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HARE DYNAMICS IN PLAIN AREAS OF SOUTH BULGARIA: EFFECT OF HABITAT FEATURES AND PREDATOR ABUNDANCE

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Abstract

Modern agriculture often leads to a reduction in small game species and loss of biodiversity. The study area includes MG-14 (35 T) square of the Universal Transverse Mercator (UTM). The density of hares during the study period varied between 0.7–2.7 ind./km^2. Their number reported in 2014–2015 is significantly higher than in the other years. In 2018, the lowest hare density was reported in the study area. Most were counted in May. The density of hares was positively related to habitat diversity and negatively to Wild cat density.

Key words: *Canis aureus*, *Felis silvestris*, habitat heterogeneity, *Lepus europaeus*, Shannon index, *Vulpes vulpes*.

Introduction

A decrease in small game species has been reported in a number of studies in Europe (Kuijper et al. 2009, Ronnenberg et al. 2016, Sliwinski et al. 2019). European hare (*Lepus europaeus* Pallas, 1778) is an important representative throughout Europe, despite its declining populations (Reichlin et al. 2006, Zhelev et al. 2013, Cukor et al. 2018, Hacklander and Schai-Braun 2019, Schai-Braun et al. 2019). The decline in the species' density has been reported since the 1960s and 1970s (Edwards et al. 2000) and has continued into recent decades (Jennings et al. 2006, Reichlin et al. 2006, Takacs et al. 2009, Karp and Gehr 2020).

A number of studies have attributed the species' population decline to agricultural intensification and crop diversity decrease (Smith et al. 2004, Baldi and Farago 2007, Wrzesien and Denisow 2016, Canova et al. 2020). Other studies have highlighted the importance of shelters for young individuals, which can have a significant impact on certain physiological processes as well as survival (Hacklander et al. 2002, Zellweger-Fischer et al. 2011, Karp and Gehr 2020).

Changes in agricultural practices may also lead to changes in some of the hares' habits, such as an increase in home-range size (Smith et al. 2004, Schai-Braun et al. 2013). European hare live at shorter distances from their shelters, i.e. hedges, fences etc., in contrast to European rabbit (*Oryctolagus cuniculus* L., 1758) (Santili et al. 2013). In the absence of adequate shelter, they are forced to cover greater distances to reach food resources, hence the likelihood of predation increases (Petrovan et al. 2013, Canova et al. 2020).

The predation rate of European hare population and its preference for certain terrains seem to be largely related to the density of Red fox (*Vulpes vulpes* L., 1758) (Goszczynski and Wasilewski 1992, Reynolds and Taper 1995, Misiorowska and Wasilewski 2008, Cukor et al. 2018). Another important factor largely determining losses in hares is climate (Slamechka et al. 1997; Pikula et al. 2004; Smith et al. 2005; van Wieren et al. 2006; Beukovic et al. 2013, 2016).

The average European hare density in Bulgaria between 2012 and 2013 was 1.8 ind. per km^2 (Zhelev et al. 2013). The population density varied from 1.99 to 8 ind./km^2; in 60 % of the habitats, it was mostly less than 2 ind./km^2 (Zhelev 2015). As a result, Bulgaria ranks among the countries with low density of this hunting species.

The aim of this study is to trace the population dynamics of European hare in a low-density area and to identify some of the factors that limit it.

Material and methods

Study area

The study area is MG-14 (35 T) square of the Universal Transverse Mercator (UTM system, Fig. 1). It covers mainly Sakar Mountain and a small part of the lower Thracian lowland. It is characterized by continental Mediterranean climate. Monthly average range of temperature is from 8 to 13.5 °C over the year and the amount of precipitation is between 500 and 900 mm, reaching a maximum in winter and a minimum in summer/autumn.

The duration of the snow cover is shorter compared to all other areas in Bulgaria (Kopralev 2002). The habitats include Austrian pine plantations (3.8 %), Oak forests represented by Hungarian oak (*Quercus frainetto* Ten.), Austrian oak (*Quercus cerris* L.), and Downy oak (*Quercus pubescens* Willd.) (1.27 %), mixed deciduous forests with dominating presence of Downy oak (4.92%); wet riparian forests (1.54 %); shrubs with dominating presence of Jerusalem thorn (*Paliurus spina-christi* Mill.) found in pastures and hay meadows (34.8 %); vineyards including tree and shrub strips (11.07 %); arable lands with tree and shrub strips (37 %); populated locations (mainly small settlements) (3.8 %); and surface waters (1.8 %) randomly distributed in the area. Maritsa River flows through the western part of the MG-14 square.

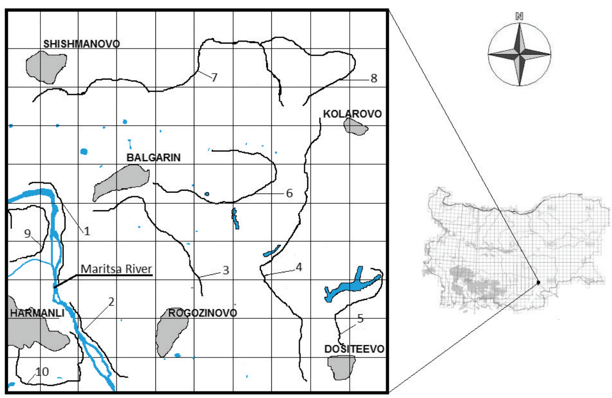

Fig. 1. Study area and transects in MG-14 (35 T).

Note: the black lines are the numbered transects; all water areas are marked in blue and the settlements in gray are marked with the respective names.

Field methods

Density data were collected by means of 10 linear transects measuring 44.39 km in length and 50 m in width, 25 m of each side of the observer (Fig. 1). For better reporting during the field visits, trained dogs were used, which searched at a distance of 50 m on both sides of the observer. They found the hares, but were not allowed to chase them.

The transects were set systematically to represent the whole diversity and percentage distribution of the areas, thus guaranteeing the representativeness of the sample. Six reports were made annually between March and July. Hares are not hunted in the study area due to low density. The density was calculated as the arithmetic mean of all observations during the respective year. Reports were made during daylight hours between 6:30 am and 5:00 pm. For each hare found, its location, the land in which it was found and the time period were recorded. Each transect was counted at different times to avoid data distortion. The number of tracks of Golden jackal (*Canis aureus* L., 1758), Red fox and Wild cat (*Felis silvestris* Schreber, 1777) were recorded during each report. We then calculated the relative density of the three species using the Formozov-Malyshev-Pereleshin formula (1) (Acevedo et al. 2008):

$$D = \frac{\pi}{2} \cdot \frac{x}{S \cdot M}, \quad (1)$$

where: D is population density (ind./km^2); x – total number of recorded tracks (on all transects); S – total length of all transects, km; M – daily activity pattern – average distance covered by the species in a day, km.

Based on data from previous studies (Sillero-Zubiri 2009, Sunquist and Sunquist 2009), the following daily average mobility values were adopted for each of the species: 15 km for the Golden jackal, 5 km for the Red fox, and 7 km for the Wild cat. Habitat diversity assessment was performed using the Shannon diversity index (SDI) (Liding et al. 2008, Kuchma et al. 2013).

Statistical methods

We used the GLMMs model, first testing the differences between densities of European hares over the years and months, then the relationship between hare density, habitat diversity indices, and the relative density of the Golden jackal, Red fox and Wild cat over the years. For each year, the data were taken from all reports made. The dependent variable was the European hare density per km^2, calculated for each transect; the categorical variables were years, and the independent variables were the diversity indices and the relative densities of predatory mammals. The significance of different habitats for hares was established by calculating the number of individuals per km^2 for each habitat and comparing them over the years using a GLMMs model with a log link function and Poisson distribution. Hare density was a dependent variable, years and habitat type were categorical variables. The area of each habitat was determined using QGIS 3.10 (QGIS Development Team 2020). All statistical analyses were performed with Statistica 10 StatSoft, Inc. (2011).

Results

Hare density during the study period varied between 0.7–2.7 ind./km^2. The relative densities of predator species also varied (Table 1).

The number of European hare reported in 2014–2015 was significantly higher than in other years. The lowest density was reported in 2018 (Table 2). The greatest number of hare was counted in May, after which the number of reported individuals decreased (Fig. 2).

During our study fluctuation of the established hare density was observed. It increased monthly from March to May, then gradually decreased (Fig. 2).

Hare density was positively related to habitat diversity and negatively to Wild cat density (Table 3).

There is a positive relationship between hare density and three habitat types: pastures, cereal crops and vineyards (Table 4).

Table 1. Density of species studied.

Year	*Lepus europaeus*	*Canis aureus*	*Vulpes vulpes*	*Felis silvestris*
	ind./km²			
2014	1.8 ±1.6 (0–4)	1.3	0.4	0.4
2015	2.7 ±2.1 (0–6)	2.65	0.7	0.5
2016	1.4 ±0.8 (0–2.5)	0.8	0.75	0.75
2017	0.8 ±1 (0–2.6)	1.4	0.54	0.54
2018	0.7 ±0.9 (0–2)	1.1	0.57	0.6
2019	1.3 ±0.7 (0–2)	0.57	0.94	1.06
2020	1.2 ±1.2 (0–3.4)	0.27	0.47	0.7

Note: for European hare ind./km² ±SD (min-max).

Table 2. Differences between European hare number by year and month in all study periods.

Effect	Level of effect	Column	Estimate	Standard error	Wald - stat.	Lower CL-95, %	Upper CL-95, %	*p*
Intercept		**1**	**0.335565**	**0.093465**	**12.88993**	**0.15238**	**0.518753**	**0.00033**
year	**2014**	**2**	**0.297493**	**0.140594**	**4.47736**	**0.02193**	**0.573052**	**0.034347**
year	**2015**	**3**	**0.71008**	**0.111543**	**40.52596**	**0.49146**	**0.9287**	**0**
year	2016	4	-0.09206	0.187471	0.24116	-0.4595	0.275373	0.623367
year	2017	5	-0.28796	0.220847	1.7001	-0.72081	0.144894	0.192275
year	**2018**	**6**	**-0.66685**	**0.310523**	**4.61174**	**-1.27546**	**-0.05823**	**0.031754**
year	2019	7	-0.3238	0.227816	2.02011	-0.77031	0.122715	0.155228
month	March	8	-0.13964	0.147411	0.89737	-0.42856	0.149278	0.343487
month	April	9	0.190071	0.11736	2.62296	-0.03995	0.420092	0.105328
month	**May**	**10**	**0.544767**	**0.097179**	**31.42501**	**0.3543**	**0.735234**	**0**
month	**June**	**11**	**-0.51604**	**0.200581**	**6.61878**	**-0.90917**	**-0.1229**	**0.010091**
Scale			0.643786	0.076947		0.50934	0.813729	

Note: in bold are the values with statistical significant; Column is a column of the model matrix corresponding to parameters; Estimate is estimated parameter value; Lower and Upper CL is confidence interval level; *p* is value for testing the significance of the parameter to the model.

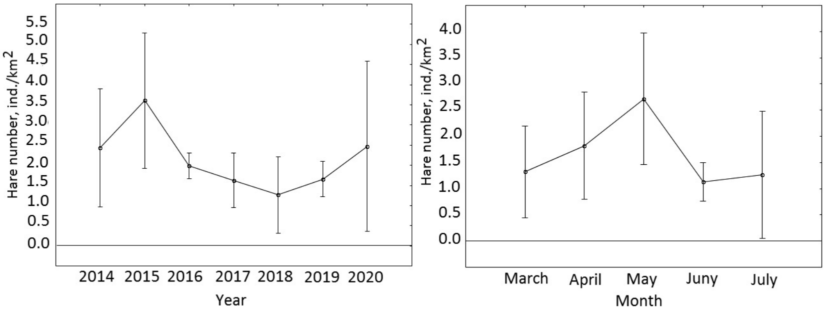

Fig. 2. European hare density (ind./km²; min-max) by year and month.

Table 3. Results of GLMMs model with Poisson distribution and log function between the number of European hare, habitat diversity and density of predator mammals.

Effect	Column	Estimate	Standard error	Wald stat.	Lower CL-95, %	Upper CL-95, %	*p*
Intercept	**1**	**1.32812**	**0.445077**	**8.90438**	**0.45578**	**2.200454**	**0.002845**
Shannon	**2**	**0.72462**	**0.203217**	**12.71448**	**0.32632**	**1.122918**	**0.000363**
Jackal density	3	-0.11179	0.081536	1.87967	-0.27160	0.048021	0.170371
Fox density	4	0.52587	0.443521	1.40581	-0.34342	1.395154	0.235753
Wild cat density	**5**	**-1.81040**	**0.468689**	**14.92038**	**-2.72901**	**-0.89178**	**0.000112**

Note: in bold is the values with statistical significant.

Table 4. Results of GLMMs model with Poisson distribution and log function between the densities of European hare in different habitats by years.

Effect	Level of effect	Column	Estimate	Standard error	Wald stat.	Lower CL-95 %	Upper CL-95 %	*p*
Intercept		1	-1.43818	0.938450	2.34856	-3.2775	0.40115	0.125399
year	2014	2	-1.03641	2.597230	0.15923	-6.1269	4.05407	0.689862
year	2015	3	0.10415	2.297978	0.00205	-4.3998	4.60810	0.963850
year	2016	4	1.02121	1.954510	0.27299	-2.8096	4.85198	0.601331
year	2017	5	-0.00152	2.299463	0.00000	-4.5084	4.50535	0.999474
year	2018	6	-0.79727	2.594891	0.09440	-5.8832	4.28863	0.758657
year	2019	7	-0.27950	2.301123	0.01475	-4.7896	4.23062	0.903324
habitat	**pastures**	**8**	**3.07561**	**0.950022**	**10.48082**	**1.2136**	**4.93762**	**0.001206**
habitat	**cereal crops**	**9**	**2.74003**	**0.960444**	**8.13889**	**0.8576**	**4.62246**	**0.004333**
habitat	**vineyards**	**10**	**1.95011**	**0.974020**	**4.00849**	**0.0411**	**3.85915**	**0.045272**
habitat	deciduous forest	11	-0.99531	2.596295	0.14696	-6.0840	4.09334	0.701455
habitat	coniferous	12	-3.16699	3.329380	0.90483	-9.6925	3.35847	0.341489
habitat	meadows	13	-0.43645	2.303234	0.03591	-4.9507	4.07781	0.849706

Note: in bold is the values with statistical significant.

There are no significant relationships with other habitat types, and the general pattern is not significant altogether (Table 4).

Discussion

European hare density reported in this study is lower than the one established in a number of European countries. Wasilewski (1991) reported density between 25 and 30 ind./km^2 in Central Poland, Panek and Kamieniarz (1999) established hare density from 8 to 28 individuals in relation with landscape structure. In Czech Republic density of hares was established 2.3 to 4.7 ind./km^2 (Pikula et al. 2004). In Northern Italy Rosin et al. (2009) reported density to 74 ind./km^2, this is one of the highest densities in Europe. In Germany, hare density was between 1 and 10.7 ind./km^2 in different areas in 2005 as above from 11 to 14.5 ind./km^2 from 2002 to 2005 (Strauss et al. 2008). Although significantly lower hare density was reported in Poland (4.1–9.5 ind./km^2) (Kamieniarz et al. 2011), it is higher than the one in the present study. The highest density estimate in this study is close to the lowest found for some regions of Europe (Canova et al. 2020). Studies of European hare density in Bulgaria from the last decade confirm the results of the present one. Zhelev (2015) established an average density for the plain habitats of Bulgaria of 1.9 ind./km^2, which is the lowest recorded density so far. The same author points at a significant decrease in European hare density after 1970, which is clearly expressed after 1994. The results of the current study align with the hare population trend in Bulgaria. During the study period there was no decrease in hare density.

Population trend follows a common pattern increasing from March to May and decreasing in the following months: this latter data can reflect a real decrease of local population due to juvenile's mortality or dispersal, but can reflect a lower visibility of individuals. Studies in some European countries have cited climatic factors (Slamechka et al. 1997; Smith et al. 2005; Beukovic et al. 2013, 2016), predation (Haerer et al. 2001) and diseases (Smith et al. 2005) as causes of mortality of young hares. The increased mortality at an early age has been identified as a determining factor in the decline of hares in Europe. The survival of the young is negatively affected by rainfall, but less so if hares use border habitats (hedgerows, shrubs, etc.) (Karp and Gehr 2020). Previous studies have indicated lower autumn hare density in Bulgaria (Zhelev 2015). According to the author, the lower autumn densities are a result of compromised accuracy of reporting due to vegetation height and reduced visibility.

The abundance of European hare in the present study was positively related to habitat diversity, as expressed by Shannon Index. Some authors (Smith et al. 2004, Canova et al. 2020) have established a positive relationship between hare density and habitat diversity. Various studies in Europe (Canova et al. 2020, Schai-Braun et al. 2020) have found a relationship between hare densities and set-aside places, on one hand, and the length of shelter belts and hedgerows, on the other. These variables were not tested in the present study due to the lack of set-asides; furthermore, hedgerows and shelter belts in the study area are evenly distributed. Hare density in our study was negatively related to Wild cat density. It seems that where there are more cats, fewer hares are observed. The study area falls into high-density Wild cat habitats (Petrov 1995). At the same time, studies of the food spectrum during the autumn-winter season indicate rodents as the main victims of Wild cats in Bulgaria (Petrov 2003). Due to the low density of hares in this study, they are unlikely to have any effect on the population. Rather, the two species have different habitat preferences. Wild cat is a species found in various habitats, but is most commonly present in forest and shrubs (Sarmento et al. 2006, Lozano 2010). Probably the negative association between the presence of hares and Wild cats is related to differences in preferred habitats rather than predation in study area. Further research is needed. In the present study, the linear model did not highlight a relationship between the relative densities of Red foxes and Golden jackal and that of hares. However, in a number of studies, predation has been identified as one of the possible causes of mortality in hares (Haerer et al. 2001). Some authors have found that foxes are the most common cause of loss, both in farm European hares (Reynolds and Taper 1995, Karmiris 2006, Sokos et al. 2014, Cukor et al. 2018) and in those from wild populations (Goszczynski and Wasilewski 1992, Misiorowska and Wasilewski 2008). According to some studies, predation is responsible for 31 to 50 % of total hare mortality (Goszczynski and Wasilewski 1992, Misiorowska and Wasilewski 2012) and hares and foxes density are inversely and significantly related (Vangan et al. 2003). Our model did not find a relationship between fox density and hare density. This may be due to the low densities established in both species. Thus, as a result of the low density of hares, they might not be foxes' priority prey. Golden jackal is the second predator which our model finds unrelated to hare densities. Studies of the species in Bulgaria discuss hares as accidental rather than priority prey of them (Stoyanov 2012). This is the most probable reason for lack of such a relation between the two species, or they might once again have different habitat preferences.

Pastures, cereal crops and vineyards are areas positively related to the number of reported individuals, although the model is not significant. Previous studies have indicated cereals (Sliwinski et al. 2019) and grass communities (Vangan et al. 2003, Kamieniarz et al. 2011) as having a positive effect on hare density. Grass communities in the study area are dominated by Jerusalem thorn, which offers ample hiding places for hares, while the adjacent arable lands normally represent sources of food that are attractive to hares, as shown by other similar studies (Smith et al. 2004, Kamieniarz et al. 2011, Canova et al. 2020). Vineyards are another example of areas attractive to hares. Vineyards and grass in rotation with winter cereals were positively associated with the number of hares shot in Italy (Santili and Galardi 2006). Zhelev (2015) points to vineyards as high-density (7–10 ind./km^2) areas of European hares. The positive associations with the abundance of hares and vineyards may be due to the ecotone effect caused by the vineyards in a monotonous environment. However, the general pattern in our analysis involving habitats is not significant and we cannot say with certainty that these habitat areas are essential for hares. Despite finding a variation in hare density over the years, this study has not confirmed an increase in density, which may be due to other factors limiting hare population in the area.

Conclusion

Present study describes the density of European hare in part of Southeastern Bulgaria. The results showed that the density of hare is lower than in a number of European countries. The density is fluctuated between the study years and the peak of the reported hares is in May. Hare density was positively related to habitat diversity, three habitat types and negatively to Wild cat density. Although hares were not hunted in the study area, their density does not increase. Results obtained in this study should be taken into account in further management of hare's population.

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