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Forest Habitat Loss and Fragmentation in Central Poland during the Last 100 Years

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The process of habitat fragmentation consists of two components – habitat loss and fragmentation per se. Both are thought to be among the most important threats to biodiversity. However, the biological consequences of this process such as species occurrence, abundance, or genetic structure of population are driven by current, as well as previous, landscape configurations. Therefore, historical analyses of habitat distribution are of great importance in explaining the current species distribution. In our analysis, we describe the forest fragmentation process for an area of 178 km^2 in the northern part of Mazowsze region of central Poland. Topographical maps from the years 1890, 1957 and 1989 were used. Over the 100-year period, forest coverage in this area changed from 17% to 5.6%, the number of patches increased from 19 to 42, while the area of the forest interior decreased from 1933 ha to 371 ha. The two components of fragmentation were clearly separated in time. Habitat loss occurred mainly during the first period (1890–1957) and fragmentation per se in the second (1957–1989). Moreover, we recorded that only 47.7% of all the currently (in 1989) afforested areas constitute sites where forests previously occurred (in 1890 and 1957). For forest dwelling organisms characterized by low dispersal abilities, the effective forest coverage seems to be a half of the real forest area in the studied landscape. New afforestations should be planned especially to increase those patches which contain ancient forest, where various plants and animals sensitive to fragmentation may have survived.

Keywords fragmentation, landscape history, forest continuity, deforestation, ancient forest, afforestation
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1 Introduction

Habitat fragmentation is one of the most important transformations of the environment significantly affecting abundance and distribution of species in the modern landscape (Saunders et al. 1991, Fahrig 2003, Ewers and Didham 2006). In general, this process leads to a decreased amount of suitable habitat, increased isolation between patches and, as a consequence, the occurrence of edge-related effects. However, a detailed analysis of this process suggests that we should describe it as a combination of two components – habitat loss and fragmentation per se (e.g. Fahrig 2003). The reactions of forest dwelling organisms may differ in situations where a huge intact forest is partially cut, compared to where the overall habitat area is unchanged, but the total number of patches increases. However, both components are most often treated jointly in analyses of deforestation and not described in detail.

Habitat fragmentation (in the broad sense) and its ecological consequences are relatively well known in the case of forest ecosystems that have been converted into arable land over several centuries throughout Europe. Forest fragmentation significantly affects several aspects of reproduction and demography of organisms; reduces dispersion, abundance and anticipated life expectancies of subpopulations. It also renders habitat more vulnerable to invasions of exotic and eurytopic species (Redpath 1995, Fahrig 2002, Doherty and Grubb 2002, Levey et al. 2005, Mazgajski and Rejt 2006, Bolger 2007). Therefore, knowledge about habitat fragmentation in space and time is crucial for biodiversity conservation planning.

Reliable analysis of forest fragmentation and its impact on organisms requires that historical changes in habitat configuration should be taken into account (Dzwonko 2001, Gu et al. 2002, Uotila et al. 2002). The existing pattern of forest distribution in the current landscapes has been shaped over hundreds of years (e.g. Kouki et al. 2001). Forest fragmentation was driven mainly by landscape transformations made by humans and depended on the development of civilization in a given region. Therefore, the distribution of forest patches in the modern landscape is a consequence of recent as well as historical human activity (Partel et al. 1999, Kouki et al. 2001). As a consequence, the present distribution of some species in the landscape can be better explained by the historical distribution of the habitat than by the current landscape configuration (Jonsell and Nordlander 2002, Schrott et al. 2005, Helm et al. 2006). Because of this, knowledge about the historical landscape is necessary to better understand forest distribution in the modern landscape and to explain the occurrence of forest dwelling organisms (Marcucci 2000, Gu et al. 2002, Castellon and Sieving 2006, Johansson et al. 2008). This topic is especially important in light of recent programs aimed at increasing forest coverage in many European countries.

In analysis of long term landscape changes, simple differences in forest cover (or more general the share of a particular habitat) and especially changes in patch characteristics should be described. For many forest dwelling organisms the effect of landscape characteristics like patch size, shape and isolation, presence of corridors etc. on probability of their occurrence, extinction and recolonization is well known (e.g. Hinsley et al. 1995, Bellamy et al. 1996b). Therefore knowledge of the patch pattern arrangement in the environment as well as species requirements, allows predicting species occurrence or distribution both for contemporary and historical landscapes (e.g. Bailey et al. 2002). For such analysis data should be gathered not only for changes in overall forest cover, but detailed descriptions of patch characteristics should be made. However, such data concerning Poland are scarce, and papers published to date focused mostly on changes in forest cover in particular administrative or geographical units (Maruszczak 1950, Szymański 1993b, Degórska 1996).

In this paper we used historical maps to describe the pattern of forest fragmentation in the northern part of the Mazowsze region in Central Poland. This part of Mazowsze has one of the smallest forest covers in Poland – ca 16.3% (value for the whole country is 29%). Therefore, we assumed that this area would be very useful for analysis of forest fragmentation history. The aim of our work is to quantify and describe in detail the phenomenon of deforestation in the region during the last century in the context of its consequences for biodiversity conservation. We paid special attention to distinguishing between the two components of the fragmentation process.

2 Material and Methods

2.1 Study Area

The analysis was conducted in the Ciechanów Upland (a part of North Mazowsze Lowland) in Central Poland. In this region farmland predominates, and forest cover is very low. The mean annual temperature is +7 °C, annual precipitation reaches 650 mm and the length of the growing season is 210 days (Matuszkiewicz 2001). Poor and semi-rich pine forests (Querco roboris Pinetum and Serratulo Pinetum) and oak-hornbeam associations (Tilio Carpinetum) dominate as potential vegetation in the study area (according to Matuszkiewicz 2001 and references therein). In 32 studied forest patches in this area, 1659 trees were measured (methods and details see Żmihorski et al. 2010), among them birch (*Betula* sp.) and pine (*Pinus sylvestris*) predominate (26 and 22% of measured trees, respectively), but oak (*Quercus* sp., 13%), and alder (*Alnus glutinosa*, 13%) also constitute an important part. The study area represents a landscape typical for most Polish farmland predominated by arable fields and meadows, with small and mid-sized forest patches and scattered built-up areas. The farmland is quite possibly, typical of the farmland of other central European countries, allowing us to refer our results to a broader scale.

2.2 Methods

We studied a 178 km^2 rectangular plot (ca. 13 km × 14 km), located ca. 100 km north of Warsaw (centroid of the area 52.851°N; 20.999°E). We managed to find topographic maps for this location which used the same scale (1:100 000) from three different time periods: ca 1890, 1957 and 1989. Maps from other periods were usually on a larger scale. In such large scale maps precise details may be lacking (the smallest forest patches could be omitted). Therefore we eliminated the possibility of using such large scale maps as it would be difficult to compare the results. Also a comparison of data from topographic maps with those from administrative land use inventories indicates that results obtained from a 1:100 000 map analyses are quite reliable (Szymański 1993a). The first map we used was from the "Karte des westlichen Russlands" series, and was printed in 1915. However, the map is based on an older Russian map, and thus it is assumed that presents situation in 1890 (according to Maruszczak 1950 and Szymański 1993a). In the other two maps used, the revision dates are provided.

The maps were scanned and rectified in Erdas Imagine 8.3 software, with a root mean square (RMS) error of 0.4 pixel. For every forest patch we computed: the area (ha), perimeter (m), area of the ecotone zone (ha) which covers the forest area up to 50 m from the edge, and forest interior zone (ha) i.e. the forest area situated more than 50 m away from the edge. It is a well know fact that intensity of most of the biotic and abiotic factors like air temperature, light intensity, soil moisture or increased impact of predators differs between the ecotone zone and the forest interior, and various so called "edge effects" are observed. A distance of fifty meters was chosen as an edge effect measurement because at further distances the biotic and abiotic differences start to disappear (see review by Murcia 1995). We also assessed the number of forest interior patches for every forest patch in the study area. Moreover, we computed three simple indices of the patch shape. These indices are: the proportion of the forest interior to the whole patch area, the proportion of the perimeter to the patch area, and the proportion of the perimeter of each patch to the perimeter of a circle of the same plot as a given patch (e.g. Bellamy et al. 1996a, hereafter shape index). Finally, we assessed the proportion of ancient woodlands (i.e. forest that existed in 1989 at the same locations as in the two earlier periods) to recent woodlands (i.e. those forests that existed in 1989 in locations that were previously not afforested).

3 Results

We recorded clear changes in the arrangement of forest habitat in the landscape of the study area for the three analyzed periods. First of all, the afforested area decreased threefold during the last 100 years (Table 1, Fig. 1). Also, the maximum patch size and interior area decreased greatly (more than 4 and 5 times, respectively), whereas

Table 1. Forest cover characteristics in the studied area in central Poland (178 km^2) and their changes in the years: 1890, 1957, 1989.

Study area characteristic	Values for		
	1890	1957	1989
Number of forest patches	19	24	42
Forest area [ha]	3031.0	996.5	990.7
Forest cover [%]	17.0	5.6	5.6
Ecotone area [ha]	1097.8	577.0	619.7
Interior area [ha]	1933.2	419.5	370.9
Interior patch number	20	30	28
Perimeter [m]	161622	90630	108018
Minimum forest size [ha]	1.4	0.7	1.5
Maximum forest size [ha]	809.1	378.9	180.5

the total number of forest patches increased two-fold. The smallest patch area, number of interior patches and ecotone area remained more stable in the studied landscape (Table 1). The forested area in 1989 was composed mainly of recently afforested woodland stands (52.3%) which had not existed in 1890 at the same sites. The remaining forest area (47.7%) can be treated as ancient forest, where the continuity of the forest habitat has been preserved (Fig. 1).

During the three periods under comparison, almost all patch characteristics changed. Average patch size, patch perimeter, ecotone area and especially interior area decreased significantly during the last 100 years. Shape index and proportion of patch perimeter to its area has also changed (Table 2).

Table 2. Changes of forest patch characteristics on the studied plot in central Poland (178 km^2) during three analyzed years. For the statistics, only significant results are given.

Average patch characteristics	Mean value for			Kruskal-Wallis	
	1890	1957	1989	χ^2	p
Area [ha]	159.5	41.5	23.6	9.5	0.009
Perimeter [m]	8506.4	3776.2	2571.9	10.5	0.005
Ecotone area [ha]	57.8	24.0	14.8	10.0	0.007
Interior area [ha]	101.7	17.5	8.8	10.4	0.005
Interior patch number /patch	1.1	1.3	0.7	8.9	0.011
Interior proportion [%]	35.0	20.1	13.0	9.7	0.008
Shape index (1 = perfectly round)	2.1	1.8	1.7	7.1	0.028
Ratio (perimeter/area) [m/ha]	141.7	183.9	194.8	8.0	0.019

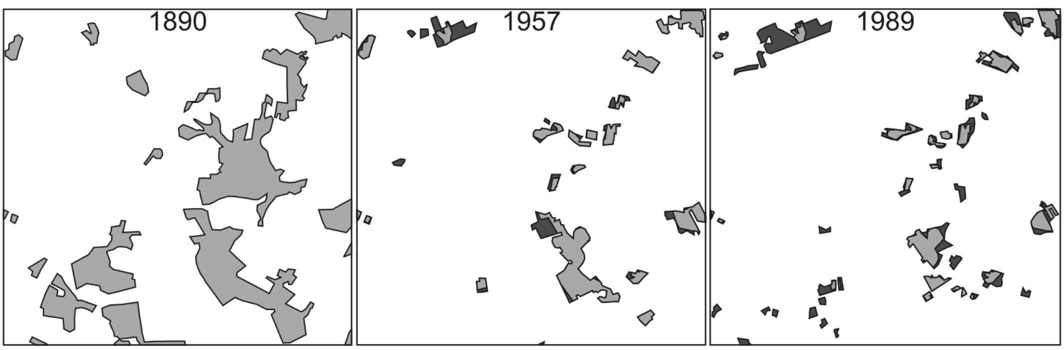

Fig. 1. Distribution of forest patches on the studied plot in central Poland (178 km^2) during the three studied years. Pale grey indicates ancient forests (afforested in all three periods), while dark grey denotes recent forests (located in the area not afforested in earlier periods).

Table 3. Rates of change of the landscape level and patch level characteristics (recalculated per one year) during the two analyzed periods (1890–1957 and 1957–1989). (+) denotes increase, while (–) decrease of a given characteristic during the analyzed period.

Spatial characteristics	Rate of changes during the two periods	
	1890–1957 (67 years)	1957–1989 (32 years)
Patch level		
Average patch size	–1.76 ha $year^{-1}$	–0.56 ha $year^{-1}$
Average patch perimeter	–70.6 m $year^{-1}$	–37.6 m $year^{-1}$
Average ecotone area per patch	–0.50 ha $year^{-1}$	–0.29 ha $year^{-1}$
Average interior area per patch	–1.26 ha $year^{-1}$	–0.27 ha $year^{-1}$
Number of forest interior patch/patch	+0.003 $year^{-1}$	–0.018 $year^{-1}$
Proportion of forest interior to whole patch area	–0.22 % $year^{-1}$	–0.22 % $year^{-1}$
Shape index (1 = perfectly round)	–0.005 $year^{-1}$	–0.003 $year^{-1}$
Proportion of forest perimeter to patch area [m/ha]	+0.63 m $year^{-1}$	+0.34 m $year^{-1}$
Landscape level		
Forested area	–30.36 ha $year^{-1}$	–0.18 ha $year^{-1}$
Forest interior area	–22.59 ha $year^{-1}$	–1.52 ha $year^{-1}$
Forest ecotone area	–7.77 ha $year^{-1}$	+1.33 ha $year^{-1}$
Perimeter	–1059.6 m $year^{-1}$	+543.4 m $year^{-1}$
Patch number	+0.07 $year^{-1}$	+0.56 $year^{-1}$

Two main components of the fragmentation process were clearly separated between the two periods. During the first period of habitat loss (1890–1957), forest area per year decreased about 170 times faster than during the second period (1957–1989) (Table 3). In that time ca 0.17% of forest cover was lost every year. Also, the rate of decrease of the interior area, which could be most important for many organisms, was also the greatest during this first period (Table 3). Moreover, the fast decrease in forest ecotone area and perimeter length during the first period were replaced by an increase of both characteristics during 1957–1989. On the other hand, the increase of forest patch numbers related to fragmentation per se in the study area, was 8 times faster during the second period as compared to the first one. However, the reduction of average patch size was faster during the first period.

4 Discussion

The process known as "habitat fragmentation" comprises many processes of habitat transformation, which most commonly are highly correlated. Fahrig (2003) showed that habitat changes commonly called "fragmentation" consist of two main processes: habitat loss and fragmentation per se. In most of studies conducted in a real landscape, these two processes are strictly correlated, thus it is difficult to study the effect of habitat loss independently from habitat fragmentation and vice versa. For this reason, the clear separation of habitat loss and fragmentation per se in the studied plot seems to be the most interesting result of our analysis.

In this area habitat loss took place mainly during the first period (1890–1957), when reduction of the afforested area reached ca. 30 ha $year^{-1}$. During this period, the process of habitat loss was very intense while that of fragmentation was low and only 5 new forest patches appeared during 67 years. Such a pattern of deforestation could be expected, as from the middle of XIX century to 1946 forest cover in Poland decreased. This decrease was due to World Wars, as well as wasteful exploitation of forests during inter-war periods (Olaczek 1976, Broda 2000). It is very surprising, however, that habitat loss was not coupled with the creation of new patches, because such a pattern is frequently observed (e.g. Ružičková 2003).

In the second period (1957–1989), reduction of forest cover almost ceased. Only 6 ha of forest disappeared during the 32 year time period and forest complexes were divided into smaller ones (Table 3). However an increase in forest cover could be expected during this period because soon after World War II, new afforestation took place. In this period the total forest cover in Poland increased (Olaczek 1976).

During the intense reduction of the habitat area with restricted fragmentation per se taking place during the first period, decline occurred in the ecotone area and interior area. The proportion of forest interior to its size also declined. However, the rate of decrease of the forest interior was about 3 times faster than the reduction of the ecotone area. At the same time, we recorded the fast reduction of the forest perimeter in the studied plot (up to 1 km year^{-1}). Such changes in forest perimeter as well as the shape index indicate high anthropopressure, as Forman (1995) presented, that patches with intense human activity are least elongated and convoluted.

It seems that this pattern of habitat fragmentation is a distinctive feature for the much larger area of North Mazowsze. Taking into consideration the history of the studied region, a very high deforestation rate was observed in XIX century. In ca 1830 forest cover of this area was estimated to be between 10 and 30%. Forest clearing took place more than ever after 1861, when social changes occurred (granting peasants the right to own property), and new lands for agriculture became necessary (Romanowska 1934). Changes that occurred from the end of XIX and beginning of XX centuries are already analyzed in this paper.

Our study area is a small part of one of the geobotanical regions of Mazowsze classified by Plit (1996). She provides forest coverage data for this region in 1889–1902 as 10% forest and ca 5% young forests and successions, in 1930–1938 – 5% forest and 2% young forests and successions, and in 1980–1990 – 6% forest and 4% young forests and successions. Our data are very similar (cf. Table 1). Some discrepancy in forest cover nowadays (10% total in Plit's data vs ca 5.6 in our study) could be explained by the fact that Plit (1996) included the presence of young forest in her studies. These young forests were probably not presented as forests in the map we analyzed in our study. Results provided by Plit (1996) suggests that observed habitat loss in the studied location took place during the First World War, and in interwar period, and was connected both with high demand of timber, wasteful exploitation of forests (time of the Great Crisis), as well as the need for agricultural land (Broda 2000).

Similar changes for habitat loss, were also observed for the Kielce region in southern Poland. Forest cover in this region in 1890 was 27.3%, 1930 – 21.5%, 1950 – 21.8%, and in 1970 – 25.5% (Szymański 1993b). Thus the deforestation rate in 1890–1950 in the Kielce area was 0.11%. This figure is similar to the 0.17% deforestation rate observed during the same time period in the studied area in North Mazowsze. Unfortunately, no data are provided about changes in patch number and their characteristics. Such changes in forest cover in the last century are not only found in Poland. Bastian and Bernhardt (1993), described anthropogenic landscape changes in Central Europe. They stated that massive deforestation started in the VII–XIII centuries, but during the last one hundred years, due to high agricultural production, landscapes become more homogenous with a dominance of agriculture.

On the basis of analyzing the historical maps, we described the pattern of forest fragmentation in the studied area. However, an important question arises: what are the ecological consequences of the specific pattern of landscape transformation observed over the last 100 years? It is impossible to determine the impact of the fragmentation process on forest dwelling organisms without faunal data from earlier periods and without modeling their population dynamics. However, Fahrig (2003) concluded that habitat loss has many more negative consequences for biodiversity compared to fragmentation per se. Therefore, it was in the first period in our study, when the forest habitat decreased rapidly and most negatively affected those specialized forest faunal species and species requiring large, untouched forests.

For example, nowadays two large carnivores, the wolf (*Canis lupus*) and lynx (*Lynx lynx*), inhabit the adjacent Piska Forest (forest located ca. 50 km NE from the studied site), and other vast and well-connected forests of eastern Poland, but they do not inhabit our study area (Jędrzejewski et al. 2004, Niedziałkowska et al. 2006). Similar patterns of species distribution were recorded for many forest dwelling birds (Sikora et al. 2007). It seems that such distribution could be connected with the decrease of forest cover in this area. One example is the hazel grouse (*Bonasa bonasia*) or capercaillie (*Tetrao urogallus*) which occurred in central Poland (probably also in the studied area), but became extinct in the XIX century (Tomiałojć 1990), when massive deforestation took place. This indicates that habitat loss in the selected region has important biological consequences.

The relatively small number of all forest patches in 1890 and 1957 could also deteriorate landscape connectivity, since small patches scattered in the landscape significantly decrease the average distance between patches and may increase the dispersion of forest dwelling organisms that avoid crossing open landscape (Goodwin and Fahrig 2002, Creegan and Osborne 2005). During the second period, many small patches appeared that could increase the connectivity of forest habitat. It is also possible that the process of fragmentation per se observed in 1957–1989 increased the landscape capacity for species preferring forest edges. Cumulative forest border and ecotone area increased during the second period. This increase means that the number of forest edge species (and/or their abundance) could have increased despite the overall decrease in forest cover.

In 1989, the forest cover of the studied landscape was 6%. However, using this value to assess the habitat capacity for some of the forest dwelling species may lead to bias. We recorded that less than 50% of the area currently covered by forests had woodlands growing in the same locations 100 years ago. Therefore, effective forest coverage for species characterized by low dispersal abilities seems to be half of the actual forest area in the landscape. In our opinion, this finding has great importance in evaluating habitat amount and landscape capacity. The results show that ignoring the landscape's history may lead to overestimating suitable habitat coverage for some forest species (e.g. Schrott el al. 2005). It seems that data on landscape history and forest habitat continuity should be taken into account when planning the protection of forest biodiversity in the modern landscape.

For species characterized by low dispersal abilities (e.g. some plant species, invertebrates – Dzwonko 2001, Ranius and Hedin 2001), recently created forest patches (also known as recent woods – see Dzwonko 2001) isolated from the ancient forests are useless. Forest continuity may be a crucial characteristic for the distribution and occurrence of many specialized forest species (Sverdrup-Thygeson 2001, Jonsell and Nordlander 2002, Penttilä et al. 2006). We found that 47.7% of all the currently afforested areas constitute sites where forests previously occurred. This value seems to be quite high for an area which has been utilized by agriculture for centuries. We have found similar data for the Kujawy region in Poland, located west of our study site, with landscape strongly transformed to agriculture. In three studied subregions Degórska (1996) found that only 2%, 7%, and 46% of forest occurred in the same place during the last two hundred years.

From an ecological point of view, how the planning of new afforestation is carried out, is important. In the planning process it is especially important to take into consideration species with low dispersal abilities, or species which avoid crossing open landscape. New forests should be planted very close to forests which are already present. This closeness helps create large patches with considerable interior area, as well as helps facilitate dispersal from the older part of a forest. Fortunately, most of the new forests in the studied location are connected with old forest (cf. Fig. 1). However Olaczek (1976) notes that new afforestations frequently are planted without any connection to existing forests. In his opinion such an increase in total forest cover will not stop fragmentation of forest nor lead to the creation of large forests. Thus in new afforestations, both historical aspects of forest presence over time, as well as current forest distribution should be taken into consideration.

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