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LANDSCAPE ECOLOGICAL ANALYSIS OF TAURKALNE FOREST TRACT FRAGMENTATION

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Analysing spatial and temporal changes in forest landscapes is an important aspect of landscape ecology, 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 plantations, and forest road networks - were created based on visual deciphering of an orthophoto maps. Six land cover classes, three clear-cut classes, 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

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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).

The aim of this study is to evaluate the impact of harvesting and associated actions on forest landscape-ecological structure in three situations using quantitative methods.

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. Area is covered mostly with forest (83%), significant amount from them is comprised by wet forests - therefore it can be defined as a forest landscape. Scots pine (*Pinus sylvestris*), Silver birch (*Betula pendula*) and Norway spruce (*Picea abies*) 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.

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. These materials provide the reliable information on land cover in a high resolution. Visible light and near-infrared images were used. As a result of visual deciphering in Arc Map 9.3 (ESRI 2006) environment, six land cover classes, three clear-cut and forest plantation classes, and three road categories were extracted from all images. Forest areas were subdivided in three types (coniferous, deciduous and mixed forest), based on land cover types.

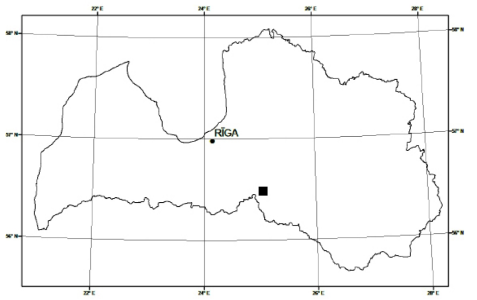

Fig. 1. The location of study plot Daudzese.

Deciphering resulted to three landscape model (categorical map) series, which were analysed, using spatial statistics software Fragstats (McGarigal et al. 2002). Based on literature (Wu et al. 2000, McGarigal 2002; Ohman & Lamas 2005; Terauds 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 level of differences between metrics characterizing the land cover type structure was 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, which was the base for calculation of higher level metrics.

RESULTS

Calculated metrics for land cover type structure

Table 1. 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 & plantation 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	-	-	-
Plantation	0.890	0.690	-	-	-

* significant changes marked with an asterisk

showed different trends for land cover types (Table 2). 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. 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.

Statistically significant differences (Table 1) between 1997 and 2009 situations were calculated only for deciduous and mixed forest classes. 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-cuts 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 increase of area (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 forests showed the smallest patches (Table 2). 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.

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.

Edge density (ED) metric shows difference between forest classes – while coniferous patch density is almost static, deciduous and mixed forests create more edge than in reference situation (by 53.67 and 30.31% respectively). Overall (landscape level) edge density shows small in-

Table 2. Basic metric values for extracted land cover classes

	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

crease (Table 2). 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.

Basic quantitative indices of fixed harvesting actions (Table 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. Forest plantations 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.

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

	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

Table 4.Basic metric values for extracted clear-cut and plantation 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
Plantation	138.92	280.40	295.51	24	44	41	5.79	6.37	7.21

The forest road network analysis (Fig. 2) showed less pronounced changes in forest road structure. 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.

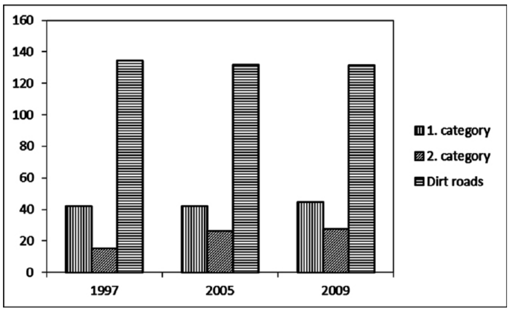

Fig. 2. Road network length (km) by category.

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 – 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. Outside the basic indicators, more specific quantification of the forest structure must include characterization of patch shape, degree of isolation and proximity, core area size and proportion in landscape, indicators of edge density and subdivision.

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.

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. After Tinker et al. (1998) "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". This fully agrees with the results of Daudzese forest spatial structure analysis.

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 structure 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 classes, 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 structure 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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