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THE EFFECTS OF SELECTED ENVIRONMENTAL FACTORS ON ROE DEER ANTLER QUALITY

Thesis of Ph.D. dissertation

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1. INTRODUCTION AND OBJECTIVES

European roe deer (*Capreolus capreolus, Linnaeus, 1758*) is highly important in Hungarian game management (FODOR 1983), thanks to its nationwide distribution, abundant population, good quality and its popularity with hunters (CSÁNYI and SZIDNAI 1994, BERTÓTI 1995).

Hungarian wildlife management, just like its German and other European counterparts, focuses on antler size, and trophies can be considered the most important management indicators (SZEDERJEI and SZEDERJEI 1971).

The development, size and quality of roe deer antlers – similarly to other deer species – are influenced by numerous factors. These factors can be classified into two groups. The first is the group of hereditary characteristics and the second one is the environmental effects. The role of genetics has been proven (e.g. HARTL et al. 1995a), however, the influence of environmental factors on deer antler size is considered more important (SUTTIE 1980, GOSS 1983).

From the environmental factors, I have examined the potential effects of soil characteristics, as well as environmental iodine distribution on roe deer antler development.

In international (e.g. DENNEY 1944, BAILEY 1984) and Hungarian literature on wildlife biology, soil attributes (e.g. soil fertility, soil types) are mentioned both as direct and indirect factors affecting the quantity and quality of wildlife populations. Despite this, the number of studies quantifying the effects of soil factors is surprisingly low. In my analysis I have tried to fill this gap by comparing data on roe deer antler weight with Hungarian soil types and soil fertility information – as qualitative and quantitative soil attributes – using GIS and statistical tools.

The connection between antler development and nutritional status had been also proven long ago (BROWN 1990). Beyond general issues of food supply however, the role of environmental microelements is not entirely revealed. Emphasis on examining the availability of microelements – similarly to grazing animal husbandry – is typical in game meat and velvet antler production in deer farms (GRACE and WILSON 2002), but even these studies lack iodine measurements.

Effects of iodine are manifested through the iodine-containing thyroid hormones in which have been related to deer antler development through their stimulating effect on general metabolism (BUBENIK 1990). However, to produce these hormones the continuous and adequate iodine supply is essential, which depends directly on the availability of iodine in the environment (UNDERWOOD and SUTTLE 1999). Through my research I will try to establish the connection between environmental iodine distribution (reflected in the iodine content of the natural water base) and antler weight.

I have addressed the following questions in my work:

1. Is it possible to find a relationship between roe deer antler weight data and the data available from the nationwide soil information map?
2. Can general qualitative soil attributes, like soil type or the quantitative soil fertility index (in this case soil evaluation number) be used to explain differences in antler weight?
3. Which Hungarian soil types provide better conditions for roe deer antler development?
4. Can the role of iodine content of the natural water base be shown in the differences in roe deer antler weight?
5. Can the effect of other environmental factors, like roe deer population density, harvest rate, the proportion of agricultural land, as well as forest edge length, be shown in the differences in antler weight?

2. MATERIALS AND METHODS

2.1. Antler weight and population data

In Hungary, all the antlers of harvested roe deer bucks are measured and evaluated by the trophy evaluation committees working in the framework of regional hunting authorities. The data of evaluated antlers are collected and stored in the National Game Management Database of Hungary (NGMD) in a standardized database (LEHOCZKI et al. 2008, CSÁNYI et al. 2010).

The analysis was based on data related to game management units (GMU), therefore all trophy evaluation data was also registered in connection to a given GMU. In my analysis I used antler weight from the available trophy evaluation data, which is the most typical and most important measurable value of roe deer trophies. Taking into account the ten-year leasing and planning periods of the Hungarian wildlife management system, I used antler weight data of 1195 hunting territories from the 1997-2006 period.

In order to eliminate their distorting effect I excluded from my analysis the antler data of one-year-old bucks and those older than seven years (see VANPÉ et al. 2007). Thus I based my research on the data of 197 633 trophies.

Instead of using yearly data I used the means calculated from the cumulated data of the ten-year period. By this I eliminated the differences between the years, that can be attributed to mostly weather conditions (CSÁNYI and SONKOLY 2003) and changes in wildlife management practices in the given area (AZORIT et al. 2002).

Using ten-year means is also justified by the idea that soil attributes and environmental iodine data can be viewed as "more constant" environmental factors, and we do not have to take into account big changes or fluctuations in the given period.

The NGMD also collects spring population and yearly harvest data for game management units (LEHOCZKI et al. 2008, CSÁNYI et al. 2010). During my statistical analyses I used roe deer density (specimen/km^2) calculated from the estimated population size, thus taking into account the effect of different densities (SCHMIDT et al. 2001, VANPÉ et al. 2007). I included into my analyses the proportion of harvested and estimated roe deer numbers, as the harvest rate, to measure the effect of hunting pressure. I used density and harvest rate values for game management units in the form of ten-year (1997-2006) means. These variables were used as indices of population size and harvest pressure describing spatial differences (MYRBERGET 1988, DEBELJAK et al. 1999, MYSTERUD et al. 2001, 2002, 2005, MIRANDA and PORTER 2003, HERFINDAL et al. 2006a, b, SCHMIDT et al. 2007, BURBAITE and CSÁNYI 2009).

2.2. Soil data

For my research I used the M=1:100 000 scale digital Agrotopography Database created by the Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences. In my study I used data on soil type and subtype and I classified them into main soil types (MST) based on STEFANOVITS (1992) and SZABOLCS (1966), and the main soil types served as the basis for further analysis. Furthermore I included soil-evaluation-number (SEN) into the analysis, which represents the natural fertility of different soils as a percentage of the most fertile soil (VÁRALLYAY 1985).

2.3. Landscape data

As the source of landscape data I used the CORINE (Coordination of Information on the Environment) Land Cover 2000 (CLC2000) database based on satellite image analysis (© EEA, Copenhagen (2009); made by the Institute of Geodesy, Cartography and Remote Sensing, commissioned by the Hungarian Ministry of Rural Development (2009), http://dataservice.eea.eu.int). The smallest mapping unit of CLC2000 is 0.25 km^2. Out of the five main land use and surface cover categories, I used the information on agricultural lands and forested areas to observe the effect of the different land cover and land use categories (described by the proportion of agricultural land area) and habitat structure (described by the edge length of forests) on antler development (MIRANDA and PORTER 2003).

2.4. Preparation of soil and landscape data

I used ArcGIS software (Environmental System Research Institute, Redlands, California, USA) for spatial analysis.

In the study I used GMUs as observation units, for which wildlife management data, like antler weight, estimated and harvested numbers were available. To project soil and surface cover data and wildlife management data into a common observation unit, I used spatial intersection (ZEILER 1997, ESRI 1995). With this GIS tool the final database contained wildlife management (antler weight, population density, harvest rate), soil (area proportions of main soil types, mean soil fertility value), as well as the land cover (area proportions of agricultural lands and forest edge lengths) data for each of the 1195 GMUs.

2.5. Data sources and preparation of environmental iodine data

To describe environmental iodine distribution, I used the iodine content of the water base providing drinking water to settlements. Data regarding the iodine content of water was provided by the National Public Health and Medical Officer Service.

According to SAJGÓ and FARKAS (1990) the iodine content of the water base is constant in time, so the results of water samples collected around the end of the 1980s were suitable for my analyses. Furthermore the results of MERKE (1965), SAJGÓ and FARKAS (1990), SAJGÓ et al. (1992), SZABÓ et al. (1993) demonstrate the connection between the iodine distribution in the water base and the environmental components available to animals on the surface.

Regarding iodine content data, it is important to note that values under 100 µg/l constitute 93.9% of the samples. Since this means that the data were skewed to the right, I used the natural base-e logarithm (ln) during the statistical analysis. Iodine concentration values (µg/l) were available for the administrative regions of 1889 settlements. Therefore, to project on the same spatial observation unit, I used spatial intersection between the digital maps containing the outlying areas of settlements and the areas of game management units and thus determined the weighted mean iodine concentration values for GMU areas.

2.6. Statistical methods

For statistical analyses I used SPSS for Windows (SPSS Inc., Chicago, Illinois, USA), ArcGIS and GoaDa (ANSELIN et al. 2006) software (LEHOCZKI et al. 2011a).

In order to preselect the main soil type variables – which showed significant multicollinearity – I first used a robust statistical method, the classification and regression tree process (BREIMAN and FRIEDMAN 1985, SPSS 2004). To measure the effects of certain environmental factors (as independent variables) on antler weight (as a dependent variable) I used a spatial lag regression model (SLM) which allowed spatial dependence to be taken into account. Correcting for spatial autocorrelation with this procedure, a "spatially delayed" variable was calculated from the data of a dependent variable and was added to the explanatory variables. This new variable represented the average value of the dependent variable calculated for the neighboring spatial units (ANSELIN 1999, HUNYADI and VITA 2008).

I qualified and compared the models built with different independent variables based on their coefficients of determination (R^2) and Akaike Information Criterion (AIC) values (REICZIGEL et al. 2007, HUNYADI and VITA 2008).

To avoid losing any values of a potentially important variable, based on the results of the regression tree, I summarized the values of main soil types that have a positive or negative effect on antler weights (see Results).

The independent variables included into the SLM regression models – aiming to determine the part of the variance of roe deer antler weight explained by the main soil types and soil fertility – are shown in Table 1.

To study the relationship between the iodine content of the water base and roe deer antler weight, I used the SLM regression process again. However, I conducted statistical analysis only with the data of those game management units which possessed iodine content data for at least 95% of their area (n=597). In the model, antler weight acts as the dependent variable, while the natural base-e logarithm (ln) of iodine concentration values acts as the independent variable. Furthermore, to examine their collective effect on antler development, I included the above described environmental factors into the analysis (Table 1.).

To further interpret the results of soil attribute analysis, I calculated the mean soil fertility index for each main soil type using soil-evaluation-number, as well as agricultural and forest land proportions (Fig. 1.).

To demonstrate antler weight changes depending on iodine contents, besides the different levels of all other studied environmental factors, I illustrated weight changes depending on iodine content on graphs (Fig. 2.).

Table 1. Spatial lag regression models relating mean roe deer antler weight to soil type, to soil fertility and to water iodine content as well as roe deer density, harvest rate, and land cover information (proportion of the agricultural areas and forest edge length), using ten-year means in the case of antler and population variables in Hungary, 1997-2006.

Model	Dependent variable	Independent variables
SLM I.	AW	SEN
SLM II.	AW	MST123
SLM III.	AW	MST456
SLM IV.	AW	SEN + D + HR + AGR + FEL
SLM V.	AW	MST123 + D + HR + AGR + FEL
SLM VI.	AW	MST456 + D + HR + AGR + FEL
SLM VII.	AW	IOD
SLM VIII.	AW	IOD + MST456 + D + HR + MG + FEL

(AW = 10-year mean values of roe deer bucks (age 2-7 yrs) antler weights (g) for each of the game management units; SEN = soil-evaluation-number (%) (soil fertility index); MST123 = summarized area proportion of skeletal soils (MST1), lithosols affected by the parent material (MST2), and brown forest soils (MST3) (%); MST456 = summarized area proportion of chernozem soils (MST4), salt affected soils (MST5), and meadow soils (MST6) (%); D = roe deer density (specimen/km^2); HR = harvest rate (%); AGR = proportion of the agricultural areas (%); FEL = forest edge length (km/km^2); IOD = base-e logarithmed water base iodine content)

3. RESULTS

3.1. Effects of the main soil types and soil fertility variables

Based on the regression tree model, meadow soils (MST6), chernozem soils (MST4) and salt affected soils (MST5) can be regarded as the main soil types having a positive effect on roe deer antler weight. A higher proportion of these main soil types inside a game management unit results in higher antler weights. Brown forest soils (MST3), skeletal soils (MST1) and lithosols affected by the parent material (MST2) show a negative effect, i.e. a higher proportion of these main soil types within a game management unit results in lower antler weights. Peaty soils (MST7), soils of swamp forests (MST8), and fluvisols and colluvium soils (MST9) have no significant effect on antler weight.

Based on the effect of main soil types (negative: MST1, MST2, MST3; and positive: MST4, MST5, MST6) their values are summarized (MST123 and MST456) and used in my further analysis, as described in Materials and methods.

Examining its substantive effect (SLM I.), the soil fertility index explains 10.4% of antler weight variance (Table 2.). During the examination of the substantive effects of main soil types, types with positive effects (SLM III., 33.1%) had almost the same explanatory value as negative ones (SLM II., 33.6%) (Table 2.).

The fourth model (SLM IV.), in which, besides the soil fertility index (SEN), roe deer density, harvest rate, agricultural land proportion and forest edge length were also involved as explanatory variables, explains 50.6% of antler weight variance (AIC = 11059, Table 2.). However the soil evaluation number did not have a significant effect on the model (P = 0,726). The fifth model (SLM V.), in which, besides the soil types with negative effect (MST123) all of the other environmental variables were involved, explains 51.8% of antler weight variance. The sixth model (SLM VI.), in which, besides the soil types with positive effects (MST456), population and surface cover variables were involved, explains 51.6% of antler weight variance. There is no big difference between SLM V. and SLM VI.; moreover this difference is almost insignificant from a biological point of view.

To further evaluate the separation of the main soil types based on their positive or negative effects on antler development, and the results of main soil types in the regression models, I defined the mean soil fertility index for each main soil type, using SEN, as well as the area proportions of agricultural and forestlands (Fig. 1.).

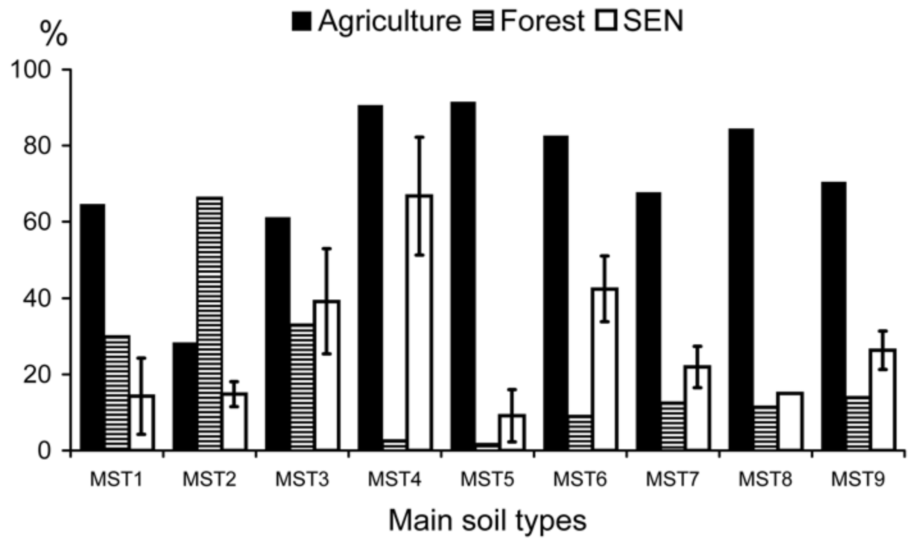

Figure 1. The means and standard deviations of soil-evaluation-numbers (SEN; soil fertility index representing the natural fertility of different soils in the percentage of the fertility of the most fertile soil) and percentages of land-use types (agriculture and forest) for each main soil types (MST) in Hungary (MSTs with negative effect: MST1 = skeletal soils, MST2 = lithosols affected by the parent material, MST3 = brown forest soils;
MSTs with positive effect: MST4 = chernozem soils, MST5 = salt affected soils, MST6 = meadow soils; MSTs without effect: MST7 = peaty soils, MST8 = soils of swamp forests, MST9 = fluvisols and colluvium soils)

According to Fig. 1., the mean soil fertility index for chernozem soils (MST4) and meadow soils (MST6), belonging to the main soil types related to higher antler weights, is over 40% (MST4 67%, MST6 42%), however for salt affected soils (MST5) it is only 9%. On the other hand, from the main soil types associated with lower antler weights (negative effect), the mean soil evaluation number for brown forest soils (MST3) is 39%, which is outstanding compared to the 14% and 15% of skeletal soils (MST1) and lithosols affected by the parent material (MST2). However, surface cover information shows a more uniform pattern inside the groups of main soil types based on their positive or negative effects. The forest cover proportions of skeletal soils (MST1), lithosols affected by the parent material (MST2), and brown forest soils (MST3) are over 30%, while the same value is under 10% for positive effect main soil types. The proportion of agricultural lands is under 65% in negative effect types, and over 80% in positive effect types.

The results of the regression models also show that, out of the soil attributes, the variance explained by soil fertility is smaller than the variance explained by main soil types (Table 2.). Moreover, in the models including population and surface cover information (SLM IV.), soil fertility lost its significant effect, while the full model with main soil type variable can be regarded as the best fitting one (SLM V. and SLM VI.).

By examining the sign of their regression coefficient two groups can be formed from the environmental variables. The variables with a positive sign, which result higher antler weights, are in one group. Based on this, the following variables have favorable, positive effects:

1. the proportion of agricultural land,
2. the proportion of chernozem, meadow and salt affected soils,
3. the density of roe deer population,
4. soil fertility.

Variables with a negative regression coefficient results lower antler weights. Therefore the following variables have adverse, negative effects:

1. forest edge length,
2. the proportion of skeletal soil, brown forest soils, and lithosols,
3. the harvest rate of roe deer population.

Table 2. Results of the spatial lag regression models

Model[a]	Independent variables	df	K	AIC	R^2
SLM I.	SEN	1192	3	11764	0.104
SLM II.	MST23	1192	3	11406	0.336
SLM III.	MST456	1192	3	11415	0.331
SLM IV.	*SEN*[b] + D + HR + AGR + FEL	1188	7	11059	0.506
SLM V.	MST123 + D + HR + AGR + FEL	1188	7	11030	0.518
SLM VI.	MST456 + D + HR + AGR + FEL	1188	7	11035	0.516
SLM VII.	IOD	594	3	5844	0.144
SLM VIII.	IOD + *MST456*[b] + *D*[b] + HR + AGR + *FEL*[b]	589	8	5613	0.428

[a] = Dependent variable is the antler weight (g). [b] = The variables did not have a significant effect ($P > 0.05$). (df = degrees of freedom; K = number of model parameters; AIC = Akaike Information Criterion; R^2 = coefficient of determination; SEN = soil-evaluation-number (%) (soil fertility index); MST123 = summarized area proportion of skeletal soils (MST1), lithosols affected by the parent material (MST2), and brown forest soils (MST3) (%); MST456 = summarized area proportion of chernozem soils (MST4), salt affected soils (MST5), and meadow soils (MST6) (%); D = roe deer density (specimen/km^2); HR = harvest rate (%); AGR = proportion of the agricultural areas (%); FEL = forest edge length (km/km^2); IOD = base-e logarithmed water base iodine content)

3.2. The effect of environmental iodine distribution

Examining the substantive effect of water base iodine concentration, which serves as a descriptor for environmental iodine content, the model explains 14.4% of antler weight variance (SLM VII., Table 2.). Based on the results of countrywide surveys, the explanatory value of the model, including other environmental variables influencing antler weight (like the main soil type variable, population and land cover attributes), rose to 42.8% (SLM VIII., Table 2.), however the MST456 (P=0.515), roe deer density index (P=0.072) and forest edge length (P=0.211) variables did not have a significant effect in the model.

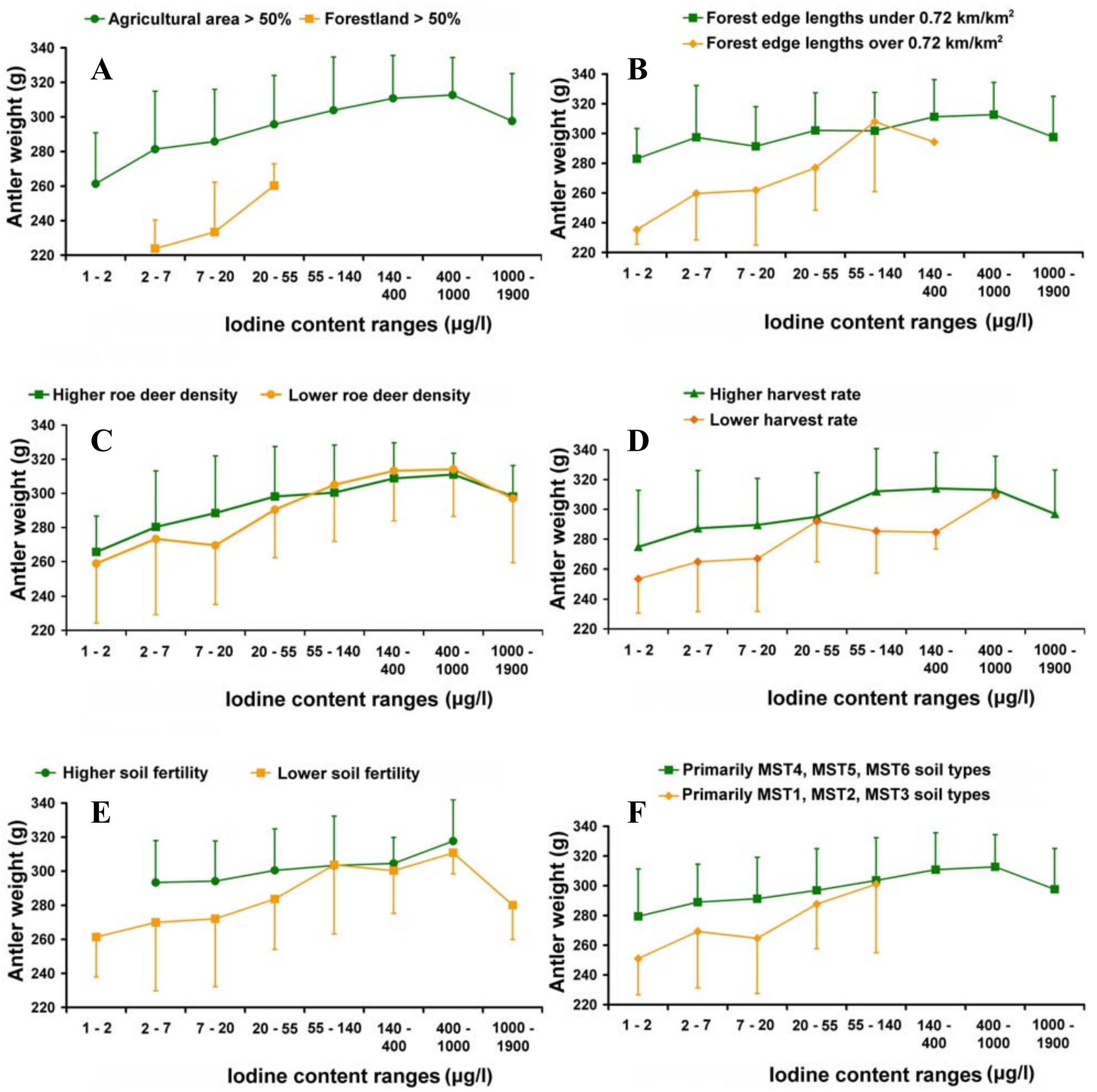

Figure 2. Tendencies in antler weight (g) values among water base iodine content intervals (µg/l) (**A**: GMUs with a higher than 50% proportional agricultural area, and GMUs with higher than 50% proportional forestland. **B**: GMUs with forest edge lengths over 0.72 km/km2, and GMUs with forest edge lengths under 0.72 km/km2. **C**: GMUs with a population density over 3.67 specimen/km2, and GMUs with a population density under 3.67 specimen/km2. **D**: GMUs with a harvest rate over 20.8%, and GMUs with a harvest rate under 20.8%. **E**: GMUs with more fertile soils (soil evaluation number > 60%), and GMUs with less fertile soils (soil evaluation number < 60%). **F**: GMUs with primarily chernozem, salt affected and meadow soil (MST456 > 50%), and primarily with skeletal and brown forest soils and lithosols affected by the parent material (MST123 > 50%))

To demonstrate the relation between the environmental iodine content and antler weights together with the influence of all the other environmental factors, I presented the variation of weight values depending on iodine content on Figure 2.

In line with the increase of environmental iodine distribution (described with the iodine content of the natural water base), antler weight values also increase up to the 401-1000 µg/l iodine content interval (mean iodine concentration 640 µg/l). It is important to note here that iodine content data over 200 µg/l constitute only 3.1% of all samples (n=58), and this should be considered when viewing results in connection with iodine content over this level.

The parallel tendency of antler weight and iodine content increase is valid for all cases. At the same time, there is significant variance in mean antler weights connected to certain iodine contents, as observed in the groups based on environmental factors (Fig. 2.).

3.3. New scientific results

1. Based on my results, soil type (as a general qualitative soil characteristic) can be better used (from a game management or wildlife biological point of view) to explain differences presented in antler weights, than the quantitative soil fertility index (soil-evaluation-number).
2. I demonstrated statistically that in Hungary, areas primarily characterized by chernozem, meadow and salt affected soils are more favorable for roe deer antler development.
3. I demonstrated statistically the role of environmental iodine distribution (described with the iodine content of the water base) in roe deer antler development. Based on my results, environmental iodine distribution can be a limiting factor in roe deer antler development.
4. I demonstrated statistically that in game management units with a higher proportion of agriculturally cultivated lands, average antler weights are higher.

4. CONCLUSIONS AND SUGGESTIONS

4.1. The effects of soil types and fertility

Soil, as one of the most essential factors of the natural environment, affects antler quality through, or in interaction with, other environmental factors. In my research, using the M=1:100 000 scale Agrotopographical Database, I could statistically describe the relationship between soil characteristics and roe deer antler weight (LEHOCZKI 2004b, LEHOCZKI et al. 2010c, LEHOCZKI et al. 2011a).

Examining the main soil types, meadow soils, chernozem soils and salt affected soils could be connected to higher antler weights. An explanation for this can be that these soils can have a higher plant biomass production. Plant biomass production of chernozem and meadow soils is high (STEFANOVITS 1992), and they provide good quality and high quantity food for herbivores, therefore providing adequate habitat for them. Although their fertility is significantly lower than that of chernozem and meadow soils (Fig. 1.), salt affected soils can also perform well in certain periods of the year (in wet springs). Furthermore, their positive role can also be explained by their low national land proportion (6%) and their "common" presence with meadow and chernozem soils – thus their effects cannot be separated.

On the other hand, brown forest soils, skeletal soils, and lithosols affected by the parent material are predominant in the habitats of roebucks with lower antler weights. Extreme soils, like skeletal soils and lithosols have the worst pedological attributes (STEFANOVITS 1992). Habitat conditions of skeletal soils and lithosols are not the typical habitats of roe deer, thus these areas are only marginally tolerated by roe deer living there.

Therefore only brown forest soils (with a good fertility index and high biomass production) (STEFANOVITS 1992) stand out with unexpected results. The unexpected results of brown forest soils can be explained with the higher forest cover proportion, i.e. with land cover attributes, because there is higher similarity in the land cover attributes of positive and negative effect main soil type groups, than in soil fertility indices (Fig. 1.).

The mean soil-evaluation-numbers are over 40% in the case of chernozem and meadow soils, but only 9% for salt affected soils. However, the proportions of forestlands are uniformly low (<10%) and the agricultural land proportions are uniformly high (>80%) for all three soil type categories. On the other hand, from the main soil types with lower mean antler weights, the mean soil-evaluation-number of brown forest soils is 39%, which is outstanding compared to the circa 15% values of skeletal soils and lithosols. However, forestland proportions in this group are uniformly over 30% (Fig. 1.). This implies that on brown forest soils, higher forest land proportions are not favorable for roe deer preferring forest-steppe habitat conditions.

Even with the separation of positive and negative effect soil types, we can see the questionable importance of the traceable effects of soil fertility, and it shows in the results of regression models as well. Based on those, soil-evaluation-number – which is a quantitative index of soil fertility – explained only 10.4% of antler weight variance, but soil type – which is the most common qualitative soil characteristics – resulted a higher (33.1% and 33.6%) explanatory value. These results show that soil evaluation methods founded on general and qualitative characteristics (like grouping into soil types) can be better applied regarding wildlife biology and game management, than special quantitative values, like the soil fertility index (given as soil-evaluation-number in terms of agricultural production, STEFANOVITS 1992).

It is also present in my models built with other independent variables. The model, containing population and land cover information besides soil type, explained 51.8% of antler weight variance, and this can be regarded as the most suitable one, while soil fertility lost its significant effect in the supplemented model (Table 2.).

By including population and land cover information as explanatory variables, the strength of the models significantly improved – creating better models with very similar explanatory values (especially biologically). Furthermore, this also proves the importance of the fact that the examination of the separate effects of certain environmental factors (e.g. soil attributes) on antler development is encumbered with the effects of other environmental factors, although scientific publications related to this topic did not emphasize this (STRICKLAND and DEMARAIS 2000, 2006).

Summarizing the above, we can say that although soil fertility is the pedological characteristic which can be described as having the highest importance in determining the performance (production) of wild animals, other environmental factors, such as type of land cover, can significantly modify its effect.

4.2. The effect of environmental iodine distribution

The results of examining the relation between the iodine concentration of the natural water base and roe deer antler weight show that the effect of environmental iodine distribution is traceable in the spatial differences of roe deer antler weight. Thus iodine deficiency can be a limiting factor that interferes with the performance of roe deer, shown in its optimal antler development (LEHOCZKI et al. 2011b, LEHOCZKI et al. 2010e).

Although I managed to describe the connection between environmental iodine content and antler weight, I did not attempt to define the limits of environmental iodine content optimal for a roebuck. Based on the literature, the effect of iodine availability and environmental presence has not been examined for deer (WILSON and GRACE 2001, GRACE and WILSON 2002). WATKINS and ULLREY (1983b) found higher thyroid gland weights in wild populations (compared to fenced and well-fed white-tailed deer), thus indicating possible iodine deficiency in the habitat. However only CLARK et al. (2000) reported goiter, the clinical symptom of iodine deficiency, in New Zealand.

No information was found about the iodine requirements of roebucks in the literature. According to the study by WATKINS et al. (1983) the iodine requirements of white-tailed deer doe can be met by feed (dry matter) containing 0.26 ppm of iodine. This result is identical to the generally recommended iodine content of feed required to cover the average iodine-need of domestic ruminants (SCHÖNE and RAJENDRAM 2009).

Artificial iodine supply is common among domestic animals (in the form of salt licks and concentrate feeds) and human nutrition (iodized salt, iodine-rich milk, meat and egg). In the case of wild animals, artificial salt licks (ATWOOD and WEEKS 2003) and concentrate feed (PUTMAN and STAINES 2004) can be used for artificial iodine supplementation. For this we should consider the notes of SCHULTZ and JOHNSON (1992), who say that the effect of artificial food supplements on body weight and antler size can vary greatly, depending on the natural food supply and the habitat; and other environmental factors can also have a further regulating effect. Beyond these, CEACERO et al. (2009) imply, based on their results, that deer can influence the intake of minerals (by selection) according to their needs.

4.3. The effect of other environmental factors involved in the study

Models containing population and land cover factors explained 51% of antler weight variance, in contrast to the 10-30% of soil attributes. Based on these results, when separately examining a given environmental factor (in my case, soil attributes), it is important that we observe the widest array of environmental factors affecting the examined variable (GILL 1956).

Besides the high importance of soils, the results of KLEIN and STRANDGAARD (1972) show the significant effects of land use, furthermore the role of land cover and land usage were proven in several deer species (CRAWFORD and MARCHINTON 1989, MYSTERUD et al. 2002). In Hungary, greater roe deer antler weight related to agricultural lands became common knowledge in the recent decades (SZEDERJEI 1971a, CSÁNYI and SZIDNAI 1994, FARKAS 2003). This shows in medaled trophy rates of counties (FARKAS 2005), as well as in the qualification of counties based on roe deer population (MÉM 1970, KOLLER and BERTÓTI 1971). However, examining several factors at the same time it is first proven statistically in my dissertation that land constituted predominantly of agricultural areas has a positive effect on buck antler weight (LEHOCZKI et al. 2010d).

Based on my results the increase of the variable characterizing habitat structure – forest edge length – negatively affects roe deer antler weight. Although edges and linear objects, like shelter belts, can play a great role in buck behavior (CSÁNYI et al. 2006), and forest edges and smaller forest patches are important elements of habitats favored by roe deer (DANILKIN and HEWISON 1996), I could not prove the role of these in antler development. The reason for this can be the resolution of the CLC2000 database (which serves as the basis for surface cover information), since important habitat structure elements (tree lines, holding covers, smaller woody patches, etc.) did not appear in the database used for my analysis. Thus the largest forest edge lengths primarily mean edges of forest blocks, which negatively affect antler weights with the increase of forest land proportions (LEHOCZKI et al. 2010d). Based on the results, to consider habitat structure, like forest edge length, we would need a vegetation map with a higher spatial resolution.

Regarding population attributes (used as the relative index of population size and harvest pressure), roe deer density is in positive correlation with antler weight. Based on my results, we cannot mention any processes contradicting the effect of density, which was proven several times (PÉLABON and VAN BREUKELEN 1998, VANPÉ et al. 2007). However it is obvious that in a lower quality area, even a smaller density population "depletes" environmental supplies, while in a better habitat, no limiting effects of environmental factors are shown even in a greater density population. Based on my results we can say that in areas with higher roe deer density, the quality of the deer population is better, and antler weights are higher (LEHOCZKI et al. 2010d, LEHOCZKI et al. 2011a). This statement, although without a research background, has already been circulating in the Hungarian professional press (e.g. SZABOLCSI 1977).

The other examined population index, the harvest rate, had a negative effect in the spatial comparison of antler weights (LEHOCZKI et al. 2010d, LEHOCZKI et al. 2011a). CSÁNYI and SZIDNAI (1994) obtained similar results when they analyzed the proportion of bucks within the cull and the proportion of medaled trophies. According to their explanation, the increasing proportion of bucks in the cull means that higher numbers of smaller antlered bucks are harvested, which in turn decreases the medaled trophy rate. The same reasons stand for the effect of higher harvest rates of roe deer populations during the examinations of spatial differences. Therefore game management practices, i.e. hunting activity, affects harvested roebuck antler weights through the proportion of harvested population compared to the estimated population number. Furthermore it is probable that with better roe deer habitats, in the framework of high quality management (based on higher population density and better population quality), selection is more closely scrutinized, therefore lowering harvest rate.

I have to mention the reliability of the data on estimated roe deer population and harvest rate used in my research. Despite the fact that reliability of population and harvest data is often disputed, it is accepted that relative differences between game management units can be well described by calculated density and harvest rate values, and these can be used as the basis for comparison (MYRBERGET 1988, DEBELJAK et al. 1999, MYSTERUD et al. 2001, 2002, 2005, MIRANDA and PORTER 2003, HERFINDAL et al. 2006a, b, BURBAITE and CSÁNYI 2009, CSÁNYI 1991).

Based on the analysis conducted with the reduced number of game management units (basis for reduction: iodine data for more than 95% of the GMU), we can say that the factors supporting or limiting antler sizes, can vary from area to area (LEHOCZKI et al. 2010d).

On the whole it is important to emphasize that the maximum value of coefficients of determination is 0.518, therefore further environmental factors other than those examined can have a considerable effect on antler development (see KRUUK et al. 2002). Besides these other factors differences between individual roe deer, lower land use (HEWISON et al. 1998, CSÁNYI et al. 2003), territorial behavior (DANILKIN and HEWISON 1996), or selective nutritional strategy (DUNCAN et al. 1998, MÁTRAI 2000) may also have a significant effect on antler weight. Further research is needed to study these and precisely identify the affecting factors.

Further and deeper conclusions on the significance of the examined environmental factors could be made, if relationships could be examined on a specimen level, with a database on their respective home range. This applies to the circle of environmental factors, as well as that of trophy evaluation data, but building these databases is a task for the future.

5. PUBLICATIONS RELATED TO THE TOPIC OF THE DISSERTATION

5.1. Publications in scientific journals with impact factor

LEHOCZKI R., CENTERI C., SONKOLY K., CSÁNYI S. (2011): Possible use of nationwide digital soil database on predicting roe deer antler weight. *Acta Zoologica Academiae Scientiarum Hungaricae*, 57 (1) 95-109. p. [IF2009: 0.514]

LEHOCZKI R., ERDÉLYI K., SONKOLY K., SZEMETHY L., CSÁNYI S. (2011): Iodine distribution in the environment as a limiting factor for roe deer antler development. *Biological Trace Element Research*, 139 168-176. p. (DOI: 10.1007/s12011-010-8655-8) [IF2009: 1.127]

5.2. Publications in scientific journals without impact factor

CSÁNYI S., LEHOCZKI R., SONKOLY K. (2010): National Game Management Database of Hungary. *International Journal of Information Systems and Social Changes*, 1 (4) 34-43. p.

5.3. Publications in Hungarian scientific journals

CSÁNYI S., LEHOCZKI R., SCHALLY G., BLEIER N., SONKOLY K. (2006): Az őz élőhely-használata alföldi, mezőgazdasági környezetben. *Vadbiológia*, 12 7-20. p.

CSÁNYI S., LEHOCZKI R., SOLT SZ. (2003): Az őz területhasználata alföldi, mezőgazdasági élőhelyen. *Vadbiológia*, 10 1-14. p.

LEHOCZKI R. (2004): Korrelációs vizsgálat az Agrotopográfiai Adatbázis talajjellemzői és az őz trófeabírálati adatok alapján. *Vadbiológia*, 11 30-40. p.

LEHOCZKI R. (2004): Talajjellemzők hatásának térinformatikai elemzése az őzagancs minőségre az Agrotopográfiai Adatbázis alapján. *Acta Agraria Kaposváriensis*, 8 (3) 77-89. p.

LEHOCZKI R., CSÁNYI S., SONKOLY K. (2010): Az agancsfejlesztés hormonális szabályozása - irodalmi áttekintés. *Vadbiológia*, 13 78-92. p.

LEHOCZKI R., SONKOLY K., CSÁNYI S. (2010): Környezeti tényezők területenkénti eltérő jelentősége az őz agancsfejlesztésében. *Vadbiológia*, 13 24-33. p.

LEHOCZKI R., SONKOLY K., ERDÉLYI K., BEREGI A., CSÁNYI S. (2010): A jód szerepe a szarvasfélék agancsfejlesztésében. *Vadbiológia*, 13 34-40. p.

5.4. Book chapter

CSÁNYI S., LEHOCZKI R. (2007): Európai őz. 257-260. p. In: BIHARI Z., CSORBA G., HELTAI M. (Szerk.): *Magyarország emlőseinek atlasza.* Budapest: Kossuth Kiadó. 360 p.

CSÁNYI S., LEHOCZKI R. (2010): Ungulates and their management in Hungary. 291-318. p. In: APOLLONIO M., ANDERSEN R., PUTMAN R. (Szerk.): *European ungulates and their management in the 21st century.* Cambridge: Cambridge University Press. 604 p.

5.5. Other scientific publications

LEHOCZKI R., CSÁNYI S., SONKOLY K. (2008): Az Országos Vadgazdálkodási Adattár céljai és feladatai. *Nimród Vadászújság*, 96 (10) 13-14. p.

5.6. Oral presentations in international scientific conferences

CSÁNYI S., LEHOCZKI R., SOLT S. (2003): Space use of roe deer in large-scale agricultural habitats in Hungary. *26th Congress of the International Union of Game Biologists, Braga, Portugal*. September 1-6, 2003. (Abstract)

LEHOCZKI R. (2007): Relations between the chemical composition and the size parameters of roe deer antlers in Hungary. *8th Roe Deer Meeting, Velenje, Slovenia*. June 25-29, 2007. (Abstract)

5.7. Oral presentations in Hungarian conferences

CSÁNYI S., LEHOCZKI R., BLEIER N. ÉS SONKOLY K. (2009): Az őz élőhely-használata mezőgazdasági környezetben. *Kari Tudományos Konferencia, Sopron, Hungary, Nyugat-magyarországi Egyetem, Erdőmérnöki Kar*. 2009. október 12. (Abstract)

LEHOCZKI R. (2003): Térinformatika alkalmazási lehetőségei a vadgazdálkodásban és vadbiológiában. *XIII. Országos Térinformatikai Konferencia, Szolnok,* 2003. szeptember 25-26. (http://www.otk.hu/frm.asp?go=cd03/tartalom.htm) (Abstract)

LEHOCZKI R. (2004): Térinformatikai módszerek alkalmazása a talajjellemzők és az őzagancs tulajdonságok országos léptékű vizsgálatában. *II. Alkalmazott Informatika Konferencia, Kaposvár*. 2004. május 20. (Abstract)

LEHOCZKI R., CSÁNYI S., SONKOLY K. (2010): Az agancsnövekedés a kor és a terület függvényében az Országos Vadgazdálkodási Adattár adatai alapján. *Szakmai nap az őzgazdálkodásról (TÁMOP). Gödöllő*, 2010. április 9.

SONKOLY K., LEHOCZKI R., CSÁNYI S. (2010): Környezeti tényezők hatása az őzagancs nagyságára. *Szakmai nap az őzgazdálkodásról (TÁMOP). Gödöllő*, 2010. április 9.

5.8. Poster presentations in international scientific conferences

BLEIER N., MÁTRAI K., LEHOCZKI R., CSÁNYI S. (2007): Cultivated plants in roe deer summer diet in agricultural environment of Hungary. *8th Roe Deer Meeting, Velenje, Slovenia*. ERICo. June 25-29, 2007. Book of Abstracts: 62. (Abstract)

LEHOCZKI R. (2003): Studying the relation between soil and roe deer antler characteristics. *Student Conference on Conservation Science, Cambridge, UK*. March 26-28, 2003. Talks and Posters: 10-11. p. (Abstract)

LEHOCZKI R. (2004): Creating digital habitat map - important part of the biotelemetry study. *Student Conference on Conservation Science, Cambridge, UK*. March 24-26, 2004. Talks and Posters: 14. p. (Abstract)

LEHOCZKI R., CSÁNYI S., SONKOLY K., CENTERI CS. (2010): Using a national digital soil database to predict roe deer antler quality in Hungary. 70-73. p. In: *19th World Congress of Soil Science, Soil Solutions for a Changing World, 1 – 6 August 2010*. Published on DVD. Brisbane, Australia: International Union of Soil Sciences. s. p.

LEHOCZKI R. (2005): How to get better results! Different GIS methods to analyzing thematic antler and soil maps. *Student Conference on Conservation Science, Cambridge, UK*. March 22-24, 2005. Talks and Posters: 11. p. (Abstract)

5.9. Poster presentations in Hungarian conferences

LEHOCZKI R., CSÁNYI S. (2003): Talajjellemzők és az őzagancs tulajdonságok közötti korreláció vizsgálata térinformatika segítségével, 1x1km-es hálózatban. *Wellmann Oszkár Tudományos Tanácskozás, Hódmezővásárhely*. 2003. október 15. (Abstract)

LEHOCZKI R., CSÁNYI S., SONKOLY K. (2009): Az őzagancs minőségét befolyásoló egyes környezeti tényezők hatásának vizsgálata. *Kari Tudományos Konferencia, Sopron, Hungary, Nyugat-magyarországi Egyetem, Erdőmérnöki Kar*. 2009. október 12. (Abstract)

LEHOCZKI R., SOLT S., CSÁNYI S. (2004): Különböző pontosságú digitális élőhelytérkép készítésének lehetőségei. *II. Alkalmazott Informatikai Konferencia, Kaposvár, Kaposvári Egyetem, Állattudományi Kar*. 2004. május 20. (Abstract)