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ORIGINAL ARTICLE

## Differences in the forest landscape structure along the Finnish–Russian border in southern Karelia

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### Abstract

This study describes forest landscape fragmentation and connectivity along the Finnish–Russian border near the Karelian Isthmus. The landscape pattern was analysed using classification data based on Landsat ETM+ and Landsat TM images in combination with systematic surveys in Finland (Finnish National Forest Inventory) ( $n=546$ ) and the authors' own fieldwork data in Russia ( $n=101$ ). On the Finnish side the forest patches are significantly smaller than on the Russian side. In addition, the Finnish forests landscape is more scattered and distances between patches of the same forest type are longer. The Russian side is more dominated by broadleaved and mixed forest stands. The disparities are due to differences in forestry policy and traditions of forest practices. The growing conditions of the areas are similar. The habitat fragmentation and habitat connectivity are important issues because the Karelian Isthmus is one of three main corridors and migrating routes connecting large Russian boreal taiga forests and their fauna and flora with Finnish isolated boreal forests.

**Keywords:** *Boreal forest, Finland, forest landscape, habitat fragmentation, Landsat, Russia.*

### Introduction

During the past 300 years, the global forest cover has reduced by almost 20% (Richards, 1990). This decrease has often been accompanied by the fragmentation of the remaining forests into smaller patches (Bryant et al., 1997; Kouki et al., 2001). As a consequence, biodiversity is disappearing at an alarming rate (Van Teeffelen, 2007). The landscape fragmentation and therefore landscape connectivity are important factors in biodiversity conservation because they affect directly the population distribution and may lead to species extinctions (e.g. Saunders et al., 1991; Andr n, 1994; With et al., 1997; Hanski, 2005). Fragmentation implies a loss of habitat, reduced patch size, an increasing distance between patches and changes in the physical environment. In addition, it may expose the remaining organisms to the conditions of a different surrounding ecosystem and also to edge effects, which are the results of the interaction between two adjacent ecosystems separated by a transition

edge (Murcia, 1995). The ecological importance of fragmentation depends both on the scale of fragmentation and on the habitat requirements of the species (Kouki et al., 2001).

Boreal forests occupy much of the circumpolar region between 50° and 70°N (Ahti et al., 1968) and it is the largest terrestrial biome on earth. Boreal forests have been affected by active forest management for centuries (Larsson & Danell, 2001). Some of the remaining near-natural boreal forest landscapes in northern Europe can be found in the Russian Karelia near the Finnish border (Burnett et al., 2003; Gromtsev & Litinski, 2003). Extensive near-natural boreal forest areas are scarce in Europe (Mykr  & Kurki, 1998) and the remaining areas are seriously threatened by fragmentation as a result of clear-cut harvesting (Burnett et al., 2003).

In the boreal forests, the landscape-level fragmentation has proceeded differently in various areas (Kouki et al., 2001). The national border between Finland and Russia is characterized by a sharp and distinctive change in the structure of the resident

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boreal forest (Martikainen et al., 1996; Jantunen et al., 2002; Kalliola et al., 2003). Some sections along the border region show up remarkably well on satellite images because there is a sharp discontinuity between two types of forest landscape between these two countries, even though these forests have similar growing conditions (Siitonen, cit. Kantola et al., 2000, pp. 83–84; Kalliola et al., 2003). On both sides of the border, Russian Karelia was under similar management regimes when it belonged to Autonomous Finland (1809–1917) and Finland (1917–1944) (Jantunen et al., 2002). Since World War II, when large areas were ceded to the Soviet Union, the history of forest management has differed clearly between adjacent areas in Finnish and Russian Karelia. On the Finnish side of the border, extensive clear-cutting operations were executed from 1950 to 1980, creating fragmented forest landscapes (Löfman & Kouki, 2001), while those on the Russian side were left almost intact due to the border policies of the former Soviet Union. Managed boreal forests tend to differ significantly in structure at the landscape level compared with boreal landscapes that have been less impacted by humans (Syrjänen et al., 1994). The effects of anthropogenic partitioning of the boreal forest landscape on a broad scale may involve complex interactions among biodiversity, ecosystem processes and landscape dynamics (Turner et al., 1995). Therefore, the Finnish forest landscapes are expected to be more fragmented than the neighbouring forests on the Russian side of the border (Syrjänen

et al., 1994; Kantola et al., 2000, pp. 83–84; Burnett et al., 2003; Kalliola et al., 2003). However, the human influence on the Russian forest landscape has been growing over recent decades, mainly as a consequence of logging activities and human-induced fires, especially in the European part of Russia (e.g. in the Karelian Isthmus) (Achard et al., 2006).

Burnett et al. (2003) studied the current status of boreal forest landscapes in the northern Russian Karelia. In addition, Jantunen et al. (2002) studied stand structure along the Finnish–Russian border near Lake Ladoga, but slightly further north than the present study area. Thus, information on the landscape pattern of the Karelian Isthmus located further south between the Baltic Sea and Lake Ladoga (Figure 1) is insufficient. Interest in this area is growing since it has a high potential for increasing timber production (Kolström et al., 2000). These actions are likely to cause a net loss of large forest patches and a reduction in overall forest age. Since the 1990s, Finland has become one of the main importers of Russian wood material (Mayer et al., 2005).

The present study area is also of great interest in biodiversity and conservation studies because it is one of the main corridors (Figure 1) for Finnish and Russian forests to interact through species dispersal and migration (e.g. Lindén et al., 2000; Mayer et al., 2005). Corridors are very important geographical features for biological conservation and biodiversity because they enhance the movement of individuals



Figure 1. Location of the study area along the Finnish–Russian border. Three small arrows indicate the three main corridors which connect Finnish forests to Russian forests through species dispersal and migration (Lindén et al., 2000; Mayer et al., 2005).

and thereby improve the survival of populations (Niemi, 2001; Vogt et al., 2007). If current logging rates continue, north-west Russia is likely to suffer a net loss of large forest patches (Burnett et al., 2003) and thus the movement between Finnish populations and Russian populations may be threatened.

This study investigates the forest landscape pattern along the Finnish–Russian border in the Karelian Isthmus. The hypothesis is that the differences in forest management affect the forest landscape fragmentation and patch connectivity along the border. Russian logging practices are known to be different from Scandinavian practices; Russian practices rely more heavily on clear-cutting and active forest regeneration has been less frequent. It is evident that these practices have created notably different forest landscape patterns between Finland and Russia. The forest landscape pattern and its fragmentation were evaluated using Landsat satellite images.

## Materials and methods

### Study area

The study area covers forest areas along the Finnish–Russian border near the Karelian Isthmus between latitudes 60°00′ and 61°30′ N and longitudes 27°00′ to 31°00′ E (Figure 1). The border between Finland and Russia crosses this area in almost a north–east to south–west direction. Forests in this region belong to the southern boreal vegetation zone (Ahti et al., 1968). The forests consist of several tree species, typically Norway spruce [*Picea abies* (L.) Karst.], Scots pine (*Pinus sylvestris* L.) and broadleaved birches (*Betula pendula* Roth. and *B. pubescens* Ehrh.). The most common understorey species are the dwarf shrubs bilberry (*Vaccinium myrtillus* L.) and lingonberry (*V. vitis-idaea* L.).

### Data

This study is based on field surveys and the use of optical remote sensing imagery (Table I). On the Finnish side of the study area, field surveys included the data of the 9th National Forest Inventory conducted by the Finnish Forest Research Institute (during the years 1996–2003). On the Russian side, the authors conducted their own field studies owing to insufficient available measured data. These field surveys were used as ground reference data for the two separate land cover classifications (e.g. Franklin & Wulder, 2002). In June 2006 101 forest plots was inventoried. They were selected to present all major forest types and some representative sites from other land cover

Table I. Satellite and GIS data used in this study.

Data type	Acquired/ published	Description
Satellite image	16 May 2000	Landsat 5 ETM+, path 187 row 17
Satellite image	9 June 2005	Landsat 5 TM, path 185 row 18
Digital land-use map	2005	Corine Land Cover 2000 product (CLC2000-Finland, 2005)
9th National Forest Inventory data	1996–2003	Finnish Forest Research Institute, 546 sample plots
Own field data	7–20 June 2006	101 circle plots, radius 20 m

types from different parts of the study region. Measurement plot selection was made using unsupervised satellite image classification and Russian thematic maps. Only sites located more than 100 m from the patch border and roads were selected. The centre point of the measurement site was decided at least 100 m before arriving at the site. Exact locations of the sites were determined using the Global Positioning System (GPS) so that coordinate decimals were even hundreds, e.g. UTM 658100 E, 6736800 N. Basal area, tree length and width by the tree species (three measurements to 10 m north, south-west and south-east from the centre) and the amount of dead wood were measured, cut stumps were calculated, and tree, field layer and other land cover coverage and stand age were estimated, plots were photographed, and notes about possible peculiarities of the site were made.

Classifications were done under a supervised classification method. For the classification of the Finnish side, forest mask consisting of forest land on upland soils was derived from the product Corine Land Cover 2000 (Table I) on a 25 m grid (CLC2000-Finland, 2005). Forests and transitional woodlands/shrubs (crown basal area of 10–30%) on mineral and rocky soil were included in the forest mask. For the classification of the Russian side, reference data on all major land cover types were collected. Spectral signatures for classified forest types (Table II) were developed using 265 plots for Finnish and 20 for Russian classification, and the classifications were tested with the whole set of reference plots, 546 and 101, respectively. For the Russian side classification, existing topographic and other thematic maps were also used. The accuracy of the Russian side classification was 80% (with kappa value  $\kappa = 0.76$ ) and 55% for the Finnish side

Table II. Classified forest land cover types, class descriptions and tree volumes.

Forest land cover types	Description	Finnish tree volumes (m <sup>3</sup> ha <sup>-1</sup> )	Russian tree volumes (m <sup>3</sup> ha <sup>-1</sup> )
Pine-dominated forests	Forests with share of pine >75%	141 (0–818), <i>n</i> = 157	240 (95–410), <i>n</i> = 22
Spruce-dominated forests	Forests with share of spruce >75%	213 (7–602), <i>n</i> = 32	327 (129–453), <i>n</i> = 14
Mixed forests	Forests with share of dominating tree species <75%	178 (10–701), <i>n</i> = 99	244 (110–364), <i>n</i> = 24
Broadleaved forests	Forests with share of broadleaved trees >75%	164 (15–310), <i>n</i> = 24	211 (80–416), <i>n</i> = 18
Others	Young saplings, clear-cut areas	3 (0–33), <i>n</i> = 234	4 (0–15), <i>n</i> = 12
Non-forests	Open lands, water bodies, built-up areas		– (–), <i>n</i> = 11

Note: data are shown as mean (range), *n*.

( $\kappa = 0.45$ ). According to the Landis and Koch (1977), kappa values of 0.41–0.60 and 0.61–0.80 indicate a moderate and substantial strength of agreement, respectively.

Before starting to calculate landscape indices, forest patches smaller than 0.5 ha were excluded from the classification for the following reasons. First, the accuracy of smaller patches is weak owing to the resolution of satellite imagery (30 m). Secondly, this study focused mainly on habitat and corridor requirements of vertebrate species because vertebrates are the group of organisms most used as indicators of maintained biodiversity in forests (Nilsson et al., 2001) and the habitat size requirement of vertebrate species is usually larger than that of non-vertebrate species (e.g. Mönkkönen & Reunanen, 1999).

All data processing was performed using Erdas Imagine 9.0 (georeferencing and image classification), ArcGIS 9.1 (basic GIS calculations and visual illustrations), and ArcView 3.2 (landscape statistics) software packages.

### Analysis

Some basic aspects of landscape fragmentation were calculated. These statistics were calculated for 10×10 km grids (Figure 2) to make data easier to visualize and to allow statistical testing of the differences. The following patch statistics were derived (McGarigal & Marks, 1995; Simberloff, 2001): proportion of class area (%TYPE), patch density (PD) per square kilometre ( $n \text{ km}^{-2}$ ), mean patch size (MPS) (ha), edge density (ED) ( $\text{m ha}^{-1}$ ), and average distance between similar forest patches (MNN) (m). The equations used for the calculation of patch statistics are presented in Appendix 1. When comparing these statistics with other studies, it should be noted that the edge indices, in particular, are affected by the resolution of the image (McGarigal & Marks, 1995). At coarse resolutions, edges may appear as relatively straight lines, whereas

at finer resolutions, edges may appear as highly convoluted lines. Thus values calculated for edge metrics should not be compared among images with different resolutions. Patch perimeter and the length of edges will be biased upward in raster images owing to the stair-step patch outline which will affect all edge indices. The magnitude of this bias will vary in relation to the grain or resolution of the image. The patch statistics were performed using ArcView 3.2 work package Patch Analyst (grid) 3.0, which is based on a Fragstats algorithm (McGarigal & Marks, 1995).

### Results

The general appearance of the forest vegetation and the overall landscape pattern are statistically different between these two regions (Table III). For example, the forest cover is more extensive on the Russian side of the border (Figure 2): forest cover on the Russian side is approximately 83.7% of all land areas, while the corresponding value for the Finnish side is only 47.86%. On the Russian side, the forests consist of mainly mixed and broadleaved forests, while on the Finnish side the main forest type is pine forest (Table III, Figure 3). In addition, the proportion of clear-cuts and young saplings (forest class “Other”) is higher on the Finnish than on the Russian side, but the total area covered by this forest class is higher on the Russian side owing the higher share of forests. The difference between these two countries can also be seen from the Landsat 5 TM satellite image (Figure 4).

On average, forest patches are smaller in Finland than in Russia (Table III). In addition, the mean distance to the nearest similar forest patch (MNN) is shorter in Finland than in Russia, except where broadleaved forest patches are concerned. Broadleaved forest patches are very scarce on the Finnish side of the border. The MNN distance of spruce forest patches is greater in Russia, although the proportion of spruce forests is about the same as in

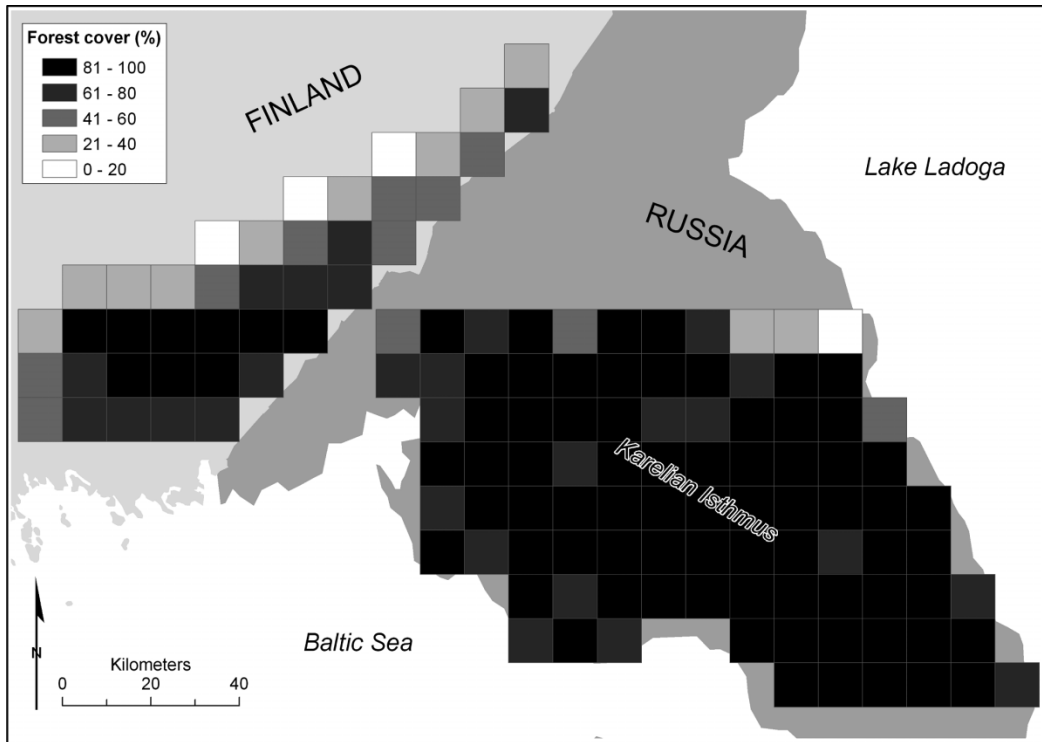


Figure 2. Forest cover along the Finnish–Russian border. Forest patches smaller than 0.5 ha are not included.

Finland. The proportion of mixed forests is significantly higher on the Russian side and the mixed forest patches are clearly larger, but the mean distance to patches of similar forest type is greater. This indicates that Russian spruce and mixed forest patches are large in size, but the few such patches are located sparsely.

Russian clear-cut and sapling patches (forest type “Other”) are much larger than the Finnish ones,  $\sim 17$  and  $\sim 1$  ha, respectively. Yet, the amount of these is clearly higher in Finland:  $\sim 13$  and  $\sim 1 \text{ n km}^{-2}$ , respectively. The overall proportions of this forest type are of the same magnitude, but the difference is still statistically significant.

## Discussion

The border region addressed in this study has witnessed a variety of forest use practices according to different cultures. Forestry in Finland is characterized by wide forest areas managed for timber production, short rotation and clear-cuttings (Kouki & Niemelä, 1997; cit. Jantunen et al., 2002). The exploitation of forests in Russia has been less intensive; although has increased during the past two decades. Therefore, the structure of the forest landscape is more scattered in Finland than in Russia and the proportion of tree species is different.

In this study, the main differences between Finnish and Russian forests along the border were found to be smaller patch size, more scattered landscape pattern and shorter distance between patches of the same forest type on the Finnish side. Conversely, the Russian forests clearly have large forest patches and the mean distance to neighbouring patches of similar forest type is remarkably longer. These findings are in good agreement with the findings of Siitonen (unpublished data, cit. Kantola et al., 2000, pp. 83–84).

It was also found that the proportion of spruce forests is similar on the both sides of the border, but on the Russian side the spruce forest patches are larger and they are located far away from each other. While the Finnish spruce forest patches are scattered, the mean distance to neighbouring forest patches is significantly shorter. This indicates that forests on the Russian side of the border are in a more natural state than the corresponding forests on the Finnish side. Jantunen et al. (2002) found similar results in their study based on the data of 46 subjectively selected forest stands representing three forest types: pine (16 stands), spruce (20 stands) and broadleaved forests (10 stands).

Because movement is critical to the survival of the animal populations, forest landscape connectivity is a vital element of landscape structure (Taylor, 1993). The present results highlight concerns about the linkage between vertebrate populations on the

Table III. Landscape characteristics along the Finnish–Russian border.

	Finland		Russia		<i>t</i> Test	<i>p</i>
	Mean	SD	Mean	SD		
All						
PD	35.56	–	7.82	–	–	–
MPS	2.81	–	12.79	–	–	–
Pine						
%TYPE	48.90	5.74	12.58	9.55	30.86	<0.001
PD	5.92	3.46	1.20	0.56	10.58	<0.001
MPS	4.22	2.20	8.22	6.02	–6.21	<0.001
ED	255.22	73.41	25.22	13.85	20.02	<0.001
MNN	40.82	18.89	168.73	84.59	–15.06	<0.001
Spruce						
%TYPE	5.98	1.81	6.73	7.96	–0.99	0.322
PD	12.88	7.56	0.94	0.65	12.30	<0.001
MPS	0.21	0.05	4.77	5.10	–9.31	<0.001
ED	17.22	12.83	16.84	15.04	0.13	0.900
MNN	69.84	19.08	237.66	188.69	–9.08	<0.001
Broadleaved						
%TYPE	0.38	0.16	16.67	10.95	–15.34	<0.001
PD	1.62	1.10	1.46	0.65	0.90	0.373
MPS	0.11	0.01	9.00	7.39	–12.55	<0.001
ED	0.19	0.21	37.31	18.22	–20.95	<0.001
MNN	294.19	136.84	124.78	40.98	9.41	<0.001
Mixed						
%TYPE	16.83	3.34	41.13	9.66	38.36	<0.001
PD	21.26	12.86	1.33	0.58	12.09	<0.001
MPS	0.36	0.08	27.05	15.19	–18.13	<0.001
ED	58.69	26.77	70.97	13.76	–3.24	0.002
MNN	41.75	9.46	79.36	18.19	–17.52	<0.001
Other						
%TYPE	27.91	6.61	23.19	9.87	3.66	<0.001
PD	12.99	7.00	1.18	0.44	13.15	<0.001
MPS	0.95	0.31	17.15	17.63	–9.41	<0.001
ED	119.26	49.63	37.19	11.91	11.63	<0.001
MNN	44.54	5.03	141.19	37.22	–26.32	<0.001

Note: %TYPE = proportion of forest types (%); PD = number of patches ( $n \text{ km}^{-2}$ ); MPS = mean patch size (ha); ED = edge density ( $\text{m ha}^{-1}$ ); MNN = mean nearest neighbour distance (m), calculated from  $10 \times 10 \text{ km}$  squares (Finland:  $n = 40$ ; Russia:  $n = 108$ ).

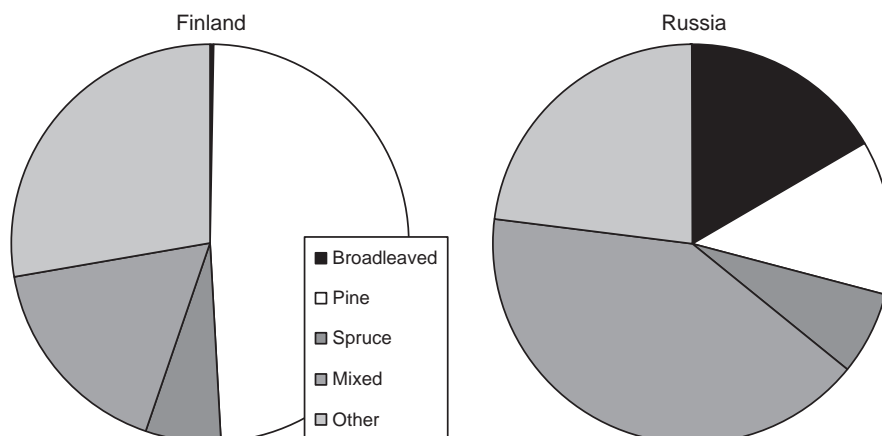


Figure 3. Proportion of forest types. The type “Other” consists of clear-cuts and young saplings. Non-forest land cover types are ignored.

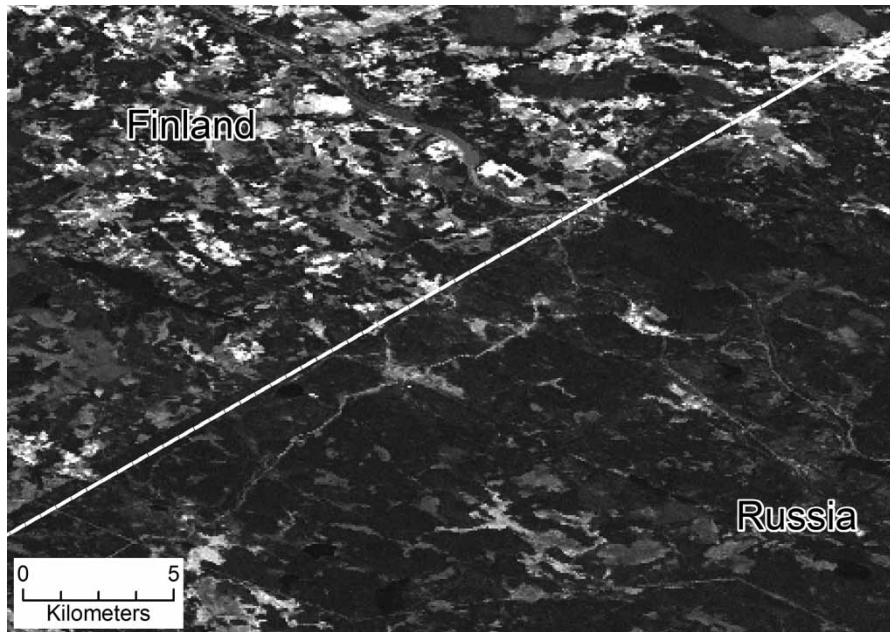


Figure 4. Example of the Landsat 5 TM satellite image along the Finnish–Russian border. The border zone is characterized by a distinct change in coloration and texture.

Russian and the Finnish side. The forests along the Finnish side of the border zone are so scattered that connections to wide forest areas in central Finland are in many cases endangered. When discussing large-scale population connectivity, it should be noted that different species have different dispersal abilities, operational scales and vital characteristics of landscape structure (Mönkkönen & Reunanen, 1999). Vital characteristics refer to some patches being optimal for reproduction or survival over the limiting season. In addition, other patches may serve as dispersal habitat or secondary resource patches, or may be totally unsuitable. For these reasons, this study was conducted on a general level. It is well known that, between the Finnish and Russian sides, the stand structure (age class distributions of the tree, field layer structure, etc.) differs (Jantunen et al., 2002), and that this has great additional significance for the populations. However, this study was intentionally focused on the overall picture of landscape structure differences along the Finnish–Russian border in southern Karelia.

This study examined one of the three main corridors linking boreal forests in Fennoscandia to the rest of the boreal forest ecosystem in Eurasia (Mayer et al., 2005, 2006). Mayer et al. (2005, 2006) concluded that this corridor is especially endangered owing to increasing harvesting on the Russian side. Private Finnish forestry companies, in particular, are importing wood from Russia. According to Mayer et al. (2005, 2006), should current harvesting rates continue and management fail to

conserve connectivity, Fennoscandian vertebrate populations may be isolated from Eurasian ones.

In conclusion, the general appearance of the forest vegetation and the overall landscape pattern differs with respect to more scattered forest landscape on the Finnish side, a higher total amount of forests on the Russian side, and different proportions of tree species. These differences are caused by different management regimes along the Finnish–Russian border.

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**Appendix A**

Appendix 1. Patch statistics used in this study (McGarigal &amp; Marks, 1995).

Landscape statistics	Equation	Unit
Proportion of forest type	$\%TYPE = \frac{\sum_{j=1}^i a_{ij}}{A} \times 100$	Per cent (%)
Patch density	$PD = \frac{n_i}{A}$	1 per square kilometre
Mean patch size	$MPS = \frac{\sum_{j=1}^{n_i} a_{ij}}{n_i}$	Hectares (ha)
Edge density	$ED = \frac{\sum_{j=1}^{n_i} p_{ij}}{A}$	Metres per hectare (m ha <sup>-1</sup> )
Mean nearest neighbour distance	$MNN = \frac{\sum_{j=1}^{n_i} h_{ij}}{n_i}$	Metres (m)

Note: %TYPE = proportion of forest types; PD = patch density; MPS = mean patch size; ED = edge density; MNN = mean nearest neighbour distance;  $i$  = type of patch (class  $i$ );  $j$  = patch in class  $i$ ;  $a_{ij}$  = area of patch  $j$  in class  $i$ ;  $A$  = total area;  $p_{ij}$  = perimeter of patch  $j$  in class  $i$ ;  $h_{ij}$  = edge to edge distance from patch  $j$  in class  $i$  to the nearest patch also in class  $i$ ;  $n_i$  = number of patches.