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BIOMETRIC CHARACTERISATION AND TAXONOMIC CONSIDERATIONS OF EUROPEAN RABBIT *ORYCTOLAGUS CUNICULUS* (LINNAEUS 1758) IN SICILY (ITALY)

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Abstract: In Sicilian Mediterranean ecosystems the European rabbit *Oryctolagus cuniculus* is a keystone species, very important for popular small game species and for ecological reasons. However, its spread across the island seems to have decreased and fragmented in recent times, but until now no accurate population management has been carried out due to the lack of ethological, ecological and taxonomic knowledge. A biometric analysis of European rabbit specimens from Sicily to widen current taxonomic knowledge was performed. In this paper, 7 body variables and 23 cranial variables of 166 and 120 individuals, respectively, were examined. Thereafter, the results were compared with biometric data from other European populations. The comparison showed that the body size and skull measurement in Sicilian specimens of European rabbit seem to be quite distinct from those given in the literature on rabbit in south-west Spain, whose populations were assigned to *Oryctolagus cuniculus algirus* subspecies, whereas it was particularly close to the average size of populations in northern Spain and southern France, assigned to *Oryctolagus cuniculus cuniculu*s. Moreover, the Sicilian taxon was not correlated with Bergmann's rule, showing characteristics that could be the result of its introduction, population management or insularity. Biomolecular analyses will be necessary to definitely clarify the taxonomy of European rabbit in Sicily.

Key Words: European rabbit, *Oryctolagus cuniculus*, Sicily, biometry, taxonomy.

INTRODUCTION

During the late Upper Pleistocene, European rabbit *Oryctolagus cuniculus* (*O. c.*; Linnaeus, 1758) was quite widespread throughout the peri-Mediterranean area and northern Europe, but during the maximum glacial period and Early Holocene its range was extremely reduced, confined only to the Iberian Peninsula and, possibly, southern France (López-Martínez, 1989, 2008; Rogers *et al.,* 1994). Today, European rabbit is, among mammals, one of the most widespread species almost worldwide, one whose spreading and distribution have been mainly influenced by humans (Clutton-Brock, 1981; Flux, 1994; Callou, 1995). In central Mediterranean islands, including Sicily, European rabbit was probably introduced by the Romans (Bodson, 1978) during the 2nd or 3rd century AD (Barrett-Hamilton, 1912; Vigne, 1988; Kaetzke *et al.,* 2003). However, some remains from Zembra, a small Tunisian island, have been dated back to between the 1st and the 3rd centuries BC (Hardy *et al.*, 1994), which means that European rabbit introduction on some islands could have occurred earlier than expected.

The only evidence of European rabbit in Sicily is from remains found in a Middle Ages site, Brucato, which dates back to the 13th-14th centuries (Bresc, 1980).

The European rabbit is considered to be a polytypic species. Indeed, 2 subspecies have been identified, *O. c. cuniculus* (Linnaeus, 1758) and *O. c. algirus* (Loche, 1858), synonymous of *O. c. huxleyi* (Haeckel, 1874), initially distinguished only on the basis of morphological characteristics such as coat colour and above all body size (Miller, 1912).

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There are 2 divergent genetic groups, coming from a common ancestor dating back to about 2 million years ago (Branco *et al.*, 2000). These divergent groups found themselves geographically isolated during the Quaternary ice-ages, one in the south-west and the other in the north-east of the Iberian Peninsula (Biju-Duval *et al.*, 1991; Branco *et al.*, 2000), before any human interference (Callou, 1995; Hardy *et al.*, 1995), and they came into contact during the last post-glacial period (Branco *et al.*, 2002). According to some authors (Alda *et al.*, 2006; Ferrand, 2008) these 2 groups could correspond to the 2 current subspecies.

Only north-west of the Iberian Peninsula are populations actually regarded as nominal subspecies, whereas populations of the south-eastern Iberian Peninsula, North Africa, Mediterranean islands and Portuguese Atlantic islands are considered subspecies of *O. c. algirus* (Branco *et al.*, 2000; Esteves, 2003). All other introduced populations and domesticated varieties are considered descendants and belong to nominal subspecies (Ferrand, 1991; Branco *et al.*, 2000). Also according to Toschi (1965), the Sicilian population of European rabbit belongs to subspecies *O. c. huxleyi*. However, this statement is based only on body size of a small sample, and has not been confirmed by any accurate research. Recent publications (Angelici and Spagnesi, 2008; Siracusa, 2008) keep ascribing Sicilian population to the same subspecies, although this subspecies has for many years now been considered synonymous with *O. c. algirus*.

Rogers *et al.* (1994) and Sharples *et al.* (1996), through the analysis of body weight and cranial characteristics in European and north-African populations, question the existence of the 2 subspecies in the western Palaearctic; indeed, as regards body size, which has been used as the main diagnostic character to separate the subspecies, there is a gradient from northern to south-western Europe and eventually to North Africa, consistent with Bergmann's rule, which states that body size in homoeothermic vertebrates decreases from cold regions to warm regions due to thermoregulation. In particular, Sharples *et al.* (1996) view the skull size as positively correlated with latitude and negatively correlated with ambient temperature.

On the Sicilian islands, the European rabbit found habitats and resources suitable for its survival and became a very important food source for predators such as the Golden Eagle (*Aquila chrysaetos*) (Di Vittorio *et al.*, 2003) and Bonelli's Eagle (*Hieraaetus fasciatus*) (Lo Valvo and Massa, 1992), as well as for very common species like the Common Buzzard (*Buteo buteo*) and Red Fox (*Vulpes vulpes*) (Fais *et al.,* 1991; Siracusa, 1997).

Up to the first half of the 20th century, the European rabbit was widely and evenly spread all over the island, but for about 40-50 yr low population densities and local extinctions have been recorded in some areas, particularly due to the occurrence of 2 viral diseases, myxomatosis during the 1980s and rabbit hemorrhagic disease (RHD) at the end of the 1990s.

However, in some areas of Sicily -especially on tiny islands- the European rabbit lives at very high densities, being the cause of soil erosion, damage to agro-ecosystems and a plant population decrease (Trocchi and Riga, 2005).

It is clear that European rabbit populations in Sicily have never been carefully managed, mainly due to a very poor knowledge of its biology and eco-ethology in the wild, and also because of a strong uncertainty about its genetic, morphometric and biogeographic characteristics.

To fill these gaps, a research project on European rabbit in Sicily was started. The first results on European rabbit morphometry are presented, comparing them with similar results from other European populations to better understand their relationships. These findings could be useful for appropriate European rabbit management in Sicily.

MATERIALS AND METHODS

Full bodies or heads of 160 rabbits were collected throughout all provinces of the Sicilian islands during the 1997-2006 period. These samples were obtained from hunters or from live capture-release sessions. Samples from dead specimens were recovered from hunters during the hunting season, which in Sicily runs from October until December and does not overlap with the species-breeding season. Live trapping sessions were carried out in December. During this time the young rabbits have achieved the same size as the adults. When possible, the sex of the sampled animal is checked by visual inspection of reproductive traits.

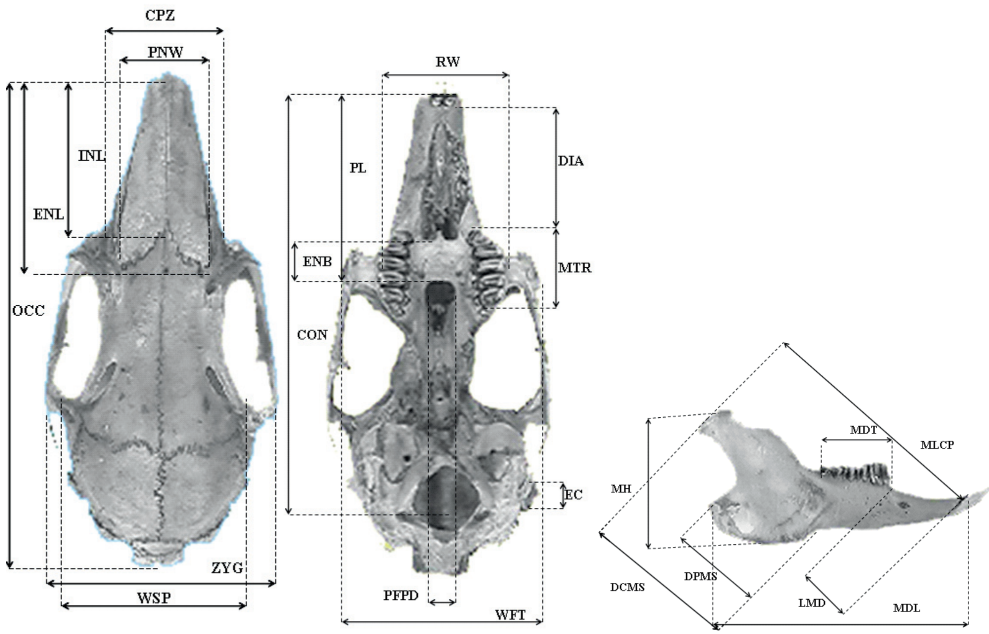
For body size characterisation we used the following morphometric variables: head length (HL), from the nares up to the base of the occipital bone; internal ear length (IE), from the base of the ear opening up to its tip; front foot length

(FF) and hind foot length (HF), from the ankle joint to the finger tips, excluding nails; total body length (BL), from the nares up to the last vertebra of the tail; tail length (T), from the dorsal base of the tail up to the last vertebra; weight (W), including internal organs.

The skulls of 120 rabbits were macerated in accordance with the method described by Onar (1999) and 23 cranial linear measurements were recorded (Figure 1).

The cranial variables and HL were measured using a digital calliper at an accuracy of 0.01 mm, FF, HF and T using a measuring scale, BL using a folding rule and W using digital balance.

First, descriptive statistics such as mean, standard deviation and range of the variables of interest was used. Thereafter, the Student's t-test was performed to verify whether biometric data differed i) between sexes within Sicilian samples or ii) between Sicilian sample and those from different countries. This test was used as it is able to reveal significant differences between means and variances of the 2 sample sets compared (Sokal and Rohlf, 1995) and, therefore, whether individuals are from different populations. Descriptive statistics and Student's t-tests were performed with STATISTICA 6.1 from StatSoft Inc. (2003).



CON	Condylobasal length	RW	Maximum width between the advanced dental rows
OCC	Occipitonasal length	PFPD	Diameter of posterior palatine foramen
MTR	Maxillary tooth row length	WFT	Distance between facial tubercles
PL	Palate length	ENB	Length of the hard palate
ZYG	Zygomatic width	DIA	Maxillary diastema length
MDT	Mandibular tooth row length	EC	Diameter of the external auditory meatus
MDL	Mandible length	MLCP	Mandible length from capitulum
ENL	External of nasal bones length	DCMS	Distance between mandibular condyle and fissure
INL	Internal of nasal bones length	DPMS	Distance between angular process and mandibular fissure
CPZ	Prezygomatic of the skull width	MH	Mandible height
PNW	Posterior of nasal bones width	LMD	Diastema mandibular length
WSP	Posterior of process over orbital width		

Figure 1: Diagram of a rabbit skull showing the measurements taken for body size characterisation.

Table 1: Means, standard deviation (SD) and range of body characteristics of wild rabbits from Sicily.

	Males			Females			Total		
	mean±SD	Range	n	mean±SD	Range	n	mean±SD	Range	n
Head length (mm)	83.5±3.9	74-91	31	82.3±4.5	72-90	31	81.8±5.2	62-91	166
Internal ear length (mm)	71.7±3.3	64-78	31	71.9±3.9	64-83	31	70.1±5.1	56-85	163
Front foot length (mm)	43.4±4.4	35-50	30	43.6±4.4	36-56	30	43.5±3.6	35-56	60
Hind foot length (mm)	87.3±4.8	76-97	29	85.1±4.3	77-94	29	85.1±6.1	76-97	58
Body length (mm)	389.4±30.8	347-455	11	387.0±19.7	354-426	12	385.9±27.5	347-455	23
Tail length (mm)	48.2±8.6	35-64	29	50.5±6.4	39-66	34	50±7.7	35-66	63
Weight (kg)	1.27±0.14	1.1-1.5	23	1.20±0.12	1.0-1.5	22	1.24±0.14	1.0-1.5	45

RESULTS AND DISCUSSION

Table 1 shows the values of the mean, standard deviation and range for each morphometric body variable for males, females and also the whole sample, which included specimens with unknown gender, whereas Table 2 shows the values of the mean, standard deviation and range for each skull variable. The total values were normally distributed in all variables (Shapiro-Wilk test; $P<0.05$).

As already observed by Taylor *et al.* (1977) in Australian samples and by Sharples *et al.* (1996) in a comparison of skull dimensions in populations from Western Europe and North Africa, no statistically significant (t-test, $P>0.05$) evidence of sexual dimorphism was observed in the Sicilian samples of European rabbit in terms of body and skull size.

Regarding the body size, our morphometric data were significantly higher than the data of the sample from Eastern Sicily described by Fallico (2000 cited by Trocchi e Riga, 2005). In comparison with the data of Fallico (2000) from the Pantelleria sample, an island which is in the Strait of Sicily and where European rabbit was introduced some centuries

Table 2: Means±standard deviation (SD) and range of skull characteristics of wild rabbits from Sicily. Abbreviations as in Figure 1.

	Males (n=11)		Females (n=15)		Total		
	mean±SD	range	mean±SD	range	mean±SD	range	n
CON	64.2±6.4	46.5-69.9	65.2±3.4	56.7-68.9	64.2±4.7	45.8-77.0	102
CPZ	16.8±1.3	13.3-18.3	17.7±1.3	15.2-19.2	18.1±2.0	13.3-22.7	119
DCMS	32.3±3.3	23.2-35.4	33.5±2.9	26.5-36.4	32.6±3.3	21.0-42.0	102
DIA	20.3±2.6	13.2-22.5	20.7±1.7	16.9-22.8	21.2±4.4	12.2-30.6	115
DPMS	21.6±2.5	15.8-24.3	22.3±2.0	17.9-24.7	22.0±2.4	13.8-29.4	101
EC	4,4±0,7	3.3-5.8	4.1±0.4	3.6-4.7	4.4±0.5	2.9-5.8	38
ENB	6.2±0.8	4.2-7.1	6.1±0.3	5.6-6.6	6.1±0.6	4.2-7.8	120
ENL	32.6±4.2	21.9-37.9	32.1±2.7	27.8-36.1	33.6±3.1	21.0-42.7	108
INL	26.4±3.3	17.8-29.4	26.0±1.7	23.6-28.8	27.0±2.8	16.4-33.9	109
LMD	15.5±1.7	11.1-17.6	15.5±1.1	13.1-17.6	16.0±1.5	11.1-18.8	105
MDL	50.1±5.1	38.1-57.1	50.5±4.5	40.9-55.7	51.3±4.3	35.2-61.7	100
MDT	14.1±1.4	10.8-15.9	14.1±1.1	12.3-16.2	13.9±1.1	10.5-17.2	109
MH	31.5±3.6	21.1-35.3	33.3±2.5	27.8-35.7	30.2±3.1	20.4-39.9	103
MLCP	52.2±5.6	37.9-58.0	52.5±4.5	41.7-58.3	52.0±5.5	34.5-64.9	101
MTR	13.8±1.2	10.9-15.3	14.0±0.9	12.0-15.1	13.9±1.0	10.8-17.0	117
OCC	73.4±7.0	53.6-81.0	75.1±3.9	64.8-78.9	74.9±5.4	53.6-90.2	114
PFPD	4.9±0.6	3.6-6.0	5.0±0.5	3.9-5.7	5.1±1.0	3.5-6.5	114
PL	28.8±3.9	18.8-31.6	29.2±2.7	23.8-32.1	34.2±5.2	18.8-35.4	115
PNW	14.1±1.5	10.9-16.8	14.6±1.3	12.4-16.2	15.2±2.0	10.9-20.7	118
RW	21.3±3.0	17.2-30.8	20.2±1.8	15.5-22.3	21.1±1.6	15.5-30.8	114
WFT	33.1±2.2	27.0-36.3	34.4±1.9	30.2-36.9	34.0±2.8	20.4-41.7	109
WSP	23.9±1.4	21.9-26.7	22.4±1.7	19.1-24.2	22.5±2.1	17.6-29.7	101
ZYG	36.6±2.1	30.8-38.6	36.5±1.9	33.2-38.6	37.1±2.1	29.5-42.6	112

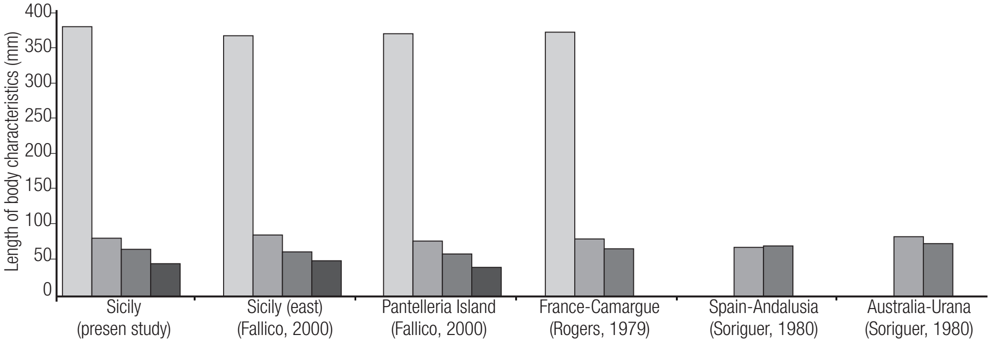


Figure 2: Comparison of some body characteristics length of European rabbit with samples from Sicily (present study); Sicily east (Fallico, 2000); Pantelleria Island (Fallico, 2000); France-Camargue (Rogers, 1979); Spain-Andalusia (Soriguer, 1980) and Australia-Urana (Soriguer, 1980). Body length, Posterior foot lenght, Internal ear lenght, Tail length.

ago (Wilkens, 1987), differences only for IE and T, significantly shorter (t-test, $P<0.001$ and $P<0.01$ respectively), were found in the present study.

The different body size of the populations of European rabbit currently present in Sicily, though showing morphometric differences statistically significant for some cases and variables, is not a small body size, as assumed by Toschi (1965).

In Figures 2 and 3 we compared the body size and the weight of other samples from different countries (Roger, 1979; Soriguer, 1980) with the Sicilian samples. The latter are situated nearer to those of northern Spain and southern France.

By t-test we also compared the values of the mean and standard deviation of eight skull variables (CON, OCC, MTR, DIA, PL, ZYG, MDL, MDT) with those from Sharples *et al.* (1996) concerning rabbits of Western Europe and North Africa. The t-test results (Table 3) show that the Sicilian sample of European rabbit is, also in this case, quite similar to those of northern Spain and southern France ($P>0.05$) and different from those of southern Spain.

Although showing some biometric differences compared with other populations of *O. c. cuniculus,* based on our morphometric considerations, Sicilian populations of European rabbit seem to have a medium body and skull size similar to those of the current populations living in northern Spain and southern France, which are assigned to the nominal subspecies, like most introduced populations of this species, and not to the *O. c. algirus* subspecies (Toschi, 1965; Angelici and Spagnesi, 2008; Siracusa, 2008) living in southern Spain.

Table 3: *P*-values (t-test) applied to compare the means of skull characteristics of European and North African samples (Sharples *et al.*, 1996) and the Sicilian sample of European rabbit. N.S.= not significant ($P>0.05$). Abbreviations as in Figure 1.

	Sicily							
	CON	OCC	MTR	DIA	PL	ZYG	MDL	MDT
British Isles	<0.001	0.005	N.S.	0.010	0.036	<0.001	<0.001	<0.001
Northern Europe	0.003	0.044	N.S.	N.S.	N.S.	0.002	<0.001	<0.001
Northern France	N.S.	N.S.	N.S.	N.S.	N.S.	0.024	<0.001	N.S.
Southern France	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Northern Spain	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Southern Spain	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	N.S.
Gibraltar	N.S.	0.049	N.S.	N.S.	N.S.	0.009	N.S.	N.S.
Nord Africa	N.S.	0.049	0.012	N.S.	N.S.	N.S.	N.S.	N.S.
Madeira	N.S.	N.S.	0.021	N.S.	N.S.	N.S.	N.S.	N.S.
Balearic Islands	N.S.	N.S.	N.S.	<0.001	N.S.	N.S.	N.S.	N.S.

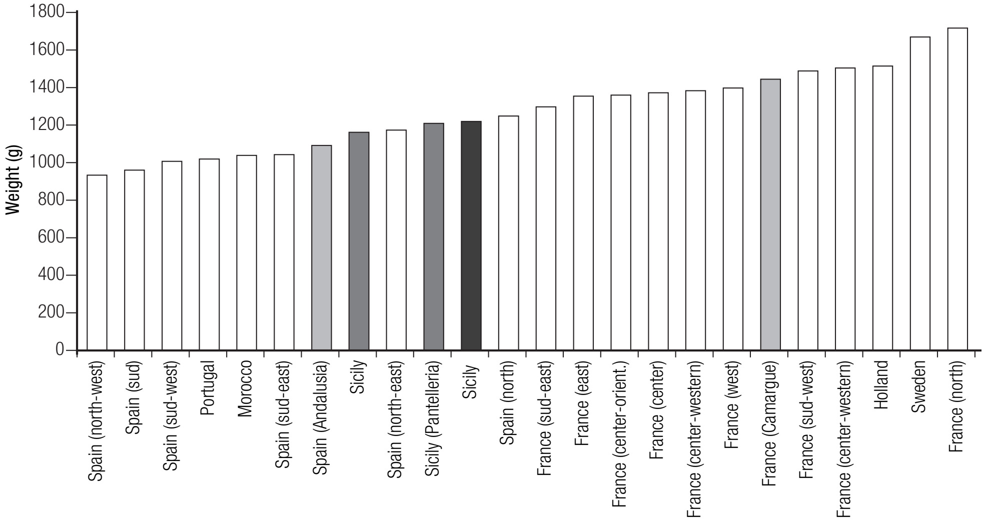


Figure 3: Comparison of weight of European rabbit recovered in western European samples. ☐ Rogers, 1979; ☐ Soriguer, 1980; ☐ Fallico, 2000; ■ this work.

It is worth recalling in this respect that the overall validity of subspecies has been called into question by Rogers *et al.* (1994) and Sharples *et al.* (1996), and that the hypothesis of cline variations has been put forward. However, even if this hypothesis is supported, our results show that the body and cranial size of Sicilian samples is not correlated with the latitude.

It cannot be excluded that in the past the European rabbit in Sicily had different characteristics compared to the current ones: the massive release of captive-breeding rabbits (more than 100000 animals in the last 50 yr), coming from continental stocks, could have affected the original population, modifying its morphometric and possibly genetic characteristics (Ferrand, 1991). According to Kaetzke *et al.* (2003), the differences found between the Sicilian populations of European rabbit and others, probably due to human intervention through domestication, was favoured by geographical isolation.

Further studies on museums specimens and biomolecular analyses will be needed to better clarify the evolutionary history of European rabbit in Sicily.

While waiting for an ultimate characterisation of European rabbit in Sicily, considering ecologic and economic importance, it is necessary to carry out a proper policy of population conservation, management and restoration not only for hunting demands. Moreover, it is highly desirable to stop restocking using captive-breeding animals of uncertain origin, which could also be a factor in the numerical decrease and fragmentation of the Sicilian population, being possible carriers of myxomatosis and rabbit haemorrhagic diseases (Blanco and Villafuerte, 1993). It would also be desirable to bring the European rabbit back to its original geographic range through the translocation of specimens collected in high-density zones where no restocking has been carried out in recent years.

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