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The implications of stand composition, age and spatial patterns of forest regions with different ownership type for management optimisation in northern Latvia

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ABSTRACT

Forests with different ownership type often form complex mosaics of stands, thus adding new challenges to the spatial planning of sustainable management in forested landscapes. This study attempted to analyse the spatial patterns and age structures of forest regions with different ownership type and to formulate suggestions for the optimisation of tactical planning of forest management planning by addressing ecological functionality at the landscape level. We hypothesised that structure of forests of various ownership groups differs significantly. National forest inventory data from 2011 was used in this study to compare spatial patterns of forest stands and clearcuts, as well as forest age structures. In total three areas with forest matrix in northern Latvia were selected for this study – owned by state, municipality and multiple private owners. Stand structure and current management regimen were characterised through the analysis of thematic landscape pattern maps and age structures of the canopy layer. Results showed significant differences between state and private patch configuration metrics. State forest stands were dominated by three tree species and a stable harvesting level. Municipal forest had largest stand patch size and the most even size of age classes in age structures. Lower road density, more complex canopy vertical structure and higher tree species richness characterised the private forest tract. We see landscape ecological planning of functionality as a way to optimise existing forest patterns. The incorporation of the modelling of future patterns under different management regimen in state, municipal and private forests could give valuable insights for more sustainable forest management.

1. Introduction

Forest ownership is regarded as the major factor influencing forest management practices, along with local site conditions, natural disturbances and land-use history (Crow et al., 1999; Bergès et al., 2013; Schaich and Plieninger, 2013). Ownership has been shown to be positively correlated with landscape structure (Stanfield et al., 2002). Different forest owners can have different goals for management of their forest holdings, which raises a need to explore how they influence stand patterns and age structures. Ownership patterns have been investigated at a European level (Pulla et al., 2013) and many studies have investigated the relation of forest ownership to landscape structure (Maltamo et al., 1997; Uuttera et al., 1998; Stanfield et al., 2002), rare species richness (Lovett-Doust et al., 2003), timber harvesting (Kittredge et al., 2003) and old forest fragmentation (Kurttila et al., 2002).

Nearly half of Europe's forests (excluding Russian Federation) are privately owned (Forest Europe and UNECE FAO, 2011; Pulla et al., 2013) and this ownership type deserves special attention. Small size of private forest holdings and ownership fragmentation has been explicitly recognised as a major problem for cost-effective management (Schmithüsen and Hirsch, 2010). Spatially complex ownership patterns, including private, can constrain management practices, for example restoration (Shinneman et al., 2010 and references therein). Among the private forest owners the proportion of enterprises is recently increasing compared to individuals (Schmithüsen and Hirsch, 2010), which indicates consolidation of properties and decrease of the number of private owners.

As all ownership types exist in Latvia, this region can be used to study how management style can influence landscapes of different ownership types within a common legal framework. Latvia represents a particularly interesting case due to the dynamic nature of

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the landscape, as the forest area increased from 27% in 1935 to 52% in 2010 (Ruskule, 2013), largely due afforestation on marginal agricultural lands during the Soviet period (Tērauds, 2011; Vanwambeke et al., 2012). These dynamic and complex mosaics of state and non-state ownership types, both industrial and non-industrial, create problems in resource management planning and nature protection (Stanfield et al., 2002).

The understanding of landscape history is mandatory in studies of forest structure and spatial patterns. Forest ownership structure in Latvia changed significantly during the 20th century. During Soviet rule (1944–1991) all forests were owned and managed either by the state or collective farms – *kolkhozs* and *sovkhozs* (Ziegler, 1990). State forests were managed in a uniform manner, but management and timber harvesting in farm forests depended on local needs. After the restoration of independence the restitution and privatisation of forest properties were carried out in the mid-1990ies (the Land reform), creating approximately 150000 private forest owners with average size of forest holdings of 8 ha (Meža nozare Latvijā, 2012). The Riga municipality also regained its ownership rights through the Land reform. In 2012, 47% of Latvia's forests were owned by the state, 50% by private owners, 2% by municipalities and the rest by other owners (Meža nozare Latvijā, 2012). Similar ownership patterns occur in Estonia (Kallas, 2002) and Lithuania (Lazdinis et al., 2009) due to the same political and economic shifts. A contrasting picture is in Poland where the majority of forest resources (approximately 85%) are still owned by the state (Brukas and Weber, 2009) and the role of private forestry is relatively insignificant. In recent years private industrial forestry companies and the Joint Stock Company *Latvian State Forests* (LVM) have been active in the purchase of individual properties (Meža nozare Latvijā, 2012).

Landscape metrics have been widely used to quantify forest patterns (e.g., Tinker et al., 1998; Stanfield et al., 2002) and several studies show that it is possible to characterise patterns with few relevant metrics (Lausch and Herzog, 2002; Leitão and Ahern, 2002). Spatial configuration of habitats influences species occurrence and behaviour in landscapes (McIntyre and Wiens, 2000). Shape of habitat patches can be an important factor in various ecological processes (Forman, 1995). Proximity index has been used to evaluate habitat patch isolation or clustering (Gustafson et al., 1994) and Euclidean nearest neighbour distance is often used to assess isolation of fragmented populations (Leitão et al., 2006).

Previous studies of forest structure and ecology in northern Latvia were focused on state forests (Tērauds et al., 2011; Madžule et al., 2012a) leaving out private forests. In a study by Rendenieks and Nikodemus (2012) spatial patterns of mature and old stands were compared between state and non-state forests in northern Latvia. The aim of this study was to analyse the spatial patterns and age structures of forest regions (spatial aggregations of forest compartments) with different ownership types and to formulate suggestions for the optimisation of forest management planning at the landscape level. We hypothesised that structure of forests of various ownership groups differ significantly. Ownership type of forest needs to be considered in tactical planning of sustainable forest management that addresses ecological functionality. This is especially topical in Post-soviet states, which are in search for more sustainable and ecologically sound forest management models (Lazdinis et al., 2007).

2. Materials and methods

2.1. Studied forest regions

In this study we defined three forest regions as spatial aggregations of forest compartments with uniform ownership types: state, municipal or private. The studied regions were located in northern Latvia (Fig. 1). Roughly similar size (1781–2063 ha) and abiotic conditions (regarding soil fertility class and moisture) enabled the comparison of these regions; however, their spatial configuration differed due to landscape history. Thus, the chosen regions match the size of an average management planning unit (2000–3000 ha) by LVM, thus making the scale of this study more relevant to forest management planning.

The selected regions were located in moraine plain with generally flat terrain, crossed by several river valleys; the altitude varied from 33 to 60 m a.s.l. The areas were located in the hemiboreal region with mostly mixed forests. Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*), birches (*Betula pendula* and *Betula pubescens*), and black alder (*Alnus glutinosa*) are the most common species. Grey alder (*Alnus incana*) and European aspen (*Populus tremula*) covered smaller areas. Some species (*Tilia cordata*, *Quercus robur*, *Salix spp*. and *Ulmus glabra*) occupied very small areas and thus were not separately analysed. The majority of analysed stands were on fertile, wet soils (*Oxalidosa*, *Hycomiosa* and *Myrtillosa mel.* forest types); 33.3% of total stand area was artificially drained, reaching 67.1% in state forest region. These forest regions serve as production forests with only small areas excluded from forestry operations – 3.1% of state forest region had status of woodland key

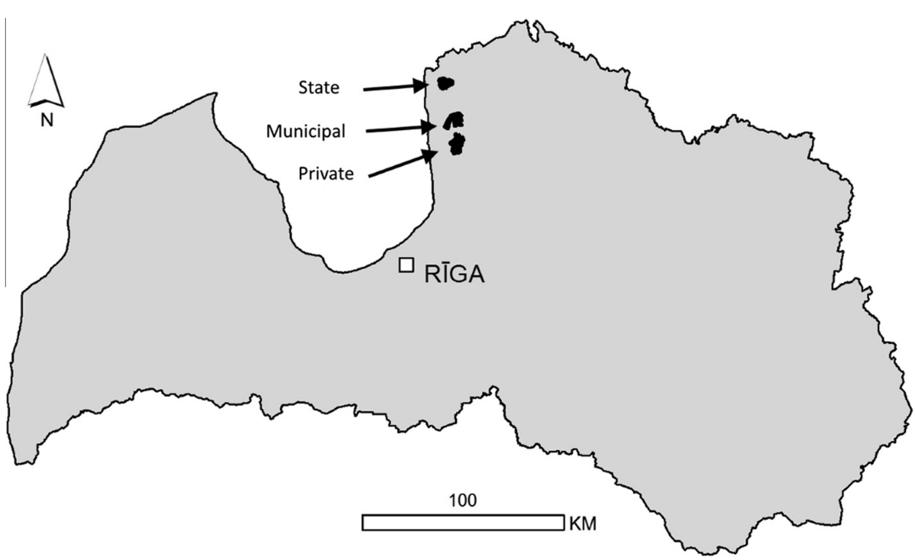

Fig. 1. The location of studied forest regions in Latvia.

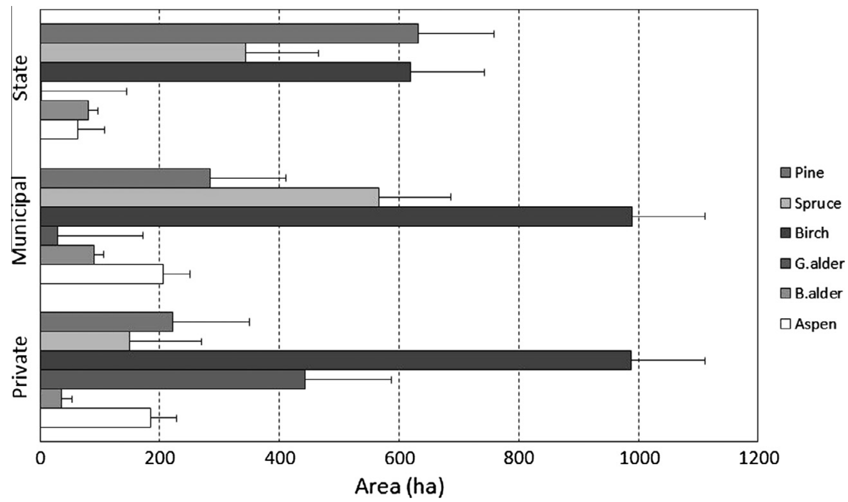

Fig. 2. Tree species composition by stand area in 2011. Standard errors are shown.

habitats (WKH). The studied regions were regarded as semi-natural habitat aggregations within the vast landscape of the North Vidzeme Biosphere Reserve, established in northern Latvia in 1998 in accordance with the UNESCO MAB programme.

The state forest region (SFT; location 57°48′24″N; 24°30′16″E) contained 1567 forest compartments (management units with similar stand age and tree species composition). It was the most compact and surrounded by agricultural land with small villages. Numerous private forest holdings are located adjacent to the boundary of this region. Since the 1930ies the majority of the SFT area has been covered with forest continuously, with the exception of swamps (Fig. 2). Afforestation of marginal agricultural lands adjacent to this region has occurred in recent decades. Forest drainage before the 1960ies consisted only of main contour ditches, but was later further developed by building dense networks that now cover the entire area of SFT. Forest road networks were developed together with the drainage system. This region is currently managed by LVM.

The municipality forest region (location 57°38′44″N; 24°35′40″E) consisted of 1069 compartments. The municipal forest consists of four large, contiguous segments, which forms a quite complex configuration. The municipal forest is the property of Riga city and is managed by Rīgas meži Ltd. It was the property of Riga city already in the 1920ies (Melnalksnis, 1923), but was nationalised after the Soviet occupation and included in state forests (Rīgas meži, 2014, pers. comm.), and reclaimed by Riga city after renewed independence in 1991. A drainage network was developed during the 1950–1960ies. No new forest roads were built after the 1970ies, but existing roads were improved in some parts. Two meadows forming gaps inside the largest segment have been continuously overgrowing with trees since the abandonment of surrounding lands in the 1980ies. The municipal forest is partially surrounded by state and privately-owned forests and partially by agricultural land, which show visible signs of abandonment and natural colonisation with forest.

The private forest region (location 57°32′40″N; 24°37′19″E) included 1962 compartments. It was located just 5 km west from the town Limbaži and adjacent residential areas. The private forest had the most complicated spatial configuration – it was composed of many relatively small and often detached forest compartments, which is typical for private forests in Latvia. According to topographical maps from 1934 forest cover then constituted of only 30% of the forested area in 2011, thus, a considerable portion of the area represents secondary forest. This area experienced major changes in land cover structure since the 1930ies, when the area consisted of several compact but isolated forest patches among mires and agricultural land. Forest land drainage has affected only a small portion of private forest and the forest road network has not been developed due to the density of existing general purpose motorways and small size of forest regions. Afforestation of abandoned agricultural lands has occurred outside the boundary of this region. In 2013, private forest consisted of holdings of 117 persons and 23 enterprises with mean area of 11.4 ha (Valsts Meža Dienests, pers. comm.).

2.2. Used data and analyses

This study utilised forest inventory data obtained from the State Forest Register – a forest information system maintained by the State Forest Service (Valsts Meža Dienests). Forest inventory data (ESRI geodatabase format) is a compilation of stand-level field inventories that are mandatory for all forests (including private and municipal) in Latvia. Selected information was used from this database – dominant species and stand age for forest compartments, number of tree species and number of canopy layers in all compartments. Clearcut patterns were extracted from the State Forest Register database retrospectively by using queries of stand age (intervals corresponding to post-clearcut regenerated young stands), which were verified using the latest orthophoto maps of corresponding areas.

Forest compartments were categorised by dominant species and thematic stand structure maps were produced with ArcMap 10 (ESRI, 2011). The layers included productive stands, non-forest areas (e.g. mires, meadows) and clearcuts. These thematic maps included also major forest road networks as cut-outs. The thematic maps were converted to fine-scale ArcGrid raster data structures. Individual forest compartments were aggregated into patches (according to categorisation by dominant species) to create thematic (categorical) pattern maps. A raster cell size of 5×5 m was chosen for each raster image. Harvesting activity in all three regions was estimated separately by comparing pattern metrics of age classes in compartments for time periods of 1988–1999 and 2000–2011.

Pattern metrics at class and landscape levels for these were estimated using FRAGSTATS 4 to capture essential compositional and configuration aspects (Leitão et al., 2006; McGarigal, 2012) of the studied regions at class and landscape levels. Seven metrics were selected (see Appendix A) to describe both composition and configuration of stand and clearcut patterns. Simple descriptive metrics like total area, number of patches, mean patch area and patch richness were calculated together with metrics characterising patch configuration and aggregation/isolation: shape index, patch proximity and Euclidean nearest neighbour distance. We used 500-m patch proximity threshold distance to calculate patch isolation. This distance was chosen, as seed dispersal outside of this range typically occurs only by large animals (Vittoz and Engler, 2007). The eight-cell neighbour method was used to calculate raster cell adjacencies.

Age of dominant species in stand and number of stand canopy layers were determined from inventory databases. Thematic maps of forest compartments with selected features were generated using ArcMap 10 to produce relative age structures for dominant trees species (the proportion of each age class as the percentage of species total area) using young, medium, mature and overmature age classes, as defined by the State Forest Service (Valsts meža Dienests, 2000). Since the age thresholds were differentiated for pine and birch by stand productivity, age intervals for medium productivity stands were used. Regarding tree species composition and age structures, it is important to note that the majority of the analysed stands were mixed; therefore, in order to simplify the analyses only dominant species were included. In addition, the forest road network was digitised using topographic maps from 2008, retrieved through the Web Map Service (WMS) in the Faculty of Geography and Earth Sciences at the University of Latvia.

2.3. Data verification and statistical tests

Latest high-resolution orthophoto maps (0.5–1 m/pixel), produced by the Latvian Geospatial information agency, were used for data verification together with field survey of 76 randomly chosen stands. Field survey was conducted in September of 2013 and included ground-truthing of selected stand characteristics from inventory data, clearcuts and forest roads infrastructure. When checked for characteristics used in analysis to define stand patterns – dominant species, stand age, forest type and presence of clearcuts, we found data to be consistent, with the exception of 4 cases of misclassification of dominant species and 9 stands that were found to be felled after 2011 (these stands were not included in analysis). Detected inconsistencies (5.2% of total number of surveyed stands) were corrected and database information approved as valid for analysis.

Pattern metric values (both at class and landscape levels) were tested with the Shapiro–Wilk test in R 3.0.1. (R Development Core Team, 2014) and were found to have non-normal distributions. For mean patch area, mean patch shape, mean patch proximity and mean nearest neighbour distance, the Kruskal–Wallis rank sum test was used to test the significance of overall differences among the three ownership types. This was followed by a Mann–Whitney U multiple pair-wise *a posteriori* test with Hochberg–Benjamini–Yekutieli adjusted *p*-values.

3. Results

3.1. Stand composition and age structures

The three forest regions differed in area of major tree species – pine, spruce and birch (Fig. 2). Private forest showed the most balanced proportions of the aforementioned species, with the other tree species occupying far less area. Pine had a much larger proportion of total forest area in the state forest compared to other regions, almost three times greater than in the PFT (35.5% versus 10.7%). The absence of grey alders stands out in state forest. In

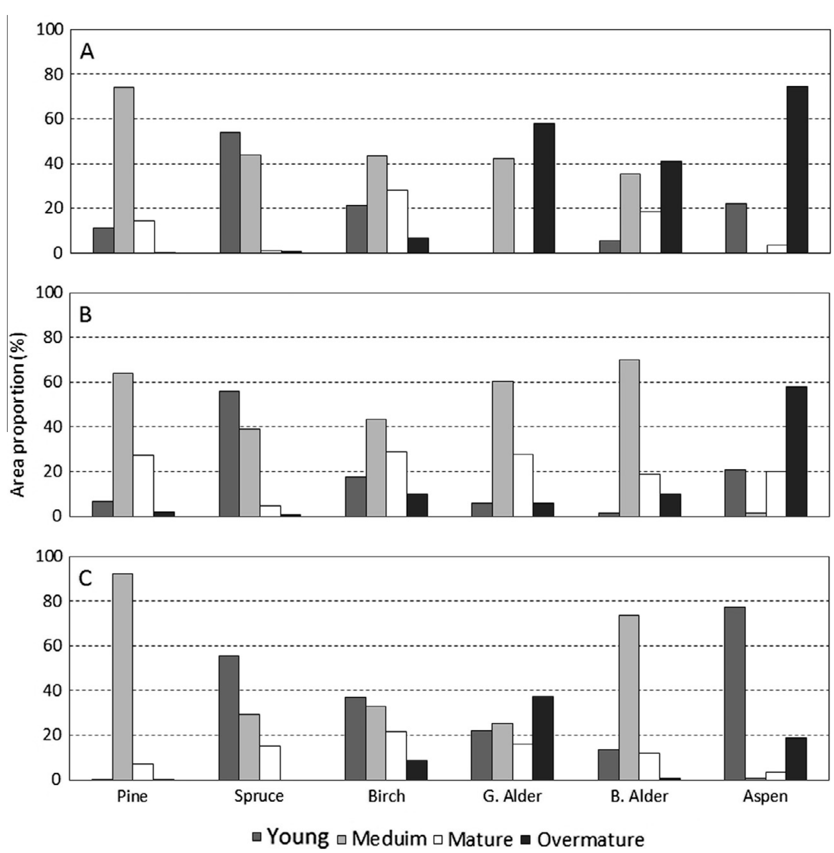

Fig. 3. Age class distributions for stands in state (A), municipal (B) and private (C) forest regions in 2011 (age thresholds modified after Valsts Meža Dienests, 2000).

the municipal forest birch dominated the species composition, reaching approximately 47%, similarly as in the private forest. Another similarity with private forest was relatively low area of pine and high area of aspen stands, which was contrasting to state forest. However, spruce stands in the municipal forest had the largest proportional area among the studied regions, ranging from 7.2% in the private forest to 26% in the municipal forest. Municipal and private forest also showed higher tree species richness – 10 compared to 8 species in the state forest. Private forest was generally similar to municipal forest with several differences. The most evident one was relatively large area of grey alder (21.5%, more than both conifer species combined), which was contrasting to almost no grey alder stands in state forest. Black alder stands occupied less area compared to state and municipal forest.

Stand age structures of six tree species (Fig. 3) indicated uneven area distribution of age classes for all species except birch. Although pine and spruce in state forest showed high proportions of young and medium-aged stands; both lacked overmature stands and also mature stands for spruce. Due to small total area, both alder species and aspen had very uneven distributions with relatively large overmature stand areas compared to pine, spruce and birch. 11.6% of the total relative area in state forest was comprised by overmature stands.

In municipal forest age structures were generally most evenly distributed, compared to the other regions. The spruce age structure had heavy domination of young stands (>50%) in all studied regions. A bell-shaped distribution and dominance of medium-aged stands for birch stands in municipal forest were very similar to those in state forest. Grey alder and black alder distributions were also dominated by medium-aged stands in municipal forest, but other age classes were also present. The aspen stand distribution showed a large proportion of overmature stands. The total relative area of overmature stands in municipal forest was 10.7% of the total area.

Medium-aged (41–110 years) pine stands in the private forest reached 93% of total pine cover in the private forest and lacked both young and overmature stands. The pine age distribution was also dominated by medium-aged stands in state and municipal forest, but not to such a great extent. Spruce and birch distributions showed decreasing area of older age groups in private forest. Grey alder stands showed almost even age group distribution with a larger area of overmature (>41 year) stands. Black alder and aspen stands were dominated by medium-aged and young stands (respectively). The total relative area of overmature stands in private forest was 13.9% of the total area.

The occurrence of multi-layered canopies in stands varied between regions of different owners (Table 1). State forest was dominated more by single and double-layer canopies, while municipal and private forest showed higher relative area of canopies with three and more layers, indicating more complex stand vertical structure.

3.2. Stand and clearcut spatial patterns

At the landscape level, pair-wise comparisons for stand patterns showed significant differences ($p < 0.01$) between state and private forest for all tested metrics (Table 1), while municipal forest was found to be different to other regions only in aspects of patch shape ($p < 0.05$), proximity and nearest neighbour distance ($p < 0.05$). The municipal forest contained the largest patches in contrast to private forest, where patches were smaller and more numerous. Stand proximity indicated that connectivity is highest in municipal forest. Isolation of stand patches, measured by Euclidean distance, was the lowest in state forest, showing significantly higher values for municipal and private forest.

Table 1
Landscape-level statistics for forest regions with different ownership types in 2011. All values except forest road density and the proportion of overmature stands were calculated from thematic raster maps.

Indicator	State	Municipal	Private
Total area (ha)	1780.8	2184.7	2062.3
Total clearcut area for 1988–2011 (ha)	320.76	410.41	698.99
Proportion of overmature stands (%)	11.6	10.7	13.9
Forest road density (km per 100 ha)	1.14	0.70	0.37
Patch number	421	366	663
Tree species richness	8	10	10
Canopy levels (% of stand number)			
1	34.9	13.7	18.0
2	38.4	28.7	29.4
3	19.5	36.5	34.0
>3	7.2	21.1	18.6
Stand and clearcut pattern metrics			
Mean patch area (ha)	4.23[1]	5.97	3.11[2]
Mean patch shape	1.82[1]	1.72[2]	1.65[3]
Mean patch proximity	694.78[1]	300.66[2]	214.81[3]
Mean nearest neighbour distance (m)	87.06[1]	175.78[2]	113.40[3]
Mean clearcut patch area (ha)	2.56	2.82[1]	2.67[2]
Mean clearcut patch proximity	46.96	16.85[1]	102.79[2]

Numbers in superscript indicate significant pairwise differences between ownership groups (single underline – $P < 0.05$; double underline – $P < 0.01$).

Mean patch area (Table 2) for pine (11.48 ha) was significantly ($p < 0.01$) higher in the state forest and together with a very high proximity value (2453.29) indicated a distinct spatial pattern character. Aspen patch proximity was significantly lower ($p < 0.01$) compared to private forest. Municipal forest showed significantly higher values for spruce ($p < 0.01$) and birch ($p < 0.05$) patch area compared to other regions. None of the species showed significant differences among regions in stand proximity. Private forest had more numerous, detached patches, which was also evident when patch density was examined by tree species, with highest values for birch, grey alder and aspen. Aspen patch proximity in private forest was significantly higher ($p < 0.01$) than in state forest, but much lower for pine and spruce.

The clearcut patterns in the private forest indicated more extensive timber harvesting than in the other two regions (Table 1), reflected by the area and proximity of clearcut patches. The clearcut area was considerably smaller in state and municipal forest compared to private forest (Table 1). Clearcut patch proximity in private forest was significantly ($P < 0.05$) higher than in municipal forest, but the largest mean clearcut area was found in municipal forest. State forest did not indicate any significant difference regarding clearcut patterns.

Table 2
Class-level statistics for tree species composition and configuration for forest regions with different ownership types in 2011. Six most common species shown.

Species	Mean patch area (ha)			Mean patch proximity		
	State	Municipal	Private	State	Municipal	Private
Pine	11.48[1]	5.16[2]	2.58[3]	2453.29[1]	167.78	77.20[2]
Spruce	2.69[1]	5.56[2]	1.81[3]	220.09[1]	336.35	30.42[2]
Birch	4.56	11.91[1]	5.85[2]	896.36	779.40	655.28
Black alder	1.72	2.66	1.17	131.38	2.67	3.09
Aspen	1.87	3.33[1]	1.86[2]	1.97[1]	19.39	36.16[2]
Grey alder	0.41	1.67	2.76	27.30	28.69	116.66

Numbers in superscript indicate significant pairwise differences between ownership groups (single underline – $P < 0.05$; double underline – $P < 0.01$).

Clearcuts in most cases were located in close proximity to overmature stand patches (Fig. 4), especially in municipal forest, where overmature stands comprised 12% of the total stand area. Old stands in all three forest regions consisted mostly of deciduous tree species – birch and aspen, which combined amounted to 60% (state forest), 83% (municipal forest) and 97% (private forest) of the total overmature stand area (respectively).

4. Discussion and conclusions

4.1. Structure of state, municipal and private forests

Although all three regions generally were managed for timber production, main structural characteristics varied between ownership groups. Schaich and Plieninger (2013) reported that private forests were more structurally diverse compared to state-owned forests in southwestern Germany, and Maltamo et al. (1997) showed similar findings in central Finland. Lower tree species diversity was found in state forest, where main commercial timber trees (pine, spruce and birch) combined covered 91% of the total stand area. Together with the lack of grey alder and less complicated stand vertical structure, this is attributable directly to forest management practices (e.g. replanting and thinning). From a management perspective, traditional forestry prefers replacement of grey alder stands with more valuable coniferous trees, but in private forests grey alder stands are abundant and often reach maturity due to lack of owner investment in stand tending. For a long time forest regulations have allowed natural regeneration of clearcuts, as long as the densities of viable trees given in harvest regulations were met. Private owners largely have relied on natural regeneration and overall the proportion of clearcuts regenerated with adapted seedling nursery stock has been low till 2004 (Zemkopības Ministrija, 2007). Most of the small private forest owners were not interested in investments in forest regeneration after harvesting and profits from timber sales were not reinvested. This, of course, neglects the large gains in productivity that have been made in tree breeding (Kozlowski, 2002). This resulted in a situation where the management style in private forests was incoherent in contrast to forests owned by state and municipalities. Results also indicated the lack of young pine stands in private forest, contrasting to grey alder and aspen, which is most likely due to the preference to natural regeneration of stands after clearcuts. In contrast, the majority of state forests have been continuously managed in full cycle (before and after the restoration of independency) with replanting of clearcuts with bred planting material (Meža nozare Latvijā, 2012). Forest road density also showed that state forest has the most developed management infrastructure among studied regions.

Stand patterns showed significant differences between state and private forest in aspects of patch area, shape, proximity and nearest neighbour distance. At landscape level state forest was shown to have large, spatially aggregated stand patches (particularly for pine and spruce) with more complex shapes compared to private forest. Patches of other species' except aspen were not found to be significantly different in terms of proximity. This is in line with Maltamo et al. (1997) who found higher connectivity of forest patches in all developmental stages in a study in central Finland. However, in this study metrics like proximity and Euclidean distance are inevitably biased in favour of state and municipal forest due to the existing configuration of private forest, which is typical to private forests in Latvia.

4.2. Forest history and harvesting

The past history of forest management in Latvia can largely explain the existing structure of the forest landscape (Tērauds et al., 2011). In addition, natural afforestation on marginal agricultural lands has largely increased forest cover (Penēze, 2009; Nikodemus et al., 2005). The abundance of grey alder stands in private forest is a consequence of afforestation of abandoned arable lands that took place in Latvia (Ruskule et al., 2012) and elsewhere in Europe (Sirami et al., 2007; Kuemmerle et al., 2009; Feranec et al., 2010) during the second half of the 20th century. When reaching maturity, these forests forming today on abandoned lands will influence forest policy in the future. The pronounced dominance of young spruce stands in state and municipal forest (Fig. 3) indicates the consequences of planting spruce as the prime target species during the 1960–1970ies (Laiviņš, 1998; Tērauds et al., 2011). During that time, artificial regeneration dominated greatly over natural regeneration in state forests (Tērauds et al., 2011). Such large-extent planting of spruce plantations, regardless of soil type and moisture, led to the uneven age structure at the country level. Large amounts of spruce timber is expected to be available for felling around 2040 and under current forest policy this may intensify harvests even more. However, by then the pine reserve might have started to be depleted, depending on planned future harvests in state forests. Those two examples from past policy consequences illustrate the importance of forest history for policy making and forest management today.

A study in western USA (Spies et al., 1994) showed that significantly higher levels of harvesting causing mature forest

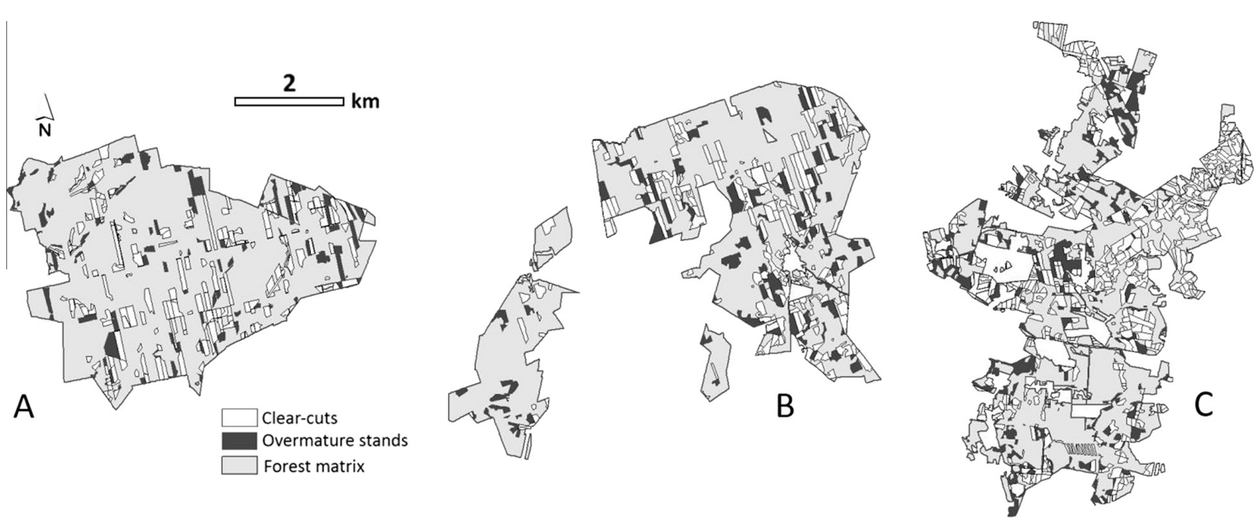

Fig. 4. Clearcut (1988–2011) and overmature stand patterns in studied forest regions (A – state; B – municipal and C – private).

fragmentation were found in private versus federally-owned forests. Significant differences for harvesting patterns were found between 1988–1999 and 2000–2011 mean harvest patch area values in municipal and private forest We explain the great increase in harvested area in private forest by the interaction between fragmented ownership types and profit-driven attitude of non-industrial private owners, i.e., owners of newly gained farms quickly harvested the small woods that they had for immediate income. In state and municipal forest felling rates were stable, although felling statistics indicate a national-level rise of felled volumes after 2008 (Centrālā Statistikas Pārvalde, http://csb.gov.lv/).

4.3. Implications for forest management

Ownership structure in state and municipality forests is more convenient for management planning at landscape scale than in private forests. Regarding the vast area managed and FSC certificate standards, introduction of spatial considerations (harvest scheduling with regard to conservation) into meaningful forest management plans would be the most effective in state forests. A similar conclusion can be drawn for municipality forests, but due to their small area it might not be as effective. The state forests in Latvia contain the bulk of protected area for conservation of biodiversity, compared to the area within private forests −17.5% of the state forest area has harvest restrictions, compared to 7.4% of the area in private forests (Valsts Meža Dienests, unpublished). It has been advocated that restoration efforts to halt the decline of biological diversity should focus on areas that have not already been depleted in species, i.e. by creating habitat aggregations (Hanski, 2011; Halme et al., 2013). This, coupled with the evidence that state forests are in general less fragmented with more core area, suggests that landscape planning to increase ecological functionality should focus on particular regions of the state owned forest where biological diversity is higher. Study of metapopulations suggests that approximately 20–30% of suitable habitat in a landscape is necessary for maintenance of certain specialist species' populations at a viable state, and achieving this is more feasible by designating particular regions for creating aggregations of suitable habitat (Andren, 1994; Hanski, 2011 and references therein). The Joint Stock Company *Latvian State Forests* (LVM) had already begun to employ this type of management, by designation of particular areas where the protected forest area would be higher, detailed pre-inventory of biological values is made, and less intensive management is utilised, such as no cutting during the bird nesting season. Regarding harvest planning, several authors (Franklin and Forman, 1987; Li et al., 1993; Gustafson, 1996) advocated that clustering clearcuts and increasing the clearcut size can reduce impact on forest interior (of large contiguous patches containing overmature stands) and optimise the rentability of harvesting operations. At the same time it has been noted that the risk of windthrow damage increases with larger clearcut areas (Zeng et al., 2004). Clearly strategic to operational planning in state and municipal forest can easily incorporate the above considerations, as there is only one owner.

In this study private forest was found to have complicated spatial configuration, i.e. more numerous and small patches, of which a considerable area consisted of overmature stands (13.9% of total area). The overmature stands can be expected to contain a considerable amount of structures important for biodiversity, such as dead wood (Madžule et al., 2012a), which can develop in a relatively short period of time (Madžule et al., 2012b). Thus, although more fragmented and influenced by clearcut harvesting, these stands can potentially contribute to biodiversity of the landscape. Thus, this matrix consisting of fragmented small patches might provide a variety of different habitats for generalist species, but lacks undisturbed core habitats, for example large (>10 ha) overmature aspen patches. Nevertheless, small-scale private forests can have particular conservation potential on a landscape scale (Schaich and Plieninger, 2013), particularly as they comprise a large portion of all European forests. If management regulation is identical for all production forests regardless of ownership, it is huge challenge to optimise existing stand patterns for biodiversity conservation in private forests at the landscape level, as shown in a simulation study in Eastern Finland (Kurttila et al., 2002). Moreover, privately-owned forests are subjects to great variety of management goals, thus promoting structural heterogeneity. Owners of large and medium properties often prioritize timber production but for small owners other management goals like recreation, nature conservation and firewood may also be important (Schaich and Plieninger, 2013).

A promising solution to management issues in private forests of Europe is cooperation of small forest owners – one good example is Sweden (Kittredge, 2003). Cooperation of individual owners would enable the optimisation of the management forested landscapes through spatial planning. Optimisation of forest management plans for multiple private owners (*sensu* Kurttila et al., 2001; Jumppanen et al., 2003) shows a potential for more ecologically sound management.

Configuration and composition of forest landscapes are important issues that conventional management plans fail to address (Baskent and Keles, 2005). Since landscape issues are becoming more and more respected within the legal regulations at all levels, the designation and optimisation of forest management plans should consider possible development scenarios of the forest landscapes. Landscape ecological planning (Leitão and Ahern, 2002; Lakovskis, 2011) and modelling of future landscape changes scenarios resulting from change in management need to be carried out specific to ownership groups, thereby providing valuable insight into the future trajectories of state, municipal and private forest landscapes.

4.4. Conclusions and limitations of the study

Our results partially confirmed the proposed hypothesis: the structure of state forest was found to be significantly different from private forest for the majority of tested stand characteristics. However, municipal forest characteristics were found to be significant only for several indices. It can be concluded that in this case forest management explains at least some of analysed structural characteristics.

The conclusions of this study were limited by several factors. Firstly, present configurations of forest regions inevitably reflect soil growth conditions, large-scale forest fragmentation and afforestation in the past. Since we could not avoid this bias completely, we chose regions for analysis as representative and comparable as possible and also included a short review of landscape history to clarify these influences. Nonetheless, such comparisons can provide useful and necessary information about actual structure of forests, representative to specific ownership types. Secondly, the analysed regions were partially adjacent to private or state forests that were not included in this analysis – this means that the chosen boundaries do not necessarily define these regions ecologically as separate landscapes. However this study attempted to explain and interpret the differences of tract internal structures specific to ownership type and to determine the implications for sustainable management.

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Appendix A

Description of pattern metrics utilised in analyses (after McGarigal, 2012).

Metric	Units	Description
Total area (TA)	ha	Total area of the landscape
Number of patches (NP)	Number	Total number of patches (at class or landscape level)
Mean patch area (AREA_MN)	ha	Average area of the patch (at class or landscape level)
Mean patch shape (SHAPE_MN)	–	Measure of patch shape. Average patch perimeter, divided by the square root of patch area, adjusted by a constant to adjust for a square standard (at class or landscape level)
Mean patch proximity (PROX_MN)	–	Measure of patch isolation. Average sum of patch area, divided by the nearest edge-to-edge distance squared between the patch and the focal patch of all patches of the corresponding patch type whose edges are within the specified distance of the focal patch (Gustafson and Parker, 1994) (at class and landscape level)
Mean Euclidean nearest neighbour distance (ENN_MN)	m	Measure of patch isolation. Average distance to the nearest neighbouring patch of the same type, based on shortest edge-to-edge distance (at class or landscape level)
Patch richness (PR)	Number	The number of different patch types present within the landscape boundary (at landscape level)

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