Red deer on the move: home range size and mobility in Bulgaria

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Abstract
The red deer is a main game species in Bulgaria, as well as in large parts of Europe. However, its behaviour has not been studied in depth on a local scale, especially on the Balkans. This study presents the first GPS telemetry data for red deer in Bulgaria – in the Central and Eastern Balkan Mountains, the Rhodopi Mountains and the lowlands of North-eastern Bulgaria. 18 individuals (2 subadult stags, 12 adult stags and 4 adult hinds) were tracked, accumulating a total of 1159 (for males) and 1464 (for females) GPS fixes. In spite of the pronounced individual differences, all stags were more mobile (average step length/12 h = 857 m) and had larger home ranges (average HR = 7393 ha) than hinds (average HR = 2085 ha, average step length/12 h = 448 m). Three of the individuals (1 hind and 2 stags) dispersed, forming two distinct home ranges. The results from this study outline the need for detailed studies on the behavior of the species, as a vital part of its management and conservation.

Key words: Cervus elaphus, GPS telemetry, territory, core area, range.

Introduction
The red deer (Cervus elaphus L., 1756 Artiodactyla: Cervidae), one of the large ungulates native to Europe, is also an important game species on the continent. It is listed as “least concern” in the IUCN Red list of Threatened Species and its global population trend has been assessed as increasing and not severely fragmented (Lovari et al., 2018). However, the assessment includes some concerning conclusions, such as the following: continuing decline and extreme fluctuations in the extent of occurrence; continuing decline and extreme fluctuations in the area of occupancy; and continuing decline and extreme fluctuations in the number of locations. This brings up the need to study its populations in depth – data on their ecology, demography, behaviour, main threats and trends is vital for the species’ effective management and conservation.

Currently, most of these data are lacking for parts of the red deer’s range. Studies on aspects of the red deer’s behaviour, such as its home range sizes, mobility and habitat selection have been published for: Slovakia (Kropil, Smolko, & Garaj, 2015), Slovenia (Debeljak, Džeroski, Jerina, Kobler, & Adamič, 2001;
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Jerina, 2009, 2012), Portugal (Alves, Alves da Silva, Soares, & Fonseca, 2014), the Netherlands (Ensing et al., 2014), Belgium (Alain M. Licoppe, 2006; Am M Licoppe, Crombrugghe, & De Crombrugghe, 2003; Prévot & Licoppe, 2013), Norway (Bonenfant et al., 2004; Godvik et al., 2009; Kleveland, 2007; Mysterud, Bischof, Loe, Odden, & Linnell, 2012), Sweden (Jarnemo, 2011), Italy (Bocci, Monaco, Brambilla, Angelini, & Lovari, 2010; Lovari et al., 2007; Luccarini, Mauri, Ciuti, Lamberti, & Apollonio, 2006), Austria (Duscher, Filli, Reimoser, & Lainer, 2009; Schmidt, 1993), Hungary (Náhlik, Sándor, Tari, & Király, 2009; Szemethy, Heltai, Matrai, & Peto, 1998), France (Adrados, Baltzinger, Janeau, & Pépin, 2008; Bonenfant et al., 2004; Hamann, Klein, & Saint-Andrieux, 1997; D. Pépin, Adrados, Mann, & Janeau, 2004; Dominique Pépin, Morellet, & Goulard, 2009), Poland (Borkowski & Ukalska, 2008; Kamler, Jędrzejewska, & Jędrzejewski, 2007; Kamler, Jedrzejewski, & Jedrzejewska, 2008; Theuerkauf & Rouys, 2008), the Czech Republic (Koubek & Hrabe, 1996; Prokešová, Barančeková, & Homolka, 2006), Switzerland (Duscher et al., 2009; Patthey, 2003; Suter, Suter, Kriisi, & Schütz, 2004), Spain (Braza & Alvarez, 1987; Carranza, Hidalgo de Trucios, Medina, Valencia, & Delgado, 1991; San José, Braza, Aragon, & Delibes, 1997), Scotland (Catt & Staines, 1987; Clutton-Brock, Iason, & Guinness, 1987; Hinge, 1986; Osborne, 1984; Welch, Staines, Catt, & Scott, 1990) and Germany (Georgii, 1980; Georgii & Schröder, 1983).

However, studies on this topic on the Balkans are practically missing. The aim of this work is to present the first red deer GPS-telemetry data for Bulgaria with analysis of the home range sizes and mobility. The species had a very large population density in the country during the 80s (approx. 60 000 ind.), but since then its population has been rapidly declining. Hunting managers also note the apparent deterioration of the trophy qualities of Bulgarian red deer (size, weight, etc.). All of this makes the current topic an important first step in improving the management and conservation of the species not only in Bulgaria, but on the Balkans as a whole.

Materials and Methods

Study area

This study was conducted in four locations 1. Central and 2. Eastern Balkan Mountains, 3. Rhodopi Mountains and 4. Lowlands of North-eastern Bulgaria (Table 1). These areas have diverse altitudinal and vegetation gradient. The altitude ranges from 304 to 2350 m.a.s.l.: average of 385 m for Eastern Balkan Mountain (range: 151 – 820 m); 304 m for North-eastern Bulgaria (range: 173 – 510 m); 760 m for Central Balkan Mountain (range: 167 – 2323 m) and 1524 m for Rhodopi Mountain (range: 695 – 2184 m).

The forest vegetation in the study areas is forming altitudinal belts in the following order (Asenov, 2006): 1. Lower altitudes (300-800 m.a.s.l.) are covered with xero-thermophilic oak (Quercus sp.) and hornbeam (Carpinus sp.); 3. The areas between 800 and 1900 m.a.s.l. are commonly covered with common beech (Fagus sylvatica) with the exception of Rhodopi Mountain where it is generally replaced by a coniferous belt; 4. The coniferous (mainly Abies alba, Pinus sp. and Picea abies) belt consists of scattered patches in Central / Eastern Balkan Mountains and the lowlands of North-eastern Bulgaria, while in Rhodopi Mountain it consists most of the upper altitude forest best. The areas above 2200 m.a.s.l. are generally sub-alpine meadows often covered with Juniperus sp. The main dominant tree species in the four parts of our study area are as follows: North-eastern Bulgaria (Carpinus betulus, Robinia pseudoacacia, Quercus cerris, Tilia tomentosa); Eastern Balkan Mtn (Q. cerris, C. betulus, Fagus sylvatica, Pinus sylvestris, P. nigra, Carpinus orientalis, Q. petraea, F. sylvatica, C. betulus, P. sylvestris, P. nigra, R. pseudoacacia, P. abies, Q. frainetto, Q. petraea, C. orientalis, T. tomentosa); Rhodopi Mtn (P. sylvestris, P. nigra, P. abies, A. alba, F. sylvatica, C. orientalis).

The Central Balkan area covers one national park (Central Balkan National Park) and about 10 State Hunting or State Forest Enterprises. The other four areas cover only State Hunting or State Forest Enterprises. State Hunting Enterprises are Forestry Enterprises (for management of forests and timber production), with additional sets of activities for intensive game management (including intensive supplementary ungulate feeding).
Capture and handling of the animals
During the period 2016-2019 we captured 18 red deer: 2 subadult stags, 12 adult stags and 4 adult hinds (Table 1). Two of the individuals (a male and a female) were captured in a box trap and sedated, while the other 16 were sedated directly by stalking from a hunting stand. For sedation a mixture of Sedin (4ml) + Ketamine (2 ml) or Sedin (3ml) + Ketamine (1 ml) + Zoletil (1ml) per 100 kg was used. The time to full sedation was between 15 - 35 min. After the sedation, the animals where examined, aged according to their dental status and antler development (males), weighted, measured and tagged with an ear tag. All manipulations lasted less than 15 minutes, with animals eyes covered during the procedure (Fig. 2).

Figure 1. Study area and 100 % minimum convex polygons from the locations of the GPS-collared red deer

All animals were equipped with Followit GPS/GSM collars. The data collected by the collars included local date and time, GPS location, altitude and activity record. The data was monitored online (http://geo.followit.se) and extracted for further analyses with GIS instruments.

Data collection and spatial analyses
A total of 1159 (for males) and 1464 (for females) GPS fixes were collected through the study period for an average of 304 tracking days for the males and 194 days for the females. The collars were set to take a location at a different interval, ranging from 6 to 12 hours, depending on the season. This called upon the need for sub-sampling to equal time frame, to be able to compare home range data and mobility across individuals throughout the whole study period. 12 hours between each location fix (at 00:00 and 13:00) were chosen (Table 1) to compromise between the shortest step length (length between fixes), the continuousness of the data flow and the possible effect of correlated locations. An average of 592 resampled fixes for the males and 338 resampled fixes for the females were used for the home range estimation. The period of tracking, the number of tracking days, the total number of fixes and the number of resampled fixes for each individual are presented in Table 1.
Spatial analyses
All spatial analyses were conducted with ArcGis Desktop 10.2.2 – ArcMap (ESRI). The subsampling of the locations to 12 hour interval and the calculation of individual displacement (the Euclidean distance between each location) for this timeframe were done with ArcMET 10.2.2.v3 extension for ArcGIS Desktop (Wall, 2014) – modules Resample tool (for 12 hours resampling), KDE UD Model (for home range size estimation), Create Percent Contours (for estimation of core area and total home range size) and Path tool (for calculation of step length displacement and speed). A fixed kernel density distribution (Worton 1989) with h-ref smoothing factor and raster resolution of 30 m was used for the utility distribution (kernel) modelling of the home range.

Statistical analyses
The statistical analyses and the accompanying plots were done with Statgraphics Centurion 18.1.11 (Statgraphics Technologies, Inc.). The individuals were grouped as males and females to be studied for differences in their home range and mobility. Due to the variability and skewness of data for the home range size and mobility of the males (>2), the median was used instead of average in the group statistical comparisons. The differences are tested with two-tailed probabilities at 0.05 significance, within the 95.0% confidence level, alpha was reported with 0.01 significance only where strong differences were observed. Where appropriate, the average values were also reported for comparison purposes with other studies.

The variation of the Euclidean distances in 12 hours displacement was plotted with violin graph with cosine function and interval width (h) at 10 %. Mann–Whitney statistic was used to test for gender-specific differences. G test of goodness-of-fit was used to compare the difference in the home range size proportion (1:1) of before and after dispersal in three individuals.

Results

Home range size and shape
The home range sizes of the tracked deer show significant variability (Table 2). Males tend to have more variable in size core and total home range areas than the females (Fig. 3).

Three of the GPS-collared red deer (two males, at about two years old and one female at about three years old) showed a dispersal pattern with two well defined home ranges (individuals M01, M2 and F8 – Table 2, Figure 4).
Table 1. Captured and collared red deer individuals for the period of 2016-2019 – sex, approximate age, region of capture, period of tracking, number of tracking days, total number of fixes, number of resampled fixes for each individual, capture method and current status

| Deer ID | Name      | Sex | Age     | Region                  | Period of tracking          | # tracking days | total # of fixes | # of resampled fixes | Capture method        | Current status        |
|---------|-----------|-----|---------|-------------------------|----------------------------|-----------------|------------------|-----------------------|------------------------|-----------------------|
| M00     | Kutzar    | Male| adult   | Central Balkan Mtn      | 7.2.2016 - 16.2.2018        | 741             | 1824             | 1267                  | sedation by stalking    | current status unknown |
| M01     | Voden     | Male| ~ 2 years | Central Balkan Mtn     | 17.2.2017 - 11.7.2017       | 145             | 571              | 288                   | sedation by stalking    | current status unknown |
| M1      | Chavdar   | Male| ~ 2 years | Central Balkan Mtn     | 19.10.2017 - 17.4.2018      | 181             | 706              | 362                   | sedation by stalking    | killed by wolves        |
| M2      | Anton     | Male| ~ 2 years | Central Balkan Mtn     | 17.1.2018 - 10.11.2018      | 297             | 1530             | 547                   | sedation by stalking    | malfunctioned collar, unknown |
| F3      | Antonia   | Female| adult | Central Balkan Mtn      | 17.1.2018 - 9.03.2018        | 51              | 204              | 102                   | sedation by stalking    | killed by wolves        |
| M4      | Boyan     | Male| ~ 2 years | Central Balkan Mtn     | 25.1.2018 - 13.6.2019       | 504             | 2529             | 987                   | sedation by stalking    | ongoing tracking       |
| F5      | Vili      | Female| ~ 6-8 years | Central Balkan Mtn     | 25.1.2018 - 13.6.2019       | 504             | 2545             | 992                   | sedation by stalking    | ongoing tracking       |
| M6      | Goran     | Male| ~ 2 years | Central Balkan Mtn     | 16.2.2018 - 9.3.2019        | 386             | 1937             | 769                   | sedation by stalking    | collar not working, most likely poached |
| F7      | Divna     | Female| ~ 5-6 years | Central Balkan Mtn     | 27.2.2018 - 13.6.2019       | 471             | 2333             | 931                   | sedation by stalking    | ongoing tracking       |
| F8      | Poli      | Female| ~ 3 years | Eastern Balkan Mtn      | 13.3.2018 - 16.8.2018       | 156             | 775              | 310                   | trapping                | malfunctioned collar, ind. alive |
| M9      | Delcho    | Male| ~ 1.5 years | Eastern Balkan Mtn     | 13.3.2018 - 13.6.2019       | 457             | 2265             | 899                   | trapping                | ongoing tracking       |
| M10     | Chocho    | Male| ~ 5-6 years | North-eastern Bulgaria | 24.9.2018 - 12.06.2019     | 261             | 1273             | 517                   | sedation by stalking    | ongoing tracking       |
| M11     | Simo      | Male| ~ 7-8 years | North-eastern Bulgaria | 17.11.2018 - 12.6.2019      | 207             | 975              | 405                   | sedation by stalking    | ongoing tracking       |
| M12     | Emil      | Male| ~ 6-7 years | Central Balkan Mtn     | 14.1.2019 - 13.6.2019       | 150             | 743              | 293                   | sedation by stalking    | ongoing tracking       |
| M13     | Zhevko    | Male| ~ 1.5 years | Central Balkan Mtn     | 17.2.2019 - 12.6.2019       | 207             | 540              | 231                   | sedation by stalking    | ongoing tracking       |
| M14     | Zaro      | Male| ~ 4-5 years | Rhodopi Mtn            | 28.2.2019 - 12.6.2019       | 104             | 486              | 170                   | sedation by stalking    | ongoing tracking       |
| M15     | Dian      | Male| ~ 3-4 years | Central Balkan Mtn     | 9.3.2019 - 12.6.2019        | 95              | 453              | 188                   | sedation by stalking    | ongoing tracking       |
| M16     | Ivo       | Male| ~ 6-7 years | Rhodopi Mtn            | 12.3.2019 - 25.5.2019       | 74              | 387              | 148                   | sedation by stalking    | poached                |
The size comparison of the first (before dispersal) and the second (after dispersal) core and total areas for these individuals show statistically significant difference (G-test of goodness-of-fit, p<0.01: for core area M01 - G = 155.24; M2 - G = 69.89; F8 – G = 302.07; for overall home range M01 - G = 671.99; M2 - G = 847.45; F8 – G = 32.85)

The core areas size range from 192 to 6044 ha for males and from 44 to 1319 ha for females. There is no statistically significant difference between the core area sizes of the home range in males and females (Mann-Whitney W-test to compare medians, W = 17.0, p > 0.05).

The total male home range varies from 1461 to 39908 ha, while in females the home range is considerably smaller (186 to 4861 ha). (Mann-Whitney W-test to compare medians, W = 20.0, p > 0.05)

Table 2 Home range (HR) size (core and total areas) and number of tracking days for the estimation of the home range.

| Deer ID | Sex  | Age           | Core HR size, ha | Total HR size, ha | Days in HR |
|---------|------|---------------|------------------|-------------------|------------|
| M00     | Male | adult         | 791              | 4215              | 741        |
| M01-1   | Male | ~ 2 years     | 680              | 3282              | 36         |
| M01-2   | Male | ~ 2 years     | 296              | 1509              | 102        |
| M1      | Male | ~ 2 years     | 192              | 1461              | 181        |
| M2-1    | Male | ~ 2 years     | 1110             | 4065              | 115        |
| M2-2    | Male | ~ 2 years     | 1540             | 7125              | 180        |
| F3      | Female | adult       | 44               | 186               | 51         |
| M4      | Male | ~ 2 years     | 4423             | 20591             | 504        |
| F5      | Female | ~ 6-8 years | 66               | 400               | 504        |
| M6      | Male | ~ 2 years     | 1791             | 11264             | 386        |
| F7      | Female | ~ 5-6 years | 138              | 665               | 471        |
| F8-1    | Female | ~ 3 years   | 1319             | 4861              | 98         |
| F8-2    | Female | ~ 3 years   | 573              | 4312              | 58         |
| M9      | Male | ~ 1.5 years  | 759              | 6721              | 457        |
| M10     | Male | ~ 5-6 years  | 426              | 2309              | 261        |
| M11     | Male | ~ 7-8 years  | 664              | 5799              | 207        |
| M12     | Male | ~ 6-7 years  | 386              | 1709              | 150        |
| M13     | Male | ~ 1.5 years  | 329              | 1532              | 207        |
| M14     | Male | ~ 4-5 years  | 6044             | 39908             | 104        |
| M15     | Male | ~ 3-4 years  | 620              | 2849              | 95         |
| M16     | Male | ~ 6-7 years  | 840              | 3953              | 74         |

Four of the males (M4, M10, M13 and M15) have fragmented core areas. M4 (about two years old male) has three varying in size core areas (1116, 435 and 2872 ha) distributed between densely located villages. M10 (~ 5-6 years old) has two as the second one is recently formed. M15 is caught in the Central Balkan National Park, but after moving to the surrounding hunting enterprises splits its core area into two parts (114 and 506 ha). None of the females has fragmented core areas.

There is significant overlap in the home ranges between males and males, males and females and females – females. The males not only partially overlap each other’s home range, but some of the males (M00, M11, M14) completely overlap the core areas of other males. Three of the males (M2, M4, M6) also show almost complete overlap of their core areas.

Mobility
Both male and female red deer show great variability in their 12 hours displacement (Table ). The males are twice as mobile as females (median: 606 m vs. 367 m 12 h displacement), and the difference is statistically significant (Mann-Whitney W-test on medians, W = 0, p = 0.00349). The interquartile range is also confirming this pattern (753 m in males vs. 421 m in females). The maximum observed displacement for the 12 hour period is 16017 m for the males and 4252 m for the females.

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**Figure 3.** Comparison of the core and total area in males and females. Boxes – the interquartile range (25-75 percentiles); middle line in boxes – median values; diamonds – average values; whiskers – minimum and maximum values within the 95.0% confidence level; circles – outliers; circles with plus sign - “Far outside” outliers, points more than 3 times above the interquartile range.

**Figure 4.** Home range (core and total area of the GPS-collared red deer: 1 - Central Balkan Mtn (individuals M00, M01, M1, M2, F3, M4, F5, M6, F7, M12, M13, M15); 2 - Rhodopi Mtn (individuals M14 and M16); 3 - North-eastern Bulgaria (individuals M10 and M11); 4 - Eastern Balkan Mtn (individuals F8 and M9).
Table 3. Mobility comparison in males and females with sample size

| MALES | Sample size | Average, m. | Median, m. | Min., m | Max., m | Range, m | Interquartile range, m |
|-------|-------------|-------------|------------|--------|---------|---------|------------------------|
| M00   | 1266        | 732         | 452        | 7      | 7307    | 7300    | 732                    |
| M01   | 287         | 678         | 447        | 49     | 7200    | 7152    | 504                    |
| M1    | 361         | 666         | 552        | 12     | 3137    | 3125    | 618                    |
| M2    | 573         | 814         | 599        | 14     | 8998    | 8984    | 663                    |
| M4    | 986         | 1113        | 743        | 11     | 10195   | 10184   | 1002                   |
| M6    | 768         | 809         | 669        | 8      | 8604    | 8595    | 688                    |
| M9    | 898         | 1028        | 800        | 8      | 6822    | 6814    | 804                    |
| M10   | 516         | 911         | 602        | 20     | 5738    | 5718    | 907                    |
| M11   | 404         | 984         | 560        | 16     | 5106    | 5090    | 957                    |
| M12   | 292         | 622         | 510        | 0      | 4129    | 4129    | 511                    |
| M13   | 230         | 693         | 603        | 11     | 3540    | 3529    | 588                    |
| M14   | 169         | 1003        | 607        | 0      | 16017   | 16017   | 811                    |
| M15   | 187         | 648         | 460        | 14     | 3843    | 3829    | 476                    |
| M16   | 118         | 667         | 493        | 56     | 4632    | 4576    | 510                    |

| FEMALES | Sample size | Average, m. | Median, m. | Min., m | Max., m | Range, m | Interquartile range, m |
|---------|-------------|-------------|------------|--------|---------|---------|------------------------|
| F3      | 101         | 354         | 333        | 11     | 1041    | 1030    | 264                    |
| F5      | 991         | 518         | 480        | 5      | 2362    | 2357    | 448                    |
| F7      | 930         | 434         | 352        | 11     | 2162    | 2151    | 394                    |
| F8      | 309         | 294         | 188        | 0      | 4252    | 4252    | 254                    |

The 12 hour mobility of the males and females differ not only in the median and interquartile values but also in the density distribution of the all displacement distances (Table 3). Females are showing three distinctive peaks of these densities (around 200, 350 and 500 m), while the males have two more compact peaks (around 450 and 600 m).

The maximum displacement speed for the 12 hour step length observed in the male red deer was 0.78 km/h (median - 0.05 km/h, interquartile range - 0.06 km/h), while in the female it was 0.39 km/h (median and interquartile range - 0.03 km/h).

Discussion

Sample size
The captured red deer in our study show a skewed sex ratio of males to females (14:4). This was caused by the extreme cautiousness of the females, related to capture/stalking, compared to the males. This skewedness might introduce a bias in the averaged home range size and mobility. Yet, the literature review for the red deer home range size in other countries (see below) shows similarities. Further on, the average sample size of the fixes (males vs. females) in our study are similar (505 : 584, for the resampled fixes used for home range estimation and mobility). All this allows us to assume that if a bias exists, it will have a minimal effect.

Home range size and shape
The home range sizes obtained from our analysis correlate to results from some other studies in Europe. The red deer classified as ‘migratory’ in Luccarini et al. (2006) in the Italian Alps have similar mean HR sizes to ours, ranging from 1141-1289 ha, while the ‘stationary’ individuals have HR of 260-843 ha. The same is true for the ‘shifter’ hinds studied by Bocci et al., (2010) – with HR sizes of 142-1699 ha, whereas the ‘resident’
individuals in the same study exhibit much smaller ranges (74-593 ha). Other research in the Alps also confirms our results - Duscher et al. (2009) report HR varying from 5 to 340 hectares for females in winter and 130 to 790 hectares in summer in an Austrian study site with supplementary feeding. In the Swiss study site (without supplementary feeding) ranges varied between 150 and 8990 ha (higher than our results) in winter and 170 and 5350 ha in summer (similar to our results). The male Slovakian red deer in the Western Carpathians (migrant and resident with HRs 6393±2800 and 1762±678 ha respectively) apparently are most similar to the Bulgarian (Kropil et al., 2015). The red deer studied in Poland are also close to our results: 3600 ha for males and 840 ha for females (Kamler et al., 2008).

The hinds studied in Spain (Carranza et al., 1991) also exhibit similar HR sizes (258.4 ± 59.0 ha), whereas the stags’ are much smaller than those obtained in our study (655.4 ha). Our results also fall in line with the sizes reported for Scotland - 406-1008 ha for females and 1062-3059 ha for males (Catt & Staines, 1987). According to two studies in France the females’ HR measure 444-1921 ha and 536-538 ha respectively (similar to our results), but the males’ HR are much lower than ours (977-1466 ha) (Hamann et al., 1997; Dominique Pépin et al., 2009). It is worth noting that despite the similar total HR size reported by Hamman er et al. (1997), the Bulgarian red deer hinds exhibit a larger core area (44-1319 ha), compared to the French (76-200 ha). However, most publications do not report core area sizes. Other studies reporting similar values to ours are published from Hungary: in a lowland area: 6697 ha for stags and 2555 ha of hinds (Szemethy et al., 1998); in Zala County: 1310 ± 700 ha in summer and the 2570 ± 1,130 ha in winter; in Sopron 530 ± 415 ha in summer and 1,140 ± 600 ha in summer for hinds (Náhlik et al., 2009).

There is also a number of studies that report much smaller HR sizes than the results of our study: in Sardinia (Italy) - 36.5 ha hinds and 65.0 ha stags (Lovari et al., 2007); in the German Alps: 65 ha during winter, 167 ha in spring and autumn and 121 ha in summer for hinds (Georgii, 1980); and 113 ha in winter and 386 ha from spring to autumn for stags (Georgii & Schröder, 1983); Slovenia: 90–2107 ha (average 460

**Figure 5.** Comparison between male and female red deer mobility. Boxes – the interquartile range (25-75 percentiles); middle line in boxes – median values; diamonds – average values; whiskers – minimum and maximum values within the 95.0% confidence level; circles – outliers; the perimeter outside boxes shows the probability density of the of the 12 hours step-length displacement in males and females.
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ha) (Jerina, 2012); Czech republic: 35-174 ha for females and 84-429 ha for males in different seasons (Koubek & Hrabe, 1996); Belgium: 529 ha (Prévot & Licoppe, 2013), Norway in summer (293.84 ha in summer 237.92 ha in winter (Kleveland, 2007).

Our results regarding the overlapping of home ranges between males/males, females/males and females/females are in agreement with other studies (Carranza et al., 1991; Catt & Staines, 1987; Staines, Crisp, & Parish, 1982). Concerning the differences between males and females, Jerina (2012) reports 580 ha versus 400 ha HRs respectively for Slovenia, whereas in our study area the difference is much larger, close to 10 times larger HR for the males compared to females. A much smaller difference is also observed in all the papers cited above.

Mobility

Most other studies do not report the mean displacement per day. However, this data is important, especially since it has applications in other methodological approaches. For example, the Random Encounter Model (REM) used to estimate the population density of species without individual recognition, relies on a number of parameters, including the mobility of the species (Rowcliffe, Field, Turvey, & Carbone, 2008). However, this parameter may vary greatly within the species’ distribution range, depending on habitat, climate, predators, anthropogenic disturbance and other factors. This is why the best estimates of population density can be achieved only by applying data from local individuals of the same species (Popova, Stepanov, Ahmed, Genov, & Todev, 2018).

In our case, the results are similar to those observed in France and Denmark where hinds moved 1.7-3.5 km/24h (Hamann et al., 1997) and 0.45 km/24h (Jeppsen, 1987) respectively. However, another study reports moving distances for stags of 1.5-2.3 km and 1.5-7.6 km/24h for hinds (D. Pépin et al., 2004). This is dissimilar to our estimation, according to which the males are twice as mobile as the females. Results from Spain also show a higher mean daily displacement - 3.04 to 4.21 km/24h for females and 4.3 km/24h for males (Carranza et al., 1991). Pépin et al. (2009) report a velocity of 1.63 km/h, which is twice as high as the obtained for Bulgarian male red deer. However, it should be noted that our estimation is based on a 12h step length and the actual travelled distance by the individuals can be much larger, and thus the actual velocity is most likely higher.

In conclusion, we can infer that Bulgarian red deer have HR sizes in the higher end of the spectrum for Europe, including very high values, rarely reported in the literature. However, their daily mobility is similar or lower than the values observed in other parts of Europe. The large similarity with the results reported from Białowieża National Park (BNP), Poland and the Western Carpathians, Slovenia (Kamler et al., 2008; Kropil et al., 2015) are expected. The three study areas have similar habitats – mainly broadleaved forests with well-preserved biodiversity and presence of large carnivores: gray wolves (Canis lupus L.) in all three, brown bear (Ursus arctos L.) in the Bulgarian and Slovenian study sites and Eurasian lynx (Lynx lynx L.) in the Polish and Slovenian study sites. As Kamler et al. (2008) suggest large carnivores might be one of the possible explanations for the observed large home ranges and high mobility – in these conditions the ungulates (as main prey) should manage the trade-off between foraging and avoiding predators, thus increasing their overall movement. Another important factor that should be considered is the hinting pressure. Most of our study area falls within National Hunting Enterprises, where hunting is permitted throughout the year, which could also explain the larger HRs. Moreover, trophy hunting in Bulgaria is aimed mainly at males, contributing additionally to their disproportionally large ranges compared to the females’. Additional evidence supporting this hypothesis is the fact, that two of the studied stags exhibit a marked change in their behavior with the beginning of the hunting season within the areas not belonging to a Hunting Enterprise. M6, occupying mainly a Forestry Enterprise, moves to the Central Balkan National Park (where hunting is strictly forbidden) within 3 weeks of the hunting season’s start. Similarly, M2 also retreats to its second home range closer to the National Park’s borders. Unfortunately, M6 and M16 were poached, which indicates a considerable problem.

Our study, as the first of its kind on the Balkans, forms an important basis for further investigation of the spatial and behavioral characteristics of the red deer, which will contribute to its better management and conservation.
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