Is there a forest transition outside forests?
Trajectories of farm trees and effects on ecosystem services in an agricultural landscape in Eastern Germany[1]

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Abstract
Most industrial countries have experienced a transformation of land use: from decreasing to expanding forest areas, the so-called forest transition. Outside closed forests, European rural landscapes exhibit a diversity of tree-based agricultural systems, but the question of whether this forest transition has also affected 'trees outside forests' has rarely been studied. The aim of this study is to analyze the spatial-temporal dynamics of farm trees and woodlands in an agricultural landscape in Eastern Germany from 1964 to 2008, based on aerial photographs and digital orthophotos. Taking a landscape ecological perspective, we quantify farm tree dynamics, disentangle processes of gain and loss in the socialist and post-socialist periods of Eastern Germany, and assess differences in ecosystem services provided by farm trees. A substantial increase of overall tree cover by 24.8% was observed for the selected time period, but trajectories have been disparate across different farm tree classes. The increase in tree cover was stronger in steep valleys than on hills and plateaus, indicating a significant interdependence between topography and trajectories of change. Patch numbers of farm trees did not increase, which suggests that the expansion of tree cover is mostly due to a spatial expansion of previously existing tree patches. Overall net gains in tree cover were rather similar during the socialist and post-socialist eras. The general increase in tree cover was accompanied by increases in agriculture-related ecosystem service provision, but the increase in pollination and pest control services was much lower than that in water purification services. These findings present the first empirical evidence from an industrialized country that there is also an ongoing 'forest transition' outside closed forests. Potential, partially counteracting drivers of change during the socialist and post-socialist periods have mainly been related to farm policies and the environmental consciousness of land users and society as a whole.

Keywords
Agricultural intensification, Driving forces, GIS, Land-use transitions, Landscape ecology, Trees outside forests

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1 Introduction

During the 19th and 20th centuries, most industrial countries experienced a nationwide transformation of land use: from decreasing to expanding forest areas, a phenomenon commonly termed 'forest transition' (Lambin and Meyfroidt, 2010). Forest transition theory postulates that a country's forest cover generally declines as it develops socially and economically, but this trend will eventually be reversed and forest cover may actually expand (Mather, 1992). This pattern results in a 'U-shaped curve' for forest cover over time (Barbier et al., 2010) and is composed of two separate, overlapping trajectories of land use: a) a gradual reduction of deforestation and b) the recovery of forest area after transition (Grainger, 1995). There is ample empirical evidence, both historical and current, for the halting of deforestation and a trend reversal through reforestation and afforestation in several European countries, including Austria (Krausmann, 2006), Denmark (Mather et al., 1998), France (Mather et al., 1999), and Switzerland (Mather and Fairbairn, 2000). In Germany, both in the East and in the West, forest surface has slightly but permanently increased from 1950 to the 2000s. More significant has been a rapid 19% increase of growing stock (and subsequently of carbon stocks) from 1987-2002, to an average of 320 m^3 ha^{-1} (Kauppi et al., 2006). The drivers of this process are strongly place-specific, but include technological changes (which reduced pressure to clear additional forest for livestock or crops), the substitution of wood fuels by fossil fuels, the introduction or strengthening of forest legislation, and the abandonment of marginal farmland, which made way for reforestation or afforestation processes in central Europe (Mather, 2001).

Outside closed forests, European rural landscapes exhibit a diversity of tree-based land-use systems (Auclair et al., 2000), but the question of a forest transition within these systems has rarely been studied, and there are no consistent global and (referring to developed countries) national data on the coverage or extent of these systems (Shvidenko et al., 2005). They have been conceptualized as 'trees outside forests' (FAO, 2001), 'farm trees' (more related to single trees; Arnold and Deewes, 1997), or 'farm woodlands' (more related to small forest stands; van der Horst, 2006). The FAO has defined them indirectly as 'all trees excluded from the definition of forest and other wooded lands' (FAO, 2000, p. 40). Farm trees and woodlands are common throughout the world, both in traditional cultural landscapes (e.g. hedgerows or wood-pastures) and in recently modified landscapes (e.g. rainforest remnants in Central America) (Manning et al., 2006). They can be the product of spontaneous regrowth or have been planted, domesticated, and cultivated. Farm trees and woodlands represent seminatural habitats within the farmland mosaic and form part of a 'high-quality agricultural matrix', which is increasingly coming to the attention of researchers in landscape ecology (Grashof-Bokdam et al., 2009) and conservation biology (Vandermeer and Perfecto, 2007). In this paper, we relate the term 'farm trees' both to single trees and small woodlands in agricultural landscapes.

Farm trees have been conceptualized as 'keystone structures', because their effect on ecosystem functioning is believed to be disproportionately high relative to the small area occupied by any individual tree (Gibbons et al., 2008). Their ecological importance is particularly high in intensively farmed landscapes (Skaloš and Engstová, 2010). Farm trees create high structural diversity in agricultural landscapes, thereby providing a great number of microhabitats and permitting multi-directional movements of biota across landscapes and ecological networks (Manning et al., 2009). They are also important ecosystem service providers in, for example, buffering groundwater pollution (Ryszkowski and Kedziora, 2007), controlling surface-runoff and soil erosion (Pattanayak and Mercer, 1997), sequestering carbon (Plieninger, 2011, in press), providing biofuels (Plieninger et al., 2006) and fulfilling cultural ecosystem services (McCollin, 2000).

A number of case studies from around the world have reported that farm trees and woodlands are in serious decline (Plieninger and Schaar, 2006; Gibbons et al., 2008). Among the most common threats are direct legal or illegal clearing, a lack of tree regeneration, and pathogens degrading tree health (Manning et al., 2006). Central Europe's agricultural landscapes (in which trees and woodland fragments are embedded) have experienced critical landscape changes in the past fifty years, which have often resulted in a degradation of ecological resilience (Rescia et al., 2010). A series of drivers of rural landscape change has been identified (Verburg et al., 2010), of which the following have potential negative impacts on farm trees: the intensification and upscaling of agriculture through, among other factors, land consolidation programs, increased mechanization, drainage, irrigation, and inputs of agrochemicals (on the most productive agricultural lands); agricultural extensification, marginalization, and overgrowth of abandoned agricultural lands (in areas where socio-economic conditions for agriculture are less favorable); and urban and infrastructural sprawl. A set of countervailing drivers that lead to the appearance of ecologically valuable elements in agricultural landscapes has been termed 'greening' (Hersperger and Bürgi, 2009). It includes the maintenance and plantation of trees, which has often been enabled through public funds, nature conservation acts, and compensating measures as well as through the activities of farmers, extension services, local conservation organizations, and land development agencies (Kristensen and Caspersen, 2002; Schleyer and Plieninger, 2011, in press).

In Eastern Germany, farm tree trajectories are assumed to have been critically impacted by the legacy of 'socialist agriculture'. This model of land use in the former German Democratic Republic (GDR) ideologically and practically promoted agro-commodity production at large scale and triggered extraordinarily comprehensive and rapid pushes for agricultural intensification (Schmidt, 1990). In this context, large-scale landscape interventions (so-called complex meliorations) were performed between 1965 and the first half of the 1970s to allow heavy machinery to operate (Gross, 1996; Philipp, 1997; Schmidt, 1990). Measures included elimination of 'disturbing' and 'inoperable' hedgerows, groups of trees, alleys etc. and upscaling of plot size up to 300 ha. The 1980s experienced a certain 'correction stage', in which – besides other measures – establishment of shelterbelts as a measure against soil erosion was promoted. In 1990, the breakdown of the socialist regime and German unification imposed a profound structural change for agriculture (Philipp, 1997). Property rights on land were privatized or restituted to the legal owners. This step revived a rather fragmented land-ownership structure. Most of the restituted landowners quickly leased their land to restructured and reorganized agricultural cooperatives, whose production goals had been determined before 1990 by the central planning system. The transition process has also resulted in substantially smaller agricultural production units – being now joint stock companies, limited liability companies, or producer cooperatives – with heterogeneous interests, different production portfolios, and economic potential (Laschewski, 1998). The 1992 Mac Sharry reforms of the Common Agricultural (CAP) of the European Union marked a transition from price support for agricultural produce to direct income support. Since then, farmers in the EU received substantial amounts of direct subsidies that were paid per crop area. For larger cereal farmers, the payments were conditional on setting-aside at least 15% –

10% of their croplands from 1996 onwards, a regulation that has been suspended since 2007 (Silvis and Lapperre, 2010).

While the overall change of Europe's cultural landscapes has been frequently studied at different scales (see Antrop, 2005, for an overview), the trajectories of farm trees and woodlands in terms of land cover and landscape structure remain little understood. Among the existing studies, most have focused on the effects of hedgerows of different densities, spatial structures, and management intensities on the composition of several plant and animal species groups (for example LeCoeur et al., 1997; Wehling and Diekmann, 2009). Information about the spatial and temporal dynamics and land-use determinants is thus available for hedgerows (e.g. Burel and Baudry, 1990; Deckers et al., 2005; Kristensen, 2003; Kristensen and Caspersen, 2002; Petit et al., 2003), but not for other classes of farm trees and woodlands. Most studies have not distinguished between the effects of tree gains and losses, making the analysis of a potential forest transition difficult. There is a particular lack of studies relating farm tree trajectories with the provision of ecosystem services. The aim of the present study is to fill these gaps by analyzing the spatial-temporal dynamics of farm trees and woodlands in an agricultural landscape in Eastern Germany, from 1964/65 (henceforth '1964') to 2008, based on aerial photographs and digital orthophotos. Taking a landscape ecological perspective, we: (1) quantify spatial-temporal dynamics of farm trees over a period of 44 years; (2) disentangle processes of gain and loss in the socialist and post-socialist periods of Eastern Germany; (3) assess differences in ecosystem services provided by farm trees between 1964 and 2008, using a set of landscape metrics. The results are interpreted in the light of forest transition theory, focusing on agricultural intensification and extensification in the socialist (between 1964 and 1990) and post-socialist (1990-2008) periods as potential drivers of change. As it takes some time before policy changes translate into observable landscape changes (especially in the case of trees), the studied periods of 1964-1992 and 1992-2008 can be considered congruent with these eras. We aim to provide a perspective on the dynamics of farm trees and woodlands that may be valuable for evaluating woodland patch dynamics in other agroecosystems beyond our study area.

2 Study area

An area of 28,050 ha within the Upper Lusatia region in Eastern Germany was selected as a case study (Fig. 1). The landscape is dominated by arable land (77% cover), while forests (10%), pastures (5%) and areas of arable land interspersed with significant areas of natural vegetation (5%) occur in fragments. Settlements and traffic infrastructure covered 3% in 2000 (European Environmental Agency, 2011a). Mean elevation is around 170-200 m asl. The area is drained through the Spree river system and its tributaries. Dominant soils are Luvisols and Cambisols. The prevailing loess sediments make the area a highly productive agricultural landscape that has been under cultivation for centuries. The climate is subcontinental, with an average annual precipitation of 650-700 mm and an average annual temperature of about 8.5°C (Mannsfeld and Syrbe, 2008). The area features various classes of farm trees and woodlands, including alleys, hedgerows, woodlots, and riparian woodland. Frequent tree species are *Quercus robur, Tilia cordata, Carpinus betulus, Fraxinus excelsior, Betula pendula, Sorbus aucuparia, Populus tremula,* as well as cultivated apple (*Malus* sp.), pear (*Pyrus comunis*), cherry (*Prunus avium*), and plum (*Prunus domestica*) trees. Large parts of the agricultural landscape (19.2%) have been designated as Special Protection Areas (SPAs) under the EU Directive on the Conservation of Wild Birds; sites protected under the EU Habitats Directive ('sites of community importance', partially overlapping with SPAs) cover 6.2% of the area (European Environmental Agency, 2011b).

3 Methods

3.1 Datasets used

The number, area, and spatial configuration of a population of tree patches was examined through analyses of aerial photographs and digital orthophotographs for the years 1964/65 (the earliest set of photographs with broad coverage available for the study area) and 2008, as well as a collection of aerial photographs from 1992 that was only available for a part of the study area. The earliest available set of aerial photographs, dated from 1964, was acquired as grayscale imagery at a scale of 1:20,000 for the Northern part of the study area. For the Southern part, images from 1965 were available at a scale of 1:12,500. Hardcopies were obtained from the German Federal Archives (*Bundesarchiv*). Scanned imagery had grain sizes between 1.2 m (Northern part) and 0.7 m (Southern part), which allowed the identification of even small tree crowns. Grayscale aerial photographs from 1992 at a scale of 1:12,000 were obtained from the Saxony State Office for Environment, Agriculture, and Geology. We geocoded the images using ArcGIS 9.3, with a positional accuracy of around 1.0-2.5 m. The images were projected onto the UTM coordinate system (datum: WGS 84, zone 33). For 2008, digital orthophotos were available, which were provided in UTM projection and 0.2 m ground resolution from the Saxony Land Survey Administration. We used state habitat and land-use maps (which captured some farm tree classes) and 1:25,000 analogue and digital topographic maps as ancillary datasets.

3.2 Farm tree classification

We selected those areas that were classified as agricultural land in the CORINE (Coordinated Information on the European Environment) 2000 land cover maps (European Environmental Agency, 2011a): non-irrigated arable land, pastures, complex cultivation patterns, land principally occupied by agriculture, with significant areas of natural vegetation. Some smaller areas had to be eliminated because no historical aerial photographs were available. In the remaining dataset, we randomly selected 100 quadrates of 50 ha size each. Tree classes considered in the photointerpretation were defined according to patch typology, geometry, and prevailing woody plants (Table 1) (see Kleinn, 2000, for a discussion of classifying trees outside forests). The remaining area outside trees and woodlands in the plots (e.g. arable land, pastures, and villages) was uniformly classified as ‘agricultural matrix’, as the focus of this study was on land cover changes and ecosystem services of farm trees and woodlands, not on the landscape as a whole.

3.3 Spatio-temporal database, 1964-2008

All tree patches were first digitized from the 2008 images, which provided the best ground resolution. The mapped areas were then compared to those digitized from the 1964 images. This was a complex task due to the older images having lower spatial and radiometric resolution. Tree patches were hence identified and interpreted in each image on-screen, based on texture and tone, which allows identification of physiognomic tree features. Individual patches were then digitized as polygons and stored in the GIS database. Several viewing options were used to aid in the identification of change and subsequent recording of the trees on the photographs. We used a single photo interpreter and double-checked points of doubt with the ancillary datasets (mainly taking information from the state habitat and land-use maps and from the 1960s editions of topographic maps. To limit photo interpretation errors we located a randomly chosen subset of 20 plots on the ground in July 2010 and checked the accuracy of around 5 farm tree patches per plot. Accuracy of farm tree classification was ca. 97%. The minimum mapping unit for a tree patch to be included in the analysis was a bit less than 20 m^2 (corresponding to a circle of 2.5 m radius), which corresponds to the smallest area that could be reliably mapped in both the 1964 and 2008 datasets. Differences in tree cover and patch numbers between 1964 and 2008 among the plots were tested with a paired Wilcoxon signed rank test, and net changes were calculated both at landscape level and at the level of individual farm tree classes. Differences according to landscape position between the plots were tested with an unpaired Mann-Whitney U test.

3.4 Analysis of gains, losses, and persistence, 1964-1992-2008

To get a more comprehensive picture of the farm tree trajectories, we performed an analysis of gains, losses, and persistence across three points in time on a 10 km² subsection of the study area for which we obtained 1992 aerial photographs. Farm tree net gains were calculated by dividing the number and area of newly identified patches by the total number and area of patches counted in the previous census. Net farm tree loss was defined as the number and area of missing patches divided by the total number and area of farm trees counted in the previous census. However, net changes alone only summarize quantities of categorical changes between points in time (Käyhkö et al., 2011; Pontius et al., 2004). This is especially problematic for the assessment of tree populations, as losses in one area may be compensated by gains elsewhere, creating zero net change. However, a lost ancient tree is usually very different in ecological quality than a newly recruited tree. Therefore, we assessed more detailed indicators of transition by calculating ‘swapping’: change in location if a given quantity of tree loss at one location is accompanied by the same quantity of tree gain at another location (Pontius et al., 2004). Total change of farm trees and woodlands in the landscape equals the sum of loss and gain or the sum of the swap and net change.

3.5 Selection of ecosystem service indicators

For each of the 100 plots, the composition and spatial configuration of the farm tree network in 1964 and 2008 was described by a set of landscape metrics, which we selected as indicators for two broad ecosystem services: a) insect-based pollination and pest control services and b) water purification services. Provision of these ecosystem services is closely related to the amount and spatial configuration of farm trees and woodlands and is of utmost importance in agroecosystems (Zhang et al., 2007). The most meaningful indicators were derived from a literature review, which also revealed that the relationship between landscape metrics and ecosystem services is far from well-defined and highly variable in strength. For insect-mediated ecosystem services, four indicators seem especially important: the amount of natural habitats in the landscape (expressed as the percentage of tree and woodland patches in an agroecosystem), the complexity of these habitats (expressed through edge density), their connectivity (measured through mean Euclidean nearest neighbor distance), and the mean distance of any point in the agricultural matrix to the next habitat (measured through mean Euclidean distance of the matrix to the next farm tree or woodland) (Holzschuh et al., 2010; Östman et al., 2001; Tscharntke et al., 2005). The literature review showed that the proportion of woodland cover adjacent to waterbodies (measured within a 50 m buffer around waters), the functional buffer width (defined as the shortest distance between a water body and the agricultural matrix beyond the riparian woodlands), and the proportion of buffer voids (defined as the percentage of riparian edges without tree cover) are relevant parameters for water purification services, specifically with regard to biological and chemical oxygen demand, nitrogen, phosphorous and other nutrient inputs, as well as pesticide inputs (Baker et al., 2006; Brauman et al., 2007; Dosskey, 2001; Uuemaa et al., 2005). We calculated these indices using ArcGIS and FRAGSTATS (McGarigal and Marks, 1995). Differences in indices between temporal layers were analyzed using a Wilcoxon signed rank test for paired samples (of indicators for insect-based ecosystem services) and a Mann-Whitney U test for unpaired samples (of water purification indicators).

4 Results

4.1 Spatial-temporal dynamics, 1964-2008

With a mean cover of 6.9% and 8.7%, farm trees and woodlands covered important parts of the agricultural landscape both in 1964 and 2008. In both periods, there was at least one tree patch in each of the 100 plots studied. However, the proportions of individual farm tree classes were distributed quite heterogeneously (Fig. 2): In 1964, woodlots accounted for only 7.6% of patches in terms of number, but represented 58.9% of total farm tree area. Vice versa, alleys and tree rows covered only 6.4% of farm tree area, but accounted for 55.0% of the total number of patches due to their fragmented appearance. In 2008, woodlots were even more dominant in the landscape, accounting for 61.2% of tree cover. More than 79% of the tree patches were smaller than 0.05 ha in 2008; however, 94% of the farm tree cover was in patches of 0.05 ha size and above (Fig. 3).

Our study found significant changes in farm tree and woodland cover. From 1964 to 2008 cover increased by approximately 25%, while the number of patches only experienced a moderate, non-significant increase (Table 2). The trajectories of farm tree classes were disparate. The strongest net gains in land cover were found for hedgerows, alleys, isolated trees, and tree groups. A countervailing trajectory was detected for scattered fruit trees, which decreased significantly by 37.2%. The development of the number of patches was less striking and non-uniform: There was a significant increase of patch number of shrublands; but this was not accompanied by an increase in area, which indicates an increasing fragmentation of shrublands. Patch numbers of tree groups and woodlots also increased significantly, while that of riparian woodland decreased (which may be an expression of coalescing patches). The high standard errors indicate a generally high variation between plots. We found significant differences in farm tree dynamics according to landscape position: Mean increase of tree cover was 27.9% in plots that included the steep river valleys, while it amounted to 21.8% for the Loess-covered hills and plateaus ($p<0.001$). This resulted in a strong contrast of total tree cover: between 5.8% in the hills and plateaus and 11.7% in the valleys (2008). Fig. 4 illustrates the configuration of farm trees and woodlands in 1964 and 2008 in a plot of relatively high and another of rather low rates of change, respectively.

4.2 Analysis of gains and losses, 1964-1992-2008

The analysis of a 10 km²-subsection of the study area separated the landscape changes into two periods (1964-1992 and 1992-2008) that correspond with the socialist and the post-socialist eras. The net gain in farm tree cover was similar in both periods, amounting to 15.4% and 14.0% respectively (Fig. 5). However, the trajectories of the different tree classes were very different (Table 3): Net cover of alleys, tree rows, and riparian woodlands increased in both periods, but the increase was much stronger in the post-socialist era. Scattered fruit trees were lost in both periods, but the net loss rate also increased after 1992. Tree groups and woodlots increased at similar rates in both periods. Other farm tree classes changed back and forth, from and to other land cover classes: Hedgerows took a V-shaped trajectory, with net losses until 1992, but stronger net gains since 1992. Shrublands had a Λ-shaped trajectory, as they increased until 1992 and decreased later on.

Table 3 shows not only a net gain of farm tree cover, but overall high dynamics. Both tree gains and losses occurred simultaneously, and the level of turnover through time was high. Altogether the persistence was 79.5% for the socialist period and 89.1% for the post-socialist period. Persistence has greatly increased for all tree classes in the latter period, which indicates much stronger dynamics during the socialist era. Total change in tree cover has clearly decreased, from 56.5% to 35.9%. Hedgerows, shrublands, and isolated trees experienced high loss rates in the socialist era. In contrast, the woodlot class was relatively persistent. The majority of change instances during the socialist era was characterized by swapping (total 41.0%), which means that categories increased (gain) and decreased (loss) simultaneously within the area. Thus, the amount of lost trees was compensated in other parts of the study area by trees gains and vice versa. Net change, which outlines categorical changes outside swapping, was a smaller part of the total change in both periods: Between 1964 and 1992, swap had caused 73% of total change. Between 1992 and 2008 it was 61% of total change.

4.3 Changes in provision of ecosystem services, 1964-2008

We found a significant increase for six out of seven metrics used to indicate ecosystem services provision (Table 4). For insect-based pollination and pest control services, however, the extent of this increase was quite different between the three indicators used. Percentage of landscape, habitat complexity (edge density), and habitat connectivity (expressed through low nearest-neighbor distances) increased strongly, while mean Euclidean distance between agricultural matrix and trees remained almost unchanged. At class level, woodlots and riparian buffers contributed most effectively to the high percentage of landscape and edge density (Table 5). Alleys and tree rows were also significant contributors to high edge density. Due to their large patch number, alleys, tree rows, and riparian buffers led to the lowest mean Euclidean matrix-tree distances. The performance of all three indicators of water purification services increased strongly between 1964 and 2008: The proportion of trees in a 50 m buffer around waters grew by 45.6%, while the proportion of buffer voids decreased by 40.1%, and functional buffer width gained 83.7%. Values of all indicators for water purification services improved at a rate clearly above the total change rate of tree cover. In contrast, indicator values for insect-mediated ecosystem services improved at a rate below the rate of tree cover increase.

5 Discussion

5.1 Trajectories of change in landscape structure and ecosystem services provision

In this study we observed a substantial increase of overall farm tree cover between 1964 and 2008, but trajectories have been very disparate across the different tree classes. In particular, scattered fruit trees showed an opposite trend and decreased strongly. There was a stronger increase in tree cover in the steep valleys than in the hills and plateaus, indicating a significant interdependence between topography and trajectories of change (Deckers et al., 2005). Most of these valleys are protected areas within the European Natura 2000 network. As tree regrowth was continuous and had started before establishment of these nature reserves in the 1990s, we suspect that topography (that inhibited the high-intensity agricultural management that was performed on hills and plateaus) has been more influential on tree dynamics than targeted conservation efforts. Interestingly enough, the increase of overall tree cover was not accompanied by a similar increase in patch numbers. Moreover, tree cover increase seems to concentrate on plots that had elevated tree cover levels in 1964. Both observations suggest that the expansion of farm tree cover is rather due to a spatial expansion or growth of already existing tree patches (maybe in consequence of reduced land-use pressure), and can only partly be related to the establishment of new tree patches.

Forest cover trajectories are in general closely linked to overall patterns of land-use change (Barbier et al., 2010), and this seems to be even truer with respect to farm trees which are right at the edge of arable lands and grasslands. Field evidence indicates that trees and shrubs abounded much more frequently on grasslands than on arable lands. Since arable land use is usually financially more attractive than any kind of farm tree uses, a reduction of ‘disturbing’ farm trees is more likely to take place on plots that already are, or intended to be, used for crop production. Not least is this reflected in the focus of land consolidation and melioration measures on arable land before 1990 and by higher and faster rising leasehold prices for arable land after 1990. While leasehold prices for both arable land and grassland in Saxony have been increasing steadily since 1991, the increase was stronger for arable land (from about 71 € ha^{-1} in 1991 to about 126 € ha^{-1} in 2007) than for grassland (1991: 51 € ha^{-1}; 2007: 72 € ha^{-1}) (Winkler et al., 2010). This is exacerbated by the fact that soil quality in the case study region is rather high, so that arable farming in particular enables high profits and yields. In Saxony, grain production rose from 48% of arable land in 1993 to 59% in 2008 while forage crops decreased from 22% to 16%, an intensification that may have further discouraged the maintenance of farm trees on arable land (Statistisches Landesamt Sachsen, 2011). Also, plots of greater land-cover diversity seem to harbor more tree elements than plots that contain only few, large land-cover patches as farm trees are often located on field edges. We further found that overall net gains in tree cover were rather similar in the socialist and in the post-socialist eras, but changes in tree cover were more dynamic during socialist times, showing both stronger losses and stronger gains – a lower degree of persistence and a higher turnover – than in the post-socialist period.

The general increase in tree cover was accompanied by increases in agriculture-related ecosystem service provision, but there were distinctive differences between insect-based and hydrological services. Insect-mediated ecosystem services depend on mature and undisturbed habitat structures such as farm trees that are allocated in the immediate adjacency to cropland (see Holzschuh et al., 2010). This is particularly crucial in simple, low-diversity landscapes such as the study area, where many pollinating and pest controlling insect populations are fragmented, small, and isolated (Tscharntke et al., 2005). However, farm tree cover increased little in the hills and plateaus, which are predominantly used for crop cultivation. Therefore, the increase in pollination and pest control services was much lower than the overall increase in farm trees and woodlands would suggest. In turn, water purification services increased disproportionately, since farm trees providing these particular services expanded right where these services can be provided most effectively, in particular in the river valleys. This illustrates nicely that the provision of ecosystem services in agricultural landscapes depends not only on landscape composition (in this case the quantity of farm trees), but also on landscape configuration (here the spatial distribution of farm trees) (Goldman et al., 2007). Other ecosystem services besides those studied here also exhibit pronounced differences in their dependence on specific spatial arrangements of farm trees. For example, carbon sequestration can be achieved both through closed forests and open agroforestry systems (Plieninger, 2011, in press). In contrast to that the perceived beauty of an agricultural landscape depends on trees that are scattered across farmlands (Schaich et al., 2010). Enhancement of farmland biodiversity demands a configuration of trees into a well-connected network of patchy woodlands and mainly linear 'green veins' of small woody landscape elements (Grashof-Bokdam et al., 2009). Specific landscape mosaics are particularly needed to support the resilience of agroecosystems against minor and major, small- and large-scale disturbances (Tscharntke et al., 2005).

5.2 Socio-economic drivers of forest transition in the socialist and post-socialist periods

This study presents the first empirical evidence for an industrialized country that there is indeed also an ongoing 'forest transition' outside of closed forests. We now turn to the question concerning what driving forces may have caused or at least influenced the observed spatial-temporal dynamics. In this context, it is important to note that there are important differences between farm tree and forest transitions: While deforestation has often been triggered – at least partly – by exploiting the resource 'forest/wood' itself, this motive seems to be much less relevant for farm trees and woodlands and is very likely not the dominant objective of removing them. What is more, agricultural intensification, in particular mechanization, rather than agricultural expansion has usually led to a strong decline of farm trees. This is at odds with prominent findings in empirical research on forest transition processes where agricultural intensification has often slowed down deforestation (e.g. Lambin and Meyfroidt, 2010). In the following, we will use Mather and Fairbairn's (2000) distinction of drivers into a) 'active factors', in particular the perception of some sort of crisis caused more or less by deforestation (e.g. fuel wood scarcity or flooding events) that in turn leads to regulations or other policies to counter deforestation and/or to promote reforestation, and b) 'passive' or 'permissive factors', such as changing socio-economic conditions, technological developments as well as changing 'climates of thought'.

During the socialist period, the removal of particular types of farm trees together with the vast increase in plot size and farming intensity indeed caused severe soil erosion problems and, thus, led to reductions in agricultural productivity. As a response to this 'crisis' 'green' policies to reduce the removal of farm trees and to promote the plantation of new farm trees were implemented. However, their success was only very moderate, and fostering production remained the predominant objective of socialist agricultural policies (Schmidt, 1990). Thus, the problems related to farm tree removal further increased, leading to the implementation of even stricter regulations and technical standards in the 1980s. For example, planting tree rows along farm roads and at the edges of farm plots as well as preserving farm trees was now compulsory when carrying out melioration measures (Philipp, 1997; Schmidt, 1990). The quality of the resulting farm tree structures was rather low, as usually non-native and fast-growing trees, in particular poplars, were planted to save costs and to achieve quick results. Passive factors contributing to the transition process include a general deceleration in land consolidation and melioration measures in the late 1970s and 1980s, coming along with a reduction in what was considered to be the 'optimal' grain size of agricultural landscapes. Not least of the reasons for these changes were decreasing financial means available as well as an increasing environmental awareness and role for nature protection (Janzen, 1987). Further, melioration measures were concentrated on the potentially most productive plots, while disregarding less productive or degraded plots (Quast, 1990). As a consequence, 'remnant' or 'split-off' plots that could not be used efficiently by heavy machinery were preserved and became de facto set-aside land suitable for farm tree establishment (Phillip, 1997).

We argue that the drastic social, economic, and political changes that took place after 1990 continued and amplified the above-mentioned ('active') responses to the 'crisis' of reduced farm-tree-related ecosystem services. In particular, a stricter regulatory framework was introduced. The Saxony Nature Conservation Act, implemented in 1992, banned the removal of and damage to shrublands and scattered fruit trees. Additionally, specific landscape elements, such as hedgerows, tree rows, and isolated trees may be designated for protection by state agencies if they are considered a characteristic component of the landscape. Since 2003, these regionally defined legal restrictions have been complemented by the cross-compliance element within the CAP which stipulates that farmers will only receive full direct payments if they respect defined standards based on existing EU and national regulations (Dupraz et al., 2010). In this context, Germany has established specific standards for Good Farming Practices, including the preservation of farm trees. Cross compliance interdicts farmers to fully or partly remove (1) hedgerows longer than 20 m, (2) tree rows of at least five trees and longer than 50 m, (3) woodlots from 100 m^2 to 2,000 m^2 in extent, and (4) isolated trees which have been designated as natural monuments (Plieninger, 2011, in press). Both legal provisions are efficiently implemented and are likely to have contributed to the lower turnover of farm trees in the post-socialist period. However, the results of this study show that they have not been effective in halting the decline of scattered fruit trees.

In addition to these legislative measures, several payment schemes for ecosystem services – financed by public or private bodies – were implemented after 1990 (Sattler and Nagel, 2010).

For example, the EU co-financed scheme ‘Environmentally Friendly Agriculture’ offered specific premiums for the maintenance of scattered fruit trees. Other project-related funding for planting of scattered fruit trees, hedgerows, shrubs, and riparian woods includes the state-financed Contractual Nature Conservation Schemes and the activities of the so-called Landcare Associations (LCA) that are financed through various private sources. Generally, the dimension of these schemes has been low compared to the total farm tree area. In the context of the Contractual Nature Conservation Schemes, for example, only 49 ha of hedgerows were planted between 2000 and 2006, a further 120 ha of hedgerows were regenerated and supplemented, and 2,700 scattered fruit trees were planted on 21 ha in the whole state of Saxony (Deimer et al., 2007). Therefore, these schemes can explain the increase in tree cover only to a minor degree. A more powerful driver fostering the transition process may have been the increasing diffusion of environmental conservation ideas among the public in the 1990s, which has changed prevailing ‘climates of thought’ (Lambin and Meyfroidt, 2010). Counteracting socio-economic forces, however, have also exerted influence on the farm tree transition in the post-socialist period. For example, EU agricultural policies of the 1990s excluded those pieces of farmed land covered by farm trees from payments, which provided an incentive for farmers expand crop surface by clearing trees (at least in cases where their removal was not legally restricted). The necessity to use every available plot most efficiently may have been intensified by the fierce competition between the now-privatized farm enterprises that followed the introduction of a market economy after 1990. Possible explanations for the strong overall net gain include that farm trees and woodlands have expanded in size due to natural growth that has not been actively restrained by land users. Indeed, farm restructuring after 1990 led to a decrease in average plot size and to smaller agricultural firms and involved an increase of field edges, where farm trees are frequently located. While the mean size of farm units in Saxony was 152 ha in 1991, this number dropped to 106 ha in 1993 and subsequently increased only slightly to 110 ha in 2007 (Statistisches Landesamt Sachsen, 2011). Similarly, EU payments for the compulsory set-aside (that comprised around 11% of croplands in Saxony up to the suspension of set-aside in 2007, Statistisches Landesamt Sachsen, 2011) provided additional space for trees in the agricultural landscape.

It is important to note that the overarching changes in land use and related policies presented here temporally match the expansion of farm tree cover. This approach explores potential drivers, but does not prove a firm causality. Further research, possibly through a spatially explicit integration of socio-economic and land-cover data (compare Baumann et al., 2011), is therefore needed to confirm that the discussed factors have indeed acted as driving forces of a ‘forest transition outside forests’. Here, a particular challenge is to match the different geographical scales, at which proximate causes and underlying drivers influence the complex dynamics of trees outside forests (Lambin and Geist, 2006).

5.3 The conundrum of increasing farm tree cover

The substantial increase in cover for almost all farm tree classes and even for the socialist period is puzzling, as this finding is different to the trajectories of change identified in other European landscapes. Usually a strong decrease of farm trees, in particular hedgerows, had been identified for the period after WW II, and net gains had only been observed from the 1990s onwards (e.g. Burel and Baudry, 1990; Petit et al., 2003; Deckers et al., 2005). Therefore, the rigor of our method needs to be scrutinized. We consider the empirical results robust, due to an elevated number of samples (100 quadrates) and their substantial size (50 ha each). Further, the use of aerial photographs within a GIS environment and consistent analysis through a single photo interpreter is arguably more objective and reliable compared to methods that solely rely on secondary information, such as maps with their inherent uncertainties (Vuorela et al., 2002). Moreover, the basic trend of increasing farm tree cover can be corroborated for the period from 1992 onwards through analysis of habitat mapping data of the state of Saxony (Schleyer and Plieninger, 2011, in press). It should be noted, however, that trees outside forests are usually very small landscape structures, thus mapping is difficult and error-prone. We have aimed to minimize such errors by selecting/assessing only patches larger than 20 m^2. Still, the absolute values for gross gains and gross losses may be overstated. In contrast, we consider the assessment of the net changes between the years 1964, 1992 and 2008 to be quite robust. One major difference to the mentioned studies is that we did not limit our analysis to changes in hedgerow cover, but rather included a broader suite of farm tree and woodland classes. Due to their linear structures, hedgerows are more likely to be removed in the course of land consolidation and melioration measures aiming at creation of larger farming units. Another important difference is that our case study region does not exhibit fragmented or small-scale farming structures, small plot sizes, 'high nature value' land-use systems, and large proportions of seminatural grassland, which is typical for many studies on hedgerows, have been performed.

6 Conclusions

This study has assessed changes in small landscape elements over two major political periods. In revealing a considerable increase of farm trees and woodlands in an intensive farming region, we seek to put in a new light the prevailing view that scattered trees are in general decline. Rather, we stress that coarse-grained and long-term intensively cultivated agricultural landscapes may have had low tree cover throughout their younger history. Increases in farm tree cover were followed by improvements in ecosystem services provision, in consequence of concrete alterations in landscape composition and configuration. These findings have been interpreted as being the result of a combination of a) successful greening policies (both regulatory and incentive-based), b) an increasing environmental consciousness, and c) responses to negative environmental effects from extensive farm-tree removals. These factors have been able to outweigh high land-use pressures resulting from political paradigms, market forces, and agricultural subsidies. However, this study also stresses the role of surprises such as the German unification, an exogenous, abrupt, and accidental transformation processes that has fundamentally altered the political, economic, and social framework that governs farm trees in Eastern Germany. Some broader lessons on the management and conservation of farm trees and woodland in intensively used agricultural landscapes at the European scale can be derived. First, establishing farm trees within the matrix of simply structured agricultural landscapes is a powerful tool to provide connectivity for insect populations and to enhance ecosystem services, but the right spatial configuration of these trees is crucial. Second, simple, coarse-grained landscapes have their own distinct trajectories of change for farm trees. They may offer a higher potential for increasing farm tree cover than more complex landscapes, as even slight increases in farm tree cover lead to great improvements in ecosystem services provision. Third, both legislation and incentive schemes have been unable to halt the decline of scattered fruit trees, while other classes of farm trees that require less management have expanded. Therefore, it needs to be studied whether simpler tree-based systems such as woodlots are able to provide the ecosystem services that have traditionally been delivered by scattered fruit trees and other complex land-use systems of high-nature value.

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Tables

Table 1
Classification of farm trees and woodlands according to patch typology, geometry, and prevailing woody plants.

Class	Patch typology	Geometry	Prevailing woody plants
Alleys, tree rows	More than 3 trees, length > 10 m, width < 30 m	Linear features	Trees
Hedgerows	Length > 10 m	Linear features	Shrubs
Isolated trees	1 tree distant > 5 m from other trees	Point features	Trees
Riparian woodlands	Distant < 10 m to waterbodies, width < 30 m	Linear – polygon features	Trees
Scattered fruit trees	> 5 fruit trees, < 5 m distant	Polygon	Fruit trees
Shrublands	Contiguous shrubs	Polygon	Shrubs
Tree groups	2-5 trees, not more than 5 m distant	Polygon	Trees
Woodlots	> 5 contiguous non-fruit trees, < 5 m distant	Polygon	Trees

Table 2
Mean number of patches and area of tree classes per plot (± S.E.) (n=100), 1964 and 2008.

	1964		2008		Change 1964-2008			
	Patches (n km^{-2})	Area (m^2 km^{-2})	Patches (n km^{-2})	Area (m^2 km^{-2})	Patches (n km^{-2} and %)	p	Area (m^2 km^{-2} and %)	p
Alleys, tree rows	35.4 ± 2.6	4,406 ± 581	35.9 ± 2.8	7,114 ± 968	0.5 ± 2.9 1.3%	n.s.	2,708 ± 570 61.5%	<0.001
Hedgerows	2.1 ± 0.3	534 ± 121	3.0 ± 0.4	1,263 ± 250	0.9 ± 0.5 42.9%	n.s.	729 ± 267 136.5%	0.008
Isolated trees	4.4 ± 0.6	257 ± 33	4.9 ± 0.5	420 ± 53	0.5 ± 0.6 10.9%	n.s.	163 ± 50 63.2%	0.002
Riparian woodlands	10.3 ± 1.3	12,930 ± 1,935	8.0 ± 1.0	17,017 ± 2,259	-2.2 ± 1.1 -21.8%	0.037	4,088 ± 897 31.6%	<0.001
Scattered fruit trees	1.3 ± 0.3	6,811 ± 2,050	1.0 ± 0.3	4,277 ± 1,667	-0.1 ± 0.3 -9.1%	n.s.	-2,534 ± 824 -37.2%	0.003
Shrublands	3.6 ± 0.5	2,884 ± 711	5.8 ± 1.0	2,772 ± 659	2.2 ± 0.9 62.6%	0.012	-112 ± 719 -3.9%	n.s.
Tree groups	2.4 ± 0.4	505 ± 90	3.6 ± 0.5	824 ± 114	1.2 ± 0.5 51.3%	0.017	318 ± 124 63.0%	0.011
Woodlots	4.9 ± 0.5	40,600 ± 5,450	5.6 ± 0.5	53,022 ± 6,480	0.7 ± 0.3 14.8%	0.027	12,423 ± 2,370 30.6%	<0.001
Total trees	64.4 ± 3.5	68,927 ± 6,745	68.0 ± 3.8	86,709 ± 7,617	3.7 ± 3.6 5.7%	n.s.	17,783 ± 2,509 24.7%	<0.001

Table 3
Relative change from a) 1964 to 1992 and b) 1992 to 2008 in ha. Percentages refer to the original tree cover in a) 1964 and b) 1992.

a) 1964-1992

	Gain	Loss	Total change	Swap	Net change	Persistence
Alleys, tree rows	4.7 ha	3.5 ha	8.1 ha	6.9 ha	1.2 ha	1.9 ha
Hedgerows	0.0 ha	1.0 ha	1.1 ha	2.1 ha	-1.0 ha	0.0 ha
Isolated trees	0.2 ha	0.3 ha	0.5 ha	0.5 ha	0.0 ha	0.0 ha
Riparian woodlands	5.1 ha	4.4 ha	9.5 ha	8.8 ha	0.7 ha	6.1 ha
Scattered fruit trees	1.8 ha	2.4 ha	4.2 ha	4.8 ha	-0.6 ha	3.8 ha
Shrublands	5.4 ha	3.8 ha	9.1 ha	7.5 ha	1.6 ha	0.2 ha
Tree groups	0.7 ha	0.2 ha	1.0 ha	0.5 ha	0.5 ha	0.1 ha
Woodlots	16.9 ha	7.1 ha	24.0 ha	14.1 ha	9.9 ha	44.4 ha
Total	28.4 ha	16.2 ha	44.7 ha	32.4 ha	12.2 ha	62.8 ha
Total (%)	36.0%	20.5%	56.5%	41.0%	15.4%	79.5%

b) 1992-2008

	Gain	Loss	Total change	Swap	Net change	Persistence
Alleys, tree rows	4.8 ha	2.4 ha	7.2 ha	4.8 ha	2.4 ha	4.0 ha
Hedgerows	0.7 ha	0.0 ha	0.7 ha	0.0 ha	0.7 ha	0.0 ha
Isolated trees	0.4 ha	0.1 ha	0.6 ha	0.3 ha	0.3 ha	0.1 ha
Riparian woodlands	6.5 ha	1.6 ha	8.1 ha	3.3 ha	4.8 ha	9.5 ha
Scattered fruit trees	0.6 ha	1.6 ha	2.1 ha	3.1 ha	-1.0 ha	4.0 ha
Shrublands	2.0 ha	5.3 ha	7.2 ha	10.5 ha	-3.3 ha	0.3 ha
Tree groups	1.0 ha	0.4 ha	1.4 ha	0.8 ha	0.6 ha	0.4 ha
Woodlots	14.3 ha	6.0 ha	20.2 ha	11.9 ha	8.3 ha	55.4 ha
Total	22.8 ha	10.0 ha	32.7 ha	20.0 ha	12.8 ha	81.2 ha
Total (%)	25.0%	10.9%	35.9%	21.9%	14.0%	89.1%

Table 4
Indicators for ecosystem services of farm trees at landscape level, 1964 and 2008 (mean ± S.E.).

	1964	2008	Change 1964-2008	p
Pollination and pest regulation services				
Percentage of landscape (%)	6.9 ± 0.7	8.7 ± 0.8	24.7%	<0.001
Edge density (m ha^{-1})	76.4 ± 5.2	92.9 ± 5.8	21.5%	<0.001
Mean Euclidian nearest-neighbor distance (m)	31.8 ± 2.0	27.1 ± 2.9	-14.9%	<0.001
Mean Euclidian distance matrix-tree (m)	104.4 ± 5.3	106.0 ± 5.7	1.5%	n.s.
Water purification services				
Tree cover in buffer (%)	21.5 ± 2.6	31.3 ± 3.9	45.6%	<0.001
Proportion of buffer voids (%)	50.1 ± 4.5	30.1 ± 4.3	-40.1%	<0.001
Mean functional buffer width (m)	7.8 ± 1.4	14.3 ± 2.6	83.7%	<0.001

Table 5
Indicators for insect-based ecosystem services of farm trees at class level, 2008 (mean ± S.E.).

	Alleys, tree rows	Hedgerows	Isolated trees	Riparian woodlands	Scattered fruit trees	Shrublands	Tree groups	Woodlots	Total
Percentage of landscape (%)	0.7	0.1	0.0	1.7	0.4	0.3	0.1	5.3	8.67
Edge density (m ha^{-1})	24.5	5.1	1.9	25.7	3.2	6.8	2.7	27.8	72.9
Mean Euclidean nearest-neighbor distance (m)	25.8	229.1	181.4	65.6	302.2	126.0	241.5	140.8	87.6
Mean Euclidian distance matrix-tree (m)	194.9	331.3	301.5	258.4	327.2	299.6	320.2	216.5	106.0

Figures

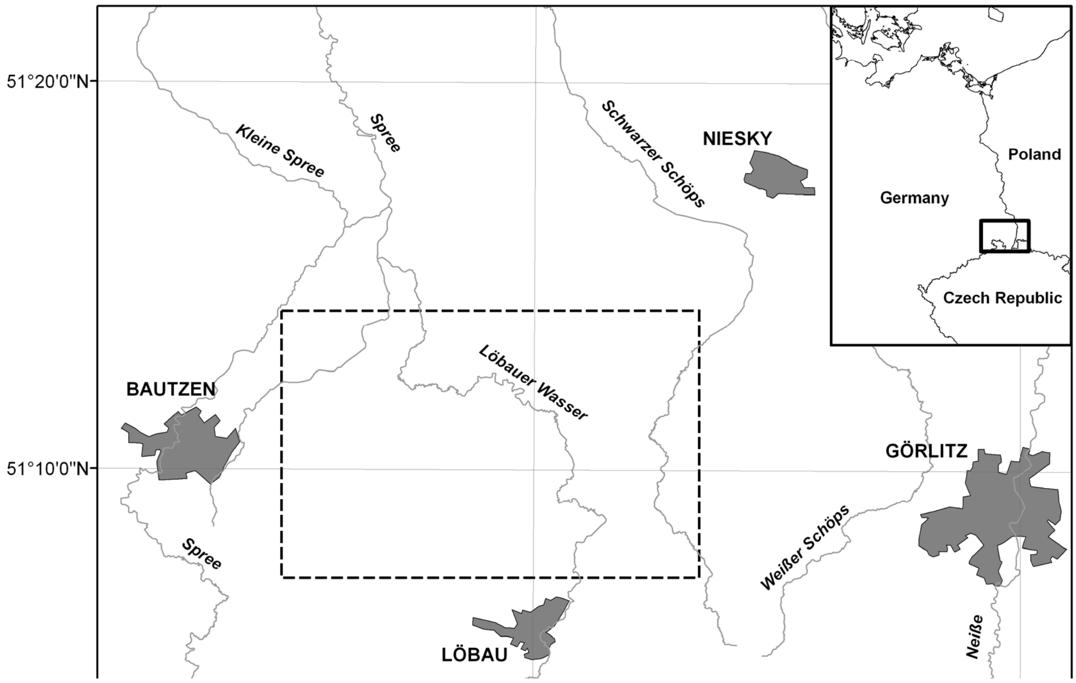

Fig. 1. Location of the Upper Lusatia study area in Germany. The dashed rectangle represents the 28,050 ha study area in which random samples were selected.

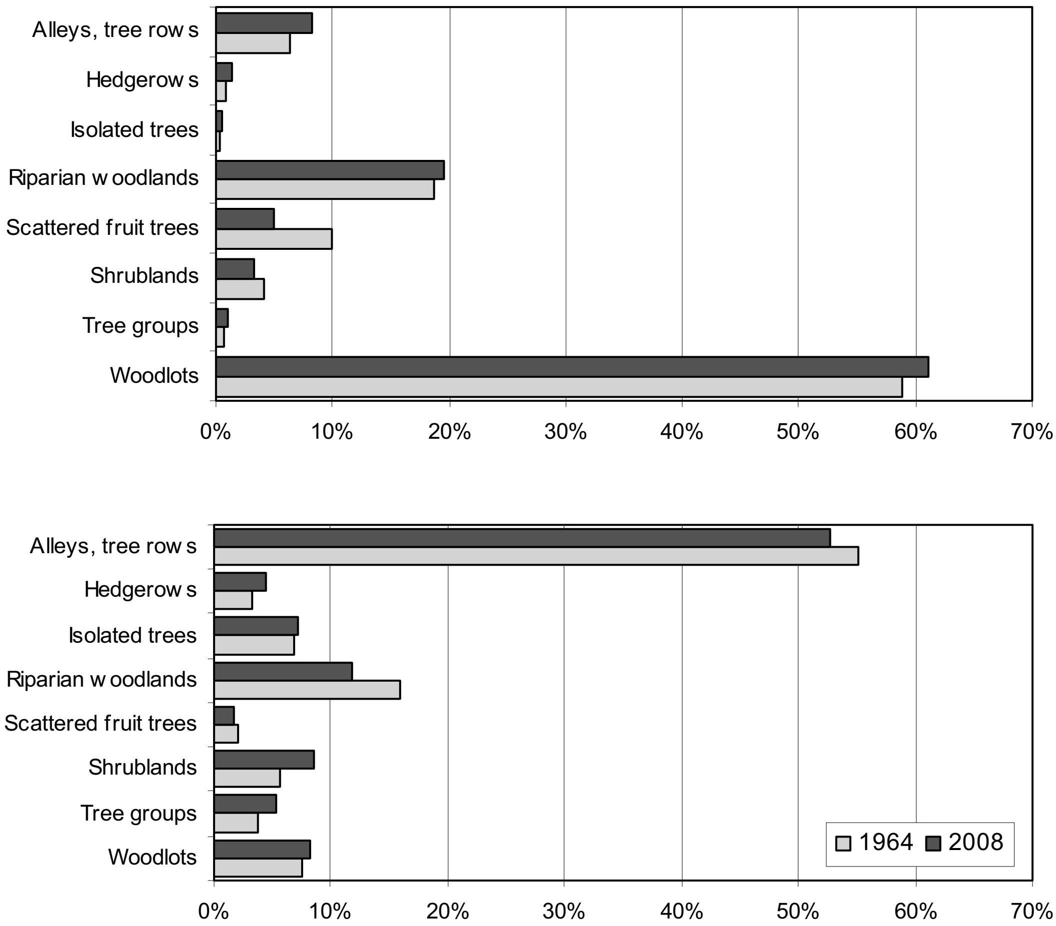

Fig. 2. Percentage of total area (above) and number (below) of farm tree patches, by tree class, 1964 and 2008.

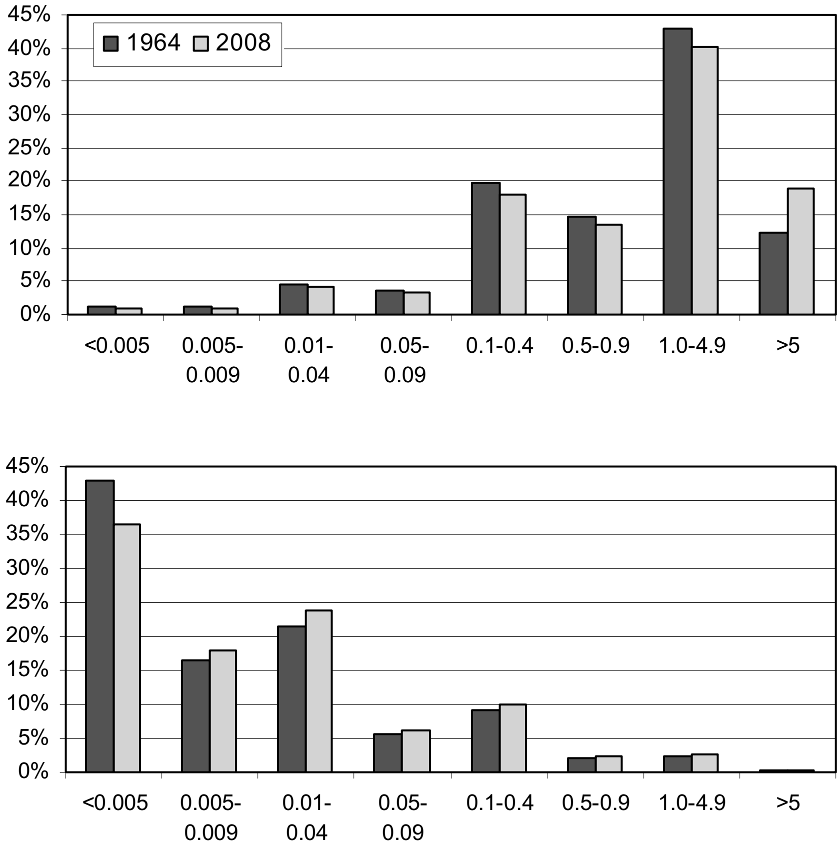

Fig. 3. Percentage of total area (above) and number (below) of farm tree patches, by patch-size in ha.

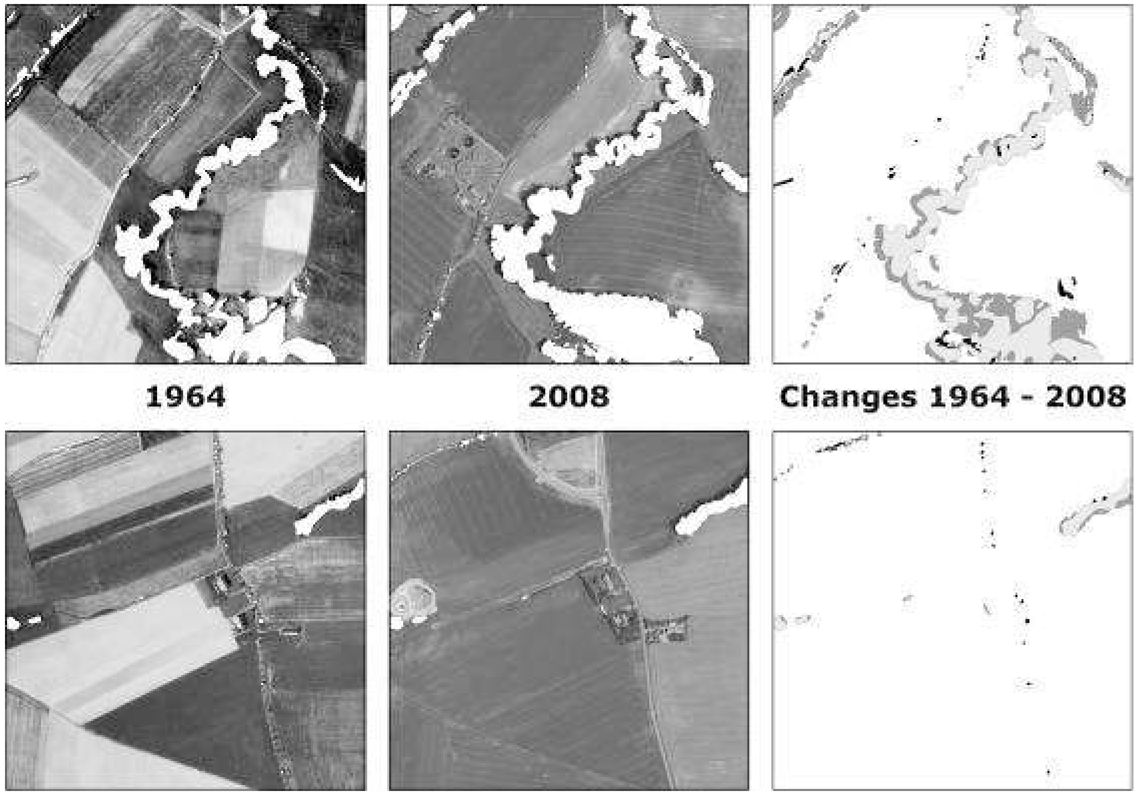

Fig. 4. Mapped tree cover in white in aerial photographs from 1964 (left) and 2008 (center), and resulting tree cover change (right). in the selected examples are indicative of plots of overall high dynamics (above) and low dynamics (below). In the change map, light gray shows persistent trees, black refers to lost trees, and dark gray to gains in farm trees.

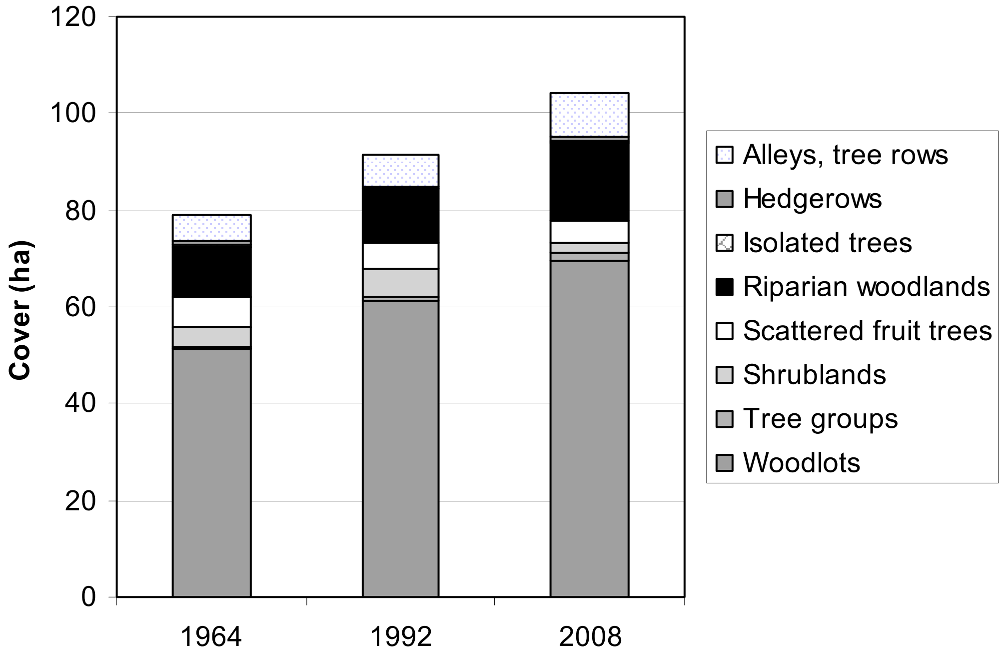

Fig. 5. Total area of the eight tree classes in a 10 km² subsection of the study area.