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Iodine Distribution in the Environment as a Limiting Factor for Roe Deer Antler Development

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Abstract The iodine-containing hormones produced by the thyroid gland play a role in the complex neuro-hormonal regulation of antler development. The proper function of the thyroid depends on the adequate iodine supply of the organism, which is directly related to the iodine content of food and drinking water. The purpose of this study was to explore the connection between the iodine content of the water base, which has a strong correlation with the iodine concentration of environmental components available to animals, and the antler weight of roe deer (*Capreolus capreolus*) shot in Hungarian hunting areas. Using a general linear model, controlling for the collective effects of other environmental factors (deer population density, harvest rate, land use, and soil fertility information), the iodine content of the water base explained 51.4% of the total variance of antler weights. The results suggest that antler weights increase with increasing iodine concentration regardless of other factors; thus, the environmental iodine distribution can be a limiting factor suppressing roe deer performance assessed here as antler weight. Further experimental studies of controlled iodine uptake are needed to define the exact physiological iodine requirements of roe deer bucks.

Keywords Iodine · *Capreolus capreolus* · Antler weight · Environmental effects · Limiting factor

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Introduction

The effects of factors influencing antler size are prevailing through a complex neuro-hormonal mechanism [1]. In this system, the iodine-containing hormones (triiodothyronine (T_3) and thyroxine (T_4)) produced in the thyroid gland were associated with antler growth cycle [2, 3]; however, their functions are not fully understood [4]. These two hormones are essential for a range of metabolic processes, controlling cellular oxidation, protein synthesis, cell differentiation, and growth [5, 6]. One of the pre-requisites of proper thyroid function is the adequate iodine supply of the organism [5]. Iodine deficiency (ID) causes impaired thyroid function and goiter, developmental abnormalities of various organs (i.e., the brain and bones), retarded growth, decreased fertility, increased perinatal mortality, and reduction in the animal performance and productivity, e.g., growth of wool, egg, and milk production [7–9].

The major sources of iodine for animals are forage plants and drinking water. Iodine uptake through food and water [10] depends directly on the availability of iodine in the environment, especially in the soil [11, 12]. The iodine concentration of soil and water is reflected in plants and in the food chain [13]; thus, low environmental iodine levels cause ID in animals [14] and humans [15].

As far as we are aware, the effect of iodine availability has not been studied in free ranging wild animals, particularly in cervids [16], where the antler cycle requires a huge metabolic effort. Since thyroid hormones (THs) are implicated in antler growth [17], it could be expected that antler development would also be influenced by the availability of iodine in food and water.

The purpose of this study was to explore whether the distribution of iodine in water can influence deer antler development. The analysis was completed on a national level by comparing the iodine content of the water base (ICWB) to trophy measurement data of the respective game management units (GMU). Data from roe deer (*Capreolus capreolus*, Linnaeus, 1758) were used because roe deer is the most abundant big game species in Hungary, occurring throughout the whole country in high densities. The populations are characterized by their excellent trophy quality. Hungarian cervid management is focused on antler size, and trophy is considered to be the most important management indicator [18]. The ICWB data were adequate for our analyses because the iodine concentration of soil was found to be highly correlated with the iodine concentration of the water-bearing layer of the soil [19, 20]. Furthermore, Sajgó and Farkas [21] and Sajgó et al. [22], working with the same ICWB dataset, found that where the ICWB was high, the iodine level was high also in milk and eggs, and where ICWB was low, the milk and eggs were also extremely low in iodine and human goiter appeared to be endemic. These results also demonstrated the connection between the iodine distribution in the water base and the environmental components available to animals on the surface.

In our analysis, we controlled for the effects of environmental factors that might influence antler size, namely, land use type [23], soil fertility [24], population density [25], and wildlife management practices [26].

Materials and Methods

Trophy Scoring and Population Data

In Hungary, it is mandatory to present all antlers of roe deer shot during the hunting season to Trophy Scoring Committees. Antlers are measured according to the Confederation

International du Chasse (CIC) system of trophy scoring. Antler scores are collected and stored in the National Game Management Database of Hungary (NGMD; awarded the CIC Edmond Blanc Diploma in 2008).

The spatial bases of the antler data are the areas of GMUs. The GMUs (n=1,195) are adjoining to each other and covering 98.8% of the whole country. The average size of the GMUs is 76.9 km^2 (the legally determined minimum size is 30 km^2, maximum size 547.6 km^2). The spatial information on GMU boundaries is collected and stored in the NGMD. This database provides a dynamic tool for the follow-up of trophy evaluation data from any area within the country on a spatial basis.

Antler weights (in grams) of roe deer bucks shot between 1997 and 2006 (n=233,294 antlers) were used in the study. Although hard antlers are effectively dry [27], they were nevertheless allowed to dry for 24 h before weight measurement to standardize their humidity content. Mean values over 10 years for GMUs (n=1,195) were calculated from the 10-year data series in order to neutralize the effects of yearly variations that were mostly the result of changing weather conditions and game management activities in the region [26].

The NGMD also contains annual spring roe deer population data and game management reports for all GMUs. Roe deer densities based on estimated spring population sizes were used in the analysis to filter out the effect of density dependence. If the number of harvested roe deer bucks is higher, then the proportion of smaller antlered bucks is also higher in the cull (S. Csányi, unpublished results); therefore, harvest ratios (the proportion of harvested numbers and estimated roe deer numbers) were calculated and used in the analysis as a filtering factor.

Because the antler data were obtained from animals harvested by hunters and game managers provided the population data, hunter selectivity and dependability of game managers may have influenced the sample [28]. As it was assumed that the data were similarly biased, we also assumed that instead of absolute values the patterns of differences could be used better on the GMU level. Moreover, the Hungarian hunting system is strictly regulated, so the hunting season and the age distribution of the bags were similar, thus yielding a homogenous sample.

Data Source and Preparation of Water Iodine Content Data

Data on the ICWB were provided by the National Public Health and Medical Officer Service. In order to determine their iodine content, water samples were collected at the end of the 1980s from natural water resources of settlements utilized for supplying drinking water. The iodine content of water samples (microgram per liter) was measured by the internationally accepted Sandell–Kolthoff method. Since Sajgó and Farkas [21] found that the iodine content of individual water sources was constant over time and the survey data were considered representative for the settlement administrative areas, we concluded that they were suitable for our analysis.

The spatial bases of the iodine data are the settlement administrative areas. Water iodine concentration data were available for 1,889 settlements representing 80% (74,000 km^2) of the whole country, with an average size of 39.2 km^2 (minimum—1.4 km^2, maximum—483.2 km^2).

The iodine concentration data were grouped into six categories covering equal concentration ranges. Water samples with iodine content below 200 μg/l represented 96.9% of the total number of samples (n=1,831). A group of 18 samples (1%) fell into the 201–400-μg/l range of iodine concentration, while 15 (0.8%) samples fell in the 401–600-μg/l range, 5 (0.3%) in the 601–800-μg/l range, 8 (0.4%) in the 801–1,000-μg/l range, and 12 (0.6%) in the range with iodine levels higher than 1,001 μg/l. Since the iodine data were skewed to the right, the natural base-e logarithm (ln) of the data series was taken and was used in the statistical analysis.

Antler data were associated, as mentioned to 1,195 GMUs and iodine data were associated to 1,889 settlements. However, antler and iodine data had a different plot structure, so they often did not match one to one (i.e., a GMU matching an iodine region). Thus, we intersected the iodine association and GMU polygons in ArcGIS (software version 9.1, ESRI Inc., Redlands, CA, USA) to develop a dataset relating iodine content to antler scores at identical spatial survey units. From the 73,238 km^2 for which we had iodine data, we used only the 10 km^2 or larger plots, to which we assigned antler scores depending on the associated GMU. GMUs involving several settlements and associated with a very heterogeneous iodine data set were discarded, so that the 7,324 potential 10-km^2 plots were reduced to 7,141.

Soil and Landscape Data

The soil fertility information was extracted from the digital soil information map (agrotopography map) prepared by the Hungarian Academy of Sciences, Research Institute of Soil Science and Agricultural Chemistry. Fertility was characterized by soil evaluation numbers (SEN), a special soil fertility index representing the natural fertility of different soils as percentages of the fertility of the most fertile soil [29]. The Hungarian CORINE Land Cover 2000 database (CLC2000), prepared by the Institute of Geodesy, Cartography and Remote Sensing of Hungary, was used as a source of landscape information. For each GMU, the average SEN and the proportion of the agricultural areas and forestlands were calculated. The SEN, agricultural, and forest cover data were utilized with the purpose of controlling for the effects of differences in soil fertility, land use, and habitat types on antler size.

Statistical Analysis

All statistical tests were performed with the SPSS 14.0 for Windows software (SPSS Inc., Chicago, IL, USA). The Kolmogorov–Smirnov test completed on the trophy scoring data showed normal distribution of data ($P<0.001$).

A general linear model (GLM) was set up for the examination of the effect of ICWB on antler weight using the natural base-e logarithm (ln) of the iodine data as a fixed factor and population, land cover, and soil fertility information as covariates. A GLM was used as control for the collective effects of a range of potential factors that might influence trophy size including roe deer population density and harvest rate as well as the proportion of agricultural and forested areas and soil fertility for each of the GMUs. The mean values over 10 years of antler and population variables were used in the model.

We used only the above-mentioned, presumably most important, environmental elements as covariates in the model because our aim was to check the effect of ICWB on antler weight and not to explore all of the environmental factors and their importance in antler development.

Results

Parallel with the increase of ICWB, the antler weight of roe deer steadily increased up to 401–1,000 μg/l iodine concentration (mean iodine concentration of 640 μg/l), but then it started decreasing despite the further increase of iodine levels (Fig. 1).

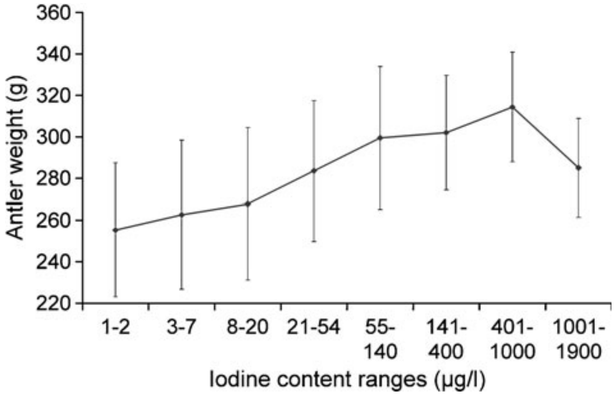

Fig. 1 Trends in mean antler weights (gram) belonging to different iodine contents of the water base (ICWB) groups (microgram per liter). The *X*-axis shows iodine content ranges in base-e logarithmed scale (1 ln μg/l) with untransformed values

The results of the GLM were used in order to control for the collective effect of a range of potential factors that might influence trophy size, and the ICWB explained 51.4% of the total variance of trophy weights ($F_{121,\ 7019}=61.32$, $R^2=0.514$, $P<0.001$; Table 1).

Discussion

Our findings indicate that the distribution of iodine in the environment has a determinant effect on roe deer antler weight and that ID can be an additional limiting factor constraining optimal deer performance for antler weight.

The need of a continuous and adequate iodine supply for thyroid hormone synthesis has been demonstrated [5]. Similar to their role in the productivity (live weight gains, growth of wool and horns) of domestic ruminants [8, 30], THs were also associated with the weight gain [31], the nutritional status [32], and the nutritional and metabolic activity [33] of deer. The results of the study of Hamr and Bubenik [34] and Seal et al. [35] demonstrated that TH levels were influenced by the current food intake and diet energy content, so consequently range quality and habitat differences were reflected in the levels of THs in white-tailed deer (*Odocoileus virginianus*, Zimmermann, 1780).

In association with antler development, THs are required for the expression of seasonal changes in red deer (*Cervus elaphus*, Linnaeus, 1758) stags [3]. In white-tailed deer, Bubenik et al. [2] showed that T_3 utilization rate in the growing antler correlated with the intensity of antler growth. Based on the results of Brown et al. [36], T_4 played a synergistic role in antler initiation and growth. Pantić [37] emphasized the connection between the thyroid and the quality of antler development in roe deer, and Sempéré and Boissin [38] found that T_4 concentration increased in late fall and early winter when the antlers were growing. Apart from the above findings, based on the interpretation of Bubenik [17] and Bubenik and Bubenik [39], THs probably do not act as primary stimulators of antler growth and they are not directly involved in the antler development, rather as metabolically active hormones, they promote all growth processes including antler development and play an important role as modulators of seasonal rhythms.

Table 1 General Linear Model Results from the Analysis of Roe Deer Antler Weight (Gram) as a Function of Water Iodine Content (Base-e Logarithmed, lnICWB), Using Roe Deer Density (*D*), Harvest Rate (HR), Land Cover Information (Proportion of the Agricultural Areas [AGR] and Forestlands [FOR]), and Soil Fertility (Soil Evaluation Number, SEN) as Covariates

Source	Type III sum of squares	*df*	Mean square	F	*P*	R^2
Corrected model	5,202,173.2207	121	42,993.1671	61.32	0.001	0.514
Intercept	2,616,743.8546	1	2,616,743.8546	3,732.28	0.001	
D	18,137.6010	1	18,137.6010	25.87	0.001	
HR	371,681.4576	1	371,681.4576	530.13	0.001	
AGR	138,327.0523	1	138,327.0523	197.30	0.001	
FOR	992.2871	1	992.2871	1.42	0.234	
SEN	45,753.8762	1	45,753.8762	65.26	0.001	
lnICWB	805,659.0765	116	6,945.3369	9.91	0.001	
Error	4,921,100.5336	7,019	701.1113			
Total	551,747,776.3439	7,141				
Corrected total	10,123,273.7544	7,140				

The above findings lend support to our results indicating that iodine levels may influence roe deer performance, such as antler development, through the mechanisms of thyroid function.

Using the national database of ICWB and roe deer antler parameter, we found positive correlation between iodine distribution and antler size. According to Sajgó and Farkas [21] and Sajgó et al. [22] working with the same iodine database, the iodine content of drinking water above 50 µg/l can be considered adequate for humans. In our study, the positive effect can be detected up to the 401–1,000-µg/l level of iodine concentration. But we have to emphasize that the ICWB samples above 200 µg/l represented only the 3.1% of the total number of iodine samples ($n=58$) so that results above this threshold should be taken with great care. Although the connection between antler weights and ICWB was clear, we would not attempt to define the adequate environmental iodine “threshold” for roe deer.

The iodine content of plants (i.e., forage) is mainly dependent on the overall environmental availability of iodine [11, 12, 40], but differences were detected between various plant tissues and between plant species [41–43]. In addition, Ceacero et al. [44] suggested that deer were able to modulate mineral intake to meet requirements, and that on the other hand, relative ID can occur if goitrogenic compounds were presented in the food [13, 45].

Rerábek and Bubenik [46] remarked that ID could occur when thyroid activity is higher in deer. Watkins and Ullrey [47] reported possible ID based on the larger thyroid weight of the wild white-tailed deer compared to captive does fed a complete diet. However, the clinical manifestation of ID in the form of goiter has only been diagnosed in deer by Clark et al. [48] in New Zealand.

The iodine supplementation in livestock (salt licks, concentrate feeds) and human nutrition (iodized salt, iodine-rich milk, meat and egg) is widespread [49, 50]. In the case of wild animals, artificial mineral licks [51] and feeds [52] could be used for mineral supplementation considering the findings of Schultz and Johnson [53]. Therefore, the effects of dietary supplements on body mass and antler size may vary with diet composition and habitat, and other factors could have additional regulatory effects.

No information was found about the iodine requirements of roebucks in the literature. According to the study by Watkins et al. [54], the iodine requirements of white-tailed deer 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 (generally 0.1–0.25 mg per 1 kg consumed fodder and 0.5–0.6 ppm for lactating animals [55]).

Our overall results emphasize the limiting effect of environmental iodine concentration in antler development, but the establishment of the exact iodine requirements of roe deer bucks requires further research, including experimental field trials with controlled iodine intake and controlled environmental effects.

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