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Research paper

Cranial variability of the Serbian red fox

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ABSTRACT

We used geometric morphometric techniques to examine variability in Serbian red fox (*Vulpes vulpes*) crania. Male crania are about 5% larger than female ones and sexual size dimorphism (SSD) was significant. Also, significant cranial shape differences were found between the sexes. Males are characterized by reduced basicranial, but broader rostral and zygomatic regions. Although a slight and significant allometric effect was detected and larger specimens are smaller in the region of basicranium, cranial sexual shape dimorphism (SShD) pattern is not influenced by SSD. As small to moderate SSD in canid species is a general characteristics of the family, additional studies are needed to determine whether basicranial reduction in males, i.e. its enlargement in females, could be an important feature in characterizing cranial SShD patterns in other Canidae members. While uniform considering size, the shape of Serbian red fox crania varies geographically, as well as depending on proportion of agricultural habitats. In comparison to those from central and eastern Serbia, specimens from the northern Serbian region Vojvodina (with higher proportions of agricultural areas) have more robust crania with shorter snouts and maxillae, larger palatine bones accompanied with anteriorly moved posterior edges of the canine alveolus and laterally expanded zygomatic arches. Encompassing mostly facial and temporal cranial regions these shape changes are probably related to diet differences, although genetic diversification cannot be excluded as a possible contributing factor.

1. Introduction

The geographical distribution of the red fox (*Vulpes vulpes*, Linnaeus, 1758), the most widespread medium-sized carnivore species in the entire world, covers almost all subarctic and temperate regions in the Northern Hemisphere (MacDonald and Reynolds, 2008). Its range has increased alongside human expansion since the red fox has been introduced into Australia, where it is considered as one of the "worst invasive species" (Lowe et al., 2000). Population expansion also includes colonization of urban environments, where it is a common mesopredator species (e.g. Harris, 1977; Macdonald, 1987; Wandeler and Lüps, 1993). In Serbia it is present in all habitats across the entire territory (Ćirović, 2000). As a generalist and a widely distributed species, the composition of the red fox diet is characterized by spatial and temporal variation (Cavallini and Volpi, 1995; Kidawa and Kowalczyk, 2011). The basic food of the European red fox consists of rodents, especially slow moving microtine species (Hartová-Nentvichová et al., 2010a; Jedrzejewski and Jedrzejewska, 1992; Kauhala et al., 1998; Lanszki et al., 2007; Leckie et al., 1998; Pagh et al., 2015). However, when rodent species become scarce the red fox switches to alternative prey such as hare (Goszczyński and Wasilewski, 2002), waterfowl (Meisner et al., 2014), carrion (Meisner et al., 2014; Sidorovich et al., 2006) or anthropogenic leftovers (Doncaster et al., 1990).

The body and craniodental variability of the red fox have been the subject of numerous studies, mainly those related to geographic variation within different scales of its distribution range. Thus, several studies conducted at a broad geographic scale reported that size of craniodental traits varies depending on geo-climatic factors following Bergmann's rule (Churcher, 1960; Davis, 1977; Meiri et al., 2004; Szuma, 2008a). Moreover, geographic variation of skull traits was also observed within smaller distribution areas (Fairley and Bruton, 1984; Huson and Page, 1979, 1980; Oishi et al., 2010; Simonsen et al., 2003; Viranta and Kauhala, 2011; Yom-Tov and Geffen, 2006; Yom-Tov et al., 2007, 2013). Besides the influence of climate on phenotypes, competition between the red fox and closely related species (Dayan and Simberloff, 2005; Dayan et al., 1989, 1992; Viranta and Kauhala, 2011), as well as food availability (Meiri et al., 2007; Yom-Tov et al., 2007, 2013) cannot be omitted as possible factors causing morphological differentiation

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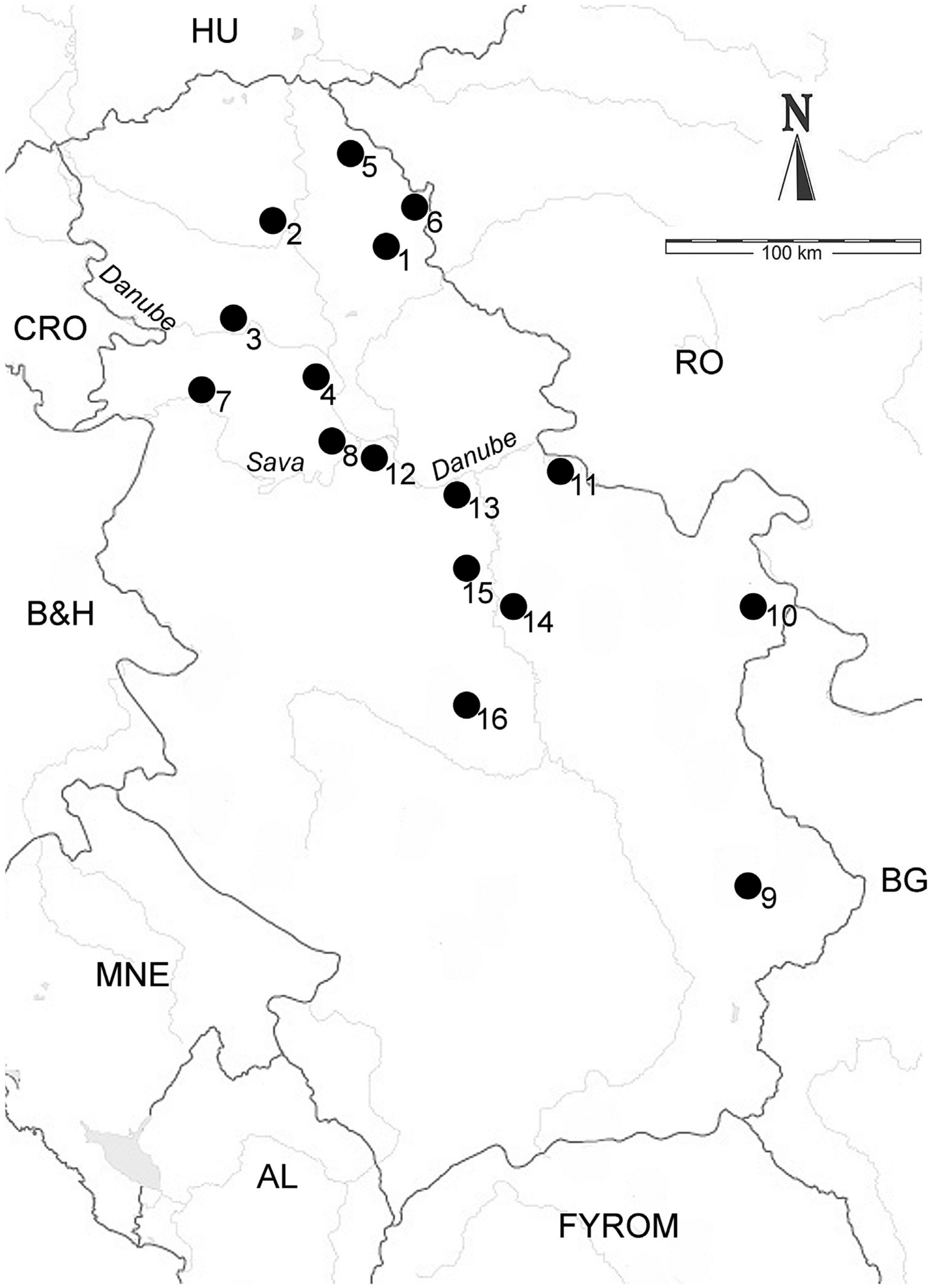

Fig. 1. Geographic distribution of red fox (*Vulpes vulpes* L., 1758) populations in Serbia: northern Serbia (1–Banatski Dvor, 2–Bečej, 3–Futog, 4–Inđija, 5–Mokrin, 6–Radojevo, 7–Sremska Mitrovica, 8–Surčin), eastern Serbia (9–Bela Palanka, 10–Negotin, 11–Veliko Gradište), central Serbia (12–Beograd, 13–Smederevo, 14–Svilajnac, 15–Velika Plana, 16–Županjevac).

in this species. Food availability is associated with the proportion of agricultural areas. According to Yom-Tov et al. (2007), an agricultural area is a municipality where more than 50% of the land is occupied by crop and livestock production. Several studies reported an increase in body (Gortázar et al., 2000) and skull (Yom-Tov et al., 2003, 2007) size of foxes living in high-productive (agricultural) habitats in comparison to those in low-productive (non-agricultural) habitats due to greater food availability from human activity.

Aside from geographic variation, craniodental size differences between the sexes, with male foxes exceeding females, have been described by many authors (Churcher, 1960; Ćirović, 2000; Dayan et al., 1989; Fairley and Bruton, 1984; Hartová-Nentvichová et al., 2010b; Huson and Page, 1979; Lynch, 1996; Simonsen et al., 2003; Szuma, 2008a,b; Viranta and Kauhala, 2011; Yom-Tov et al., 2007). However, similarly to other monogamous canids with paternal care, the sexual size dimorphism (SSD) scored in these articles is of small to moderate degree. In contrast to SSD, only a few of the above-mentioned investigations provided important insights into cranial shape differences between male and female foxes, i.e. sexual shape dimorphism (SShD) (Hartová-Nentvichová et al., 2010b; Lynch, 1996). Moreover, in canid species, including *V. vulpes*, it has been shown that size differences between the sexes may be associated with shape differences between male and female morphological structures (Hartová-Nentvichová et al., 2010b; Lynch, 1996; Porobić et al., 2016; Schutz et al., 2009).