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Morphological analysis of the aoudad: the introduced population is well adapted to the Mediterranean habitat

Morfološka analiza grivastog skakača: introducirana populacija je dobro prilagođena Mediteranskom staništu

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ABSTRACT

The aoudad is a bovid species native to North Africa and highly adaptable to different environments. Although some morphological data of aoudad has been published, the research mostly dealt with measurements taken from captive populations. Therefore, morphological data of free-ranging populations in their non-native habitat is largely unknown. The present study analysed the important morphometric parameters in a non- native Mediterranean population of aoudad. Body and horn measurements were taken on 30 free-range aoudads (20 M, 10 F) legally culled from 2014 to 2019. A descriptive analysis of the quantitative body and horn measurements was performed and an insight into population growth rates was provided. The Mediterranean population of aoudad showed higher mean values of investigated body and horn measurements and higher growth rates than in other research, ranging from *ca*. 2 – 10% for most of the measurements. The results suggest that the investigated population is well adapted to Mediterranean habitat which allowed aoudad to notably allocate energy to both body and horn development. This research is a contribution to knowledge about how specific habitat might shape aoudad population life-history traits.

Keywords: *Ammotragus lervia*, Barbary sheep, Dinaric mountains, morphometry, mountain ungulate

SAŽETAK

Grivasti skakač je autohtoni šupljorožac Sjeverne Afrike i iznimno prilagodljiv različitim staništima. Iako su morfološki podaci grivastog skakača objavljivani, istraživanja su se uglavnom oslanjala na mjere uzete iz populacija u zatočeništvu. Zbog toga, morfološki podaci slobodnih populacija grivastog skakača u stranim staništima su uvelike nepoznati. U ovom istraživanju analizirani su važni morfometrijski parametri alohtone Mediteranske populacije grivastog skakača. Prikupljene su mjere tijela i rogova 30 grivastih skakača (20 M, 10 Ž) legalno odstreljenih između 2014. i 2019. godine. Napravljena je deskriptivna analiza kvantitativnih mjera tijela i rogova i pružen osvrt na stopu rasta populacije. Mediteranska populacija grivastog skakača pokazala je više srednje vrijednosti istraživanih mjera tijela i rogova te snažniju stopu rasta za oko 2 – 10% nego što je prikazano u ostalim istraživanjima. Rezultati sugeriraju da je istraživana populacija dobro prilagođena Mediteranskom staništu koje je omogućilo značajno usmjerenje energije u tjelesni razvoj i razvoj rogova. Ovo istraživanje doprinosi znanju kako posebnosti staništa mogu oblikovati značajke životnog ciklusa populacija grivastog skakača.

Ključne riječi: *Ammotragus lervia*, Grivasti skakač, Dinaridi, morfometrija, planinski papkar

INTRODUCTION

Morphological measurements of animals have numerous applications in wildlife science (Anderson, 1982) and are in general used as indicators of growth rate (Waisbren, 1988). They can reveal the response of populations to the environmental conditions (so-called phenotypic flexibility) since local habitat conditions may affect the fitness and therefore, phenotypic expression through variation in habitat quality (Pulliam, 2000). The response to environmental variation may induce phenotypic adjustments in animals by regulating energy allocation to different traits (Naya et al., 2009, Mason et al., 2014). On the other hand, morphological measurements are recognized as very useful in wildlife/game management. They can determine trophy values (von Brandis and Brian, 2008) and provide information for practical management decisions regarding harvest quotas, age structure and population dynamics (e.g., bighorn sheep *Ovis canadensis*, Bonenfant et al., 2009).

Here, Mediterranean population of aoudad *Ammotragus lervia* was investigated, which has been illegally introduced to the southern Dinaric region of Croatia. Aoudad is a highly dimorphic caprid that originates from Northern Africa, in arid and semiarid areas, and it is considered highly adaptable to different environments (Cassinello, 1998).

Therefore, it has been introduced worldwide with several successful attempts in Europe (Mori et al., 2017). In addition, aoudad has been introduced to some countries as a breed of sheep for meat consumption, since it has high farming potential (Sharaby and Suleiman, 1988). Except in Croatia, aoudad populations are established in Spain and Italy (Cassinello, 1998). Until today, some morphological data has been published (Gray and Simpson, 1980, 1985; Rahmouni et al., 2019), but majority of studies to date have been performed on the individuals in captivity (e.g., Schilcher et al., 2013) or introduced populations to North America (e.g., Rodrıguez-Pinero and Rodrıguez-Luengo, 1992).

These researches mostly dealt with the feeding habits (e.g., Atti et al., 2002; Mimoun and Nouirqa, 2015) and invasiveness potentials of this species (e.g., Cassinello, 2018). Based on scarce available information, morphology data of free-ranging aoudad in their non-native habitat in Europe is largely unknown.

The present study aimed to analyse the important morphometric parameters in a non- native Mediterranean population of aoudad and provide an insight into the effect of habitat on morphological traits by comparing the results obtained with other morphology studies in different aoudad populations. It is apparent that when resource availability is limiting, animals will utilize their body reserves in an attempt to meet their requirements (Mason et al., 2014). Therefore, population biological response to Mediterranean habitat (e.g., limited resource availability, intense summer droughts, etc.) should be evident in both body size and horn measurements.

MATERIALS AND METHODS

Study area

This study was carried out in the southern Dinaric region, Mosor mountain (Lat 43°31'54.2573", Lon 16°38'29.1241") with the highest peak Veliki Kabal (1.339 m). Scrublands and woodlands of Sub-Mediterranean and Euro-Mediterranean vegetation dominate in the study area which is strongly influenced by the Mediterranean climate and prone to droughts (Seletković et al., 2011). During 2002 aoudad of unknown origin has been illegally released and the current population size is estimated at *ca.* 140 animals (Lazarus et al., 2019). Besides aoudad, few ungulate species coexist in the same habitat such as European mouflon (*Ovis aries musimon*) and wild boar (*Sus scrofa*), but in small numbers (Anonymous, 2016). Study area is also inhabited by grey wolves (*Canis lupus*), which regularly predate the aoudad (Gančević et al., 2016).

Data collection and analysis

Body measurements and horn growth data (Table 1) were recorded on 30 samples (20 for the males and 10 for the females) of aoudad legally culled from 2014 to 2019.

Table 1. Quantitative variables - body measurements, horn growth and body mass data

Measure	Abbreviation	Principal
Body length	LCP	The horizontal distance from the tip of the shoulder to the ischium
Withers height	HG	The size from the lower part of the front foot to the highest point of the shoulder on the withers
Chest circumference	TP	The circumference of the body behind the scapula in a vertical plane, perpendicular to the longitudinal axis of the body
Anterior cannon circumference	TCA	Anterior cannon circumference
Total horn length	THL	Length of the horn on its outer side, from its root to the tip
Horn base circumference	HBC	The circumference of the horn base
Total body mass	TM	Mass of the culled animals with viscera
Hog-dressed mass	HM	All viscera removed but with head, hide, and feet intact
Meat mass	MM	Mass of useable meat on the carcass
Dressing	DP	MM/TM in (%)

The body mass was determined with hanging type electromechanical scale (+/- 0.1 kg), while other body and horn parameters were measured by means of a flexible ruler (+/- 1 mm). All individuals at the time of the study were healthy. Age was determined by counting of horn annuli (Geist, 1966), while measurements were taken on the left horn (due to the absence of directional asymmetry in some ungulate species, see von Hardenberg et al., 2004). All measurements were taken by the same person, experienced wildlife officers using standard methodology (Merchant et al., 1982).

Following the prediction, a descriptive analysis of the quantitative body and horn measurements was performed. In this analysis mean, median, minimum, maximum and standard deviation values were estimated to summarise the measurements. The t-test for independent samples was used to compare body and horn measurement between males and females. The Pearson correlation coefficient was used to detect the linear correlation between measured variables, i.e. to describe the direction and strength of the relationship between age and several biologically meaningful variables (e.g., body mass, withers height, chest circumference, body length, horn measures). Males and females were analysed separately, based on the species expressed sexual dimorphism (Cassinello, 1998). All statistical analyses were performed in R 3.3.2 (R Core Team, 2016) in RStudio 1.1.423 (RStudio Team, 2016). Alpha level of P=0.05 was considered as statistically significant for all analyses.

RESULTS AND DISCUSSION

The representation of age categories in the sample was the same for males and females (mean age = 4.5 years), which allowed making the comparison between mean values of quantitative variables of both sexes. Males had significantly higher mean values of all quantitative variables (t- test $P<0.05$; Table 2), which is explained by the expressed sexual dimorphisms of this species (Cassinello, 1998).

As regards to the other research, the results obtained showed slightly higher mean values of *ca.* 2 – 10% of investigated quantitative variables (*cf.* Cassinello, 1997; Rahmouni et al., 2019). The findings reported here could indicate the importance of environmental factors on body and horn development. It is clear that body condition of ungulates, which is strongly correlated with horn/weapon size, is under the strong influence of environmental factors and related food availability (e.g., bighorn sheep, Festa-Bianchet et al., 2000; Alpine ibex *Capra ibex*, Büntgen et al., 2014).

Table 2. The results of descriptive analysis of the quantitative body and horn measurements (in cm) for males (m) and females (f)

Abbreviation	Mean		SD		Median		Min		Max	
	m	f	m	f	m	f	m	f	m	f
LCP	97	84.6	15.12	13.18	100	87	60	60	119	103
HG	94	80	16.01	10.11	98	82	57	57	120	91
TP	101	85.5	20.69	14.62	102	89	59	59	138	105
TCA	11	9.69	2.63	1.68	11	9.9	7	7	16.2	12
THL	60.77	41.88	11.12	11.5	62	29.3	38.5	26	78.1	60.5
HBC	27.87	19.44	5.08	3.64	26	18.5	20.6	14	38.9	25.5

*mean age = 4.5 years for both sexes

Therefore, high habitat suitability may have allowed aoudad to allocate energy to both body and horn development, although due to the small sample size and irrelevance of available data, it is hard to draw clear conclusions. Moreover, the density of other ungulate species and livestock is extremely low and there is no natural competition for resources between aoudad and other species on Mt. Mosor (M. Olujić, pers. comm.).

The dressing-out percentage was comparable and slightly higher (Table 3) than in other research, although this data comes from farmed aoudad (*cf.* Sharaby and Suleiman, 1988; Agnihotri and Vincentraju, 2001). It ranged from 43.48 to 72.06 kg for males (mean = 58.11) and from 47.06 to 63.16 kg for females (mean = 54), which represents another evidence of good body conditions of the aoudad population on Mt. Mosor.

In addition to the environmental covariates, several other factors may have affected the body and horn growth, such as anthropogenic pressure (Douhard et al., 2016), genetic basis (von Hardenberg et al., 2007) and physiological conditions (Toledano-Diaz et al., 2007). Unfortunately, such data for this study population are still lacking.

As expected, all quantitative variables were highly positively correlated with age ($r>0.8$), with different growth rates among males and females (see Table 4 for biologically meaningful variables).

Males showed higher acceleration growth in investigated variables than females, except in the THL variable (Figure 1). In wild sheep species, for example, ewes reach asymptotic mass faster than rams which occur after five years of age (e.g., mountain goat

Table 3. Descriptive data (in kg) of body mass: total mass (TM), hog-dressed mass (HM), meat mass (MM) and dressing-out percentage (DP) for males and females of free- ranging aoudad

Abbreviation	Mean		SD		Median		Min		Max	
	m	f	m	f	m	f	m	f	m	f
TM	90.56	61.4	31.99	20.38	89	60.0	23	20	142	90
HM	72.42	45.55	27.44	14.39	71	46.5	17	17.5	119	72
MM	53.56	33.2	21.51	11.09	56	33	10	10	98	48
DP (%)	58.11	54	7.04	4.34	58	53.82	43.48	47.06	72	63.16

*mean age = 4.5 years for both sexes

Table 4. Results of Person correlation coefficient among age and total mass (TM), withers height (HG), chest circumference (TP), body length (LCP), horn base circumference (HBC) and total horn length (THL) for males (m) and females (f)

Pearson's	Sex	TM	HG	TP	LCP	HBC	THL
r	m	0.882	0.857	0.815	0.843	0.777	0.862
	f	0.951	0.811	0.672	0.834	0.974	0.981

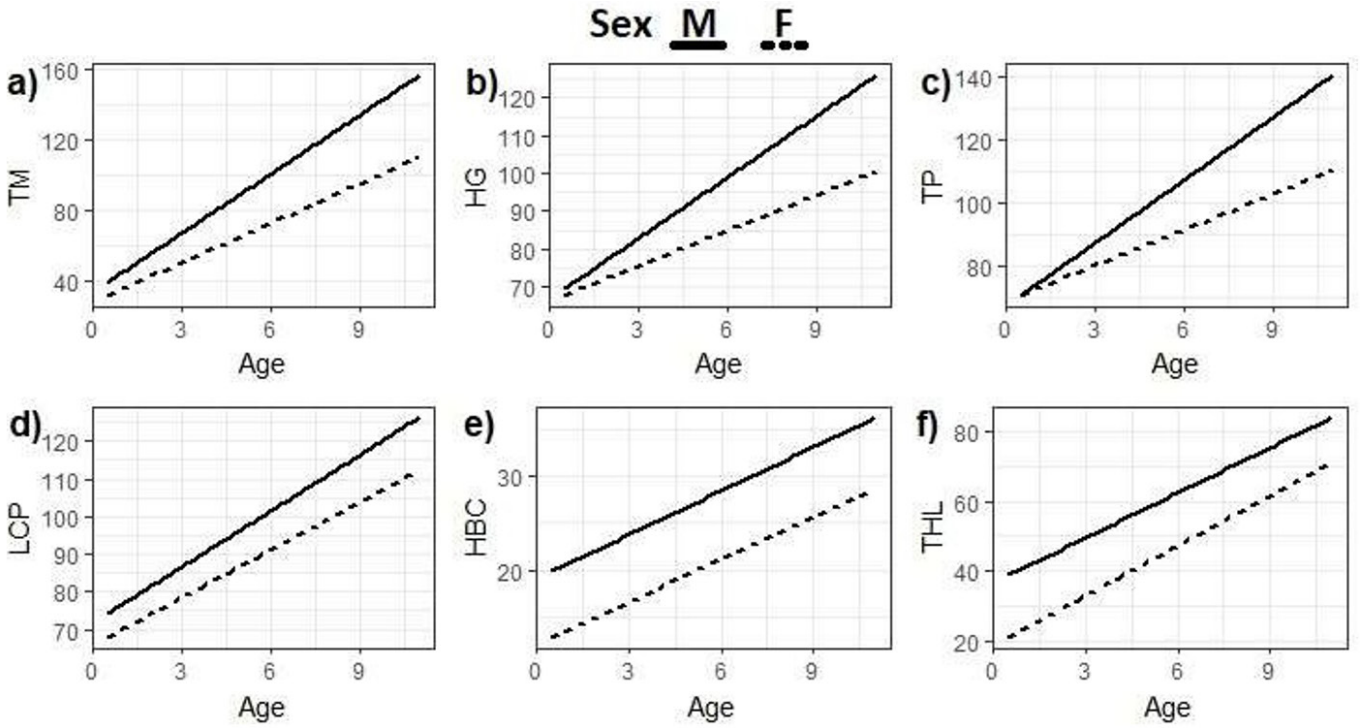

Figure 1. Relationship between a) total mass (TM), b) withers height (HG), c) chest circumference (TP), d) body length (LCP), e) horn base circumference (HBC), f) total horn length (THL) (in cm) and age for aoudad males and females hunted in the study area in Croatia from 2014 and 2019

Oreamnos americanus, Festa-Bianchet and Côté, 2008), which may explain higher acceleration growth found in females. Considering the mean age of the animals i.e. 4.5 years old, it is clear that majority of the individuals were harvested before reaching asymptotic values of the investigated variables, and therefore, showing a strong positive relationship with increasing age in both sexes.

CONCLUSION

Considering the scarce existing knowledge about the body and horn development of aoudad populations, this research might contribute to knowledge about how different habitats shape population development. Based on the quantitative morphological analysis, the results suggest that this population is well adapted to the Mediterranean habitat. To strengthen this conclusion, up-following research should be implemented to provide more relevant information about the effect of a wide set of environmental factors on morphological traits, closely related to the investigated population. Finally, it would be worth investigating the coherence of body mass and horn development to identify differences in compensatory growth rates and trade-offs in relation to environmental and genetic factors.

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