Multi-scale Analysis of Forest Fragmentation in Lithuania

ANDRIUS KUČAS[1]*, GIEDRIUS TRAKIMAS [2], LINAS BALČIAUSKAS[1] AND GEDIMINAS VAITKUS[1]

[1*] *Nature Research Centre , Akademijos 2, LT-08412, Lithuania; andrius@ekoi.lt, phone: +370 613 25360*

[2] *Centre for Ecology and Environmental Research, Vilnius University, M.K. Čiurlionio 21/27, LT-03101, Vilnius, Lithuania*

Kučas, A., Trakimas, G., Balčiauskas, L. and Vaitkus, G. 2011. Multi-scale Analysis of Forest Fragmentation in Lithuania. *Baltic Forestry* 17(1): 128–135.

Abstract

Forest fragmentation, which is usually defined as a landscape scale process that involves both loss of forest and its fragmentation per se, is important for understanding of ecological function and process. We performed a multiple-scale analysis of forest fragmentation based on 30 m spatial resolution forest/non-forest cover raster maps, derived from CORINE Land Cover database in Lithuania. We calculated forest fragmentation indexes within the fixed-set of non overlapping analysis blocks of five sizes (2.25, 7.29, 65.61, 590.49, and 5,314.41 ha) and classified them with certain category of fragmentation. Fragmentation assessed using proportion of forest was scale-dependent. In 2.25 ha size blocks 60.9% of all forest was classified as „inner" (those were at least 90% forested), but decreased rapidly in large blocks, so that less than 2% of this class were found in 5,314.41 ha blocks. The decrease of "dominant" forest (those were at least 60% forested) along the scale was less steep. In 2.25 ha blocks share of the "dominant" forest was 74.9 %, while in 5,314.41 ha blocks – 30.1 %. Fragmentation of forest landscape assessed by using two fragmentation components (proportion of forest and connectivity) was scale-dependent, more or less. Most Lithuanian forest was in fragmented landscapes. In the mid-size blocks (7.29 ha and 65.61 ha) 35.3% and 8.1%, of all forest was contained in a fully forested ("interior") blocks, while 22.6% and 27.2% was attributed to an "edge", 28.0% and 48.0% – "patch", respectively. Share of "interior" forest was smaller in larger blocks, with less than 1% of forest was classified as interior in 5,314.41 ha blocks while proportion of "patch" forest reached 74.4% at this scale. Though, relatively less fragmented forest landscapes were in the south-eastern part of the country, our results suggest that fragmentation is so prevalent it could potentially influence ecological processes on most forest landscapes of Lithuania.

Key words: ecosystems, forest fragmentation, landscape pattern, scale effect, spatial structure

Introduction

Forest ecosystems are among those highly affected by various human activities, including timber exploitation, land use for agriculture, urban and road building (Hunter 1990, Myers 1996). Human caused forest fragmentation could be either temporary after clearing and replanting the forest areas or long-lasting when caused by the expansion of agricultural and urban areas.

In Europe, forest biomes are considered to be particularly impacted by human caused fragmentation (Wade et al. 2003). Here, fragmentation of forest land has historically occurred in many countries, but for several decades till now forest area is expanding (MCPFE 2007). For instance, lowest percentage of Lithuanian forest area was 19.7% in 1948 (Brukas et al. 1998, Juodvalkis et al. 2003), since then Lithuanian forest cover was steadily growing on average 0.2% per year (Kuliešis 2006). However, increase of total forest area may be accompanied by the decrease of core forest and increased perforation or patchiness of forest areas (Kozak et al. 2007) and may cause an impact on wildlife, as there are many animal and plant species, requiring certain habitat sizes, edge zones and other characteristics of forest stands (Andren 1994, Grashof-Bokdam 1997, Gibbs 1998). Hence, data on forest fragmentation, amount of forest and its spatial pattern are valuable for quantifying of changes in forest cover associated with forest fragmentation and linkage among ecological pattern, function and process.

Different authors measure forest fragmentation in different ways and at different spatial scales (Fahrig 2003). In order to evaluate the fragmentation, which is usually defined as a landscape-scale process involving both habitat loss and fragmentation *per se*, many of forest fragmentation and connectivity measures have been described in the literature (see, Vogelmann 1995, Trani and Giles 1999, Wickham et al. 1999). These include mean forest patch size, percent of interior forest, mean forest patch density, number of forest patches, interpatch distance, forest patchiness, forest contiguity, forest continuity, total edge, etc. But many of these measures have strong relationships with amount of habitat as well as with each other (Gustafson 1998, Wickham et al. 1999). It is quite common for fragmentation studies to report individual effects of fragmentation measures without reporting the relationships among them, or do not separate the effects of habitat loss from the configurational effects of fragmentation, which makes the results difficult to interpret (Fahrig 2003).

Recently, a forest fragmentation model that distinguishes different types of fragmentation categories based on two measures: proportion of forest (i.e. habitat amount) and connectivity (configuration) has been developed by Riitters et al. (2000). With certain modifications this model has been used in the later studies of forest fragmentation (Riitters et al. 2002, Wade et al. 2003, Riitters and Coulston 2005). Using the model, categories of forest fragmentation are well visually represented and easily understood. Any specified area (state forest enterprise, municipality or town) can be quantified as having particular amount of forest, and the degree to which that forest is fragmented. Fragmentation estimates could be used by forest and conservation officials, researchers in order to analyze, assess and control fragmentation in forest landscapes.

It is generally recognized that landscape patterns are spatially correlated and scale-dependent. Hence, understanding of their structure requires multiscale information (Wu et al. 2004). In our study, we presented assessment of multi-scale forest fragmentation in Lithuania. This analysis of forest pattern such as presented herein provides a baseline, from which changes in fragmentation patterns over time could be monitored.

Material and methods

Land cover data

We used CORINE Land Cover database of the year 2000 with a minimum mapping unit of 25 ha (hereafter, „CLC"). For CORINE Land Cover database as a primary photo interpretation data source Landsat 7 ETM+ satellite imagery was used. Lithuanian territory was covered by 6 partially overlapping Landsat 7 ETM+ scenes: 185-21 (02-Mar-2000), 186-21 (10-Jun-2000), 186-22 (15-Jul-2001), 187-21 (03-Mar-2000), 187-22 (16-Mar-2000), 188-21 (07-Mar-2000), 188-22 (10-Mar-2000) and 189-21 (31-Jul-1999) (Vaitkus 2004). Standard methodology of CLC2000 database has been specified in several successive versions and updates of its technical documentation (e.g. Bossard et al. 2000).

According to the National Lithuanian CLC database, which contains 32 (of the total 44 defined) standard land cover classes in the 3rd level of CLC nomenclature, forest area makes ~32%, agricultural ~60% and other ~8% (Vaitkus 2004). For multiple-scale analysis of forest fragmentation we used 30 m spatial resolution forest/non-forest cover raster map, derived from CLC. Lithuanian CLC broad-leaved (CLC code - 3.1.1), coniferous (3.1.2) and mixed forest - (3.1.3) we grouped into one general forest class "F". The remaining classes were grouped into one non-forest class "N". Inland and marine waters treated as missing data values "M", so they did not increase the forest fragmentation during the analysis. In forest/non-forest raster map, "F" area covered ~29% (1862587.17 ha), "N" area ~69% (4500627.48 ha) and "M" ~2% (126316.80 ha) of the study area.

Fragmentation metrics

Metrics that identify patterns of forest fragmentation were based on the proportion of forest (P_f) and the forest connectivity (P_{ff}) values within a fixed set of non overlapping blocks (hereafter - "blocks"). P_f, is the ratio of the number of forest pixels over the total number of pixels within the block that are not water (missed class). P_{ff}, is the ratio of the number of pixel pairs in cardinal directions that are both forest over the number of pixel pairs in cardinal directions that are either both forested or one is forested. Fragmentation category for particular block was defined using P_f and P_{ff} values. Because both P_f and P_{ff} values are proportions, they range from 0 to 1. The model that delineates fragmentation categories is shown in Figure 1.

The P_{ff} values larger than P_f indicate that forest is more clustered (less fragmented). The P_f values larger than P_{ff} mean that non-forest is more clustered (Riitters et al. 2002). Determination rules of six forest frag-

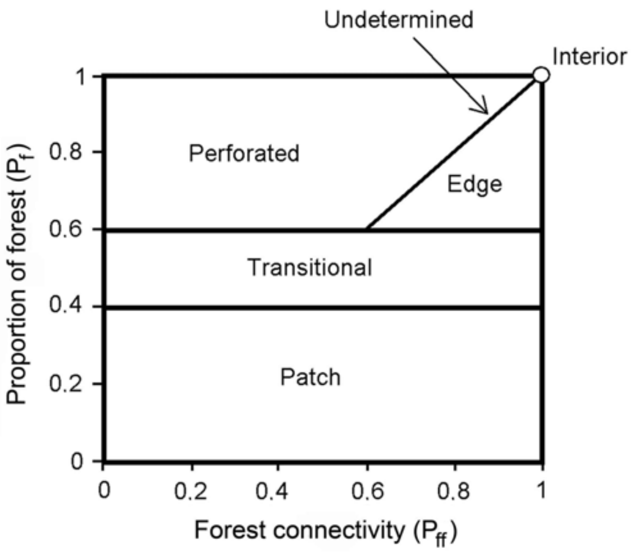

Figure 1. The model used for determination of six forest fragmentation categories based on local measurements of P_f and P_{ff} within a given block (adapted from Riitters et al. 2000 – Erratum 2)

mentation categories are presented below. Names after Riitters et al. (2000):

- "Edge", if P_f >0.6 and P_f - P_{ff} <0.
- "Perforated", if P_f >0.6 and P_f - P_{ff} >0.
- "Undetermined", if P_f >0.6 and P_f = P_{ff}.
- "Interior", if P_f =1.
- "Patch", if P_f <0.4.
- "Transitional", if 0.4≤P_f ≤0.6.

Computation of P_f and P_{ff} values within 5x5 pixel hypothetical blocks is shown in Figure 2 and Table 1.

In order to evaluate forest fragmentation on a multiple spatial scale, P_f and P_{ff} values were calculated within the blocks, which represent real landscapes, using a raster overlay at multiple scales. Forest fragmentation indexes were calculated within five selected block sizes, spanning four orders of magnitude (e.g. Ostapowicz et al. 2008) and based on grouped CLC raster grid: 2.25 ha (5x5 pixels); 7.29 ha (9x9 pixels); 65.61 ha (27x27 pixels); 590.49 ha (81x81 pixels) and 5,314.41 ha (243x243 pixels).

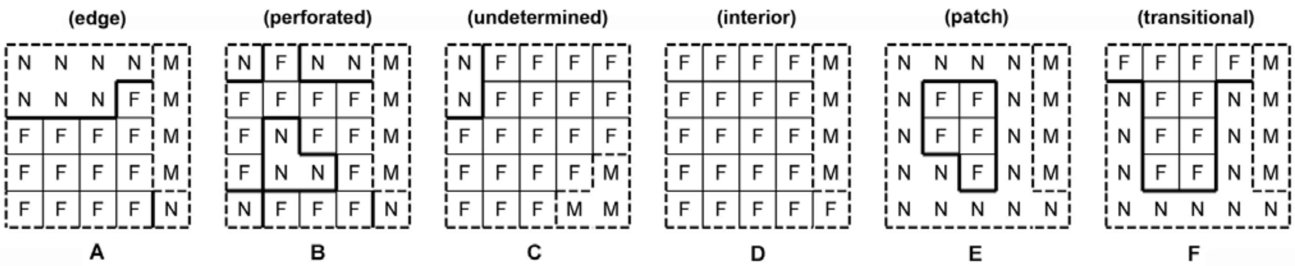

Figure 2. Illustration of measurements that identify: "edge" (A), "perforated" (B), "undetermined" (C), "interior" (D), "patch" (E), and "transitional" (F) fragmentation categories within six hypothetical blocks. Letters within the blocks indicate "F" – forest, "N" – non-forest and "M" – missing pixels. Heavy solid lines indicate {FN} connection, light solid lines – {FF}, no lines – {NN}, {MM} pixel edge types. {NN}, {MM} and dashed lines are not used in calculations. Computation of P_f and P_{ff} values is shown in Table 1

An assignment of fragmentation categories to blocks started with calculation of P_f for the entire dataset. P_{ff} values were calculated in order to define edge (A) and perforated (B) fragmentation categories (see, Table 1). For interior (D), patch (E) and transitional (F) categories, P_{ff} values were not calculated. In case P_f = P_{ff}, fragmentation category for a particular block was defined as undetermined (C).

We also set two threshold values (0.9 and 0.6) for proportion of forest (P_f) in order to evaluate this component of fragmentation separately from forest connectivity (P_{ff}), for each of the five block sizes. A landscape with a P_f of at least 0.9 was referred to as "inner", at least 60% forested landscapes were classified as "dominant". The threshold values were chosen by analogy to percolation theory (Stauffer and Aharony

Table 1. Computation of P_f and P_{ff} values for determination of fragmentation categories within six hypothetical blocks (shown in Figure 2). P_f thresholds were used to define "interior", "patch" and "transitional" fragmentation categories. P_f - P_{ff} thresholds were used to define "edge", "perforated" and "undetermined" fragmentation categories. Numbers in bold indicate values that were critical to determine particular fragmentation categories

Measurements	Fragmentation categories					
	Edge	Perforated	Undetermined	Interior	Patch	Transitional
Sum of heavy solid lines ∑{FN}	6	16	3	Ignored	Ignored	Ignored
Sum of heavy light lines ∑{FF}	18	13	30	Ignored	Ignored	Ignored
Proportion of forest $P_f = \sum"F"/(\sum"F"+\sum"N")$	13/21 = 0.619	13/21 = 0.619	20/22 = 0.909	21/21 = **1***	5/21 = **0.238***	10/21 = **0.476***
Forest connectivity $P_{ff} = \sum\{FF\}/(\sum\{FF\} + \sum\{FN\})$	18/(18+6) = 0.75	13/(13+16) = 0.448	30/(30+3) = 0.909	Ignored	Ignored	Ignored
P_f - P_{ff}	**-0.131**	**0.171**	**0**	Ignored	Ignored	Ignored

* – if P_f =1 or Pf≤0.6, calculations of {FF},{FN}, P_{ff} and P_f - P_{ff} were ignored

1991, Riitters et al. 2000), assuming a random distribution of forest in a landscape (Wade et. al. 2003, Riitters et al. 2002). These categories are somewhat arbitrary and not exclusive, landscape that meets inner criterion also meets dominant criterion.

ArcGIS Spatial Analyst tools combined with and custom Python-based forest fragmentation calculation application was used for calculations.

Results

Generally, the study area and area of landscapes that contained forest increased when larger blocks were chosen. With block size of 150 x 150 m the total study area covered 6 426 441 ha and landscapes with forest covered 2 419 329 ha (36.7%). With block sizes of 270 x 270 m, 810 x 810 m, 2,430 x 2,430 m and 7,290 x 7,290 m, the study area covered 6 466 426.8 ha, 6 554 767 ha, 6 710 918.8 ha and 7 089 422.9 ha, forested landscapes – 2 851 098 ha (44.1%), 4 158 493 ha (63.4%), 5 962 176.00 ha (88.8%) and 6 988 449 ha (98.6%), respectively. The increase of percentage of forested landscape was because larger blocks were more likely to include at least some forest, so these blocks were contributing to forested landscapes. Similarly, larger blocks subsumed more area that was outside of Lithuania, so the total amount of study area also increased.

Proportion of forest (P_f) that reflects one aspect of fragmentation i.e. amount of habitat, was scale dependent in Lithuanian forest landscapes. The percentage of both inner and dominant threshold categories diminished in broader scales (Figure 3). Responses of these metrics to changing scale were simple scaling relations. 60.9% of all forest was classified as inner in 2.25 ha size blocks, but decreased rapidly in large blocks, so that less than 2% of this class were found in 5,314.41 ha blocks. The decrease of dominant forest was less steep. In 2.25 ha blocks share of the dominant forest was 74.9%, in 65.6 ha – 61.3%, and in 5,314.41 ha blocks – 30.1%.

The fragmentation index categories reflecting both aspects of fragmentation *i.e.* amount of habitat and fragmentation *per se* were more or less scale-dependent in Lithuanian forest landscapes. Responses of interior, patch, perforated and undetermined categories to changing scale were consistent scaling relations. The percentage of interior, perforated and undetermined categories diminished in broader scales, while proportion of patch fragmentation category increased. Transitional and edge categories showed no simple scaling relations to the changing scale (Figure 4).

The interior category was most common for the two smallest block sizes whereas the patch category was most common for the three largest block sizes (Table 2, Figure 4). Perforations (non-forest areas) in the two smallest block sizes (2.25 ha, 7.29 ha) were much more common than in the large ones. The undetermined category was the least common and none of it was assigned for larger blocks. The edge and transitional categories were less common than interior category in two smallest block sizes and more common for three largest block sizes.

Distribution of Lithuanian forest fragmentation categories, in 65.61 ha and 590.49 ha blocks, are shown in Figure 5. Interior and edge forest landscapes correspond with largest forested areas in Lithuania (e.g. Dainava, Rūdninkai, Labanoras, Kazlų Rūda and Karšuva forests). At the broader scale (590.49 ha), considerable amount of interior landscapes were substituted by edge and transitional landscapes, while patch

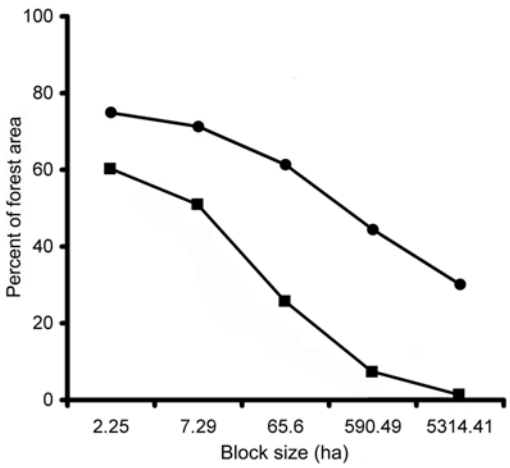

Figure 3. Scale-dependent fragmentation of Lithuanian forests: the percentage of blocks of different sizes that meet the criteria of "dominant" (●) and "inner" (■) fragmentation categories

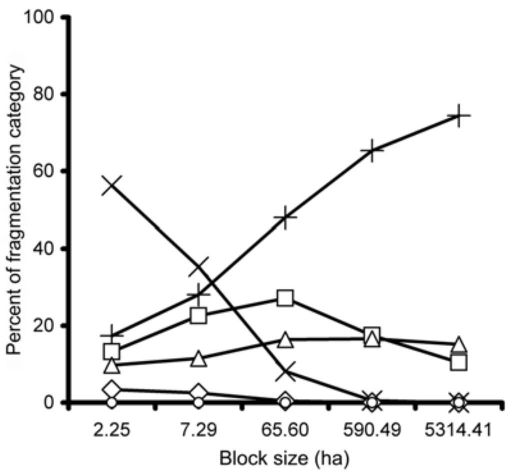

Figure 4. Distribution of fragmentation index categories in blocks of different sizes, where "interior" (×), "patch" (+), "edge" (□), "transitional" (△), "perforated" (◇), "undetermined" (○)

Table 2. Distribution of the total forest area among "patch", "edge", "transitional", "interior", "perforated" and "undetermined" fragmentation categories for five blocks

Block size	Fragmentation categories					
	Edge (10^3 ha)	Perforated (10^3 ha)	Undetermined (10^3 ha)	Interior (10^3 ha)	Patch (10^3 ha)	Transitional (10^3 ha)
5×5 pixels - 2.25 ha	320.155 (13.2%)	81.738 (3.4%)	0.635 (0.0%)	1361.315 (56.3%)	419.744 (17.4%)	235.742 (9.7%)
9×9 pixels - 7.29 ha	643.773 (22.6%)	72.565 (2.6%)	0.219 (0.0%)	1007.259 (35.3%)	799.115 (28.0%)	328.167 (11.5%)
27×27 pixels - 65.61 ha	1129.476 (27.2%)	16.993 (0.4%)	0.000 (0.0%)	336.842 (8.1%)	1994.413 (48.0%)	680.769 (16.4%)
81×81 pixels - 590.49 ha	1041.034 (17.5%)	1.771 (0.0%)	0.000 (0.0%)	31.886 (0.5%)	3897.234 (65.4%)	990.251 (16.6%)
243×243 pixels - 5314.41 ha	728.074 (10.4%)	0.000 (0.0%)	0.000 (0.0%)	0.000 (0.0%)	5202.807 (74.4%)	1057.568 (15.1%)

Percentages of total forest area for the given block size do not always sum to 100.0 due to rounding. Non-forested landscapes were ignored in calculations

landscapes subsumed portion of non-forest land. The patch landscapes covered large portion of the Lithuanian territory, representing the highly fragmented forest landscapes at broader scales. Transitional forest landscapes were mainly located between edge and patch landscapes.

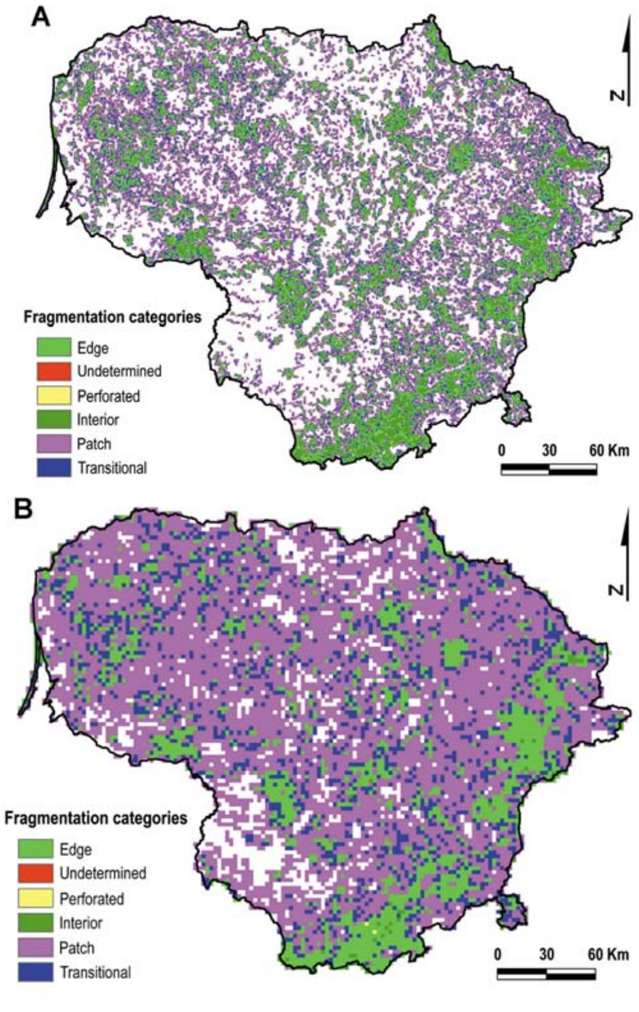

Figure 5. Distribution of Lithuanian forest fragmentation categories at: A – 65.61 ha blocks, B – 590.49 ha blocks

Discussion and conclusions

Similarly to other forest fragmentation studies completed in multiple landscape sizes (Riitters et. al. 2002, Ostapowicz et. al. 2008) the results of our study on Lithuanian forest fragmentation were scale dependent. This dependence supports the statement that there is no single "correct" or "optimal" scale for characterizing and comparing landscape patterns (e.g. Levin 1992, Wu et al., 2002) and the same spatial resolution and extent should be used in comparison between the landscapes. Moreover, because the ecological systems also operate on multiple scales multiscale landscape patterns are likely to be successful for linking landscape fragmentation pattern to the ecological pattern.

On the other hand, observed sensitivity of the forest fragmentation categories to the observational scale indicates general level of fragmentation. If forest was not fragmented, increased landscape sizes would not alter composition of forest fragmentation classes (Riitters et. al. 2002). The marked decreases in inner, which reflects a single fragmentation component - amount of forest and interior that reflects both amount of forest and connectivity, categories over the range of block sizes tested indicate that fragmentation is prevalent in the forested landscapes. Well-marked increase of patch fragmentation category that corresponds to the most fragmented forest landscapes supports the claim. The amount of dominant forest decreased by around 45% as landscape size changed over four orders of magnitude. This indicates a moderate distinction between the areas, that are mostly forested and those that are not.

Fragmentation maps (2.25 ha, 7.29 ha, 65.61 ha block size), those represent local or national-scale patterns of forest fragmentation in Lithuania (Figure 5A) compared with the soil and relief data (see, Mejeris and Vaitiekūnas 1981), suggest that most of the forest persist in the areas less favorable for agriculture, where soils are sandy, poor in nutrients, and on hilly or very wet terrain. Similar association patterns were generally observed for other areas in Europe (e.g. Wulf 1998). Broader scale fragmentation (e.g. 590.49 ha, Figure 5B) suggests regional scale fragmentation patterns. At this scale neither local forest fragmentation nor forest area are precisely represented, but it is suited for comparison of regional or global landscape patterns and tracking changes of large scale processes. At this scale, landscapes of fragmented forest categorized as patch covered 65.4% of all forested landscapes where forest did occur, but interior covered only 0.5%, suggesting a lack of large and not fragmented by the human activities forest areas in Lithuania. However, those large and not fragmented forests may serve as potential wildlife refuges.

There is shown in the literature that forest fragmentation can have an impact on plant and animal species diversity (e.g. Mikk and Mander 1995, Jansson and Andren 2003), plant colonization (Dzwonko and Gawronski 1994, Grashof-Bokdam 1997), animal movement (Gardner et al. 1992, Belisle et al. 2001), predation (Mazgajski and Rejt 2005), habitat suitability (Burke and Nol 2000) and changes in microclimate (Chen et al. 1995). Though effects of fragmentation vary from species to species, it may be summarized as follows: specialist species are more likely to be affected by the small fragmentation than generalists.

Recently, possible negative effects of the forest fragmentation on distribution of common dormouse (Juškaitis 2007) and wolves (Balčiauskas 2008) in Lithuania and Eurasian lynx in Poland (Niedzialkowska et al. 2006) were suggested. However, studies that use multiple scale fragmentation patterns and metrics that compute both components of fragmentation (i.e. amount of forest, and fragmentation *per se*) in order to assess ecological effects for the region are still lacking. We hope that our study will foster future landscape fragmentation research in order to define and quantify causes of fragmentation and possible effects of fragmentation on biodiversity and will serve as basis for the future analysis of temporal changes of forest fragmentation.

Our analysis was limited (considering temporal extent of data used) to the forest-non-forest fragmentation but distinguishing among forest vegetation types (e.g. specific habitats) and historical forest continuity would expose even more fragmentation. Although, relatively less fragmented forest landscapes were in the south-eastern part of the country. The study results suggest that fragmentation is so prevalent it could potentially influence ecological processes on most forest landscapes of Lithuania.

Acknowledgements

We thank Mikko Mönkkönen for helpful comments on earlier versions of the manuscript, Rimvydas Aleksiejūnas, Kęstutis Mizara and Vaiva Vaikasaitė for their help. We also thank HNIT-BALTIC Company for additional computing facilities. The fragmentation maps and custom Python-based forest fragmentation calculation application of this study are available from the authors.

References

Andren, H. 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. *Oikos* 71(3): 355-366.

Balčiauskas, L. 2008. Wolf numbers and distribution in Lithuania and problems of species conservation. *Annales Zoologici Fennici* 45(4): 329-334.

Belisle, M., Desrochers, A. and Fortin, M. J. 2001. Influence of forest cover on the movements of forest birds: A homing experiment. *Ecology* 82(7): 1893-1904.

Bossard, M., Feranec J. and Otahel J. 2000. CORINE Land Cover Technical Guide – Addendum 2000 (Tech. Rep. No.40). European Environment Agency, Copenhagen, 105 pē.

Brukas, A., Kuliešis, A. and Rutkauskas, A. 1998. Lietuvos miškų statistika [Statistics of Lithuanian forest]. Girios aidas, Kaunas, 72 pp. (in Lithuanian)

Burke, D. M, and Nol, E. 2000. Landscape and fragment size effects on reproductive success of forest-breeding birds in Ontario. *Ecological Applications* 10(6): 1749-1761.

Chen, J., Franklin, J. F. and Spies, T. A. 1995. Growing season microclimatic gradients from clearcut edges into old growth Douglas-fir forest. *Ecological Applications* 5(1): 74-86.

Dzwonko, Z. and Gawronski, S. 1994. The role of woodland fragments, soil types, and dominant species in secondary succession on the western Carpathian foothills. *Vegetatio* 111(2): 149-160.

Fahrig, L. 2003. Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology Evolution and Systematics* 34: 487-515.

Gardner, R. H., Turner, M. G., O'Neill, R. V. and Lavorel, S. 1992. Simulation of the scale-dependent effects of landscape boundaries on species persistence and dispersal. In: M.M. Holland, P.G. Risser, R.J. Naiman (Editors), Ecotones: the role of landscape boundaries in the management and restoration of changing environments. Chapman and Hall, New York, p. 76-89.

Gibbs, J. P. 1998. Distribution of woodland amphibians along a forest fragmentation gradient. *Landscape Ecology* 13(4): 263-268.

Grashof-Bokdam, C. 1997. Forest species in an agricultural landscape in the Netherlands: Effects of habitat fragmentation. *Journal of Vegetation Science* 8(1): 21-28.

Gustafson, E. J. 1998. Quantifying landscape spatial pattern: what is the state of the art? *Ecosystems* 1: 143-156.

Hunter, M. L. 1990. Wildlife, forests, and forestry: Principles of managing forests for biological diversity. Prentice Hall Career and Technology, Englewood Cliffs, 370 pp.

Jansson, G. and Andren, H. 2003. Habitat composition and bird diversity in managed boreal forests. *Scandinavian Journal of Forest Research* 18(3): 225-236.

Juodvalkis, A., Kairiūkštis, L. and Ozolinčius, R. 2003. Lietuvos miškų metraštis, XX amžius [The chronicle of Lithuanian forests in XX century]. Naujasis lankas, Vilnius, 632 pp. (in Lithuanian)

Juškaitis, R. 2007. Peculiarities of habitats of the common dormouse, *Muscardinus avellanarius*, within its distributional range and in Lithuania: a review. *Folia Zoologica* 56(4), 337-348.

Kozak, J., Estreguil, C., and Vogt, P. 2007. Forest cover and pattern changes in the Carpathians over the last decades. *European Journal of Forest Research* 126(1): 77–90.

Kuliešis, A. 2006. Miško kirtimų apimtį lemiantys veiksniai ir jų analizė [Factors influencing amount of forest fellings and their analysis]. *Miškininkystė* 1(59): 5-18 (in Lithuanian).

Levin, S. A. 1992. The problem of pattern and scale in ecology. *Ecology* 73: 1943–1967.

Mazgajski, T. D. and Rejt, L. 2005. Forest fragment size affects edge effect in nest predation - experiment with artificial nests. *Polish Journal of Ecology* 53(2): 233-242.

Mejeris, A. and Vaitiekūnas, J. K. 1981. Dirvožemiai [Soils]. In: A. Drobnys (Responsible editor), Lietuvos TSR Atlasas [Atlas of Lithuanian SSR]. Vyriausioji geodezijos ir kartografijos valdyba, Maskva, p. 90-91 (in Lithuanian).

Mikk, M. and Mander, U. 1995. Species-diversity of forest islands in agricultural landscape of southern Finland, Estonia and Lithuania. *Landscape and Urban Planning* 31(1-3): 153-169.

Ministerial Conference on the Protection of Forests in Europe [MCPFE] 2007. State of Europe's forests 2007. The MCPFE Report on Sustainable Forest Management in Europe. MCPFE Liaison Unit Warsaw, Warsaw, 247 pp.

Myers, N. 1996. The world's forests: problems and potentials. *Environmental Conservation* 23(2): 156-168.

Niedzialkowska, M., Jedrzejewski, W., Myslajek, R. W., Nowak, S., Jedrzejewska B. and Schmidt, K. 2006. Environmental correlates of *Eurasian lynx* occurrence in Poland - Large scale census and GIS mapping. *Biological Conservation* 133(1): 63-69.

Ostapowicz, K., Vogt, P., Riitters, K. H., Kozak, J. and Estreguil, C. 2008. Impact of scale on morphological spatial pattern of forest. *Landscape Ecology* 23(9): 1107-1117.

Riitters, K. H. and Coulston, J. W. 2005. Hot spots of perforated forest in the eastern United States. *Environmental Management* 35(4): 483-492.

Riitters, K. H., Wickham, J. D., O'Neill, R. V., Jones, K. B. and Smith, E. R. 2000. Global-scale patterns of forest fragmentation. *Conservation Ecolog*y 4(2): 3. [online]

Riitters, K. H., Wickham, J. D., O'Neill, R. V., Jones, K. B., Smith, E. R. and Coulston, J. W., 2002. Fragmentation of Continental United States Forests. *Ecosystems* 5(8): 815-822.

Stauffer, D. and Aharony, A. 1991. Introduction to Percolation Theory. Taylor and Francis, London, 192 pp.

Trani, M. K. and Giles, R. H. Jr. 1999. An analysis of deforestation: metrics used to describe pattern change. *Forest Ecology and Management* 114(2-3): 459-470.

Vaitkus, G. 2004. Lietuvos CORINE žemės danga 2000 (Projektas I&CLC2000-LT). [CORINE Land Cover 2000 in Lithuania (Project I&CLC2000-LT)]. Institute of Ecology of Vilnius University, Vilnius, (unpubl.). 50 pp.

Vogelmann, J. E. 1995. Assessment of forest fragmentation in southern New England using remote sensing and geographic information system technology. *Conservation Biology* 9(2): 439-449.

Wade, T. G., Riitters, K. H., Wickham, J. D., and Jones, K. B. 2003. Distribution and causes of global forest fragmentation. *Conservation Ecology* 7(2): 7. [online]

Wickham, J. D., Jones, K. B., Riitters, K. H., Wade, T. G. and O'Neill, R. V. 1999. Transitions in forest fragmentation: implications for restoration opportunities at regional scales. *Landscape Ecology* 14(2): 137-145.

Wu, J. 2004. Effects of changing scale on landscape pattern analysis: scaling relations. *Landscape Ecology* 19(2): 125-138.

Wu, J., Shen, W., Sun, W. and Tueller, P. T. 2002. Empirical patterns of the effects of changing scale on landscape metrics. *Landscape Ecology* 17(8): 761-782.

Wulf, M. 1998. Distribution of ancient woodlands, afforestation and clearances in relation to quaternary deposits and soil types in north-western Brandenburg (Germany). In: K.J. Kirby and C. Watkins (Editors), The ecological history of European forests. CAB International, Oxon, p. 301-310.

Received 26 November 2009
Accepted 05 April 2011

МНОГОМАСШТАБНЫЙ АНАЛИЗ ФРАГМЕНТАЦИИ ЛЕСА В ЛИТВЕ

А. Кучас, Г. Тракимас, Л. Бальчяускас и Г. Вайткус

Резюме

Фрагментация леса определяется как процесс ландшафтного уровня, включающий и уменьшение лесистости, и дробление массива per se. Фрагментация является важной составляющей понимания экологических функций и процессов. Мы выполнили фрагментарный анализ лесных массивов в различных масштабах, используя 30-метровую пространственную резолюцию лесных/нелесных растровых изображений, составленных на основе базы данных покрова Литвы CORINE. Мы рассчитали индексы фрагментации лесных массивов, используя неперекрывающиеся блоки пяти размеров (2,25, 7,29, 65,61, 590,49 и 5314,41 га) и классифицировали их как соответствующие компоненты фрагментации. Оценка фрагментации, используя пропорцию леса, зависит от масштаба. В блоках размером 2,25 га 60,9% всего леса было классифицировано как «внутренний лесной ландшафт» (территория, где лес занимает не менее 90%), но соответствующие проценты быстро убывали в больших блоках, таким образом, что менее 2% этого класса было найдено в блоках размером 5314,41 га. Убывание «доминирующего лесного ландшафта» (где лес занимает не менее 60%) с изменением масштаба было менее резкое. В блоках размера 2,25 га 74,9% всего леса было классифицировано как доминирующий лесной ландшафт, а в блоках размера 5314,41 га – 30,1%. Оценка фрагментации лесного ландшафта с использованием двух компонент фрагментации (пропорции и связанности леса) была более или менее зависима от масштаба. Большинство лесов Литвы представляет собой расчлененный (фрагментарный) ландшафт. Например, в блоках средних размеров (7,29 га и 65,61 га) были выделены «полностью лесные ландшафты» соответственно 35,3% и 8,1% от всего лесного массива; «ландшафты лесных окраин» соответственно 22,6% и 27,2%; «ландшафты с очень редким лесом (редколесье)» соответственно 28% и 48%. В двух наименьшего размера блоках «доминирующий лесной ландшафт» составлял 40-60%, тогда как в более крупных блоках его количество было значительно меньше. Полностью лесной ландшафт резко уменьшался при изменении масштаба в сторону более крупных блоков и в блоках размера 5314,41 га менее 1% территорий было классифицировано как «полностью лесной ландшафт», а пропорция «редколесья» в этом масштабе достигла 74,4%. Хотя сравнительно менее фрагментарные лесные ландшафты наблюдались в юго-восточной части страны, наши результаты показывают, что фрагментация распространена таким образом, что она потенциально может влиять на экологические процессы большей части лесов Литвы.

Ключевые слова: экосистемы, фрагментация леса, образ ландшафта, эффект масштаба, пространственная структура