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Harvesting as a factor in the recent forest spatial structure change in Latvia

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Abstract: Spatial and temporal changes in forest landscapes are an important aspect of landscape ecology research, which enables further applications in sustainable forestry planning. The focus of the study is on assessment of structural changes in forest compartments of Taurkalne forest tract study plot (10×10 km), located in southern Latvia. In this study forest harvesting was considered the mayor factor, impacting forest spatial structure today. This is a quantitative study, based on the geostatistical analysis of the land cover maps, derived from orthophotos covering years 1997, 2005 and 2009. The Fragstats software was used to calculate landscape metrics. Orthophoto maps provide high spatial resolution (0.5-1 m) “snapshot” of forest landscape structure and enables investigation of the pattern dynamics at fine scale. Three categorical maps series – land cover types, clear-cuts and planted forests, and forest road networks - were created based on visual deciphering of an orthophoto maps. Six land cover classes, three clear-cut classes and one planted forest class, and three road categories were distinguished. General results show pronounced fragmentation pattern of deciduous and mixed forest compartments. Landscape graininess and structural complexity has increased, but magnitude of changes varies over different forest cover types.

Key words: forest spatial structure, landscape metrics, fragmentation, forest harvesting

Introduction

The spatial structure of forests refers to the relative spatial arrangement of patches and interconnections between them. It represents both spatial (configuration) and non-spatial (composition) characteristics (Baskent, Jordan 1996). Forest landscape spatial structure, as well as its attributes at the level of the stand affects the ecological processes and abundance of forest species (Kurttila 2001).

The habitats are spatially structured at a number of scales, and these patterns interact with an organism perception and behaviour to drive the higher level processes of population dynamics and community structure (Johnson et al., 1992). The habitat patches - the main elements of natural heterogeneity - can be considered as the resources for species existence. According to O’Neill et al. (1998) when the distribution and pattern of resources change then the scale of resource utilization (i.e. the related ecological processes) change.

Anthropogenic actions (mainly timber harvesting and road building) can disrupt the structural integrity of landscapes and is expected to impede or in some cases facilitate ecological flows across the landscape (Gardner et al., 1993) by interfering with critical ecological processes necessary for population persistence and the maintenance of biodiversity and ecosystem health (With 1999). Logging which differs from natural disturbances in severity, frequency and spatial extent often resulted in younger, more fragmented forests, in addition to changing the composition of the landscape tree species (Mladenoff et al., 1993). Forest removal actions also tend to simplify patch shapes (Mladenoff et al., 1993, Reed et al., 1996, Tinker et al., 1998).

A forested landscape is understood to be fragmented when it contains a greater number of forest patches that are smaller and more isolated than those in an undisturbed reference landscape (Wulder et al., 2009). Fragmentation increases the dominance of edge habitat which has diverse environmental effects (Saunders et al., 1991).

All managed forests in Latvia after 2008 experienced sharp increase in annual cutting volumes (VMD, 2010) due to economic crisis. There was also a change in tactics of forestry planning by switching from irregular planning of cuttings to a block cutting method, therefore impacting forest spatial structure. The aim of this study is to evaluate the impact of harvesting and associated actions on forest landscape structure in three time points using quantitative method.

Material and methods

Study plot Daudzese is located in the Taurkalne forest tract, Southern Latvia (fig. 1). Study area dimensions are 10×10 km with a central coordinate 56˚28'40''N; 25˚03'05''E. Forests cover most of the area (83%), considerable amount from them is comprised by wet forests. Scots pine (*Pinus sylvestris L.*), Silver birch (*Betula pendula L.)* and Norway spruce (*Picea abies L.*) are the most common tree species in this area. Daudzese plot is a part of the largest continuous forest tract in Latvia with pronounced signs of harvesting actions.

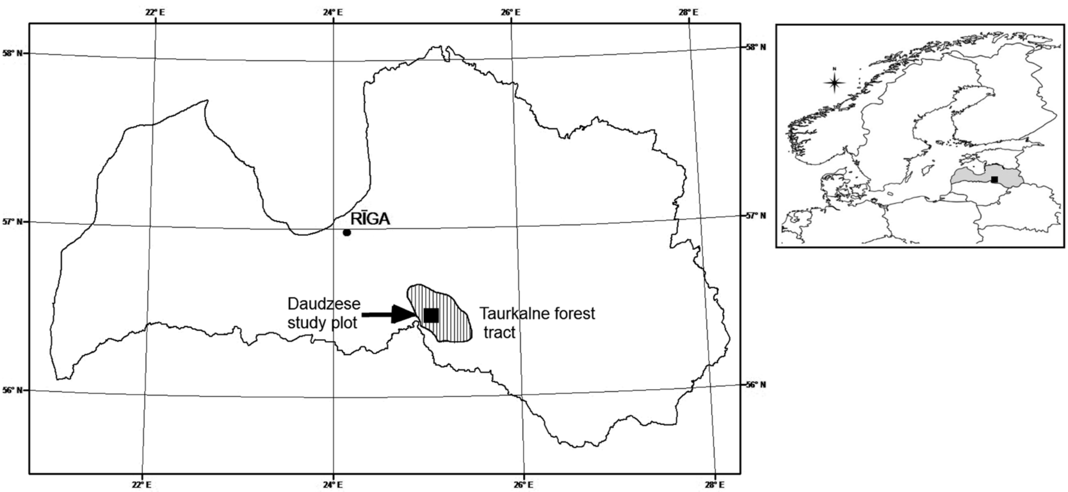

Fig. 1. The location of study plot Daudzese in Taurkalne forest tract.

Orthophoto maps, provided by the Geospatial Information Agency of Latvia (LĢIA) were the main source of information. Used map layers cover three years – 1997, 2005 and 2009 (corresponding to the images). These materials provide the reliable information on land cover in a high resolution. Visible light images (RGB, band 2) were used as a main source and colour-infrared (CIR, band 4) image was used as a supplementary data (only in 2009 image). As a result of visual digitalization in Arc Map 9.3 (ESRI 2006) environment, six land cover classes, three clear-cut and planted forest classes, and three roads categories were distinguished. Forest areas were subdivided in three types, based on land cover types, distinguished by certain ranges of pixel tonal characteristics: coniferous forest (90-115;106-114;98-125), deciduous forest (98-132;138-169;119-171) and mixed forest (76-124;106-159;110-154). Clear cut areas were characterized by pixel value range (139-196;133-203;122-193).

Digitalization resulted to three landscape models (categorical maps), which were analysed, using spatial statistics software Fragstats (McGarigal et al., 2002). Based on literature (Wu et al., 2000, McGarigal 2002, Ohman, Lamas 2005, Tērauds et al., 2008) nine landscape metrics were chosen to quantify landscape structure – CA/PLAND (class area/percentage of landscape), NP (number of patches), ED (edge density), AREA_MN (mean patch area), SHAPE_MN (mean shape index), TCA/CPLAND (total core area/core area percentage of landscape), ENN_MN (mean Euclidean nearest neighbour distance), CWED (contrast-weighted edge density) and MESH (effective mesh size).

The statistical significance levels of differences between metrics characterizing the land cover type structure were calculated using open-source statistical software R (Venables, Smith 2011). Pairwise Wilcoxon test was used to calculate p values (α=95%) for differences between patch-level metrics, from which higher level metrics was derived.

Results

Calculated metrics for land cover type structure showed different trends for land cover types (tab. 1). The most of Daudzese study plot area is covered by forests, which has changed more in composition and spatial distribution of forest types than in total coverage (fig. 2). In 2009 situation coniferous forests covered 22.85%, deciduous forests – 32.62%, mixed forests – 34.99% of total landscape area. Agricultural land area showed slight decrease by 2% due to overgrowing; other land cover types are considered static.

Table 1. Basic metric values for land cover class patterns

	Class area (ha)			Number of patches			Mean patch area (ha)		
	1997	2005	2009	1997	2005	2009	1997	2005	2009
Coniferous	3053.32	2848.56	2285.16	16	18	15	190.83	158.25	152.34
Mixed	3414.76	3322.72	3498.81	25	27	44	136.59	123.06	79.52
Deciduous	2583.85	2886.98	3261.67	21	22	30	123.04	131.23	108.72
Agricultural	343.52	338.68	336.64	10	10	10	34.35	33.87	33.66
Bogs	578.54	578.32	590.93	1	1	1	578.54	578.32	590.93
Waters	25.98	24.72	26.53	11	11	11	2.17	2.25	2.41
	Edge density (m/ha)			Mean shape index			Total core area (ha)		
	1997	2005	2009	1997	2005	2009	1997	2005	2009
Coniferous	15.76	16.50	15.33	1.96	1.95	2.14	2617.18	2400.29	1854.41
Mixed	22.66	23.77	29.52	2.05	2.03	1.99	2936.74	2837.59	2913.43
Deciduous	18.48	19.80	28.39	1.95	1.93	2.15	2055.00	2324.86	2507.17
Agricultural	3.95	3.31	3.34	1.86	1.64	1.66	144.31	164.56	161.45
Bogs	2.18	2.25	2.19	2.57	2.64	2.57	535.58	535.06	547.93
Waters	0.66	0.61	0.66	1.33	1.34	1.35	16.24	15.69	16.43
	Mean Euclidean nearest neighbour distance (m)			Contrast-weighted edge density (m/ha)			Effective mesh size (ha)		
	1997	2005	2009	1997	2005	2009	1997	2005	2009
Coniferous	311.97	350.33	425.19	9.62	9.90	9.28	119.66	102.58	80.95
Mixed	181.69	234.69	145.76	10.00	10.32	11.64	121.36	117.25	99.31
Deciduous	262.15	224.86	173.31	8.99	9.62	12.86	107.25	139.55	125.71
Agricultural	528.31	571.22	606.78	3.95	3.31	3.34	1.88	1.91	1.72
Bogs	-	-	-	1.75	1.80	1.75	33.47	33.45	34.92
Waters	604.16	667.11	548.05	0.58	0.53	0.58	0.02	0.02	0.02

Statistically significant differences between 1997 and 2009 situations were calculated only for deciduous and mixed forest classes (tab. 2). The most significant changes are indicated by mean Euclidean nearest neighbour distance (ENN_MN), mean patch area (AREA_MN) and total core area (TCA) values for deciduous and mixed forest classes. From harvesting patterns most significant changes experienced clear-cut patterns with no tree cover.

As the emphasis of this study was put on forest landscape, it further focuses on three forest types. Coniferous forests showed significant decrease in class area (30.53 to 22.85% of total landscape area) with a sharp decline after 2005. Deciduous forests experienced stable area increase (25.84 to 32.62% of total landscape area). Mean patch area (AREA_MN) has decreased for all forest types - at most for mixed and coniferous forests (by 41.78% and 20.17% respectively). In contrast to other classes, coniferous forests are indicated by a major area loss before 2005. Mixed forest pattern showed the smallest patches (tab. 1). Forest patch shape indicated the tendency of complication, with the exception of mixed forests which showed small decline in shape index values. Patch core areas showed increase for deciduous forests only.

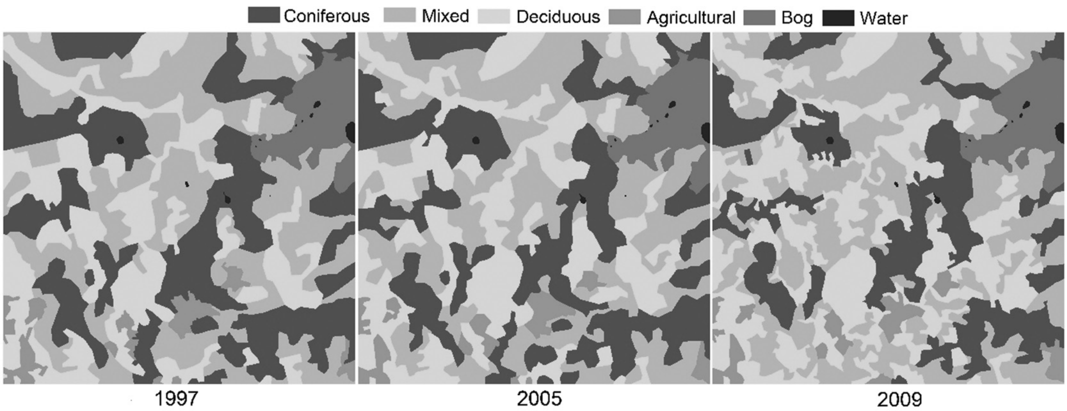

Fig. 2. The structure of land cover types in years 1997, 2005 and 2009 in study plot Daudzese

In landscape level the most pronounced changes were related to landscape graininess. Decrease of patch and core areas and decrease of patch proximity between years 1997 and 2009 showed pronounced coniferous forest cover loss. Furthermore, the increase of patch number (totally by 30.59%) and patch and edge density indicated fragmentation process (tab. 3), more specifically coniferous forest pattern is fragmented by mixed and deciduous forest patches.

Table 2. Statistical significance p values (α=95%) for changes in metric values between years 1997 and 2009

Land cover class	Edge density (ED)	Mean patch area (AREA_MN)	Mean shape index (SHAPE_MN)	Total core area (TCA)	Mean Euclidean nearest neighbour distance (ENN_MN)
Coniferous	0.800	0.450	0.860	0.470	0.280
Mixed	0.073	*0.026	0.460	*0.021	*0.041
Deciduous	0.830	0.480	0.770	0.490	*0.004
Clear-cut & planted forest class	Edge density (ED)	Mean patch area (AREA_MN)	-	-	-
No tree cover	*7.9e-05	*1.1e-07	-	-	-
Partial cover	0.900	0.490	-	-	-
Full cover	0.390	0.670	-	-	-
Planted	0.890	0.690	-	-	-

Edge density (ED) metric shows difference between forest classes – while coniferous patch density is almost static, deciduous and mixed forest patterns create more edge than in reference situation (by 53.67 and 30.31% respectively). Overall (landscape level) edge density shows small increase (tab. 1). Patch shape has become more complex, increasing landscape level mean shape index (SHAPE_MN) from 1.89 to 1.97 in 2009 situation. The patch isolation can be measured with mean Euclidean nearest neighbour distance (ENN_MN) metric. This indicator shows the decline in deciduous (33.89%) and mixed forest (19.78%) patch isolation, but coniferous forest patches has become more isolated (-36.29%). Edge contrast values (CWED) indicate the most pronounced increase for deciduous forest class. Landscape metrics include subdivision measures like effective mesh size (MESH) – the size of the patch if the area of particular class is divided in patches of identical size according to cumulative patch area distribution. This metric shows increase of area subdivision for deciduous forest class due to larger number of patches differing in size.

Table 3. Changes in landscape level metric values between years 1997 and 2009

Metric	1997	2005	2009
Number of patches (NP)	85	89	111
Patch density (PD)	0.85	0.89	1.11
Edge density (ED)	31.84	33.12	39.71
Mean patch area (AREA_MN)	117.65	112.36	90.09
Mean shape index (SHAPE_MN)	1.89	1.87	1.97
Total core area (TCA)	8305.04	8278.05	8000.81
Mean Euclidean distance (ENN_MN)	328.24	348.18	273.52
Contrast-weighted edge density (CWED)	17.44	17.74	19.72
Effective mesh size (MESH)	383.64	394.75	342.64

Basic quantitative indices of fixed harvesting actions (tab. 4) show sharp decline in area (53.93%) of clear-cuts with no tree cover, especially after year 2005. Partially and fully overgrown clear-cuts are characterized by area increase by 58.52 and 51.08% respectively in contrast to reference landscape. Planted forests show significant increase in area, mostly before 2005. Harvesting pattern change is evidenced by patch number and mean area increase of more or less overgrown clear-cuts. The mean area of clear-cuts of all types has become smaller.
The forest road network analysis showed less pronounced changes in forest road structure (fig. 3). The length of second category road has increased the most (by 55.02%) while dirt road remained almost unchanged. The first category road length has increased only by few kilometres. The spatial analysis of road network density showed minimal changes between three landscapes.

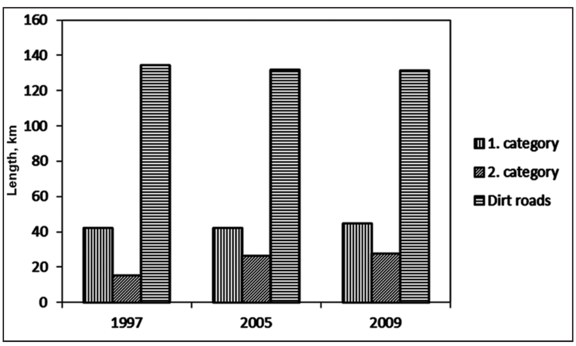

Fig. 3. Road network length by category

Table 4. Basic metric values for clear-cut and planted forest classes

	Class area (ha)			Number of patches			Mean patch area (ha)		
Tree cover	1997	2005	2009	1997	2005	2009	1997	2005	2009
No	1045.20	839.61	481.56	242	261	207	4.32	3.22	2.33
Partial	432.07	610.39	684.90	104	153	169	4.15	3.99	4.05
Full	264.20	254.65	399.15	63	67	109	4.19	3.80	3.66
Planted	138.92	280.40	295.51	24	44	41	5.79	6.37	7.21

Discussion

Landscape concept is nowadays used to emphasize in some level holistic approach to real self-regulating natural systems (Naveh 2000). Since the forest management and harvesting actions dominate forest structure today, it is important to evaluate the landscape structure and its change trends. Sustainable forest management, which is a high priority in many countries, must be based on concrete and precise indicators, characterizing the complex natural environment.

Observed changes in class and landscape levels are considered ambiguous. The analysed forest landscapes have experienced changes both in composition and configuration. The basic properties of landscape pattern – class area, number of patches and mean patch area indicated considerable area loss for coniferous forests, which were partially replaced by a younger deciduous forest patches in clear-cut areas. Mixed forests showed dynamic in aspects of patch number, mean area, isolation and subdivision. Forest harvesting activity in Latvia intensified after 2008 (VMD 2010), but clear-cut areas had increased minimally and was dominated by overgrowing processes.

The basic indicators for detecting fragmentation process is patch number, patch isolation, and patch area (if area loss included in the definition of fragmentation process) (Fahrig 2003) as well as amount of core areas and edge density. Calculated metrics for forest cover types indicate moderate fragmentation of mixed and deciduous forests and pronounced area loss of coniferous forests. Total core area and proportion (TCA/CPLAND) detected the same trends as area metrics – decrease in coniferous forest class, increase in deciduous class and no change in mixed forests. This relation can be explained by small changes in overall patch shape index values – more specific the simplification of patch shapes due to clear-cutting (Mladenoff et al., 1993).

The assumption that change in patterns of harvesting actions have an impact on forest structure change gained statistical significance only in aspects of patch isolation, mean patch size and core area size for the most dynamic and expansive forest cover classes – deciduous and mixed. Road impact on forest cover structure change was considered irrelevant. The most of landscape level changes in forest structure can be explained with overgrowing of spatially unevenly distributed clear-cuts in various rates. Clear-cutting and road-building appear to be associated with a predictable suite of changes, including a decrease in core area, an increase in edge density, and fundamental changes in the size and shape of landscape patches (Tinker et al., 1998). This fully agrees with the results of Daudzese forest spatial structure analysis.

Recent publication (Wulder et al., 2009) mentions that, forests with longer life span (particularly, coniferous), are more associated with fragmentation and area loss. This is visible in pronounced area loss of coniferous forest class. Study results agree with Wimberly & Ohmann (2004) in sense of the area increase and composition change of deciduous and mixed forests. They observed increases in broadleaf and sparse forests at the expense of large conifer forests in response to extractive forest management. Without any doubt Daudzese study plot forest pattern includes the legacy of past harvesting actions, which was not included in the analysis due to the lack of appropriate data.

This study was conducted focusing on changes in class and landscape levels, so it is no yet clear how changes were expressed at the level of individual patches.

Conclusions

To sum up, the most pronounced compositional changes in Daudzese study plot has occurred in coniferous and deciduous forest patterns, while mixed forest class showed changes in configuration. Most of the areas previously covered by conifers has been cut down and replaced by younger deciduous forests in natural succession process, what is typical situation for managed forests. Forest management actions, especially harvesting has a significant impact on forest pattern in aspects of patch isolation and amount of patch core areas. The observed changes in landscape structure are prerequisites to a wider change interpretation in context of forest biological diversity.

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