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Significance of variation in wildlife red deer carcass yields

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ABSTRACT

Deer hunting has traditionally had great relevance due to the diversity of resources obtained from it, such as meat. Our aim has been to analyse the total post-mortem weight, dressed carcass weight and carcass yield, as well as their variations as a function of years, sex, age and hunting season (autumn vs. winter). Also, predictive equations for carcass weight from total weight were performed. A total of 947 red deer (*Cervus elaphus hispanicus*) of both sexes, hunted from 1989 to 1993 in the Quintos de Mora National Reserve, Spain, were analysed. Seasonal and interannual differences were detected in all weight measures and carcass yield, conditioned by sex, age and climatic factors such as temperature. In general, to obtain a higher meat yield deer extractions should be carried out in autumn. In addition, carcass weight variation (measured on cold carcasses dressed without head and feet, keeping skin, lateral diaphragm portions, fat deposits and legs) can be considered a good indicator of body condition that integrates seasonal nutritional gains and/or losses and long-term nutritional legacies. This index provides information on the animal´s natural history and ecological environment conditions, making its standardized record an essential tool for monitoring wild game populations.

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Introduction

Deer hunting has traditionally had a great relevance due to the diversity of uses obtained from it, mainly as trophy and meat. Nowadays, hunting is not only a method of controlling and avoiding overpopulation of cervids, but its proper management allows obtaining meat of high nutritional value (Stanisz et al. 2019). The increase in human population, together with the search for healthier foods and higher demands on product quality, may have increased the consumption of meats from alternative animal species reared under natural conditions such as deer (Maggiolino et al. 2019; Serrano et al. 2020). Venison is considered as a valuable meat due to its low cholesterol and high protein and mineral content (Volpelli et al. 2003; Poławska et al. 2013). All of these may be the reasons why the global trade in game meat has steadily increased to reach a figure close to two million tonnes per year (Costa et al. 2016). Spain is the world's second largest producer and exporter of wild deer meat to the international market (Maggiolino et al. 2019).

Scientific information on hunted venison is also increasing, but although the factors that primarily influence meat quality have been extensively studied (i.e. Aidoo and Haworth 1995; Stanisz et al. 2019), scientific information on the factors that influence carcass yield variations in wild deer is very scarce. It has been assessed that hunting period influences growth (Semiadi et al. 1993), carcass traits and meat quality (Wiklund et al. 2010; Stanisz et al. 2019) of cervids, because there is a difference in the body condition of wild animals related to the access to feed and weather conditions. In addition, the information provided by carcass weight is very important due to its potential as a bioindicator of body mass in order to infer physiological states and nutritional conditions (Beldomenico et al. 2008; Smiley et al. 2022), and to help reveal the underlying drivers of fitness problems at the individual and population levels (Gingery et al. 2021). However, there are differences between the definition of carcass yield depending on how the animal is weighed after death and how the carcass is dressed. Moreover, the effect of factors such as year of death, season, sex, and age on carcass yields has not been studied in detail for wild red deer in Spain.

Therefore, the goal of the presented study was to analyse the post-mortem total weight, the dressing carcass weight and the carcass yield, and its variations depending on years, sex, age and hunting season period (autumn vs. winter). In addition, we provide predictive equations for carcass weight based on total weight which would be a useful tool for the hunting sector. We also establish the functional relationship of carcass yield as a function of the month of capture within the hunting season, for both males and females, and the variation by age and annual environmental conditions. We discuss the significance of variations in meat yields of wild deer and assess what time and type of animal are most profitable for meat yields; what

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type of weight may be most useful in body condition assessments and which climatic and environmental factors are most influential in Mediterranean ecosystems.

Materials and methods

Harvesting and sample collection

All the red deer (*Cervus elaphus hispanicus*) studied were harvested on the Quintos de Mora National Reserve, in the official hunting season under official authorization and according to the approved technical hunting plans. This state is located in central Spain on the southern slopes of Los Montes de Toledo (39°25′08″N 4°03′36″W), on the mesomediterranean bioclimatic floor with a dry-subhumid ombroclimate (Manzaneque 1988). The reserve has an area of 6864 hectares and an estimated deer population of 2500 individuals (about 36/km^2), and is managed by the Autonomous National Parks Agency, Ministry for Ecological Transition-Demographic Challenge. Every year, for more than 30 years, standardized abundance estimates have been made by means of linear transects of variable width (Tellería 1986; Álvarez 1988), with the aim of providing information on density and population trends. An integrated management of deer habitat (forest, shrubs, bushes, thickets, natural pastures, crops and ponds) is carried out to ensure an adequate supply of food, water and shelter, as well as biological corridors. Supplementary feeding is not normally provided. It is known that the deer population grows approximately 20% each year, so in order to maintain adequate population levels compatible with the carrying capacity of the environment there is a hunting programme for the maintenance and reduction of the population size. Through this population control programme an annual average of 500 deer are harvested. The samples studied were collected under authorization in accordance with legal regulations and in relation to the above-mentioned management programme.

For our purposes only deer shot in the skull were selected in order to obtain carcasses as little-damaged as posible. A total of 947 red deer (288 males and 659 females) hunted from 1989 to 1993, during the legal hunting season in Spain from October to February, were analysed. 418 were classified as hunted in autumn (months of October, November and December), and 529 in winter (months of January and February). The study includes a wide range of ages from animals born in the same year as their death to animals up to 17 years old. The age of the animals was estimated through their dentition by tooth replacement and growth marks in the dental cementum (Azorit et al. 2004; Azorit 2011). For some analyses, 4 age groups were established (see Tables 1 and 2).

Table 1. Differences in total weight, carcass weight and carcass yield between male and female Iberian red deer (*Cervus elaphus hispanicus*) hunted in autumn-winter in Quintos de Mora, Spain.

Iberian red deer	*n*	Total weight	Carcass weight	Carcass yield
Female	659	57.76 (56.27–59.24)^a	32.94 (31.93–33.95)^a	57.16 (56.39–57.94)^a
Male	288	72.38 (70.88–73.89)^b	41.89 (40.86–42.91)^b	58.04 (57.25–58.83)^a

Note: Different letters indicate significant differences at ***P* < 0.000** by Bonferroni's multiple range test.

There is a weather station in the reserve that records daily climate and temperature data, noting the maximum and minimum values and then calculating the monthly average, thus providing local climatic information for the study.

Carcass processing

It was possible to process the carcasses in the same Reserve where the animals were hunted, since there are dressing and weighing rooms for the animals and cold storage chambers for their maintenance and sanitary inspection until they are transported to authorized carcass processing plants.

Almost immediately after being hunted the animals were weighed whole, not eviscerated or refrigerated, but bled. This post-mortem body weight of the animal which was weighed whole and still warm was called *Total Weight* (TW). Each animal was assigned a serial number on which the day of death, sex, age and weight obtained using an industrial scale with an accuracy of ± 200 g (model Giropès) were noted.

Once weighed, evisceration (opening through an incision in the final area of the sternum through which the internal organs are removed and discarded), decapitation (between the occipital bone and the first cervical vertebra) and elimination of the anterior and posterior legs through the carpal-metacarpal and tarsal-metatarsal joints respectively, were performed. Removal of these parts results in a carcass that preserves the skin, lateral portions of the diaphragm and fat deposits, pelvis and legs without feet similarly to that described in Sánchez-Macías et al. (2016). The carcasses were kept in a chamber at 0–2°C for 2–4 days and weighed at this temperature, obtaining what we call *Carcass Weight* (CW) which is a cold weight of the refrigerated dressing carcass with skin.

Carcass yield (CY) was calculated similarly to Pečiulaitienė et al. (2015) with the following formula:

$$CY = (CW*100)/TW$$

where CY: carcass yield, %; CW: cold Carcass Weight, kg: TW: Total Weight or post-mortem body weight, which is a pre-dressing warm weight of the hunted animal, not eviscerated but bled, in kg.

Statistical analysis

The differences between the average parameters of groups were evaluated, and in order to evaluate the aforesaid the analysis of variance was applied and the average trends were calculated. The differences were statistically reliable when $p < 0.05$. GLM was used to find the effects of *Total Weight*, and factors such as age and temperature on *Carcass Weight* using the R package 'glmmTMB' function (Brooks et al. 2017), while R^2 values were obtained using the r.squared GLMM() function from the 'MuMIn' package (Barton 2020). In order to provide a predictive equation for *Carcass Weight* based on hunted animal *Total Weight* along with influencing factors a generalized linear model (GLM) was used, because the explanatory variables have a linear behaviour in relation to the dependent variable. This shows that the dependent variable (*Carcass*

Table 2. Variations in total weight, carcass weight and carcass yield of Iberian red deer hunted in a Mediterranean ecosystem in southern Spain as a function of factors such as year (from 1989 to 1993), hunting season (autumn: months October, November and December, and winter: months January and February), and age group (0 includes animals less than one-year-old, 1: primals and yearlings, 2: 2–3 years old, 3: adults from 3–5 years old and 4: adults and yearlings from 6–17 years old).

Year	*n*	Total weight Females	Carcass weight	*n*	Total weight Males	Carcass weight	*n*	Carcass yield Both sexes
1989	34	56.68 (53.43–59.92)[a]	33.55 (31.38–35.72)[b]	32	70.02 (65.86–74.19)[abc]	40.99 (38.06–43.92)[bc]	66	58.69 (57.34–60.06)[c]
1990	230	**54.29 (52.65–55.93)[a]**	**29.00 (27.91–30.10)[a]**	83	**66.59 (63.77–69.42)[a]**	**37.11 (35.12–39.09)[a]**	313	**55.00 (54.29–55.71)[a]**
1991	274	60.20 (58.87–61.53)[b]	33.88 (32.99–34.76)[b]	91	70.18 (67.62–72.74)[b]	39.48 (37.68–41.28)[ab]	365	56.68 (56.04–57.32)[b]
1992	110	62.59 (60.52–64.65)[c]	36.12 (34.74–37.50)[c]	72	74.43 (72.49–78.36)[c]	44.43 (42.37–46.49)[c]	182	58.52 (57.63–59.41)[c]
1993	11	65.06 (59.36–70.76)[bc]	38.17 (34.35–41.98)[c]	10	75.96 (68.55–83.37) [bc]	44.19 (38.92–49.47)[bc]	21	59.08 (56.68–61.49)[bc]
Hunting Season								
Autumn	261	**59.17 (57.20–61.15)[a]**	34.20 (32.80–35.60)[a]	157	72.48 (69.79–75.18)[a]	43.01 (41.13–44.90)[b]	418	59.18 (58.34–60.02)[b]
Winter	398	61.92 (60.12–63.71)[b]	34.13 (32.41–35.85)[a]	131	71.31 (68.98–73.65)[a]	**40.20 (38.56–41.83)[a]**	529	**56.02 (55.32–56.72)[a]**
Age group								
0 (<1)	32	**32.27 (28.82–35.73)[a]**	**18.76 (16.45–21.07)[a]**	29	**33.64 (29.07–38.21)[a]**	**20.56 (17.35–23.77)[a]**	61	58.27 (56.61–59.67)[b]
1 (1–2)	46	54.23 (51.15–57.31)[b]	31.73 (29.67–33.79)[b]	46	57.88 (54.25–61.50)[b]	32.84 (30.29–35.38)[b]	92	57.67 (56.57–58.99)[b]
2 (2–3)	57	66.31 (63.52–69.11)[c]	37.88 (36.01–39.75)[c]	54	75.50 (71.87– 79.13)[c]	43.90 (41.35–46.45)[c]	111	57.96 (56.81–59.12)[b]
3 (3–6)	210	72.80 (70.92–74.67)[d]	41.57 (40.32–42.83)[d]	112	86.32 (83.73–88.90)[d]	49.68 (47.86–51.50)[d]	322	57.69 (56.92–58.46)[b]
4 (6–17)	314	78.01 (76.32--79.70)[e]	43.22 (42.09–44.35)[e]	47	102.54 (98.98–106.10)[e]	59.22 (56.72–61.73)[e]	361	**56.30 (55.51–57.09)[a]**

Note: Different letters indicate significant differences at ***P* < 0.05** by Bonferroni's multiple range test. The values in bold are the most interesting from the point of view of the detected differences.

Weight) follows a Gaussian distribution, i.e. the GLM residuals fit adequately well to a Gaussian distribution, becoming a multiple linear regression model. The model takes the form:

$$Carcass\ Weight = \beta_0 + \beta_1 \cdot Total\ Weight + \beta_2 \cdot Age + \beta_3 \cdot Temperature + \varepsilon$$

where $\varepsilon \sim \mathcal{N}(\mu, \sigma^2)$ and ε are the errors following a Gaussian distribution (Topping 1972).

In order to establish the functional relationship between *Total Weight* and *Carcass Yield* as a function of hunting season for both males and females, and variation by age and annual environmental conditions; a generalized linear model (GLM) was also used as follows:

$$Carcass\ Yield = \beta_0 + \beta_1 \cdot Seasonal + \beta_2 \cdot Age + \beta_3 \cdot Sex + \varepsilon$$

where $\varepsilon \sim \mathcal{N}(\mu, \sigma^2)$, and ε are the errors following a Gaussian distribution (Topping 1972). The goodness-of-fit test of the models was checked using the graphical residual diagnostics provided by the 'DHARMa' package (Hartig 2019). The multicollinearity problem was tested using the variance inflation factor (VIF) test, and no substantial correlation was found between explanatory variables with VIF values less than 5 (James et al. 2013); following a rule of thumb similarly to Lavery et al. (2019) and Marcoulides and Raykov (2019), where the VIF of the variables could be less than 10, and the mean VIF not substantially greater than 1. The 'performance' package was used to check for possible multicollinearity problems by providing VIF values using the check collinearity function (Lüdecke et al. 2020). Moreover, in order to test the predictive ability of the model, the data set was divided into two parts: the data set used in the models and the test data set (i.e. i.e. 25 random entries), that were extracted from the initial complete data set. The model was then fitted with the training data. Once the model coefficients were estimated this fitted model was then used to make predictions with the test data, i.e. we used the values of the explanatory variables from these fitted data to predict the value of the model's response variable. Once this prediction is obtained, the difference between the predicted and actual values of the response data is a measure of the error on which we can estimate a measure of variability**.** Statistical analyses were performed using R version 4.2.2 (R Core Team 2022).

Results

Table 1 reports the means of total weight, carcass weight and carcass yield and the total number of individuals analysed broken down into males and females. In the parentheses next to each data is the range of variation. It can be observed that for these absolute values no significant differences are found. In males, all values are slightly higher, except for carcass yield which is very similar between both sexes. Table 2 shows variations in total weight, carcass weight and carcass yield of Iberian red deer as a function of factors such as year (from 1989 to 1993), hunting season (autumn: months October, November and December, and winter: months January and February), and age group. We can see that for the year 1990 there are statistically significant differences for both males and females compared to the rest of the years of the study. In the hunting season, these significant differences become plausible in autumn for females in total weight and in males in winter for carcass yield. If we take this analysis as a whole, the significant differences would be in carcass yield. In the breakdown by age group, there are significant differences for group 0 (less than one year old) for both females and males in total weight and carcass weight. However, for carcass yield, we see that these differences are present in group 4 (6–17 years).

Predictive equations with good fit and reliability were obtained for carcass weight as a function of total weight separately for males and females and including factors such as age and temperature as climatic data integrating the effects of seasonality according to the time of death.

The equations take the form:

$$Carcass\ Weight_{♂} = -2.6972 + 0.6017 \cdot TotalWeight - 0.2275 \cdot Age + 0.1547 \cdot Temperature$$

$$Carcass\ Weight_{♀} = -1.5194 + 0.5764 \cdot TotalWeight - 0.2508 \cdot Age + 0.1534 \cdot Temperature$$

Once the values of the other explanatory variables were known, these equations were used to make the predictions of carcass weights and thus give a prediction of what the carcass weight would be. The predictions with the test data (i.e. 25 random entries) were compared with the actual ones, constituting a very acceptable measure of error and estimate of variability and reliability of both equations. Adjusted R^2 were estimated for each of the two models, and we found high values for them. Specifically, we found an R^2 of 84.53% for females, and for males we found an R^2 of 92.1%. Moreover, all the coefficients of the explanatory variables are statistically significant at 5%.

As for the adjusted carcass yield model, the results are shown in Table 3. Although a low R^2 12.72% was obtained, the goodness of fit of the models shows that the model is valid. To analyse the goodness of fit of the models we used the graphical analysis provided by the DHARMa package of R, which indicates that there is no significant deviation in the residuals of the models. We found no multicollinearity problem through the results of the VIF values for the set of explanatory variables in the three GLMs, all VIF values were <3. The residual standard deviation gives a value of 3.0618 kg for the fitted model for females. For males, this value is 3.8577 kg. In Table 3 we can see that age always has a negative effect on the three models (carcass yield, total weight in males and total weight in females). We found the same relationship for the season of the year, i.e. as we advance in the hunting season, the yield decreases. However, the relationship with temperature is positive, since as temperature increases, yield and weight increase. Thus, there is a significant influence of age, seasonality and temperature in all models.

Discussion

It is known that deer species, especially free-ranging deer, express an annual cycle of changes in body condition, which change with age and sex, allowing speculation on variations in deer characteristics and carcass yield. In ungulates energy intake greatly affects body mass gain (Parker et al. 2009), which is an important component of individual fitness (Gaillard et al. 2000). In turn body mass is greatly affected by internal factors such as sex and age, as well as environmental conditions (habitat type and climatic conditions) (Blanckenhorn 2000).

The results of the study revealed seasonal differences in the weight of hunted males and females as well as interannual differences and differences between age groups. When sorting the data by year, by season and by age class, significant differences are observed in both sexes for the year 1990. These inter-annual variations are associated with precipitation and average temperature, since in 1990 there were significant negative variations in total weight, carcass weight and yield for both sexes. Compared to the first year of the study (1989), it was observed that rainfall was reduced by 60% (from 381 l to 233 l mm) and the average temperature was maintained (16° C), which caused an increase in the sericity index that resulted in a decrease in feed availability and intake, along with body weight and all associated data. As the years of the study progressed, these total weight values recovered due to a gradual increase in precipitation and a 6% decrease in mean annual temperature. Similar influences of temperature were detected in studies where precipitation and temperature have been integrated through an environmental sericity index (Lopez-Montoya et al. 2017). A great influence of temperature in some seasons of the year on fitness and the population in general has also been observed.

Seasonally, there are significant differences in females in autumn for total weight. In the case of males, there are significant differences in winter for carcass weight, being in this season lower than in winter due to pregnancy status and its evolution throughout the hunting season. And for both sexes, these differences are evident in carcass yield by having lower values in winter. Red deer, like other temperate ruminants, survive winters by metabolically preprogramming themselves to undergo a negative energy balance through decreased metabolism and loss of body reserves (Tyler et al. 2020). Due to thermoregulatory stress and limitations in forage access and availability (Parker et al. 1984; Parker and Gillingham 1990) fluctuations in carcass weight are reflected. Therefore, season is a variable, along with sex and age, that has statistical significance and is measured as mean monthly temperature. It influences both the production and presence of pasture and the individual's energy expenditure to counteract winter temperatures (in our case), being a variable directly related to animal weight and carcass yield. Therefore the decrease in temperature in winter seems to lead to a decrease in carcass yield (also in total and carcass weight), probably due more to thermoregulatory stress than to limitations in access and availability of food, which in a Mediterranean climate tends to be covered by the contribution of winter fruits, especially Quercus acorns (Azorit et al. 2012).

In the case of carcass yields, in males this yield decreases in winter (Table 2) as in Serrano et al. (2020), following the principle of Jarman Bell Demment and Van Soest (1985) that establishes the inverse relationship between body size and the relative rate of metabolic requirement, resulting in weight loss. In our case, it would apply intersexually, which can be associated with the Jarman Bell principle (Demment and Van Soest 1985) intraspecifically, which states that larger animals, having a lower relative metabolic rate of requirement, can decrease feed quality and thus generate weight loss. This

Table 3. Summary of the results of estimates for the three GLM models. From left to right: type of model, name of explicative variables, parameter estimate, estimate error, z-value and *p*-value. Autumn and male are the baseline categories for the categorical explanatory variables in the Carcass Yield model.

Model	Fixed effects	estimate	s. e.	z-value	*p*-value
Carcass yield	Intercept	58.9693	0.3000	196.57	<2e-16
	Seasonal (Winter)	−1.5547	0.2631	−5.91	3.47e-09
	Sex (Female)	−1.03522	0.2974	−3.48	0.0005
	Age	−0.27992	0.0356	−7.85	4.29e-15
Carcass mass for male	Intercept	−2.6972	1.0676	−2.53	0.0115
	Total weight	0.6017	0.0141	42.51	< 2e-16
	Age	−0.2275	0.1054	−2.16	0.0310
	Temperature	0.1547	0.0518	2.99	0.0028
Carcass mass for female	Intercept	−1.5194	0.7386	−2.06	0.0397
	Total weight	0.5764	0.0102	56.54	< 2e-16
	Age	−0.2508	0.0384	−6.52	6.95e-11
	Temperature	0.1534	0.0327	4.69	2.73e-06

decrease in performance and metabolic rate is due to the fact that quality feed intake is reduced at the end of the acorn-fall season and continues through the winter. Therefore, carcass yields are highest in the fall, a season in which carcasses have recovered from the summer and the rutting season and winter has not yet begun with its consequent decrease in metabolic needs. However, in females this performance remains stable throughout the hunting season (fall and winter) (Table 2). In the special case of total weight for females, which is higher in winter due to the fact that in the autumn months (October, November and December) the weight of the fetus is so insignificant that it does not represent an increase in the total weight. However, in winter this weight of the fetus is greater and therefore becomes more plausible and influences the total weight.

When classifying by age groups, these differences become plausible in both females and males for group 0 (less than one year of age) in total weight and carcass weight. If we focus our attention on carcass yield, these data show a significant difference for both sexes in age group 4 (6–17 years). With this, we can say that yield decreases with age and contrary to popular wisdom a younger animal has a higher yield although it has less meat content due to its reduced size, i.e. although it weighs less, more is used.

Obtaining information on body mass in deer populations is of vital importance for the management of big game populations. With these data, we can determine the relationship between the individual and its habitat and the quality of our populations by reflecting the demographic trajectory of the population (Morellet et al. 2007). Consequently, we can influence management from a health point of view, since by maintaining the population within the carrying limit we reduce the risk of disease transmission and we can even minimize the risks of traffic accidents with game animals (Williams et al. 2002; Seiler 2005; Mysterud 2006), since if the population is maintained at a normal density the ecological niches are not overexploited and individuals do not have to migrate to find resources. Knowing this bioindicator also favours hunting with maximum economic yield, since this data will allow us to learn when the animals are in better physical condition and therefore have more meat resources available.

In summary, carcass weight has a negative relationship with age, both in males and females, and a positive relationship with temperature. This has repercussions on carcass yield and establishes seasonal and interannual fluctuations, raising the importance of variation in meat yield to the level of bioindicator.

Conclusions

The casuistic knowledge of these variables in a natural environment gives us the tool to take maximum advantage of the meat and economic performance of the animals, which for reasons of herd management and maintenance of ecosystems must be eliminated. In general, in order to obtain a higher meat yield from the individuals extracted from a population these extractions should be carried out in autumn, since the carcass yield is significantly higher in the months of October, November and December. In terms of age ranges these extractions should be targeted at all age groups, as performance remains linear until group 4 (6–17 years old), when the decrease is significant. Our results also show that carcass weight variations (measured on cold carcass dressed without head and feet but keeping skin, lateral portions of the diaphragm, fat deposits and legs) can be considered a good indicator of body condition that integrates seasonal nutritional gains and/or losses and long-term nutritional legacies (eg, maternal effects). This index provides information on the animals´ natural history and contextualizes their habitat, ecological environment conditions and management, making the standardized record of weights a useful and necessary tool in the monitoring of wild game populations.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

All data used is available and can be provided upon reasonable request.

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