LANDSCAPE ECOLOGICAL STRUCTURE IN THE EASTERN PART OF THE NORTH VIDZEME BIOSPHERE RESERVE, LATVIA

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Latvia is a country where the forest area has increased and habitat fragmentation has reversed compared with many other European countries. In order to examine the effect of this expansion on biodiversity, vegetation maps dating from 2002 and the years 1930–1936 were used for comparative landscape structure analyses while archive materials from forest plans, and data from the national forest management database were used for land use analysis. Four landscape ecoregions in the eastern side of the North Vidzeme Biosphere Reserve were selected for analysis. Landscape structure indicators derived from landscape ecology were used for the ecological assessment of land use changes. The total number of forest patches had decreased over the study period, but mean patch size had increased for all types of landscape element. This general change was found to vary between different landscape units in the study area. The biggest change in the area of forest patches occurred in the Rūjiņa drumlin field, where the amount of forest patches decreased least and forest area increased the most. This study showed that the internal structure of the forest matrix changed substantially. This finding has implications for biodiversity protection if this trend of land use change continues.

Key words: landscape metrics, fragmentation, forest, gap analysis, Latvia.

INTRODUCTION

As a result of decreasing forest areas in many countries all over the world, one of the dominating themes of ecological landscape research is the reduction and fragmentation of forest areas, leading to many ecological problems at meta-population levels (Hanski, 1998; Jordan *et al.*, 2003). The reverse process—an increase of forest cover and a reduction in fragmentation—is being relatively less researched, yet it may have great significance for many populations which have been used to mosaic landscapes, for example (Waldhardt *et al.*, 2004; Simmering *et al.*, 2006).

The forest fragmentation process involves changes in landscape composition, structure, and function over a range of scales including habitat loss and fragmentation and increasing isolation of remaining forest patches. Habitat fragmentation is an issue of primary concern in conservation biology (Franklin *et al.*, 2002), because changes in landscape ecological structure influence biological diversity in the area (Freeman *et al.*, 2003).

In Latvia during the period between 1930 and 2002 the forest area has on average more than doubled, with an increase from 20% to 46% land cover and reaching as high as 54% in some areas. Studies of landscape dynamics show that if they continue into the future these processes can result in an increase in landscape diversity in some places, while else-

where landscape homogenisation has occurred (Nikodemus *et al.*, 2005). This process, while resulting in more forest habitat, has also brought a reduction of the area of natural grassland along with the local extinction of the typical associated animal and plant species. In Latvia, for example, alterations in land use have significantly reduced the corn-crake *Crex crex* population as compared to 1940 (Keišs, 2005).

Colonisation of agricultural lands by forest has altered the configuration of fields, isolated forest patches and larger tracts as well as the plant species and the age structure of the forest. Initially new forest stands show an increased number of plant species that reduce dramatically around the age of 40, at the time of strong light competition by the trees (the so-called stem exclusion stage (Oliver and Larson, 1990) and which increases again when forest stands reach about 80 years (Gutko *et al.*, 2001). Silvicultural activities in the older forests, such as timber harvest by clear cutting and the colonisation of former farmlands have left an impact upon the structure of forest species and age structure of forest stands. Intensive forestry leads to a decrease in the amounts of dead wood, large diameter trees, diversity of structures, smaller size of intact undisturbed stands, all of which decrease biological diversity (Angelstam *et al.*, 2006). Natural disturbances (fires, wind) are important factors for biological diversity in natural forests, and greater at-

tention is being focused in research on natural disturbance dynamics. Disturbances in forests vary in size, may be biotic or abiotic, and spatial structure varies over the landscape. It is currently acknowledged that boreal forest disturbance and successional features may vary substantially according to the characteristics of the dominant tree species, local site conditions, landscape and regional climate. Investigation of biological diversity should consider different spatial levels—tree, stand, landscape, region (Angelstam and Kuuluvainen, 2004). In this paper we consider the landscape level of the North Vidzeme Biosphere Reserve.

In many cases, the pattern of landscape-level diversity determines the choice and application of landscape metrics. Landscape metrics are widely used in ecological and geographical studies. They provide valuable understanding about the characteristics of complex landscape structures. For example, grain size and spatial extent have a significant effect on class and landscape level metrics (Wu, 2004). Patterns of bird species composition were found to be related to several landscape composition variables (such as proportions of forest types), but not to configuration variables (such as interior habitat, amount of edge) in a study by Drapeau *et al.* (2000).

The aim of this study described here was to explore the landscape structure of the eastern side of the North Vidzeme Biosphere Reserve in northern Latvia by applying selected landscape metrics to two time periods, the 1930s and 2002 in order to compare the landscape and to make some observations of the effect of the changes that have taken place. This provides an opportunity to evaluate the potential effects of reversing fragmentation by natural forest colonisation processes.

MATERIALS AND METHODS

Research area. The North Vidzeme Biosphere Reserve (NVBR) is the largest protected nature territory in Latvia with a total area of 4576 km². The NVBR represents a complex of several landscape types characterised by extensive forests, forest/farmland mosaic landscapes on moraine, agricultural landscapes on drumlins, kettle lakes, rivers, wetlands, raised bogs, semi-natural grasslands and coastal meadows. Forests cover more than 45% of the Biosphere Reserve. The study area lies within the NVBR and covers 94.5 km². It is located in the northern part of Latvia and occupies the eastern side of the North Vidzeme Biosphere Reserve (Fig. 1). The study area covers four landscape types—the Burtnieku drumlin field, the Seda depression, the Rūjiena drumlin field and the Ērgeme hilly area. This was selected because it was part of a study under an United Nations Development Programme/Global Environmental Foundation (UNDP/GEF) funded biodiversity protection project called “Biodiversity protection in the North Vidzeme Biosphere Reserve” (Anonymous, 2007).

Data assembly and analysis. Several available data bases and archive materials were used to prepare maps showing the changes in landscape structure. Topographic maps dating from 2002 were used for the most recent reference period. These were obtained from the Latvian National Mapping Agency in digital form, resolved to a scale of 1 : 10 000 and 1 : 50 000 showing the main land use classes of forest, wetland, open water and other. For the historical baseline, maps variously produced in the period 1930?1936 were used. This was supplemented by forest stand maps and data from the forest management data base, which records more detail on stand composition, species and ages than is shown on the basic maps.

Fig. 1. Location of the study area.

In order to form the required data base for the analysis, the topographical and forest stand maps were scanned, geo-referenced and then digitised. The software used for all the mapping and subsequent analysis was ArcGIS 9.1 Desktop, ArcGIS 9.1 ArcInfo Workstation, ArcView 3.2, vLATE 1.1 and Fragstats for ArcView.

The variables to be analysed were taken from those suggested in the literature (Mc Garigal. and Marks, 1995; Fitzsimmons, 2003; Wu, 2004) and also known to be capable of analysis using the Fragstats for ArcView software, which contains a number of different spatial analysis possibilities and associated statistical analysis. A total of ten variables describing landscape structure were derived from the land use maps and used in the analysis. These variables included: number of patches (NP), total area (CA), edge density (ED), total edge (TE), mean patch edge (MPE), mean shape index (MSI), mean perimeter-area ratio (MPAR), mean fractal dimension (MFRAC), mean patch size (MPS), patch size standard deviation (PSSD), Shannon's Diversity index and Shannon's Evenness index. These give comparative measures for different maps as long as the map bases, spatial resolution and digitising point intervals are the same for each map used for comparison.

The main natural disturbance scheme for boreal forest (Angelstam and Kuuluvainen, 2004) was used in the natural disturbance (GAP) analysis of forest structures. According to this natural disturbance model boreal forests are classified into three classes:

- a) cohort forests (low intensive disturbance by fire and windthrow, resulting in multi-age stands);
- b) succession forests (large-scale external disturbance such as severe high intensity fire and windthrow and external disturbance caused by ageing insects, fungal, disease, beaver, resulting in the formation of a new forest stand in place of the previous one);
- c) forests with gap-phase dynamics (no catastrophic disturbance, regeneration in small gaps opened by the collapse of dead trees leading to a multi-age forest structure, fine-grain).

Forest inventory data on stand site type in 1930 and 2002 were used classify stands by dynamics type according to Angelstam *et al.* (2006).

RESULTS

Changes of the overall landscape pattern between 1930 and 2002. In the study area, between 1930 and 2002, the proportion of forest increased from 31.6% to 48.6% (Table 1, Fig. 2). Most of the changes occurred in the Rūjiena drumlin field, where the forest areas increased by 2.9 times. As a result of these changes, using accepted terms for landscape element descriptions derived from Forman and Godron (1986) a farmland matrix prevails in the Burtnieku and Rūjiena drumlin field where forest patches take up, respectively, 41.4% and 21.9% of the area. In the Seda depression, however, the position is reversed and a forest matrix prevails where farmland patches take up 18.6% of the area. During the study period, the Ērgeme hilly area, which was a farmland matrix with forest patches (41.4%) changed to a forest matrix with farmland patches (37.7%). Thus, the main habitat composition of the landscape changed and it may be assumed that landscape functioning (in landscape ecological terminology) also changed, for example the rate of snowmelt, run off, and habitat suitability for forest species compared with open ground species etc.

Changes of the landscape structure between 1930 and 2002. The ecological assessment of the character of the land use changes that occurred as described above was carried out using landscape structure indicators (Table 2). This also revealed some significant metrics. For example, while the total number of forest patches decreased, the mean size of patches increased in all types of the landscape. Consequently, the edge length of the forest patches has also increased as has the interior habitat proportion, while the area affected by the edge zone has decreased. The biggest changes in the area of the forest patches occurred in the Rūjiena drumlin field, where the number of forest patches decreased the least and the forest area increased most of all, increasing the area of interior habitat considerably.

The mean shape index for farmlands has changed in particular in the Burtnieku drumlin field and Seda depression, where the variety of the patch shapes has decreased as a result of farmland overgrowing with forest. In the Seda depression and Ērgeme hilly area the variety of the forest patch shapes has increased. During the 1930s, farmland in the Ērgeme hilly area and Rūjiena drumlin field had the most indented perimeter shape, but by 2002, this feature became more characteristic of farmlands in the Seda depression. In total the mean perimeter/area ratio (MPAR) be-

Table 1

LAND USE TYPE IN NORTHERN LATVIA IN 1930 AND 2002

Land use type	Total study area, %		Ērgeme hilly area, %		Rūjiena drumlin field, %		Seda depression, %		Burtnieku drumlin field, %	
	1930	2002	1930	2002	1930	2002	1930	2002	1930	2002
Forest	31.6	48.6	41.4	58.8	7.4	21.9	50.3	72.3	27.5	41.4
Farmland	65.0	46.2	55.8	37.7	89.3	73.2	44.7	18.6	70.2	55.2
Other (built-up area, water swamp, infrastructure)	3.4	5.2	2.8	3.5	3.3	4.9	5.0	9.1	2.3	3.4

Fig. 2. Land use structure of different landscapes in 1930 (a) and in 2002 (b).

tween the different landscape types has been smoothed out. This has also occurred with the mean shape index.

Evaluating the above mentioned processes from the ecological point of view, it can be concluded that the structure of the landscape types has increased in similarity between 1930 and 2002. In general, it is positive that the border length of forest patch and the variety of patch shapes have increased in previously intensively used farmlands.

Internal structure analysis of forest tract. On the basis of tree species composition and age class distribution, including the oldest classes, Angelstam and Kuuluvainen (2004) defined the landscape—level stand age structure of natural boreal forests (Fig. 3a). The analysis of forest stand data from 1930 showed that in the Seda depression (Fig. 4) different aged stands were represented within forests stands (Fig. 3b), of which succession dynamics dominated. Comparison of the stand structure in 1930 with the theoretical structures for natural succession forests shows a pattern be-

Table 2

RESULTS OF VECTOR-BASED LANDSCAPE ANALYSIS IN THE ALL STUDIED LANDSCAPE TYPES

Landscape structure indicators	Ērgeme hilly area								
	Landscape level			class level					
				farmland			forest area		
	1930	2002	changes	1930	2002	changes	1930	2002	changes
NP	283	325	42	101	201	100	182	124	-58
CA, ha	23471.6	23301.1	-170.4	13480.7	9099.9	-4380.8	9990.9	14201.3	4210.4
MPS, ha				133.5	45.3	-88.2	54.9	114.5	59.6
PSSD, ha				362.3	131.6	-230.7	246.4	463.4	217.0
ED, km/ha	0.054	0.064	0.011						
TE, km	1263.3	1502.278	239.0	743.6	769.9	26.3	519.7	732.4	212.7
MPE, km	4.463	4.622	0.2	7.4	3.8	-3.5	2.9	5.9	3.1
MSI	1.62	1.712	0.092	2.067	1.742	-0.325	1.372	1.663	0.291
MPAR	0.026	0.026	0.000	0.034	0.028	-0.006	0.022	0.023	0.001
MFRAC	1.297	1.307	0.010	1.329	1.314	-0.015	1.279	1.296	0.017
Shannon's Diversity	0.682	0.669	-0.013						
Shannon's Evenness	0.984	0.965	-0.019						

Table 2 – continued

Landscape structure indicators	Rūjiena drumlin field								
	landscape level			class level					
				farmland			forest area		
	1930	2002	changes	1930	2002	changes	1930	2002	changes
NP	248	278	30	54	97	43.0	194	181	–13
CA, ha	15699.4	15447.3	–252.1	14499.6	11887.3	–2612.3	1199.8	3560.0	2360.2
MPS, ha				268.5	122.5	–146.0	6.2	19.7	13.5
PSSD, ha				618.6	278.7	–339.9	11.5	55.7	44.2
ED, km/ha	0.047	0.068	0.022						
TE, km	731.0	1054.0	323.0	544.9	695.1	150.2	186.1	358.9	172.8
MPE, km	2.9	3.8	0.8	10.1	7.2	–2.9	1.0	2.0	1.0
MSI	1.452	1.627	0.175	2.205	1.931	–0.274	1.242	1.463	0.221
MPAR	0.03	0.028	–0.002	0.036	0.029	–0.007	0.029	0.027	–0.002
MFRACT	1.299	1.307	0.008	1.343	1.32	–0.023	1.287	1.301	0.014
Shannon's Diversity	0.27	0.54	–0.270						
Shannon's Evenness	0.389	0.779	–0.218						

Landscape structure indicators	Seda depression								
	landscape level			class level					
				farmland			forest area		
	1930	2002	changes	1930	2002	changes	1930	2002	changes
NP	231	274	43	131	212	81	100	62	–38
CA (ha)	16772.5	15980.6	–792.0	7887.7	3267.2	–4620.5	8884.8	12713.4	3828.6
MPS (ha)				60.2	15.4	–44.8	88.9	205.1	116.2
PSSD (ha)				146.0	59.0	–87.0	185.5	505.4	319.9
ED (km/ha)	0.070	0.062	–0.008						
TE (km)	1089.6	990.7	–98.9	661.0	447.4	–213.7	428.6	543.3	114.7
MPE (km)	4.7	3.6	–1.1	5.0	2.1	–2.9	4.3	8.8	4.5
MSI	1.849	1.71	–0.139	2.095	1.675	–0.420	1.528	1.831	0.303
MPAR	0.025	0.029	0.004	0.03	0.031	0.001	0.018	0.024	0.006
MFRACT	1.312	1.32	0.008	1.339	1.324	–0.015	1.278	1.304	0.026
Shannon's Diversity	0.691	0.507	–0.184						
Shannon's Evenness	0.997	0.731	–0.253						

Landscape structure indicators	Burtņieku drumlin field								
	landscape level			class level					
				farmland			forest area		
	1930	2002	changes	1930	2002	changes	1930	2002	changes
NP	456	512	56	117	259	142	339	253	–86
CA (ha)	32905.8	32800.8	–105.0	23650.1	18741.6	–4908.5	9255.7	14059.2	4803.5
MPS (ha)				202.2	72.4	–129.8	27.3	55.6	28.3
PSSD (ha)				581.4	201.1	–380.3	66.0	238.8	172.8
ED (km/ha)	0.064	0.072	0.008						
TE (km)	2092.0	2346.1	254.1	1298.1	1315.1	17.0	794.0	1031.0	237.0
MPE (km)	4.6	4.6	0.0	11.094	5.077	–6.0	2.341	4.074	1.7
MSI	1.664	1.729	0.065	2.235	1.778	–0.457	1.466	1.679	0.213
MPAR	0.024	0.026	0.002	0.031	0.024	–0.007	0.022	0.027	0.005
MFRACT	1.297	1.309	0.012	1.322	1.309	–0.013	1.288	1.309	0.021
Shannon's Diversity	0.594	0.683	–0.089						
Shannon's Evenness	0.857	0.988	–0.128						

NP, number of patches, CA, total area, MPS, mean patch size, PSSD, patch size standard deviation, ED, edge density, TE, total edge, MPE, mean patch edge, MSI, mean shape index, MPAR, mean perimeter-area ratio, MFRACT, mean fractal dimension.

tween the negative exponential and Weibull function curves (Fig. 3a, b). This suggests that the landscape-level stand structure in 1930 was close to the natural distribution required for sustainable development. Dominant age of cohort forests is up to 90 years, and few forests are over 120 years. Gap dynamic forests are mostly 40–70 years of age, and old forests are missing.

In 2002, in state forests (Fig. 3), forest stands of age 30–100 years dominate. Thus, since 1930, the number of stands up to 30 years old has decreased, while the coverage of stands over 70 years has increased. While this is positive from a biological diversity perspective taking into account the natural age distribution of the disturbance dynamic types

Fig. 3. Age distributions for the three disturbance regimes in the Seda depression, NVBR:

- a) Weibull distribution corresponds to different theoretical stand age distributions in a naturally dynamic landscape driven by stand-replacing disturbance (by Johnson, 1992; Angelstam and Kuuluvainen, 2004).
- b) In state-owned forest territory of forest tract in 1930.
- c) In state-owned forest territory of forest tract in 2002.
- d) In state- and privately owned forest territory of forest tract in 2002.

(Fig. 1), the insufficiency of young stands should be considered.

Fig. 4. Location of the analysed forest area.

When private forests are included in the analysis (Fig. 4), the proportion of old stands decreases, but as the contribution of private forests is low, the overall distribution is little affected.

DISCUSSION

Since 1930, a significant decrease of farmland has been observed in the eastern part of the NVBR, similarly as in the rest of Latvia and also in many other Central and Eastern European countries (Pietrzak, 2002). The process of forest colonisation was rather more intense in areas with an uneven terrain and marginal in areas around major centres. The intensively farmed lands of the early 20th century have today notably increased the number of forest patches and also their total area, resulting in an increased number of ecotones and total border length—a precondition essential for an increased biodiversity in the area (Forman and Gordon, 1986). The new forest patches in the former agricultural areas have stimulated their fragmentation, which should be regarded as positive from the point of view of the biodiversity. Shannon's Diversity index has increased in the agricultural land matrix in the Rūjiena drumlin field, which had the most homogeneous land cover in 1930. Shannon's Diversity index for the Burtņieku drumlin field increased

relatively slightly, because already in 1930 there was a specific landscape structure where agricultural lands covered drumlins, but forests and shrubs were concentrated in the lowlands between. The overgrowing of farmlands within the larger forest tracts has decreased the fragmentation, which should be regarded as negative from the point of view of biodiversity. The above mentioned tendency is characteristic of the Seda depression, where Shannon's Diversity index has decreased.

A unique situation has developed in the Ērgeme hilly area (Table 2), where Shannon's Diversity index does not show a significant increase of landscape diversity in spite of a significant increase of forest patches. It can be explained by the fact that the patches of land cover have kept a similarity pattern as a result of the changes, but land cover of patches and the proportion between agricultural lands and forests has changed substantially, leading to a different scale but still showing the same Shannon's index. This example shows that Shannon's Diversity index does not always precisely demonstrate the essence of the changes of landscape multifunctionality. This is one of the limitations of landscape metrics which should be interpreted with care.

As a result of the landscape changes, preconditions are created for an increase of biological diversity at the landscape level, while certain landscape patch homogenization processes are being observed at the level of the ecoregion. Forest ecoregion analysis showed that the internal structure of the forest matrix has changed substantially. In 1930, very old pine and spruce stands were lacking, while at present in the state-owned forests a certain disproportion can also be observed, where there is a gap in the proportion of young forest stands in the age-distribution curves and a sufficient quantity of mid age stands.

Generally, at landscape level the age structure of state owned forests does not correspond to the natural age structure of forest ecosystems (Angelstam and Kuuluvainen, 2004).

In conclusion, this study has attempted to apply landscape metrics to analyse the changes in land cover between 1930 and 2002. In one case, the overgrown farmlands increased the landscape fragmentation and in another decreased the landscape fragmentation. From the landscape ecology point of view, process of the overgrowing of farmlands in the eastern part of the NVBR can not be assessed unequivocally: rather, the assessment of these processes should be undertaken according to ecological regions. Landscape metrics can only demonstrate what can be measured depending on the data resolution. They are not scale dependent, so that comparisons must be made on the basis of maps of the same scale or resolution. Shannon's Diversity Index in particular is capable of showing the same result for different landscapes where the general pattern is the same even if the scale is different. Within the forest stands it is difficult to find areas that correspond to the ideal models for Boreal forests. This is not surprising, since the forests have been managed for a long time and the rate of recolonisation of

forest has varied over time, leading to a far from normal forest structure. The land use changes are generally good for biodiversity, though more detailed analysis of the habitat suitability for particular species and ecological functions is needed to test this general assertion.

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AINAVU STRUKTŪRAS IZMAIŅU ANALĪZE ZIEMEĻVIDZEMES BIOSFĒRAS REZERVĀTĀ LATVIJĀ

Rakstā tiek analizētas ainavu struktūras izmaiņas Ziemeļvidzemes biosfēras rezervātā laika posmā no 1930.–1936. gada līdz 2002. gadam un to ietekme uz ainavas fragmentāciju un mežaudžu ekoloģisko struktūru. Analīzei izmantotas topogrāfiskās kartes un arhīvos esošie mežaudžu plāni, kā arī Valsts meža dienesta meža datu bāze. Analīze veikta četros ainavu ekoreģionos. Zemes lietošanas veidu izmaiņu novērtēšanai izmantoti ainavu ekoloģijā tradicionāli lietotie ainavas struktūras indikatori (plankumu skaits, vidējais malas blīvums u. c.). Pētītajā laika posmā, apvienojoties vairākiem meža puduriem, kopējais meža plankumu skaits ir samazinājies, bet vidējais plankumu izmērs minētajiem ainavas elementiem ir pieaudzis. Šīs kopējās izmaiņas dažādās ainavu vienībās pētītajā teritorijā ir notikušas ar atšķirīgu intensitāti. Lielākās izmaiņas meža plankumu platībās ir notikušas Rūjienas drumlinu laukā, kurā meža plankumu skaits ir samazinājies, bet to platība ir ievērojami pieaugusi. Pētījums parāda, ka meža matricas iekšējā struktūra ir būtiski mainījusies. Iegūtie dati ir svarīgi bioloģiskās daudzveidības aizsardzības plānošanai, kurā būtu jāņem vērā rakstā aplūkotās zemes lietošanas veidu izmaiņas.