EFFECTS OF AGE, GUT FILL, AND SEX ON DRESSED MASS – WHOLE MASS

RELATIONSHIPS OF WHITE – TAILED DEER

by

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DEDICATION

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ABSTRACT

Hunters and management agencies are often interested in whole mass of harvested white-tailed deer (*Odocoileus virginianus*) but measuring whole mass in the field is challenging, which is why hunters often dress deer. Dressed mass consists of the carcass mass minus organs in the abdominal, thoracic, pelvic cavities as well as any blood loss. Dressed mass is strongly related to whole mass but covariates of site where deer was harvested, age, sex, body fat, and lactation state of females might also improve predicting whole mass. Also, gut fill variation should help explain why some covariates are influential. Using data from three different sites, which contained deer of various ages, sexes, and lactation states of females, I analyzed the effects of site, age, sex, body fat, lactation state of females, and gut fill on relationships between dressed mass and whole mass (n = 432). Rumen-reticulum fill served as my surrogate of gut fill because these compartments comprise 50 – 70 percent of gut capacity. I analyzed linear regression models and compared them for fit and parsimony with a Bayesian Information Criterion model selection analysis. The selected model had statistically significant predictors of dressed mass, age, sex, lactation status of females, and site. Gut fill also influenced dressed mass – whole mass relationships. Variation in gut fill across sites and due to age, sex, and lactation status of females was consistent with effects of these covariates on dressed mass – whole mass relationships. Lastly, I standardized variables in the selected model to have a mean of zero and standard deviation of one to assess the extent of influence of dressed mass and covariates on whole mass. Dressed mass had a much larger influence on whole mass than covariates. Although site, age, sex, and lactation status of females are influential, the improvement in predicting whole mass is slight. First and foremost, to accurately predict the whole mass of small to large deer requires measuring animals that range widely in dressed body mass.

I. EFFECTS OF AGE, GUT FILL, AND SEX ON DRESSED MASS – WHOLE MASS RELATIONSHIPS OF WHITE – TAILED DEER

Introduction

White-tailed deer (*Odocoileus virginianus*) are widely distributed throughout much of North America, Central America, and into northern South America (Smith, 1991; Waller & Alverson, 1997). Across this large geographic area, white-tailed deer are one of the most popular, if not the most popular, game species (Hefley et al., 2013; Keyser et al., 2005; U.S. Fish and Wildlife Service, 2018). Hunters are interested in the whole mass of the animals they harvest for intrinsic reasons and to assess how much meat they can obtain (Goguen et al., 2018; Strickland et al., 2017). Whole mass from harvested animals allows managers to assess environmental influences on deer performance which has fitness implications and affects population dynamics (Brown et al., 2000; Spilinek et al., 2020). That being said, it is logistically challenging to measure an animal's whole mass in the field (Batchelor & Mead, 2007). Therefore, whole mass is rarely measured in the field. Hunters usually dress dispatched deer in the field to facilitate transporting the deer (Batchelor & Mead, 2007). Dressed mass is typically the carcass mass minus the blood loss, organs in the thoracic, abdominal and pelvic cavities (Jones et al., 2008). Dressed mass has been found to be the estimate that is most strongly related to whole mass (Hellickson, 2002; Jones et al., 2008; Woolf & Harder, 1979). Knowing if age, sex, and gut fill influence whole mass might lead to more accurate estimates.

There are biological reasons why age and sex might influence dressed – whole mass relationships. In proportion to their size, males tend to have more somatic tissue than females (Barboza & Bowyer, 2000). White-tailed deer are polygynous, and males have evolved greater somatic mass to compete for access to females during the mating season (Barboza & Bowyer, 2000; Foley et al., 2018; Gomes et al., 2021; McElligott et al., 2003; Newbolt et al., 2017). Male and female white-tailed deer can also have different food intake and diet (Beier, 1987; Weckerly, 2010). Metabolism slows down as mammals age, which might have an influence on dressed mass – whole mass relationships (Jones et al., 2008; Rogowitz, 1992; Speakman et al., 2003). As deer age, tooth wear increases, making it more challenging for older deer to chew their food and break down particles (Duarte et al., 2011; Luna et al., 2013). If diets differ across sites, gut fill likely varies, which might influence dressed mass – whole mass relationships (Aiken et al., 2015; Weckerly, 2010; Weckerly et al., 2018).

When gut fill is greater, whole-body mass is also heavier (Bhaskar, 2015; Duarte et al., 2014; Spilinek et al., 2020; Weckerly, 2010). Variation in gut fill is due to an animal's food intake and diet (Gross et al., 1985; Weckerly, 1989). The plasticity of an animal's gut capacity allows for changes in food intake when energy requirements or food quality changes (Gross et al., 1985; Weckerly, 1989). When food intake increases or diet is of low quality, it takes longer to digest and gut fill increases (Bhaskar, 2015; Luna et al., 2013). If diets differ across sites, gut fill likely varies, which might influence dressed mass – whole mass relationships (Aiken et al., 2015; Weckerly, 2010; Weckerly et al., 2018). Food intake tends to increase when female deer lactate. Lactation and providing milk to young offspring is the most energetically demanding facet of reproduction for a female deer. The response by lactating females is to increase food intake and gut fill to meet and recover energy lost from lactation (Ericsson et al., 2001; Foley et al., 2018; Luna et al., 2013; Mysterud et al., 2004; Naya et al., 2008; Parra et al., 2014). Food intake can also vary depending on an animal's age, which has been found to have some influence on rumen-reticulum fill, which serves as a surrogate of gut fill (Duarte et al., 2011).

Body fat might also be influential (Bhaskar, 2015; Parra et al., 2014). A low body fat might be associated with animals increasing food intake and, in turn, influencing gut fill (Bhaskar, 2015; Gerhart et al., 1996; Luna et al., 2012; Luna et al., 2013; Nicholson et al., 2008). Thus, body fat should influence dressed mass – whole mass relationships.

To assess the relationship between dressed mass – whole mass relationships, as well as analyze the effects of age, sex, and gut fill, I collected data from three sites. These sites had males and females of various ages, females that were lactating and not lactating, and diets that varied (Aiken et al., 2015; Weckerly et al., 2018). My objectives were:

1) estimate dressed mass – whole mass relationships,
2) examine the influence of covariates (age, sex, lactation status in females, body fat, and site) on dressed mass – whole mass relationships,
3) examine if gut fill variation coincided with influence of age, sex, lactation status in females, body fat, and site influences on dressed mass – whole mass relationships, and
4) assess the extent that dressed mass and other covariates influence whole mass.

Studies in the past have shown that some of the previously mentioned covariates do influence dressed mass – whole mass relationships but no study has considered as many covariates as in this study (Jones et al., 2008; Luna et al., 2012; Nicholson et al., 2008). Furthermore, no study has examined the influence of gut fill or the extent to which dressed mass and covariates influence whole mass. Having information vital to determining which variables can influence dressed mass is crucial to predicting whole mass.

Study Area

Data were collected from three sites in central and south Texas. One site was a 2,994-ha private ranch in Jim Hogg County, Texas. This ranch was surrounded by a 2.4 m fence to decrease the odds of deer escaping (Aiken et al., 2014; Aiken et al., 2015; Weckerly et al., 2018). The climate was semi-arid, as temperatures range from mild winters having daytime temperature averages of 11 ºC to hot summers with daytime temperatures exceeding 35 ºC (Aiken et al., 2014; Parra et al., 2014). Annual precipitation averaged 60.5 cm (Aiken et al., 2014; Aiken et al., 2015; Duarte et al., 2014; Parra et al., 2014; Weckerly et al., 2018). Available forage included western ragweed (*Ambrosia psilostachya*), prickly pear (*Opuntia*), and honey mesquite (*Prosopis glandulosa*) (Aiken et al., 2014). Deer were also provided corn (107 ha), and pellets containing 20% protein in feeders from January to October (Aiken et al., 2014; Aiken et al., 2015; Duarte et al., 2014; Weckerly et al., 2018). Feeder density was 1 per 107 ha.

Another source of data was from the Kerr Pens at the Kerr Wildlife Management Area (WMA). The Kerr Pens consisted of 24 folding pens, 6 breeding pens, and 3 rearing pens (Spilinek et al., 2020). There were 2.7 m tall fences surrounding the Kerr Pens minimizing the chance that deer could leap over the fence (Weckerly et al., 2018; Wolcott et al., 2015). Mean daily temperature was 35 ºC in the summer and 17.3 ºC in winter, as well as annual precipitation that ranged from 69.7 to 80 cm (Bhaskar, 2015; Spilinek et al., 2020; Weckerly et al., 2018). The pens consisted of mostly bare ground, some vegetation such as cowpen daisy (*Verbesina encelioides*) and common horehound (*Marrubium vulgare*), and live oak scattered throughout (*Quercus virginiana*) (Weckerly et al., 2018; Wolcott et al., 2015).

Deer were also obtained from the Kerr WMA which consists of 2,628 ha of natural habitat surrounded by a 2.6 m high fence (Aiken et al., 2015; Luna et al., 2012; Luna et al., 2013). The precipitation varied from year to year, ranging from 33.3 cm to 76.6 cm (Aiken et al., 2015). Forage in autumn and early winter included Ashe juniper (*Juniperus ashei*), silverleaf nightshade (*Solanum elaeagnifolium*), common horehound (*Marrubium vulgare*), various oaks

(*Quercus*), and Texas wintergrass (*Nassella leucotricha*) (Aiken et al., 2015; Luna et al., 2012; Luna, 2013; Warren & Krysl, 1983). Deer at Kerr WMA had access to pelleted feed during annual hunts (Aiken et al., 2015).

Methods

Deer from the Kerr Pens were collected in November and December in 2011, 2012, 2014, 2017, and 2019. The deer were either euthanized in a CO_2 chamber or dispatched by being shot in the head with a high-powered rifle (Bhaskar, 2015; Spilinek et al., 2020; Weckerly et al., 2018). The deer were required to have fasted 24 hours before being euthanized in the CO_2 chamber (Spilinek et al., 2020). Death occurred within 5 minutes of being put in the chamber (Spilinek et al., 2020). After deer were dispatched and brought to a central processing station, a midventral incision was made and all organs in the thoracic, abdominal, and pelvic cavities were removed (Spilinek et al., 2020). The dressed mass was then taken and recorded to the nearest 0.1 kg (Aiken et al., 2015; Spilinek et al., 2020). The rumen and reticulum were severed 2 cm above the esophagus and at the rumen-omasal orifice, extracted and weighed to the nearest 0.1 kg (Aiken et al., 2015; Bhaskar, 2015; Weckerly et al., 2018). The contents in the rumen-reticulum were then emptied and rinsed with tap water to remove all particles (Aiken et al., 2015; Bhaskar, 2015; Weckerly et al., 2018). Rumen-reticulum organ mass was weighed to the nearest 0.1 kg (Bhaskar, 2015). Rumen-reticulum fill (mass with contents minus rumen-reticulum organ mass) and organ mass was my indicator of gut fill as these chambers comprise about 50-70 percent of gut fill and gut mass (Bhaskar, 2015; Duarte et al., 2011; Weckerly, 2010; Weckerly et al., 2018). Rumen-reticulum organ mass was included because organ mass can change with diet (Weckerly et al., 2018). An incision was also made on the right side near the L_3 and L_4 lumbar vertebrae, after which the back fat was measured to the nearest 1.0 mm (Aiken et al., 2015).

Back fat thickness was taken because it reflects body fat (Duarte et al., 2014; Mattiello et al., 2009; Parra, 2012; Parra et al., 2014; Watkins et al., 1991). In females, lactation status was determined by whether milk could be extruded from udders (Aiken et al., 2015; Bhaskar, 2015; Parra et al., 2014).

Deer from south Texas were collected over a 30 hour period on October 16-17, 2010 (Aiken et al., 2014; Duarte et al., 2014). The deer were net-gunned from a helicopter, restrained, and transported to a processing area in a span of 45 minutes (Aiken et al., 2015). The deer were then dispatched by a shot to the head with a .22 caliber rifle and processed within 15 minutes of being dispatched (Aiken et al., 2014; Weckerly et al., 2018). Deer from south Texas were processed like deer from Kerr Pens with the exception that age was estimated from tooth replacement and wear (Duarte et al., 2014; Parra et al., 2014).

Deer were collected from Kerr WMA in November and December, 2009 and 2010, during public hunts. Deer were shot and killed with high-powered rifles. At the check station where hunters checked in their harvested animals, deer were aged according to tooth replacement and wear patterns and processed identical to how deer were dissected at the other two sites.

Regressions were built to assess whether dressed mass alone or whether some or all covariates influenced dressed mass – whole mass relations. I also coded age two ways, to the nearest year and as age categories yearling (1.5 years), adult (2.5), and older adults (>2.5). Age categories were delineated considering that tooth replacement and wear can accurately age deer to these age categories (Aiken et al., 2015; Luna et al., 2012; Severinghaus, 1949). A model selection analysis was conducted to choose a parsimonious model with the strongest fit to whole mass. I used Bayesian Information Criterion (BIC) to select the regression. I chose BIC over the popular Akaike Information Criterion (AIC) because BIC takes sample size into consideration and because AIC tends to select more complex and thus less parsimonious models (Acquah, 2010; Aho et al., 2014; Yates et al., 2021). The south Texas site served as the reference site, females were the reference category for sex, and nonlactating females were the reference category for lactation status.

Models for gut fill were built using rumen reticulum contents (hereafter rumen reticulum fill) and rumen reticulum organ mass as response variables. Predictors were dressed mass, site, sex, female lactation status, and age. Because there might be nonlinear relationships between dressed mass and rumen reticulum contents and organ mass, these variables were naturally log transformed (Lee, 2020). To assess the extent of influence of dressed mass and remaining covariates on whole mass I reanalyzed the selected model where I standardized all variables so that each had a mean of 0 and a standard deviation of 1.0 (Li et al., 2023; Lyon, 2014).

Results

Each site had a different total number of deer (Table 1). Kerr WMA had 90 deer, 32 being male and 58 being female. Forty-two of the 58 females were lactating while 16 of them were not lactating. The Pens had a total of 242 deer, 105 males and 137 females, 18 of which were lactating and 119 were not lactating. There were 100 deer from south Texas, 50 males and 50 females, 34 of the females were lactating and 16 were not lactating. For mass of deer, south Texas tended to have higher dressed mass and whole mass (Table 1). Males had an average whole mass of 76.69 kg, nonlactating females had an average of 43.03 kg, and lactating females had an average of 46.48 kg. In regard to dressed mass, males had an average dressed mass of 59.66 kg, nonlactating females had an average of 32.1 kg, and lactating females had an average of 32.98 kg.

For the model selection analysis, the model with predictors of dressed mass and covariates of sex, lactation status, age, and site were selected (Table 2). The model had a BIC that was at least 7 units smaller than any other model. Nonetheless, all the models seemed to fit the data well because r^2 values were the same and there was a relatively small range in residual standard deviations.

In the selected model dressed mass was positively related to whole mass (Table 3, Figure 1). Each covariate was also influential. In relation to dressed mass, lactating females and south Texas deer had the heaviest whole mass. Age was positively related to whole mass.

For rumen reticulum fill, covariates for site, sex, lactation, and age were influential (Table 4a). Similar to the selected model predicting whole mass, lactating females and south Texas deer had the greatest rumen reticulum fill. Also, age was positively related to rumen reticulum fill. A similar pattern was evident for the response variable of rumen reticulum organ mass (Table 4b). If rumen reticulum fill was influenced by all these factors, and rumen reticulum fill is a surrogate of gut fill, then gut fill varies and can influence dressed mass – whole mass relationships. Diets for deer differed among the sites, leading to gut fill variation among the sites.

It was evident from the selected model where predictors and response variable were standardized that dressed mass had the greatest influence on whole mass (Table 5). For a one standard deviation change in dressed mass, whole mass changed by 0.97 standard deviations. None of the remaining covariates had a standardized coefficient greater than 0.074 (absolute value).

Discussion

The results I obtained show that dressed mass did indeed predict whole mass, as expected from other studies (Hellickson, 2002; Jones et al., 2008). Most of the covariates that I analyzed (age, sex, lactation status in females, and site) were influential. Body fat was the one covariate that was not influential. Age, sex, and lactation status influencing whole mass were not surprising as other studies have found that these covariates were influential (Hellickson, 2002; Simard et al., 2014).

Presumably, males have more somatic muscle mass than females (Barboza & Bowyer, 2000). Consequently, there should have been a larger proportion of dressed mass in regard to whole mass in males than in females (Barboza & Bowyer, 2000). My results contradict this expectation. The sex coefficient for males (0.652) was positive, meaning that males, on average, ended up having proportionally more gut mass than females. Data had been collected approaching and during the mating season. The mating season is an energetically demanding time for males. To prepare for the rigors of mating, males might have increased food intake. This could have prompted increased gut fill and greater disparity between dressed and whole-body mass.

Due to not having the known age of every deer, the age of deer were placed into age categories. These age categories consisted of yearlings (1.5 years), adults (2.5 years), and older adults (> 2.5 years). These age categories were delineated because it can be difficult to accurately age deer that are older than 2.5 years solely by the amount of tooth wear (Gee et al., 2002; Storm et al., 2014). The covariate of age categories, however, was not in the selected model. The one site that did have the known age of the deer was the Kerr Pens. Kerr Pens was also the site with the largest sample size of deer (n = 242). The only site having the known age also being the site with the largest sample size might have been a reason why the covariate of age categories was not selected. If Kerr Pens only had age categories to age deer, age categories and not age might have been influential. Tooth wear and replacement as an aging technique is commonly used but is not always accurate, sometimes leading to overestimating or underestimating a deer's age (Foley et al., 2021; Gee et al., 2002; Storm et al., 2014). Furthermore, it is likely that there are differences in tooth wear between male and female deer (Van Deelen et al., 2000). Older animals increase their rumen-reticulum capacity to increase their food retention time, due to the struggle of breaking down larger particles because of worn cheek teeth (Duarte et al., 2011). When there is substantial tooth wear deer probably lengthen food retention time (Duarte et al., 2011). Duarte et al. (2011) for example, found that age-related factors can influence rumen-reticulum fill.

Like age categories, the covariate of back fat was also not included in the selected model. Back fat reflects body fat, which is a strong indicator of body condition (Mattiello et al., 2009; Watkins et al., 1991). Thus body fat has a positive influence on white-tailed deer survival and reproduction (Simard et al., 2014). Usually, when there is higher body mass, there is higher body fat. However, body fat is only a small part of the body mass of an animal (Monteith et al., 2013; Watkins et al., 1991). Thus, body fat did not have a noticeable influence on whole mass and was not a covariate in the selected model.

Gut fill can increase as animals age. This is likely due to the fact that, as tooth wear increases with age, breaking down particles becomes more difficult (Duarte et al., 2011; Luna et al., 2013). This leads to larger particles resulting in a greater gut fill (Duarte et al., 2011; Veiberg et al., 2007). Metabolism also slows down as mammals age which might affect appetite (Jones et al., 2008; Rogowitz, 1992). However, my findings, in regard to age, seem to relate more to gut fill than to metabolism. My age coefficient (0.571) was positive. If a slowing metabolism with age was influential, the age coefficient should have been negative. This is because organs would probably end up regressing in size which should then reduce the disparity between dressed and whole-body mass (Holliday et al., 1967; Naya et al., 2008; Penzo-Méndez & Stanger, 2015).

Lactating females also had larger gut mass. This was likely caused by an increase in food intake (Müller et al., 2013; Naya et al., 2008). Since provisioning milk to offspring is energetically demanding, females were most likely making up for the energy lost during lactation in the previous summer (Ceacero et al., 2016; Jenks et al., 1994; Luna et al., 2013; Moen, 1978; Naya et al., 2008; Parra et al., 2014; Therrien et al., 2008).

Gut fill also varied with sites. The deer collected from the South Texas Ranch and Kerr WMA sites were free-ranging animals. Available forage differed between these two sites. Animals from the Kerr Pens were provided a controlled diet. Since the diets varied among the three sites, gut fill also varied. This might explain why site was influential (Aiken et al., 2015; Weckerly, 2010; Weckerly et al., 2018). In future studies the diets of deer will likely differ from the diets of deer in my study. Gut fill will likely differ from animals in my study which will probably alter dressed mass – whole mass relationships of deer from other sites differently than in my study.

In my study male dressed mass ended up being 78% of whole mass and female (lactating and nonlactating) dressed mass was around 76%. Previous studies have looked at relationships between dressed mass and whole mass, as well as different covariates, and found differing proportions of dressed mass to whole mass. Weiner (1973) found the dressed mass, as a percentage of whole mass, in roe deer (*Capreolus capreolus*) was around 65.1% in adults and 58.7% in younger deer. Feldhamer & Marcus (1994) looked at the dressed mass – whole mass relationships of female sika deer (*Cervus nippon*) and found that, across three age categories, dressed mass appeared to be 70% - 72% of whole mass. Hellickson (2002) looked at the physical characteristics of deer such as dressed mass, shoulder height, and chest girth to predict whole mass. Dressed mass was the estimate most strongly related to whole mass across age categories and in both sexes. For females, relationships varied across age classes. Jones et al. (2008) analyzed the dressed mass – whole mass relationships among age categories and sex of black-tailed deer (*O. hemionus columbianus*). Relationships differed among the age categories and between males and females, with differing dressed mass – whole mass ratios for males and females across the age categories. Hamerstrom & Camburn (1950) found dressed mass – whole mass relationships of white-tailed deer which did not vary much between ages or sex.

No other study has considered as many covariates as my study. The covariates that were influential included, sex, lactation status in females, age, and site. Before my study, the only covariates that were considered were sex and age (Hellickson, 2002; Jones et al., 2008; Woolf & Harder, 1979). Nonetheless, dressed mass alone had the overwhelming influence on whole mass. One reason why the influential covariates were not strongly related to whole mass was that gut fill often was associated with covariates, and gut fill represents a small part (<5 percent) of whole mass (Müller et al., 2013; Weckerly, 2010). Consequently, including influential covariates only improved the precision of predicting whole mass by 0.5 kg or less (Table 2). Therefore, including covariates that are statistically significant ($P < 0.05$) does not necessarily translate into substantial increases in accurately predicting whole mass.

For purposes of accurately predicting whole mass from dressed mass the vital consideration is dressed and whole mass data. Associated with the large geographic range of white-tailed deer is a wide range in body sizes of deer throughout that geographic expanse (Smith, 1991; Waller & Alverson, 1997). To accurately estimate whole mass from dressed mass of hunter harvested animals requires obtaining deer from across the spectrum of small to large from the entire geographic range. Including covariates that might also influence dressed – whole mass relationships is a secondary consideration.

Table 1. Means and ranges (parentheses) of data (whole mass, dressed mass, age, and back fat thickness) measured for lactating and nonlactating female and male white-tailed deer (*Odocoileus virginianus*). Data was collected from three different sites. Whole mass and dressed mass were measured in kg and back fat thickness was measured in mm.

			Variable			
Sex	Lactation	*n*	Whole mass	Dressed mass	Age	Back fat
			Kerr hunt			
Female	Yes	42	39.14 (31.4,48.2)	28.08 (22.3,34.6)	4.12 (1.5,8.5)	0.22 (0,0.79)
Female	No	16	40.33 (28.5,49.5)	30.08 (21.6,36)	3.25 (1.5,8.5)	0.53 (0,2.06)
Male	-	32	45.67 (30.9,75.5)	35.13 (24.3,59.8)	2.78 (1.5,8.5)	0.34 (0,1.27)
			Kerr pens			
Female	Yes	18	45.44 (39.6,53.8)	32.83 (27.6,38.1)	6.89 (5.5,10.5)	4.85 (0,15.88)
Female	No	119	46.17 (37.3,57.9)	35.48 (27.7,44.9)	4.89 (3.5,12.5)	11.89 (0,47.63)
Male	-	105	62.89 (41.04,89.42)	49.91 (31.54,72.422)	4.02 (1.5,8.5)	6.52 (0,25.4)
			South Texas			
Female	Yes	34	46.48 (35.83,70.31)	32.98 (24.04,45.81)	4.29 (1.5,7.5)	0.47 (0.08,1.91)
Female	No	16	43.03 (31.75,55.34)	32.1 (22.23,41.28)	3.31 (1.5,5.5)	1.002 (0.16,1.91)
Male	-	50	76.69 (38.56,106.14)	59.66 (27.67,83.01)	4.06 (1.5,7.5)	2.09 (0.08,3.81)

Table 2. Summary of Bayesian Information Criterion model selection analysis of various models estimating whole body mass from dressed body mass (DM) and various covariates of white-tailed deer (*Odocoileus virginianus*). The summary shows the ΔBIC (BIC score of a model minus model with smallest BIC) values, residual standard deviation, r-squared values, and the number of parameters (nPar) estimated. The covariates were the area where deer was collected (AR), sex (S), age (A), age categories (AC, yearling (1.5yrs), adult (2.5), older adult (>2.5)), age recorded to nearest year, whether or not the animal was lactating (L), and back fat thickness (BF). The selected model is represented in bold font. The dressed mass was measured in kg and back fat thickness was measured in mm.

Models	Delta BIC	Residual standard deviation	r^2	nPar
DM	156.2	2.38	0.98	3
DM+AR	104.7	2.21	0.98	5
DM+S	149	2.34	0.98	4
DM+A	105.6	2.23	0.98	4
DM+AC	117	2.23	0.98	6
DM+S+A	111.7	2.23	0.98	5
DM+S+AC	112.9	2.21	0.98	7
DM+S+L	89.6	2.17	0.98	5
DM+S+A+L	58.7	2.08	0.98	6
DM+S+AC+L	83.6	2.12	0.98	8
DM+BF	151	2.35	0.98	4
DM+S+BF	133	2.29	0.98	5
DM+S+A+BF	93.1	2.17	0.98	6
DM+S+AC+BF	117.5	2.21	0.98	8
DM+AR+S	97.8	2.18	0.98	6
DM+AR+A	7.2	1.96	0.98	6
DM+AR+AC	102.9	2.18	0.98	7
DM+AR+S+A	11.6	1.96	0.98	7
DM+AR+S+AC	105.4	2.18	0.98	8
DM+AR+S+L	68.7	2.1	0.98	7
DM+AR+S+A+L	**0.0**	**1.93**	**0.98**	**8**
DM+AR+S+AC+L	72.2	2.08	0.98	9
DM+AR+BF	110.7	2.21	0.98	6
DM+AR+S+A+BF	17.6	1.96	0.98	8
DM+AR+S+AC+BF	110.2	2.17	0.98	9

Table 3. Coefficients, standard errors, t values, and p values of the selected model, which takes into account dressed mass, the site the white–tailed deer (*Odocoileus* virginianus) was collected from, sex, age, and whether or not the animal was lactating. Dressed mass was measured in kg. Reference categories were south Texas for site, females for sex and lactating females for lactation status. Kerr represents the data from the Kerr Pens. Hunt represents the data from the 2009 hunts at Kerr WMA.

Coefficients	Estimate	Standard Error	t	p
Intercept	5.925	0.498	11.9	<0.001
Dressed mass	1.154	0.013	90.3	<0.001
Hunt	-1.531	0.318	-4.8	<0.001
Kerr	-2.256	0.259	-8.7	0.033
Sex	0.652	0.305	2.1	<0.001
Age	0.571	0.064	9.0	<0.001
Lactation	-1.229	0.292	-4.2	<0.001

Table 4. Coefficients, standard errors, t values, and P values of models estimating wet mass of rumen-reticulum fill (4a) and another model estimating rumen-reticulum organ mass (4b) of white–tailed deer (*Odocoileus virginianus*). Wet mass of rumen-reticulum contents and organ mass as well as dressed mass (Dwt) were log-transformed in the event of a non-linear relationship. Reference categories were south Texas for site, females for sex, and lactating females for lactation status. Kerr represents the data from the Kerr Pens. Hunt represents the data from the 2009 hunts at Kerr WMA.

Table 4a.

Coefficients	Estimate	Standard Error	t	p
Intercept	0.591	0.386	1.5	0.126
Log(Dwt)	0.177	0.111	1.6	0.112
Hunt	-0.211	0.067	-3.1	0.002
Kerr	-0.455	0.055	-8.2	<0.001
Lactation	-0.264	0.069	3.9	0.001
Sex	0.154	0.062	-2.5	0.0126
Age	0.063	0.012	5.2	<0.001

Table 4b.

Coefficients	Estimate	Standard Error	t	p
Intercept	-1.110	0.199	-5.6	<0.001
Log(Dwt)	0.391	0.058	6.8	<0.001
Hunt	-0.416	0.035	-12	<0.001
Kerr	-0.514	0.029	-18	<0.001
Lactation	-0.225	0.035	6.4	<0.001
Sex	0.083	0.032	-2.6	0.009
Age	0.02	0.006	3.1	0.002

Table 5. Standardized coefficients and standard errors of predictors and covariates in the selected model containing the dressed mass of the white-tailed deer (*Odocoileus virginianus*), the area the deer were collected from, sex, age, and whether or not females were lactating. Dressed mass was measured in kg. Whole mass, dressed mass, and covariates were log transformed to have a mean of 0 and standard deviation of 1. Reference categories were south Texas for site, females for sex, and lactating females for lactation status. Kerr represents the data from the Kerr Pens. Hunt represents the data from the 2009 hunts at Kerr WMA.

Coefficients	Estimate	Standard Error
Intercept	0.000	0.006
Dressed mass	0.966	0.011
Kerr	-0.074	0.009
Hunt	-0.041	0.009
Sex	0.021	0.01
Age	0.068	0.008
Lactation	0.034	0.008

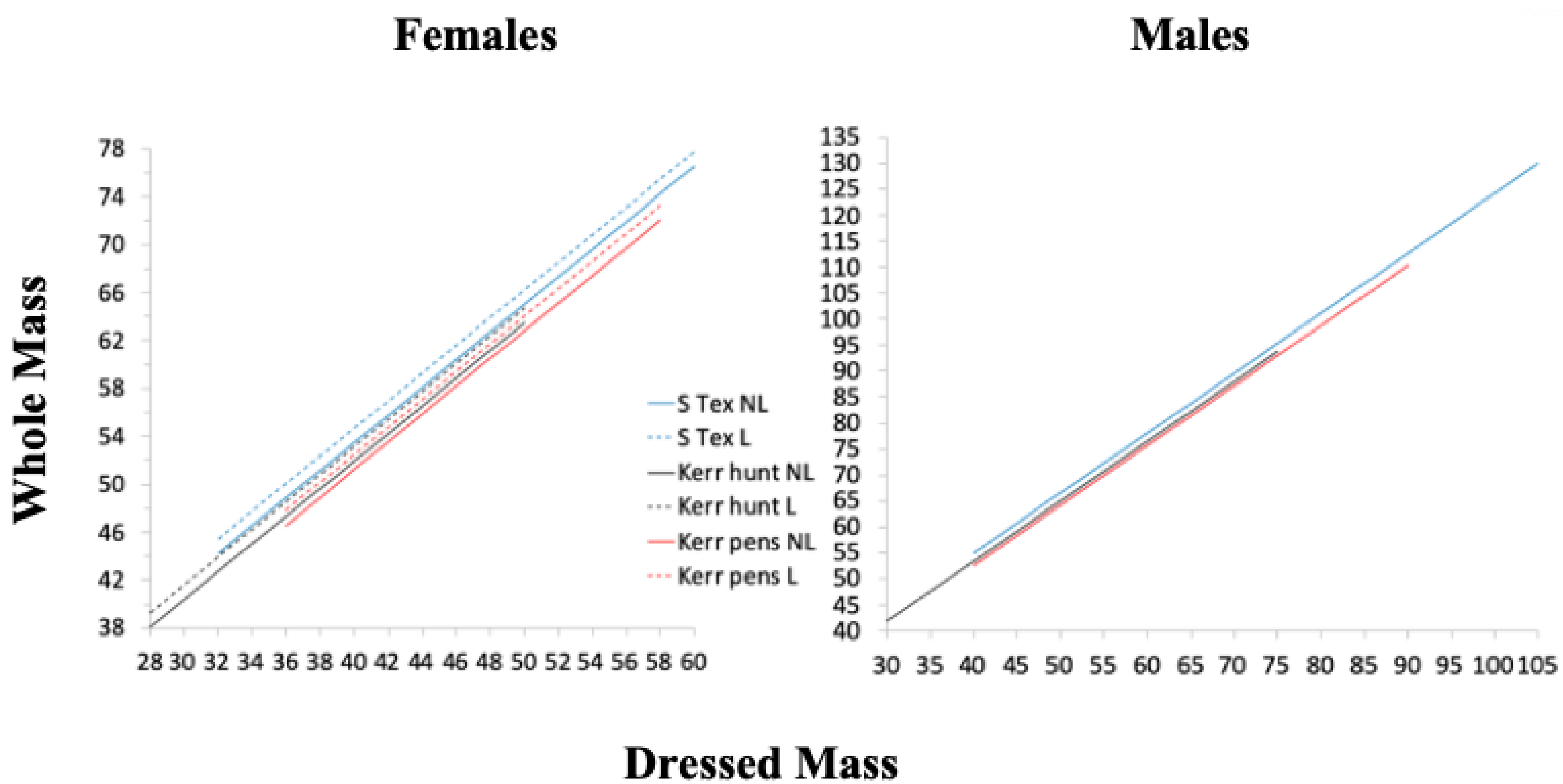

Figure 1. Linear regressions of dressed mass – whole mass relationships of female and male white-tailed deer (*Odocoileus virginianus*). The deer were collected from three separate sites. These regressions account for the sex of deer and whether or not females were lactating. The regressions are estimated from the selected model (Table 2). Table 3 reports the coefficients of the selected model. Age is accounted for by using the mean value.

LITERATURE CITED

Acquah, H. D.-G. (2010). Comparison of Akaike information criterion (AIC) and Bayesian information criterion (BIC) in selection of an asymmetric price relationship. *Journal of Development and Agricultural Economics*, *2*, 001-006.

Aho, K., Derryberry, D., & Peterson, T. (2014). Model selection for ecologists: the worldviews of AIC and BIC. *Ecology*, *95*, 631-636.

Aiken, M., Duarte, A., Luna, R., Wolcott, D., & Weckerly, F. (2014). Daytime declines in rumen–reticulum fill of male white-tailed deer (*Odocoileus virginianus*) from south Texas. *Canadian Journal of Zoology*, *92*, 637-642.

Aiken, M. R., Wolcott, D. M., Duarte, A., Luna, R. S., Starns, H. D., & Weckerly, F. W. (2015). Use of rumen–reticulum fill to examine nutrient transfer and factors influencing food intake in white-tailed deer (*Odocoileus virginianus*). *Canadian Journal of Zoology*, *93*, 439-445.

Barboza, P. S., & Bowyer, R. T. (2000). Sexual segregation in dimorphic deer: a new gastrocentric hypothesis. *Journal of Mammalogy*, *81*, 473-489.

Batchelor, B., & Mead, A. J. (2007). Correlation of sex, age, and body mass with hoof size in white-tailed deer from the Piedmont Wildlife Refuge, Georgia. *Georgia Journal of Science*, *65*(2), 89.

Beier, P. (1987). Sex differences in quality of white-tailed deer diets. *Journal of Mammalogy*, *68*, 323-329.

Bhaskar, G. (2015). *Rumen-reticulum and liver mass relationships in white-tailed deer (Odocoileus virginianus) differ between females and males* Texas State University. San Marcos.

Brown, T., Riley, S., Enck, J., Lauber, T., Curtis, P., & Mattfeld, G. (2000). The future of hunting as a mechanism to control white-tailed deer populations. *Wildlife Society Bulletin*, *28*, 797-807.

Ceacero, F., García, A. J., Landete-Castillejos, T., Komárková, M., Hidalgo, F., Serrano, M. P., & Gallego, L. (2016). The many axes of deer lactation. *Journal of mammary gland biology and neoplasia*, *21*, 123-129.

Duarte, A., Luna, R. S., Starns, H. D., & Weckerly, F. W. (2014). Intraspecific scaling of rumen-reticulum fill might depend on dietary fiber. *The American Midland Naturalist*, *172*, 329-337.

Duarte, A., McCullough, D., & Weckerly, F. (2011). Does rumen–reticulum capacity correlate with body size or age in black-tailed deer? *European Journal of Wildlife Research - EUR J WILDL RES*, *57*, 1131-1136.

Ericsson, G., Wallin, K., Ball, J. P., & Broberg, M. (2001). Age-related reproductive effort and senescence in free-ranging moose, *Alces alces*. *Ecology*, *82*(6), 1613-1620.

Feldhamer, G. A., & Marcus, M. A. (1994). Reproductive performance of female sika deer in Maryland. *The Journal of Wildlife Management*, *58*, 670-673.

Foley, A. M., Hewitt, D. G., DeYoung, R. W., Schnupp, M. J., Hellickson, M. W., & Lockwood, M. A. (2018). Reproductive effort and success of males in scramble-competition polygyny: Evidence for trade-offs between foraging and mate search. *Journal of Animal Ecology*, *87*, 1600-1614.

Foley, A. M., Lewis, J. S., Cortez, O., Hellickson, M. W., Hewitt, D. G., DeYoung, R. W., . . . Schnupp, M. J. (2021). Accuracies and biases of ageing white-tailed deer in semiarid environments. *Wildlife Research*, *49*, 237-249, 213.

Gee, K. L., Holman, J. H., Causey, M. K., Rossi, A. N., & Armstrong, J. B. (2002). Aging white-tailed deer by tooth replacement and wear: a critical evaluation of a time-honored technique. *Wildlife Society Bulletin*, *30*, 387-393.

Gerhart, K. L., White, R. G., Cameron, R. D., & Russell, D. E. (1996). Body composition and nutrient reserves of arctic caribou. *Canadian Journal of Zoology*, *74*, 136-146.

Goguen, A. D., Riley, S. J., Organ, J. F., & Rudolph, B. A. (2018). Wild-harvested venison yields and sharing by Michigan deer hunters. *Human Dimensions of Wildlife*, *23*, 197-212.

Gomes, M. A., Ditchkoff, S. S., Zohdy, S., Gulsby, W. D., & Newbolt, C. H. (2021). Patterns of testosterone in male white-tailed deer (*Odocoileus virginianus*): Seasonal and lifetime variation. *Ecology and Evolution*, *11*, 5320-5330.

Gross, J. E., Wang, Z., & Wunder, B. A. (1985). Effects of food quality and energy needs: changes in gut morphology and capacity of *Microtus ochrogaster*. *Journal of Mammalogy*, *66*, 661-667.

Hamerstrom, F., & Camburn, F. L. (1950). Weight relationships in the George Reserve deer herd. *Journal of Mammalogy*, *31*, 5-17.

Hefley, T. J., Hygnstrom, S. E., Gilsdorf, J. M., Clements, G. M., Clements, M. J., Tyre, A. J., . . . VerCauteren, K. C. (2013). Effects of deer density and land use on mass of white-tailed deer. *Journal of Fish and Wildlife Management*, *4*, 20-32.

Hellickson, M. W. (2002). *Age-specific physical characteristics, activity, and behavior patterns of male white-tailed deer in southern Texas* University of Georgia Athens, USA.

Holliday, M., Potter, D., Jarrah, A., & Bearg, S. (1967). The relation of metabolic rate to body weight and organ size. *Pediatric research*, *1*, 185-195.

Jenks, J. A., Leslie Jr, D. M., Lochmiller, R. L., & Melchiors, M. A. (1994). Variation in gastrointestinal characteristics of male and female white-tailed deer: implications for resource partitioning. *Journal of Mammalogy*, *75*, 1045-1053.

Jones, R. L., Weckerly, F. W., & McCullough, D. R. (2008). Influence of age and sex on dressed-whole body weight relationships in black-tailed deer. *California Fish and Game*, *94*, 137-142.

Keyser, P. D., Guynn Jr, D. C., & Hill Jr, H. S. (2005). Population density-physical condition relationships in white-tailed deer. *The Journal of Wildlife Management*, *69*(1), 356-365.

Lee, D. K. (2020). Data transformation: a focus on the interpretation. *Korean journal of anesthesiology*, *73*, 503-508.

Li, X., Ma, Y., & Pan, Q. (2023). Standardization of continuous and categorical covariates in sparse penalized regressions. *Statistical Methods in Medical Research*, *32*, 41-54.

Luna, R., Duarte, A., & Weckerly, F. (2012). Rumen–reticulum characteristics, scaling relationships, and ontogeny in white-tailed deer (*Odocoileus virginianus*). *Canadian Journal of Zoology*, *90*, 1351-1358.

Luna, R. S. (2013). *Body size, rumen-reticulum functions, and dietary nutrition of white-tailed deer* Texas State University-San Marcos.

Luna, R. S., Duarte, A., & Weckerly, F. W. (2013). Influence of body size on dietary nutrition of white-tailed deer *Odocoileus virginianus*. *Journal of Fish and Wildlife Management*, *4*, 53-62.

Lyon, A. (2014). Why are normal distributions normal? *The British Journal for the Philosophy of Science*, *65*(3), 621-649.

Mattiello, S., Andreoli, E., Stefanelli, A., Cantafora, A., & Bianchi, A. (2009). How to evaluate body conditions of red deer (*Cervus elaphus*) in an alpine environment? *Italian Journal of Animal Science*, *8*, 555-565.

McElligott, A., Naulty, F., Clarke, W. V., & Hayden, T. (2003). The somatic cost of reproduction: What determines reproductive effort in prime-aged fallow bucks? *Evolutionary Ecology Research*, *5*, 1239-1250.

Moen, A. N. (1978). Seasonal changes in heart rates, activity, metabolism, and forage intake of white-tailed deer. *The Journal of Wildlife Management*, *42*, 715-738.

Monteith, K. L., Stephenson, T. R., Bleich, V. C., Conner, M. M., Pierce, B. M., & Bowyer, R. T. (2013). Risk-sensitive allocation in seasonal dynamics of fat and protein reserves in a long-lived mammal. *Journal of Animal Ecology*, *82*, 377-388.

Mysterud, A., Langvatn, R., & Stenseth, N. C. (2004). Patterns of reproductive effort in male ungulates. *Journal of Zoology*, *264*(2), 209-215.

Müller, D. W., Codron, D., Meloro, C., Munn, A., Schwarm, A., Hummel, J., & Clauss, M. (2013). Assessing the Jarman–Bell principle: scaling of intake, digestibility, retention time and gut fill with body mass in mammalian herbivores. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, *164*, 129-140.

Naya, D. E., Ebensperger, L. A., Sabat, P., & Bozinovic, F. (2008). Digestive and metabolic flexibility allows female degus to cope with lactation costs. *Physiological and Biochemical Zoology*, *81*, 186-194.

Newbolt, C. H., Acker, P. K., Neuman, T. J., Hoffman, S. I., Ditchkoff, S. S., & Steury, T. D. (2017). Factors influencing reproductive success in male white-tailed deer. *The Journal of Wildlife Management*, *81*, 206-217.

Nicholson, K. L., Peterson, W. J., & Ballard, W. B. (2008). Comparisons and trends in white-tailed deer, *Odocoileus virginianus*, body fat in Northeastern Minnesota, 1974-1990. *The Canadian Field-Naturalist*, *122*, 253-261.

Parra, C. A. (2012). *Body weight and age influences on liver weight in white-tailed deer (Odocoileus virginianus): Implications for reproductive effort* Texas State University. San Marcos, Texas.

Parra, C. A., Duarte, A., Luna, R. S., Wolcott, D. M., & Weckerly, F. W. (2014). Body mass, age, and reproductive influences on liver mass of white-tailed deer (*Odocoileus virginianus*). *Canadian Journal of Zoology*, *92*, 273-278.

Penzo-Méndez, A. I., & Stanger, B. Z. (2015). Organ-size regulation in mammals. *Cold Spring Harbor Perspectives in Biology*, *7*(9), a019240.

Rogowitz, G. L. (1992). Postnatal variation in metabolism and body temperature in a precocial Lagomorph. *Functional Ecology*, *6*, 666-671.

Severinghaus, C. W. (1949). Tooth development and wear as criteria of age in white-tailed deer. *The Journal of Wildlife Management*, *13*, 195-216.

Simard, A., Huot, J., De Bellefeuille, S., & Côté, S. D. (2014). Influences of habitat composition, plant phenology, and population density on autumn indices of body condition in a northern white-tailed deer population. *Wildlife Monographs*, *187*, 1-28.

Smith, W. P. (1991). *Odocoileus virginianus*. *Mammalian Species*(388), 1-13.

Speakman, J., Acker, A., & Harper, E. (2003). Age-related changes in the metabolism and body composition of three dog breeds and their relationship to life expectancy. *Aging Cell*, *2*, 265-275.

Spilinek, S. G., Reitz, R., & Weckerly, F. W. (2020). Rumen–reticulum organ mass and rumen mucosa surface area of white-tailed deer (*Odocoileus virginianus*) consuming two energy diets. *Canadian Journal of Zoology*, *98*, 725-732.

Storm, D. J., Samuel, M. D., Rolley, R. E., Beissel, T., Richards, B. J., & Van Deelen, T. R. (2014). Estimating ages of white-tailed deer: Age and sex patterns of error using tooth wear-and-replacement and consistency of cementum annuli. *Wildlife Society Bulletin*, *38*, 849-856.

Strickland, B. K., Jones, P. D., Demarais, S., & Dacus, C. M. (2017). Adjusting for body mass change in white-tailed deer during hunting season. *Wildlife Society Bulletin*, *41*, 286-293.

Therrien, J.-F., Côté, S. D., Festa-Bianchet, M., & Ouellet, J.-P. (2008). Maternal care in white-tailed deer: trade-off between maintenance and reproduction under food restriction. *Animal Behaviour*, *75*, 235-243.

U.S. Fish and Wildlife Service. (2018). *2016 National Survey of Fishing, Hunting and Wildlife-Associated Recreation*. U.S. Fish & Wildlife Service.

Van Deelen, T. R., Hollis, K. M., Anchor, C., & Etter, D. R. (2000). Sex affects age determination and wear of molariform teeth in white-tailed deer. *The Journal of Wildlife Management*, *64*, 1076-1083.

Veiberg, V., Mysterud, A., Bjørkvoll, E., Langvatn, R., Loe, L. E., Irvine, R. J., . . . Stenseth, N. C. (2007). Evidence for a trade-off between early growth and tooth wear in Svalbard reindeer. *Journal of Animal Ecology*, *76*, 1139-1148.

Waller, D. M., & Alverson, W. S. (1997). The white-tailed deer: a keystone herbivore. *Wildlife Society Bulletin*, 217-226.

Warren, R., & Krysl, L. (1983). While-tailed deer food habits and nutritional status as affected by grazing and deer-harvest management Texas. *Rangeland Ecology & Management/Journal of Range Management Archives*, *36*, 104-109.

Watkins, B. E., Witham, J. H., Ullrey, D. E., Watkins, D. J., & Jones, J. M. (1991). Body composition and condition evaluation of white-tailed deer fawns. *The Journal of Wildlife Management*, 39-51.

Weckerly, F. (2010). Allometric scaling of rumen–reticulum capacity in white-tailed deer. *Journal of Zoology*, *280*, 41-48.

Weckerly, F., Bhaskar, G., Duarte, A., Luna, R. S., & Starns, H. D. (2018). Heavier rumen–reticulum organs in white-tailed deer (*Odocoileus virginianus*) is consistent with dietary bulk not quality. *Canadian Journal of Zoology*, *96*, 748-752.

Weckerly, F. W. (1989). Plasticity in length of hindgut segments of white-tailed deer (*Odocoileus virginianus*). *Canadian Journal of Zoology*, *67*, 189-193.

Weiner, J. (1973). Dressing percentage, gross body composition and caloric value of the roe-deer. *Acta theriologica*, *18*(11), 209-222.

Wolcott, D. M., Reitz, R. L., & Weckerly, F. W. (2015). Biological and environmental influences on parturition date and birth mass of a seasonal breeder. *PLoS ONE*, *10*, 1-17.

Woolf, A., & Harder, J. D. (1979). Population dynamics of a captive white-tailed deer herd with emphasis on reproduction and mortality. *Wildlife Monographs*, *67*, 3-53.

Yates, L. A., Richards, S. A., & Brook, B. W. (2021). Parsimonious model selection using information theory: a modified selection rule. *Ecology*, *102*(10), e03475.