**Morphological differentiation amongst Zulu sheep populations in KwaZulu-Natal, South
Africa, as revealed by multivariate analysis**

Bafowethu S. Mavule^a, Francesca M. Sarti^b, Emiliano Lasagna^{b#}, Nokuthula. W. Kunene^a

^aDepartment of Agriculture, University of Zululand, P Bag X1001, KwaDlangezwa, 3886, South
Africa.

^bDipartimento di Scienze Agrarie, Alimentari e Ambientali, Borgo xx giugno, 74, 06121 Università
degli Studi di Perugia, Italy.

#Corresponding author: Dr. Emiliano Lasagna, Dipartimento di Scienze Agrarie, Alimentari e
Ambientali, Università degli Studi di Perugia, Borgo XX giugno, 74, 06121 Perugia (PG), Italy –
Tel. +39 075 5857102 – Fax: +39 075 5857122 – Email: emiliano.lasagna@unipg.it

17 **ABSTRACT**

18 Understanding morphological structure and variation of Zulu sheep is crucial for its identification
19 and preservation. We measured fourteen linear body measurements and scored 5 qualitative traits to
20 evaluate the morphological variation and relationships among eight Zulu sheep populations in
21 KwaZulu-Natal. Sheep were sampled from Empangeni, Escourt, Eshowe, Jozini, Msinga,
22 Mtubatuba, Nongoma, and Nquthu rural communities. Dark brown coat colour, either in solid form
23 or white patched, was most frequent amongst studied sheep. There were significant variations in
24 body measurements amongst sheep populations from different areas. Sheep from Nqutu measured
25 highest in most morphometric variables while sheep from Empangeni measured lowest.
26 Discriminant analysis identified rump-width, head-width, heart-girth, thorax-depth and tail-length
27 as the most distinguishing variables amongst sheep populations. Hierarchical cluster analysis
28 revealed two major groups, one formed by Empangeni, Mtubatuba and Nongoma, the other by
29 Jozini, Msinga and Eshowe populations. Estcourt and Nqutu distanced themselves from these
30 groups as individual entities. About 62% of individual sheep could be correctly identified with the
31 populations from which they were sampled. Nqutu had the highest percentage (88.9%) of correct
32 assignment whilst Mtubatuba had the lowest (46.7%). High assignment errors were ascribed to a
33 certain gene flow between sheep populations. The overall significant morphostructural variation
34 amongst Zulu sheep populations, infers considerable genetic variability within the breed and its
35 populations. Maintaining this genetic variation is very crucial for the continuity of the breed, as it
36 provides animals with options to respond to change in climate, disease or consumer preference.

37

38 **Keywords:** Body measurements, Genetic variability, Characterisation, Conservation.

39

40 **INTRODUCTION**

41 Sheep like all other livestock species are recognised as important components of livestock
42 biodiversity. In the rural communities of South Africa livestock production provides a livelihood for
43 the majority of the population. Indigenous livestock breeds form the backbone of livestock
44 production because of their ability to survive and produce under harsh environmental conditions
45 (Ramsay et al., 2000; Kunene and Fossey, 2006). Nevertheless these breeds have received little
46 attention from researchers and commercial farmers and are thus consequently depleting.

47 The Zulu sheep breed is a type of Nguni sheep predominantly found in the northern part of
48 KwaZulu-Natal (Kunene et al., 2009). According to Kruger (2001), the Nguni people upon
49 migrating down the east coast of Africa between 200 and 400 AD, brought with them sheep. These
50 sheep are generally referred to as Nguni sheep. The dispersal of settlers from this point on led to the
51 division of the flock into now known three groups; the Pedi sheep in Sekukunniland, the Swazi
52 sheep in Swaziland and the Zulu sheep in KwaZulu-Natal (Kunene et al., 2007). Further spread of
53 Zulu sheep into different locations of KwaZulu-Natal has fragmented the breed into isolated
54 subpopulations occupying different ecological, socio-cultural and management environments. It is
55 quite possible that these subpopulations may have developed into different “types” of Zulu sheep.
56 The extent to which these sheep populations vary genetically has not been documented. Such
57 information is essential for the development of appropriate breeding and conservation programme
58 of the breed (FAO, 2007). Moreover, information obtained from the characterisation process would
59 contribute significantly in defining the morphological standard of Zulu sheep from both variability
60 and the mean point of view.

61 Unfortunately official data on the census of the Zulu sheep are not available at the present time;
62 anyway in another survey (Mavule et al., 2013a) around four thousand heads were reported for the
63 same populations; with the highest number in the area of Msinga.

64 Apart from the preliminary studies conducted by Kunene et al. (2007) as well as Mavule et al.
65 (2013b), which investigated in part the morphological structure of Zulu sheep, there are no sources

66 of information differentiating amongst Zulu sheep populations. Kunene et al. (2007) used only three
67 flocks which were mainly obtained from research institutions, thus, inherent variation among and
68 within the existing communal sheep populations were not fully represented. A wide coverage of
69 geographic area would have given a better representation of the populations on ground. Moreover
70 few traits were used in differentiating the studied populations and thereby restricting the study to
71 the use of univariate analysis, whereas the current trend in livestock classification involves the use
72 of multivariate statistical tools (Yakubu et al., 2010).

73 Canonical discriminant analysis, a multivariate technique, assess morphological variation between
74 sheep populations; by identifying the most discriminating measurements and appropriately
75 discriminating different sheep types by simultaneous consideration of all measured variables
76 (Traoré et al., 2008b). Its use has been extensively applied in goats (Jordana et al., 1993; Herrera et
77 al., 1996; Capote et al., 1998; Zaitoun et al., 2005; Dossa et al., 2007; Traoré et al., 2008a), few
78 such studies exist in sheep (Riva et al., 2004; Carneiro et al., 2010; Legaz et al., 2011).

79 Morphological diversity is a good reflector of ecological selection regimes and history of a breed
80 (González et al., 2011). In addition, phenotypes are an expression of genetic characteristics,
81 modified by environmental conditions and variance in both genetics and environment may affect
82 phenotypic variance (Yakubu et al., 2010; Kunene et al., 2014). It is in the context of these
83 assertions that this study exclusively depended on morphometric measurements and geographic
84 locations to unravel the characteristic of genetic diversity amongst Zulu sheep populations, which is
85 most relevant for managing the present and future genetic diversity of the breed.

86 The objective of this study therefore, was to evaluate morphological variation amongst Zulu sheep
87 populations in different geographical locations of KwaZulu-Natal, exploring the possibility of
88 differentiating between these populations. Understanding these attributes is crucial in formulating
89 breeding and conservation schemes where sheep taken from different populations are involved. A

morphological standard of a “Zulu sheep breed” could also be set taking in to account the more frequent body features in the populations.

MATERIALS AND METHODS

Study Area

The study was carried out in eight areas of KwaZulu-Natal, South Africa, selected on the basis of inhabiting Zulu sheep. The areas are namely Empangeni, Eshowe, Jozini, Mtubatuba, Nongoma, Msinga, Nqutu and Estcourt (see Fig 1). They lie in the region between latitudes 27° 07' to 29° 00' S and longitudes 29° 52' to 32° 04' E with the altitude ranging from 90 to 1900 m above sea level, and annual rainfall ranging from 600 mm to over 1 400 mm.

Data collection

A total of 803 ewes, were sampled from the 8 studied areas of KwaZulu-Natal. The number of ewes sampled in each area were: 101 (Empangeni), 100 (Estcourt), 99 (Eshowe), 100 (Jozini), 100 (Msinga), 97 (Mtubatuba), 104 (Nongoma), and 102 (Nqutu).

Age of each animal was determined by the dentition method as well as making enquiries from the farmers. Only sheep with two pairs of incisors and above were considered in order to minimise age effects. A scale was used to determine body weight (BW) of each animal sampled. Sheep were weighed in the morning before feeding to minimise post-prandial gut variation. A textile measuring tape was used to obtain different body measurements from each sampled animal (with records taken to the nearest cm) after restraining and holding the animal in an unforced position. The body parts were measured as described by Taye et al. (2010) and Yakubu et al. (2010). Morphometric traits recorded were head length (HL), head width (HW), ear length (EL), heart girth (HG), body length (BL), wither height (WH), thorax depth (TD), rump height (RH), rump width (RW), rump length

114 (RL), shin circumference (ShC), tail length (TL) and tail circumference (TC) (Figure 2). Records
115 were also taken on qualitative traits such as: coat colour, face colour, presence or absence of horns,
116 shape of horns, and type of ears.

117

118 *Statistical Analysis*

119 The SPSS statistical package version 19 (SPSS, 2010) was used for all the data analysis. All the
120 variables included in the study were preliminarily analysed to observe their individual behaviour
121 (normality and homoscedasticity). Some outliers in the dataset, caused by errors in the
122 measurements and identified in box plots, were removed by deleting the individual data points.
123 Frequencies for each level of the qualitative traits were calculated using crosstabs of descriptive
124 statistics of SPSS. Means were computed for each variable per area. Mean comparison for each
125 biometric characteristic for different populations was done using univariate analysis of variance of
126 the General linear model, with area from which sheep were sampled included in the model as the
127 source of variation. The significance of the differences among the means was estimated using
128 Tukey's method at probability level of 5%.

129 Canonical discriminant analysis was performed to obtain canonical variables on thirteen out of
130 fourteen linear body measurements of Zulu sheep chosen by the represented variance. Canonical
131 coefficients and Mahalanobis distances between the populations were based on these selected traits.
132 The standardized discriminant function was used to screen for the most discriminating variables
133 between areas and for area identification. Wilks' lambda was used to test the significance of the
134 discriminant function while the Bartlett's V transformation of lambda (chi-square statistic) was later
135 used to compute the significance of lambda. The ability of this function to identify group
136 membership is indicated as the percentage of individuals correctly classified from the sample that
137 generated the function. The robustness of the function was validated using split-sample validation

138 of the SPSS package (SPSS, 2010). The means obtained were then used to group Zulu sheep in
139 clusters, using SPSS hierarchical cluster analysis.

140

141 **RESULTS**

142 Table 1 shows frequencies of each level of the qualitative traits recorded in each of the areas
143 studied. Pooled percentages for each studied variable are also given. Dark-brown colour was the
144 most predominant colour in Zulu sheep, occurring in either solid or mixed form. Solid dark brown
145 (26.6%) was overall the most common, followed by dark-brown patched with white (23.9%) and
146 brown patched with white (17.5%). Other colours found, in descending order of occurrence were
147 solid brown (6.9%), fawn (6.8%), black and white (5.6%), fawn and white (5.1%), white (3.4%) and
148 black (1.5%). Sheep from Eshowe were the only population that was predominantly fawn coloured.
149 Seventy three per cent of animals studied in all sheep populations were polled and 26.9% were
150 horned. Of the horned sheep, those with bud horns dominated in all areas studied, except for Nqutu
151 area where curved horns dominated (66.1%). In total, spiral shaped horns (14.5%) occurred least
152 compared to buds (49.7%) and curved horns (35.8%). However Sheep with spiral shaped horns
153 were proportionately higher in Jozini (33.3%), Msinga (31.1%) and Empangeni (33.3%) than sheep
154 with curved horns. Very little incidences of sheep with gopher ears (2.0%) were identified. The
155 greatest proportion of sheep studied had natural ears (78.2%) while 19.70% of sheep had elf ears
156 (Figure 3). Ear orientation was found to be either horizontal (70.3%) or dropping (28.9%). Greater
157 percentages of sheep with dropping ears were found in Eshowe (100%) and Empangeni (90.5%)
158 whilst sheep with horizontal ears dominated in Jozini (55.3%), Msinga (85.7%), Estcourt (77.2%),
159 Nongoma (60.8%), Nqutu (87.6%), and Mtubatuba (56.1%).

160 The tail type was overall long fat (39.5%) and long thin (33.7%) across all populations studied.
161 Empangeni however had a relatively high proportion of short fat tails (33.3%) and all other tail

162 types were fairly represented. Estcourt sheep tail types were all long thin except for 2% which had
163 docked tails.

164

165 **Table 1** Percentages of class levels of qualitative traits scored in Zulu sheep per area studied in
166 KwaZulu-Natal.

Traits	Empangeni	Estcourt	Eshowe	Jozini	Msinga	Mtubatuba	Nongoma	Nqutu	Overall
<u>Coat colours</u>									
Dark-brown	27.3	26.7	22.7	37.9	25.7	9.0	14.6	28.1	26.6
Brown	2.3	7.9	9.1	12.1	6.4	5.1	7.3	1.1	6.9
Fawn	6.8	4.0	68.2	3.7	6.9	6.4	11.4	2.2	6.8
White	0.0	4.0	0.0	3.7	5.5	1.3	3.3	0.0	3.4
Dark-brown and white	40.9	27.7	0.0	17.3	26.6	24.4	19.5	27.0	23.9
Brown and white	4.5	16.8	0.0	17.3	17.3	29.5	28.5	11.2	17.5
Fawn and white	0.0	7.9	0.0	2.9	5.0	19.2	7.3	1.1	5.1
Black	2.3	2.0	0.0	1.5	1.4	1.3	0.0	2.2	1.5
Black and white	11.4	3.0	0.0	3.7	4.5	2.6	7.3	12.4	5.6
Other	4.5	0.0	0.0	0.0	0.7	1.3	0.8	14.6	2.7
<u>Horn presence</u>									
Absent	71.4	0.0	83.3	85.4	69.4	80.5	74.2	68.4	73.1
Present	28.6	100.0	16.7	14.6	30.6	19.5	25.8	31.6	26.9
<u>Horn shapes</u>									
Curved	16.7	0.0	100.0	19.0	22.2	25.0	26.1	66.1	35.8
Spiral	33.3	0.0	0.0	33.3	31.1	0.0	4.3	1.8	14.5
Buds	50.0	100.0	0.0	47.6	46.7	75.0	69.6	32.1	49.7
<u>Ear types</u>									
Gopher	0.0	0.0	0.0	4.6	0.6	0.0	7.3	0.0	2.0
Natural	66.7	94.1	100.0	59.6	70.3	78.0	65.0	96.6	78.2
Elf	33.3	5.9	0.0	35.8	29.0	22.0	27.6	3.4	19.7
<u>Ear Orientations</u>									
Horizontal	9.5	77.2	0.0	55.3	85.7	56.1	60.8	87.6	70.3
Dropping	90.5	22.8	100.0	44.7	14.3	43.9	39.1	12.4	28.9
<u>Tail types</u>									
Long Fat	33.3	0.0	91.7	50.0	34.8	32.5	46.3	51.1	39.5
Long Thin	19.0	98.0	8.3	24.7	31.6	30.0	42.3	5.1	33.7
Short Fat	33.3	0.0	0.0	22.6	16.8	20.0	2.4	2.8	10.6
Short Thin	14.3	0.0	0.0	2.7	1.3	2.5	8.9	1.1	3.0
Docked	0.0	2.0	0.0	0.0	15.5	15.0	0.0	39.9	13.3

167

168

169 Table S1 shows marginal means for each of the body measurements of Zulu sheep in studied areas.
170 Univariate analysis revealed significant differences in morphometric measurements between sheep
171 populations. Sheep from Nqutu and Estcourt generally had higher body measurements whilst sheep
172 from Empangeni measured lowest. A general consideration of qualitative traits and body
173 measurements shows the Estcourt and Nqutu populations fairly morphologically separated from
174 the others. The rest of the populations fell within the intermediate range. The data matrix was then
175 subjected to canonical discriminant analysis for *post hoc* analysis. Out of 14 variables subjected to
176 the analysis, 10 were selected by stepwise discriminant procedure (Table 2). All the selected
177 variables were significant in discriminating between Zulu sheep populations. However, RW
178 followed by HW, HG, TD and TL had more discriminant power as shown by their Wilks' Lambda
179 and F to remove values.
180 Moreover the discriminant analysis obtained tolerance values greater than 0.5, an indication that
181 there was no collinearity problem among the 10 most discriminating morphological variables.
182

183 **Table 2** Morphological traits selected by stepwise discriminant analysis to best differentiate
 184 between Zulu sheep populations.

Variable	Wilks' Lambda	F to Remove	P-Level	Tolerance
RW	0.180	16.186	0.001	0.583
HW	0.166	12.04	0.001	0.678
HG	0.155	9.954	0.001	0.621
TD	0.156	9.206	0.001	0.73
TL	0.153	8.347	0.001	0.853
HL	0.147	6.536	0.001	0.625
BL	0.147	6.476	0.001	0.686
TC	0.141	4.676	0.001	0.697
RL	0.140	4.382	0.001	0.617
EL	0.138	3.897	0.001	0.955

185 RW, rump width; HW, head width; HG, heart girth; TD, thorax depth; TL, tail length; HL, head
 186 length; BL, body length; TC, tail circumference; RL, rump length; EL, ear length.

187

188 Table S2 shows the highest possible correlation between morphological variables and canonical
 189 functions extracted by discriminant analysis. Respective eigenvalues and percentage contribution of
 190 each canonical function towards total morphometric variance are also shown in the same table. A
 191 total of seven canonical functions (CAN1 to CAN7) were extracted from 13 morphological traits;
 192 RH was not included in the analysis because determined a very low variability. CAN1, CAN2,
 193 CAN3, CAN4, CAN5, CAN6, and CAN7 accounted for 43.8, 23.7, 12.1, 11.0, 5.1, 2.4, and 1.8% of
 194 the total variation, respectively. The first four canonical variates (CAN1 to CAN4) represented a
 195 total of 90.6% of the total variation. CAN1 had highest positive correlations with RW. CAN2 had
 196 high absolute correlations with TL, HG and TC. CAN3 had high positive correlations with TD and

197 HL. CAN4 had high absolute correlations with variables; BL, HW, EL, BW and WH. CAN5 and
198 CAN6 were dominated by large loadings from ShC and RL, respectively. The eigenvalues obtained
199 for corresponding canonical functions describe how much discriminating ability a function
200 possesses.

201 Mahalanobis distance values between the eight sheep populations are shown in Table 3 and
202 depicted in the dendrogram as shown in Figure 4. All pairwise distances were significant. Nqutu and
203 Empangeni (20.37) had the largest distance between each other while Empangeni and Nongoma
204 populations (3.16) had the smallest distance. Nqutu sheep population generally was furthest from all
205 other sheep populations, but nearer to Estcourt. Two major clusters exist, one formed by
206 Empangeni, Mtubatuba and Nongoma and the other by Jozini, Msinga and Eshowe. Estcourt and
207 Nqutu joined these major clusters as individual entities at distant, with the latter being furthest
208 (Figure 4). Must be pointed out that the difference between Estcourt and Nqutu *versus* the others
209 subpopulations was observed both in the qualitative scored traits (Table 1) and in the morphological
210 measures (Table S1) already discussed.

211

212

213 **Table 3** Mahalanobis distance between Zulu sheep populations of KwaZulu-Natal based on
 214 morphometric measurements.

215

	Empangeni	Mtubatuba	Nongoma	Jozini	Msinga	Eshowe	Estcourt	Nqutu
Empangeni								
Mtubatuba	4.54							
Nongoma	3.16	4.71						
Jozini	9.22	7.50	8.84					
Msinga	9.65	6.53	6.43	5.59				
Eshowe	9.53	5.15	7.48	6.33	11.77			
Estcourt	13.00	8.82	8.92	6.94	10.79	4.96		
Nqutu	20.37	16.91	18.73	15.99	16.35	13.01	10.87	

216

217 Discriminant function analysis was able to correctly classify 62.2% of individual sheep into their
 218 original populations (Table 4). Nqutu had the highest (88.9%) correct assignment while Mtubatuba
 219 had the lowest (46.7%). About the worst misclassification, approximately 27% of sheep from
 220 Mtubatuba were classified as Nongoma, 21.4% of Estcourt sheep as Jozini and 18.2% of
 221 Empangeni and Nqutu sheep respectively as Nongoma and Eshowe.

222

223 **Table 4** Predicted group membership percentages of Zulu sheep populations in selected areas of KwaZulu-Natal by discriminant analysis.
 224

Municipality	Empangeni	Estcourt	Eshowe	Jozini	Msinga	Mtubatuba	Nongoma	Nqutu	Total
Empangeni	75.80	0.00	0.00	0.00	0.00	6.10	3.60	0.00	100.00
Estcourt	0.00	76.20	13.60	11.10	6.10	0.00	0.00	0.00	100.00
Eshowe	0.00	0.00	59.10	9.70	0.00	0.00	0.00	18.20	100.00
Jozini	0.00	21.40	4.50	63.90	5.60	1.40	4.20	4.20	100.00
Msinga	0.00	2.40	4.50	6.10	75.50	2.00	4.10	6.10	100.00
Mtubatuba	13.30	0.00	0.00	13.30	0.00	46.70	10.70	0.00	100.00
Nongoma	18.20	3.60	3.60	5.40	5.40	26.70	67.90	0.00	100.00
Nqutu	0.00	0.00	0.00	0.00	0.00	0.00	11.10	88.90	100.00

225 **DISCUSSION**

226 The description of the Zulu sheep given in the present study show that the breed is small bodied
227 compared to other breeds described elsewhere (Dossa et al., 2007; Traoré et al., 2008b). For
228 instance, mature Doper sheep described by Fourie et al. (2002) had an average height at withers of
229 63.7 and 62.9 cm, heart girth of 92.8 and 88.3 cm and live weight of 57.5 and 50.8 kg, respectively.
230 Overall, the Dorper described was bigger than the Zulu sheep described by Kunene et al. (2007) in
231 KwaZulu-Natal with WH of 64 cm, HG of 80 cm and LWs of 38 kg, whose finding the present
232 study confirmed. This study also confirms the results of Kunene et al. (2007) that gopher ears were
233 less frequent in Zulu sheep. Coat colour occurrences in Kunene et al. (2007) study also confirmed
234 the findings of the current work. However, there were differences in the naming of brown colours
235 because the authors used a few populations, thus the distinction of these was less pronounced. What
236 was identified as brown in the work of Kunene et al. (2007) could be what was termed dark brown
237 in the current study. Brown followed by brown and white was the most dominant colour in their
238 study which is dark brown and dark brown and white in the current work. The authors also reported
239 tan colour as one of the colours found in Zulu sheep, which was not used in the current study. This
240 study concurred with Kunene et al., (2007) in the high occurrence of polled sheep against the
241 horned. Other qualitative traits presented in Table 1 were not studied by Kunene et al. (2007), but
242 have been used extensively elsewhere in characterising small ruminants (Herrera et al. 1996; Traoré
243 et al., 2008a; Traoré et al., 2008b).

244 The smaller size observed in Empangeni sheep could be attributed to a probable inbreeding
245 depression even if that was not highlighted in a previous molecular study carried out on the same
246 population (Kunene et al., 2014); flocks in this area are in fact reported to have been founded upon
247 small initial stock; which has resulted in mating of closely related animals exacerbated by prevalent
248 uncontrolled mating system in these areas (Mavule, 2012). Kunene et al. (2007) presented similar
249 findings that sheep at the University of Zululand and KwaMthethwa (areas in Empangeni) were

250 smaller sized compared to sheep at Makhathini Research Station. About Nqutu and Estcourt larger
251 size, a crossbreeding with exotic germplasm for the former and an improved management practices
252 for the second one can be supposed. Though not presented in the present study, the farmers at
253 Nqutu reported to have crossbred their sheep with Merino and Dorper breeds whereas sheep in
254 Estcourt are kept under semi intensive management practices. Because of that reasons these two
255 populations are quite bigger than the others. This confirmed assertions by Kosgey et al. (2008) who
256 indicates that good management practices can bring about a remarkable improvement in
257 productivity of the presumed less productive indigenous genetic resources. Similarly, Dossa et al.
258 (2007) also hypothesise that much of the morphological variation is under genetic control and can
259 respond to improved management practices. Kosgey et al. (2008) in Kenya highlights that by simple
260 improvements in housing, feeding and basic prophylaxis and breeding practices the productivity of
261 sheep under similar conditions increases significantly.

262 Only five basic measurements (RW, HW, HG, TD and TL) consistently could be important in
263 differentiating among Zulu sheep populations, than acquiring a substantial number of
264 measurements. Some of the measurements selected in the present study are similar to those obtained
265 by earlier researchers (Sarti et. al, 2001; Riva et al., 2004; Carneiro et al., 2010; Legaz et al., 2011;
266 Pieramati et al., 2011) in morphological differentiation of sheep breeds.

267 The first two canonical variables explained 67.5% of the total variation, a figure lower than that
268 obtained by Traoré et al. (2008b) of 100% in Burkina Faso sheep and that obtained by Zaitoun et al.
269 (2005) of 93.1% in native goat breeds in Jordan. Such a low percentage implies that morphometric
270 differences among populations in this study were not high enough to differentiate sub-populations
271 into distinct breeds. Whereas in both afore-mentioned cases, the researchers were able to clearly
272 differentiate breeds or sub breeds by the canonical variates obtained. The low differentiation
273 assessed among Empangeni, Nongoma and Mtubatuba sheep and Jozini, Msinga and Eshowe sheep
274 using the Mahalanobis distance and the large classification errors obtained using discriminant

analysis did not give enough statistical support to separate these sheep populations into different breeds. Implying that, though the breed manifested great morphometric variation across populations, individual populations could not be singled out as separate types. Low differentiation among populations by Mahalanobis distances (62.2%) could be ascribed to high gene flow between sheep populations (Jimcy et al., 2011). Large distances among Zulu sheep populations in general and among populations of Empangeni, Mtubatuba, and Nongoma and populations of Nqutu and Estcourt in particular show noticeable morphological diversities. Nevertheless, relatively shorter distances among Empangeni Mtubatuba and Nongoma and Jozini, Msinga and Eshowe appear to substantiate the assertion that morphological character systems are to some extent determined by similarities in ecological, geographical and historical variables. Due to spatial proximity to each other, sheep populations of Mtubatuba, Empangeni and Nongoma share some morphostructural similarity.

CONCLUSION

The original target of the study is to define a breed standard for Zulu sheep. The present research identified a morphological significant variation amongst Zulu sheep populations, inferring considerable genetic variability. Maintaining this genetic variability is very important for the continuity of the breed, as it provides animals with numerous options to respond to changing climate, disease challenges or consumer preference. In the hypothesis of the foundation of a new Zulu sheep breed, Nqutu and Estcourt sheep populations were found outstanding from the other Zulu sheep populations and so less suitable to this process. The present morphometric information could be used as the basis for further characterisation and could also aid future decisions on the conservation and improvement of the Zulu sheep. The reversal for these populations to pure Zulu sheep could be investigated by molecular genetics. Also molecular genetic

299 characterisation, which is currently underway, will hopefully help clarify the existing diversities
300 amongst some of the populations and evolutionary history of the breed.

301

302 **ACKNOWLEDGEMENTS**

303 The field research was fully financed by the South African Department of Agriculture, Forestry and
304 Fisheries (DAFF, Special mention of Tlou Chokwe and George Shole) and the University of
305 Zululand (project number: 5509/04). The National Research Foundation (NRF, GUN number:
306 76352) also provided financial assistance to the first author while undertaking his MSc study.

307 This research was also supported by NRF/MAE - “Executive programme of scientific and
308 technological co-operation between the Italian republic and the republic of South Africa for the
309 years 2014-2016 - Projects for the exchange of researchers”.

310 Data used in this paper are a part of Bafowethu Sibanda Mavule’s Master of Agriculture (Animal
311 Science) in the University of Zululand, South Africa.

312 The authors want to thank the two anonymous referees for their valuable comments and
313 constructive suggestions.

314

315 **REFERENCES**

316 Capote, J., Delgado, J.V., Fresno, M., Camacho, M.E., Molina, A., 1998. Morphological variability
317 in the Canary goat population. *Small Rum. Res.* 27, 167-172.

318

319 Carneiro, H., Louvandini, H., Paiva, S.R., Macedo, F., Mernies, B., McManus, C., 2010.
320 Morphological characterization of sheep breeds in Brazil, Uruguay and Colombia. *Small Rum. Res.*
321 94, 58-65.

322

323 Dossa, L.H., Wollny, C., Gauly, M., 2007. Spatial variation in goat populations from Benin as
 324 revealed by multivariate analysis of morphological traits. *Small Rum. Res.* 73, 150-159.
 325

326 FAO, 2007. The state of the world's animal genetic resources for food agriculture, Commission on
 327 Genetic Resources for Food and Agriculture, Food and Agriculture Organization of the United
 328 Nations, Rome, Italy.
 329

330 Fourie, P.J., Naser, F.W.C., Olivier, J.J., Van der Westhuizen, C., 2002. Relationship between
 331 production performance, visual appraisal and body measurements of young Dorper rams. *S Afr J*
 332 *Anim. Sci.* 32, 256-262.
 333

334 González, A., Luque, M., Rodero, E., González, C., Aguilera, R., Jiménez, J., Sepúlveda, N., Bravo,
 335 S., 2011. Use of Morphometric Variables for Differentiating Spanish Hound Breeds. *Int. J.*
 336 *Morphol.* 29, 1248-1255.
 337

338 Herrera, M., Rodero, E., Gutierrez, M.J., Pena, F., Rodero, J.M., 1996. Application of multifactorial
 339 discriminant analysis in the morphostructural differentiation of Andalusian caprine breeds. *Small*
 340 *Rum. Res.* 22, 39-47.
 341

342 Jimcy, J., Raghavan, K.C., Sujatha, K.S., 2011. Diversity of local goats in Kerala, India, based on
 343 morpho-biometric traits. *Livestock Research for Rural Development*, 23.
 344

345 Jordana, J., Ribo, O., Pelegrin, M., 1993. Analysis of genetic relationships from morphological
 346 characters in Spanish goat breeds. *Small Rum. Res.* 12, 301-314.
 347

348 Kosgey, I.S., Rowlands, G.J., Van Arendonk, J.A.M., Baker, R.L., 2008. Small ruminant
 349 production in smallholder and pastoral/extensive farming systems in Kenya. *Small Rum. Res.* 77,
 350 11-24.

351

352 Kruger, I., 2001. The indigenous sheep breeds of South Africa, Genetic resource department, ARC-
 353 Animal improvement institute (ARC-AII).

354

355 Kunene, N.W., Fossey, A., 2006. A survey on livestock production in some traditional areas of
 356 Northern Kwazulu Natal in South Africa. *Livestock Research for Rural Development*, 18.

357

358 Kunene, N.W., Nesamvuni, E.A., Fossey, A., 2007. Characterization of Zulu (Nguni) sheep using
 359 linear body measurements and some environmental factors affecting these measurements. *S. Afr. J.*
 360 *Anim. Sci.* 37, 11-20.

361

362 Kunene, N., Bezuidenhout, C., Nsahlai, I., 2009. Genetic and phenotypic diversity in Zulu sheep
 363 populations: Implications for exploitation and conservation. *Small Rum. Res.* 84, 100-107.

364

365 Kunene, N.W., Ceccobelli, S., Di Lorenzo, P., Hlophe, S.R., Bezuidenhout, C.C., Lasagna, E.,
 366 2014. Genetic diversity in four populations of Nguni (Zulu) sheep assessed by microsatellite
 367 analysis. *Ital. J. Anim. Sci.* 13, 76-82.

368

369 Legaz, E., Cervantes, I., Pérez-Cabal, M., De La Fuente, L., Martínez, R., Goyache, F., Gutiérrez,
 370 J., 2011. Multivariate characterisation of morphological traits in Assaf (Assaf. E) sheep. *Small*
 371 *Rum. Res.* 100, 122-130.

372

373 Mavule, B.S., 2012. Phenotypic characterization of Zulu sheep: Implications for conservation and
 374 improvement, Department of Agriculture, University of Zululand, South Africa.
 375

376 Mavule, B.S., Muchenje, V., Kunene, N., 2013a. Characterization of Zulu sheep production system:
 377 Implications for conservation and improvement. *Scientific research and essays*. 8, 1226-1238.
 378

379 Mavule, B.S., Muchenje, V., Bezuidenhout, C.C., Kunene, N.W., 2013b. Morphological structure
 380 of Zulu sheep based on principal component analysis of body measurements. *Small Rum. Res.* 111,
 381 23-30.
 382

383 Pieramati, C., Lasagna, E., Panella, F., Piro, F., Giontella, A., Sarti, F.M., 2011. Suitability of linear
 384 scoring in meat sheep: The practical case of Merinizzata Italiana breed. *Ital. J. Anim. Sci.* 10, 51-53.
 385

386 Ramsay, K., Harris, L., Kotze, A., 2000. Landrace Breeds: South Africa's Indigenous and Locally
 387 Developed Farm Animals. Pretoria, South Africa.
 388

389 Riva, J., Rizzi, R., Marelli, S., Cavalchini, L.G., 2004. Body measurements in Bergamasca sheep.
 390 *Small Rum. Res.* 55, 221-227.
 391

392 Sarti, F.M., Panella, F., Bogani, D. 2001. The most suitable traits in the Appenninica sheep for meat
 393 selection. *Zootecnia e nutrizione animale* 27, 65-74.
 394

395 SPSS, 2010. Statistical Package for the Social Sciences, SPSS Inc., Chicago, USA.
 396

397 Taye, M., Girma, A., Solomon, G., Sisay, L., Abebe, M., Markos, T., 2010. Traditional
398 management systems and linear body measurements of Washera sheep in the western highlands of
399 the Amhara National Regional State, Ethiopia Livestock Research for Rural Development, 22.

400

401 Traoré, A., Tamboura, H.H., Kabore, A., Royo, L.J., Fernandez, I., Alvarez, I., Sangare, M.,
402 Bouchel, D., Poivey, J.P., Francois, D., 2008a. Multivariate analyses on morphological traits of
403 goats in Burkina Faso. *Archiv. Tierzucht.* 51, 588-600.

404

405 Traoré, A., Tamboura, H.H., Kaboré, A., Royo, L.J., Fernández, I., Álvarez, I., Sangaré, M.,
406 Bouchel, D., Poivey, J.P., Francois, D., Toguyeni, A., Sawadogo, L., Goyache, F., 2008b.
407 Multivariate characterization of morphological traits in Burkina Faso sheep. *Small Rum. Res.* 80,
408 62-67.

409

410 Yakubu, A., Salako, A.E., Imumorin, I.G., Ige, A.O., Akinyemi, M.O., 2010. Discriminant analysis
411 of morphometric differentiation in the West African Dwarf and Red Sokoto goats. *S. Afr. J. Anim.*
412 *Sci.* 40, 381-387.

413

414 Zaitoun, I.S., Tabbaa, M.J., Bdour, S., 2005. Differentiation of native goat breeds of Jordan on the
415 basis of morphostructural characteristics. *Small Rum. Res.* 56, 173-182.

416

417

418

419 **FIGURE CAPTIONS**

420

421 **Figure 1.** Map illustrating municipal boundaries and rural areas from which sheep were sampled.

422

423 **Figure 2.** Morphometric variables studied and their reference points.

424

425 **Figure 3.** Different types of ears found in Zulu sheep: a) natural ears, b) gopher ears and c) elf ears.

426

427 **Figure 4.** Dendrogram showing morphological relationship between Zulu sheep.

428

429

Figure 1

Figure 2

Figure 3

Figure 4