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# Living a dog's life: a putative gray wolf in a feral dog group

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**Abstract:** The gray wolf and the domestic dog are closely related species that can interbreed and produce fertile offspring. In settings where unrestrained dogs are present in the wild, hybridization can happen naturally. However, the behavior of the resulting hybrids and their ecological impact is largely understudied. In September–November 2018, a putative gray wolf was repeatedly camera-trapped in a group of 10 presumably feral dogs in a remote mountainous area (the Osogovo Mountain) along the border between Bulgaria and North Macedonia. The most feasible explanation for this individual's atypical behavior is that it is of hybrid origin (assumption based on phenotype). To the best of our knowledge, this is the first documented observation of such a kind. A discussion of its recruitment and position in the group is presented, setting the basis for further investigation of the complex interaction between wolves, dogs and hybrids in the wild.

**Keywords:** camera trapping; hybridization; social structure.

## Introduction

The gray wolf (*Canis lupus* Linnaeus, 1758) is the direct ancestor of the domestic dog (*Canis familiaris* Linnaeus, 1758) (Vilà et al. 1997). Being this closely related, dogs and wolves can interbreed (producing fertile offspring) and have continued to exchange genetic material after the initial divergence (Benirschke 1967, Vilà et al. 1997, Wayne et al. 1997, Pilot et al. 2018). However, the process of domestication has influenced not only the morphology but also the ecology and behavior of the domestic dog compared to its wild ancestor (Saetre et al. 2004). These differences are of special interest when studying feral dogs (dogs that live without direct contact with humans nor directly depend on them for food) (Boitani et al. 2016, Hughes et al. 2016), i.e. in conditions close to the wolf's.

The social ecology of the gray wolf is well studied (Bibikov 1985, Mech and Boitani 2003). Gray wolves live in single-family units (packs), formed and maintained by the social bonds among the members. Their social system is a linear hierarchy, where dominance and subordinance are regulated by agonistic behavior. The established social control of reproduction in the packs serves two important purposes: (1) it limits the number of reproducing individuals; (2) the non-reproducing individuals might increase the chances of pup survival (Packard et al. 1983, Boitani and Ciucci 1995, Marshall-Pescini et al. 2017).

The social structure in feral dogs represents a grouping of breeding individuals and their pups and sub-adults. There is no evidence that agonistic behavior in dogs plays the same role and leads to the formation of a hierarchical structure like the one observed in wolves. Furthermore, there is no indication of social control on reproduction. The very loose connections in these groups define them not as a real pack (like in wolves), but rather as a group of individuals (Boitani et al. 2006). Consequently, the population dynamics in these groups is unregulated by environmental and ecological conditions (Boitani and Ciucci 1995, Boitani et al. 2016, Marshall-Pescini et al. 2017). This, among other reasons, forms the basis for the unprecedented free-ranging dog population, making it the most common carnivore on the planet (Gompper 2014). Dogs inhabit not only urbanized areas but also rural landscapes and even protected areas, where their interactions with wildlife are frequent and problematic due to increased risk of disease transmission, direct predation, disturbance and competition (Young et al. 2011, Doykin et al. 2016). Especially interesting are the relationships between dogs and the native wild canids. Specifically, in the case of the gray wolf, in addition to the aforementioned effects (notably disease transmission and competition), the sympatry with dogs may result in hybridization (Lescureux and Linnell 2014, Pilot et al. 2018). Given the relatively high levels of hybridization observed in Bulgaria (Moura et al. 2014), this appears to be one of the major threats for the conservation of the wolves in the country. In this study, we present an account of a putative gray wolf living

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with a group of feral dogs in a remote mountainous area in Southwestern Bulgaria. To the best of our knowledge, no case like this has been documented before. We further discuss the possible hybrid status of the individual and its recruitment and position in the group.

## Materials and methods

The current study is based on camera trap data obtained during an ongoing research on the gray wolf and its prey in the Osogovo Mountain (Southwestern Bulgaria, bordering North Macedonia) (Zlatanova et al. 2018, Popova et al. in press). The study started in 2016, as 26 camera traps were set up in 32 locations in the Bulgarian part of Osogovo. Part of the camera traps, located near the border with North Macedonia, are serviced by Border Police staff, who also use their own camera traps (model Ltl Acorn) to monitor border security. The camera traps were set up to take three consecutive pictures (5 s apart) and a 10-s video upon triggering. The next series of photos and a video could be taken 1 min after the previous triggering. The resulting photos and videos allowed the identification of different dog individuals with unique coat patterns, and in some cases their sex (when testicles or characteristic urinating posture were observed). The study area is scarcely populated by humans, and the closest human settlement is a scattered collection of houses (most of which are abandoned), a part of a nearby small village.

## Results

Three camera traps (models Bestguarder DTC-880V, Shenzen, China, Ltl Acorn 6210, Figure 1) positioned along the Bulgarian/North Macedonian border (at a distance between 0.9 km and 2 km from each other) captured a group of 11 individuals, among which 10 were feral dogs and one was a putative gray wolf (Figure 2) with no sign of mutual aggressive behavior or fear.

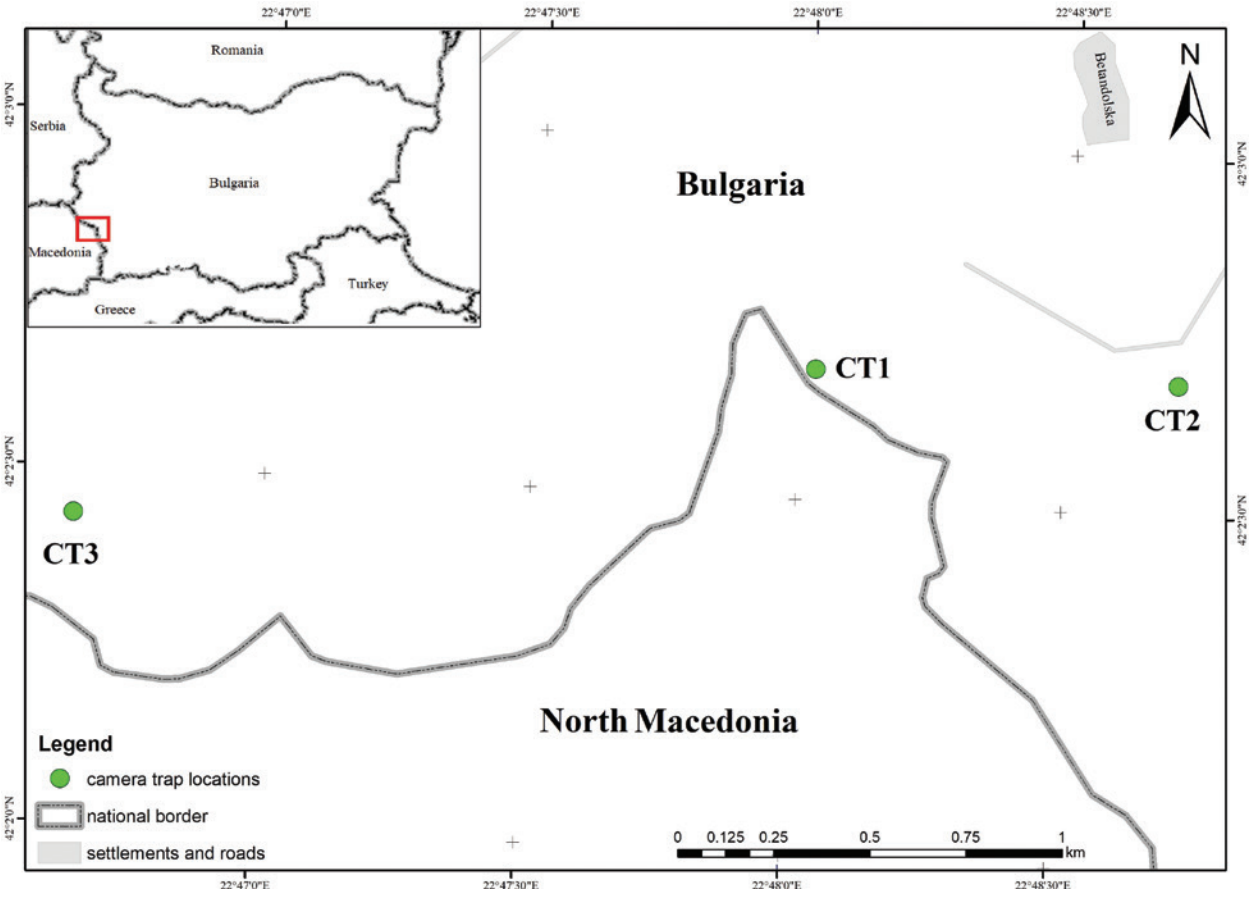


**Figure 1:** Locations of the three camera traps on the Bulgarian/North Macedonian border in the Osogovo Mountain that captured the studied group of canids.

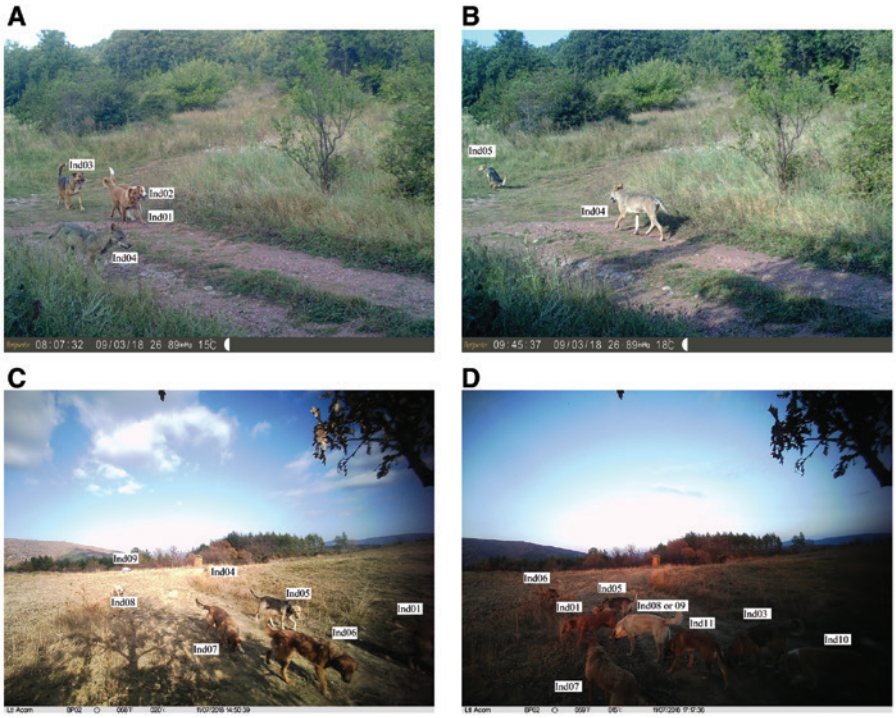


**Figure 2:** Camera trap photos of the group with labeled individuals: (A) and (B) are from location CT1, (C) and (D) are from location CT3.

A total of five independent recordings of the group were registered:

- Camera trap CT1 – on 03.09.2018 at 08:07 h and 9:45 h – five individuals of the group;
- Camera trap CT2 – on 25.10.2018 at 16:15 h – four individuals of the group;
- Camera trap CT3 – on 07.11.2018 at 14:50 h and 17:17 h – 10 individuals of the group.

A detailed description of the individuals was taken based on their coat patterns (Supplementary Appendix 1). We assumed that all the 11 individuals belonged to the same group, as they were repeatedly observed together for a period of 2 months. The unquestionable "dogs" were adult individuals which did not bear any marks usually put on dogs processed by dog shelters, meaning that they most likely had not been captured, castrated and released again. The group consisted of obviously unrelated dogs (judging by their coat patterns), except for three pairs that appeared to be originating from the same litters (Ind01 and Ind11; Ind06 and Ind07; Ind08 and Ind09; Figure 2). The putative wolf (Ind04) was a young male individual, judging by its size, body proportions and the visible testicles (Figure 2B). It possessed a few traits that are not typical of Bulgarian wolves (Spassov 2008): (1) a wide black band on the back which was dark and clearly differentiated from the coat color on the sides of the body (in comparison with the narrower and grayish band in typical Bulgarian wolves, which smoothly merges with the coat color on the sides of the body); (2) lack of black stripes on the dorsal part of the front legs (which is well defined in typical Bulgarian wolves); and (3) a narrower head that was not as massive as in typical wolves.

## Discussion and conclusion

A numerous group like this, inhabiting an area away from humans, most likely consists of feral dogs (Boitani 1983, Boitani et al. 2016). A group formed by wolves and dog-like individuals has been observed in Spain (Godinho et al. 2011), as well as a group of few wolf-like individuals with one dog, in Italy (Salvatori, pers. com.), but so far there has not been a documented case a of a large dog group with a putative wolf. This makes the current observation a first, opening a whole new dimension to the discussion surrounding the gray wolf's conservation in Europe.

The presence of the aforementioned features in the putative wolf and its behavior might suggest that the individual is not a pure gray wolf but rather a wolf × dog hybrid, although it is very difficult to certainly conclude without genetic confirmation (Kusak et al. 2018). This

hypothesis is feasible due to the reportedly widespread hybridization in Bulgaria (Moura et al. 2014), even among individuals with a typical gray wolf phenotype.

Hybridization between wolves and dogs typically occurs when the number of free-ranging dogs is high, the wolf population is under strong hunting pressure and its structure is disrupted (Bibikov 1985, Vilà and Wayne 1999, Andersone et al. 2002, Mech and Boitani 2003, Hindrikson et al. 2017). These factors are all present in the Osogovo Mountain, which is scarcely populated by humans, with only small settlements of widely scattered (and in many cases abandoned) houses. This suggests the presence of many unrestrained dogs, which was confirmed by the censuses of the two local forestry units (State Forestry "Nevestino" and State Hunting Enterprise "Osogovo") in recent years. They indicate between 4 and 27 times more free-ranging dogs than wolves on their grounds. At least a proportion of these dogs undergo the process of feralization and become independent of humans. Furthermore, the gray wolf is a game species in Bulgaria, and its hunting is permitted throughout the year. In the grounds of the State Hunting Enterprise, which is focused on enhancing the ungulate populations for hunting purposes, wolves are severely persecuted. Subsequently, the strong hunting pressure breaks down the social structure of the groups and forms a prerequisite for hybridization.

"Black" or melanistic wolves are camera trapped or killed in many parts of the study area (Zlatanova et al. 2018). Melanism in gray wolves is caused by past and recurring (Randi and Lucchini 2002, Verardi et al. 2006, Godinho et al. 2011, Hindrikson et al. 2012, Khosravi et al. 2014, Galaverni et al. 2017) or recent (Anderson et al. 2009, Caniglia et al. 2013, Galaverni et al. 2017, Pilot et al. 2018) hybridization with dogs. However, in some cases, no trace of hybridization has been detected in the ancestry of black wolves (Randi and Lucchini 2002, Apollonio et al. 2004). Without DNA analysis, the status of the black individuals observed in Osogovo cannot be identified with certainty, but their hybrid origin seems probable.

In the case of the observed group in Osogovo, a few issues need to be addressed. Firstly, it is the question of how the putative wolf joined the group. Assuming it is the product of hybridization, there are two possibilities: either the cross is between a male dog and a female wolf or between a male wolf and a female dog. Many studies report that hybridization in wolf × dog crosses is asymmetrical, i.e. most cases involve breeding between a male dog and a female wolf (Vilà and Wayne 1999, Vilà et al. 2003, Godinho et al. 2011). However, the reverse case has also been documented in the wild (Hindrikson et al. 2012). This leads to two possible hypotheses for the origin of the putative wolf: (1) it was born in a wolf pack and joined the feral dogs during dispersal; (2) it was born in the feral dog group (through a female dog) and did not disperse. Given the aforementioned asymmetry, the first hypothesis appears more plausible in the absence of DNA analysis.

The typical behavior of wolves toward dogs is aggressiveness (Fritts and Paul 1989, Kojola et al. 2004, Lescureux and Linnell 2014, Peltola and Heikkilä 2015, Wierzbowska et al. 2016), but in cases where the wolf is in a state of social isolation, it could alter its behavior completely and display playful or submissive behavior (Bibikov 1985). Additional support for this hypothesis provides the fact that the putative wolf is a young individual (probably recently dispersing), repeatedly limping with its front left leg in different recordings (Supplementary Appendix 2), which indicates a long-lasting trauma. Thus, its social exclusion and reduced foraging ability might have led it to join the feral group. All of the group members were relatively large individuals, and being this numerous, the group is likely to hunt on larger prey (e.g. roe deer *Capreolus capreolus* Linnaeus, 1758) in order to fulfill their energy requirements. The recruitment of the putative wolf could only enhance their hunting success, as hybrids have been shown to prey on wild boar (*Sus scrofa* Linnaeus, 1758) and roe deer, similarly to wolves and feral dogs (Wierzbowska et al. 2016, Bassi et al. 2017).

Apparently, the problem with wolf × dog hybridization in Bulgaria is serious and is part of a common concern for the genetic status of the wolves in Europe (Randi 2011). Hybridization has been reported in other parts of the continent, notably in Italy (Randi et al. 2000, Verardi et al. 2006, Iacolina et al. 2010, Caniglia et al. 2013), Latvia and Estonia (Andersone et al. 2002, Hindrikson et al. 2012), Scandinavia (Klütsch et al. 2011, Vilà et al. 2003), Serbia (Milenković et al. 2006), the Iberian peninsula (Godinho et al. 2011, Pacheco et al. 2017, Torres et al. 2017), Poland (Okarma 2015) and Croatia (Majić 2014, Kusak et al. 2018). Once hybridization has occurred, it is difficult to stop it, especially when the hybrids are fertile (Allendorf et al. 2001); thus their proportion in the population grows progressively. The genetic pollution caused by this process can pose a threat to small wolf populations or even induce loss of adaptations leading to the extinction of distinct taxons (Allendorf et al. 2001, Randi 2008, Iacolina et al. 2010, Lescureux and Linnell 2014). It should be noted, however, that based on the results of Anderson et al. (2009), the melanistic K locus mutation found in North American and Italian wolves (caused by past hybridization) has a molecular signature of positive

selection and is more frequent in forested habitats and thus might have adaptive benefits (Hedrick 2009, Godinho et al. 2011). Some authors suggest behavioral differences in hybrids, such as synanthropic behavior and livestock depredation (Bibikov 1985, Bassi et al. 2017), which can also negatively impact the public perception of wolves. However, the behavior and ecology of the free-ranging wolf × dog hybrids are largely understudied and their ecological impact is still unknown (Godinho et al. 2011, Lescureux and Linnell 2014). The results of our study may serve as a first step toward a better understanding of the complex wolf/dog/hybrid relationships in the wild and their impact.

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## References

Allendorf, F.W., R.F. Leary, P. Spruell and J.K. Wenburg. 2001. The problems with hybrids: setting conservation guidelines. Trends Ecol. Evol. 16: 613–622.

Anderson, T.M., B.M. VonHoldt, S.I. Candille, M. Musiani, C. Greco, D.R. Stahler, D.W. Smith, B. Padhukasahasram, E. Randi, J.A. Leonard, C.D. Bustamante, E.A. Ostrander, H. Tang, R.K. Wayne and G.S. Barsh. 2009. Molecular and evolutionary history of melanism in North American gray wolves. Science 323: 1339–1343.

Andersone, Z., V. Lucchini, E. Randi, J. Ozolinësï and K. Ëemeri. 2002. Hybridisation between wolves and dogs in Latvia as documented using mitochondrial and microsatellite DNA markers. Mamm. Biol. 67: 79–90.

Apollonio, M., L. Mattioli and M. Scandura. 2004. Occurrence of black wolves in the Northern Apennines, Italy. Acta Theriol. (Warsz.) 49: 281–285.

Bassi, E., A. Canu, I. Firmo, L. Mattioli, M. Scandura and M. Apollonio. 2017. Trophic overlap between wolves and free-ranging wolf × dog hybrids in the Apennine Mountains, Italy. Glob. Ecol. Conserv. 9: 39–49.

Benirschke, K. 1967. Sterility and fertility of interspecific mammalian hybrids. In: (K. Benirschke, ed.) Comparative aspects of reproductive failure. Springer-Verlag New York Inc., New York, pp. 218–233.

Bibikov, D.I. (Ed.) 1985. The wolf. History, systematics, morphology, ecology. Nauka Publishers, Moscow, Russia.

Boitani, L. 1983. Wolf and dog competition in Italy. Acta Zool. Fenn. 174: 259–264.

Boitani, L. and P. Ciucci. 1995. Comparative social ecology of feral dogs and wolves. Ethol. Ecol. Evol. 7: 49–72.

Boitani, L., P. Ciucci and A. Ortolani. 2006. Behaviour and social ecology of free-ranging dogs. In: (P. Jensen, ed.) The behavioural biology of dogs. CAB International, pp. 147–165.

Boitani, L., F. Francisci, P. Ciucci and G. Andreoli. 2016. The ecology and behavior of feral dogs: a case study from central Italy. In: (J.A. Serpell, ed.) The domestic dog: its evolution, behavior and interactions with people. Cambridge University Press, New York, pp. 342–368.

Caniglia, R., E. Fabbri, C. Greco, M. Galaverni, L. Manghi, L. Boitani, A. Sforzi and E. Randi. 2013. Black coats in an admixed wolf × dog pack is melanism an indicator of hybridization in wolves? Eur. J. Wildl. Res. 59: 543–555.

Doykin, N., E. Popova, V. Zlatanov, P. Petrov and D. Zlatanova. 2016. Preliminary data on the distribution of free-ranging dogs (*Canis familiaris* L.) in NP Vitosha, Bulgaria. Annu. l'Université Sofia "St. Kliment Ohridski" Fac. Biol. 101: 11–22.

Fritts, S.H. and W.J. Paul. 1989. Interactions of wolves and dogs in Minnesota. Wildl. Soc. Bull. 17: 121–123.

Galaverni, M., R. Caniglia, L. Pagani, E. Fabbri, A. Boattini and E. Randi. 2017. Disentangling timing of admixture, patterns of introgression, and phenotypic indicators in a hybridizing Wolf population. Mol. Biol. Evol. 34: 2324–2339.

Godinho, R., L. Llaneza, J.C. Blanco, S. Lopes, F. Álvares, E.J. García, V. Palacios, Y. Cortés, J. Talegón and N. Ferrand. 2011. Genetic evidence for multiple events of hybridization between wolves and domestic dogs in the Iberian Peninsula. Mol. Ecol. 20: 5154–5166.

Gompper, M.E. 2014. Free-ranging dogs and wildlife conservation. Clim. Chang. 2013 – Phys. Sci. Basis 1: 312.

Hedrick, P.W. 2009. Wolf of a different colour. Heredity (Edinb.) 103: 435–436.

Hindrikson, M., P. Männil, J. Ozolins, A. Krzywinski and U. Saarma. 2012. Bucking the trend in wolf-dog hybridization: first evidence from Europe of hybridization between female dogs and male wolves. PLoS One 7: 1–12.

Hindrikson, M., J. Remm, M. Pilot, R. Godinho, A.V. Stronen, L. Baltrūnaité, S.D. Czarnomska, J.A. Leonard, E. Randi, C. Nowak, M. Åkesson, J.V. López-Bao, F. Álvares, L. Llaneza, J. Echegaray, C. Vilà, J. Ozolins, D. Rungis, J. Aspi, L. Paule, T. Skrbinšek and U. Saarma. 2017. Wolf population genetics in Europe: a systematic review, meta-analysis and suggestions for conservation and management. Biol. Rev. 92: 1601–1629.

Hughes, J., D.W. Macdonald and L. Boitani. 2016. Roaming free in the rural idyll: dogs and their connections with wildlife. In: (J.A. Serpell, ed.) The domestic dog: its evolution, behavior and interactions with people. Cambridge University Press, New York, pp. 369–384.

Iacolina, L., M. Scandura, A. Gazzola, N. Cappai, C. Capitani, L. Mattioli, F. Vercillo and M. Apollonio. 2010. Y-chromosome microsatellite variation in Italian wolves: a contribution to the study of wolf-dog hybridization patterns. Mamm. Biol. 75: 341–347.

Khosravi, R., M. Asadi Aghbolaghi, H.R. Rezaei, E. Nourani and M. Kaboli. 2014. Is black coat color in wolves of Iran an evidence of admixed ancestry with dogs? J. Appl. Genet. 56: 97–105.

Klütsch, C.F.C., E.H. Seppälä, T. Fall, M. Uhlén, Å. Hedhammar, H. Lohi and P. Savolainen. 2011. Regional occurrence, high frequency but low diversity of mitochondrial DNA haplogroup d1 suggests a recent dog-wolf hybridization in Scandinavia. Anim. Genet. 42: 100–103.

Kojola, I., A. Hakala, S. Heikkinen, S. Ronkainen and S. Kokko. 2004. Interactions between wolves *Canis lupus* and dogs *C. familiaris* in Finland. Wildl. Biol. 10: 101–105.

Kusak, J., E. Fabbri, A. Galov, T. Gomerčić, H. Arbanasić, R. Caniglia, M. Galaverni, S. Reljić, D. Huber and E. Randi. 2018. Wolf-dog hybridization in Croatia. Vet. Arhiv. 88: 375–395.

Lescureux, N. and J.D.C. Linnell. 2014. Warring brothers: the complex interactions between wolves (*Canis lupus*) and dogs (*Canis familiaris*) in a conservation context. Biol. Conserv. 171: 232–245.

Majić, A. 2014. Final Report LIFE08 NAT/SLO 000244 SloWolf. Ljubljana.

Marshall-Pescini, S., S. Cafazzo, Z. Virányi and F. Range. 2017. Integrating social ecology in explanations of wolf–dog behavioral differences. Curr. Opin. Behav. Sci. 16: 80–86.

Mech, L.D. and L. Boitani. 2003. Wolf social ecology. In: (L.D. Mech and L. Boitani, eds.) Wolves: behaviour, ecology and conservation. University of Chicago Press, Chicago, pp. 1–34.

Milenković, M., V. Habijan-Mikeš and R. Matić. 2006. Cases of spontaneous interbreeding of wolf and domestic dog in the region of southeast banat (Serbia). Arch. Biol. Sci. 58: 225–231.

Moura, A.E., E. Tsingarska, M.J. Dabrowski, S.D. Czarnomska, B. Jedrzejewska and M. Pilot. 2014. Unregulated hunting and genetic recovery from a severe population decline: the cautionary case of Bulgarian wolves. Conserv. Genet. 15: 405–417.

Okarma, H. 2015. Grey wolf [in Polish]. H20, Bibice.

Pacheco, C., J.V. López-Bao, E.J. García, F.J. Lema, L. Llaneza, V. Palacios and R. Godinho. 2017. Spatial assessment of wolf-dog hybridization in a single breeding period. Sci. Rep. 7: 1–10.

Packard, J.M., L.D. Mech and U.S. Seal. 1983. Social influences on reproduction in wolves. In: (L.N. Carbyn, ed.) Wolves in Canada and Alaska. Their status biology and management. Canadian Wildlife Service Report Series, pp. 66–77.

Peltola, T. and J. Heikkilä. 2015. Response-ability in wolf–dog conflicts. Eur. J. Wildl. Res. 61: 711–721.

Pilot, M., C. Greco, B.M. vonHoldt, E. Randi, W. Jędrzejewski, V.E. Sidorovich, M.K. Konopiński, E.A. Ostrander and R.K. Wayne. 2018. Widespread, long-term admixture between grey wolves and domestic dogs across Eurasia and its implications for the conservation status of hybrids. Evol. Appl. 11: 662–680.

Randi, E. 2008. Detecting hybridization between wild species and their domesticated relatives. Mol. Ecol. 17: 285–293.

Randi, E. 2011. Genetics and conservation of wolves *Canis lupus* in Europe. Mammal Rev. 41: 99–111.

Randi, E. and V. Lucchini. 2002. Detecting rare introgression of domestic dog genes into wild wolf (*Canis lupus*) populations by Bayesian admixture analyses of microsatellite variation. Conserv. Genet. 3: 31–45.

Randi, E., V. Lucchini, M.F. Christensen, N. Mucci, S.M. Funk, G. Dolf and V. Loeschcke. 2000. Mitochondrial DNA variability in Italian and east European wolves: detecting the consequences of small population size and hybridization. Conserv. Biol. 14: 464–473.

Saetre, P., J. Lindberg, J.A. Leonard, K. Olsson, U. Pettersson, H. Ellegren, T.F. Bergström, C. Vilà and E. Jazin. 2004. From wild wolf to domestic dog: gene expression changes in the brain. Mol. Brain Res. 126: 198–206.

Spassov, N. 2008. Wolf (Canis lupus). In: (S. Miteva, B. Mihova, K. Georgiev, B. Petrov, D. Wansink, eds.) The mammals of conservation importance in Bulgaria. Neo Art, Sofia, pp. 222–233.

Torres, R.T., E. Ferreira, R.G. Rocha and C. Fonseca. 2017. Hybridization between wolf and domestic dog: first evidence from an endangered population in central Portugal. Mamm. Biol. 86: 70–74.

Verardi, A., V. Lucchini and E. Randi. 2006. Detecting introgressive hybridization between free-ranging domestic dogs and wild wolves (*Canis lupus*) by admixture linkage disequilibrium analysis. Mol. Ecol. 15: 2845–2855.

Vilà, C. and R.K. Wayne. 1999. Hybridization between wolves and dogs. Conserv. Biol. 13: 195–198.

Vilà, C., P. Savolainen, J.E. Maldonado, I.R. Amorim, J.E. Rice, R.L. Honeycutt, K.A. Crandall, J. Lundeberg and R.K. Wayne. 1997. Multiple and ancient origins of the domestic dog. Science 276: 1687–1689.

Vilà, C., C. Walker, A.K. Sundqvist, O. Flagstad, Z. Andersone, A. Casulli, I. Kojola, H. Valdmann, J. Halverson and H. Ellegren. 2003. Combined use of maternal, paternal and bi-parental genetic markers for the identification of wolf-dog hybrids. Heredity (Edinb). 90: 17–24.

Wayne, R.K., D.J. Girman, K.P. Koepfli, L.M. Lau, E. Geffen and C.R. Marshall. 1997. Molecular systematics of the Canidae. Syst. Biol. 46: 622–646.

Wierzbowska, I.A., M. Hędrzak, B. Popczyk, H. Okarma and K.R. Crooks. 2016. Predation of wildlife by free-ranging domestic dogs in Polish hunting grounds and potential competition with the grey wolf. Biol. Conserv. 201: 1–9.

Young, J.K., K.A. Olson, R.P. Reading, S. Amgalanbaatar and J. Berger. 2011. Is wildlife going to the dogs? Impacts of feral and free-roaming dogs on wildlife populations. Bioscience 61: 125–132.

Zlatanova, D., E. Popova and A. Stojanov. 2018. Large carnivore monitoring in Osogovo mountain with active participation of local partners – results and analyses. Kyustendil. https://doi.org/10.13140/RG.2.2.31714.02242.

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