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Cranial variability of the Serbian golden jackal: Geographic variation, sexual dimorphism and allometry

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ABSTRACT

Geometric morphometric approaches were employed for the first time to explore skull size and shape changes in golden jackal (*Canis aureus*) from Serbia. We examined three different, but connected aspects of its cranial variability: geographic variation, sexual dimorphism and allometry. To elucidate the pattern of cranial size and shape variation, we analyzed ventral crania of subadults and adults from two geographic regions of Serbia. For both age groups there were no significant size, but significant shape differences between golden jackals from northeastern and central Serbia. The observed shape differences were subtle, probably due to recent range expansion of this species in the Balkans and a strong founder effect in the newly established populations. The detected significant sexual size and shape dimorphisms (SSD and SShD) were slight and more evident in adult crania. Although the SShD observed in adult crania is influenced by SSD, factors responsible for the non-allometric component of shape variation, and not pure size differences between sexes, are those that are most important for generation of SShD in this species. A monogamous reproductive system, male parental care, omnivorous and opportunistic feeding behavior and the absence of division of labor between males and females in activities other than parental care, could all be related to the driving of morphological similarity between the sexes.

1. Introduction

The golden jackal (*Canis aureus* L., 1758) is the most widely distributed canid species, inhabiting northern and eastern Africa, Asia Minor, the Middle East, central and southern Asia, and southeastern Europe (Jhala and Moehlman, 2004). However, Koepfli et al. (2015) showed that African and Eurasian golden jackals are genetically distinct and independent lineages, and that African golden jackals likely represent a separate species, African golden wolf (*Canis anthus*). The present distribution of the Eurasian golden jackal also comprises parts of central Europe (Arnold et al., 2012; Mitchell-Jones et al., 1999). Apart from Greece, where the jackal population has decreased and is listed as vulnerable in the national Red List (Giannatos et al., 2005), European populations are rapidly increasing and widening their ranges (Arnold et al., 2012; Kryštufek et al., 1997). Thus, recent records of jackal sightings in Slovakia, Ukraine, Belarus, Poland, Estonia and Lithuania (Trouwborst et al., 2015) suggest that both Caucasian and southeastern Europe populations are spreading towards the north. In Europe, the Balkan Peninsula is considered as the core area of its distribution (Arnold et al., 2012; Kryštufek et al., 1997; Šálek et al., 2014). However, in Serbia jackals neared extinction due to extensive poisoning, particularly after World War II. The initial intention was to control the size of the wolf population and to lessen the damage they caused to domestic animals. Only two small relict jackal populations survived, one in the Srem region and the other in eastern Serbia (Milenković, 1983, 1987). At the beginning of the 1980s, the species quickly started to spread and increase in number (Savić et al., 1995), which led to fusion of the two relict populations and extension of their range. Now, this covers more than a half of the territory of Serbia (Ćirović et al., 2008; Zachos et al., 2009) and local populations show high densities (Šálek et al., 2014). The golden jackal is described as an opportunistic species, using a wide range of food sources (Macdonald, 1979) enabling survival in different environments at high local densities (Jhala and Moehlman, 2004; Šálek et al., 2014).

Despite the abundance of surveys concerning golden jackals, particularly those dealing with population ecology, craniometric studies on this species are generally deficient and primarily focus on inter-population differences (Demeter Von and Spassov, 1993; Koepfli et al., 2015; Kryštufek and Tvrtković, 1990; Stoyanov, 2012;

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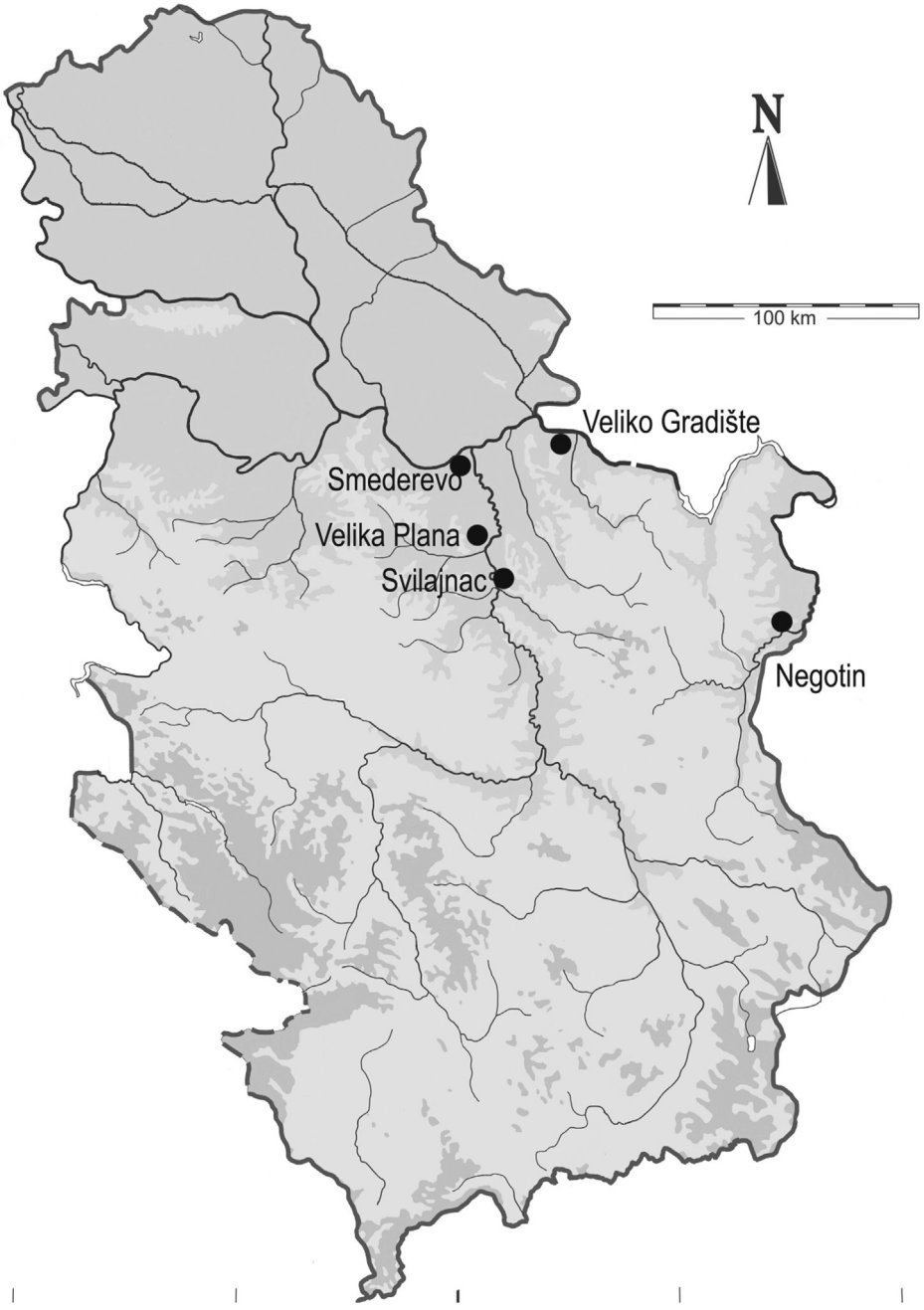

Fig. 1. Geographic distribution of the analyzed locations of golden jackals (*Canis aureus* L., 1758) from northeastern (Negotin and Veliko Gradište) and central (Smederevo, Velika Plana and Svilajnac) Serbia.

Van Valkenburgh and Wayne, 1994). In an investigation on variability and identity of the golden jackals of Dalmatia, Kryštufek and Tvrtković (1990) compared some skull characteristics between Dalmatian jackals and those from the rest of the Balkan Peninsula, Asia Minor, the Caucasus, North Africa and Ethiopia. They found that Dalmatian jackals are morphologically distinct from their counterparts from the Balkan Peninsula and Africa and appeared to be most similar to the jackals from Asia Minor. Van Valkenburgh and Wayne (1994) performed a comprehensive morphometric study on populations of three jackal species (*Canis adustus*, *Canis mesomelas* and *C. aureus*) throughout their ranges. Analyzing craniodental morphology, they explored four possible manifestations of character displacement (divergence in size, divergence in shape, reduced morphological variability and reduced sexual dimorphism) in the three species. The craniometric study of Stoyanov (2012) showed that skulls of Bulgarian jackals did not differ from those of other European jackals except for Dalmatian ones, while Koepfli et al. (2015) used cranial and dental data to demonstrate that golden jackals from North Africa are distinct from Eurasian and East African ones.

Sexual size dimorphism (SSD) in the golden jackal was found in several of the aforementioned studies on body and skull morphology, with males larger than females (Demeter and Von Spassov, 1993; Kryštufek and Tvrtković, 1990; Stoyanov, 2012; Van Valkenburgh and Wayne, 1994). Van Valkenburgh and Wayne (1994) demonstrated that the extent of sexual dimorphism varies by locality and is not pronounced as is typical of other canid species. Stoyanov (2012) reported significant differences between