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Diet analysis of the grey wolf (*Canis lupus*) in the Western Carpathians

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Abstract. The research was focused on diet preferences of the grey wolf (*Canis lupus*). This involved analysis of scat and microscopic identification of prey based on hair patterns found in the scat. The collection of scat samples for diet was carried out in the High Tatras, but samples were also collected from the Low Tatras. Our diet analysis also confirmed trends in the wolf diet preferences. The most frequent prey species was the Cervidae group, more specifically the red deer (*Cervus elaphus*) and the roe deer (*Caprelous caprelous*), followed by wild boar (*Sus scrofa*).

Key words: grey wolf, prey, diet analysis, hair identification, High Tatras, Low Tatras

Introduction

Large carnivores have an important role in our ecosystem. One of them is predation, an essential ecological function affecting the structure of ecosystems through direct and indirect effects (Ripple *et al.* 2014). Apex predators are essential components of ecosystems and usually dependent on mesophilic herbivores to cover their energy requirements. There are many factors which influence prey selection, such as the abundance of individuals participating in the hunt, vulnerability, and risk, which are influenced by species, behaviour, ecology, and prey availability (Ferretti *et al.* 2019).

Gray wolf (*Canis lupus*) is the largest species of Canidae and the second largest terrestrial predator in Europe after the brown bear (*Ursus arctos*) (Boitani 2000). It is considered to be one of the most distributed large carnivores in the world and has a stabilizing and sanitation role in the ecosystem (Ripple *et al.* 2014). The majority of prey killed by wolves are cubs in their first year of life, old or weakened individuals, or individuals in poor condition during winter (Okarma 1991). Therefore, wolves affect the population status of their prey by eliminating less vital individuals. It is a kind of natural selection that drives evolution (Darwin 2007).

The wolf has a relatively continuous distribution in Slovakia, currently inhabiting most of the eastern and central Slovak mountain ranges, while it also marginally inhabits some mountain ranges in western Slovakia. The Slovak wolf population belongs to a larger population called the Carpathian population, which consists of 340-450 wolves. In fact, the Western Carpathians form a single ecosystem for the wolf including the Czech and Hungarian parts (Kutal and Rigg 2008). The population is also concentrated in the Eastern Carpathians including Poland and Ukraine. A relatively large percentage of wolf packs in the Western Carpathians have territories that have international borders (Kutal and Rigg 2008). The range has increased mainly in the south-central and north-eastern part of western Slovakia. The trend of range expansion is consistent with the fact that the wolf population in Slovakia is stable or increasing (Antal *et al.* 2016).

The wolf, as a generalist and opportunistic predator (Becker *et al.* 2008), is known to display diverse and adaptive foraging strategies across its range (Sin *et al.* 2019), following a geographic pattern. Prey usually consist of large wild ungulates such as elk (*Alces alces*) and reindeer (*Rangifer tarandus*) in northern Europe (Zlatanova *et al.* 2014), and red deer (*Cervus elaphus*) in central and eastern Europe (Jędrzejewski *et al.* 2012). Conversely, typical prey in southern Europe are medium-sized ungulates such as wild boar (*Sus scrofa*) and roe deer (*Capreolus capreolus*) (Petridou *et al.* 2019). In regions with low availability of wild ungulates, they may prey on small wild mammals, fish, and birds (Peterson and Ciucci 2003), but they also turn to anthropogenic resources such as livestock (Petridou *et al.* 2019). In southern European countries, they consume various fruits or berries (Meriggi *et al.* 1991). Plants can be also found in the scat, which helps them to regurgitate excess stomach acids or to get rid of parasites (Duľa 2016).

Because of this feeding behaviour, the wolf has always been considered by humans as a competitor (for wildlife species or livestock) and has been persecuted in a constantly reinforcing conflict which has been presented with various intensity across its range (Boitani *et al.* 2010). Coexistence between large carnivores and humans is possible, but under favourable management policy to avoid a return to unsustainable levels of lethal control, conflicts need to be reduced in ways that are effective and acceptable (Sillero-Zubiri and Laurenson 2001). Therefore, it is crucial to study wolf diet and consequently to assess this impact on areas with wild and domestic prey populations (Petridou *et al.* 2019).

One of the most serious human-carnivore conflicts in Slovakia is livestock loss. It has been frequently argued that "over-populated" wolves started to kill domestic animals as an alternative source of prey when the number of wild animals decreased (Rigg and Gorman 2004). However, losses appear to be lower in Slovakia compared with other areas in Europe. Wolves in Slovakia affect a minority of farms and have an insignificant impact on the agricultural sector (Rigg and Finďo 2000). Several studies have also supported that livestock does not represent a significant part of wolf diet (Rigg and Gorman 2004; Sin *et al.* 2019; Guimarães *et al.* 2022).

Until now, many foreign studies have been carried out to determine the diet preferences of wolves in different types of habitats with various types of prey (e.g., Ferretti *et al.* 2019; Guimarães *et al.* 2022; Lippitsch *et al.* 2024). Understanding and monitoring wolf-prey relationships is important in terms of potential consequences on ecosystems and moreover also concerning human-wolf conflict (Ferretti *et al.* 2019). Nevertheless, there are still regions with poor knowledge about wolf trophic ecology, as in the case of the Slovak Carpathians (Guimarães *et al.* 2022). In Slovakia, several studies have been conducted on diet preferences of wolf (e.g., Strnádová 2002; Rigg and Gorman 2004; Duľa 2016, Guimarães *et al.* 2022). According to Litvaitis *et al.* (1996), it is essential to have an abundance of information about the trophic ecology of a species before management actions are implemented. If large carnivores do not have a major impact on livestock or populations of protected wild animals in a studied area, then predators should not be persecuted on the premise that they are reducing populations of this species.

One of the most common methods for determining the diet preferences of carnivores is hair identification from scat. It consists of collecting scat, from which the majority of prey species is identified according to their contents. Identification of mammalian species by examining hair in the scat is widely used in wildlife ecology, biology, and forensic science (Sari and Arpacik 2018). The challenge of analysing wolf scats is to accurately identify their main prey - red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*) - on the basis of residual hair in the scats, given that they show strong similarity in common qualitative and quantitative traits (Teerink 2003).

Our aim was to determine and analyse the diet of wolf in our selected locality in the Western Carpathians. This aim includes identifying the main components of the wolf's diet, with a particular focus on the role of wild ungulates versus domestic animals, utilizing microscopic identification of hairs from scat samples to identify prey species. For this was used macroscopic and microscopic hair identification of the prey. The results may increase our understanding of the diet preferences of wolf in these localities, which are still poorly studied. It may also contribute to a more positive image of wolves, which are still considered by many people as a dangerous predator that kills herds of cattle and sheep.

Material and Methods

Study area

The research was carried out in Slovakia, in the High Tatras and in some parts of the Low Tatras (Fig. 1). These mountains are part of the Western Carpathian Mountains. The highest peaks are Gerlachovský štít

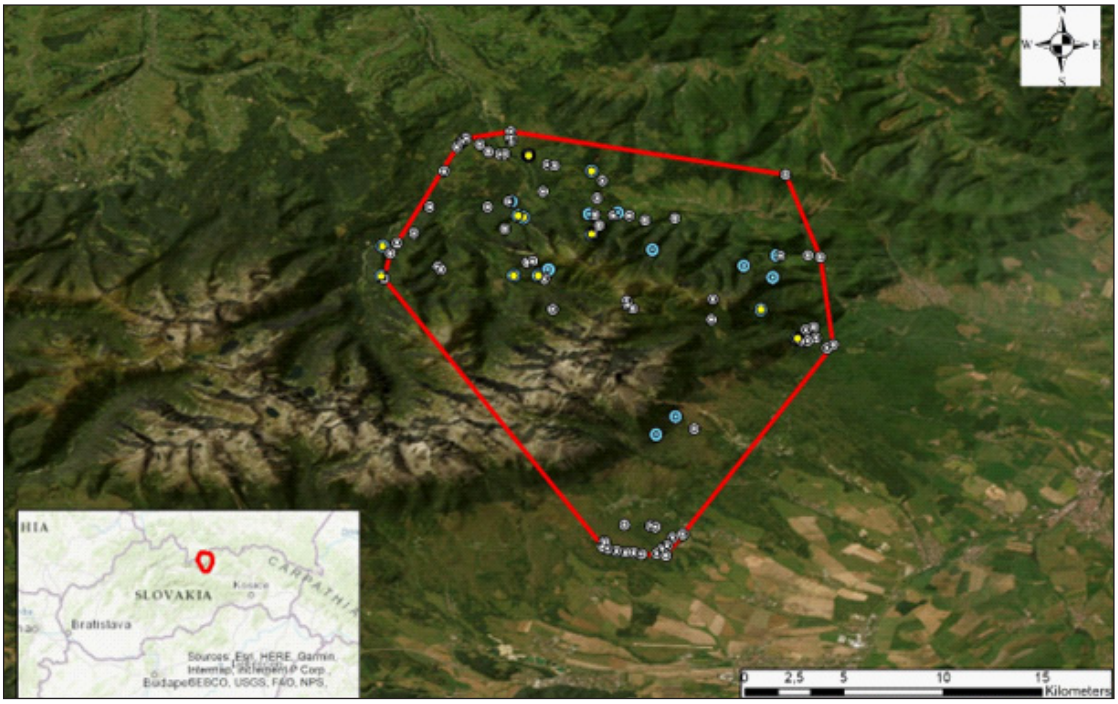

Fig. 1. Map of study area with waypoints: red points for captured videos of wolf occurrence from camera traps, points for all camera traps in the field and blue points for all habit signs of wolf such as scats and footprints. The red border represents a polygon bounded by points with confidence interval 95% (Source: Esri map).

with an altitude of 2655 m a.s.l. (High Tatras) and Ďumbier with an altitude of 2043.4 m a.s.l.

The High Tatras belong to the Carpathian province, more precisely to the sub-province of the Western Carpathians. The area is characterised by high annual atmospheric rainfall and low climatic evaporation. The High Tatras are very variable in terms of habitat. The most typical formation remains of the glacial period are natural lakes (tarns). The dominant tree species is spruce (*Picea abies*). A special feature compared to other mountain ranges in Slovakia is the absence of beech in the central part of the High Tatras, along with a small amount of fir. On the other hand, there is a large proportion of limber pine (*Pinus cembra*) and larch (*Larix decidua*). We can find representatives of foothill, thermophilic, hydrophilic, forest, mountain, and alpine species. The most well-known animal of the High Tatras is Tatra chamois (*Rupicapra rupicapra tatrica*). Among large carnivores, there is currently a relatively strong population of brown bear (*Ursus arctos*), lynx (*Lynx lynx*) and grey wolf (*Canis lupus*) (TANAP 2021).

The Low Tatras as a geomorphological unit belongs to two distinct zones of the central Western Carpathians. The western part of Ďumbier belongs to the zone of core mountains and the eastern Kráľovohoľská part of the Vepor zone. In the Low Tatras we can differentiate five climatic-geographical types. The flora of the Low Tatras includes mainly mountain species, but there are also many alpine plants. The dominant plant community in the Low Tatras is forest, which covers about 70% of the total area. The most widespread are mixed forests with beech (*Fagus sylvatica*), fir (*Abies alba*), spruce (*Picea abies*), mountain maple (*Acer pseudoplatanus*), sycamore (*Acer platanoides*), and ash (*Fraxinus excelsior*). Extensive and relatively well-preserved forest communities provide habitats for large carnivores, including wolf (*Canis lupus*), brown bear (*Ursus arctos*) and lynx (*Lynx lynx*) (Jasík 2004; NAPANT 2021).

Scat collection

We collected scats by opportunistic sampling (routes used by wolves, trails, paths, and dirt roads), by following wolf tracks in the snow (Fig. 2), and by following potential wolf tracks (De Marinis and Asprea 2006). These transects were chosen on the assumption of wolf presence or movement, or by presence of wolves on camera traps. Wolf scat was identified by size (diameter 3 cm), content (large bone fragments, amount of hair) and location of discovery (Fig. 3). Scat samples that were collected were placed in plastic zip-lock bags and labelled with the location of the find, coordinates, date, and, if possible, elevation. The scats were immediately stored in a fridge or in a freezer after collection for processing (depending on whether we analysed them immediately or a few days later). The wolf scats were collected in the High Tatras from autumn 2021 to autumn 2023 (n = 99 scats). We also collected several samples (n = 15 scats) from the Low Tatras, which were included in the study for comparison, despite their smaller quantity compared to other localities. Thus, we had a total of 114 scats for analysis.

Diet analyses

If it was possible, we weighed each scat and measured the volume of scat. The scats were then frozen and stored in the freezer. For analysing the wolf

Fig. 2. Wolf footprints found on transect during tracking around area of High Tatras (Photo: A. Trabalíková, 2021-2023).

Fig. 3. Wolf scat found on transects in area of High Tatras (Photo: A. Trabalíková, 2021).

diet, we used macroscopic and microscopic identification of prey remains (usually hair, but in some cases other remains such as bones or cartilage).

Samples were defrosted, then placed in a bowl with added detergent (ethanol) (Smietana and Klimek 1993). Then they were washed through a sieve with a mesh size of 1.0 mm. Some of the scat samples were already in washed condition because of rain. The remaining material after sieving was placed on a light-coloured plastic mat and dispersed with pincers (Spaulding *et al.* 2000).

Afterwards, macroscopic analysis of scats was done by identification of larger fragments of undigested food such as cartilage, teeth, or hair (Duľa 2016). Then we used microscopic identification of prey species according to taxonomic keys (Teerink 2003; De Marinis and Asprea 2006), as well as by comparison with reference material from the Dipartimento Scienze della vita in Siena. For this we used a microscope Olympus BX40 (Olympus, Japan), using the zoom size 20x. Mammalian hair found in wolf scats was identified by colour, length, texture, and by microscopic examination of the cuticular structure and the medulla (De Marinis and Asprea 2006).

However, red deer and roe deer hair can be more clearly identified when it is a winter coat (Fig. 4, Fig. 5), in some cases it was not possible to determine exactly which species it was. In this case, where it was not possible to differentiate between red deer and roe deer hair in the scat, this hair sample was analysed as Cervidae. The number of particular species presented in scat was determined on the basis of a percentage estimate.

Data processing

Subsequently, we created a data set (diet_data) from identified samples, which contained the following information for each sample: site, locality, elevation, date, coordinates, and percentage of food item. To express the representation of the different food components in scats, we used a parameter of frequency of occurrence (FO). This was expressed as the number of samples containing a given food item to the total number of samples (Duľa 2016). The frequency of occurrence method used in the diet analysis of wolves is a form of descriptive statistics that provides a straightforward empirical summary of data without making inferences or predictions about trends beyond the sampled population. This method calculates the proportion of scat samples containing specific prey types, thus depicting the diet preferences of wolves based on the collected data. Unlike inferential statistics, this method does not involve hypothesis testing or generalization to broader populations; it strictly represents observations within the sample, making it a preferred approach in ecological studies for illustrating the feeding habits of animal species. For each food category and prey species, FO was calculated: FO (%) = (1) n / nscats * 100, where n is the number of scats containing a certain food item and nscats is the total number of samples examined (Lippitsch *et al.* 2024). We also calculated relative frequency of occurrence (RFO).

Results

From our results, we determined that the group Cervidae appeared to be the dominant prey in wolf diet in the area from which we collected scats. Regarding the frequency of occurrence of food item in the scats, we found the following results (Table 1). As we expected, the Cervids group represented the largest proportion of food item (Fig. 6), accounting for up to 92.98%. Closer subdivision of this group into species, we calculated 59.65% for red deer and 20.18% for roe deer. The wild boar represented 22.81%. Two samples of sheep (Low Tatras) were identified, which represented only 1.75%.

For our study we also calculated relative frequency of occurrence (Table 1). The order of prey species was the same, but the values slightly differed. For

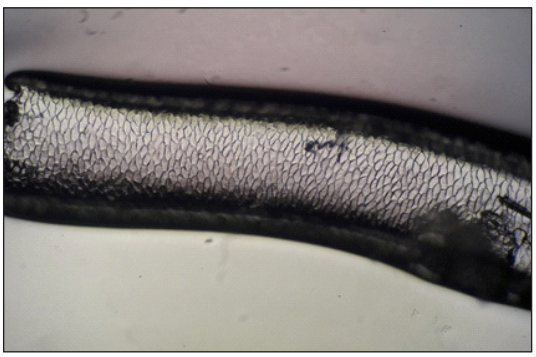

Fig. 4. Sample of roe deer hair from winter coat (short cells) under microscope.

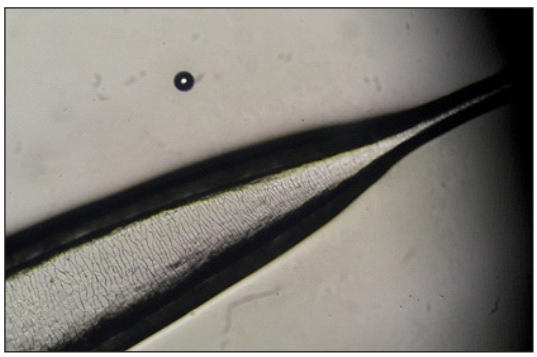

Fig. 5. Sample of red deer hair from winter coat (long cells) under microscope.

Frequency of occurrence (FO)		Relative frequency of occurrence (RFO)	
Food item	%	Food item	%
Red deer	59.65	Red deer	60.71
Roe deer	20.18	Roe deer	20.54
Cervids	92.98	Cervids	94.64
Wild boar	22.81	Wild boar	23.21
Sheep	1.75	Sheep	1.79

Table. 1. On the left: Frequency of occurrence wolf prey in the scats relative to the total number of scats. On the right: Relative frequency of occurrence wolf prey relative to food item (wild ungulates/livestock).

most preferable cervids it was (94.64%), divided on red deer (60.71%) and roe deer (20.54%), then for wild boar (22.81%) and for sheep (1.79%) (Fig. 7).

Discussion

Most studies focused on wolf diet use this method of analysing hair samples from the scats (Debrot *et al.* 1982; Teerink 2003; De Marinis and Asprea 2006). We chose this method of identifying wolf prey on the basis of morphological samples of prey in the scats mainly because of its simplicity and cost-effectiveness. Direct analysis of hard parts is easily available for a wide range of researchers (Casper *et al.* 2007), and morphological analysis can analyse even highly degraded scats, which could not be identified anymore (Tollit *et al.* 2009). A disadvantage is that this method is sometimes limited by human subjectivity, wherein the wrong prey species is identified. False negative results can be also caused by the absence of hair, bones, or other parts of prey in the scat (Mumma *et al.* 2016).

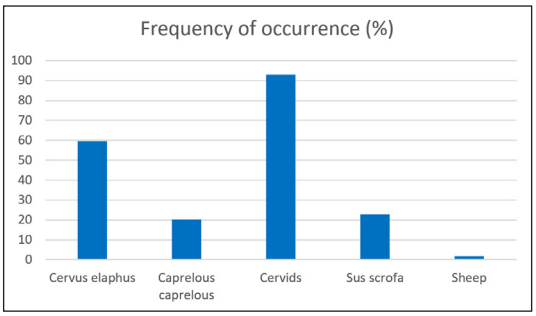

Fig. 6. Plot of frequency of occurrence wolf prey in the scats relative to the total number of scats (wild ungulates or livestock).

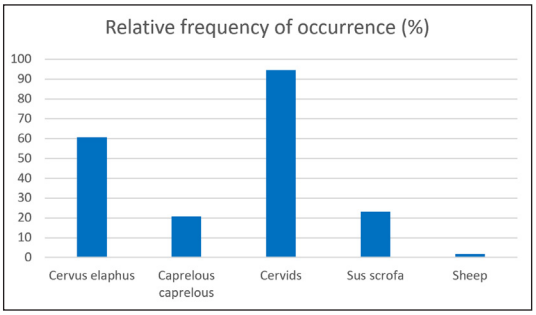

Fig. 7. Plot of relative frequency of occurrence wolf prey relative to food item (wild ungulates or livestock).

Nowadays, molecular methods, which are more accurate but still relatively expensive, are becoming more and more common. For example, in a study by Mumma *et al.* (2016), it was shown that molecular methods identify prey species more precisely. Other molecular studies have shown great promise using real-time PCR to quantify the proportion of prey DNA in the scats as an index proportion of prey in predator diets (Matejusova *et al.* 2008).

The biggest problem in macroscopic and microscopic analysis of hair in a wolf scat is the correct identification of red deer and roe deer hair. These two species have very similar (sometimes almost identical) qualitative traits (colouration, profile, cuticle pattern, pattern of medulla) described in many identification keys used for hair identification of many mammalian species (Debrot 1982). However, they show fewer similarities in comparison of quantitative traits (length, diameter, number of cells in the medulla) in their hair. Nevertheless, we are conscious that the identification of these two species just on the basis of microscopic hair analysis may lead to possible confusion between these two species, as their hair structure and pattern are very similar. For this reason, some studies include the total group of Cervidae in their results. This group then also includes samples where it was not possible to distinguish exactly which species was presented. If a species is not identified by any of the methods, it is then described as "undetermined" (Duľa 2016; Sin *et al.* 2019).

According to some studies from Slovakia, wild ungulates account for more than 90% of the biomass consumed by wolves in Slovakia (Finďo *et al.* 2002; Rigg and Gorman 2004). The main prey species is red deer, followed by wild boar and roe deer. "From these three species, red deer is the preferred prey of wolves in much of Europe" (Guimãres *et al.* 2022). Since we have results in the form of frequency of occurrence (FO) and relative frequency of occurrence (RFO), we were focused mainly on articles that also included them in their study. Our research confirmed the current trends in diet preferences of wolf in Slovakia. In the study completed by Finďo *et al.* (2002) about wolf diet preferences in three areas (eastern Slovak mountains, Tatra Mountains, and the central part of central Slovakia), cervids had a FO with a value of 69%. The second most preferred species was wild boar (21%). Only two samples (one from High Tatras and one from Low Tatras) contained chamois remains, and only one sample contained brown hare remains.

If we compare our results to the latest research on wolf diet preferences in Slovakia (Guimãres *et al.* 2022), it has been shown that wolf prey include mostly wild, large-sized ungulates such as red deer, roe deer, and wild boar. Total frequency of occurrence, which included all four studied areas (Pol'ana, Vepor Mountains, Muráň Planina, National Park, and Poloniny National Park) was 47.7% for red deer, 34.7% for wild boar, and 15.9% for roe deer. So wild ungulates represented 98% FO in total. Concerning livestock, the FO for sheep was

0.6%. Despite conducting research in several localities (whereas we focused on a greater quantity of smaller areas) the preference for wild ungulates as the primary source of wolf diet was once again confirmed. Duľa (2016) also confirmed wolf preference for wild ungulates. For unidentified cervids the value of FO was 51.56%, followed by 4.68% for red deer and 1.56% for red deer. This was followed by wild boar, where FO was 54.68%.

In our study, wild boar was in third place following red deer and roe deer. Strnadová (2000) concluded that wild boar may be locally preferable to cervids. In the Carpathian Mountains, deep snow presents a bigger obstacle for wild boars, which makes them more vulnerable (Strnadová 2000).

We also did not find any sign of rabbits, rodents, or birds in our samples, likely due to the local presence of abundant ungulate prey (Ferretti *et al.* 2019). Alternatively, the quantity of these food sources may be insignificant, and thus not detected in our samples. In the study by Guimãres *et al.* (2022) the amount of brown hare and rodents was not considered significant.

On the other hand, livestock, did not represent a significant component of the wolf diet and only two samples of livestock were found (Guimãres *et al.* 2022), consistent with our study. We found hair of domestic sheep in two samples, and these scats were discovered in the Low Tatras. In Slovakia, the wolf is still often considered to be a dangerous animal that kills livestock on a large scale. However, many studies have contradicted these arguments. According to Rigg and Gorman (2004) even regions with the highest levels of reported losses and during the period when herds are grazing on pastures, livestock is not the main prey of wolf in Slovakia. The low level of predation by wolves on livestock in another study suggests that wolves in Slovakia are not dependent on livestock. Therefore, the argument for public hunting of wolves to prevent high losses of sheep and protect food security in Slovakia has a lack of evidence to support it (Kutal *et al.* 2024).

The number of livestock in the diet of wolves is small, but attacks on livestock, especially sheep, are quite frequent during the grazing season. Farms with properly utilised guard dogs tend to have significantly fewer losses than other farms. Compensation for damage caused by wolves has been available since 2003, but farmers and shepherds still tend to have a negative attitude toward them (Wechselberger *et al.* 2005).

Wolves primarily focused on larger prey rather than on smaller prey. If we consider studies from our neighbouring countries with similar habitats and climate, we can see the following data. Research of Jędrzejewski *et al.* (2012), done in Poland, again showed a preference for red deer (FO = 59.9%) in the wolf diet. Roe deer (FO = 32.6%) and wild boar (FO = 5.0%) followed next, but wild boar was less preferred. Sin *et al.* 2019, who conducted research in Romania, confirmed a preference for wild ungulates. Frequency of occurrence for wild ungulates was 82.59% in total. However, different results were observed. In this case, wild boar (FO = 64.37%) dominated in the diet, followed by roe deer (FO = 14.9%) and red deer (FO = 3.32). Domestic species represented 13.77% of FO in total. Surprisingly, dogs were in first place (FO = 9.72%), followed by goat (FO = 2.31%), sheep (FO = 0.93%), and horse (FO = 0.81%) – likely a carcass. The occurrence of dog in wolf scats was probably due to the higher number of stray dogs wandering in the country. In addition, it has been noticed that domestic ungulates have become less important in the wolf diet in Romania recently.

The shift of domestic prey to wild prey in wolf diet became more common across Europe (Merrigi and Lovari 1996). This is generally associated with an increasing abundance of wild prey and decreasing human activities in mountainous areas (Milanesi *et al.* 2012). In Hungary, research by Lanszki *et al.* 2012 agrees with the preference of wild ungulates and the predominance of wild boar in wolf diet. They calculated relative frequency of occurrence for each study species. The order of importance of wild ungulates was red deer (67.7%) and wild boar (16.1%), followed by roe deer (12.9%), and mouflon (3.2%). Their results are similar to those found in the northern Carpathians. The number of consumed livestock in this study was lower than in other central European studies with similar research (Gula 2008), and much lower than in studies in southern Europe, where wolves may rely on livestock as a food source more extensively (Iliopoulos *et al.* 2009). They also did not observe a preference for hares, whereas in studies in some Mediterranean areas (Salvador and Abad 1987), hares were a seasonally significant prey sources for wolves. In summary, the main prey of wolves returning to the forested mountainous area of northern Hungary consisted primarily of wild ungulates during all seasons during the year.

An additional study in Germany represented by Wagner *et al.* (2012) determined that wolves select mainly wild ungulates as prey (FO = 97.0% in total). However, red deer and wild boar did not dominate in the diet, and instead roe deer (FO = 56.2%) predominated. One reason for this could be that roe deer represents one of the most abundant cervid species in this area and therefore, it is one of the most common prey species encountered by wolves. Furthermore, it is a smaller prey species which has a suitable body size and is not a high risk for wolves when we consider hunting.

A more recent study by Lippitsch *et al.* (2024) carried out in Germany has again confirmed the preference of wild ungulates in wolf diet. Additionally, the diet of wolves in Germany still primarily consists of roe deer and not red deer or wild boar as in the case of other European countries. Roe deer in this study had a frequency of occurrence with a value of 51.1%. It was followed by wild boar with value of 33.5%. Red deer was third with a value of 12.2%. Domestic animals did not represent a significant component of wolf diet, with a frequency of occurrence of only 1.6%.

Conclusion

In this study, the main aim was to analyse the diet of wolves in chosen areas of the High Tatras and in parts of the Low Tatras. To achieve this goal, we analysed several articles for comparison, primarily from Slovakia and neighbouring countries and, in

case of lack of information, also from more distant countries. We analysed wolf scats using microscopic identification of hair from scat samples to identify prey species. From the results of this diet analysis, we obtained information about the role of wild ungulates versus domestic animals in diet preferences of wolves in studied areas.

The diet analysis of wolf scat samples confirmed a current trend in Slovakia as well as in other European countries with a similar climate and landscape structure, that the of wolf individuals was dominated by wild ungulates, and red deer in particular. Wild boar and roe deer were also preferred prey represented in smaller amounts. However, as we did not use the three-cluster distribution method for differentiation between red deer and roe deer hair there are still some questions regarding preference for red deer versus roe deer. The representation of domestic animals in the wolf diet was also confirmed, but constituted a very small percentage of total diet, supporting other studies done in Slovakia with similar results. Thus, in our study areas, domestic animals did not represent the main component of the wolf diet. Nonetheless, wolf is still considered by many people to be a dangerous predator, responsible for killing livestock in large quantities. Thus, it remains important to conduct regular research on the wolf diet. The results from diet analyses studies should be presented more regularly to the public to increase awareness of wolf behaviour. Moreover, the continued presence of a healthy wolf population also helps to regulate overpopulated wild ungulates, which, as we know, devastate the surrounding vegetation. It is very important to note that research on large carnivores, and thus wolves, plays an important role in understanding, representing, and preserving these irreplaceable predators in our ecosystems. We must make informed choices about how we manage these populations in the future as nature, and therefore animals, can survive without us, but we cannot without nature.

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