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Post-release dispersal and home range of translocated red deer in the Vojvodina province (Serbia)

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Abstract

Monitoring of 38 (12 male and 26 female) red deer translocated from Ivo Wildlife Park (Romania) to hunting ground "Bosutske Forest" (Vojvodina, Serbia) was conducted from 2017 to 2021. The red deer were translocated in lieu of the managing authority's efforts to counteract the effects of red deer losses due to catastrophic flooding in the region. All animals were ear-tagged, while 7 males and 10 females were fitted with GPS collars. A total of 2,288 valid signals were analyzed (565 from males and 1,723 from females). In addition, 1,333 sighting records were collected from eight observation posts (480 in 2019, 670 in 2020 and 183 in 2021). We determined the movements and spatial distribution of translocated animals in the new habitat and estimated their home range sizes. Home range was calculated using the minimum convex polygon method, while the core area was calculated using the kernel density estimator method. The greatest straight-line distance from the acclimatisation enclosure was essentially the same for both sexes (average 6.0 km for males and 6.4 km for females). A non-significant relationship existed between the number of days in captivity and the greatest straight-line distance, as well as between days in captivity and the core area of the home range. The estimated home range of males was 12.8 km^2 (range 0.2–36.1), smaller than that of females (20.6 km^2, range 0.4–68.7), but this difference was not statistically significant. Observations made independently showed mostly herds of 4 to 6 individuals (52.3%), while large herds (≥ 10 individuals) were rare. Participation of translocated and resident animals in mixed herds was common during the monitoring period (62.3%). Our results showed that a high level of acceptance of the new habitat and social cohesion between translocated and resident animals was achieved. We believe that this is due to two main reasons: firstly, the long-term stay in a large acclimatisation enclosure prior to release and secondly, year-round supplemental feeding coupled with an abundant natural food supply in this unique forest area also contributed to successful acclimatisation.

Keywords: *Cervus elaphus*; population; habitat; home range size; red deer; management

Introduction

Red deer are the most frequently reintroduced species of wild ungulates, and this practice also involves translocating animals from one population to another (Putman and Apollonio 2014). There are many factors that have led to the decline and local extinction of original red deer populations in different parts of Europe, beginning with excessive hunting (both planned and illegal) and ending with habitat loss and fragmentation (e.g. due to deforestation and logging, warfare, intensive agriculture, urbanization, development of transport infrastructure) becoming the key ones. Besides, sometimes catastrophic floods can cause major damage to the population and its habitat, especially in forest hunting areas along large rivers and their tributaries (Marković and Stankov 2010, Wuczyński and Jakubiec 2013, Ugarković et al. 2020). However, the relocation of red deer to mitigate the damage caused by disastrous floods has rarely been the subject of long-term studies.

An essential activity and an integral part of any translocation and reintroduction programme is the monitoring of their progress after the release of animals. Monitoring the behaviour of translocated individuals can be a valuable indicator of the progress of the implemented programme (IUCN/SSC 2013). In general, data on the movement, spatial distribution and individual home range of red deer after release in a new habitat, obtained with modern equipment, are still lacking (La Morgia et al. 2011). Successful examples of such activities include the reintroduction of the elk (*C. e. canadensis*) in the Ontario area of Canada (Rosatte et al. 2007, Ryckman et al. 2010, Yott et al. 2011), or the reintroduction of the endangered Corsican deer subspecies (*C. e. corsicanus*) in central and eastern Sardinia (Riga et al. 2022), which are based on the long-term mo-

nitoring of the large numbers of animals of both sexes and different ages using VHF or GPS/GSM radio collars. This modern equipment was also used in western Serbia in the reintroduction of red deer on Mount Tara (Mladenović et al. 2022), which together with our earlier study on animal translocation in the province of Vojvodina (Stankov et al. 2019) represents the beginning of the application of GPS collars in Serbia for monitoring the movements of animals after their release from the acclimatisation enclosure.

There are many native red deer populations that have been studied throughout Europe using VHF or GPS/GSM radio collars. These studies vary considerably in terms of the duration and number of collared individuals, or in terms of habitat composition and fragmentation, population density, supplementary feeding, altitude, the influence of climatic factors, presence of large predators, and the intensity of human disturbance, particularly in relation to hunting (e.g. Kamler et al. 2007, Pépin et al. 2008, Jerina 2012, Smolko et al. 2018, Chassagneux et al. 2020, Laguna et al. 2021, Meisingset et al. 2022). Referring to a comparative and very detailed review of the results obtained in the aforementioned studies, several authors concluded that the red deer is an example of a species characterized by large fluctuations in home range size (Jarnemo et al. 2023). Furthermore, the red deer is known to be a notoriously difficult game species in terms of conservation and sustainable management efforts in forest ecosystems. The difficulty arises mainly from the perceived damage caused by browsing and bark-stripping (Apollonio et al. 2010, Arnold et al. 2018, Månsson et al. 2021). Therefore, further studies are needed in anthropogenically modified forest areas that are used and managed particularly intensively (various fences and supplementary feeding). It also goes without saying that care must be taken to ensure the absence of large predators, and no agricultural lands are present in the forest area.

An autochthonous and viable population of red deer in the transboundary area of the well-known lowland pedunculate oak forests (*Quercus robur*), which occupy about 40,000 ha in eastern Croatia (Spačva basin) and about 11,000 ha in northwestern Serbia ("Bosutske Forest" area), suffered severe losses in the second half of May 2014. At the time of this short period, the extreme rainfall in the Sava river basin (more than 200 litres per square meter) combined with other factors led to an immediate rise in water levels on the lower reaches of the Sava River and its tributaries, causing catastrophic flooding never recorded before (The Government of the Republic of Serbia 2014). At that time, a total of 76 drowned red deer were registered, 34 of them in the Serbian hunting ground "Bosutske Forest", managed by PC Vojvodinašume, and 42 in the neighbouring Croatian hunting ground "Spačva", managed by Hrvatske šume d.o.o. (Stankov et al. 2019).

In order to mitigate the consequences of the described flood disaster on the environment and the local population, including the strengthening of the red deer population in this unique forest area, an international project "ForestFlow" was launched, which was financed through the IPA cross-border cooperation mechanism between Croatia and Serbia. Thanks to this project, on December 15, 2017, a total of 38 red deer were translocated from the Eastern Carpathians in Romania (12 ♂ and 26 ♀) to the Serbian hunting ground "Bosutske Forest" 17 (7 ♂ and 10 ♀) of which were fitted with GPS collars.

The first aim of the work was to determine the movements and spatial distribution of these animals in the new forest habitat after release from the acclimatisation enclosure and to determine their home range sizes. Secondly, but not less importantly, we assessed whether the translocated animals integrated successfully into the resident red deer population.

Materials and methods

Study area

The red deer translocation site, the "Bosutske Forest" hunting ground with an area of 14,912 ha, is located in the province of Vojvodina, northern Serbia (Figure 1). It is part of the Gornji Srem forest complex, which is managed by the Public Forestry Company "Vojvodinašume", Novi Sad.

Currently, the hunting ground consists of two different units: an open area (13,712 ha) and a fenced land (1,200 ha) intended for intensive breeding of red deer (*Cervus elaphus*) and wild boar (*Sus scrofa*). The dominant land cover category is forested land (11,897 ha), with a significant proportion of reeds, moors and heaths (1,072 ha), as well as meadows and pastures (648 ha). In addition, there are numerous areas unproductive for red deer, such as the fenced plots for the regeneration of pedunculate oak

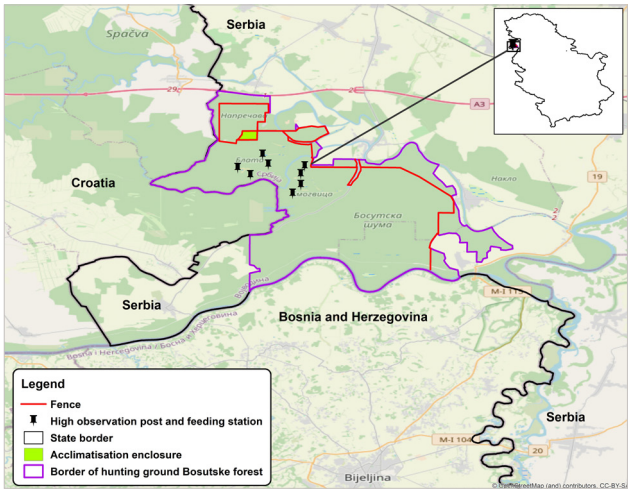

Figure 1. Map of the study area in the Vojvodina province (Serbia) showing hunting ground Bosutske Forest and a part of the famous lowland pedunculate oak forests (*Quercus robur*) in eastern Croatia (Spačva basin)

Solid black pins designate the positions of the observation posts on the left and right banks of the Studva River.

(1,048 ha), an artificial pond (57 ha), public and forestry roads (230 ha), pastures for domestic livestock (2,710 ha) and the water surface of the Sava, Bosut and Studva rivers (597 ha). In spring 2022, the red deer population wandering around freely was estimated at 356 animals, while in the fenced area the live board numbered 90 animals. Other game species are roe deer (*Capreolus capreolus*), brown hare (*Lepus europaeus*), golden jackal (*Canis aureus*), red fox (*Vulpes vulpes*), wild cat (*Felis silvestris*), European badger (*Meles meles*), common pheasant (*Phasianus colchicus*), mallard (*Anas platyrhynchos*) and Eurasian teal (*Anas crecca*).

Most of the hunting ground is covered by natural stands of middle-aged pedunculate oak (*Quercus robur*) with a significant proportion of narrow-leaved ash (*Fraxinus angustifolia*) and hornbeam (*Carpinus betulus*). There is a great diversity of plant species, especially in the strata of low trees and shrubs and in numerous meadows (Grčanac 2014, Jokanović et al. 2020). Before the construction of the Sava river embankment (1932), the entire hunting ground was regularly flooded, while larger depressions (ponds) were under water all year round, which rarely happens today. The terrain is flat and lies at an elevation of 77 to 85 m a.s.l. BES.

The climate is described as semi-continental with clear seasonal patterns (Grčanac 2014). The average annual temperature is 11.0°C with an average annual precipitation of 632 mm; the average number of snow days per year is 35 with an average snow depth of 12 cm. Other climatic data were provided from on-site measurements.

Details of the actual borders and location of fences around the study area are shown in Figure 1.

Data collection

Our study was based on a translocated group of 38 adult red deer (12 ♂ and 26 ♀) from the Harghita County, central Romania. A total of 7 males and 10 females were fitted with GPS collars (LifeCyclePro series – Lotek Wireless, approximate weight is 0.6 kg each). The collars were programmed to record GPS signals every 13 hours and were fitted with a mortality sensor. All procedures were performed by experienced veterinarians and during the translocation no losses were incurred. All red deer were transported into the 63-hectare acclimatisation enclosure for quarantine purposes (30 days).

The release of the relocated group was begun after 112 days (April 6, 2018), when two gates on the south side of the acclimatisation enclosure were opened. The first valid GPS signal received from the wild was counted as the date of leaving the acclimatisation enclosure.

Two released five-year-old individuals (male and female) were found dead in their new habitat (M6 on November 29, 2018 and F2 on December 1, 2018), so these two collars were removed and put on new individuals of the same sex and age, selected from the translocated herd (#M6 on January 23, 2019 and #F2 on June 18, 2019).

Additional post-release observations were made from eight observation posts on roofed viewing platforms which were established on the edges of a small grazing area, where additional food and salt were provided. Observations were carried out twice a day, depending on the season of the year, early in the morning (between 05:00 and 08:00, 06:00 and 08:30) and in the early evening (between 14:00 and 17:00, 15:00 and 18:00, 16:00 and 19:45, 16:30 and 21:30). A total of 24 feeding stations were established (Figure 6S, Supplements).

Over the period from January 1, 2018, to December 31, 2020, data on the state of vegetation in the hunting ground "Bosutske Forest" (e.g. start of grass growth, acorn yield, foliation dates and canopy closure, groundwater level and presence of mosquitoes) and intensity and type of forestry management operations (type, spatial extent and dynamics, disturbance level) were collected.

Statistical analyses

All data obtained from GPS-collared animals were preliminary analysed with the tools of the GPS Web Service (Lotek 2017) and visualized in Google Earth Pro (https://google-earth-pro.en.softonic.com/). From the latter the maximum distance obtained from GPS-collared animals was calculated as the straight-line distance from the edge of the acclimatisation enclosure to the farthest edge of the home range. The signals obtained were further processed using ArcGIS, version 10.8.2 software package (ESRI 2011) and ArcGIS Home Range Toolbox (Rodgers et al. 2015) according to the methods and procedures described by MacLeod (2013). Minimum convex polygons (MCP) were constructed for each of the collared animals which emitted signals useful for the analysis. We interpreted the polygons as "home range area sizes" for the animals and measured them in km^2. Kernel density estimation was further performed using ArcGIS with the Home Range Toolbox which created 50% contour plots (kde 50%) from the signals (h is the smoothing parameter set to 0.01), which we interpreted as the "core home range area sizes" and also measured in km^2. Prior to analyses, all distance and area data values were converted into logarithms.

We tested for differences between sexes in maximum distance, home range size, home range core area and duration of stay in acclimatisation enclosure by linear regression, while possible sex and age effects on maximum distance, MCP and kde 50% was tested by ANOVA. Patterns that existed were interpreted and reported. In all analyses, the statistical significance cutoff point was $p < 0.05$. All statistical analyses were performed using STATISTICA 12.5 software package (StatSoft 2014).

As an aid in visualization and interpretation, thematic base maps of the Bosut forest complex (e.g. forest types, forest origin, tree species, forest age structure) were generated using ArcGIS Desktop 10.8.2 software package (ESRI 2011). The datasets used were retrieved from the Forest Inventory Database of the Sremska Mitrovica Fo-

rest Administration, which is maintained by this Administration for the purposes of forest management and sustainable use.

Results

Within the monitoring period from November 23, 2017, to March 19, 2020, the death toll among 38 translocated red deer was 2 (5.3%), namely one male (M6) and one female (F2) aged five years (Table 1). The cause of death of the male was the excessive consumption of corn as supplementary food, while the cause of death of the female remains unknown.

There is a significant difference between males and females in the number of days they spent in the acclimatisation enclosure (F-test$_{1,14} = 6.10$, $P = 0.027$). The six collared males spent more days in the acclimatisation enclosure (mean number of days = 232, range = 159–288) than the ten females (mean number of days = 172, range = 128–268). In the period June–July 2018, 50% of the GPS-collared females were accompanied by calves. The start of calving during the observation period was on April 25, 2019, April 18, 2020 and April 23, 2021.

The greatest straight-line distance from the acclimatisation enclosure did not differ between males and females (F-test$_{1,14} = 0.012$, $P = 0.915$, absolute values converted to *ln*). On average, females were recorded at a greater distance than males (6.4 km and 6.0 km, respectively, absolute values), and for two females we recorded a distance of over 13 km (Figure 2). We categorized these females as migratory individuals.

A series of regressions were performed to determine the possible effects of the number of days spent in the acclimatisation enclosure (AE) and home range parameters (maximum distance (d_{max}) from AE, home range size expressed in terms of MCP and core range size expressed in terms of kde 50%, absolute values converted to *ln*). None of the

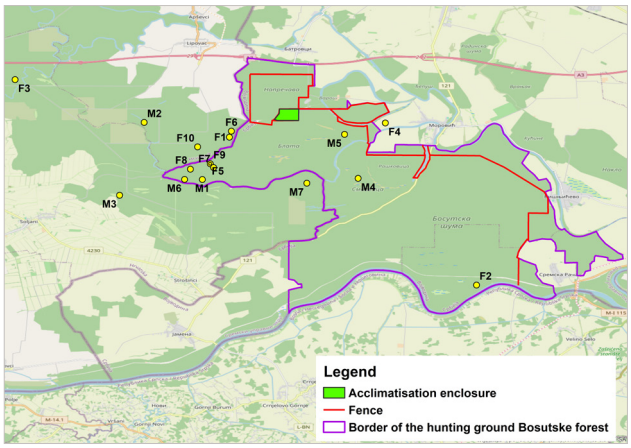

Figure 2. The greatest straight-line distance (2.3–13.7 km) from the acclimatisation enclosure (mean distance: male = 6.0 km and female = 6.4 km) in the "Bosutske Forest" area (Serbia) and Spačva basin (Croatia)

The data are presented in absolute values. Tests of sexual dimorphism were conducted on values converted into natural logarithms (ln)

Table 1. Recapitulation of data collected from the translocated animals (Length of holding period in the acclimatisation enclosure – total area of AE is 63 ha, post-release movement and home range size of translocated red deer in the "Bosutske forest" area)

ID	Age	Days held in AE	Period of monitoring	Emitted GPS signals [n]	The greatest distance moved		Total / Core home range [km^2]
					[date]	[km]	
M1	4	159	24.11.2017–23.12.2019	125	24.9.2018	5.96	15.63 / 0.60
M2	3	202	24.11.2017–2.3.2020	73	9.11.2018	7.22	18.11 / 2.45
M3	3	271	24.11.2017–4.2.2020	121	12.9.2018	9.71	36.07 / 1.19
M4	3	*	24.11.2017–5.12.2019	15	30.11.2019	4.72	0.25 / 0.02
M5	4	278	23.11.2017–19.12.2018	42	25.11.2018	2.33	4.26 / 1.84
M6	5	193	24.11.2017–30.11.2018	50	17.9.2018	6.59	10.52 / 1.97
#M6	5	0	23.1.2019–15.11.2019	97	14.11.2019	3.56	7.59 / 1.05
M7	5	288	24.11.2017–15.9.2019	42	4.10.2018	4.15	9.94 / 0.87
F1	3	130	1.12.2017–9.9.2018	5	30.6.2018	3.41	3.68 / 0.39
F2	5	171	25.11.2017–1.12.2018	68	31.10.2018	13.66	68.79 / 2.20
#F2	5	0	18.6.2019–23.1.2020	83	24.12.2019	5.62	0.49 / 0.03
F3	4	161	25.11.2017–12.3.2020	122	1.12.2019	13.54	65.58 / 4.17
F4	3	155	24.11.2017–19.3.2020	465	15.4.2019	4.06	12.22 / 0.69
F5	3	156	25.11.2017–18.3.2020	228	26.2.2019	5.02	10.66 / 1.48
F6	4	210	24.11.2017–5.1.2020	25	14.7.2018	3.22	8.40 / 1.39
F7	3	196	24.11.2017–13.10.2019	54	11.3.2019	5.04	8.12 / 0.74
F8	4	144	24.11.2017–15.11.2019	281	9.4.2019.	5.98	13.92 / 1.85
F9	4	128	24.11.2017–28.11.2019	321	26.2.2019.	5.02	22.90 / 1.40
F10	3	268	24.11.2017–10.3.2020	71	27.12.2019	5.03	12.16 / 1.64

Notes: M stands for male and F for female.

* This GPS collar transmitted signals irregularly and was later repaired at an authorized service centre (faulty signals excluded from further analyses).

Two collars put on animals, which emitted mortality signals and were subsequently replaced.

The data presented here expressed in absolute values were converted into natural logarithms prior to analyses.

regressions were significant (number of days / d_{max} : adjusted $R^2 = –0.03405962$, $P = 0.488587$; number of days / MCP : adjusted $R^2 = –0.04814280$, $P = 0.585858$; number of days / kde 50% : adjusted $R^2 = –0.05437938$, $P = 0.641561$). The regressions were not significant when two migrating females were removed from the analyses. However, maximum distance from the AE had an effect on home range size (d_{max} / MCP : adjusted $R^2 = 0.83128847$, $P = 0.000001$), with animals at greater distances from the AE tending to have larger home ranges (Figure 3). Core area is also affected by distance from the AE, for all animals (adjusted $R^2 = 0.20860148$, $P = 0.042975$), but not when the two migrating females were excluded from the analysis (adjusted $R^2 = –0.02994184$, $P = 0.445581$). Only significant regressions were graphically presented.

Differences between the red deer males and females in home range size and core range size were not significant according to our data (sex / MCP : $F\text{-test}_{1,14} = 0.12$, $P = 0.734$; sex / kde 50% : $F\text{-test}_{1,14} = 0.001$, $P = 0.981$).

During the observation period, a total of 1,333 follow-up observations were collected (480 from May to December 2019, 670 from January to December 2020, and 183 from January to April 2021). Observations were conducted from high observation posts distributed throughout the study area (see Figure 1) to provide experienced individuals with vantage points from which they could observe the activities of undisturbed animals (foraging in open areas and feeding stations). No red deer were present in 4.8% of the observations. Most observations were of herds containing 4–6 animals (52.3%), while sightings of large herds (≥ 10 animals) or single animals were rare (3.5% and 3.9%, respectively). Mixed herds dominated the observations (78.3%). Where herds were composed of animals of a single sex, female herds tended to be larger than male herds (mean = 3.7, range = 2–8, 150 observations for females; mean = 2.6, range = 2–5, 114 observations for males). The translocated animals were present in 830 observations (62.3%) in mixed herds, while GPS-collared animals were present in 620 (46.5%) of the total number of observations.

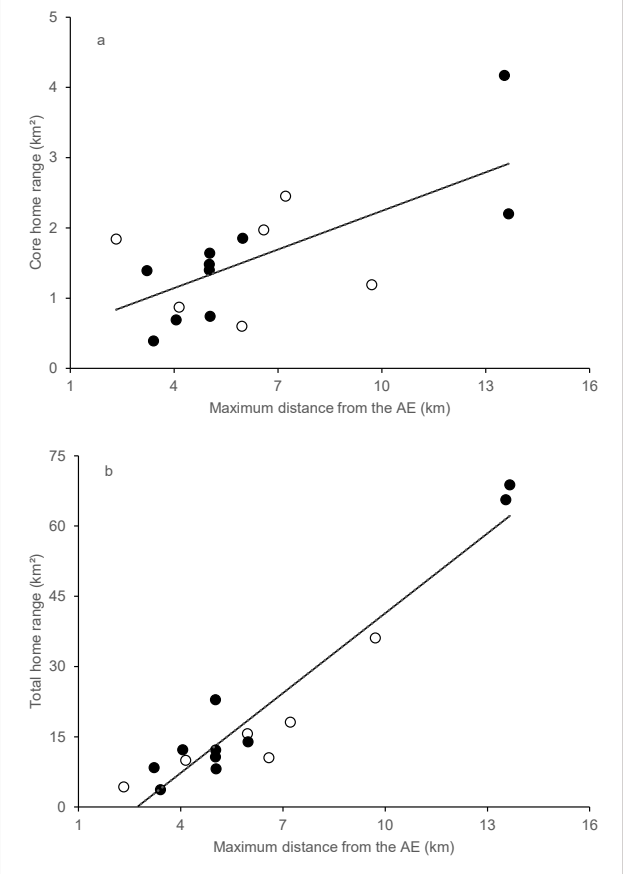

Figure 3. Relationship between maximum distance from the acclimatisation enclosure (AE) and the core (a) and total (b) home range

Solid black points denote female red deer, and white points denote male red deer. Tests of the regression equations were conducted on values converted into natural logarithms, while the graphs were developed from original data

Discussion and conclusions

The estimated spring number of red deer in the hunting ground "Bosutske Forest" was from 322 to 350 individuals (period 2019–2020). The losses of red deer (mainly due to hunting) were registered at 32–42 animals or average 11.2% of the total population, with females being hunted more than males. Red deer were hunted in the fall and winter months (September to January). No extreme weather events were recorded during the survey period. In 2019, a mosquito infestation was recorded in the area (particularly in June) and that was also a year with a bountiful crop of oak acorns. Disturbance events included moderate pressure in the study area due to regular forestry activities and low disturbance related to hunting activities. A periodic and low disturbance during the observation period resulted from acorn collection by the local community (33 days in total in 2019) and sporadic passages of migrants attempting to cross the border to Croatia. A total of 338.8 tons of supplementary forage was distributed throughout the study period (2017–2020) to 24 feeding stations (Figure 6S, Supplements).

Pre-release holding periods – hard (immediate release), semi-soft (4–10 days) and soft (6–16 weeks) – have been studied in several reintroduction programmes for elk (Rosatte et al. 2007, Ryckman et al. 2010) and red deer (Mladenović et al. 2022), but rarely when individuals are translocated from one population to another. These authors point out that dispersal after release from the enclosure appears to be related to the duration of captivity. They also suggest that post-release dispersal movements were influenced by factors such as large-scale differences in habitat, food availability, the presence of large predators (especially wolves and brown bears), roads, human disturbance, prevailing winds, sex and age distribution of released groups, and hydropower corridors. In our study, the greatest distance to the acclimatisation enclosure ranged from

2.3 to 13.7 km (Table 1), which differs drastically from the results of the aforementioned authors (up to 200 km in Ontario, Canada, and 24 km in western Serbia). We believe that this result is partly due to limited opportunities for the movement of the red deer in the study area, as well as an ample abundance and variety of food, and absence of large predators and stray dogs.

Although the holding period before release set by us ranged from 128 to 288 days, the size of the acclimatisation enclosure (63 ha) seemed to have a positive effect on acceptance of the new habitat conditions. Further we note that our results suggested that adequate social cohesion between translocated and resident individuals was also established. After translocation, judging by the GPS signals received, almost all GPS-collared translocated individuals frequently returned to the acclimatisation enclosure during the monitoring period, where they stayed again for a few days or months, and *vice versa*.

The performance and reliability of GPS collars has been studied in different habitat types and in different game species – elk (Gamo et al. 2000, Vance et al. 2017), mouflon (Bourgoin et al. 2009), red deer (Stache et al. 2012), caribou and bison (Jung et al. 2018). These authors suggest that fewer 3D GPS signals are transmitted from forests (treetops) and hilly terrain compared to clearings and flatter terrain. It can be concluded that the large forest cover of the "Bosutske Forest" hunting ground (≈ 80%) was the main reason for the lower number of GPS signals received than the planned number of signals (6,231 vs. 26,894), especially since in these deciduous floodplain forests, where the canopy and forest strata are well developed (Grčanac 2014).

Some authors found that GPS collars work better at night, which can be explained by the fact that red deer are less active during the day and therefore signal more frequently at night when they visit pastures and other open areas (Zweifel-Schielly and Suter 2007). They point out that GPS collar failures are to be expected during research and that it is extremely important and mandatory to check the correctness of each collar in the field before placing it on an animal. In their research in the Swiss Alps, out of 18 collars fitted to red deer, 11 stopped working long before they had reached their expected lifespan. This is also confirmed by our experience since several collars were repaired during our study. In addition, the results of our study corroborate the results from western Serbia (Mladenović et al. 2022), who have shown that GPS collars should not be purchased and/or put on the animals prior to release from acclimatisation enclosure. This practice may, as in our study, result in significantly more 3D GPS signals being transmitted during captive husbandry of translocated animals than after their release (63.3% vs. 36.7%).

Understanding and predicting space-use patterns by red deer are particularly important for intensively managed populations and hunting grounds (Reinecke et al. 2014, Månsson et al. 2021), which are among of the most important features for the whole area of "Bosutske forest" (Serbia) and Spačva Basin (Croatia). Knowledge of space use is necessary to mitigate the damage caused by red deer in agriculture and forestry, but also for wise and sustainable hunting management of its habitats and populations (Jarnemo et al. 2023). The most important biological characteristics of red deer include the differences determined by sexual dimorphism in behaviour between males and females, and a diverse and strong mating behaviour. During mating, the male herds separate, and the stronger males approach the hinds, while those of poorer condition wander alone in search of the hinds. Thus, we surmise that the movements of males are influenced by access to females, while the movements of females are influenced by competition for resources related to the rearing of fawns, especially regarding the distribution of high-quality plant food (Kamler et al. 2007, 2008).

The movement and behavioural patterns of red deer depend not only on sex, but also on the influence of abiotic factors (temperature, wind and precipitation), the presence of large predators (wolf and brown bear), season (autumn-winter vs. spring-summer), supplemental feeding, habitat composition (agriculture vs. forest or agroforestry) and human activities (e.g. hunting, hiking, local community activities, tourism). This has been shown in numerous studies in different habitats across Europe and with different cultivation methods and management systems (Luccarini et al. 2006, Kamler et al. 2007, 2008, Náhlik et al. 2009, Jerina 2012, Reinecke et al. 2014, Kropil et al. 2015, Smolko et al. 2018, Zlatanova et al. 2019, Chassagneux et al. 2020, Laguna et al. 2021, Csányi et al. 2022, Meisingset et al. 2022). That is why to compare our results with the results of the mentioned authors for several reasons is difficult. Our study is based on the monitoring of adult individuals translocated from small, fenced hunting ground situated in a highland area (Harghita County) of central Romania. Moreover, the hunting ground "Bosutske Forest" is a typical lowland area with intensive supplementary feeding throughout the year, mostly covered by human-modified forests of pedunculate oak, narrow-leaved ash and hornbeam. The absence of large predators and a decades-old high fence towards the agricultural fields are also important.

Some of the latest research has shown that habitat composition has an influence on the size of the individual activity range of red deer, especially the proportion of forest, which is negatively related to the size of the annual and seasonal individual activity range (Jarnemo et al. 2023). These authors also found that females in a mixed forest-agriculture landscape had on average a three times larger individual activity range compared to a forest landscape. As already pointed out, the translocated red deer in our study were only experienced a forested landscape without agricultural fields and had limited opportunities to enter the adjacent mixed forest-agricultural landscape.

Since our research was conducted in the lowland floodplain and typical forest area of the region, our results

indicate that the red deer showed large variations in home range size (MCP, range = 0.49–68.79 km^2). This result is consistent with the results obtained in three different areas in Germany (0.79–63.0 km^2) based on three estimation methods (Reinecke et al. 2014). Furthermore, our results showed that the core areas in the "Bosutske forest" area (50% kernel density estimates), mean = 1.44 km^2, range = 0.03–4.17 km^2) are up to 20% of the assessed home ranges (95% kernel, mean = 8.12 km^2, range = 0.09–23.10 km^2). Our results correspond well to the results obtained for female red deer in two different regions in Sweden, especially in the Kolmården region, which is dominated by forest land: 50% kernel, mean = 1.63 km^2, range = 0.37–6.45 km^2 and 95% kernel, mean = 8.10 km^2, range = 1.54–39.14 km^2 (Jarnemo et al. 2023).

We conclude that a high degree of acceptance of the new habitat occurred in the translocated red deer and that social cohesion was established between the translocated and resident red deer. That can be attributed to a long period of stay in a large acclimatisation enclosure (63 ha) and can be achieved by regular and intensive supplementary feeding throughout the year which can compensate for any deficit in the productivity of the native forests. Under the data obtained, we can offer a tentative explanation for the interesting results revealed by us, namely that red deer tend to have larger home range sizes further from the acclimatisation enclosure (Figure 3). We suppose that microhabitat differences in the forest composition and supply of cover and forage are the main reasons. We note that the distribution of 3D GPS positions is denser in the eastern, southern and south-western parts of the study area for males (Figure 4S, Supplements), and in the eastern and southwestern parts for females (Figure 5S, Supplements). These correspond to the location of younger and mixed pedunculate oak, narrow-leaved ash and hornbeam forests which provide both ample cover and forage. As the distance from the acclimatisation enclosure increases, middle-aged and older pedunculate oak forests dominate, providing less cover and forage. Also, in our opinion, cross-boundary synchronisation of forest and wildlife management practices is necessary to effectively manage red deer since several animals crossed the national border into Croatia.

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Supplement

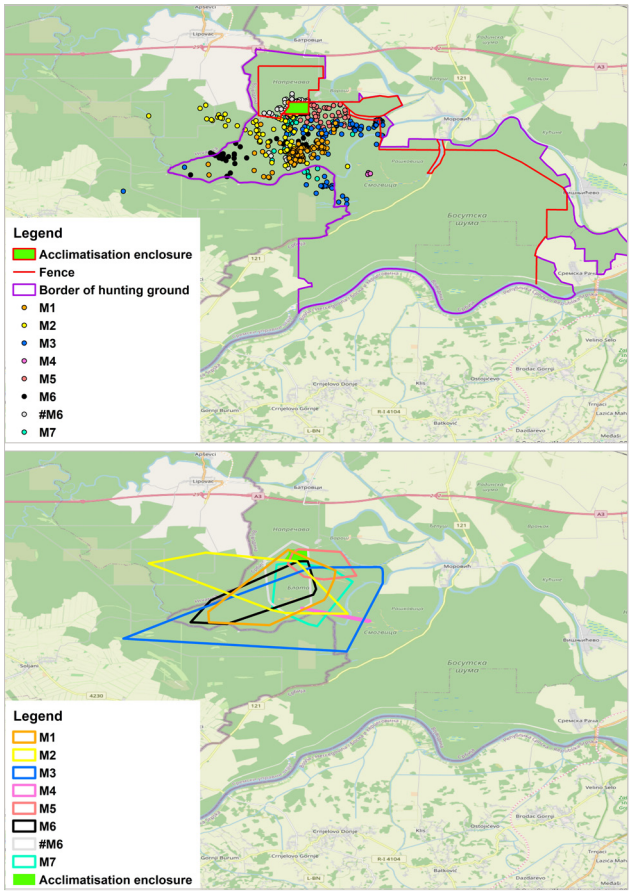

Figure 4S. Distribution of male GPS positions (n = 565) transmitted from May 2018 to March 2020, and post-release total home ranges (20–3,610 ha) in the "Bosutske Forest" area (Serbia) and Spačva basin (Croatia)

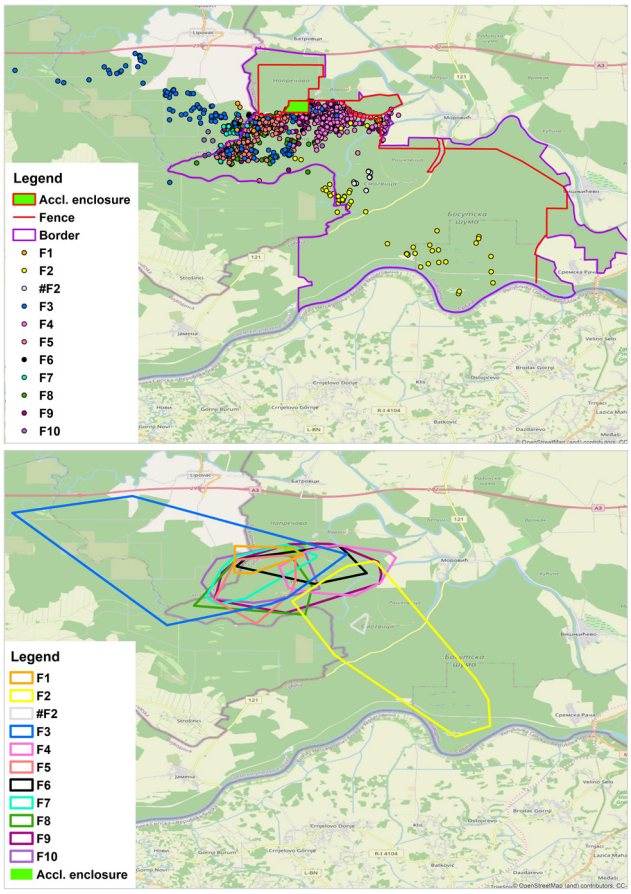

Figure 5S. Distribution of female GPS positions (n = 1,723) transmitted from April 2018 to March 2020, and post-release total home ranges (40–6,870 ha) in the "Bosutske Forest" area (Serbia) and Spačva basin (Croatia)

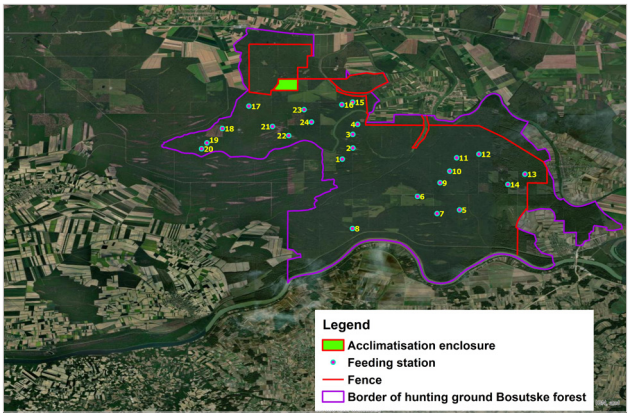

Figure 6S. Distribution of twenty-four feeding stations in the hunting ground "Bosutske Forest"