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# Environmental correlates of Eurasian lynx occurrence in Poland – Large scale census and GIS mapping

*Magdalena Niedziałkowska*[a,*], *Włodzimierz Jędrzejewski*[a], *Robert W. Mysłajek*[b], *Sabina Nowak*[b], *Bogumiła Jędrzejewska*[a], *Krzysztof Schmidt*[a]

[a]*Mammal Research Institute, Polish Academy of Sciences, Waszkiewicza 1c, 17-230 Białowieża, Poland*

[b]*Association for Nature WOLF, Twardorzeczka 229, 34-324 Lipowa, Poland*

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ABSTRACT

Based on data from the National Lynx Census, carried out in Poland in 2000–2001, and using Geographic Information System, we analysed nine habitat characteristics in 56 circular sample plots (113 $km^2$ each), where lynx (*Lynx lynx*) have been recorded, and 118 plots with no signs of their presence. In plots with lynx the forest cover (on average 68%) was two times higher and the forest fragmentation lower than in plots with no lynx records. The plots with and without lynx differed significantly also in the number of villages and towns, length of main motorways and railways. Lynx occurrence was negatively associated to human settlements and transportation infrastructure. Logistic regression analysis showed that sufficient forest cover (>40%) and the short straight-line distance to the eastern or southern border of Poland (as a proxy of the distance to a more contiguous range of lynx in Europe) are the two most important variables explaining lynx distribution. We conclude that, in Poland, increase of forest fragmentation and transportation infrastructure may become important threats to lynx populations.



## 1. Introduction

The Eurasian lynx (*Lynx lynx*, Linnaeus, 1758), a typical forest species, lives in low density, maintains large territories and has limited ability to migrate through areas changed by humans (Breitenmoser et al., 1993; Jędrzejewski et al., 1996, 2002a,b; Schmidt et al., 1997; Schmidt, 1998). Alike other large carnivores (Simberloff, 1998; Carroll et al., 2001) lynx is a quintessential 'flagship species' of conservation concern especially in the areas of its reintroduction or recovery (Schadt et al., 2002a,b). All activities aimed at lynx conservation have to be based on good knowledge about its habitat preferences and other environmental factors that influence population dynamics. So far, however, habitat use by Eurasian lynx was studied mostly at a small scale of local population (Sunde et al., 2000) or in the restitution areas, where habitat choice of lynx was partly predetermined by humans (Kramer-Schadt et al., 2004).

In Poland, lynx has been protected since 1995, and it is listed in a Polish Red Data Book as near threatened (Głowaciński, 2001). The Polish population is estimated at about 200 individuals (Jędrzejewski et al., 2002a). In this study, we analysed the data collected during the National Census of Wolves and Lynx in Poland (Jędrzejewski et al., 2002a, 2004, 2005) to identify large-scale environmental correlates of lynx distribution in a native population. The aims of our study were to assess the relationships between lynx occurrence and: (1) forest cover and fragmentation, (2) density of villages, towns, motorways, other roads, and railways, (3) the distance to more contiguous lynx populations in Russia, Lithuania, Belarus, Ukraine, and Slovakia.

* *Corresponding author:* Tel.: +48 85 68 27 787; fax: +48 85 68 27 752/12 289.
E-mail address: mrogala@bison.zbs.bialowieza.pl (M. Niedziałkowska).
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## 2. Methods

### 2.1. Study area

The National Census of Wolves and Lynx covered whole Poland (about 311,900 km$^2$, 49°00′–54°50′ N, 14°08′–24°09′ E). The country's area are mainly plains with 91% of the territory below 300 m a.s.l. Uplands (301–500 m a.s.l) cover 6% and mountains (500–2499 m a.s.l) 3% of the country. All mountain ridge (Świetokrzyskie Mts., Sudety Mts., and the Carpathians) are located in southern Poland. Landscape of northern Poland (Masurian Lakeland and Pomerania) was shaped by glaciers (mainly by the Riss, 310,000–130,000 years BP, and the Würm glaciations, 70,000–10,000 years BP). Poland is located in the temperate climate zone, and its climate has a transitional Atlantic-continental character. Mean temperature of January varies from 0 to 1 °C along the Baltic coast and the western part of country to −5.5 °C in the north-east and −7 °C in the mountains. Mean temperature of July ranges from 10 °C in the mountains, to 16.5 °C at the sea, and 19 °C in south-west. Annual precipitation is about 500–650 mm in lowlands to 1200–1500 mm in the mountains.

The mean density of human population is 124 inhabitants/km$^2$ but various regions differ from an average of 60 person/km$^2$ in the north-east to nearly 400 in the Upper Silesia, SW Poland (Statistical Yearbook of the Republic of Poland, 2002). About 60% of Poland's territory is covered by agricultural land, with a dominance of arable fields, and smaller shares of meadows, pastures, and orchards. Forests cover 29% of the country (Fig. 1). A great majority of forests are commercial stands, dominated by Scots pine (*Pinus sylvestris*) – 70% and spruce (*Picea abies*) – 6%. Among deciduous trees, more important are oaks (*Quercus robur* and *Q. petraea*), ash (*Fraxinus excelsior*), maples (*Acer platanoides* and *A. pseudoplatanus*), beech (*Fagus sylvatica*), hornbeam (*Carpinus betulus*), birches (*Betula verrucosa* and *B. pendula*) and alder (*Alnus glutinosa*). Only 1.5% of the country's area is protected by national parks and reserves (Leśnictwo, 2005).

Three native species of ungulates occur in whole Poland: roe deer (*Capreolus capreolus*), red deer (*Cervus elaphus*), and

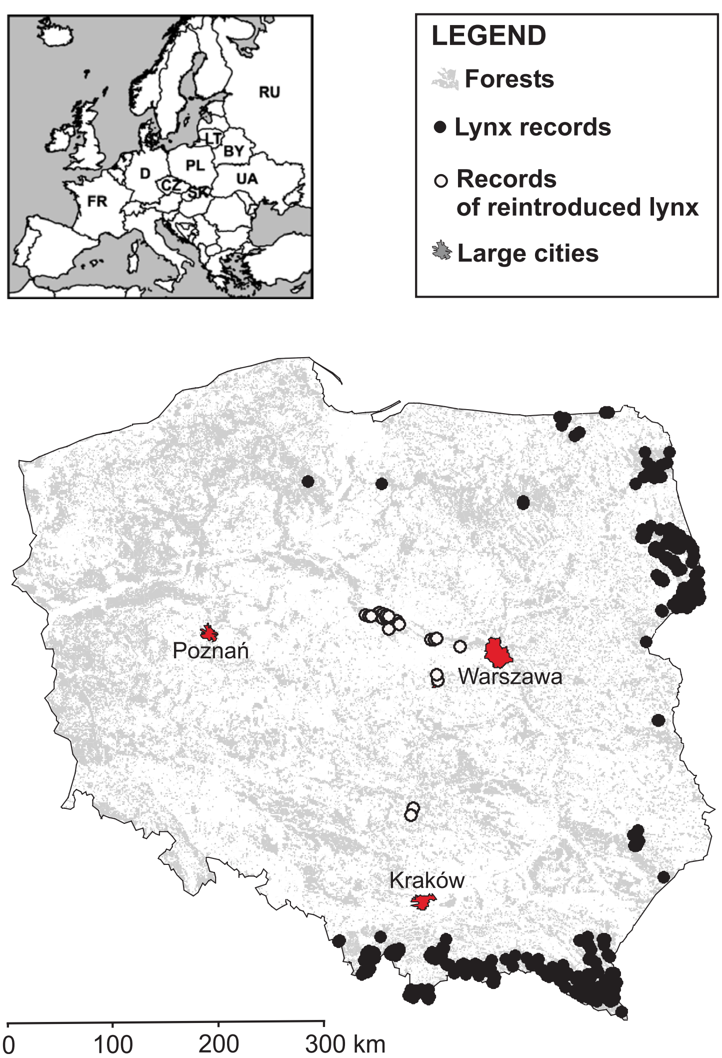


**Fig. 1 – Distribution of lynx (*Lynx lynx*) in Poland, from National Census of Wolves and Lynx data in 2000–2001 (after Jędrzejewski et al., 2002a). Lynx originating from the population reintroduced in central Poland were not considered in this study.**

wild boar (*Sus scrofa*). In north-eastern and eastern part, moose (*Alces alces*) and a few isolated populations of European bison (*Bison bonasus*) occur. In the Tatra Mts. an endangered population of chamois (*Rupicapra rupicapra*) has survived. Natural populations of lynx occur in the eastern and southern parts of Poland (Fig. 1). In central Poland, there lives a reintroduced population of lynx in the Kampinos Forest (Böer et al., 2000). To avoid bias of human influence on lynx habitat choice (i.e., human decision about release sites), the records of reintroduced lynx were not taken into consideration in this study. In Poland, the lynx coexist with two other large carnivores: the wolf (*Canis lupus*) which occurs in eastern part of the country (Jędrzejewski et al., 2004, 2005), and the brown bear (*Ursus arctos*) inhabiting the Carpathians, SE Poland (Jakubiec and Buchalczyk, 1987).

### 2.2. Collection and analysis of data

All data on lynx observations were obtained during the National Census of Wolves and Lynx carried out in 2000–2001 (Jędrzejewski et al., 2002a). The census was conducted by the services of the Polish State Forestry and National Parks, under the supervision of the Mammal Research Institute, Polish Academy of Sciences in Białowieża (MRI PAS). All year round, the forest and national park personnel recorded lynx tracks, kills, and other observations. One or two times during the winter, the mapping of fresh lynx tracks and trails was performed by inspecting the forest roads after a new snowfall. Also, interviews with local people and hunters were conducted. All data were sent to MRI PAS, where they were analysed in the program MapInfo 6.5 (Mapinfo Corporation, 2001).

The obtained records of lynx in Poland (Fig. 1) formed a data base for lynx habitat analysis. We selected 174 circular sample plots of 12-km diameter each (area 113 $km^2$). The size of the sample plot was equivalent to about 75% of the average lynx's territory studied by radio tracking in Białowieża Primeval Forest, E Poland (Jędrzejewski et al., 1996; Schmidt et al., 1997). In total, the sample plots covered 19,679 $km^2$ (6.5% of the country) and included 56 plots, where lynx occurrence has been recorded, and 118 plots with no signs of their presence. The latter ones were randomly chosen in the whole study area excluding the biggest cities. As the range of lynx cover only a small part of the country (see Fig. 1) we had to choose more plots with no lynx records than those with their occurrence to make the habitat comparisons reliable.

For all sample plots, we analysed the following parameters: (1) percent forest cover, (2) forest fragmentation (number of forest patches >1 ha, which were separated by open areas), (3) river length (we included only large and medium-sized rivers and not streams and small waterways), (4) length of main roads (international and national motorways), (5) length of secondary (regional) roads (the other two categories: district roads and communal roads were not included), (6) length of railways, (7) number of villages (usually <1000 inhabitants), (8) number of towns (>1000 inhabitants), (9) the shortest straight-line distance to the eastern or southern border of Poland, as a proxy of the distance to lynx populations in Lithuania, Russia, Belarus, Ukraine, and Slovakia. The variables 1 and 2 were obtained from a database granted to us by the General Directorate of the Polish State Forests (Ministry of Environment, Warsaw). The variables 3–9 were measured or counted on the numerical maps prepared by the IMAGIS Company.

## 3. Results

Data obtained during the National Census of Wolves and Lynx carried out in 2000–2001 showed that lynx occurred in eastern and south-eastern part of Poland, not further than 143 km from the northern, eastern or southern state border (Fig. 1, Table 1). Indeed, the nearest distance to the state border (a proxy of the distance to lynx populations in the countries east or south of Poland) was one of the most significant differences between sample plots with and without lynxes (Table 1).

The number of lynx records in the lynx plots ranged from 1 to 23 in one sample plot (Table 1). Mean forest cover in sample plots with lynx was twice bigger than in plots without lynx (Table 1). As many as 70% of plots with lynx were placed in areas, where forest cover exceeded 60% (Fig. 2). The differences in frequency distributions of the plots in forest cover classes were significant between lynx and non-lynx samples (G-test for goodness of fit, $G = 38.3$, df = 4, $P < 0.001$; Fig. 2). Another factor important for lynx distribution was forest frag-

**Table 1 – Habitat characteristics of sample plots with lynx (n = 56) and those with no lynx recorded (n = 118) in Poland**

| Parameter (*n*, km, or %) | Plots with lynx records | | Lynx-free plots | | Statistical significance of difference (*P*) |
|---|---|---|---|---|---|
| | Mean ± SE | Min–max | Mean ± SE | Min–max | |
| Total number of lynx records | 5.1 ± 0.6 | (1–23) | 0 | – | – |
| Straight-line distance to the state border (km) | 19 ± 3 | (6–143) | 123 ± 13 | (6–564) | 0.0001 |
| Forest cover (%) | 68 ± 2 | (37–97) | 34 ± 2 | (1–95) | 0.0001 |
| Number of villages | 3.3 ± 0.2 | (0–8) | 5.1 ± 0.2 | (0–13) | 0.0001 |
| Number of towns | 0.2 ± 0.1 | (0–2) | 0.6 ± 0.1 | (0–4) | 0.001 |
| Length of main motorways (km) | 2.2 ± 0.6 | (0–13.9) | 5.3 ± 0.6 | (0–36) | 0.008 |
| Forest fragmentation (*n* forest patches) | 13.3 ± 0.8 | (3–33) | 16.6 ± 0.7 | (2–41) | 0.01 |
| Length of railway (km) | 3.8 ± 0.7 | (0–19.0) | 6.7 ± 0.7 | (0–30.1) | 0.03 |
| Length of secondary roads (km) | 8.5 ± 1.0 | (0–30.5) | 10.4 ± 0.8 | (0–35.6) | ns |
| Length of rivers (km) | 9.3 ± 0.9 | (0–24.2) | 10.5 ± 0.7 | (0–27.5) | ns |

Sample plots were circles of diameter 12 km (area of each plot – 113 $km^2$). Comparison of lynx and lynx-free plots was done with Kruskal–Wallis non-parametric ANOVA. Ns, non-significant.

mentation (Table 1). In plots without lynx woodlands were notably more fragmented than in plots with these predators recorded (Table 1).

The plots with and without lynx differed significantly in the number of villages and towns (Table 1). Most of the plots with lynx (75%) embraced no more than four villages and towns (pooled), and the lynx did not occur in plots with more than 10 villages and towns (Fig. 3). The frequency distributions of the two types of plots in classes of settlement number differed significantly ($G = 31.9$, df = 7, $P < 0.001$; Fig. 3).

The lynx occurrence was notably negatively associated to the density of main motorways and railways (Table 1). As much as 77% of lynx plots did not contain any main motorways, compared to 53% of plots without lynx (Fig. 4). The difference in plot distribution was statistically significant ($G = 18.19$, df = 7, $P < 0.02$). The lengths of secondary roads and rivers did not affect lynx distribution.

We conducted a logistic regression analysis to find which of the studied environmental variables were most strongly associated to the lynx occurrence in Poland. The best model contained two factors: forest cover and straight-line distance

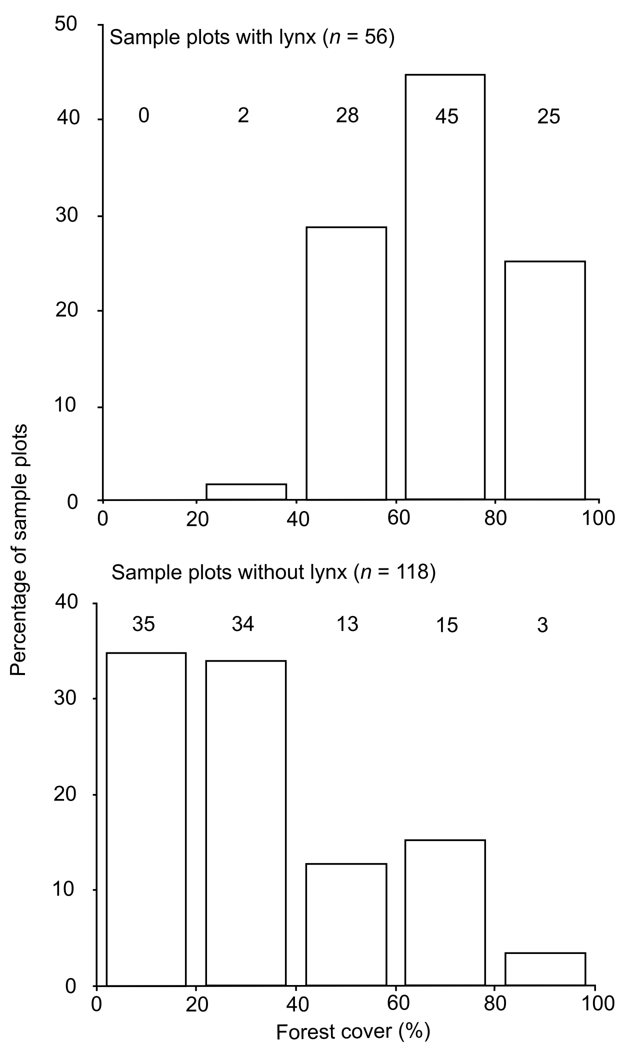


**Fig. 2 – Frequency distributions of sample plots (circular plots, 113 km$^2$ each) with and without lynx in classes of forest cover.**

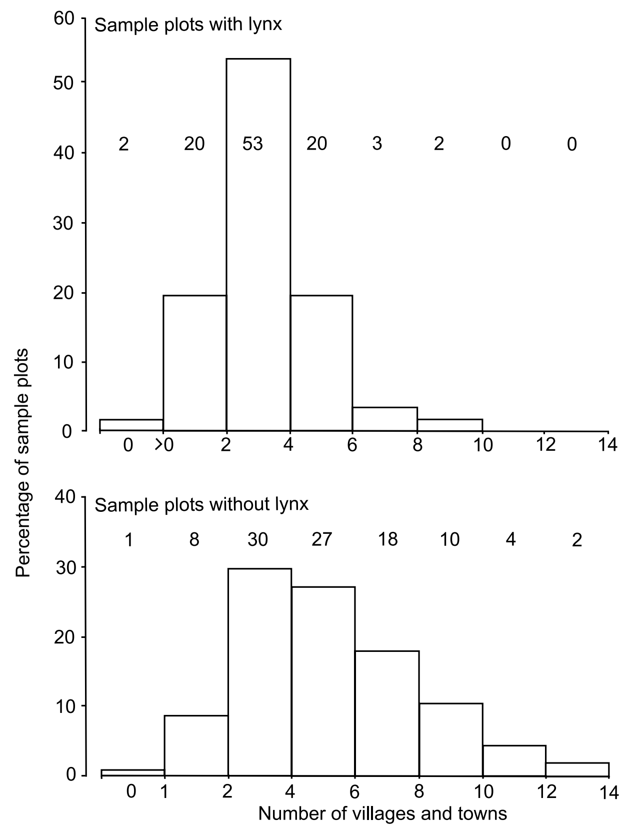


**Fig. 3 – Frequency distributions of sample plots with and without lynx in relation to the number of villages and towns (pooled) in a plot.**

to the state border, and it correctly classified over 87% plots with lynx and over 91% plots without lynx (Table 2). This result suggested that short distance from the existing populations and sufficient forest cover (>40%) are the two necessary conditions for the lynx to inhabit the area.

As some of the independent variables were mutually correlated (Pearson's $r < -0.6$ or $>0.6$ in pairs: forest cover – number of villages, forest cover – number of towns, length of main motorways – number of towns, length of railway – number of towns), we conducted the principal component analysis to find the factors affecting lynx distribution in Poland. PCA yielded results similar to those of the logistic regression: the two main components explaining 38% of variation in lynx occurrence were: forest cover, number of villages and towns (dominant loadings in component 1), and distance from the border (dominant loading in component 2).

Next, we checked whether large woodlands in western part of Poland (high forest cover but long distance from the contemporary range of the species) are a good potential habitat for lynx reintroduction or relocations. Out of no-lynx plots in western Poland, we selected those ($n = 13$) that had forest cover over 40% and compared them with lynx plots. Forest cover (67 ± 4%, mean ± SE, in potential lynx habitats and 68 ± 2% in lynx plots, respectively), forest fragmentation (12.1 ± 1.2 and 13.3 ± 0.8 forest patches), number of villages (3.0 ± 0.5 and 3.3 ± 0.2) and towns (0.3 ± 0.2 and 0.2 ± 0.1) did not differ significantly between potential and actual lynx hab-

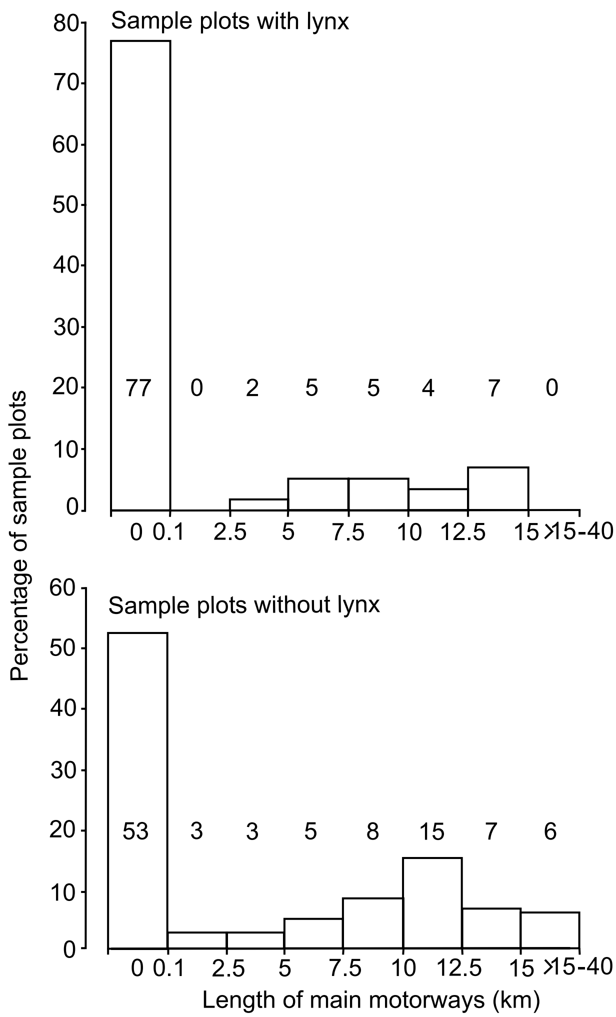


**Fig. 4 – Frequency distributions of sample plots with and without lynx in classes of main motorway length per plot.**

itats (Mann–Whitney *U*-test, *P* from 0.4 to 0.7). However, highly forested plots in western Poland had, on average, 2–3-fold longer networks of transportation infrastructure: 6.0 ± 1.0 km of main motorways in potential lynx plots versus 2.2 ± 0.6 km in lynx plots ($P = 0.02$), and 8.5 ± 1.4 km versus 2.8 ± 0.7 km of railways ($P = 0.006$).

**Table 2 – Logistic regression analysis of habitat variables explaining lynx distribution in Poland, based on 56 sample plots with lynx and 118 plots without lynx**

| Variable/group of sample plots | Statistical parameter |
|---|---|
| | Significance (*P*) |
| Distance from the state border (km) | <0.00001 |
| Forest cover (%) | <0.00001 |
| | Percent of correct classifications |
| Sample plots with lynx (%) | 87.5 |
| Sample plots without lynx (%) | 91.5 |

Logistic regression model is statistically significant at $P < 0.00001$.

## 4. Discussion

In our study, the most powerful variables predicting the occurrence of Eurasian lynx were percentage forest cover and a distance to a more contiguous geographic range of the species to the East and South of Polish state borders. Lynx occurrence was negatively associated with dense networks of transportation infrastructure and human settlements. The predators appeared also sensitive to lack of forest connectivity: extensive woodlands in western and north-western Poland are so far inaccessible to dispersing lynx, which first would have to cross the central part of the country, heavily deforested and densely populated by humans.

In Poland, lynx occurred in areas where forest cover exceeded 40%. In Switzerland, they required even higher forest cover (Schadt et al., 2002a). The analysis of European-scale coarse data (50 × 50 km grid cell) showed that lynx occurred predominantly in regions with forest cover >50% (Mikusiński and Angelstam, 2004). Nielsen and Woolf (2002) showed that core areas of bobcats (*Lynx rufus*) in southern Illinois contained 61% forest cover. In southern Yukon, Canada lynx (*L. canadensis*) also selected forests (spruce, pine and riparian willow) over open area, and the dense immature stands (30–35 years) were preferred over mature stands (Mowat and Slough, 2003). In this respect, the only exception among species in genus *Lynx* is the Iberian lynx (*L. pardina*) that prefers shrubs (high percentage cover of tall shrubs) and avoids tree cover (Palomares, 2001). In contemporary Europe, large, continuous forests required by the Eurasian lynx are rare and occur mainly in the mountains (Schadt et al., 2002a) and the eastern and northern regions of the continent (Linnell et al., 2001; Andrén et al., 2002).

Large carnivores usually avoid human disturbance and urban areas (Palma et al., 1999; Jędrzejewski et al., 2004, 2005; Nams et al., 2006). Their primary habitats contain lower number of settlements, roads and railways, as urban areas and linear infrastructure create serious problems for dispersal (Mech et al., 1988; Schadt et al., 2002a,b; Singleton et al., 2002; Cain et al., 2003; Kaczensky et al., 2003; Kramer-Schadt et al., 2004). Collisions with vehicles and poaching are among the most important causes of mortality of large carnivores including big cats (Jędrzejewski et al., 1996; Kerley et al., 2002; Riley et al., 2003; Ferreras et al., 2004; Kramer-Schadt et al., 2004).

Beier (1995) reported that, in California, juvenile cougars (*Felis concolor*) dispersed through habitat corridors having ample woody cover, whereas they avoided highways, urban and night-lit area. They, however, regularly crossed highways under the bridges built over watercourses (Beier, 1995). In Poland, subadult lynx followed wooded areas during dispersal and the routes of their migration were strongly determined by the spatial distribution and connectivity of forests (Schmidt, 1998). Based on empirical data from the Swiss, Czech, and Slovenian populations, Schadt et al. (2002a) came to conclusion that just one habitat variable suffices to describe lynx distribution in central Europe, namely the connectivity of forested and non-forested semi-natural areas on a scale of about 80 $km^2$. That scale corresponds to the average home range of a female lynx in the temperate zone (Schmidt et al., 1997). Thus, connectivity of forests is essential for long-term viability of native populations of the Eurasian lynx and successful reintroductions of these animals.

Our results, together with other European studies, allow us to discuss the future of the Polish lynx population. Ban for hunting and legal protection of the lynx since 1995 was not a sufficient conservation measure and the range of lynx has not increased during the last decade (Jędrzejewski et al., 2002a). In the near future, two large-scale alterations to wildlife habitat will continue to take place in Poland. First, the regression of extensive agriculture and abandonment of cultivated land has been conducive to spontaneous forest succession as well as deliberate afforestration. This trend, most manifest in eastern Poland, favours forest-dwelling species, including lynx. On the other hand, the traffic on the existing motorways doubled in the recent decade (1990–2000), and the country is facing fast development of transportation infrastructure, mainly highways. This will contribute to habitat fragmentation and further isolation of source populations of large carnivores, e.g., in Augustów Forest and Knyszyn Forest, NE Poland (Jędrzejewski et al., 2004). Unfortunately, the construction projects frequently neglect the need for sufficient number, size and proper location of wildlife passes across the highways. If this tendency continues, Polish population of the lynx may be seriously threatened in the next decades. The results of our analyses will be used as recommendations for planning wildlife passes across the high-traffic motorways Olsztyn–Augustów–Białystok (NE Poland) and Bielsko–Biała–Zwardoń (S Poland). However, there is an urgent need of further research that would quantify the barrier effect of transportation infrastructure and forest fragmentation in Poland to large carnivore dispersal.

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