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Body Weight Estimation from Different Morphometric Measurements in Anatolian Hares, *Lepus europaeus*

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Abstract.- In the present study, the simple regression analysis using the different morphometric measurements of hares was performed for the estimation of body weight of brown hares (*Lepus europaeus*) from Anatolia (juveniles versus adults). There was a strong linear relationship between body weight (BW) and ear length (EL) and condylobasal length (CBL) in juvenile Anatolian hares. On the other hand, there was a medium linear relationship between BW and tail length (TL) and CBL in adult Anatolian hares. The prediction models determined explained 94% and 41% of the variation in BW of juvenile and adult Anatolian hares, respectively. The BW showed the highest correlation coefficient value with the CBL ($r = 0.964$; $p < 0.01$) in the juvenile hares. Similarly, the BW showed the highest correlation coefficient value with the CBL ($r = 0.582$; $p < 0.01$) in the adult hares. Our study revealed that juvenile Anatolian hares presented a greater variability than did adults Anatolian hares with respect to all traits measured. The present study may help scientist to get more information about biologic aspect of mammal species such as Anatolian hare which is at low density in wildlife.

Key words: Anatolian hare, *Lepus europaeus*, body weight estimation, regression analysis, phenotypic correlation.

INTRODUCTION

Body weight is an essential component in studies of mammalian ecology, taxonomy, physiology and paleobiology (Talbot and McCulloch, 1965; Cattet *et al*., 1997; Damuth and MacFadden, 1990; Millien and Bovy, 2010; Dyck and Morin, 2011; Demirbaş *et al*., 2013). Unless direct weighing is practical (*e.g.* in many large-bodied animals or because of incomplete samples and remote localities), researchers attempt to use some body measurements to predict body weight of wild animals (Talbot and McCulloch, 1965; Donadio *et al*., 2005; Jansen and Jenks, 2011; Thiemann *et al*., 2011). Brown hare (*Lepus europaeus*) from Anatolia has an uninterrupted distribution in Anatolia; however, the number of them seems to have declined during the last few decades due most probably to habitat narrowing, pollution, disease and illegal hunting (Sert, 2006; Demirbaş, 2010). Furthermore, as Anatolian hares are still commonly being consumed as a food by local people and hunters, researchers can probably get some remaining body parts of hares not eaten (*e.g.,* head, hind food, tail, ear) or the parts can easily be reached to the researchers, and so these body parts may be used to predict body weight. Body weight estimation has already been practiced through various measurements (*e.g.* skeletal, dental or body measures) using simple or multiple regression analysis in many extinct and living mammalian species in wildlife (Fandos *et al*., 1989; Cattet and Obbard, 2005; Millspaugh and Brundige, 1996; Egi, 2001; Calzade *et al*., 2003; Bassano *et al*., 2003; Mendoza *et al*., 2006; Figueirido *et al*., 2011).

Donadio *et al*. (2005) generated a predictive model to predict body weight from hind foot length for exotic European hare, *Lepus europaeus* in the southern Neotropics. However, those populations were not native, since the hares were introduced in the area from Europe in the late 1800s as reported by Grigera and Rapoport (1983). McCulloch and Talbot (1965) stated that if there are not significant differences between populations of the same species, statistical relationships are valid for body weight estimation. Sert (2006) and Demirbaş *et al*. (2013) also recorded that far distances could cause

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significant differentiations in the morphometric characteristics within the same species of hares. Such situations might be expected to affect the accuracy of body weight prediction.

The hypotheses of this study were: (1) whether the regression models to predict body weight in Anatolian hares were reliable for both juveniles and adults; 2) to find out which body part measurement is having the highest correlation with the body weight in both juvenile and adult hares. These hypotheses were tested using body weights and morphometric measurements taken from 33 adult *L. europaeus* specimens and 13 juvenile *L. europaeus* specimens from central Anatolia.

MATERIALS AND METHODS

Study area and data collection

A total of 46 Anatolian hares (33 adults and 13 juveniles), which were hunted during autumn and winter hunts (October - December) of 2012 to 2013 in Kırıkkale province (N39º50'N, 33º31'E) from central Anatolia were examined for estimating their body weight. The body weights and morphometric measurements (total body length, tail length, hind foot length and ear length) from each sample were taken immediately after death. Also, condylobasal lengths were measured from the skulls cleaned in laboratory. The climate in the area is continental, with arid and hot summer, and cold and snowy winter. According to the climatic data obtained by Kırıkkale meteorological station during the years 1960 to 2012 in the area, the mean annual temperature was 12.5ºC and the precipitation was 373.5 mm; the coldest month was January, with average -3ºC and hottest month was July, with average 30.8ºC. The area covers an area of 4615 km^2 and has approximately 49.530 ha forest area, composed of a mixture of oak (*Quercus* sp.) and pine (*Pinus* sp.) forest. Remainder area consists of mainly farmland and open steppes (grass steppes and tragacanthic steppes). *Quercus* scrubs, Fabaceae, Asteraceae and Poaceae are the dominant vegetation types in the area (Dönmez, 2002; İnci *et al*., 2013). Red fox (*Vulpes vulpes*), badger (*Meles meles*), wolf (*Canis lupus*), wild boar (*Sus scrofa*), least weasel (*Mustela nivalis*), and beech marten (*Martes foina*) are the mammals which occur sympatrically with the hares.

The sampled hares were divided into 2 age groups (juvenile and adult) according to the "Stroh sign" which is located at the tip of the ulna bone (Stroh, 1931), the pronouncedness of sutures in the cranial bones (between the frontal and sagittal bones) and the morphological structure of processus supraorbitalis (Suchentrunk *et al*., 2000). Body measurements (mm), body weight (g), and condylobasal length (mm) of the specimens were taken, using a tape measure, a scale of 50 g of precision, and a dial caliper to an accuracy of 0.05 mm, respectively, according to Harrison and Bates (1991).

Abbreviations used for characteristics measured are as follows: BW, body weight; TL, tail length; HFL, hind foot length; EL, ear length; CBL, condylobasal length. Differences between age groups and sexual differences within the age groups in body weight and morphometric measurements were investigated using either the Mann-Whitney U test or the student t-test depending on the normality (Shapiro-Wilk) and variance homogeneity (Levene) test results. Measures of both sexes were combined in subsequent analysis since there was no statistically significant differences found between them. On the contrary, there were significant differences in all traits between age groups. Therefore, juvenile and adult samples were evaluated separately.

Data analysis

The TL, HFL, EL and CBL were used as independent, while the BW was considered as dependent variable for both juvenile and adult hares. Linear, quadratic and cubic effects of the independent variables were analyzed as follows;

$$Y = \beta_0 + \beta_1 X + \beta_2 X^2 + \beta_3 X^3 + e$$ (Neter *et al*., 1996).

Where Y= BW; β_0 = the intercept; X = independent variables such as TL, HFL, EL and CBL; β_1, β_2 and β_3= regression coefficients; and e = random error. In order to choose the best or the most suitable models among all assumed models, the *Cp* (Conceptual predictive) and the *AIC* (Akaike information criterion) were used as defined in Kaps and Lamberson (2004).

Phenotypic correlations among all measurements were calculated. Statistical analyses were done using the statistical package program SPSS v.15 (SPSS Inc., Chicago, IL) for the descriptive statistics and phenotypic correlations and the SAS v.8.2 (The SAS Institute Inc., Cary, NC) for the regression analysis.

RESULTS

Descriptive statistics for the body weight and morphometric measurements of Anatolian hares are presented in Table I. The BW was found to have the highest variations among the traits measured in both juvenile and adult hares. Also, juveniles showed a greater variability than adults with respect to all traits measured.

Table II shows the regression analysis results of hare BW on the TL, HFL, EL and CBL using single observations for both juvenile and adult

Table I.- Descriptive statistics for body weight (g) and morphometric measurements (mm) of Anatolian hares from Kırıkkale province (body weight (BW), tail length (TL), hind foot length (HFL), ear length (EL), condylobasal length (CBL), standard deviation (±SD), coefficient of variation (CV)).

Body trait	N	Range	Mean±SD	CV (%)
Juvenile				
BW	13	550-2600	1512±689.98	45.63
TL	13	55-85	73.33±11.75	16.02
HFL	13	97-130	116.93±12.19	10.42
EL	13	77-120	94.8±12.44	13.12
CBL	13	52-78.4	66.25±8.70	13.14
Adult				
BW	33	2300-4200	3292±471.51	14.32
TL	33	75-120	99.85±9.76	9.77
HFL	33	135-160	145.54±7.24	4.97
EL	33	95-120	110.05±6.13	5.57
CBL	33	80-91.7	85.60±3.02	3.53

Table II.- Regressions of the Anatolian hares' body weight on the morphometric measurements (tail length (TL), hind foot length (HFL), ear length (EL) and condylobasal length (CBL)) using single observations. Thereby, the coefficient of determination (R^2) gives the proportion of variations in Anatolian hare body weight explained by morphometric measurements.

Age group	Variable*	Intercept	Linear	Quadratic	Cubic	R^2
Juvenile	TL	-1946.45	46.73***			0.63
		14911	-450.86	3.56		0.76
		54593	-2163.85	27.86	-0.11	0.78
	HFL	-2846.25	37.04			0.42
		4747.42	-97.25	0.58		0.43
		317541	-8433.62	74.16	-0.21	0.51
	EL	-2437.72	41.83**			0.56
		-1385.97	19.65	0.11		0.57
		30147	-967.87	10.29	-0.03	0.58
	CBL	-3575.68***	76.41***			0.92
		-169.35	-29.48	0.80		0.93
		18009	-879.67	13.93	-0.06	0.93
Adult	TL	917.40	23.39**			0.25
		3649.82	-32.20	0.24		0.26
		-38138	1267.78	-13.06	0.04	0.29
	HFL	1407.97	12.76			0.03
		42809	-550.77	1.91		0.09
		-615091	12913	-89.76	0.20	0.12
	EL	1072.37	19.79			0.06
		-478.55	48.41	-0.13		0.06
		-233213	6525.95	-60.05	0.18	0.08
	CBL	-4820	94.73***			0.33
		-70735	1642.40	-9.07		0.37
		1382807	-49379	587.35	-2.32	0.40

*For abbreviations of variables, see Table I.
**$p < 0.01$, ***$p < 0.001$

hares. The R^2 values indicate that CBL (R^2 = 0.92 - 0.93) was associated highly with BW followed by TL (R^2 = 0.63 - 0.78), EL (R^2 = 0.56 - 0.58) and HFL (R^2 = 0.42 - 0.51) in the juvenile hares. Similar patterns were observed for the adult hares but R^2 values were quite low ranging from 0.03 to 0.40. The quadratic and cubic terms were not significant for all measurements in both juvenile and adult hares. The linear term was significant ($p < 0.01$) for all measurements except the HFL in the juvenile hares and for the TL and CBL in the adult hares.

Table III presents the results of 15 different models for predicting body weights of the juvenile and adult hares. The *Cp* value (3.62) determined the model including EL and CBL to be better than other models in juveniles while the *Cp* (2.63) for the model including TL and CBL was found to be better than other models in adults. Additionally, R^2 values (0.95) for models including HFL, EL, CBL and TL, HFL, EL, CBL of the juveniles were better compared to other models. Likewise, R^2 values (0.44, 0.45) for models including TL, HFL, CBL and TL, HFL, EL, CBL of the adults were better compared to other models including TL and CBL. The *AIC* values predicted a preference for the same models in juveniles and adults like the *Cp* values. The model including EL and CBL could explain body weight best in juveniles while the model including TL and CBL could explain body weight best in adults. As a result, the best models in juvenile and adult hares explained a different amount of variation shown in Table IV.

Phenotypic correlations between the BW, TL, HFL, EL and CBL were computed (Table V). In the juvenile hares, BW showed the highest correlation coefficient value with the CBL ($r = 0.964$; $p < 0.01$). In the adult hares, BW similarly showed the highest correlation coefficient value with the CBL (r = 0.582; $p < 0.01$).

Table III.- Conceptual predictive (*Cp*), coefficient of determination (R^2) and Akaike information criterion (*AIC*) of different models predicting body weights of the Anatolian hares.

Age group	Independent variable*	*Cp*	R2	AIC
Juvenile				
	EL CBL	3.62	0.94	136.91
	HFL EL CBL	4.15	0.95	136.96
	TL HFL EL CBL	5.00	0.95	137.21
	TL CBL	5.00	0.93	138.49
	CBL	5.04	0.92	138.53
	TL HFL CBL	5.48	0.94	138.73
	TL EL CBL	5.55	0.94	138.82
	HFL CBL	7.01	0.92	140.50
	TL EL	60.06	0.66	160.85
	TL HFL EL	60.11	0.67	162.47
	TL	63.41	0.63	159.85
	TL HFL	64.87	0.63	161.75
	EL	76.13	0.56	161.96
	HFL EL	76.31	0.57	163.67
	HFL	104.03	0.42	165.64
Adult				
	TL CBL	2.63	0.41	358.67
	TL HFL CBL	3.43	0.44	359.29
	HFL CBL	3.51	0.39	359.65
	CBL	4.04	0.33	360.29
	TL EL CBL	4.60	0.41	360.65
	TL HFL EL CBL	5.00	0.45	360.78
	HFL EL CBL	5.35	0.39	361.47
	EL CBL	5.90	0.34	362.15
	TL	7.93	0.25	363.94
	TL HFL	9.61	0.26	365.66
	TL EL	9.74	0.25	365.77
	TL HFL EL	11.55	0.26	367.60
	EL	16.46	0.06	370.67
	HFL	17.64	0.03	371.49
	HFL EL	17.96	0.07	372.31

*For abbreviations of variables, see Table I.

DISCUSSION

Body weight estimation has been practiced through various measurements (*e.g.* skeletal, dental or body measures) using simple or multiple regression analysis in many extinct and living mammalian species in wildlife (Fandos *et al*., 1989; Cattet and Obbard, 2005; Millspaugh and Brundige, 1996; Egi, 2001; Calzada *et al*., 2003; Bassano *et al*., 2003; Mendoza *et al*., 2006; Figueirido *et al*., 2011). Fandos *et al*. (1989) stated that the best predictors of body weight were horn length for male Spanish ibex (*Capra pyreninaica*), body length for female Spanish ibex, and chest girth for both sexes in the chamois (*Rupicapra rupicapra*) from Iberian peninsula. Jansen and Jenks (2011) identified a strong linear relationship between body weight and body length, head and chest circumferences in pumas (*Puma concolar*) from the Black Hills, USA.

Table IV.- The best models developed to predict body weight from predictor variables in juvenile and adult hares.

Age group	Model	*p* values			
		Intercept	β_1	β_2	R^2
Juvenile	$(BW_j) = - 3867.64 + 9.97 (EL) + 66.66 (CBL)$	< 0.001	0.1035	< 0.001	0.94
Adult	$(BW_a) = - 4364.48 + 14.19 (TL) + 72.72 (CBL)$	0.0435	0.0740	< 0.01	0.41

Table V.- Phenotypic correlation coefficients between the body weight (g) and morphometric measurements (mm) of Anatolian hares from Kırıkkale province (body weight (BW), tail length (TL), hind foot length (HFL), ear length (EL), condylobasal length (CBL)).

Age group	TL	HFL	EL	CBL
Juvenile				
BW	0.796**	0.654**	0.755**	0.964**
TL		0.856**	0.834**	0.757**
HFL			0.789**	0.670*
EL				0.683*
Adult				
BW	0.503**	0.200	0.257	0.582**
TL		0.236	0.391*	0.443*
HFL			0.404*	-0.061
EL				0.353

*$p < 0.05$, **$p < 0.01$

Their predictive equation accounted for 89% of the variation in body weight of pumas. Donadio *et al*. (2005) found a similarly good linear relationship between log-transformed weight and hind foot length from exotic lagomorphs in the southern Neotropics and their models explained 58.4% and 71.6% of the variation in body weight of hares (*Lepus europaeus*) and rabbits (*Oryctolagus cuniculus*), respectively. There was a strong linear relationship between body weight and ear length and condylobasal length in juvenile Anatolian hares in the present study. On the other hand, there was a medium linear relationship between body weight and tail length and condylobasal length in adult Anatolian hares. The linear models found in the present study explained 94% and 41% of the variation in body weight of juvenile Anatolian hares and adult Anatolian hares, respectively.

Demirbaş *et al*. (2013) suggested that the phenotypic and some morphometric variations among Anatolian hare populations were due to the polymorphism related to the local adaptations and high level of admixture of gene pools in Anatolia. Our study revealed that juvenile Anatolian hares showed a greater variability than did adult Anatolian hares with respect to all traits measured. Additionally, the body weight showed the highest correlation coefficient value with CBL in both juvenile and adult hares. On the other hand, Jansen and Jenks (2011) stated that chest circumference is an important measurement that helps explain body weight in pumas.

Such and similar studies may help scientist to get more information about biologic aspect of wild animals such as Anatolian hare which is at low density in wildlife. Despite shortcomings of the hare samples, an attempt was made to predict the body weight from morphometric measurements of the Anatolian hares. The predictive equation of body weight for juvenile hares found in the present study could be helpful for more reliable estimation, but the model found for adult hares could only be helpful for an approximate estimation of body weight with caution since R^2 values was at medium level. This low degrees of accuracy in estimations for adult Anatolian hares may result from not strong correlations between all traits measured.

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REFERENCES

BASSANO, B., BERGERO, D. AND PERACINO, A., 2003. Accuracy of body weight prediction in alpine ibex, *Capra ibex*, L., 1758, using morphometry. *J. Anim. Physiol. Anim. Nutr. (Berl).*, **87**: 79–85.

CALZADE, J., HAYDON, D.T. AND PALOMARES, F., 2003. Estimating the size of European rabbits consumed by predators: Relationship between body mass and tooth dimensions. *Acta Theriol*., **48**: 101–111.

CATTET, M.R.L., ATKINSON, S.N., POLISCHUK, S.C. AND RAMSAY, M.A., 1997. Predicting body mass in polar bears: is morphpmetry useful? *J. Wildl. Manage.*, **61**: 1083–1090.

CATTET, M.R.L. AND OBBARD, M.E., 2005. To weigh or not to weigh: conditions for the estimation of body mass by morphometry. *Ursus*, **16**: 102–107.

DAMUTH, J. AND MACFADDEN, B.J., 1990. Body size and its estimation. In: *Body size in mammalian paleobiology: Estimation and biological Implications* (eds. J. Damuth and B.J. MacFadden), Cambridge University Press, New Tork, USA, pp. 1–10.

DEMİRBAŞ, Y., 2010. *Türkiye Lepus Linnaeus, 1758 Cinsinin Taksonomik Durumu (Mammalia: Lagomorpha)*. Ph.D. thesis. University of Kırıkkale, Turkey

DEMİRBAŞ, Y., ALBAYRAK, İ. AND YILMAZ, A., 2013. Studies of ecomorphological variations of the European hare (*Lepus europaeus*) in Turkey. *Arch. Biol. Sci. Belgrade*, **65**: 559–566.

DONADIO, E., PAULI, J.N. AND BONINO, N., 2005. A method to estimate body mass and relative age of exotic lagomorphes in the southern Neotropics. *Acta. Theriol.*, **50**: 81–89.

DÖNMEZ, A.A., 2002. Flora of Karagüney Mountain (Kırıkkale). *Turk. J. Bot.*, **26**: 417–451.

DYCK, M.A. AND MORIN, P., 2011. *In vivo* digestibility trials of a captive polar bear (*Ursus maritimus*) feeding on harp seal (*Pagophilus groenlandicus*) and arctic charr (*Salvelinus alpinus*). *Pakistan J. Zool*., **43**: 759-767.

EGI, N., 2001. Body mass estimates in extinct mammals from limb bone dimensions: the case of North American hyaenodontids. *Palaeontology*, **44**: 497–528.

FANDOS, P., VIGAL, C.R. AND FERNANDEZ-LOPEZ, J.M., 1989. Weight estimation of Spanish ibex, *Capra pyrenaica*, and Chamois, *Rupicapra rupicapra* (Mammalia: Bovidae). *Z. Säugetierk.*, **54**: 239–242.

FIGUEIRIDO, B., PEREZ-CLAROS, J.A., HUN, R.M. AND PALMOVIST, P., 2011. Body mass estimation in amphicyonid carnivoran mammals: A multiple regression approach from the skull and skeleton. *Acta Palaeontol. Pol.*, **56**: 225–246.

GRIGERA, D.E. AND RAPOPORT, E.H., 1983. Status and distribution of the European hare in South America. *J. Mammal.*, **64**: 163–166.

HARRISON, D.L. AND BATES, P.J.J., 1991. *The Mamma1s of Arabia*. Harrison Zoological Museum Publication, UK.

İNCİ, S., ALBAYRAK, İ. AND WILSON, C.J., 2013. Bioecology of the wild boar (*Sus scrofa* Linnaeus 1758) in Kırıkkale province, Turkey. *Hacettepe J. biol. Chem.*, **41**: 143–150.

JANSEN, B.D. AND JENKS, J.A., 2011. Estimating body mass of pumas (*Puma concolor*). *Wildlife Res.*, **38**: 147–151.

KAPS, M. AND LAMBERSON, W.R., 2004. *Biostatistics for animal science*. CABI Publishing, Cambridge.

MCCULLOCH, J.S.G. AND TALBOT, L.M., 1965. Comparison of weight estimation methods for wild animals and domestic livestock. *J. appl. Ecol.*, **2**: 59–69.

MENDOZA, M., JANIS, C.M. AND PALMQVIST, P., 2006. Estimating the body mass of extinct ungulates: a study on the use of multiple regression. *J. Zool*., **270**: 90–101.

MILLEN, V. AND BOVY, H., 2010. When teeth and bones disagree: body mass estimation of a giant extinct rodent. *J. Mammal.*, **91**: 11–18.

MILLSPAUGH, J.J. AND BRUNDIGE, G.C., 1996. Estimating elk weight from chest girth. *Wildl. Soc. B.*, **24**: 58–61.

NETER, J., KUTNER, M.H., NACHTSHEIM, C.J. AND WASSERMAN, W., 1996. *Applied Linear Regression Models*. McGraw-Hill Higher Education, Irwin, Chicago.

SERT, H., 2006. *Akdeniz ve Güneydoğu Anadolu Bölgesi ile Orta, Avrupa, Ortadoğu ve Güney Afrika Yaban Tavşanı Populasyonlarında Ekomorfolojik ve Moleküler Varyasyonlar (Lagomorpha: Lepus)*. Ph.D. thesis. University of Akdeniz, Turkey.

STROH, G., 1931. Zwei sichere Altersmerkmale beim Hasen. *Berl. Tierarztl. Wschr.*, **12**: 180–181.

SUCHENTRUNK, F., ALKON, P.U., WILLING, R. AND YOM-TOV, Y., 2000. Epigenetic dental variability of Israeli hares (*Lepus* sp.): ecogenetic or phylogenetic causation?. *J. Zool. Lond.*, **252**: 503–515.

TALBOT, L.M. AND MCCULLUCH, J.S., 1965. Weight estimations for east African mammals from body measurements. *J. Wildl. Manage.*, **29**: 84–89.

THIEMANN, G.W., LUNN, N.J., RICHARDSON, E.S. AND ANDRIASHEK, D.S., 2011. Temporal change in the morphometry-body mass relationship of polar bears. *J. Wildl. Manage.*, **75**: 580-587.

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