

Article

Wolf (*Canis lupus*) Predation in Pastoral Livestock Systems: Case Study in Croatia

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Abstract: The predation of livestock by gray wolf (*Canis lupus*; hereafter, wolf) is a problem throughout eastern Europe and poses a threat to sustainable pasture-based livestock production in some areas. In Croatia, farmers have alarmed the public with news of frequent wolf attacks in the last decade, and wolves, as protected animals, are perceived as a pest and a threat. The aim of this study was to analyze and present the frequency of attacks and killed/injured domestic animals in Croatia. During the ten-year period (2010–2020), 13,359 attack events were reported, where it was determined, with certainty, that the attack was by the wolf. In these attacks, 19,111 domestic animals were killed and 4634 were injured. Predation events occurred predominantly (92.71%) in three counties located in southern Croatia (sub-Mediterranean Croatia), whose total area is 11,170 km² (19.74% of the total area of Croatia). The most frequently killed species were sheep (64.78% of all killed animals), which was followed by goats (19.28%) and cattle (9.59%). The highest frequency of attacks and animals killed was recorded in the summer followed by spring and autumn, and the lowest was in winter. The majority of attacks (79.57%) occurred in the morning and during the day. The animal with the highest average number killed per attack was sheep (1.64), which was followed by goats (1.38), cattle (0.99), horses (0.94), donkeys (0.95), and guardian dogs (0.92). During the studied period, in the three counties with the most frequent attacks, 11.72% of the average goat population, 6.34% of the cattle population, and 5.61% of the sheep population were killed. Wolf predation in sub-Mediterranean Croatia presents a threat to the population of domestic ruminants dominantly kept in pastoral livestock systems, and additional efforts need to be made to achieve co-existence between the wolf population and farmers.

Keywords: sheep; goat; cattle; attacks; depredation; sustainable farming; grazing systems



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1. Introduction

In 2021, livestock farming in Croatia accounted for 38.7% of the total income from agricultural production [1]. Intensive livestock production is based on cattle, pig and poultry farms, which are mainly located in the north and east of Croatia, as the arable land is suitable for growing crops. In the mountainous and coastal regions of Croatia, grazing livestock is widespread on the basis of sheep and goat farms and the use of karst pastures (grassland) and silvo pastures [2]. Pastoral livestock systems are used for food production and provide income for rural people, but they also have important ecological (fertilizing the soil with manure, increasing the proportion of grass and density of swards, contributing to overall biological diversification, preventing fires) and cultural functions [3–7]. The domestic animals used in this sustainable pasture-based livestock production system usually belong to one of the endogenous breeds that are part of the traditional culture [8]. The future of karst pastures and the conservation of endogenous breeds depend on each other; therefore, both must be managed in an appropriate manner [4]. A potential threat to pastoral livestock farming and its sustainability has been the recolonization and spread of the protected wolf (*Canis lupus*), which is the most

widespread large carnivore in Central Europe in the EU [8–10]. In general, sheep are most frequently attacked by wolves, which is followed by other livestock such as goats and cattle [11]. Wolf attacks cause stress to livestock, have economic costs, and instill negative attitudes among farmers and parts of the public [12,13]. Intensive efforts are being made to achieve the sustainable co-existence of wolves and pastoral livestock systems [9,13].

In certain parts of Croatia, wolf attacks on domestic animals have been frequently reported in recent years, and it seems that wolves approach households, roam the streets without fear, and seek prey. Farmers perceive wolf population as ‘a plague’ and are distressed by wolves preying on their livestock [14]. Similar trends have been reported in other countries [15–17].

There are nine wolf populations in Europe, of which the Dinaric-Balkan population is the most numerous, along with the Carpathian population. The Croatian wolf population is part of Dinaric-Balkan population, which live in Slovenia, Croatia, Bosnia, Herzegovina, Montenegro, Macedonia, Albania, Serbia, Bulgaria and Greece [18]. The estimated population size in this area is about 3900 individuals [19]. Since 1995, the gray wolf has been on the endangered species list in Croatia and has been placed under strict protection. Hunting is prohibited except with the permission of the competent ministry [20]. In the period from 2005 to 2012, 113 permits were issued to hunt wolves, and 77 were shot (28 out of 53 permits in the Dalmatia region, 21 out of 27 in Lika, 25 out of 27 in Gorski Kotar, and 3 out of 3 in central Croatia). The highest number of permits was issued in Dalmatia, as this is where the highest number of livestock predations was reported. According to the report on the status of the wolf in Croatia [21], no permits have been issued since 2013 due to the estimated decline in the wolf population. In 2013, the wolf population was estimated at a minimum of 142 and a maximum of 212 individuals, i.e., an average of 177 individuals across 49 packs. It is assumed that only 26 packs live permanently within the Croatian territory, while 23 live on the border with Slovenia and Bosnia and Herzegovina [21].

To our knowledge, there are no accurate published data on the frequency and number of wolf attacks on domestic animals in Croatia in recent times. Therefore, the aim of this paper was to analyze number of wolf attacks and number of killed/injured animals depending on different parameters in Croatia.

2. Materials and Methods

2.1. Study Area

According to the official reports of attacks by wolves on domestic animals, eleven counties were identified where attacks occurred. In only three counties (Zadar, Šibenik-Knin and Split-Dalmatia County) were the frequency and number of attacks considered relevant. In two counties (Lika-Senj and Dubrovnik-Neretva County), the frequency and number of attacks were less frequent, while in six counties, predation by wolves can be considered rare and sporadic during the analyzed period. The counties with the most frequent attacks cover a total area of 11,170 km² (Zadar County 3646 km², Šibenik-Knin County 2984 km², Split-Dalmatia County 4540 km²). These counties, together with Dubrovnik-Neretva County (1781 km²), belong to Dalmatia, which is in the southern coastal region of Croatia. The area belongs mainly to the sub-Mediterranean vegetation zone, where pubescent oak (*Quercus pubescens* Willd.) is the predominant forest tree species. In the lower, warmer part, pubescent oak is accompanied by oriental hornbeam (*Carpinus orientalis* Mill.); in the border zone with the holm oak (*Quercus ilex* L.) forests, there are coniferous species of holm oak associations, although rarely is there holm oak. Pubescent oak is often found in combination with other deciduous tree species, such as oriental hornbeam, nettle trees (*Celtis* spp.), manna ash (*Fraxinus ornus* L.) and hop hornbeam (*Ostrya carpinifolia* Scop.). The smaller part of the area belongs to the EU–Mediterranean vegetation zone with stands of holm oak as the predominant forest tree species. The holm oak frequently occurs together with other species such as olive tree (*Olea europaea* L.), carob tree (*Ceratonia siliqua* L.), strawberry tree (*Arbutus unedo* L.), mock privet (*Phillyrea latifolia* L.), Mediterranean buckthorn (*Rhamnus alaternus* L.) and terebinth (*Pistacia terebinthus* L.). Holm oak forests also

include laurel (*Laurus nobilis* L.) and tree heath (*Erica arborea* L.) [22]. The climate is humid, with a mean minimum temperature in the coldest month of less than 2 °C and a mean annual precipitation of more than 1200 mm [22]. The absolute minimum air temperature in the sub-Mediterranean vegetation zone is −11.4 °C, and the absolute maximum air temperature is 38.1 °C. In the EU–Mediterranean zone, the absolute air temperature varies between the absolute minimum of −5.7 °C and the absolute maximum of 38.1 °C. The average annual precipitation in the EU–Mediterranean zone is 933.94 mm, while in the sub-Mediterranean zone, it is 1233.41 mm. The altitude ranges from sea level to 1831 m above sea level [22].

All five counties border with Bosnia and Herzegovina, where wolf migrations across areas is likely to occur.

2.2. Population of Domestic Animal Species

According to the annual reports of the Croatian Agency for Agriculture and Food for the period 2010–2020 [23], the average number of sheep in Croatia, during the studied period, was 579,263, with a minimum of 531,209 in 2014 and a maximum of 617,379 in 2010. The number of sheep in the five counties, most affected by wolf attacks, represents 46.72% of the total sheep population in Croatia (16.54, 12.15, 9.94, 7.47 and 0.82% in Zadar, Lika-Senj, Šibenik-Knin, Split-Dalmatia and Dubrovnik-Neretva County, respectively). The average goat population in Croatia from 2010 to 2020 was 63,107 animals, with the lowest population being 52,093 animals in 2011 and the highest population being 71,872 animals in 2020. The number of goats in the five counties affected by wolf attacks represents 54.99% of the total goat population in Croatia (19.92, 18.70, 10.38, 3.17 and 2.82% in Zadar, Split-Dalmatia, Šibenik-Knin, Lika-Senj and Dubrovnik-Neretva County, respectively). The average number of cattle during the studied period was 473,205, with the lowest number in 2018 (465,111 cattle) and the highest in 2011 (500,193). The number of cattle in the five counties most affected by wolf attacks represents 9.31% of the total cattle population in Croatia (17.93, 11.14, 6.81, 6.35 and 1.85% in Lika-Senj, Split-Dalmatia, Zadar, Šibenik-Knin and Dubrovnik-Neretva County, respectively).

In individual counties, the average number of sheep counted was 26.3 sheep/km², 3.4 goats/km² and 1.87 cattle/km² in Zadar County, 19.5 sheep/km², 2.2 goats/km² and 2.1 cattle/km² in Šibenik-Knin County, and 9.3 sheep/km², 2.5 goats/km² and 2.5 cattle/km² in Split-Dalmatia County. In Dubrovnik-Neretva County, there were 2.6 sheep/km², 1.0 goats/km² and 1.0 cattle/km², and in Lika-Senj County, there were 13.1 sheep/km², 0.4 goats/km² and 3.35 cattle/km².

2.3. Data Collection and Analysis

Official claims for wolf predation must be reported to the Ministry by livestock owners within 24 h. Once the damage/s is/are reported, a kill-site inspection is conducted by trained personnel within three days. The data used in this paper were collected from 1 January 2010 to 31 December 2020 by inspectors following reported attacks on livestock and suspected attacks by wolves. The data are provided by the Ministry of Economy and Sustainable Development (Class: UP/I-008-01/23-03/2; Registry Number: 517-14-2-1-23-1).

The report contains information about the expert and the location of the damage event; the injured party; the damage event according to the injured party; the protection of the animals during the attack according to the farmer/shepherd; signs of the presence of predators and the location of the damage; a description of the animals found and signs of an attack on them (individually); an expert opinion on the damage; and a proposal by the expert for compensation.

The data obtained by the Ministry and included in the analyses were: county, protection methods (taken, partially taken, or not), altitude, distance of damaging event from resident's house, the predator (probable wolf/sure wolf), date of attack, season of attack, time of day of attack, domestic animal species, breed, number of animals killed, and number of animals injured (Figure 1).

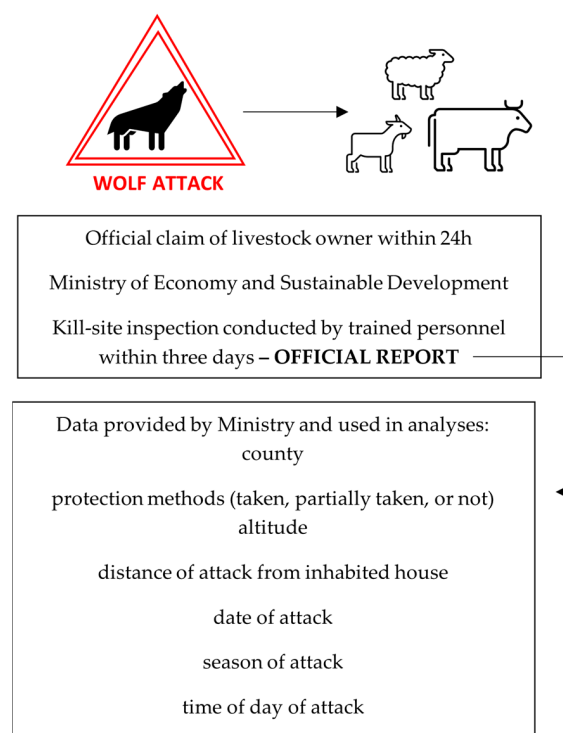


Figure 1. Graphical framework of research process.

Only data where the predator was for certain a wolf were included in the analyses. Of the total number of reports, 1405 cases did not specify the time of day the attack occurred. These reports included 1880 animals killed and 287 animals injured. Seasons were analyzed as autumn (September, October, and November), winter (December, January, February), spring (March, April, May), and summer (June, July, August). Time of day was analyzed as morning (5 a.m. to 8 a.m.), day (8:01 a.m. to 5 p.m.), evening (5:01 a.m. to 9 p.m.), and night (9:01 p.m. to 4:59 a.m.). Altitudes of attacks were analyzed as follows: ≤ 250 m, 251–500 m, and ≥ 501 m. The distance of attacks from the resident's house was analyzed as follows: ≤ 200 m, 200–600 m, 601–1000 m, and ≥ 1001 m.

2.4. Compensation Measures for Wolf Damage

Compensation for wolf damage in Croatia is regulated by two legal acts: the Nature Protection Act and the Special Rulebook [24,25]. Based on these acts, a legal or physical person to whom a wolf may cause economic or other damage (the injured party) is obliged to carry out all permissible measures and interventions in a reasonable manner and at their own expense. This includes effective fencing, targeted holding of goods and their movement to prevent the occurrence of damage. In the case of damage caused by a wolf to domestic animals, the injured party is entitled to compensation in the amount of the actual damage if prescribed actions and measures have been taken. Prescribed actions and measures include the presence of a guardian dog (the Tornjak breed is recommended), an electric fence, and adequate housing for the animals (farmers can receive subsidies for these measures). Herds with more than 25 animals must be supervised by shepherds and guardian dogs. If the farmer has only partially taken the prescribed measures, compensation is reduced by 25% to 50%, and if no measures have been taken, the farmer is not entitled to compensation. The amount of compensation for damage is determined by an agreement between the Ministry of Culture and the injured party on the basis of the findings obtained during the expert examination [26].

2.5. Statistical Analysis

Data were analyzed using SAS V9.4 [27] and R 4.2.2 Software [28].

To determine the frequency of wolf attacks and the number of animals killed and injured per year, season, and time of day, the chi-square goodness-of-fit procedure was used (all values in contingency tables were > 5) and differences in the average number of killed animals were determined by two-way ANOVA. Differences in the number of attacks, killed and injured animals per year was determined using a pairwise nominal independent function (*pnif*) in R 4.2.2 Software.

Using PROC UNIVARIATE in SAS, we found that the data do not fit assumption of a linear model (skewness > 1 and kurtosis > 10). To determine the contribution of independent variables to the average number of killed animals per attack, we used a generalized linear regression model with Poisson distribution (PROC GENMOD). Model output showed that data were overdispersed (the residual deviance divided by the respective degrees of freedom of the model was > 1). Thus, quasi-Poisson regression with PROC GENMOD in SAS was chosen to fit overdispersed data. Models containing all independent variables (year, season, time of day, altitude, protection measures, distance of damaging event from resident's house) and different available link functions (cloglog, log, logit, probit, identity, inverse, powerminus2, power2) were made in order to find best model. The model with the link function 'log' resulted in the lowest AIC value and was chosen to best fit the data. Independent variables that had no contribution to the model ($p > 0.05$) were excluded from the model. The goodness-of-fit of the model was made with a chi-square test based on the residual deviance and degrees of freedom. The quasi-F value was calculated using null and residual deviance and degrees of freedom.

3. Results

During the period between 2010 and 2020, 13,359 attack events were reported that were determined with certainty to be wolf attacks. Overall, 19,111 individuals were killed and 4634 were injured. Damage to two or three different species of animals during the same attack was reported in $n = 573$ (4.29%) cases, and a total of $n = 931$ (4.87%) animals ($n = 538$ sheep (57.79%), $n = 309$ goats (33.19%), and $n = 37$ dogs (3.97%)) were killed and $n = 258$ (5.57%) were injured ($n = 137$ sheep (53.10%), $n = 86$ goats (33.33%) and $n = 22$ dogs (8.53%)).

Attacks were reported from eleven Croatian counties, but only five counties can be considered areas of permanent wolf predation (Figure 2). The highest number of wolf attacks ($n = 12,385$; 92.71%) occurred in Šibenik-Knin ($n = 5024$ or 37.61%), Split-Dalmatia ($n = 4865$ or 36.42%) and Zadar County ($n = 2495$ or 18.68%) and less frequently in Lika-Senj and Dubrovnik-Neretva County ($n = 519$ or 3.89% and $n = 296$ or 2.22%, respectively). In these counties, the number of domestic animals killed was the highest in Split-Dalmatia County ($n = 6760$ or 35.37%), which was followed by Šibenik-Knin ($n = 6466$ or 33.83%), Zadar ($n = 3999$ or 20.93%), Lika-Senj ($n = 978$ or 5.12%) and Dubrovnik-Neretva County ($n = 463$ or 2.42%). The number of injured animals was the highest in Šibenik-Knin County ($n = 1674$ or 39.51%), which was followed by Zadar ($n = 1456$ or 34.36%), Split-Dalmatia ($n = 815$ or 19.24%) and Lika-Senj County ($n = 180$ or 4.25%).

The frequency of total attack events differed significantly between years ($\chi^2 = 104.82$, $df = 10$, $p < 0.0001$) (Figure 3). The *pnif* analysis showed a significant difference in total attack events between 2010 and 2015, 2018 (*pnif*, $p = 0.05$) and 2020 (*pnif*, $p = 0.0001$). The number of total attack events differed significantly between 2011 and 2015, 2018 and 2019 (*pnif*, $p = 0.01$), and 2020 (*pnif*, $p = 0.0001$). A significant difference in the number of total attack events was found between 2012 and 2015 and 2018 (*pnif*, $p = 0.005$), 2016 (*pnif*, $p = 0.05$), 2019 (*pnif*, $p = 0.01$), and 2020 (*pnif*, $p = 0.0001$). The number of total attack events differed significantly between 2013 and 2015 and 2018 (*pnif*, $p = 0.01$), 2019 (*pnif*, $p = 0.05$), and 2020 (*pnif*, $p = 0.0001$). A significant difference in the total attack events was found between 2014 and 2015 (*pnif*, $p = 0.05$) and 2020 (*pnif*, $p = 0.0001$). The number of total attack events was significantly different between 2015 and 2017 (*pnif*, $p = 0.05$) and 2020 (*pnif*, $p = 0.0001$). During 2016, we found a significantly different number of total attack events compared to 2020 (*pnif*, $p = 0.0001$). The number of total attack events was significantly

different between 2017 and 2018 and 2019 (*pnif*, $p = 0.05$), and 2020 (*pnif*, $p = 0.0001$). During 2018 and 2019, we found a significant difference in the number of total attack events compared to 2020 (*pnif*, $p = 0.0001$). The frequency of all killed and injured animals also differed significantly between years ($\chi^2 = 91.14$, $df = 10$, $p < 0.0001$ and $\chi^2 = 158.42$, $df = 10$, $p < 0.0001$, respectively). The *pnif* analysis showed a significant difference in the number of killed animals between 2010 and all other years (*pnif*, $p = 0.001$) except 2020 (*pnif*, $p = 0.0551$). A significant difference in the number of killed animals was found between 2011 and other years (*pnif*, $p = 0.0001$), 2012 (*pnif*, $p = 0.05$) and 2014 (*pnif*, $p = 0.005$). The number of killed animals was significantly different between 2012 and 2015 (*pnif*, $p = 0.001$), 2016 (*pnif*, $p = 0.005$), 2018 (*pnif*, $p = 0.01$) and 2020 (*pnif*, $p = 0.0001$). During 2013, the number of killed animals significantly differed compared to 2015 and 2016 (*pnif*, $p = 0.05$), and 2020 (*pnif*, $p = 0.0001$). An analysis showed a significantly different number of killed animals between 2014 and 2015 and 2016 (*pnif*, $p = 0.01$), 2018 (*pnif*, $p = 0.05$), and 2020 (*pnif*, $p = 0.0001$). During 2015 and 2016, the number of killed animals was significantly different than in 2019 (*pnif*, $p = 0.005$) and 2020 (*pnif*, $p = 0.0001$). The number of killed animals during 2017 was significantly different from that during 2020 (*pnif*, $p = 0.0001$). A significant difference was found in the number of killed animals during 2018 and 2019 (*pnif*, $p = 0.01$) and 2020 (*pnif*, $p = 0.0001$). A significant difference was found between 2019 and 2020 (*pnif*, $p = 0.0001$).

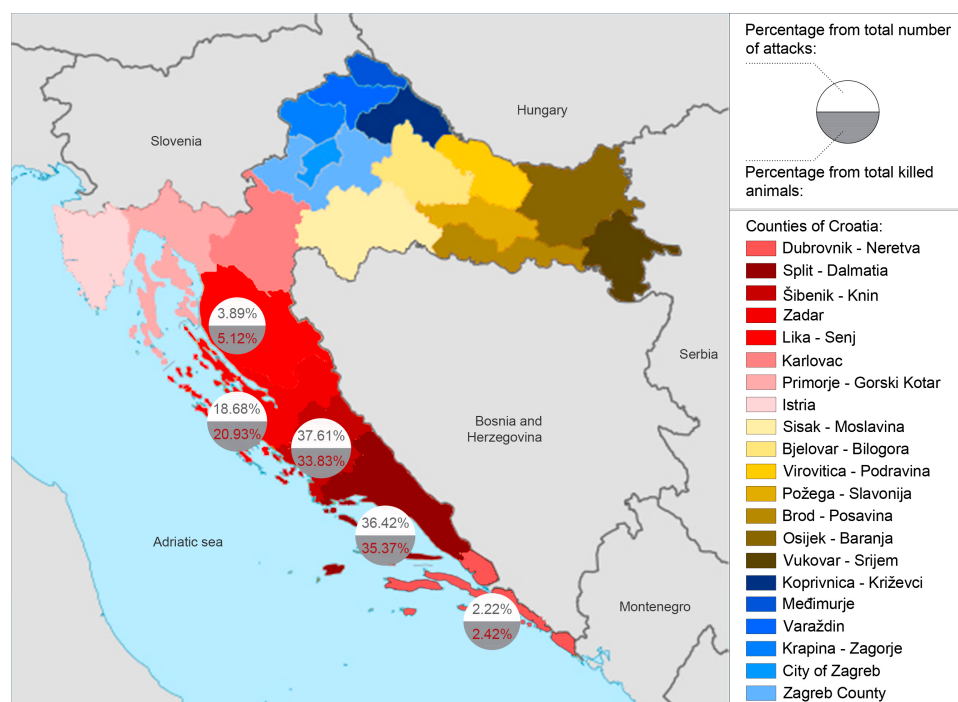


Figure 2. Map of counties in Croatia with highest frequency of wolf attacks on domestic animals.

Regarding the number of injured animals, the *pnif* analysis showed a significant difference between 2010 and 2012 and 2013 (*pnif*, $p = 0.01$), and all other years (*pnif*, $p = 0.0001$), except 2014 (*pnif*, $p = 0.0847$). The number of injured animals during 2011 significantly differed from the majority of analyzed years (*pnif*, $p = 0.05$) except for 2016 (*pnif*, $p = 0.946$) and 2017 (*pnif*, $p = 0.220$). A significant difference in the number of injured animals was found between 2012 and 2015, 2017, 2018, 2019 and 2020 (*pnif*, $p = 0.0001$), and 2016 (*pnif*, $p = 0.01$). During 2013, the number of injured animals was significantly different from the number in 2015, 2017, 2018, 2019 and 2020 (*pnif*, $p = 0.0001$), and 2016 (*pnif*, $p = 0.005$). During 2014, the number of injured animals was significantly different from the number in 2015, 2016, 2017, 2018, 2019 and 2020 (*pnif*, $p = 0.0001$). A significant difference in the number of injured animals was found between 2015 and 2016 and 2019 (*pnif*, $p = 0.0001$), 2017 (*pnif*, $p = 0.005$) and 2020 (*pnif*, $p = 0.05$). During 2016, the number of injured

animals was significantly different than in 2018 and 2019 (*pnif*, $p = 0.0001$), and 2020 (*pnif*, $p = 0.05$). In 2017, the number of injured animals was significantly different than in 2018 and 2019 (*pnif*, $p = 0.001$). In 2018, the number of injured animals was significantly different than in 2019 (*pnif*, $p = 0.005$) and 2020 (*pnif*, $p = 0.01$), while in 2019, it was significantly different than in 2020 (*pnif*, $p = 0.0001$). The highest number of attacks and killed animals was reported in 2020.

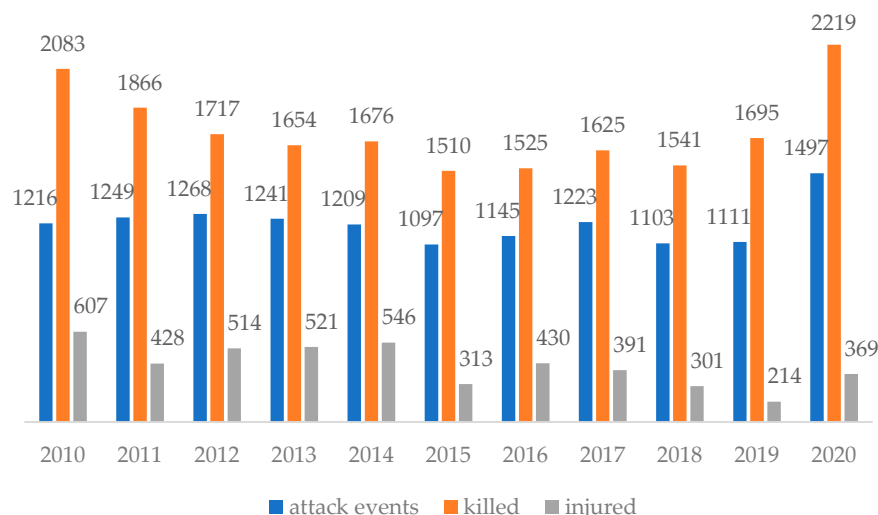


Figure 3. Number of wolf attacks and number of killed and injured animals per year.

The most frequently attacked domestic animal species in Croatia is sheep, with 64.88% of all animals killed and 72.21% of all animals injured in the studied period (Figure 4). In second place is the goat with a very similar frequency of killed and injured animals (19.30% and 19.05%, respectively), while cattle is in third place with 9.59% of all killed animals and 4.70% of all injured animals. Other domestic animals, i.e., donkeys, horses, pigs and guardian dogs were attacked less frequently (Figure 5) with 1.38, 0.62 and 0.04% of all animals killed and 1.17%, 0.60% and 0.15% of all animals injured, respectively. The frequency of guardian dogs killed was 4.23% and those injured constituted 2.09% of all predator attacks reported.

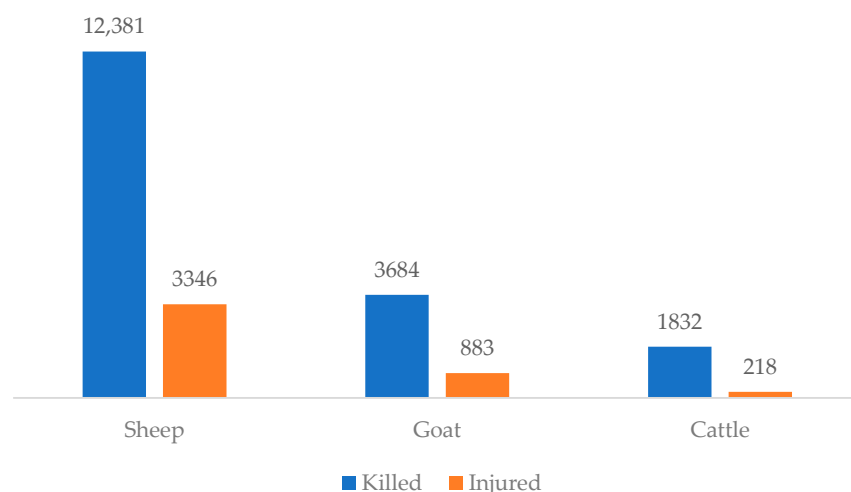


Figure 4. Number of killed and injured animals per most frequently attacked species during period 2010–2020.

The frequency of sheep killed was significantly different among the years studied ($\chi^2 = 56.07$, $df = 10$, $p < 0.0001$) with the lowest value reported in 2018 and the trend increasing from 2018 to 2020 (Figure 6). The *pnif* analysis showed a significant difference

in the number of killed sheep between 2010 and other analyzed years (*pnif*, $p = 0.0001$; 2020 $p = 0.005$). In 2011, the number of killed sheep was significantly different from that in 2013, 2014, 2015, 2016, 2017, 2018 and 2019 (*pnif*, $p = 0.0001$). The number of killed sheep was significantly different between 2012 and 2014 (*pnif*, $p = 0.05$), 2019 (*pnif*, $p = 0.01$), 2020 (*pnif*, $p = 0.001$), and 2015, 2016, 2017 and 2018 (*pnif*, $p = 0.0001$). A significant difference was found in the number of killed sheep between 2013 and 2015 and 2017 (*pnif*, $p = 0.01$), and 2016, 2018 and 2020 (*pnif*, $p = 0.0001$). In 2014, the number of killed sheep was significantly different than in 2015 and 2017 (*pnif*, $p = 0.05$), 2016 (*pnif*, $p = 0.001$), and 2018 and 2020 (*pnif*, $p = 0.0001$). In 2016, the number of killed sheep was significantly different than in 2019 (*pnif*, $p = 0.01$) and 2020 (*pnif*, $p = 0.0001$). The number of killed sheep was significantly different between 2017 and 2018 (*pnif*, $p = 0.05$) and 2020 (*pnif*, $p = 0.0001$). In 2018, the number of killed sheep was significantly different than in 2019 and 2020 (*pnif*, $p = 0.0001$) as well as between 2019 and 2020 (*pnif*, $p = 0.0001$).

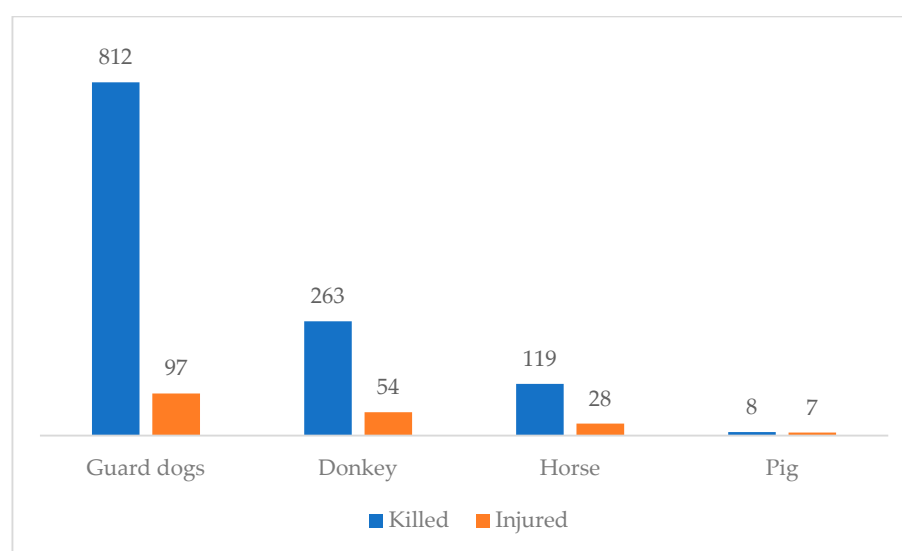


Figure 5. Number of killed and injured animals per less frequently attacked species during period 2010–2020.

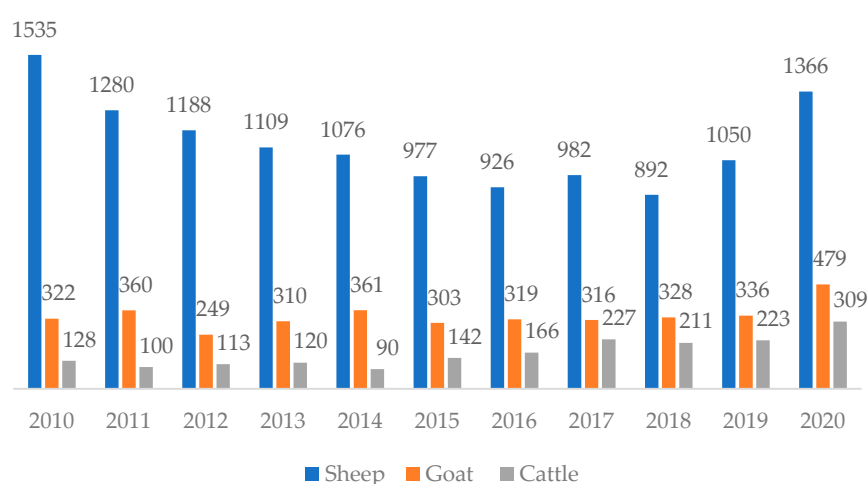


Figure 6. Number of killed sheep, goat and cattle during period 2010–2020.

The frequency of goats killed also differed significantly ($\chi^2 = 39.30$, $df = 10$, $p < 0.0001$) among the analyzed years, with the lowest number reported in 2012, and the trend increasing through 2020. The *pnif* analysis showed a significant difference in the number of killed goats between 2010 and 2012 (*pnif*, $p = 0.01$) and 2020 (*pnif*, $p = 0.0001$). The number of killed goats in 2011 was significantly different than in 2012 (*pnif*, $p = 0.0001$) and 2020

(*pnif*, $p = 0.001$). In 2012, the number of killed goats was significantly different than in 2013 and 2017 (*pnif*, $p = 0.05$), 2016 and 2018 (*pnif*, $p = 0.01$), 2019 (*pnif*, $p = 0.001$), and 2014 and 2020 (*pnif*, $p = 0.0001$). In 2013, 2014, 2015, 2016, 2017, 2018 and 2019, the number of killed goats was significantly different than in 2020 (*pnif*, $p = 0.0001$).

The frequency of cattle killed differed significantly ($\chi^2 = 24.61$, $df = 10$, $p = 0.006$) between years, with the lowest number reported in 2011 and the trend increasing toward 2020. The *pnif* analysis showed a significant difference in the number of killed cattle between 2010 and 2014 and 2016 (*pnif*, $p = 0.05$), 2017, 2018, 2019 and 2020 (*pnif*, $p = 0.0001$). In 2011, the number of killed cattle was significantly different from 2015 (*pnif*, $p = 0.01$) as well as 2016, 2017, 2018, 2019 and 2020 (*pnif*, $p = 0.0001$). The number of killed cattle significantly differed between 2012 and 2016 (*pnif*, $p = 0.005$), and 2017, 2018, 2019 and 2020 (*pnif*, $p = 0.0001$). In 2013, the number of killed cattle significantly differed from the number in 2016 (*pnif*, $p = 0.01$) as well as in 2017, 2018, 2019 and 2020 (*pnif*, $p = 0.0001$). In 2014, the number of killed cattle was significantly different from 2015 (*pnif*, $p = 0.001$) as well as in 2016, 2017, 2018, 2019 and 2020 (*pnif*, $p = 0.0001$). A significant difference was found in the number of killed cattle between 2015 and 2017, 2019 and 2020 (*pnif*, $p = 0.0001$) as well as 2018 (*pnif*, $p = 0.0005$). The number of killed cattle in 2016 was significantly different from that in 2017 (*pnif*, $p = 0.005$), 2018 (*pnif*, $p = 0.05$), 2019 (*pnif*, $p = 0.01$) and 2020 (*pnif*, $p = 0.0001$). In 2017, 2018 and 2019, the number of killed cattle was significantly different than that in 2020 (*pnif*, $p = 0.001$).

The number of wolf attacks and the number of animals killed and injured per season are shown in Figure 7. A significant difference was found in the frequency of animals killed ($\chi^2 = 16.00$, $df = 3$, $p = 0.001$) and injured ($\chi^2 = 25.71$, $df = 3$, $p < 0.0001$) per season, with the highest frequency in summer, followed by spring and autumn, and the lowest was in winter. The *pnif* analysis showed a significant difference in the number of killed animals between autumn and winter (*pnif*, $p = 0.0001$), autumn and spring (*pnif*, $p = 0.05$), autumn and summer (*pnif*, $p = 0.0001$), winter and spring (*pnif*, $p = 0.0001$), winter and summer (*pnif*, $p = 0.0001$) and spring and summer (*pnif*, $p = 0.0001$). The *pnif* analysis showed a significant difference in the number of injured animals between autumn and winter (*pnif*, $p = 0.0001$), autumn and spring (*pnif*, $p = 0.0001$), autumn and summer (*pnif*, $p = 0.0001$), winter and spring (*pnif*, $p = 0.0001$), winter and summer (*pnif*, $p = 0.0001$) and spring and summer (*pnif*, $p = 0.0001$).

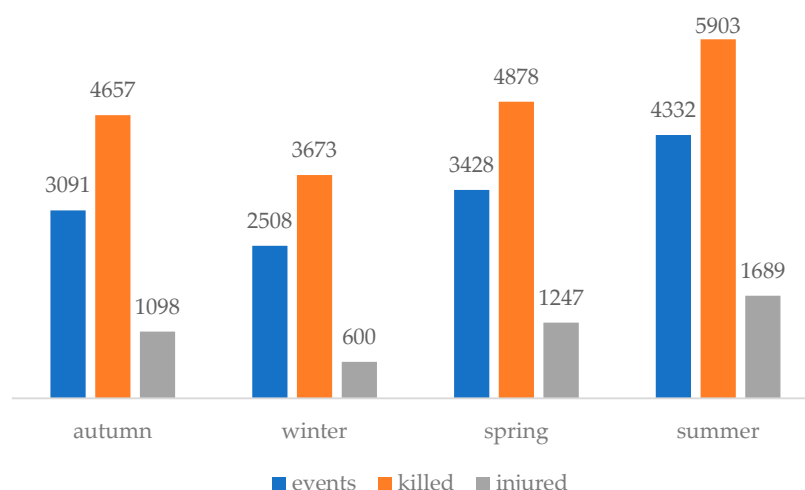


Figure 7. Total number of wolf attack events, killed and injured animals per season.

The frequency of attacks was significantly different by season ($\chi^2 = 57.14$, $df = 3$, $p < 0.0001$) and followed the same pattern as the number of animals killed and injured. The *pnif* analysis showed a significant difference in the number of attacks between autumn and winter (*pnif*, $p = 0.0001$), autumn and spring (*pnif*, $p = 0.0001$), autumn and summer (*pnif*,

$p = 0.0001$), winter and spring ($pnif, p = 0.0001$), winter and summer ($pnif, p = 0.0001$) and spring and summer ($pnif, p = 0.0001$).

The frequency of sheep killed according to season differed significantly ($\chi^2 = 98.34$, $df = 3$, $p < 0.0001$) with the lowest number killed in winter and the highest in summer (Figure 8). The $pnif$ analysis showed a significant difference in the number of killed sheep between autumn and winter ($pnif, p = 0.0001$), autumn and spring ($pnif, p = 0.0001$), autumn and summer ($pnif, p = 0.0001$), winter and spring ($pnif, p = 0.0001$), winter and summer ($pnif, p = 0.0001$) and spring and summer ($pnif, p = 0.0001$).

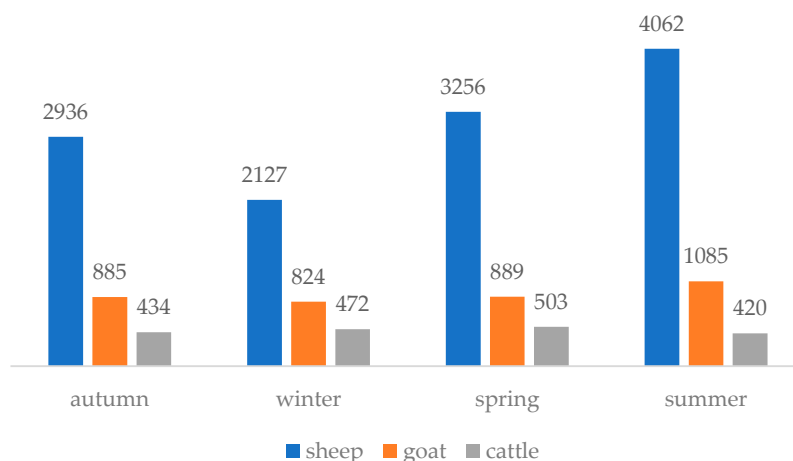


Figure 8. Number of killed most attacked domestic species per season.

The frequency of goats killed differed significantly ($\chi^2 = 13.21$, $df = 3$, $p = 0.0042$) between seasons, with the highest number killed in summer compared to the other seasons. The $pnif$ analysis showed a significant difference in the number of killed goats between autumn and summer ($pnif, p = 0.0001$), winter and summer ($pnif, p = 0.0001$), and spring and summer ($pnif, p = 0.0001$). However, an absence of significance was observed between autumn and winter ($pnif, p = 0.140$), autumn and spring ($pnif, p = 0.924$) and winter and spring ($pnif, p = 0.116$).

The frequency of cattle also differed significantly between seasons ($\chi^2 = 13.50$, $df = 3$, $p = 0.0037$), with the number of cattle killed being lower in autumn and summer compared to winter and spring (Figure 7). The $pnif$ analysis showed a significant difference in the number of killed cattle between autumn and spring ($pnif, p = 0.0242$) and spring and summer ($pnif, p = 0.0063$). However, the absence of significance was observed between autumn and winter ($pnif, p = 0.2070$), autumn and summer ($pnif, p = 0.6320$), winter and spring ($pnif, p = 0.3210$) and winter and summer ($pnif, p = 0.0817$).

In dogs, summer and autumn were also the seasons with the highest number of animals killed, which was followed by winter and spring ($\chi^2 = 61.78$, $df = 3$, $p < 0.0001$; not shown in Figure 7). The same distribution between seasons was found for the frequency of injured sheep, and the differences were significant ($\chi^2 = 11.96$, $df = 3$, $p = 0.0075$), similar to injured goats ($\chi^2 = 95.81$, $df = 3$, $p < 0.0001$) and injured cattle ($\chi^2 = 30.69$, $df = 3$, $p < 0.0001$; not shown in Figure 8). In the less frequently attacked species, the same distribution by season was found for injured donkeys ($\chi^2 = 24.96$, $df = 3$, $p < 0.0001$) and dogs ($\chi^2 = 8.44$, $df = 3$, $p = 0.038$) as for all killed animals.

The frequency of all attacks differed significantly ($\chi^2 = 53.83$, $df = 3$, $p < 0.0001$) between parts of day, with the number of attacks being highest in the morning and during the day as compared to the evening and night (Figure 9). The $pnif$ analysis showed a significant difference in the number of attack events between morning and day ($pnif, p = 0.0001$), morning and evening ($pnif, p = 0.0001$), morning and night ($pnif, p = 0.0001$), day and evening ($pnif, p = 0.0001$), day and night ($pnif, p = 0.0001$) and evening and night ($pnif, p = 0.0001$).

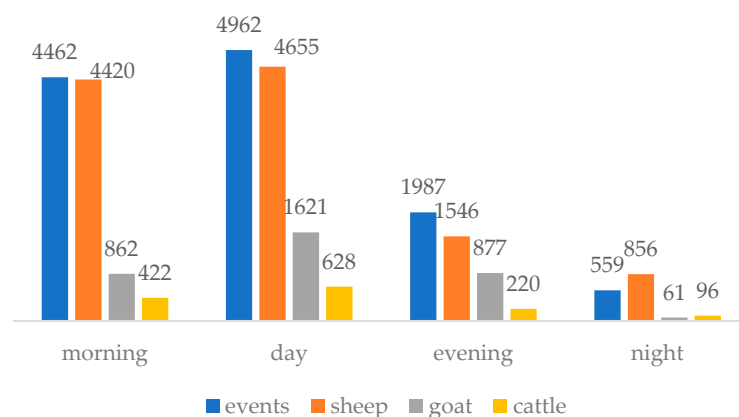


Figure 9. Number of attack events and killed animals per time of the day.

A similar distribution was found for the frequency of killed sheep ($\chi^2 = 133.38$, $df = 3$, $p < 0.0001$) and cattle ($\chi^2 = 13.83$, $df = 3$, $p = 0.0031$), while for goats, the frequency was highest during the day, but with a similar distribution during the morning and evening ($\chi^2 = 75.73$, $df = 3$, $p < 0.0001$), as compared to the night. The *pnif* analysis showed a significant difference in the number of killed sheep between morning and day (*pnif*, $p = 0.05$), morning and evening (*pnif*, $p = 0.0001$), morning and night (*pnif*, $p = 0.0001$), day and evening (*pnif*, $p = 0.0001$), day and night (*pnif*, $p = 0.0001$) and evening and night (*pnif*, $p = 0.0001$). Regarding the number of killed goats, a significant difference was found between morning and day (*pnif*, $p = 0.0001$), morning and night (*pnif*, $p = 0.0001$), day and evening (*pnif*, $p = 0.0001$), day and night (*pnif*, $p = 0.0001$) and evening and night (*pnif*, $p = 0.0001$). The absence of significance was observed between morning and evening (*pnif*, $p = 0.719$). The number of killed cattle was significantly different between morning and day (*pnif*, $p = 0.0001$), morning and evening (*pnif*, $p = 0.0001$), morning and night (*pnif*, $p = 0.0001$), day and evening (*pnif*, $p = 0.0001$), day and night (*pnif*, $p = 0.0001$) and evening and night (*pnif*, $p = 0.0001$).

The frequency of dogs killed differed significantly ($\chi^2 = 41.53$, $df = 3$, $p < 0.0001$) between parts of day, with higher values in the morning, day and night (29.52, 29.22 and 26.96%, respectively) than in the evening (14.321%; not shown in Figure 9).

The changes in the frequency of sheep killed according to the part of the day within the season are shown in Figure 10. The frequency of sheep killed during morning attacks differed significantly ($\chi^2 = 22.20$, $df = 3$, $p < 0.0001$) among seasons, being significantly different between autumn and winter (*pnif*, $p = 0.0001$), autumn and spring (*pnif*, $p = 0.0001$), autumn and summer (*pnif*, $p = 0.0001$), winter and spring (*pnif*, $p = 0.0001$), winter and summer (*pnif*, $p = 0.0001$) and spring and summer (*pnif*, $p = 0.0001$). Attacks during the day resulted in a significantly different number of sheep killed ($\chi^2 = 39.06$, $df = 3$, $p < 0.0001$) between seasons. Namely, a significant difference was found autumn and winter (*pnif*, $p = 0.0083$), autumn and spring (*pnif*, $p = 0.0001$), autumn and summer (*pnif*, $p = 0.0001$), winter and spring (*pnif*, $p = 0.0001$), winter and summer (*pnif*, $p = 0.0001$) and spring and summer (*pnif*, $p = 0.0001$). A significantly different number of sheep were killed in evening attacks during different seasons ($\chi^2 = 16.17$, $df = 3$, $p = 0.0010$); a significant difference was found between autumn and winter (*pnif*, $p = 0.0001$), autumn and spring (*pnif*, $p = 0.0001$), autumn and summer (*pnif*, $p = 0.0001$), winter and spring (*pnif*, $p = 0.0001$), winter and summer (*pnif*, $p = 0.0001$) and spring and summer (*pnif*, $p = 0.0001$). The number of sheep killed during the night was significantly different ($\chi^2 = 138.36$, $df = 3$, $p < 0.0001$) between seasons; a significant difference was found between autumn and spring (*pnif*, $p = 0.0001$), autumn and summer (*pnif*, $p = 0.0001$), winter and spring (*pnif*, $p = 0.0001$), and winter and summer (*pnif*, $p = 0.0001$). An absence of significance was found between autumn and winter (*pnif*, $p = 0.803$) and spring and summer (*pnif*, $p = 0.806$).

The frequency of goats killed per part of day within the season was similar to sheep (not shown in Figure 10). The exception was the higher number of goats killed during the

day in the winter compared to the other seasons ($\chi^2 = 8.23$, $df = 3$, $p = 0.0415$). For cattle, it was found that the frequency of killed animals during evening attacks was the same in the spring and summer, and the number of killed cattle during night attacks was not different in all seasons ($\chi^2 = 3.25$, $df = 3$, $p = 0.3547$; not shown in Figure 10).

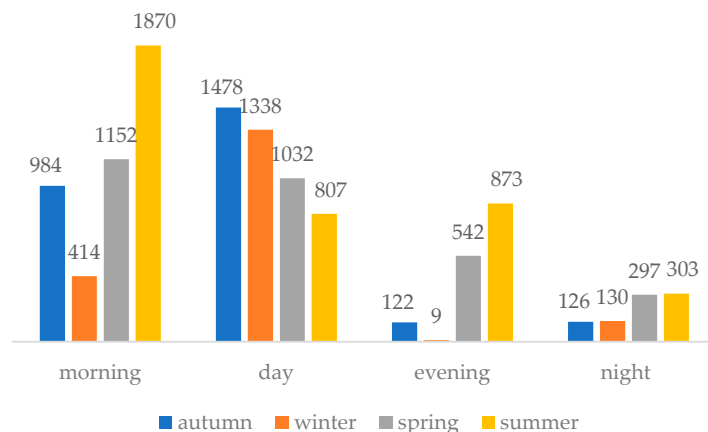


Figure 10. Number of killed sheep during different parts of the day per season.

The average number of animals killed per attack was significantly different by species ($F = 65.25$, $df = 5$, $p < 0.0001$), with the highest value for sheep and goats (Figure 11). Compared to the total number of horses, donkeys, and dogs killed, the average number of animals killed per attack was high for these species. According to quasi-Poisson regression analysis, the average number of killed animals per attack during analyzed period showed a significant trend ($Y = 1.365 + 0.994x\text{year} + 0.966x\text{season} + 1.15x\text{status of protection measures} + 0.944x\text{species} + 1.074x\text{altitude}$; quasi-F value = 61.77, $p = 0.0001$).

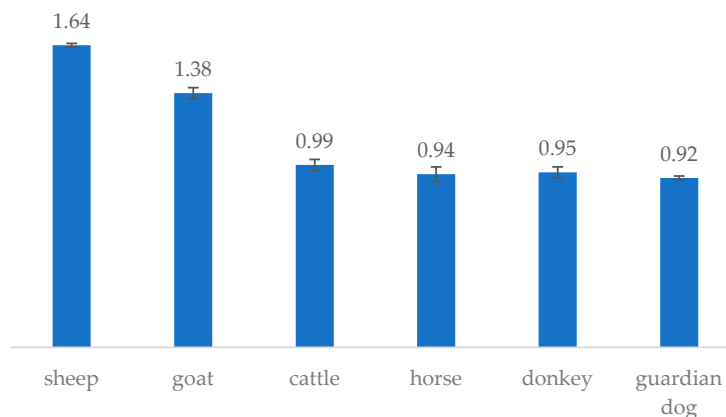


Figure 11. Average number of killed animals per attack.

The average number of sheep killed per attack was higher in autumn and winter ($F = 10.25$, $df = 3$, $p < 0.0001$) than in spring and summer. A similar result was found for goats ($F = 16.87$, $df = 3$, $p < 0.0001$), while the average number of cattle killed per attack was higher in winter and spring than in fall and summer ($F = 8.38$, $df = 3$, $p < 0.0001$; Figure 12).

The average number of sheep killed per attack was higher at night ($F = 60.71$, $df = 3$, $p < 0.0001$) than during the day, evening, and morning, respectively; similar results were found for goats ($F = 10.92$, $df = 3$, $p < 0.0001$) but not for cattle ($F = 1.06$, $df = 3$, $p = 0.3638$; Figure 13).

Domestic animals were predominantly killed and injured while grazing (87.86% and 84.72%, respectively). Overall, 32.97% of attacks occurred at altitudes below 250 m, 49.46% occurred at 251–500 m, and 17.57% occurred above 501 m. The frequency of all animals killed below 250 m was 32.38%, while 46.99% were at 251–500 m and 20.63% were above 501 m. The frequency of attacks depending on the distance from the resident's house was

distributed as follows: 21.13% of attacks occurred within 200 m, 22.97% occurred within 201–600 m, 21.11% occurred within 601–1000 m, and 34.79% occurred within more than 1001 m from the resident's house. The frequency of all animals killed at different distances from the residence was 21.86%, 21.76%, 20.05%, and 36.32% for distances ≤ 200 m, 201–600 m, 601–1000 m, and ≥ 1001 m, respectively. The frequency of sheep killed with increasing distance from the resident house was 24.33%, 23.00%, 19.47% and 33.20%, for goats, it was 13.90%, 19.01%, 24.03% and 43.06%, and for cattle, it was 13.23%, 16.68%, 17.39% and 52.71%, respectively.

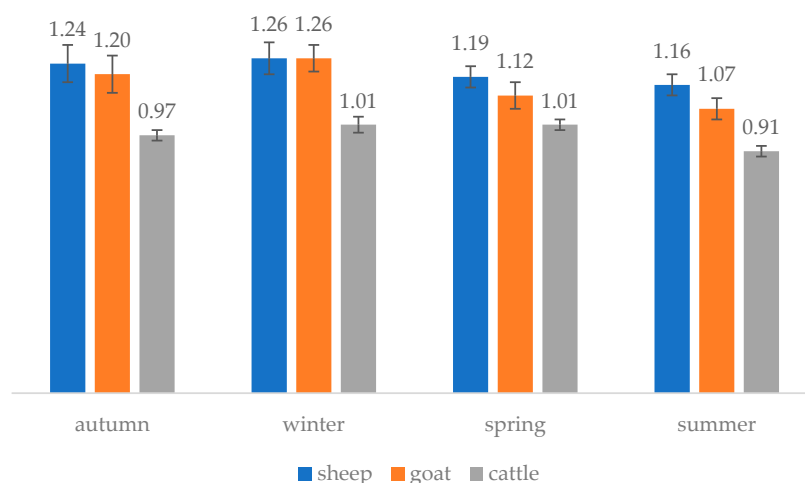


Figure 12. Average number of killed sheep, goat and cattle per season per attack.

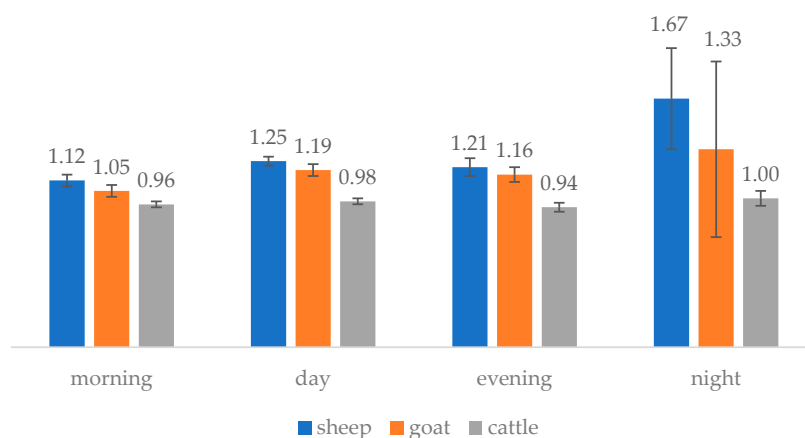


Figure 13. Average number of killed sheep, goat and cattle per time of the day per attack.

4. Discussion

The results obtained in the present study are based on official data on compensation claims by farmers whose livestock were attacked and killed/injured by wolves. Numerous previously published studies on wolf predation used similar data sources [29–32]. In the present study, we encountered some limitations using the official claims database. Namely, some data from official claims could not be provided to us due to general data protection regulation (such as the coordinates of farms). In addition, certain variables were not reported in an adequate way to be useful in the analysis (such as protection measures). Thus, some objectives of the research could not be achieved due to an inadequate (narrow) form of the data (such as the exact type of protection measures, landscape features, vegetation, etc.).

Comparing the number of reported attacks and animals killed in previous studies with those in the present study, large differences were found due to the different sizes of the area studied, geographic and climatic conditions, and the abundance and avail-

ability of wild ungulates and domestic animals. The observed trend in the number of attacks and killed animals during the analyzed period can be attributed to different factors. One of them includes possible changes in wolf population size. Since 2013, wolves were not hunted in Croatia due to there being an estimated decrease in population size, and no hunting has been allowed until the present day to prevent further the decline of the wolf population. Thus, it can be expected that the wolf population since 2013 has increased, resulting in an increase in attacks and killed animals during 2020. In favor of this, there have been more and more frequent encounters of humans with wolves near resident houses, villages and roads [33]. In addition, a lack of (appropriate) prevention measures and/or adequate livestock management could have also contributed to the observed trend during the analyzed period. On the other hand, not all attacks and killed animals are reported, and in general, official claims do not present an exact number of attacks and killed animals over time. Namely, in unofficial conversations with livestock owners, they stated the following reasons for not reporting livestock depredation: lower compensation than the real value of damage, not having time to deal with the claim procedure and/or less valuable animals were depredated (killed animal(s) was (were) older and/or sick). Despite these reasons, a significant trend in the average number of killed animals over the analyzed time period was found.

Regarding the dietary preferences of wolves, they have been reported to feed predominantly on wild ungulates [16]. A lower availability of wild ungulates forces wolves to seek other food sources, and available livestock becomes an essential component of the wolf diet. In southern Croatia, where wolf attacks are most common, the wild ungulate population is not very large, and densities are less than 1 head per 100 ha [34,35]. Therefore, domestic animals are valuable prey for wolves in this area. Higher predation on domestic animals has also been reported in other southern European countries where there are fewer wild ungulate populations [36–39].

In most studies conducted in Mediterranean countries, sheep are the most common domestic animal species, followed by goats and cattle, which is consistent with the results of the present study [34,36].

The total number of sheep in the three counties with the most frequent attacks is higher than that of goats or cattle, and sheep herds are frequent and larger. Regarding the average number of animals per species in the three counties with the most frequent wolf attacks and the total number of animals killed per species, it was found that goats are the most vulnerable species, as 11.72% of the goat population was killed during the studied period, which was followed by cattle (6.34%) and sheep (5.61%). In addition, Octenjak et al. [35] reported a higher proportion of goat remains in wolf stomachs compared to other domestic animal species. The higher vulnerability of goats may be attributed to their behavior during grazing, where goats tend to browse more, go deeper into the brushwood, move farther away from shepherds and become easier prey.

According to Meriggi and Lovari [36], a higher proportion of livestock is expected in the diet of wolves from late spring to autumn. Vila et al. [40] proposed three biological seasons for wolf packs, namely the nomadic period in winter and early spring (November–April), denning in the late spring and summer (May–July), and the post-weaning period in late summer and autumn (August–October). During the post-weaning period, attacks on sheep and goats may increase by 48% and decrease by 30% during winter and early spring [41]. This is due to increased food requirements after weaning and the higher growth rate of wolf pups, resulting in more attacks in late summer and early autumn [42]. In the present study, the total number of attacks and sheep killed increased from spring, peaked in summer, and decreased in winter, and this is consistent with expected seasonal changes. Sheep in sub-Mediterranean Croatia are kept indoors in winter until lambing, and the grazing season begins after lambing. For goats and cattle, there were seasonal variations, but the relative number of animals killed differed less between seasons.

Seasonal variation in the number of attacks and livestock killed may be less evident in pastoral farming systems with mild winters, where livestock can graze on pastures during

the winter months and as a consequence become more accessible prey [36]. In certain areas, wolf packs also remain near households throughout the year and during the day, attacking and killing livestock. Similar changes in wolf behavior have been reported by other authors [43,44].

The predominant frequency of wolf attacks observed in the present study in the morning and during the day differs from previous studies in which predominantly nocturnal attacks were observed [45,46]. This can be explained by the fact that in the Croatian counties with the most frequent wolf attacks, where livestock are mostly kept in pastoral production systems, grazing happens during the day and even in winter, so animals are accessible as prey in the morning and during the day. However, it was found that the average number of sheep, goats, and cattle killed per attack was highest at night. This is due to the fact that livestock are housed in pens and/or objects during the night, and a greater number of animals are more accessible at the same time.

Although it has been reported that protective methods such as electric fences, guardian dogs, night fencing, and the such help reduce wolf attacks [19], the present study found that 85% of attacked animals were killed despite using protective measures. However, in the present study, detailed information on the type of protection measures were not available, and it is not possible to draw valuable conclusions regarding effectiveness of protection measures, especially type of fencing. Regarding the large number of killed dogs (812 animals) kept as guardian animals, it seems that some changes could be beneficial. More detailed analysis should be conducted regarding the breed of guardian dogs used, as larger breeds such as the Tornjak are more appropriate than smaller breeds. Many previous studies have found that compensation measures do not have a long-term and sustainable effect on limiting or mitigating conflicts between farmers and wolves [36–39].

Šuba et al. [47] reported that dominantly surveyed farmers (84.1%) find wolf hunting an effective way to reduce depredation. However, studies showed that wolf hunting may not be efficient in the long-term prevention of depredation. It seems that hunting causes unwanted shifts in wolf populations [48–52]. Higher reproduction rates of wolves can be expected, disruptions in pack structure cause more dispersed individuals that will need to hunt, and if pups' parents or older members of the pack are culled out, other members of the pack need provide food for them, and livestock becomes available and easier prey [47–52]. Thus, killing wolves should not be the only method used in the prevention of depredation, and non-lethal methods are suggested [53].

It seems that in south Croatia where the wolf attacks on domestic animals are the most frequent, their vulnerability is higher due to the lower availability of wild ungulates. An increase in the number of wild ungulates and/or better livestock management could be beneficial in decreasing the number of wolf attacks and killed domestic animals. Further research needs be conducted to obtain more detailed information regarding the wolf attacks (farm size, breed, animal age, exact type of protection method on each farm, cost of compensation). Nonetheless, it seems that interventions in wolf management plans will be needed in order to prevent any further increase in predations and damages in pastoral livestock farming systems such as in southern Croatia.

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