–	7.1	–
Age			12	13				19	
m		5	8	9				12	
P. tremula									
%	0.2	0.1	–	–	–	–	–		–
Age									
m	4								
Salix spp.									
%	34.9	71.2	2.7	14.6	6.4	1.6	10.0	12.5	15.6
Age									
m	6	11		7.5	2.5	3	5	12	2
A. platanoides									
%	–	–	–	9.8	–	–		–	–
Age									
m				6					

mosaic pattern of afforestation. In contrast to the invading species, the forest surrounding the field 7 was dominated by *B. pendula* and *A. incana* (Table 1). Age of *P. abies* in 2011 was 12 years and height reached up to 6 m. Soil types in the field were Stagnosols and Luvisols, formed on loamy sand.

Impact of soil conditions on afforestation

Sandy loam, loam and silt loam predominated in the sampling plots, where content of clay ranged from 10 to 19%, silt—25–56%, and sand—29–64%, while thickness of plough (Ap) horizon was varying between 5 and 38 cm (Table 3). Results of soil properties in sampling plots are demonstrated in Table 3.

The PCA ordination of Ap horizon soil properties along with density of trees in sampling plots extracted two principal components, which together explained 61.01% of the total variation (Fig. 3). However, only the first axis, which explained 40.08% of the total variation, was statistically significant ($P < 0.005$). The first axis sample scores were positively correlated with sand content ($r = 0.87$) and density of trees ($r = 0.59$). The other factors were negatively related with this gradient: content of silt ($r = -0.81$), clay ($r = -0.72$), total N ($r = -0.73$) and P ($r = -0.57$), and pH_{KCl} ($r = -0.68$) value.

The PCA ordination indicates that soils with a higher sand content provide more favourable conditions for development of shrubs and trees (Fig. 3). In

Table 3 Soil properties of the Ap horizon in sampling plots

Soil properties	Open space			Afforestation patches		
	Average	Min	Max	Average	Min	Max
Thickness of Ap horizon (cm)	24	5	34	23	5	38
Clay (%)	14	11	19	12	10	16
Silt (%)	40	27	56	33	25	48
Sand (%)	45	29	63	55	37	64
Organic carbon (mg kg^{-1})	11.84	0.97	24.62	10.10	7.90	12.26
Total nitrogen (mg kg^{-1})	0.25	0.08	0.72	0.20	0.11	0.36
pH$_{KCl}$	5.19	4.97	5.69	5.17	4.52	6.54
Total phosphorus (mg kg^{-1})	335	161	525	359	141	531
Total potassium (mg kg^{-1})	861	456	1,096	818	385	1,129

the opposite direction, the density of trees is less on soils with higher clay and silt content and on soils with higher pH$_{KCl}$ and total P, N content, and perhaps—organic C, total K content and thicker Ap horizon. Thus, invasion of trees is enhanced on poor sandy soils. This suggests that one of the important factors affecting the afforestation is soil texture in the plough horizon, which is related to nutrient availability.

Character of herbaceous vegetation

The herbaceous vegetation in fields 1 and 2 was fairly homogenous and dominated by perennial grassland species, e.g. *Dactylis glomerata*, *Phleum pratense* and *Festuca pratensis* (Table 4). However, humid areas of field 2 were colonized by *Phragmites australis.* In the afforestation patches, the herbaceous vegetation was very sparse, consisting of *Poa* spp. and *Agrostis* spp. A similar pattern of vegetation was observed in field 3, but *D. glomerata* was much more abundant. Field 4 showed a mosaic pattern of herbaceous vegetation, dominated by *F. pratense*, *Aegopodium podagraria*, and *Elytrigia repens* (Table 4). On the dry and sandy slope at the southern edge of the field, a community of *Hieracium pilosella*, *Fragaria vesca*, *Jasione montana* had developed. Also in the field 5 (2) a mosaic of herbaceous vegetation had developed, dominated by *D. glomerata*, *Bromopsis inermis*, and *Anthoxanthum odoratum*, while in some places the dominant species were *Anthriscus sylvestris*, *F. pratensis,* and *Deschampsia caespitose* (Table 4). In the field 5 (1) overgrown by a continuous birch stand the dominant species were *Hieracium umbellatum*, *Agrostis tenuis*, *Solidago virgaurea*, and *Phleum pratense* (Table 4).
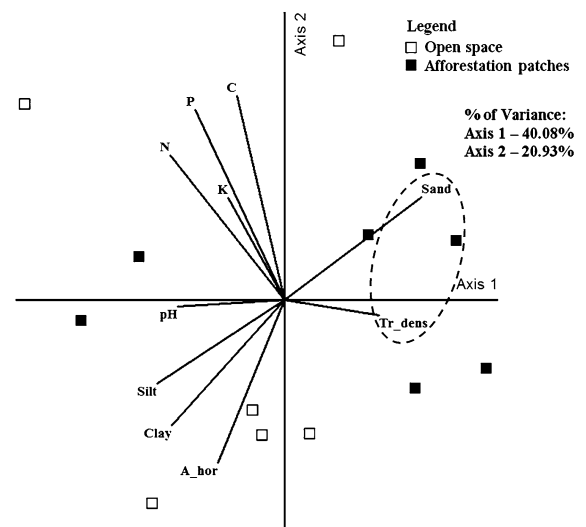

Fig. 3 PCA ordination of the sampling plots based on soil Ap horizon variables and tree density: *A_hor* thickness of Ap horizon, *Clay* % of clay, *Silt* % of silt, *Sand* % of sand, *N* content of total nitrogen, *P* content of total phosphorus, *K* content of total potassium, *Org_C* content of organic carbon, *Tr_dens* density of trees, *pH* pH$_{KCl}$ value. *Note* only the first PCA axis was significant

This patch was surrounded by a 2–5 m belt composed of a diverse herbaceous species community of *F. vesca*, *Festuca ovina*, *Carex sylvatica* and *Lycopodium clavatum*. Fields 6 and 7 were dominated by *D. glomerata*, *P. pratense*, *Elytrigia repens* and *F. pratensis*. In the ploughed area of field 7, now covered by a dense stand of *B. pendula*, the herbaceous layer was very sparse and composed of *Lysimachia nummularia*, *E. repens* and *H. umbellatum* (Table 4).

Table 4 Dominant herbaceous species in the studied fields

Species name	No. of the field								
	1	2	3	4	5 (1)	5 (2)	6	7 (1)	7 (2)
Achillea millefolium	x	x	x			x (x)			
Aegopodium podagraria				x			x		
Anthoxanthum odoratum						x			
Anthriscus sylvestris	x		x			x			
Agrostis tenius	(x)	(x)	(x)	x (x)	(x)	(x)			(x)
Bromopsis inermis						x			
Calamagrostis arundinacea	(x)				x				
Cirsium arvense	x								
Dactylis glomerata	x (x)	x	x (x)	x (x)		x (x)	x (x)		x
Deschampsia caespitosa	(x)					x			
Elytrigia repens	x (x)		x	x (x)			x	(x)	x
Festuca pratensis	x (x)	x (x)	x	x		x	x		x
Fragaria vesca				(x)	x	(x)			
Geranium palustre									x
Hieracium pilosella						x			
Hieracium umbellatum					(x)			(x)	
Hypericum maculatum		x							
Jasione montana				x		x			
Lysimachia nummularia								(x)	
Lycopodium clavatum					x				
Phleum pratense	x (x)	x	x (x)	x (x)	x (x)	x	x (x)		x (x)
Phragmites australis		x							
Solidago virgaurea	x (x)				x (x)	(x)			
Taraxacum officinale	x (x)	x	x (x)	x (x)		x (x)	x (x)		
Trifolium arvense	x								
Trifolium medium				x					
Veronica chamaedrys			(x)						

x dominant species in open field; (*x*) most abundant species within the afforestation patches

The most dominant species in the open fields on formerly cultivated grasslands [fields 3, 6 and 7 (2)] were grasses—*D. glomerata*, *F. pratensis* and *P. pratense,* forming stable comunities, while on former arable land (fields 1 and 2) the herbs, e.g. *Taraxacum officinalis*, *Ahillea millefolium*, *Hypericum maculatum* were more widespread. Within the afforestation patches under dense shrub and tree canopies [field 5(1) and 7(1)] the herbaceous layer was sparse (1–2% of projective cover), formed mostly by the shade tolerant species, e.g. *Lysimachia nummularia, H. umbellatum*, *Poa* spp. and *Agrostis* spp.

The ecotone area in fields 4 and 5 supported species typical for forest edge communities and semi-natural grasslands (e.g. *F. vesca*, *F. ovina*, *J. montana).* Rare and protected grassland species (e.g. *Platanthera* spp., *Dactylorhiza maculata* and *Dactylorhiza incarnate*) as well as indicator species of semi-natural grasslands (e.g. *F. vesca*, *Lychnis viscaria*, *Briza media*, *Pimpinella saxifraga*, *Galium boreale*) were recorded in fields 3, 5, and 6, indicating renaturalization of the grassland.

Discussion

The observed successions on abandoned agriculture land were very diverse in spatial character and in the composition of the tree species colonizing the field. The afforestation pattern depends on the interactions

of many factors like topography, geology, level of ground water, soil physical, chemical properties and non-predictable events (seed rain). The previous land use and initial stage of succession formed by herbaceous species colonizing the abandoned fields also affect afforestation (Alard et al. 2005; Prach et al. 2001b; Kopecký and Vojta 2009; Rosenthal 2010).

The classical view of Clements (1936) regards succession as a predictable process involving successive substitutions of serial plant communities, which can be modelled by Markov transition matrices (Korotkov et al. 2001; Liu and Taylor 2002; Benabdellah et al. 2003). According to this concept tree cover development in the hemiboreal zone in Europe is initiated by invasion of pioneer species such as *A. incana*, *P. tremula* and *Salix* spp. (Korotkov et al. 2001). These species are light demanding and are well adapted for establishment in open fields. A leading role of *A. incana* in colonization of abandoned agricultural land was observed in a previous study from the same study area, although colonization of field by *P. abies* and *B. pendula*, which hindered development of dense stands of *A. incana*, was also noted (Gutko et al. 2001).

The Clementsian dogma (Clements 1936) clearly can not be used to describe the observed succession in our study. It is well known that the initial floristic composition formed by invading and initially present plants (Egler 1954) in areas after disturbance, can determine the paths of succession. After the initial colonization, the ability of participating plant species to tolerate the changing conditions (e.g. shade), and the ability of the species to inhibit further establishment of other species, are factors that need to be considered (Connell and Slatyer 1977). Late successional species can be present at the onset of secondary succession, and thus multiple pathways of succession are possible (Connell and Slatyer 1977). This was observed in our study, as in some fields the succession was dominated by early successional species (*A. incana*, *B. pendula*, and *P. tremula*), while in others *P. abies* had invaded. A high share of spruce was typical of sites with a mosaic pattern of afforestation (fields 4, 6 and 7, and to a lesser extent field 3) and where the fields had previously been used as meadow or pasture.

Interspecies composition affects succession and is interrelated with various environmental factors such as humidity and soil richness (Benabdellah et al. 2003) In some cases, increased soil fertility can enhance the growth of shrubs, while in others it may increase density of the herbaceous layer, thereby excluding trees from successions (Alard et al. 2005). In our study, the density of woody species was higher in fields with higher sand content in soils, while on more fertile soils (with higher content of clay and silt and/or total P, N, C, K and pHKCl) the afforestation process was less intense (Fig. 3). On previously cultivated grasslands with richer soils the development of a dense cover of herbaceous vegetation with, for example, *D. glomerata*, *P. pratense* and *Festuca pratensi* probably hindered establishment of tree species, which is consistent with the inhibition model of succession (Egler 1954). The colonization by woody species in field 6, which was used previously as meadow and pasture, started only 8 years after abandonment, forming scattered patches of *P. abies*. There, a dense cover of herbaceous vegetation probably inhibited establishment of light-demanding pioneer tree species, but not shade-tolerant *P. abies*. However, this did not appear to be the case in other fields. For example, in field 5 a continuous afforestation pattern formed by dense *B. pendula* stand developed in a very short period of time (in 2–3 years), after the field had been mowed for several years before abandonment. In that case, poor soils and absence of dense cover of herbaceous vegetation, formed by grasses typical for cultivated grasslands, e.g. *D. glomerata*, *P. pratense* and *F. pratensi* did not prevent establishment of a pioneer species. In other cases, the spatial distribution of the woody patches within a field also can depend on heterogeneity of environmental conditions within the field. For example, in field 6, *P. abies* had invaded the raised part of the field, while humid conditions in the lower part favoured *Salix* spp. colonization.

The mosaic pattern of the afforestation and the low relative area (3–30% of the field) covered by woody patches in the studied fields shows that development of a closed canopy tree cover can be delayed for 15–20 years, depending on particular conditions at each location. In a study conducted in the UK, Harmer et al. (2001) found that the colonization of the fields by woody species can be delayed by 10–42 years and that the degree of colonization was negatively associated with loamy soils. In the Mediterranean region, arrested succession can last for 20–55 years referring to Sirami et al. (2007).

In fields that previously were used for cultivation of crops, the herbaceous vegetation cover had formed a

mosaic structure, with numerous open gaps. The factors causing lack of herbaceous vegetation in these gaps is not known, but they may represent patches of available space free of competition for future establishment of woody species. These patches of invading trees on previously cultivated fields will then result in a mosaic pattern of afforestation.

Dominance of one or another tree species in the field might also be explained by the time of the year when the seeds are spread and presence of herbaceous vegetation on the field at that time. For example, seed of *P. abies* and *P. sylvestris* is dispersed in spring (March–May), when herbaceous vegetation has not yet developed to an extent that hinders penetration of seeds into the soil. Seed dispersal of *P. tremula* and *Salix* spp. occurs in summer (May–June) and *B. pendula* at the end of the summer (July–August), when the greater part of the abandoned fields is covered by dense herbaceous vegetation. This might explain why the early successional species were less successful in invading the studied meadows, compared to arable land.

Species composition and the spatial character of afforestation patches are also influenced by chance events such as wind, which affects dispersal of seeds in relation with the size and configuration of fields. Although some studies have highlighted the importance of distance from the seed source and species composition of nearby forests as decisive factors in development of secondary succession on abandoned fields (Daugaviete 2009), clearly additional factors are involved (e.g. size of the field and environmental conditions). Certainly, the dominant species in forests surround the studied fields were not always those that were most common in afforestation patches (Table 5). Seeds of *P. abies* and *P. sylvestris* can disperse at distances up to 200 m from the source (Korotkov et al. 2001). However, since these species begin to disperse seeds in March, when fields can be still covered by snow (especially if there is crust on the snow), wind can blow the seeds over very large distances (Gailis, personal communication). The wind-dispersed pioneer species, e.g. *B. pendula* and *P. tremula*, produce a large amount of seeds that can be spread over 1–1.5 km (Korotkov et al. 2001). Thus, it might be expected that the tree density in the neighbouring forest would not be a major factor regulated invasion success on the field, i.e., the presence of a few individuals with seed might be sufficient to feed the initial invasion.

The limiting factor in development of the afforestation process starting from the edge of the forest most probably is not distance to the seed stand (as dispersal of the seeds by wind occurs over much larger distances), but rather is related to more favourable conditions for growth of woody species in the ecotone zone (Auzins, personal communication). This factor has greater importance in large homogeneous fields, while in smaller fields or fields with more complex shapes, topography and environmental conditions can be suitable for afforestation throughout the field.

In our study, on very large fields with strait edges, plain topography and uniform environmental conditions, the afforestation proceeded from the forest edge and sometimes developed into linear patches, (e.g. fields 1 and 2). In smaller fields with more complex shapes and hilly topography, where environmental conditions were more diverse, the pattern of secondary succession was rather complex, usually developing as mosaic patches, not always having direct connection to the forest edge (e.g. fields 3, 4, 5 and 6). In very small fields surrounded by forest, continuous afforestation pattern was observed to occur in fields 5 and 6 simultaneously over the entire field in a rather short period of time.

Afforestation also has a significant impact on biodiversity. The mosaic pattern of woody patches at the early stage of succession creates diverse shading conditions, which provides suitable conditions for survival of both shade-tolerant and shade-intolerant species, thus increasing species diversity within the herbaceous vegetation layer (Gutko et al. 2001). Furthermore, a mosaic structure of vegetation can provide larger variety of habitats suitable for different animal species, thus increasing overall biological diversity of the area, although reducing number of species dependent on open habitats.

Clearly, the social-economic and biological diversity aspects of the process have to be considered when planning the future use of the abandoned agriculture land. Local society usually shows dissatisfaction about natural afforestation processes that lead to loss of traditional rural landscape. On other hand, there is rather low interest or lack of resources in management of the former agriculture land. Therefore natural afforestation seems to be the most reasonable land use option at the present stage. An essential issue for further studies is potential use of abandoned agriculture land, as well as constraints and benefits of

Table 5 Dominant tree species in the surrounding forest and in the field given in order of dominance

No. of field	Dominant tree species in surrounding forests			Dominant tree species within the field		
	>50%	10–50%	<10%	>50%	10–50%	<10%
1		*P. abies* *B. pendula* *A. incana*	*T. cordata* *F. excelsior* *P. tremula* *U. glabra* *Q. robur* *U. laevis* *P. sylvestris*	*B. pendula*	*Salix* spp.	*P. tremula*
2	*B. pendula*	*P. tremula*	*P. abies* *A. incana* *P. sylvestris* *Salix* spp.	*Salix* spp.	*B. pendula*	*P. abies* *A. incana* *P. tremula*
3	*B. pendula*	*P. abies*	*P. tremula* *A. incana* *P. sylvestris*	*B. pendula*	*P. abies*	*P. sylvestris* *Salix* spp.
4		*P. tremula* *P. abies* *A. incana* *B. pendula*		*P. abies*	*Salix* spp. *B. pendula*	*A. platanoides* *A. incana* *P. sylvestris*
5 (1)		*B. pendula* *P. sylvestris* *A. incana*	*P. tremula* *Q. robur* *P. abies*	*B. pendula*	*P. abies*	*Salix* spp. *P. sylvestris* *A. incana*
5 (2)		*B. pendula* *P. sylvestris* *A. incana*	*P. tremula* *Q. robur* *P. abies* *Salix* spp.	*B. pendula*	*P. abies* *P. sylvestris*	*Salix* spp. *A. incana*
6	*A. incana*	*B. pendula* *P. tremula*	*P. abies* *P. sylvestris*	*P. abies*	*Salix* spp.	
7 (1)		*B. pendula* *A. incana*	*P. tremula* *P. abies* *Salix* spp.	*B. pendula*	*P. abies* *Salix* spp.	*A. incana*
7 (2)		*B. pendula* *A. incana*	*P. tremula* *P. abies* *Salix* spp.	*P. abies*	*Salix* spp.	

particular afforestation patterns. Afforestation process can be viewed from perspective of how it contributes to the multifunctionality of the landscape and its ecological, social and economic consequences.

When due to socio-economic changes afforestation becomes a dominant process in reorganizing the land-use structure, it leads to reshaping of the landscape structure and functionality. In the areas formed by agriculture matrix, the natural afforestation process

can bring a range of benefits, including provision of ecological services, e.g. biodiversity conservation, soil retention, regulation of micro-climate, noise reduction, fire wood, as well as increase aesthetic values of the landscape and recreational possibilities (Lovell et al. 2010). However, in areas of the central part of Latvia that are dominated by forest and mosaic landscape structure, afforestation of the former agriculture land usually is regarded as a process leading to

homogenization and loss of traditional rural landscape (Nikodemus et al. 2005). At the initial stage of afforestation, a mosaic pattern can increase the heterogeneity of landscape, while in a long-term perspective the gaps between the tree patches will be closed, resulting in increasing dominance of forest matrix.

Depending on the afforestation pattern the developing forest stands might become more uniform or diverse with regard to species composition and age structure. For example, in case of linear and continuous afforestation patterns the course of succession will be faster and result in rather uniform forest stands, while a mosaic afforestation pattern will result in a longer time for canopy closure, but the age structure and species composition will be much more complex. Thus, the biological value of the stand might be relatively high, but the future economic value is likely low, particularly considering the delay in harvest time (at least 20 years). Therefore retaining of a mosaic pattern of afforestation could be promoted in protected areas, while linear and continuous afforestation could be considered as a low investment-demanding opportunity for the commercial use of the land.

Conclusions

The natural afforestation process is influenced by wide range of ecological as well as socio-economic factors (e.g. former land use, present marginalization processes as well as the interests and ability of land owners regarding active use of the land). The plethora of factors involved makes it very difficult to predict the course of succession. The study indicated multiple possible scenarios of the course of succession and its spatial character in relation to former land use, field size and configuration, environmental conditions and chance events. For example, in previously cultivated grassland on rich soils dense cover of herbaceous vegetation develops, which probably hinders establishment of tree species. Under such conditions colonization of the field by trees is slower and usually forms a mosaic afforestation pattern. On sandy soils or arable lands, abandoned after ploughing, colonisation of the field by tree species can be rather fast, forming a continuous afforestation pattern.

References

Alard D, Chabrerie O, Dutoit T, Roche P, Langlois E (2005) Patterns of secondary succession in calcareous grasslands: can we distinguish the influence of former land uses from present vegetation data? Basic Appl Ecol 6:161–173

Alriksson A, Olsson MT (1995) Soil changes in different age classes of Norway spruce (*Picea abies* (l.) Karst.) on afforested farmland. Plant Soil 168–169:103–110

Antrop M (2005) Why landscape of the past are important for the future. Landsc Urban Plan 70:21–34

Armolaitis K, Aleinikoviene J, Baniūniene A, Lubyte J, Zekaite V (2007) Carbon sequestration and nitrogen status in arenosols following afforestation or following abandonment of arable land. Balt For 13(2):169–177

Bartha S, Meiners SJ, Pickett STA, Cadenasso ML (2003) Plant colonization windows in mesic old field succession. Appl Veg Sci 6:205–212

Bell S, Nikodemus O, Peneze Z, Kruze I (2009) Management of cultural landscapes: what does this means in the former Soviet Union? a case study from Latvia. Landsc Res 34:425–455

Benabdellah B, Albrecht KF, Pomaz VL, Denisenko EA, Logofet DO (2003) Markov chain models for forest succession in the Erzgebirge, Germany. Ecol Model 159:145–160

Benjamin K, Bouchard A, Domon G (2007) Abandoned farmlands as components of rural landscapes: an analysis of perceptions and representations. Landsc Urban Plan 83:228–244

Bürgi M, Hersperger AM, Schneeberger N (2004) Driving forces of landscape change—current and new directions. Landsc Ecol 19:857–868

Clements F (1936) Nature and structure of the climax. J Ecol 24:252–284

Connell JH, Slatyer RO (1977) Mechanisms of succession in natural communities and their role in community stability and organization. Am Nat 111:1119–1144

Daugaviete M (2009) The qualitative characteristics of naturally-developed deciduous forest stands in abandoned agricultural lands. In: Substantiation of deciduous trees cultivation and rational utilisation, new products and technologies. State Research Programme, 2005–2009. Proc Riga Latvian State Inst Wood Chem: 23–27 (in Latvian with English summary)

Egler FE (1954) Vegetation science concepts. I. Initial floristic composition—a factor in old-field vegetation development. Vegetatio 4:412–417

Falkengren-Grerup U, ten Brink DJ, Brunet J (2006) Land use effects on soil N, P, C and pH persist over 40–80 years of forest growth on agricultural soils. For Ecol Manag 225:74–81

Fjellstad WJ, Dramstad WE (1999) Patterns of change in two contrasting Norwegian agricultural landscapes. Landsc Urban Plan 45:177–191

Forest Soil Co-Ordinating Centre (2006) Manual IIIa: sampling and analysis of soil. In: ICP forests, 2006: manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. Hamburg (Germany): UNECE ICP Forests Programme Co-ordinating Centre. p 26. þannexes. Available on line:http://icp-forests.net/page/icp-forests-manual

Gleason HA (1926) The individualistic concept of the plant association. Bull Torrey Bot Club 53:7–26

Gutko Z, Brumelis G, Liepins I, Nikodemus O, Tabors G (2001) Plant species richness, and Shannon diversity and evenness during secondary succession on abandoned agriculture land in Latvia. Proc Latvian Acad Sci 55:36–42

Hagen-Thorn A, Callesen I, Armolaitis K, Nihlgård B (2004) The impact of six European tree species on the chemistry of mineral topsoil in forest plantations on former agricultural land. For Ecol Manag 195:373–384

Harmer R, Peterken G, Kerr G, Poulton P (2001) Vegetation changes during 100 years of development of two secondary woodlands on abandoned arable land. Biol Conserv 100:291–304

Hietel E, Waldhardt R, Otte A (2004) Analysing land-cover changes in relation to environmental variables in Hesse, Germany. Landsc Ecol 19:473–489

Hytteborn H, Maslov AA, Nazimova DI, Rysin LP (2005) Boreal forests of Eurasia. In: Andersson F (ed). Coniferous forests, ecosystems of the world, vol. 6. Elsevier, Amsterdam, pp 23–99

IUSS Working Group WRB (2007) World Reference base for soil resources 2006, first update 2007. World Soil Resources Reports No. 103. FAO, Rome

Jongman RHG (2002) Homogenisation and fragmentation of the European landscape: ecological consequences and solutions. Landsc Urban Plan 58:211–221

Kent M, Coker P (1992) Vegetation description and analysis. A practical approach. Wiley, Chichester, p 363

Kopecký M, Vojta J (2009) Land use legacies in post-agricultural forest in the Doupovské Mountains, Czech Republic. Appl Veg Sci 12:251–260

Korotkov VN, Logofet DO, Loreau M (2001) Succession in mixed boreal forest of Russia: Markov models and non-Markov effects. Ecol Model 142:25–38

Kristensen SP (1999) Agricultural land use and landscape changes in Rostrup, Denmark: processes of intensification and extensification. Landsc Urban Plan 46:117–123

Kristensen LS, Thenail C, Kristensen SP (2004) Landscape changes in agrarian landscape in the 1990s: the interaction between farmers and the farmed landscape. A case study from Jutland. Den J Environ Manag 71:231–244

Liu J, Taylor WW (2002) Integrating landscape ecology into natural resource management. Cambridge University Press, Port Chester, p 259

Lovell ST, Mendez VE, Erickson DL, Nathan C, DeSantis S (2010) Extent, pattern, and multifunctionality of treed habitats on farms in Vermont, USA. Agrofor Syst 80:153–171

Łowicki D (2008) Land use changes in Poland during transformation: case study of Wielkopolska region. Landsc Urban Plan 87:279–288

Mander Ü, Palang H, Ihse M (2004) Development of European landscape, Editorial. Landsc Urban Plan 67:1–8

Merilä P, Smolander A, Strömmer R (2002) Soil nitrogen transformations along a primary succession transect on the land-uplift coast in western Finland. Soil Biol Biochem 34:373–385

Ministry of Agriculture (2009) Forestry sector in Latvia. Available online http://www.zm.gov.lv/doc_upl/meza_platiba.pdf

Mund M, Kummetz E, Hein M, Bauer GA, Schulze ED (2002) Growth and carbon stocks of a spruce forest chronosequence in central Europe. For Ecol Manag 171:275–296

Nierop KGJ, van Lagen B, Buurman P (2001) Composition of plant tissues and soil organic matter in the first stages of a vegetation succession. Geoderma 100:1–24

Nikodemus O, Bell S, Grīne I, Liepiņš I (2005) The impact of economic, social and political factors on the landscape structure of the Vidzeme uplands in Latvia. Landsc Urban Plan 70:57–67

Nikodemus O, Karklins A, Klavins M, Melecis V (2008) Augsnes ilgtspējīga izmantošana un aizsardzība. LU Akadēmiskais apgāds, Riga, pp 254 (in Latvian)

Palang H, Helmfrid S, Antrop M, Alumäe H (2005) Rural landscape: past processes and future strategies. Landsc Urban Plan 70:3–8

Palang H, Printsmann A, Konkoly Gyuro E, Urbanc M, Skowronerk E, Woloszyn W (2006) The forgotten rural landscapes of Central and Eastern Europe. Landsc Ecol 21:347–357

Peneze Z (2009) Latvijas lauku ainavas izmaiņas 20. un 21. gadsimtā: cēloņi, procesi un tendences. Dissertation, University of Latvia [Transformations of the of Latvian rural landscape in 20th and 21st centuries: causes, processes and tendencies] (in Latvian)

Peneze Z, Nikodemus O, Kruze I (2009) Izmaiņas Latvijas lauku ainavā 20. un 21. gadsimtā. Acta Universitalis Latviensis. Earth Environ Sci 724:168–183 [Changes in Latvian Rural Landscape during the 20th–21st century] (in Latvian with English summary)

Prach K, Bartha S, Joyce CB, Pyšek P, van Diggelen R, Wiegleb G (2001a) The role of spontaneous vegetation succession in ecosystem restoration: a perspective. Appl Veg Sci 4:111–114

Prach K, Pyšek P, van Diggelen R, Bastl M (2001b) Spontaneous vegetation succession in human-disturbed habitats: a pattern across seres. Appl Veg Sci 4:83–88

Reger B, Otte A, Waldhardt R (2007) Identifying patterns of land-cover change and their physical attributes in a marginal European landscape. Landsc Urban Plan 81:104–113

Ritter E, Vesterdal L, Gundersen P (2003) Changes in soil properties after afforestation of former intensively managed soils with oak and Norway spruce. Plant Soil 249:319–330

Romero-Calcerrada R, Perry GLW (2004) The role of land abandonment in landscape dynamics in the SPA 'Encinares

del río Alberche y Cofio', Central Spain, 1984–1999. Landsc Urban Plan 66:217–232

Rosenthal G (2010) Secondary succession in a fallow central European wet grassland. Flora 205:153–160

Sirami C, Brotons L, Martin JL (2007) Vegetation and songbird response to land abandonment: from landscape to census plot. Diversity Distrib 13:42–52

Sitzia T, Semenzato P, Trentanovi G (2010) Natural reforestation is changing spatial patterns of rural mountain and hill landscapes: a global overview. For Ecol Manag 259:1354–1362

Smal H, Olszewska M (2008) The effect of afforestation with Scots pine (Pinus silvestris L.) of sandy post-arable soils on their selected properties. II. Reaction, carbon, nitrogen and phosphorus. Plant Soil 305:171–187

Stoate C, Báldi A, Beja P, Boatman ND, Herzon I, van Doorn A, de Snoo GR, Rakosy L, Ramwell C (2009) Ecological impacts of early 21st century agricultural change in Europe—a review. J Environ Manag 91:22–46

Tilman D (1987) Secondary succession and the pattern of plant dominance along experimental nitrogen gradients. Ecol Monogr 57:189–214

Tullus A, Tullus H, Vares A, Kanal A (2007) Early growth of hybrid aspen (Populus × wettsteinii Hämet-Ahti) plantations on former agricultural lands in Estonia. For Ecol Manag 245:118–129

Vesterdal L, Ritter E, Gundersen P (2002) Change in soil organic carbon following afforestation of former arable land. For Ecol Manag 169:137–147

Wall A, Heiskanen J (2003) Water-retention characteristics and related physical properties of soil on afforested agricultural land in Finland. For Ecol Manag 186:21–32

Wall A, Hytönen J (2005) Soil fertility of afforested arable land compared to continuously forest sites. Plant Soil 275:247–260