Acta Theriologica 44 (1): 67–75, 1999.
PL ISSN 0001–7051

Relationships between density of brown hare *Lepus europaeus* and landscape structure in Poland in the years 1981–1995

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Panek M. and Kamieniarz R. 1999. Relationships between density of brown hare *Lepus europaeus* and landscape structure in Poland in the years 1981–1995. Acta Theriologica 44: 67–75.

The relationships between the density of brown hare *Lepus europaeus* Pallas, 1778 and landscape structure were analysed on the basis of data collected for 11 study areas between 1991 and 1994, and hunting reports from all the 49 provinces of Poland covering the period 1981–1995. The average autumn density of hares in study areas (8–28 ind/km^2, estimated by strip census) decreased with the number of forest edges and increased with the number of permanent cover areas per km of transects. In the provinces of the country, the hare abundance index (hunting bag, ranging from 0.07 to 5.18 ind/km^2) decreased with both the proportion of large fields and forests in all the years. The negative effects of large fields and forests on the hare abundance index increased in the study period.

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Key words: *Lepus europaeus*, population density, landscape structure

Introduction

The density and hunting bag of the brown hare *Lepus europaeus* Pallas, 1778 differ in various regions of Poland. The location of small and large hunting bag areas of this species suggests that the differences are related to such basic landscape features as forest cover and size of crop fields (Pielowski *et al.* 1993, Pielowski and Pinkowski 1995). Over the period of the last dozen or so years the number of hares in Poland has considerably decreased. The reasons for this decline have not been explained. As the most probable reason, increasing impact of disease and pollution factors has been mentioned. However, the impact seems to be dependent on local habitat conditions (Pielowski 1990, Pielowski *et al.* 1993). Thus, both the differences in the hare density in individual regions of Poland and the pattern of its changes in time may be related to differences in the landscape structure.

The objective of this study was to examine the relationship between the landscape structure (ie such features as size of crop fields, occurrence of permanent

cover and treestands, forest cover) and the density of hare population in Poland, and to estimate the changes in this relationship between 1981 and 1995.

Material and methods

The relationships between the hare density and the landscape structure were analysed on the basis of data collected for 11 study areas in the years 1991–1994 and hunting reports from all the 49 provinces of the country covering the period from 1981 to 1995.

The study areas of 90–200 km^2 were located in various regions of the country (Fig. 1). Agricultural landscape dominated in these areas, while forests accounted for 3–21% of the areas. The main crops were cereals (41–58% of the agricultural area), but in each area there where also beets and potatoes (10–20%), grasses (2–25%), and other crops. The study areas differed as regards the nature and intensity of agriculture, as judged by the size of crop fields and the occurrence between them of such structures with permanent spontaneous vegetation as strips, ditches, roadsides and other types of idle land. The same group ran the hunting management on all of the study areas, therefore the same rules regarding hunting were followed on all of them.

The hare density in these areas was estimated annually in November by strip census (Pielowski 1969). Census strips were 100 m wide and were made of a line of 7 persons. The length of census routes in individual areas was from 39 to 76 km. For analyses, average hare densities from 4 years have been used, which permitted to eliminate the effect of changes from year to year.

The agricultural landscape structure in each study area was determined in the winter of 1994, by random line transects of 30 km that crossed crop field areas (parts of strip census routes). When making the transects all crossed crop fields and structures with permanent spontaneous vegetation

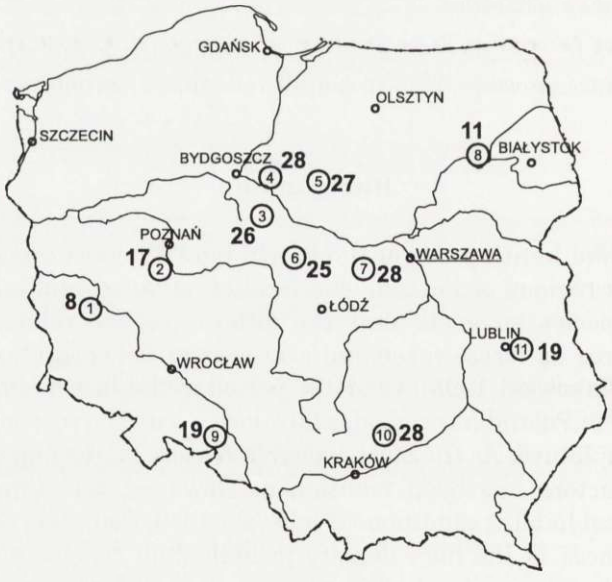

Fig. 1. Location of 11 study areas in Poland and average autumn densities of hares (individuals per km^2 of field area) in these areas in the years 1991–1994. 1 – Nowa Sól, 2 – Czempiń, 3 – Kruszwica, 4 – Chełmża, 5 – Rypin, 6 – Krośniewice, 7 – Sochaczew, 8 – Łomża, 9 – Biała, 10 – Pińczów, 11 – Lublin.

(balks, strips, ditches, roadsides, remises and fallow areas) were counted. Structures with spontaneous vegetation were divided to treestands, permanent cover areas without trees more than 1 m wide and balks, ie unploughed strips with permanent herbaceous vegetation usually 0.3–0.6 m wide located between grounds of different owners. It was assumed that a crop field was a stretch of land where single type of crop was grown (eg, cereals, alfalfa etc) or which was ploughed, and which was divided from other similar stretches of land by another crop or ploughed stretch of land, or by a structure with spontaneous vegetation wider than 1 m (then usually other than balk). The occurrence of forests in the study areas was assessed using 1:25 000 maps with the map graticule of 2 × 2 km. A count was taken how many times the map graticule lines crossed edges of forests (> 10 ha). The occurrence of the above named variables determining the landscape structure was described as their number per km.

The hunting reports used in the study referred to the hunting districts leased by hunting clubs and accounted for 90% of hunting grounds in Poland or about 80% of the country's area. The reports included information on the total area of the districts, both forest and field one, divided into private and state farm fields. The division into the two types of ownership may be identified with the division of crop fields into broken-up ones (from < 1 ha to 10 ha – small fields) and large ones (usually > 10 ha – large fields). The proportion of forests (forest area/total area) and the proportion of large fields (state farm area/field area) in individual provinces were calculated for each year. These proportions were practically stable during the study period. As an index of the hare abundance in individual provinces the hunting bag per km^2 of fields in a given year was used. According to Pielowski *et al.* (1993) the hunting exploitation of the hare population in Poland was taking place in accordance with constant rules (up to 15% of autumn numbers), therefore the hunting bag was a good indicator of this species' abundance.

Results

The ranges of landscape variables in 11 study areas and correlations found between some of these variables are shown in Table 1. Average autumn densities of hares in these areas, for the years 1991–1994, were from 8 to 28 individuals per km^2 of fields (Fig. 1). The densities were negatively correlated with the number of treestands and forest edges per km (Table 2). In stepwise multiple regression analysis (forward method) the number of forest edges per km showed a negative effect, whereas the number of permanent cover areas per km had a positive effect. Changes in these variables explained 93% of the variation in the hare density

Table. 1. Ranges of variables describing the landscape structure in 11 study areas of Poland (from line transects) and correlations (coefficient r) found between them (ns – $p > 0.05$, * – $p < 0.05$, ** – $p < 0.01$, *** – $p < 0.001$).

Variable	Number per 1 km	Correlations between variables			
		2	3	4	5
1. Fields	5.7–17.7	0.884 ***	0.602 *	–0.710 *	ns
2. Balks	0.6– 5.6	–	ns	–0.738 **	ns
3. Permanent cover	0.9– 4.5	–	–	ns	ns
4. Treestands	0.2– 1.1	–	–	–	ns
5. Forest edges	0.1– 0.5	–	–	–	–

Table. 2. Results of simple correlations (coefficient r) and stepwise multiple regression analysis (partial regression coefficient a) between average autumn density of hares (individuals per km^2 of fields) and variables describing landscape structure (number of elements per km of transect) in 11 areas of Poland in 1991–1994 (ns – $p > 0.05$, * - $p < 0.05$, ** – $p < 0.01$, *** – $p < 0.001$).

Variables	Correlations (r)	Multiple regression (a)
Fields	ns	ns
Balks	ns	ns
Permanent cover	ns	2.85 **
Treestands	−0.672 *	ns
Forest edges	−0.912 ***	−54.4 ***
Constant	–	25.3
R^2	–	0.931

between study areas (Table 2). The other variables proved to be not significant, although after removal of the effect of forest edges, the number of crop fields gave a positive effect and the number of treestands gave a negative effect, both close to significance (partial correlation coefficients: 0.603, $p = 0.06$ and −0.521, $p = 0.1$, respectively), which disappeared (partial correlation coefficients: 0.117, ns and −0.197, ns, respectively) after inserting stronger correlated number of permanent cover areas (partial correlation coefficient: 0.820) into the regression equation. These changes probably resulted from mutual correlations between some habitat variables, eg the number of permanent cover areas was positively correlated with the number of crop fields (Table 1).

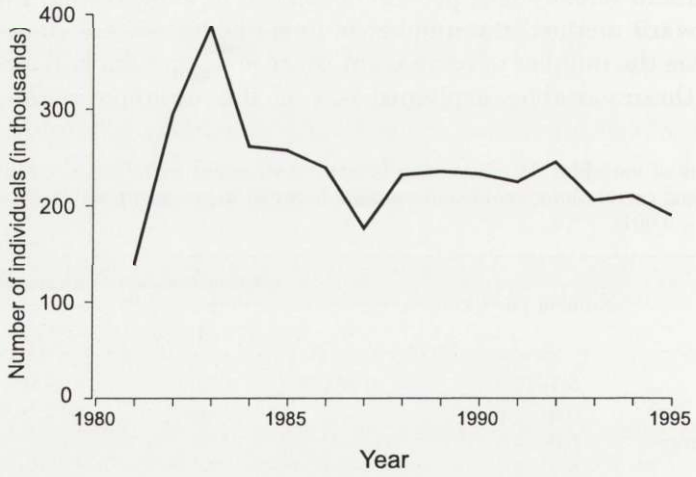

Fig. 2. Changes in the hunting bag of hare in Poland between 1981 and 1995.

Table. 3. Multiple regressions between an index of hare abundance (hunting bag per km^2 of fields, transformed to logarithms) and proportion of large fields and forests for 49 provinces in Poland between 1981 and 1995 (ns – $p > 0.05$, ** – $p < 0.01$, *** – $p < 0.001$).

Year	Partial regression coefficients		Constant	R^2
	Large fields	Forests		
1981	−1.02 ***	−0.92 ns	0.307	0.421
1982	−0.98 ***	−1.32 **	0.698	0.525
1983	−0.73 ***	−1.59 ***	0.866	0.562
1984	−1.32 ***	−0.97 **	0.663	0.700
1985	−0.99 ***	−1.05 ***	0.625	0.657
1986	−0.98 ***	−0.96 ***	0.574	0.668
1987	−1.48 ***	−0.87 **	0.481	0.745
1988	−1.31 ***	−1.04 **	0.593	0.673
1989	−1.17 ***	−1.28 **	0.651	0.637
1990	−1.43 ***	−1.37 ***	0.732	0.700
1991	−1.79 ***	−1.16 **	0.711	0.747
1992	−1.57 ***	−1.21 ***	0.721	0.762
1993	−1.52 ***	−1.34 ***	0.659	0.756
1994	−1.53 ***	−1.48 ***	0.708	0.751
1995	−1.71 ***	−1.31 ***	0.617	0.676

An overall hunting bag of hares in Poland increased between 1981 and 1983, while slowly declined between 1984 and 1995 (Fig. 2). In various provinces and years the hare bag was from 0.07 to 5.18 ind/km^2 while the maximum value for various years was from 9 to 56 times greater than the minimum one. The proportion of forests in various provinces ranged from 0.11 to 0.49, whereas the proportion of large fields accounted for 0.01 to 0.59 of field areas. A significant year effect on the relationship between the hare bag (after logarithmic transformation) and above landscape variables was found (ANCOVA, $F_{14,705} = 3.782$, $p < 0.001$), then separate analyses for each year were performed. In all the years, the hare bag decreased with the increase both in the proportion of large fields and forests (only in 1981, the partial regression coefficient for the proportion of forests was not significant, $p = 0.06$). Differences in these two landscape variables explained from 42% to 76% of the variation in the hare bag between provinces, depending on the year (Table 3).

In order to estimate the changes in the relationship between the hare bag and the landscape structure in the study years, analyses of the changes in above partial regression coefficients (Table 3) in time were carried out. The partial regression coefficients for the proportion of large fields declined between 1981 and 1995, ie the negative effect of the occurrence of such fields on the hare bag increased in that period (Fig. 3). The partial regression coefficients for the proportion of forests did not change significantly between 1981 and 1995 ($r = -0.365$, $p = 0.2$). However,

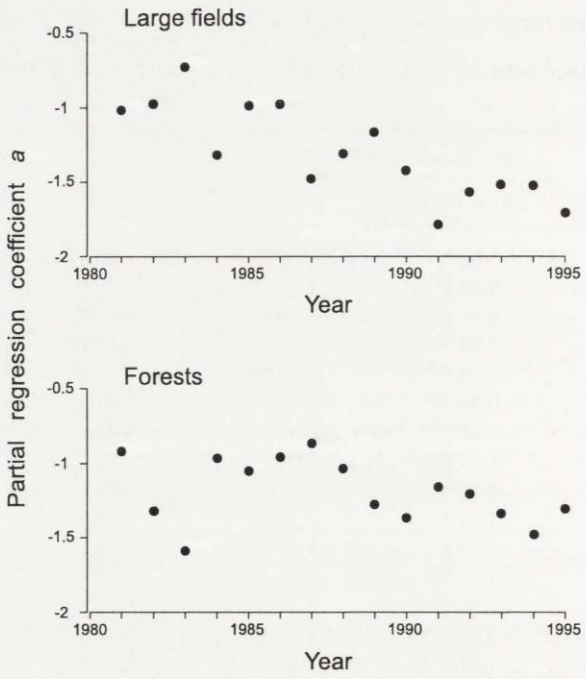

Fig. 3. Partial regression coefficients (a) from multiple regression between hare abundance index (hunting bag per km^2 of field area) and the proportions of large fields and forests for 49 provinces of Poland in the years 1981–1995 ($r = -0.826$, df = 13, $p = 0.0002$ for large fields, and $r = -0.817$, df = 10, $p = 0.001$ for forests in 1984–1995).

after excluding the data for the period from 1981 to 1983, the partial regression coefficients for the proportion of forests declined in subsequent years 1984–1995, ie the negative effect of forests on the hare bag increased in that period (Fig. 3).

Discussion

The negative impact of forests on the hare density on neighbouring fields may be related in the first place to the pressure of predators, in particular the red fox. According to Goszczyński (1985), the penetration of fields by foxes and some other predators was greater in forest-neighbouring areas than on open fields. The fox predation was considered an important factor in the hare population dynamic (Goszczyński *et al*. 1976, Pielowski 1976, Spittler 1976, Goszczyński and Wasilewski 1992, Reynolds and Tapper 1995). Wasilewski (1991) found that in areas with a field-forest mosaic, the survival of young hares was lower than in forest-free areas, but the survival of adult hares was higher. This he explained by lower losses due to agrotechnical measures thanks to periodical moving of hares to forests. Such

an use of mid-field forests was also observed by Bresiński (1983). Nevertheless, the positive impact of forests as temporary shelters was probably usually lesser than their negative influence due to an increased pressure of predators.

The observed negative impact of forests on hare density increased between 1984 and 1995, which may be related to the increase in the number of foxes. This predator's population has been increasing in Poland at least since the end of the 1980s, especially in the western, more wooded part of the country (Kamieniarz 1996). Thus, the increase in the fox number may be one reason for the observed decline in the hare population in Poland.

In the 1970s, Bresiński (1976, 1983) did not find any differences in local densities of hares on small and large fields in western Poland, and Pielowski and Raczyński (1976) claimed that differences in the size of fields did not cause any significant differences in the living conditions of the hare. However, absence of any differences in local densities on fields of different sizes does not rule out the existence of such differences between areas of different field sizes. In addition, the negative impact of large fields on the hare density observed here increased in the 1980s and early 1990s, which means that it may have been not significant earlier.

Crop fields of large acreage have a negative impact on hares' use of space and on their feeding resources. Such a field structure makes for limited availability of various crops suitable for feeding in home ranges of hares. Also, field edges, often containing strips of wild vegetation including species preferred by hares as food, are then less available (Homolka 1983, Frylestam 1986, 1992, Tapper and Barnes 1986, Kovacs and Buza 1992, Meriggi and Alieri 1992). The preference of hares for field edges and a more stable spatial structure of a population in areas where fields are more broken up were observed in Poland by Lewandowski and Nowakowski (1993). According to Endler and Jezierski (1995), small fields in Poland provide hares with better feeding conditions because the diet of hares turned out to be more diversified in areas with small fields than with large ones. Poor feeding resources may be a reason for low reproduction of hares (Hansen 1992).

Various mid-field treestands and areas of permanent cover are preferred by hares also as shelters, especially out of the vegetation season (Bresiński and Chlewski 1976, Prigioni and Pelizza 1992). However, in our study areas, the density of hares increased only with the number of permanent cover areas without trees, whereas the number of treestands proved to be not significant after removal of effects of other habitat variables. Also Bresiński and Chlewski (1976) and Bresiński (1983) found that local densities of hares in their study areas were not correlated with the occurrence of treestands. It seems that mid-field treestands may have a certain negative effect on the hare density by making it easier for various predators to occupy agricultural landscape, whereas such an effect may be smaller in the case of permanent cover without trees.

Under the conditions prevailing in Poland, large fields of state farms are usually characterised by greater intensity of agrotechnical measures as compared to small

fields of private farmers. Furthermore, in many regions of the country with a large proportion of large fields, also small fields seem to be characterised by more intensive land cultivation than in the regions with only small, broken up fields. Agrotechnical measures, such as soil tilling, mowing and pesticide spraying are known as important causes of hare mortality, especially of young animals (Kałuziński and Pielowski 1976, Pielowski 1975, 1990).

The observed, increasing negative effect of large fields on the hare density indicates to an ever increasing impact of detrimental environmental factors on the dynamic of hare populations in regions with fields of such a structure. This may be related to the decreasing diversification of the agricultural landscape or the increasing intensity of agrotechnical measures. The observed increase in the negative impact of large fields on the hare density may be also related to factors independent of agriculture to which, nevertheless, hares are more susceptible in areas of intensive agricultural economy, eg pollution and disease factors named by Pielowski (1990) and Pielowski *et al.* (1993)

Acknowledgments: We are grateful to W. Bresiński, Z. Pielowski and M. Pinkowski for help in data collection and for critical review of the manuscript. Financial support for this research was partially provided by the Committee for Scientific Research within the project 6 P205 093 07.

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Received 1 September 1997, accepted 10 November 1998.