HUNGARIAN UNIVERSITY OF AGRICULTURE AND LIFE SCIENCES

DOCTORAL SCHOOL OF ANIMAL BIOTECHNOLOGY AND ANIMAL SCIENCE

ANALYSIS OF ADAPTATION TO THE ENVIRONMENTAL FACTORS THROUGH THE EXAMPLE OF THE EUROPEAN ROE DEER (*CAPREOLUS CAPREOLUS* LINNAEUS, 1758)

Thesis of PhD Dissertation

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1. Introduction and objectives

1.1. Background

In wildlife biology and behavioural ecology, one of the most important research fields is the habitat use of wildlife species. In this regard, results are required in many aspects of game management, e.g. habitat management planning, game damage prevention and installation of game management equipment. Research methods of wildlife biology have been improved tremendously in the last few decades, which allows us to collect large amounts and accurate data more easily.

Roe deer (*Capreolus capreolus*) is one of the most common wild ungulate species in Europe. Several studies in Europe described the spatio-temporal patterns of Roe deer movements, home range size and habitat use.

Roe deer can use very diverse areas, such as forested, agricultural and mixed habitats with various patches: all are characterised by different attributes. If we compare the habitat use among Roe deer that live in the same study area, but in different habitats, we can obtain information on which habitats provide the necessary resources for the animals in a smaller area, as the home ranges are expected to be smaller where the resources are more abundant. Because of the environmental factors and biological, behavioural characteristics of a given species, the habitat use can change seasonally. For research and management purposes it is important to know, that which time periods during the year can be treated as different "seasons". These seasons can be determined by analysing the relations and correlations among shorter time periods.

During their movements, Roe deer pass through various natural and artificial landscape features. Certain features, such as fenced highways, roads or other human facilities, or even rivers and canals can act as barriers that restrict animal movement. The barrier role of natural watercourses is still debatable, as water crossing is a known phenomenon in the case of European and Siberian roe deer (*Capreolus pygargus*). Every Cervid species is capable of swimming, e.g. Moose (*Alces alces*) and Reindeer (*Rangifer tarandus*) are at home in water and on land, but there are species unable to swim or without the need for crossing water. However, little information is available on water crossings by Roe deer. There are studies about river crossings by terrestrial mammals, but roe deer was not examined regarding this behaviour.

In the habitat used by game animals, human activities with variable intensity occur throughout the year. Typical forms are agricultural and forest management operations, as well as recreational activities (e.g. sports, dog walking, hunting, etc.). According to several studies, these disturbances may cause changes in the habitat use of Roe deer. Live Brown hare (*Lepus europaeus*) captures that come with increased human presence and loud noise are organised every winter. This activity can cover large areas, but its possible effect on Roe deer has not been examined previously.

1.2. Aims

In order to understand the spatial behaviour and the habitat use of Roe deer in open largescale agricultural landscapes, the former Institute for Wildlife Conservation of the Szent István University (SZIU-IWC, Department of Wildlife Biology and Management of the Hungarian University of Agriculture and Life Sciences) conducted a research programme in Jász-Nagykun-Szolnok County, between 2001 and 2010, which I joined in 2007. As a result of the technological improvements, that time I was able to work with GPS-GSM collars, that allowed me to collect large number of localisations with high accuracy.

The first few GPS-GSM collars were installed on Roe deer captured in the floodplain forest of the river Tisza, but it became clear in the first stage of the research that those individuals use the surrounding agricultural lands as well.

Later, other Roe deer were captured and tagged in agricultural habitats further from the forest, which allowed to analyse the habitat use of Roe deer tagged in different areas.

The aims and questions of my study were the following:

Analysis of the home range sizes of Roe deer tagged in floodplain forests adjacent to river Tisza and in agricultural habitats:

1. Is there any difference between the home range sizes of Roe deer tagged in floodplain forests adjacent to river Tisza and in agricultural habitats?
2. Is there any difference between the home range sizes of Roe bucks and does?
3. Is there any difference among the monthly home range sizes, is it possible to identify any seasonality?

Detailed analysis of river crossings across the Tisza:

4. Does the Tisza act as a barrier for the Roe deer movements in the study area?
5. Are there seasonal or daily differences in the pattern of river crossings?
6. Is there any difference between males and females in terms of the proportion of „swimmers" or the number of river crossings?
7. Do the changes in the water level have any effect on the river crossings?

Analysis of – assumably – the most intensive human disturbance in the study area:

8. Does the live brown hare capture cause long or short-term changes in the habitat use of the examined Roe deer?

2. Material and methods

2.1. Study area

The study took place near Tiszapüspöki, on the hunting ground of the Hofi Géza Hunting Club. The area of the game management unit is 5,238 ha, of which 8.8% is not suitable for game management. The majority (73.8%) of the hunting area is covered by agricultural land, only 6.6% of the area is forested, which mainly consist of floodplain forests. In 45% of the forested areas, the quality of the shrub level – that serves as a food supply for many game animals – was good or exceptional, while it was poor only in 10% of the forested habitats. The agricultural lands are characterised by fields of medium and large size. The edges of the arable fields are left untreated at several places, furthermore many ditches with tall grass and bushes, roadside forest belts, and small reedy, sedgy patches can be found, thus the small game can easily find shelter. The game field management is good, the amount, parcel size and food supply of the game fields is appropriate. Regarding the topology, the hunting ground lays on a flat lowland area. The river Tisza acts as border along a 15 km long section, and a 2-3 km long section of a warm water channel crosses the southern part of the area. The width of the Tisza in the study area varies between 50-160 m (depending on the water level). The hunting ground is a small game area, with outstanding Pheasant (*Phasianus colchicus*) and Brown hare populations. Furthermore, the population size and quality of the Roe deer population is also good. With relatively low harvest rates, the population sizes grew during the study period. In order to protect the small game populations, intensive predator management was performed.

2.2. Capturing and tagging of Roe deer

The capturing and tagging of Roe deer was carried out on four occasions: January 17-18, 2007; October 4, 2007; January 22-23, 2008 and

October 10, 2008. In winter, Roe deer were tagged in the floodplain forest, while in autumn, tagging was performed in agricultural habitats. When the captures were organised in the forest, standing nets were hanged on the line clearances of the floodplain forest, forming a U shape, similar to a large sack. This is necessary because when deer detect the drivers and the net, they often escape to side directions from the drive. The drive was oriented parallel to the Tisza River. Nets were hung also along the starting line of the drive, so that if the drivers saw individuals running towards the drive, a counter-drive could be started. In the agricultural habitat, the same method was followed, the only difference was that the nets were hung on the standing maize plants instead of trees. Catchers were hiding near the nets, and after capture immediately held and carefully freed the animals from the net. This was followed by mounting the collars on the neck of the Roe deer. In total, 18 individuals were captured and tagged (5 males and 8 females in the floodplain forest, 4 males and 1 female in the agricultural land) (**Table 1.**). The individuals were equipped with GPS-GSM collars, that are capable of positioning by using satellite signals.

Table 1. Information on captured and tagged Roe deer (D: death, CM: collar malfunction)

Collar number	Sex	Collar code	Estimated age at tagging	Tagging		First localisation	Last localisation	Number of localisations	Total tracking time (days)	Lost due to
				Date	Place					
C03136	male	**B1**	3 years	17.01.2007	floodplain forest	17.01.2007	13.07.2007	1 416	177	D
C03137	female	**S1**	3-4 years	17.01.2007	floodplain forest	17.01.2007	16.09.2008	4 840	608	D
C03138	female	**S2**	2 years	18.01.2007	floodplain forest	18.01.2007	07.03.2009	6 197	779	CM
C03139	young female	**SG1**	1 year	18.01.2007	floodplain forest	18.01.2007	16.05.2009	6 743	849	CM
C03140	female	**S3**	3-4 years	17.01.2007	floodplain forest	17.01.2007	20.06.2008	4 088	520	CM
C03141	male	**B2**	3 years	17.01.2007	floodplain forest	17.01.2007	23.05.2009	6 797	857	CM
C03142	male	**B3**	3 years	18.01.2007	floodplain forest	18.01.2007	20.12.2008	5 588	702	CM
C03143	female	**S4**	2 years	18.01.2007	floodplain forest	18.01.2007	23.04.2009	6 528	826	CM
C03144	female	**S5**	2 years	18.01.2007	floodplain forest	18.01.2007	29.01.2009	5 834	742	CM
C03146	male	**B4**	3 years	17.01.2007	floodplain forest	17.01.2007	04.10.2007	2 049	260	D
C03145	male	**B5**	2-3 years	04.10.2007	agriculture	04.10.2007	27.04.2008	1 649	206	D
C03147	male	**B6**	2-3 years	04.10.2007	agriculture	04.10.2007	24.07.2008	2 351	294	D
C03136a	female	**S6**	3-4 years	22.01.2008	floodplain forest	22.01.2008	07.04.2010	5 710	806	CM
C04511	male	**B7**	2 years	22.01.2008	floodplain forest	22.01.2008	06.11.2009	5 006	654	CM
C04516	female	**S7**	3-4 years	23.01.2008	floodplain forest	23.01.2008	30.07.2009	4 295	554	CM
C04512	male	**B8**	2 years	10.10.2008	agriculture	10.10.2008	28.04.2010	3 883	565	CM
C04514	male	**B9**	2 years	10.10.2008	agriculture	10.10.2008	24.06.2010	4 296	622	CM
C04533	female	**S8**	6 years	10.10.2008	agriculture	10.10.2008	03.04.2010	3 733	540	CM

2.3. Localisations

The collars recorded localisations in every 3 hours (every day at 0, 3, 6, 9, 12, 15, 18, 21 o'clock) on a SIM card (well known from cell phones), then sent them as an SMS via the GSM system to another SIM card, located in the former SZIU-IWC. From this SIM card – with the aid of an antenna and an adapter – I downloaded the date to a computer. This method is advantageous, as it collects data regardless of the time of the day and the weather, therefore no field work is required after tagging the animals. The large number of localisations allows researchers to track movements and habitat use with high accuracy.

2.4. Data processing and assessment

The visualisation of the localisations of the 18 individuals, the calculations and visualisation regarding the home ranges, moreover examination of the river crossings and human disturbance was conducted by using the ArcView GIS 3.1 (ESRI Inc.) software. The localisations that originated from unquestionably incorrect measurements were excluded from the analyses.

2.4.1. Comparison of the home range sizes

I determined the annual, seasonal and monthly home range sizes of the captured Roe deer with the Minimum Convex Polygon (MCP) method. I visualised the home ranges with the Spatial Analyst and the Spatial Movement Analysis extensions for ArcView, and I calculated the area sizes with these, as well. As the duration of tracking was variable among the individuals, furthermore the animals were tagged and lost on different dates of the years, only complete annual, seasonal and monthly datasets were used in the respective analyses. In the case of each individual, I excluded the year, season and month in which the animal was captured and lost from the annual, seasonal and monthly comparisons, respectively. This helped to avoid possible biases caused by the fact that MCP area size correlates with the number of localisations, as this way each individual had the same number of localisations for a given period because of the uniform 3 hours frequency of the localisations. The low sample sizes prevented the comparison of the annual and seasonal datasets.

The sample size from calculating the monthly home range areas proved to be sufficient for classification based on sex and tagging site (floodplain forest or agriculture), therefore these data were used in the statistical analyses.

All available data were grouped by the sex of the individual and the place of tagging, followed by MCP area size comparisons between males and females, and between individuals tagged in the floodplain forest and the agricultural habitat with Mann-Whitney test. In order to confirm the results, the monthly mean of the home range size was calculated in each sex and tagging site group, and the monthly means were compared with paired t-test.

I applied Kruskal-Wallis test to compare the monthly home range sizes (each individual combined), then Mann-Whitney tests were used as post hoc test to find the differences between the month pairs. The level of significance was verified by using Bonferroni test.

2.4.2. Analysis of the crossings across the river Tisza

In this analysis, the examined data originated from the 13 individuals that were tagged in the floodplain forest.

I aggregated the number of river crossings, then grouped the examined occasions by sex, season and the time of the day. The proportion of „swimmers” was compared between the sexes with Fisher's exact test.

The number of river crossing proved to be extremely high in the case of one doe (S4). In order to avoid biases caused by this outlier value, I excluded this individual from the statistical analyses regarding the comparison of the number of crossings between the different groups.

The number of crossings in the sexes was normalised to crossing/individual/year value, then the sexes were compared with unpaired t-test. Concerning the time of the day, the number of crossings was calculated as crossing/individual, then the data between daytime and nighttime were compared with unpaired t-test. The number of crossings in the different seasons was given in crossing/individual/season, the differences were analysed with Kruskal-Wallis test.

In order to examine whether the water level of the river Tisza had an effect on the crossings or not, I collected the daily water level data of the Tisza at Szolnok for the period between 2007 and 2010 from the National Water Level Service. I calculated averages for the water levels of the crossing days and all of the non-crossing days, then compared them with Wilcoxon rank sum test with continuity correction.

2.4.3. Analysis of the effect of the live brown hare captures on the Roe deer tagged in the agricultural habitat

In the study area, the most intensive human disturbance can be identified as the live brown hare captures organised by the game manager in every winter. The number of participants in such an event can exceed 100 people. During the capture, 70-80 drivers form a line and move across the selected areas in order to drive the hares in the direction of a 500 m long net that lays on the ground. The catchers hide behind the net, and lift its upper cord just before a hare would run over it. The captured animals are immediately removed from the net and put into wooden boxes. In order to increase the success of the capture, the drivers make a lot of noise by clapping, screaming, and sometimes even by (illegally) using firecrackers. A drive can be 1,5-2 km long. In the study area, 3-14 capture days were organised in every winter.

For the capture days of the 2007/08., 2008/09. and 2009/10. winters, I calculated the daily movement distances (by adding up the distances between the localisations collected with a 3-hour frequency) of the examined individuals, and compared them to each other. Home ranges of the 5 Roe deer that were captured and tagged in the agricultural habitat were involved in the analysis. In the case of each capture day, individuals with home ranges overlapping with the given capture area were separated, then I created an overlapping and a non-overlapping group. Because of the small individual sample sizes, each day of each individual was included in the analysis. If at least one localisation of the animal fell in the capture area, that day of the individual belonged to the overlapping group, otherwise it was a member of a non-overlapping group. This means that any examined Roe deer could belong to the overlapping group on certain days, while it was assigned to the non-overlapping group on other days. The daily distance movements of the two groups were compared with unpaired t-test (with Welch's correction). The capture area and the daily movements were examined on the created maps one by one.

For the statistical analyses performed in my study I used InStat v3.05 (Graphpad Software Inc.) and R (R development Core Team, 2014) software.

3. Results

3.1. Home range sizes of the examined Roe deer

3.1.1. Comparison of the home range sizes of Roe deer tagged in floodplain forests adjacent to river Tisza and in agricultural habitats

In the case of Roe deer tagged in the floodplain forest, the minimum of the monthly home range size was 10.4 ha, the maximum was 1,007.3 ha, the mean was 135.5 ha, SD was 150.4 ha, while the median was 82.6 ha. The results were the following in the case of Roe deer tagged in agricultural habitat: minimum: 10.7 ha, maximum: 1,631 ha, mean: 433.8 ha, SD: 351.9 ha, median: 396.3 ha (**Figure 1.**).

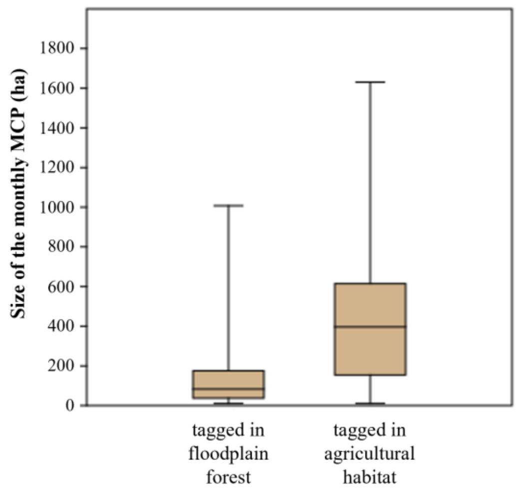

Figure 1. Monthly home range sizes of Roe deer tagged in floodplain forests and in agricultural habitats

The home ranges of deer tagged in agricultural habitats were significantly larger (Mann-Whitney $U = 3,769$; $p < 0.0001$).

The home range sizes of individuals tagged in the floodplain forest did not increase to the same extent as it occurred in the case of Roe deer living in the agricultural habitat. Based on the monthly visualisation of the data, two periods can be separated: from May to September and from October to April. No definite difference can be observed in the first period, while in the second period, the home ranges of deer living in the agricultural habitat were remarkably larger.

In order to confirm these results, I compared the monthly means calculated from the MCP sizes of individuals tagged in the floodplain forest and agricultural habitats. This analysis also indicated that the animals tagged in the floodplain forest used smaller home ranges ($t = 3.584$; $df = 11$; $p = 0.0043$).

3.1.2. Comparison of home range sizes of males and females

The monthly minimum of home ranges used by buck was 10.7 ha, the maximum was 1,631 ha, the mean was 245 ha, SD was 302.9 ha, the median was 113.3 ha. In the case of does, the results were the following: minimum 10.4 ha, maximum 1,007.3 ha, mean 165.4 ha, SD 181.7 ha, median 92.6 ha (**Figure 2.**).

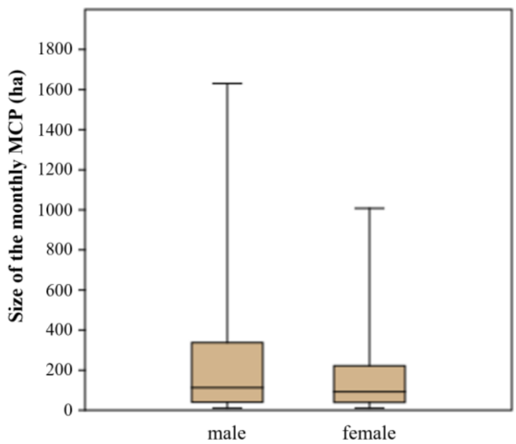

Figure 2. Monthly home range sizes of the tagged Roe bucks and does

According to my results, there was no statistically significant difference (Mann-Whitney U = 10,911; $p = 0.12$ NS) between the home range sizes of the two sexes on an annual basis.

In order to confirm these results, I compared the monthly means calculated from the MCP sizes of bucks and does, which showed no significant difference ($t = 2.084$; $df = 11$; $p = 0.061$ NS) either.

3.1.3. Comparison of the monthly home range sizes of the examined individuals

The minimal monthly MCP sizes were between 10.4 ha and 51.3 ha, maximums were between 151.4 ha and 1,462.4 ha, means were between 43.4 ha and 455.7 ha, SDs were between 33.6 ha and 378.1 ha, while medians varied between 24.6 ha and 327 ha (**Figure 3.**).

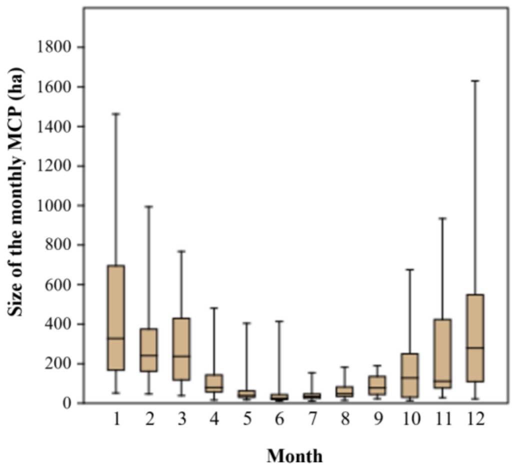

Figure 3. Monthly home range sizes of the tagged Roe deer

According to the Kruskal-Wallis test, the monthly home range sizes were different from each other ($chi^2 = 144.7$; $p < 0.05$). According to the Mann-Whitney U tests (performed as post hoc tests), the values of May, June, July, August and September were different from the area sizes of December, January, February and March. The values of April and November were diefferent from the ones of June and July, moreover there was a difference between November and May. The MCP sizes of October were not different from the values of any other month.

3.2. Analysis of the crossings across river Tisza

3.2.1. The number of crossings

Ten Roe deer out of 13 crossed the Tisza at least twice, which means that no individual swam across the river without returning (**Table 2.**).

Table 2. Dates and times of river crossings across the Tisza by the tagged Roe deer

Collar code	Time and date of river crossing	Time and date of returning
B1	17.04.2007. 09:00	17.04.2007. 18:00
	25.04.2007. 09:00	25.04.2007. 12:00
	25.04.2007. 15:00	25.04.2007. 18:00
S1	17.01.2007. 12:00	18.01.2007. 15:00
	31.07.2007. 15:00	02.08.2007. 03:00
	15.07.2008. 03:00	15.07.2008. 06:00
S3	07.05.2007. 12:00	07.05.2007. 18:00
	01.11.2007. 12:00	03.12.2007. 00:00
	03.12.2007. 06:00	X
B2	15.10.2007. 06:00	15.10.2007. 09:00
	31.01.2008. 15:00	02.02.2008. 03:00
B3	02.04.2007. 00:00	05.04.2007. 06:00
	24.04.2007. 21:00	27.04.2007. 09:00
	03.05.2007. 06:00	06.05.2007. 06:00
S4	10.10.2007. 18:00	16.10.2007. 06:00
	16.10.2007. 21:00	18.10.2007. 06:00
	18.10.2007. 18:00	22.10.2007. 12:00
	23.10.2007. 18:00	24.10.2007. 06:00
	24.10.2007. 18:00	25.10.2007. 06:00
	26.10.2007. 18:00	27.10.2007. 06:00
	27.10.2007. 21:00	29.10.2007. 06:00
	01.11.2007. 18:00	03.11.2007. 06:00
	03.11.2007. 18:00	31.12.2007. 15:00
	01.01.2008. 00:00	05.03.2008. 15:00
	15.10.2008. 00:00	16.10.2008. 03:00
S5	25.04.2007. 06:00	25.04.2007. 09:00
	12.05.2007. 06:00	12.05.2007. 15:00
	13.05.2007. 09:00	15.05.2007. 21:00
B4	07.08.2007. 06:00	07.08.2007. 09:00
S6	22.01.2008. 15:00	22.01.2008. 21:00
	06.04.2009. 09:00	06.04.2009. 12:00
S7	15.06.2008. 15:00	15.06.2008. 18:00

During the study period, three Roe deer (S2, SG1, B7) did not cross the river at all. The other 10 individuals (4 males and 6 females) crossed the river 63 times in total. The S4 doe crossed the river 22 times during the study period, which is 3.7 times more than the second largest number of crossings. In order to avoid possible biases, I excluded this individual from these analyses.

Roe deer crossed the river in every time of the day in each season. I found no difference in the distribution of „swimmers" between the sexes. ($P = 1.00$ NS). Four out of five bucks and six out of eight does crossed the river. There was no difference in the aggregated number of crossings ($t = 0.7974$; $df = 7$; $P = 0.4514$ NS) either. The number of crossings proved to be different between the times of the day ($t = 4{,}082$; $df = 16$; $P = 0.0009$): more river crossings occurred during the day than at nighttime (**Figure 4.**).

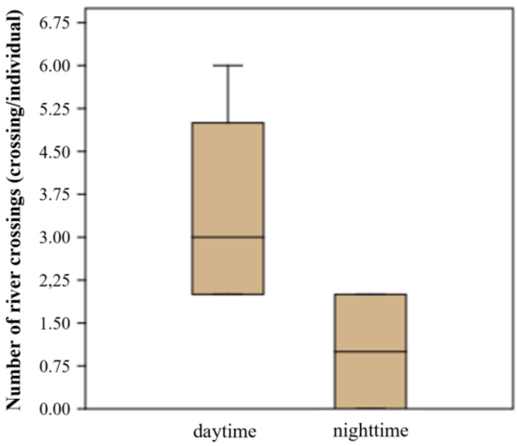

Figure 4. Number of river crossings during the day and at nighttime

The absolute number of river crossings was the highest in spring (winter: 8, spring: 22, summer: 8, autumn: 3), however I found no statistically significant difference in the frequency of crossings (normalised to crossing/individual/season) among the seasons (Kruskal-Wallis test: $KW = 2.535$; $P = 0.469$ NS).

The tracked Roe deer crossed the Tisza in different numbers and with various frequency. Some animals returned on the day of the crossing, e.g. the B1 buck crossed the river twice (in one direction in the morning, then returned in the evening). From October, 2007 to March, 2008, the home range of the S4 covered both sides of the river. During this period, that individual crossed the river 20 times, out of which 17 happened in less than one month. From

November to December, it spent 58 days on one side of the Tisza, then from January and March it stayed on the other side without crossing the river for 64 days. After that it returned, then it crossed the river again for the next time in October, 2008. As I mentioned earlier, I excluded this individual from the analyses regarding the number of river crossings because of the outlier values. Another female (S3, tagged in January, 2007) spent a half day on the other side of the Tisza on May 7, 2007, then stayed there for 32 days from 1 November, 2007, and eventually moved its home range completely to that side on December 3. Two does (S1 and S6) swam across the river right away as they were released at the end of the tagging. One of them returned on the same day, while the other on the next day. In summary, I concluded that the river crossings can said to be occasional, the S4 female meant the only exception, as it crossed the Tisza regularly.

3.2.2. The effect of the water level

I found a difference in the water level between the days with crossings, and the non-crossing days (Wilcoxon rank sum test with continuity correction: W = 31.854; $p < 0.05$) (**Figure 5.**).

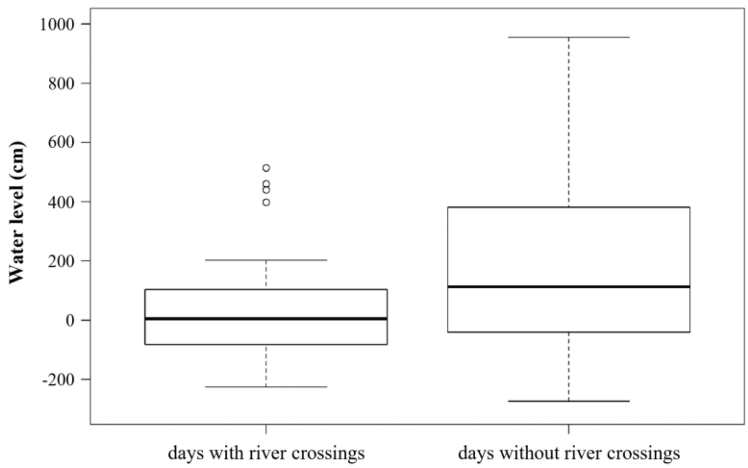

Figure 5. Water levels of the Tisza on the days with crossings, and on the non-crossing days

The separate analysis of the water level data on the days with crossings showed that 90% of all crossings happened under a 200 cm water level.

3.3. Analysis of the human disturbance

Table 3. presents the dates of the live brown hare captures in the three examined years and the related daily movement distances of the tagged individuals. The values with grey background reflect to the days when the capture overlapped with the localisations of the given individual on the given day.

Table 3. Dates of the live brown hare captures in the three examined years and the related daily movement distances of the tagged individuals

2007/2008		
Date of brown hare capture	movement distance (m)	
	B5	B6
nov. 27.	2168	1826
nov. 28.	1579	2100
nov. 29.	2448	3634
nov. 30.	2931	3488
dec. 01.	6041	5838
dec. 15.	3298	5726
dec. 16.	6946	5074
dec. 17.	2818	2504
dec. 18.	643	3193
dec. 19.	4834	5207
dec. 20.	1496	1649
dec. 21.	1393	1655
dec. 22.	1666	1604
dec. 23.	1360	3462

2008/2009			
Date of brown hare capture	movement distance (m)		
	B8	B9	S8
dec. 27.	2736	3529	4887
dec. 28.	4667	4203	3908
dec. 29.	1424	2692	2214
dec. 30.	4401	6427	5158
dec. 31.	4555	4508	7182
jan. 02.	3488	2837	3928
jan. 03.	3260	4343	4446
jan. 04.	4466	4445	5002
jan. 05.	3714	1897	1670
jan. 06.	4935	4350	5472
jan. 07.	5408	11008	6289
jan. 08.	5445	4310	3272
jan. 09.	2536	4174	2733

2009/2010			
Date of brown hare capture	movement distance (m)		
	B8	B9	S8
dec. 15.	3943	1796	4605
dec. 16.	1099	2546	5904
dec. 17.	5779	3071	3201

Values with grey background: The days when the capture overlapped with the localisations of the given individual.

The daily movement distances were larger in the case of Roe deer that had localisations overlapping with the area of the live brown hare captures (Welch's approximate $t = 3,116$; $df = 26$; $P = 0.0044$).

By examining the capture area and the daily Roe deer localisations on the created maps one by one, it can be observed that when the drive reached the location of the animals, they escaped from the disturbed area, then returned shortly after the end of the capture. When the capture area fell near to an examined Roe deer, but did not cover the location of the individual directly, no extreme movements occurred.

4. Discussion and conclusions

4.1. Home range sizes of the examined Roe deer

4.1.1. Comparison of the home range sizes of Roe deer tagged in floodplain forests adjacent to river Tisza and in agricultural habitats

According to my results, the home ranges of the examined Roe deer living in a mixed (consisting of a floodplain forest and the adjacent agricultural land) habitat were significantly smaller than that of individuals living in solely agricultural habitats. Several publications suggested that, the home ranges of Roe deer that use forests too, might be smaller than home ranges of individuals living solely in open agricultural areas, bit I did not find any simultaneous comparative study with examined areas close to each other. Most researches in this field concluded that, shelter and food supply are the most important influencing factors regarding the habitat selection. The floodplain forest provides both of these continuously, throughout the year, while they are available only periodically on the agricultural land. Based on these information we can conclude that if the resources necessary for survival can be found in a smaller area, using smaller home ranges is sufficient. This is confirmed by the monthly datasets, as the MCP sizes were similarly small in both habitat types from May to September, while in the rest of the year, there was a significant difference between them. In the floodplain forest, the human disturbance is less frequent due to the lack of agricultural activities. By visiting the agricultural lands, Roe deer can supplement the food sources of the floodplain forest, moreover the plant stands on the arable fields offer good cover during the vegetation period. In summary, we can assume that the home ranges of Roe deer living in mixed (consisting of a floodplain forest and the adjacent agricultural land) habitats are smaller because of the permanent cover, food supply and tranquility provided by the forest.

4.1.2. Comparison of home range sizes of males and females

As bucks show territorial behaviour (in the rutting season) and does give birth to the fawns then raise them, it could be assumed that the home ranges used by the two sexes are different in size. In spite of this, my results suggest that there was no difference between the home range sizes of the two sexes on an annual basis. It is likely that the periodical differences in the behaviour and the biology of the two sexes balance each other. Another interpretation of the results is that the differences between the sexes do not affect the habitat use to such an extent that it would result in different home range sizes. Several studies found – and my earlier analyses confirmed – that both males and females perform shorter or longer excursions, furthermore the territorial behaviour of the bucks is a well-known phenomenon. It has been also described that the areas used by does with and without fawns are different. Based on analysing the datasets from my study area, these differences were not so remarkable that it would cause significant differences in the home range sizes of males and females. From these results we can conclude that in a plain, lowland area without large carnivores the two sexes needed an area of nearly the same size for their survival throughout the year.

4.1.3. Comparison of the monthly home range sizes of the examined individuals

The seasonal variability of the habitat use in Roe deer has been examined by several studies. Comparison of the results from these publications is not possible or limited, because the definition of the seasons is vague. The 3 months long calendar seasons cannot be clearly distinguished from an ecological point of view, but the comparison among the monthly data reveals differences that allow to separate the seasons applicable for Roe deer. According to my results, two main periods can be distinguished in a year: the intervals spread from November to March and from May to August (the remaining 3 months serve as transitions). The two seasons can be identified as winter and summer, with short transitions.

I found the winter home range sizes to be larger than the summer ones, which is in accordance with the majority of literature cited in my work. The possible explanation of this is the weaker food supply and cover during winter, which makes the Roe deer use larger areas in order to survive.

4.2. Analysis of the crossings across river Tisza

4.2.1. The number and time of crossings, possible reasons

It was found in a study, that Cervids are solid swimmers, and as a matter of fact, they cross water bodies more often than observations would suggest. The reasons for this can be the search for food, the rutting season, carnivore avoidance or even the increasing population density.

Based on the results obtained by grouping the examined animals with different approaches, only a few differences were found in the patterns of river crossings. Crossings across river Tisza occurred in each season in both sexes. Being aware of the behavioural differences between the sexes, I presumed that those will be reflected by the river crossings, but my results did not confirm that. Moreover, the weather (therefore also e.g. the water temperature, etc.) can be variable season to season, but this did not seem to affect the river crossings.

By analysing the number of crossings in the different times of the day, I found that the examined individuals crossed the Tisza in the daytime significantly more often than at nighttime. The possible reason for this is that deer can orient themselves better under the better conditions provided by daylight.

The exact reasons for the river crossings cannot be determined based on my results, only assumptions can be made. Several studies reported that, a few times females moved a few kilometres away from their ordinary home range. According to some, the reasons for this can be meteorological factors (e.g. snow depth, temperature change), predator pressure and competition for resources. In my study, no doe moved further than 1-2 km from the Tisza after crossing the river. Instead, they stayed closed to the bank of the river for hours or days, then returned. With attention to the short movement distances, meteorological factors or food competition are unlikely to explain the river crossings.

According to certain literature sources, Roe deer escape into the water when chased by dogs. Escaping into the water is a successful strategy for avoiding predators in the case of other Cervids [e.g. White-tailed deer (*Odocoileus virginianus*)], as well. In the study area, only stray dogs can be dangerous for adult Roe deer (however, the game manager is actively managing their numbers). It is possible, that Roe deer choose to escape from them through the water. Two examined individuals swam across the river right away as they were released at the end of the tagging. Assumably, these water crossings were catalysed by the stress of being captured and tagged, but the two individuals (S1, S6) returned in a few days, then crossed the river again on later dates, therefore I did not exclude them from the analyses.

4.2.2. The effect of the water level

I found information on „swimming" Cervids and other mammals in many publications, but none of them contained water level data and findings about how it affected the water crossings. In the study period, there was a difference in the water level between the days with crossings, and the non-crossing days: the number of crossings was higher at lower water levels. Further analyses showed that 90% of all crossings happened under a 200 cm water level. According to the professional hunters (employed by the game manager), the water level never was low during the study period that would allow Roe deer to cross the river without swimming. The river width and the river flow rate can change with the water level, which suggest that, probably not the water depth itself is the key factor. It seems to be rational that a lower water level – that means a narrower river with a lower flow rate) – offers a better opportunity for a safer swim across the river.

Several studies identified rivers and lakes as barriers for mammals [e.g. Reindeer, Moose, Red deer (*Cervus elaphus*)], but the water bodies examined in those were remarkably larger than the river Tisza.

4.3. Analysis of the live brown hare capture, the most intensive human disturbance in the study area

As found in several studies, Roe deer may change their habitat use at different levels of risk (e.g. with changes in the hunting pressure), but it usually does not mean leaving their regular home range. Hunting with the stalking method has no effect on the habitat use of Roe deer while Wild boar (*Sus scrofa*) and small game driven hunts – especially when dogs are used – affects their behaviour significantly, even if Roe deer is not harvested during those hunts. The data and the maps show that, live brown hare captures caused changes in the habitat use of Roe deer only when the localisations of the individuals fell into the area of the drive. In those cases, the individuals escaped from the given area, then returned after the drive has ended. It seems that this occasional and short-in-time activity with increased human presence and noise (and similar activities) causes some disturbance for the Roe deer, but changes the habitat use only for a short time and in a small area. One may ask, what would happen if these disturbances became regular. Studies with remarkably larger sample sizes reported that driven hunts in which dogs were used, had long-lasting effects on the habitat use of Roe deer. These kinds of hunts were organised multiple times within a hunting season. Danger can be avoided not only by escaping but also by hiding. In the case of Roe deer, a French study suggested that the selection between the two methods is variable, animals often choose to hide from the danger instead of trying to escape.

4.4. General conclusions, practical recommendations

The distribution and population size of Roe deer indicates that, the species adapts successfully to different habitats (determined and affected by different environmental factors). Based on the available literature and my results, it can be assumed that beyond the most important and known influencing factors, other components of the environment (that are unknown or difficult to identify) or their interactions may also affect the behaviour (in our case, the habitat use) of Roe deer.

The different home range sizes measured in the examined habitat types suggest that, Roe deer can follow two different habitat use strategies even in a game management unit with a relatively small area such as in this study. It would be an interesting research opportunity to measure home range sizes in a large and closed forest stand with the same methodology, then to compare the results to those presented in my study. Considering these findings, my practical suggestion is that if Roe bucks living in agricultural habitats cannot be found at their usual location, it is worth to search for them in a larger area. This is also known by some local professional hunters. In contrast, bucks living in forested habitats are less likely to move larger distances, thus they should be found closely where they are regularly observed. Obviously, the success of this game observation and hunting strategy can be highly variable.

According to my results, two main periods (winter and summer with short transitions) can be distinguished in the year from the Roe deer’s point of view. The comparison of the monthly home range sizes allowed me to identify the periods that form coherent seasons. It confirmed the findings of an earlier study, therefore when the goal of a study is to examine the seasonality in any species, I recommend to analyse the home range sizes of shorter periods, as this allows researchers to identify the periods that can be applied as actual seasons.

I concluded that, the river Tisza does not act as a barrier for Roe deer. River crossings were occasional, and seemed to be timed randomly. Considering that, the home range used by one of the does covered both sides of the river, and another individual – after a few crossings – eventually moved its home range to the other side, the reasons and explanations for river crossings require further research. If two populations that live on two sides of smaller watercourse or a river with a width similar to the Tisza's show different qualities, the disparity is probably caused by the difference of the habitat quality or other environmental factors.

The literature cited in my work suggests that disturbance can have different – or no – impact on the behaviour of Roe deer, because this can depend on other environmental factors, as well. In the present study, the live brown hare capture (which is an occasional, short-in-time activity, but can be considered as an intensive disturbance) had no remarkable effect on the habitat use of Roe deer. It would be interesting to examine hunting methods with which Roe deer is harvested and/or dogs are used, as according to the results of several studies, these can be important influencing factors. The effects of both could be examined during driven hunts on hunting grounds, where big game species are typical. Based on my results, it can be recommended that, when Roe does and fawns are harvested, the hunt should be carried out in a short time, and not regularly, as the occasional disturbance probably causes less stress and does not change the habitat use of Roe deer.

In summary, although Roe deer is one of our most studies big game species, there are still many open questions regarding its habitat use. Some general tendencies can be observed, but the differences caused by the environmental factors have a remarkable effect on the habitat use. Examining and understanding that which factors lead to behavioural changes in different habitats still offers numerous research opportunities that could extend the results of the present study.

5. New scientific results

1. Based on highly accurate GPS-telemetry data from the study area, I found that the home range sizes of Roe deer living in mixed, forested-agricultural habitat were smaller than that of Roe deer living in the neighbouring, mostly agricultural habitat. In the 5,000 ha study area, the different environmental factors determined by the habitat types resulted in home ranges of different sizes.
2. I found that within the analysed years, there was no statistically significant difference between the monthly home range sizes of the examined Roe bucks and does, the individuals of the two sexes used areas of similar sizes during the year.
3. Based on comparing the monthly home range sizes of the individuals, I found that two main periods can be distinguished in a year: the intervals spread from November to March (winter) and from May to August (summer). The two periods were separated only by short transitions (April, September-October). The winter home ranges were larger than the summer areas.
4. I found that the river Tisza did not act as a movement barrier for the examined Roe deer in the study area. Three quarter of the examined individuals crossed the river, crossings occurred in each season. I found no statistically significant difference among the seasons, however the absolute number of river crossings was the highest in spring. The individuals crossed the river Tisza in the daytime more often than at nighttime. The proportion of individuals that crossed the river was equal between bucks and does, furthermore there was no significant difference between the annual number of crossings in the two sexes.

5. Based on the data analyses, I found that the water level affected the crossings across the river Tisza: the number of crossings was higher at lower water levels.
6. I found that the live brown hare capture (which is an occasional activity with potential disturbance) changed the movement pattern of Roe deer only for a short period, for the day of the capture. At the time of the disturbance, the individuals left the area that was directly involved, but then returned in a short time.

6. Publications related to the topic of the dissertation

Publications in peer-reviewed international journals with impact factor

Tóth, B., Schally, G., Bleier, N., Lehoczki, R., Csányi, S. (2016): First description of spatial and temporal patterns of river crossings by European roe deer (*Capreolus capreolus*): characteristics and possible reasons. ***Italian Journal of Zoology*** 83(3): 423-433. (IF 2016: 0,921)

Publications in peer-reviewed journals

Tóth, B., Bleier, N., Lehoczki, R., Csányi, S. (2012): Application of the LoCoH method in the analysis of roe deer habitat use. ***Review on Agriculture and Rural Development*** 1(1): 67-71.

Tóth, B., Bleier, N., Lehoczki, R., Schally, G., Csányi, S. (2011): Habitat use of roe deer in a floodplain forest and the neighbouring agricultural area. ***Agrár- és Vidékfejlesztési Szemle*** 6(1): 106-111.

Publications in Hungarian scientific journals

Tóth, B., Bleier, N., Lehoczki, R., Schally, G., Csányi, S. (2010): Az őz élőhelyhasználata egy ártéri erdőben és az azzal határos mezőgazdasági területen. ***Vadbiológia*** 13: 48-58.

Tóth, B., Bleier, N., Schally, G., Lehoczki, R., Csányi, S. (2014): Otthonterület-becslési módszerek összehasonlítása az őz területhasználatának elemzésében. ***Vadbiológia*** 16: 51-62.

Other publications

Csányi, S., Bleier, N., Juhász, V., Tóth, B., Schally, G. (2017): Az őzek viselkedése alföldi, mezőgazdasági környezetben. ***A vadgazdálkodás időszerű kérdései*** 15.: Őz hosszútávon – Őzgazdálkodásunk több

szemszögből. Országos Magyar Vadászkamara, Dénes Natúr Műhely Kiadó, Budapest, Magyarország: 32-41.

Tóth, B., Lehoczki, R., Csányi, S. (2015): Kettéosztva – de mennyire? ***Magyar Vadászlap*** 24(10): 50-51.

Bleier, N., Juhász, V., Tóth, B., Csányi, S. (2015): Csapatban vagy magányosan? ***Magyar vadászlap*** 24(2): 32-33.

Oral presentations in international conferences

Tóth, B., Bleier, N., Lehoczki, R., Schally, G., Csányi, S. (2011): Habitat use of roe deer in a floodplain forest and the neighbouring agricultural area. ***X. Wellmann International Scientific Conference***, Hódmezővásárhely, Hungary, 5th May 2011.

Oral presentations in Hungarian conferences

Tóth, B., Schally, G., Csányi, S. (2014): Őzek Tiszán innen, Tiszán túl – Hogyan befolyásolja a Tisza folyó a környezetében élő őzek területhasználatát? ***A Magyar Etológiai Társaság XVI. Kongresszusa***, Tihany, Magyarország, 2014. november 28-30.

Tóth, B. (2011): Az őz élőhely-preferenciája egy mezőgazdasági területekkel határos ártéri erdőben. ***„Tehetségnap – 2011" Tudományos Diákköri Rendezvény***, Szent István Egyetem, Gödöllő, Magyarország, 2011. május 25.

Tóth, B. (2010): Az őz élőhelyhasználata egy ártéri erdőben és az azzal határos mezőgazdasági területen. ***XII. Országos Felsőoktatási Környezettudományi Diákkonferencia***, Sopron, Magyarország, 2010. április 6-7.

Poster presentations in international conferences

Tóth, B., Heidrich, M., Schally, G., Kovács, I., Bleier, N., Csányi, S. (2015): Does the human disturbance lead to changes in habitat use? - Responses of roe deer to live brown hare capture. ***Student Conference on Conservation Science***, Tihany, Hungary, 1-5. September 2015.

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Tóth, B., Bleier, N., Lehoczki, R., Csányi, S. (2012): Application of the LoCoH method in the analysis of roe deer habitat use. ***XI. Wellmann International Scientific Conference***, Hódmezővásárhely, Hungary, 10th May 2012.

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