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Research Article

Effects of factors associated with the decline of brown hare abundance in the Vojvodina region (Serbia)

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Abstract

The decline of brown hare populations has been observed throughout Europe for decades. The situation is similar in Serbia where the brown hare population dropped significantly. Vojvodina region in the northern part of Serbia represents a typical farmland habitat with over 80% of the agricultural area. Over the last decades, there were noticeable changes in agricultural production, climate, and fluctuation of the predator abundance. Therefore we assessed the effect of crops, fox abundance, and climate variables on brown hare using multiple regression analyses for the period of 26 years. The percentage of root crops and alfalfa and clover seemed to have a positive effect while the percentage of meadows and maximum measured summer temperatures had a negative effect on the brown hare population. Other variables didn't have a significant impact however fox abundance should be taken into account since the population highly increased over the last decade.

Introduction

The European brown hare (*Lepus europaeus*) is one of the most recognizable small game species of farmland habitats in Europe. While still common it has suffered a gradual decline since the 1960s due to several factors. Factors that are mostly attributed to this decline are changes in habitat and agriculture practices, predator numbers, and climate (Smith et al., 2005).

In most countries in Europe, the landscape has dramatically changed during the last century due to changes in agricultural practices. The process called agricultural intensification is often defined as achieving as high an output per unit of land area with the maximum efficiency possible (Tivy, 1990). Agricultural intensification has led to effects such as reduction of grass areas, larger fields, decreasing crop diversity, increasing input of fertilizers, and pesticides (Tscharntke et al., 2005). These changes have affected brown hare populations throughout Europe (Tapper and Barnes, 1986; Schmidt et al., 2004; Smith et al., 2005; Báldi and Faragó, 2007; Santilli and Galardi, 2006; Kamieniarz et al., 2013; Lush et al., 2014; Panek, 2018). Also, one of the assumptions is that brown hare is affected by the lack of weeds in areas with intensively cultivated crops (Tapper and Barnes, 1986; Hackländer et al., 2002).

It is known that the brown hare is part of the diet of most of the carnivores that inhabit this type of habitat. Among predators, red fox has frequently been recognized as one of the main explanations for the decline in hare numbers (Reynolds and Tapper, 1995; Slamečka et al., 1997; Schmidt et al., 2004; Panek et al., 2006). Hell et al. (1997) noted the increase of predation pressure of red fox on brown hare during the last century. Rodents, lagomorphs, birds, carrion, insects, and fruits are considered the main food of red foxes (Jędrzejewski et al., 1989; Lindström, 1989; Doncaster et al., 1990). The stake of brown hare in the fox diet varies in Europe and depends on many factors such as habitat conditions and the proportion of available food sources. Also, notable is the trend of increasing the density of foxes in most of Europe, mainly due to rabies vaccination, a reduction in hunting and increasing urbanization (Goszczyński et al., 2008). However, some papers (Santilli and Galardi, 2016) also found little relationship between brown hare and fox abundance so this factor needs to be further investigated.

The relationship between climate variables and the brown hare population was also found however it seems to be very complex. The temperature has been positively associated with brown hare abundance, especially affecting litter size and prolonging breeding season (Hewson and Taylor, 1975; Meriggi and Alieri, 1989). High precipitation has been noted to negatively affect the brown hare numbers (Smith et al., 2005; Wieren et al., 2006; Rödel and Dekker, 2012), although low rainfall during summer also had a negative effect (Frylestam, 1979).

Brown hare is a common steppe type of game that adapted and became typically associated with agricultural ecosystems (Vaughan et al., 2003; Jennings et al., 2006) which cover most of the study area in Vojvodina (Serbia). Papers about the status of brown hare in Serbia (and the Vojvodina region) show the effect of previous management practices, climate factors, and red fox abundance on the population (Ristić et al., 2012; Beuković et al., 2013; Popović et al., 2014; Ponjiger et al., 2019). To some extent, they explain certain factors of the brown hare's decline, but there is the need for reviewing other factors often attributed to hare decline.

In this study, we analyze the simultaneous associations between agricultural land-use (percentage of crop categories), the number of red foxes harvested, climate effects, and the population of European brown hare in the Vojvodina region (Serbia) during 26 years.

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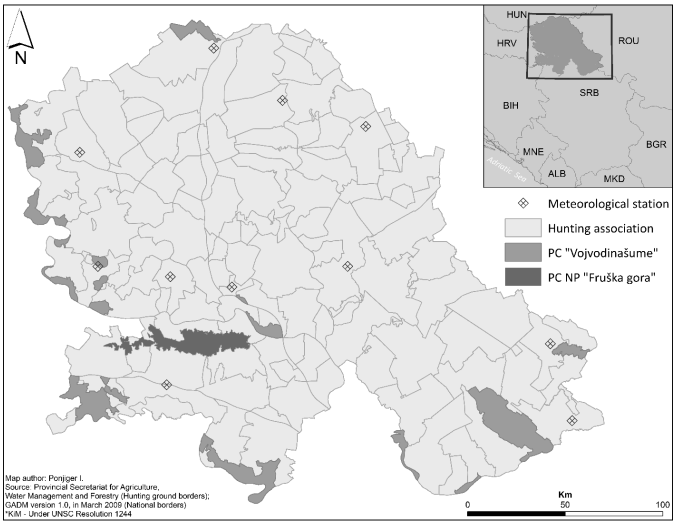

Figure 1 – The area of AP Vojvodina and hunting grounds managed by hunting associations that are the subject of the research. A colour version of this figure can be viewed in the online version of this article.

Materials and methods

Study area

The Republic of Serbia has a total of 8828528.29 ha of hunting areas. In the northern part of Serbia, the Autonomous Province of Vojvodina has a total of 2152695.60 ha of areas considered as hunting grounds. Hunting associations manage 120 hunting grounds with an area of 2006910.85 ha (The Law on Game and Hunting, Official Gazette of RS, 18/2010). The subject of this research was hunting grounds managed by hunting associations, mainly because of the similarity of habitat conditions and game managed (Fig. 1). Besides two low mountains Fruška Gora (539 m) and Vršačke Planine (641 m), Vojvodina is mostly lowland, flat region. The largest part of the area is agricultural land which covers about 83.3% of the total area, while forests cover about 6.7%. Infertile land accounts for about 10% (built-up areas and inland water areas) (Statistical Yearbook of the Republic of Serbia, 2017). This type of agricultural habitat is mostly suitable for managing roe deer, brown hare, pheasant, and grey partridge, which are the most abundant species in these hunting grounds. Other areas and hunting grounds are managed by the public enterprise "Vojvodinašume" and the Fruška gora National Park. These hunting grounds were excluded from the research because of the differences in the habitat conditions, and the type of game and management. These hunting grounds are mainly heavily forested areas and manage different types of game, such as red deer, wild boar, fallow deer, and mouflon. Also, these hunting grounds are mostly fenced.

Data

The paper aimed to determine the factors affecting the fluctuation in the number of brown hare during the 26 years in changing agriculture and climate environment. Data on brown hare were obtained from the Hunting Association of Vojvodina based on hare spring counts in the period from 1993 to 2019. Spring counts are obligatory for all the hunting clubs that are members of the Hunting Association of Vojvodina. Spring counts are carried out annually at the end of February and throughout March in all of the hunting grounds. The method of counting is similar for all hunting grounds. Hare numbers on individual hunting grounds are determined by utilizing the strip-transect method. Hares are counted on three transects with estimated highest, average and lowest densities which in total represent 10% of the total hunting ground area. The practice has shown that this way gives a realistic assessment of the population for the entire hunting ground. Data from all hunting clubs are collected by the Hunting Association which is then processed and appropriate management measures are recommended. Hunting was carried out throughout the observed period. We provided the data on hunting but did not include cull in the final analysis since cull quotas are closely related to population numbers and are determined based on spring counts. Also, to make sure the hunt is justified at the beginning of hunting season after the first hunt analyses are carried out by the Hunting Association whether hunting should proceed or not. Hunting season slightly changed throughout this period. Today hare hunting season begins on the 15^{th} of October and ends on 30^{th} November. Data on fox cull was given since there is no available data on the fox population. However, fox culling quotas are regulated in individual hunting ground annual management plans and thus can be taken into account as a reliable source for estimating the population abundance. Hunting bags were already proven to be a potential method for monitoring fox population (Heydon and Reynolds, 2000; Heydon et al., 2000; Goszczyński et al., 2008; Porteus et al., 2019). Data on annual crops/harvested areas were obtained from the Statistical Office of the Republic of Serbia. Available data were grouped by similar types of crops for the purpose of this paper (Tab. 1).

Data on climate variables were obtained from Meteorological Yearbooks published by the Republic Hydrometeorological Service of Serbia. Mean temperature, maximum and minimum recorded temperature, and precipitation were used from 11 climatic stations. In order to determine the reason for the brown hare decline in the Vojvodina region, we defined ten variables that can be divided into three groups (Tab. 2). Agricultural land use (crops) with four variables, five climate variables, and one variable concerning predator impact. One variable (industrial crops) was excluded due to collinearity.

Statistical analysis

All analyses were carried out using the IBM SPSS (ver. 23). Multiple regression models were applied to assess the relationship between the spring brown hare numbers (t+1) and the effects of selected habitat variables. To generate predictive equations for the significance, nonsignificant variables were removed from the final regression model. All

Table 1 – Description of model variables used in the analyses of European brown hare annual spring counts records (t+1) from Vojvodina region, 1993–2019.

Variable	Description
Cereals	% of winter and spring cereals (wheat, corn, barley, oats, rye)
Industrial crops	% of sunflower, rape, soybean
Root crops	% of sugar beat, carrot, potato
Meadows	idem
Alfalfa and clover	idem
Fox cull	annual number of red fox culled
Mean annual precipitation	in mm
Mean precipitation March-September	in mm
Mean annual temperature	in °C
Maximum recorded annual temperature	in °C
Minimum recorded annual temperature	in °C

Table 2 – Descriptive statistics of the ten variables used in the study (Industrial crops excluded due to colinearity).

Variable	Mean	Range	Std. Dev.
Cereals [%]	63.39	9.07	2.27
Root crops [%]	4.66	3.24	0.82
Meadows [%]	1.91	0.86	0.20
Alfalfa and clover [%]	3.40	1.34	0.37
Fox cull	9089.54	5980.00	1586.63
Precipitation annual [mm]	627.94	618.60	151.27
Precipitation March-September [mm]	408.63	479.00	126.85
T_{mean} [°C]	11.70	2.90	0.91
T_{max} [°C]	38.65	8.40	2.07
T_{min} [°C]	−18.95	20.00	4.74

Table 3 – Results of multiple linear regression analysis, with brown hare spring population ($t+1$) as the dependent variable - y (or criteria).

Variable	β	S.E.	t	Sig.	Tolerance	VIF
Constant	3.587	1.669	2.150	0.045		
Root crops	0.482	0.145	3.319	0.004	0.769	1.301
Meadows	−0.873	0.254	−3.435	0.003	0.520	1.925
Alfalfa and clover	1.128	0.232	4.854	0.000	0.611	1.637
T_{max}	−1.240	0.438	−2.828	0.011	0.731	1.368

R^2=0.785, Adjusted R^2=0.739
Std. Error of the Estimate=0.04214
F=17.298, Sig.=0.000, N=26

data were log-transformed. Multicollinearity was checked using a correlation matrix (Pearson's bivariate correlations) on all dependent and independent variables. Variables that were above .80 coefficient were removed from the regression. This way annual hare cull and industrial crops were excluded from the regression analysis. While it is evident that hare cull affects the population it should be noted that it is closely related to the population number as mentioned in the previous section. Therefore, it was excluded in order to test other variables. Multiple linear regression requires the relationship between the independent and dependent variables to be linear. The linearity assumption was tested with scatterplots to make sure the relationship was linear. Normal distribution was determined via the Kolmogorov-Smirnov test of normality and using histograms of data. We performed Multiple Linear Regression analysis using the stepwise method, to evaluate the effect of mentioned variables on hare population (t+1). Independent variables were selected by the stepwise procedure. To avoid multicollinearity, we included collinearity statistics (Tolerance and VIF). Tolerance should be >0.1 (or VIF<10) for all variables, which they are (Tab. 3). The Durbin-Watson d=1.629, which is between the two critical values of 1.5<d<2.5. Therefore, we can assume that there is no first-order linear auto-correlation in our multiple linear regression data.

Results

The average number of hares for the observed period was 250816.6 (Std. Deviation=45560.21, N=26). Annual numbers varied, however, a negative trend can be seen (Fig. 2). For comparison, the average hare count for the first 10 years was 273400.9, while for the last 10 years it was 212253.2. The maximum of hares counted was 326901 in 1995, while the minimum was 154990 in 2014. While the population fluctuated a drastic decrease is evident especially after 2010. On this basis, it was calculated that the average density for the same period was 12.5 individuals/100 ha.

Crop categories used (Fig. 3) show drastic changes in agriculture practices. Most notable is the rise in industrial crop areas. Even though this variable was dropped due to multicollinearity it is still evident that these changes affect the brown hare population, however, we couldn't show it statistically in the final model. Areas with root crops and alfalfa and clover had been decreased significantly, while cereals dropped around 10%.

A standard multiple regression analysis was performed to predict the effect of selected variables on the brown hare population in Vojvodina. Preliminary analyses were performed to ensure there was no violation of the assumption of normality, linearity, and multicollinearity. A significant regression equation was found with 78.5% (R^2) of the explained variance of the hare spring population (t+1), by the inclusion of 4 variables with significant regression coefficients (Tab. 3). Hare numbers increased with the increase of root crops and alfalfa and clover planted and decreased with the increase of the meadows and maximum summer temperatures. The final model excluded variables since they didn't seem to have a significant impact on the hare population. The VIF maximum value was 1.925 excluding serious multicollinearity risks.

Discussion

General consent is that habitat diversity is probably a key factor in brown hare abundance (Meriggi and Alieri, 1989; Smith et al., 2004). As agricultural land became a dominant type of habitat for brown hare it is noted that diversity of crops provides necessary food and shelter (Santilli et al., 2004, 2014; Cardarelli et al., 2011; Kamieniarz et al., 2013). Santilli and Galardi (2016) had shown that crop variety is a significant factor in hare abundance. As noted Vojvodina is a dominant agricultural habitat with over 80% agricultural land. Research in an intensively used arable land had shown that crops have a significant share in brown hare diet and thus influence the brown hare population (Reichlin et al., 2006). In the same research, it was found that most of the hare diet in different parts of the year consists mainly of wheat, sugar beat tubers, alfalfa, barley, and soy and it was most evident during May when over 83% of used plants were cultivated crops. The regression model for factors affecting the population of brown hare in the Vojvodina region partially confirms some of the previous research on this topic.

Our model showed that the annual abundance of root crops and alfalfa and clover had affected hare abundance. Pavliska et al. (2018) also found alfalfa and clover to be positively related with brown hare which is linked with diet analysis (Reichlin et al., 2006; Schai-Braun et al., 2015). The reduction of root crop areas was marked as one of the significant factors leading to the decline of brown hare in Denmark (Schmidt et al., 2004). Areas with alfalfa, clover, and root crops have continuously been decreasing in Vojvodina, thus having an impact on brown hare along with the increase of areas of other types of crops (cereals and industrial crops).

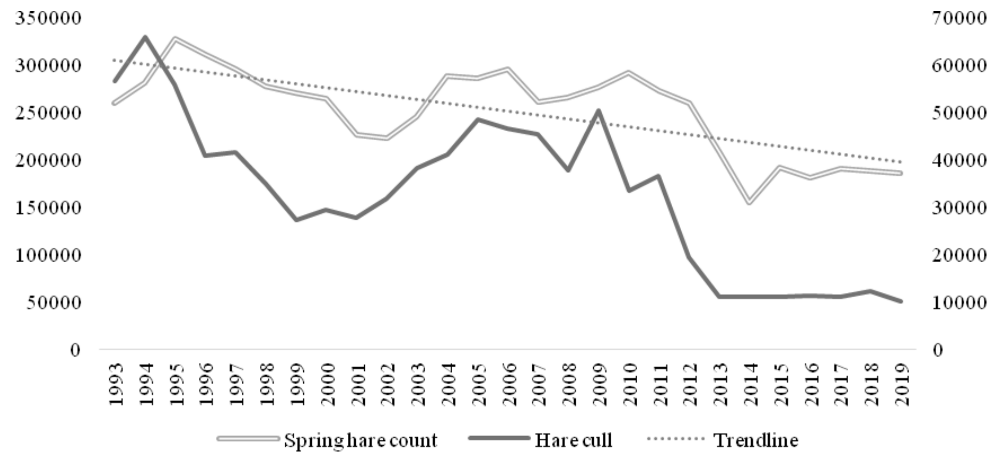

Figure 2 – Changes in the brown hare population in spring hare counts and annual cull (right axis) in Vojvodina region for the 1993–2019 period.

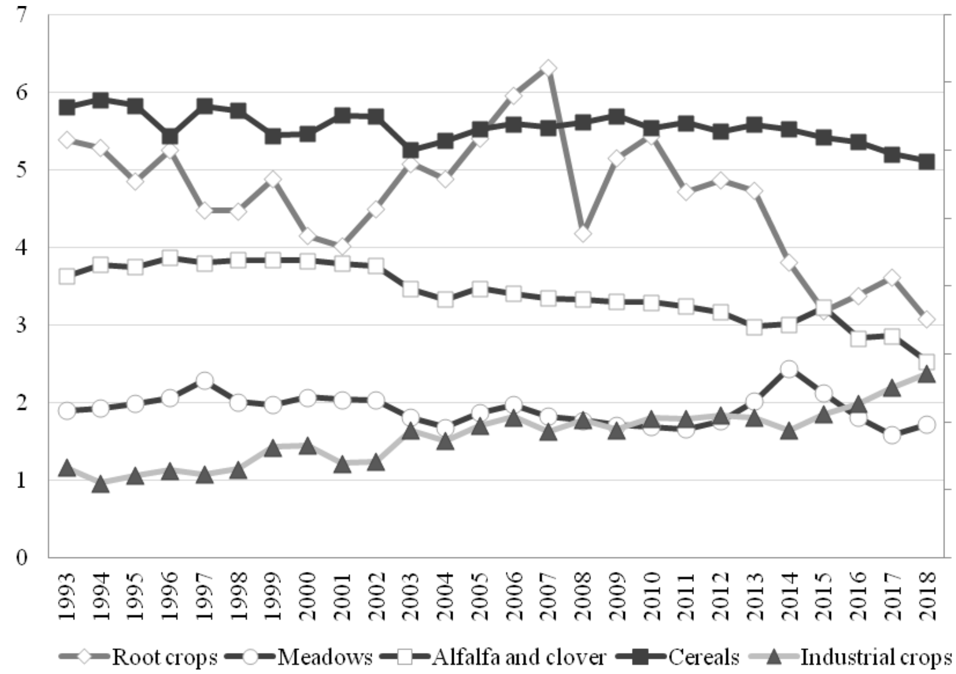

Figure 3 – Total areas of five crop categories in Vojvodina region (root crops, meadows and alfalfa and clover % on the left primary axis; cereals and industrial crops % on the right secondary axis).

While a common habitat for brown hare, grass fields seem to negatively affect hare population. It was found that this occurs in dominant agricultural areas (Frylestam, 1980; Pepin, 1986, 1987; Marboutin and Aebischer, 1996; Vaughan et al., 2003; Pavliska et al., 2018). The negative impact of grass patches among arable land on hare distribution may be attributed to predator avoidance. Grass fields have been proved to attract red foxes due to the abundance of small rodents (Russell and Storch, 2004). Our model also found meadows to be negatively related to brown hare. As mentioned above this is probably explained by predominant agricultural areas in Vojvodina and predator, mostly fox, abundance.

Previous studies show that the effect of climate variables is very complex and while climate alone cannot be solely attributed to hare decline it does effects other factors. The temperature was found to be positively correlated with hare populations (Meriggi and Alieri, 1989; Nyenhuis, 1995). Mild winters also positively affect hare (Hewson and Taylor, 1975; Hackländer et al., 2002). High precipitation was negatively linked with hare population but also low precipitation during summer months (Frylestam, 1979; Eiberle et al., 1982; Slamečka et al., 1997). Even though there is a trend of an increase of average annual temperatures and the occurrence of mild winters in Vojvodina these variables didn't significantly predict hare population. We found that maximum recorded summer temperatures negatively affect the hare numbers. While we didn't find the relation between precipitation and hares this result can be related to Tmax which is often attributed to dry heat waves during summer. Summer drought and its side effects such as diseases were also found to be the reduction factor by other authors (Frylestam, 1979; Eiberle et al., 1982; Slamečka et al., 1997; Santilli et al., 2004).

Many papers show the negative effect of predators as the cause of hare decline. Foxes are cited as the primary negative influence (Erlinge et al., 1984; Reynolds and Tapper, 1995; Panek and Kamieniarz, 1999; Vaughan et al., 2003). The risk of predation is complex and seems to increase with the decrease in habitat heterogeneity (Smith et al., 2004). We found no statistically significant influence of fox abundance on hare population. However, this is probably due to the fact that there have been certain changes between fox and brown hare population dynamics. Fox population is thought to be dramatically increased since the rabies vaccination in 2010 (Ponjiger et al., 2019). However, fox cull remained the same resulting in the increase of fox population to an unknown extent. This change in fox population and stagnation of fox cull resulted in the difficulty to determine the true effect of fox abundance on brown hare which is estimated as increased.

Cereals were positively associated with hare abundance (Smith et al., 2005; Santilli and Galardi, 2006). Large grain fields often decrease the diversity of available sources of food (Schmidt et al., 2004). Grain fields are preferred by brown hares because grain is an important element in their diet, especially winter cereals during winter and early spring (Tapper and Barnes, 1986; Reichlin et al., 2006). Cereals make up the majority of crops in Vojvodina (over 60%). However, possibly due to the abundance of cereals in the study area we found no significant impact on hare variability. Also, one shortcoming could be the lack of data on the percentage of winter cereals which are important during periods with a lack of other sources of food.

Industrial crops have previously been attributed as a negative factor (Santilli and Galardi, 2006). On the contrary, some of the crops classified as industrial, such as oilseed rape, have been pointed out as having a positive effect (Smith et al., 2005; Sliwinski et al., 2019). Since these crops are generally cultivated in wide monocultures, presumably, they are avoided by brown hare. Industrial crops were dropped from the regression model due to multicollinearity. However, there is a dramatic rise in the percentage of area cultivated by this type of crops.

The results of the present study indicate that the changes in crop variety and maximum summer temperatures could be linked to brown hare population dynamics in Vojvodina. This area deeply modified by agriculture also experiences a change in agricultural measures over the past few decades. The changes have an effect on brown hare, but also indicate the changes in population dynamics of other species present. Our study implies that hare population in Vojvodina is vulnerable during summer heatwaves. Also, a decrease of variety in agricultural crops, mostly of root crops and alfalfa and clover affects negatively. Therefore, habitat diversity tends to be an important element in the brown hare population management. A possible shortcoming of this study is the lack of data on the shift from small diverse fields into larger homogenous monocultures which is also a process that is happening in this region. Proper management of brown hare population in Vojvodina as a farmland area should aim for greater diversification of crops, monitoring of climate conditions, mostly during summer and predation control. This would lead to more accurate hunting quotas and sustainable hunting.

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