Article

Does Wolf Management in Latvia Decrease Livestock Depredation? – An Analysis of Available Data

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Abstract: In Latvia, livestock depredation by wolves has increased during the last two decades. Most attacks had occurred in summer and autumn within wolf hunting season. Cumulative numbers of wolf attacks and number of affected sheep per year at regional forest management units were analyzed in relation to estimated wolf density, extent of culling and proportion of juveniles, as well as sheep density and estimated number of wild prey. The response variables (cumulative number of attacks and cumulative number of affected sheep) were modelled by a negative binomial regression, testing effects of every covariate separately and building models from the significant covariates. Depredation level was related to sheep density and estimated wolf population size. No reducing effect was found for culling, and even greater depredation rate was expected at higher proportions of culled wolves. Estimated number of wild prey or proportion of juvenile wolves had an insignificant effect. However, greater numbers of affected sheep were expected at higher red deer density, suggesting increased opportunistic livestock depredation when the red deer may locally outcompete the preferred wolf prey – roe deer.

Keywords: wolf; *Canis lupus*; livestock; sheep; depredation; Latvia

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1. Introduction

For centuries humans have had diverse and complicated relationships with wolves [1], and livestock depredation has been one of the main human-carnivore conflicts in the history of this relationship [2—3]. Despite greater livestock losses due to diseases, harsh weather conditions or other reasons [2,4] wolf attacks on livestock are what contributed to negative attitude towards them [2, 3, 5—6], persecution and even complete eradication of this predator in many countries [1]. Due to successful and relatively recent recovery of wolf populations and increased depredation associated with prolonged livestock herding and breeding in absence of wolves, derogation and more extensive application of lethal control is being reconsidered [7]. Mitigation of the conflicts with wolves is important to ensure conservation of wolves as an important part of the ecosystem, to maintain habitual lifestyle and sources of income of local people and to improve attitudes towards these carnivores [8—10].

Compared to other European countries [11—14] livestock depredation by wolves in Latvia in the 20th century is rather low [15], varying from 9 to 79 reported cases per year [16], although it can cause significant damages to individual farmers. Currently there are no subsidies for acquisition of preventive measures and no compensations paid for lost animals [15]. As wolf is hunted in Latvia, culling is seen as a management measure to decrease the amount of the depredation. Lethal control of carnivore populations in order to reduce depredation and support livestock industry is used in many countries [1, 4, 17], however, effectivity of hunting is unclear and even questioned in some cases [8—9, 18—21], as there are many factors influencing the occurrence of depredation and the impact hunting has on it [8, 12, 17—18, 22—24].

We investigated relationship between reported livestock depredation in Latvia and available data on estimated density of wolves and their wild prey, as well as culling. Specifically, we looked for a negative impact of wolf hunting on reported number of attacks and affected livestock. As

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hunting can disrupt pack structure and may cause juvenile individuals to resort to livestock depredation [17], we also examined the relationship of depredation rate and juvenile proportion, which was estimated according to observed age structure among the culled individuals.

2. Materials and Methods

2.1. Wolves in Latvia

The study area, wolf management and routine sampling of culled individuals in Latvia is described in more detail by Šuba et al. [25]. Wolves are distributed throughout the whole country. A hunting season from 15th July until 31st March and a hunting quota were introduced in Latvia in 2004. Quota is set annually for the whole country and amount of livestock depredation is one of the considerations upon deciding its size. The quota has been increased since its introduction and for the last decade it has been around 270–300 wolves per hunting season. In Latvia, the hunting pressure is considered to be rather high and harvest mortality was estimated to be around 37% in last two decades [25]. Main prey species for wolves are roe deer (*Capreolus capreolus*) and wild boar (*Sus scrofa*) and to a lesser extent red deer (*Cervus elaphus*) and Eurasian beaver (*Castor fiber*) [15, 26].

Figure 1. Borders of local forestry units of Latvian State Forest Service (red) and statistical regions (black). Summary statistics on wolf attacks on sheep, wildlife abundance and number of sheep are provided in Tables.

2.2. The data

The data we analyzed in this study, referring to a period from 2004 until 2022, were obtained from the Latvian State Forest Service (SFS) and the Agricultural Data Center via the Central Statistical Bureau of Latvia. The SFS conducts game census and investigates reports on livestock depredation by wild carnivores, while the Agricultural Data Center compiled data on livestock number per statistical region per year.

In this study, we focused on wolf attacks on sheep as they comprised 90% of all reported livestock depredation cases. The SFS data corresponding to 10 regional forestry units (Fig. 1) were published at the SFS website [16, 27] or available upon request. Reports on livestock depredation included information on date, location, numbers of killed, injured and lost sheep, as well as circumstances of the attack and applied preventive measures. In this study, victims were pooled into a single category (i.e., affected sheep). Data on applied livestock protection measures at sites where depredation had occurred ($n = 506$) were available for years 2000–2020. Effectiveness of preventive measures was evaluated according to available recommendations [21, 28–30].

Estimated numbers of wolves, as well as red deer, roe dear, wild boar, and Eurasian beaver by the SFS within the forestry units were used to account for wolf density and availability of wild prey. The number of culled wolves per forestry unit per year was used to account for hunting pressure. However, as this number was expected to correlate with estimated abundance, the culling intensity was expressed as the ratio between the number of culled individuals and estimated number of wolves at the forestry unit. Summary statistics of SFS local forestry units is given in Table 1.

Table 1. Summary statistics (minimum, maximum and median values per year) on wolf attacks on sheep and applied wildlife data of Latvian State Forest Service local forestry units (Fig. 1) from 2004 to 2022.

	Dienvidkurzeme	**Ziemeļkurzeme**	**Zemgale**	**Rīga Regional**
Reported wolf attacks on sheep	1–9 (3)	1–8 (3)	5	1–4 (1)
Total number of affected sheep	1–61 (20)	1–50 (17.5)	26	1–24 (12.5)
Estimated number of wolves	95–337 (169)	77–260 (158)	11–129 (88)	5–45 (14)
Number of culled wolves	20–42 (28)	17–55 (39)	3–39 (14)	1–11 (5)
Age structure	175 juv 30 subad 130 ad	163 juv 36 subad 171 ad	85 juv 11 subad 58 ad	26 juv 4 subad 21 ad
Estimated numbers of other wildlife (thousands)	red deer 4.9–14.3 (10.8) roe deer 13.4–38 (22.4) wild boars 2.4–12.7 (7.2) beavers 4.9–13 (7.7)	red deer 6.6–13.6 (10.6) roe deer 7.3–22.6 (9) wild boars 1.2–11.4 (6.1) beavers 3.0–8.4 (4.0)	red deer 1.9–13.9 (10.2) roe deer 13.6–27.4 (22.9) wild boars 2.3–11.1 (4.0) beavers 3.4–12.3 (7.0)	red deer 1.3–4.3 (2.0) roe deer 8.9–28.9 (17.4) wild boars 0.8–5.8 (2.3) beavers 4.1–10.6 (5.7)

Table 1. (Continued).

	Sēlija	**Dienvidlatgale**	**Austrumlatgale**
Reported wolf attacks on sheep	1–6 (1)	1–12 (2)	1–11 (3.5)
Total number of affected sheep	1–31 (11)	7–68 (12)	2–58 (16)
Estimated number of wolves	63–190 (151)	39–189 (124)	68–180 (99)
Number of culled wolves	5–37 (22)	4–36 (15)	6–53 (20)
Age structure	101 juv 24 subad 82 ad	50 juv 10 subad 45 ad	57 juv 6 subad 56 ad
Estimated numbers of other wildlife (thousands)	red deer 2.2–7.7 (5.2) roe deer 11.1–28.3 (18.4) wild boars 1.6–7.5 (3.7) beavers 2–7.7 (6.6)	red deer 0.5–3.1 (1.4) roe deer 10.1–25.4 (16.5) wild boars 1.9–5.9 (3.0) beavers 7.9–13.0 (11.6)	red deer 0.2–1.8 (0.7) roe deer 9.2–15.1 (12.2) wild boars 1.3–4.3 (2.7) beavers 6.2–8.6 (7.3)

Table 1. (Continued).

	Centrālvidzeme	Ziemeļvidzeme	Ziemeļaustrumi
Reported wolf attacks on sheep	1–28 (2)	1–9 (3.5)	1–9 (1)
Total number of affected sheep	1–277 (14)	3–76 (27)	2–62 (5)
Estimated number of wolves	11–205 (61)	41–143 (79)	33–169 (70)
Number of culled wolves	4–47 (19)	2–42 (28)	3–45 (19)
Age structure	71 juv 15 subad 68 ad	139 juv 17 subad 73 ad	103 juv 10 subad 65 ad
Estimated numbers of other wildlife (thousands)	red deer 1–7.2 (4.5) roe deer 8.9–21.5 (13.5) wild boars 2.4–7.3 (4.2) beavers 5.0–8.9 (6.4)	red deer 1.5–4.7 (3.7) roe deer 12.6–41.2 (20.1) wild boars 1.1–10 (4.4) beavers 5.4–11.9 (6.5)	red deer 0.7–5.1 (2.7) roe deer 6.1–23.3 (10.0) wild boars 1.0–6.3 (2.6) beavers 4.1–8.4 (4.9)

Data on number of sheep at five statistical regions of Latvia (Fig. 1) were used to account for regional variation of sheep density. A summary on sheep numbers from 2004 to 2022 is given in Table 2. As borders of the statistical regions differed from borders of the forestry units, data from individual or adjacent statistical regions corresponding to 2–6 neighboring forestry units within common or negligibly differing borders were pooled. The calculated number of sheep per km^2 was referred to all the forestry units within the array. Data on wolf age structure from 2004 until 2021 were obtained by the authors from examined legally culled individuals and otherwise found carcasses (see Šuba et al. [25] for more details). Teeth samples for age assessment were prepared according to methods described by Klevezal [31]. The age was determined by microscopic inspection and counting increment lines in cross-section of the extracted canine. For the purpose of this study, the age was assigned to three age classes, namely juveniles (i.e. individuals born in spring prior to opening of the hunting season), subadults (individuals aged one year) and adults (individuals aged two years and older). This allowed inclusion of some adult individuals from which the tooth sample was unavailable and precise age remained undetermined. In total, 1902 individual wolves of known location were aged. As the number of aged wolves from individual forestry units per year was often insufficient for credible estimates, data from 3 to 4 neighbouring forestry units were combined and calculated proportion of juveniles among the sampled individuals was assigned to every forestry of the array.

Table 2. Summary statistics on minimum, maximum and median number of sheep of five Latvian statistical regions (Fig. 1) from 2004 to 2022.

	Kurzeme	Zemgale	Pierīga	Vidzeme	Latgale
Non-urban area (km^2)	12995	10678	8562	15750	14463
Number of sheep (thousands)	4.4–19.0 (12.9)	2.0–14.6 (10.7)	3.8–17.8 (11.8)	7.0–33.5 (23.1)	20.0–28.5 (26.3)

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Table 3. Investigated variables and coefficients corresponding to sheep depredation by wolves and available data.

Variable	Coefficient
Cumulative number of wolf attacks on sheep per year	1
Cumulative number of affected sheep in wolf attacks per year	1
Intercept	β_{int}
Centrālvidzeme SFS forestry unit	$\beta_{forestry[CV]}$
Dienvidkurzeme SFS forestry unit	$\beta_{forestry[DK]}$
Dienvidlatgale SFS forestry unit	$\beta_{forestry[DL]}$
Rīga Regional SFS forestry unit	$\beta_{forestry[RR]}$
Sēlija SFS forestry unit	$\beta_{forestry[S]}$
Ziemeļaustrumi SFS forestry unit	$\beta_{forestry[ZA]}$
Ziemeļkurzeme SFS forestry unit	$\beta_{forestry[ZK]}$
Ziemeļvidzeme SFS forestry unit	$\beta_{forestry[ZV]}$
Number of sheep per 1 km² in respective region	β_{sheep}
Estimated number of red deer in current year in current year (in thousands)	$\beta_{wild[redd]}$
Estimated number of roe deer in current year in current year (in thousands)	$\beta_{wild[roed]}$
Estimated number of wild boars in current year in current year (in thousands)	$\beta_{wild[wildb]}$
Estimated number of beavers in current year in current year (in thousands)	$\beta_{wild[beav]}$
Estimated number of red deer in previous year in previous year (in thousands)	$\beta_{prevwild[redd]}$
Estimated number of roe deer in previous year in previous year (in thousands)	$\beta_{prevwild[roed]}$
Estimated number of wild boars in previous year in previous year (in thousands)	$\beta_{prevwild[wildb]}$
Estimated number of beavers in previous year in previous year (in thousands)	$\beta_{prevwild[beav]}$
Estimated number of wolves in current year	β_{wolf}
Logit-transformed proportion of culled wolves in current year	β_{wcull}
Logit-transformed proportion of culled wolves in previous year	$\beta_{prevwcull}$
Logit-transformed proportion of juvenile wolves in current year	β_{wjuv}

2.3. Data analysis

First, we presented information on reported livestock depredation cases and number of affected sheep. Apart from general description, the timing of attacks and relationship with estimated wolf density within the country were analysed. Afterwards depredation cases within local forestry units were examined in relation to available data.

Cumulative number of attacks and affected sheep per year within a regional forestry unit were treated as response variables. Covariates included nominal variables corresponding to forestry units and quantitative variables, namely, number of sheep per 1 km², estimated number of wolves, proportion of juvenile wolves, proportion of culled individuals in current and in previous year and abundance of prey species in current and in previous year (Table 3). Estimated prey density was expressed in thousands. Both proportion variables (i.e., proportion of culled individuals and juveniles) were transformed by a logit function, in one case assuming the value of −7 below 0.1% and in two cases taking the value of 7 when exceeding 100% as slightly more individuals per forestry were culled than estimated to be present.

The relationship between number of attacks or affected sheep and the covariates was investigated by means of a negative binomial regression. The sample size contained 58 records of response variables (cumulative numbers per year) and associated values of the covariates. The effect of each covariate on dependent variables was tested separately with a null model by the likelihood ratio test. Also, we investigate five models containing combinations of multiple covariates. Covariates assumed to be correlated with each other, such as prey density or proportion of culled wolves in current and previous season, as well as estimated number of wolves and proportion of culled

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individuals, were not included into the same model. Finally, additional models were investigated, which contained the covariates found to be significant in previous analyses. All the statistical analyses were conducted by the software R [32] and applying the package MASS.

3. Results

During the study period, number of reported and verified wolf attacks on livestock, as well as number of affected sheep have considerably fluctuated with a slightly increasing trend (Fig. 2).

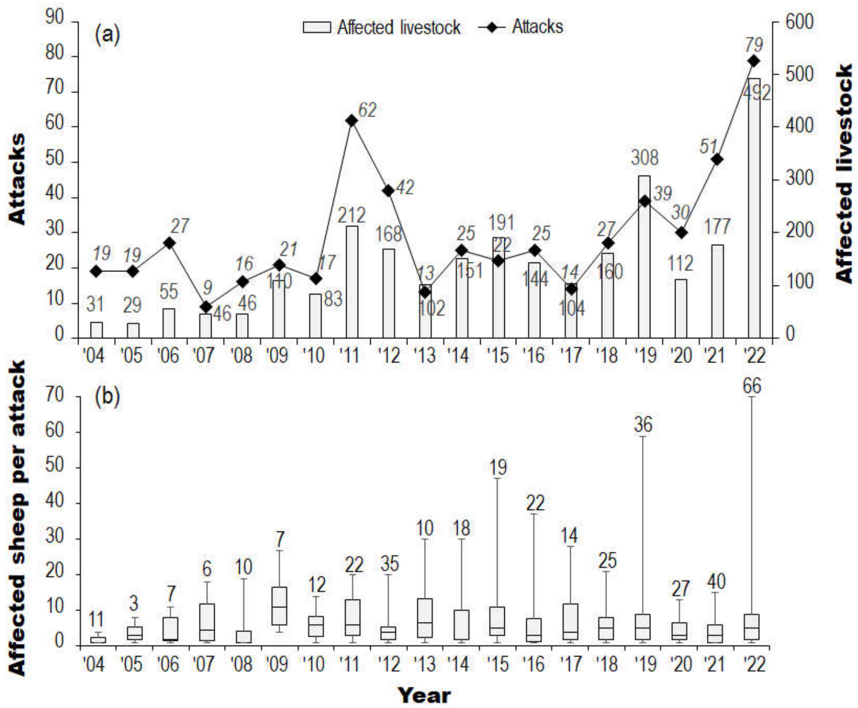

Figure 2. Number of reported wolf attacks and affected livestock (a) and number of affected (i.e. killed, injured or lost) sheep per attack (b, minimum, maximum, median, inter-quartile range, number of cases shown) in Latvia from 2004 to 2022 (data from the Latvian State Forest Service).

The mean number of affected sheep per reported attack had increased from 2.6 (in 2004–2009) to 5.5 (in 2017–2022) with a slope of 0.219 (SE = 0.077) per year (Fig. 3). This increase was found to be statistically significant (linear regression analysis, $F_{1,17} = 8.16$, $p = 0,011$).

No livestock protection measures were used in 181 (35.8%) of reported depredation cases. In 266 (52.6%) cases, the applied preventive measures were considered as inappropriate (electric fences with only one or two wire lines, electric, wood or barb-wire fences less than 1 m high, chained guarding dogs). Only 10 (2%) farms, where depredation occurred, used preventive measures that could have been considered effective (e.g. presence of shepherd or appropriate electric fencing (at least 1.2 m high, with 5 or 6 wire lines or mesh weave). In 49 (9.7%) cases there was no information in the reports about the use of preventive measures.

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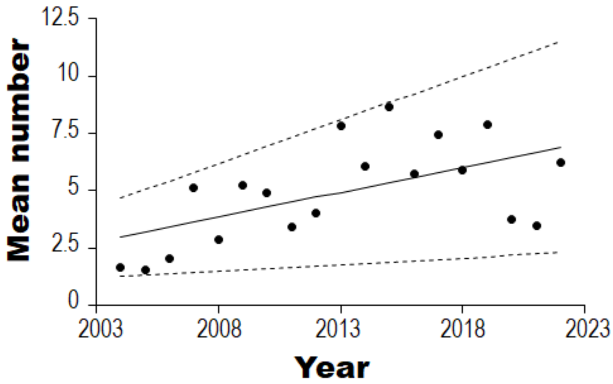

Figure 3. Increase in mean number of affected sheep per reported wolf attack in Latvia from 2004 to 2022 (solid and dashed lines indicate the linear trend and 95% confidence intervals, respectively; data from the Latvian State Forest Service).

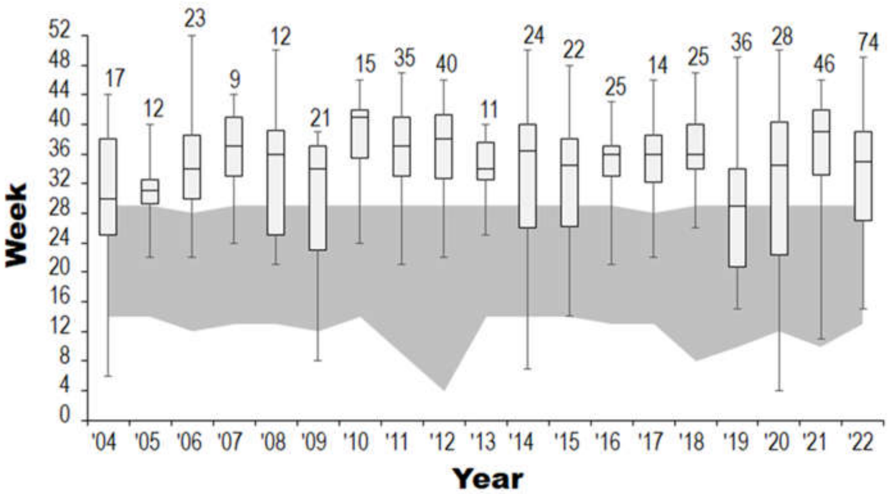

Figure 4. Timing of reported wolf attacks on livestock throughout the year (earliest, latest, median, inter-quartile range and number of cases). Grey shading indicates period of closed hunting season for wolves.

Wolf attacks were reported throughout the year, but the majority occurred in summer and autumn (Fig. 4). As wolf hunting season was opened in 15th July, in most years it covered the period, when the majority of the attacks were reported.

Overall, the total number of wolf attacks and affected sheep increased with estimated wolf density in the country (Fig. 5), which was determined to be a significant factor according to negative binomial regression and likelihood ratio tests (for the number of the attacks, $\lambda_{LR} = 5.911$, df = 1, $p = 0.015$; for the number of affected sheep, $\lambda_{LR} = 20.849$, df = 1, $p < 0.001$). However, investigation at the level of SFS local forestry units revealed other relationships, in which estimated number of wolves no longer had such a significant effect.

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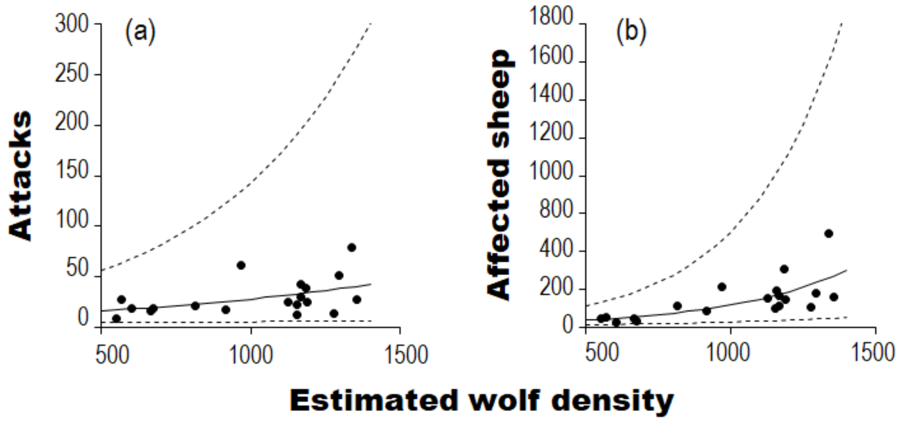

Figure 5. Observed and predicted number of reported attacks (a) and affected sheep (b) per year by wolves according to estimated wolf density (solid and dashed lines indicate the expected number and 95% confidence intervals according to a negative binomial regression, respectively; data from the Latvian State Forest Service).

Table 4. Coeficients of covariates and statistics of negative binomial regression models (overdispersion parameter, adjusted Akaike information criterion, difference, weight, and evidence ratio) describing cumulative number of wolf attacks on sheep per year at SFS local forestry units. Significant coefficients indicated by asterisks (* – $p < 0.05$, ** – $p < 0.01$, *** – $p < 0.001$).

Coefficients (± SE)	θ (± SE)	AIC$_c$	Δ	ω	ER
β_{int} = 0.742 (± 0.366)* β_{sheep} = 0.442 (± 0.195)* β_{wcull} = 0.263 (± 0.124)*	5.96 (± 3.07)	243.65	0	0.562	1
β_{int} = 0.293 (± 0.316) β_{sheep} = 0.55 (± 0.196)**	5.13 (± 2.44)	245.39	1.73	0.236	2.4
β_{int} = 1.501 (± 0.163)*** β_{wcull} = 0.345 (± 0.125)**	4.71 (± 2.09)	246.37	2.71	0.145	3.9
β_{int} = 0.999 (± 0.374)** $\beta_{forestry[CV]}$ = -0.304 (± 0.376) $\beta_{forestry[DK]}$ = -1.086 (± 0.368)** $\beta_{forestry[DL]}$ = -1.279 (± 0.391)** $\beta_{forestry[RR]}$ = -1.234 (± 0.669) $\beta_{forestry[S]}$ = -0.858 (± 0.335)* $\beta_{forestry[ZA]}$ = -0.824 (± 0.351)* $\beta_{forestry[ZK]}$ = -1.173 (± 0.377)** $\beta_{forestry[ZV]}$ = -0.099 (± 0.28) β_{wolf} = 0.007 (± 0.003)*	12.6 (± 11.0)	250.02	6.37	0.023	24.1

Table 4. (Continued).

Coefficients (± SE)	θ (± SE)	AIC$_c$	Δ	ω	ER
β_{int} = 1.127 (± 0.101)***	3.81 (± 1.52)	250.96	7.31	0.015	38.6
β_{int} = 1.735 (± 0.221)*** $\beta_{forestry[CV]}$ = -0.482 (± 0.387) $\beta_{forestry[DK]}$ = -0.736 (± 0.344)* $\beta_{forestry[DL]}$ = -1.042 (± 0.389)** $\beta_{forestry[RR]}$ = -1.735 (± 0.649)** $\beta_{forestry[S]}$ = -0.79 (± 0.348)* $\beta_{forestry[ZA]}$ = -1.042 (± 0.355)** $\beta_{forestry[ZK]}$ = -0.736 (± 0.344)* $\beta_{forestry[ZV]}$ = -0.253 (± 0.289)	8.58 (± 5.69)	252.47	8.82	0.007	82.1
β_{int} = 0.826 (± 0.496) $\beta_{forestry[CV]}$ = -0.545 (± 0.367) $\beta_{forestry[DK]}$ = -0.128 (± 0.393) $\beta_{forestry[DL]}$ = -0.867 (± 0.39)* $\beta_{forestry[RR]}$ = -1.436 (± 0.638)* $\beta_{forestry[S]}$ = -0.489 (± 0.342) $\beta_{forestry[ZA]}$ = -0.84 (± 0.34)*	14.5 (± 14.3)	252.52	8.87	0.012	46.4

$\beta_{forestry[ZK]}$ = -0.359 (± 0.352) $\beta_{forestry[ZV]}$ = -0.14 (± 0.276) β_{sheep} = 0.539 (± 0.225)* β_{wcull} = 0.113 (± 0.135)					

By expressing the number of wolf attacks on sheep according to available covariates via negative binomial regression, local forestry unit ($\lambda_{LR} = 18.17$, df = 8, $p = 0.02$), mean number of sheep per km² ($\lambda_{LR} = 7.724$, df = 1, $p = 0.005$) and proportion of culled wolves in current year ($\lambda_{LR} = 6.74$, df = 1, $p = 0.009$) had a significant effect, while other covariates had no significant effect on the intercept (likelihood ratio tests, $p > 0.05$). Statistics of negative binomial regression models containing combinations of these covariates and the estimated wolf density are given in Table 4. However, the proportion of culled wolves had a positive coefficient values, i.e., higher expected depredation rate at higher culling intensity. Other covariates, such as density of other wildlife species and proportion of juveniles had an insignificant effect on cumulative number of depredation cases according to likelihood ratio tests ($p > 0.05$). Mean number of sheep per km² had also a significant effect on the cumulative number of affected sheep ($\lambda_{LR} = 6.616$, df = 1, $p = 0.01$). The most parsimonious models according to AIC values included forestry, as well as estimated number of wolves and red deer among the factors (Table 5). Likelihood ratio tests revealed no significant effect of other covariates ($p > 0.05$).

Table 5. Coeficients of covariates and statistics of negative binomial regression models (overdispersion parameter, adjusted Akaike information criterion, difference, weight, and evidence ratio) describing cumulative number of affected sheep in wolf attacks per year at SFS local forestry units. Significant coefficients indicated by asterisks (* – $p < 0.05$, ** – $p < 0.01$, *** – $p < 0.001$).

Coefficients (± SE)	θ (± SE)	AIC_c	Δ	ω	ER
β_{int} = 1.486 (± 0.41)*** β_{sheep} = 0.833 (± 0.226)*** $\beta_{wild[redd]}$ = 0.075 (± 0.031)*	1.505 (± 0.287)	474.97	0	0.423	1
β_{int} = 1.564 (± 0.42)*** β_{sheep} = 0.674 (± 0.221)** β_{wolf} = 0.005 (± 0.002)*	1.462 (± 0.277)	476.68	1.71	0.18	2.4
β_{int} = 1.414 (± 0.427)*** β_{sheep} = 0.798 (± 0.233)*** $\beta_{wild[redd]}$ = 0.06 (± 0.041) β_{wolf} = 0.002 (± 0.003)	1.512 (± 0.289)	476.98	2.01	0.155	2.7
β_{int} = 2.128 (± 0.349)*** β_{sheep} = 0.65 (± 0.226)**	1.379 (± 0.259)	478.07	3.09	0.09	4.7
β_{int} = 2.982 (± 0.311)*** $\beta_{forestry[CV]}$ = -1.048 (± 0.586) $\beta_{forestry[DK]}$ = -3.085 (± 0.778)*** $\beta_{forestry[DL]}$ = -0.521 (± 0.438) $\beta_{forestry[RR]}$ = -1.419 (± 0.56)* $\beta_{forestry[S]}$ = -1.366 (± 0.504)** $\beta_{forestry[ZA]}$ = -1.585 (± 0.438)*** $\beta_{forestry[ZK]}$ = -3.389 (± 0.934)*** $\beta_{forestry[ZV]}$ = -0.547 (± 0.442) $\beta_{wild[redd]}$ = 0.311 (± 0.078)***	1.922 (± 0.386)	478.94	3.97	0.058	7.3
β_{int} = 2.291 (± 0.463)*** $\beta_{forestry[CV]}$ = -0.449 (± 0.634) $\beta_{forestry[DK]}$ = -2.657 (± 0.78)*** $\beta_{forestry[DL]}$ = -0.632 (± 0.439) $\beta_{forestry[RR]}$ = -0.826 (± 0.629) $\beta_{forestry[S]}$ = -0.99 (± 0.507) $\beta_{forestry[ZA]}$ = -1.21 (± 0.465)** $\beta_{forestry[ZK]}$ = -2.86 (± 0.938)** $\beta_{forestry[ZV]}$ = -0.111 (± 0.473) $\beta_{wild[redd]}$ = 0.225 (± 0.087)** β_{wolf} = 0.007 (± 0.004)	2.026 (± 0.411)	479.05	4.07	0.055	7.7

Table 5. (Continued).

Coefficients (± SE)	θ (± SE)	AIC$_c$	Δ	ω	ER
β_{int} = 1.988 (± 0.465)*** $\beta_{forestry[CV]}$ = 0.712 (± 0.497) $\beta_{forestry[DK]}$ = -0.894 (± 0.461) $\beta_{forestry[DL]}$ = -0.602 (± 0.458) $\beta_{forestry[RR]}$ = -0.264 (± 0.611) $\beta_{forestry[S]}$ = -0.246 (± 0.428) $\beta_{forestry[ZA]}$ = -0.606 (± 0.435) $\beta_{forestry[ZK]}$ = -0.697 (± 0.475) $\beta_{forestry[ZV]}$ = 0.658 (± 0.4) β_{wolf} = 0.011 (± 0.003)***	1.85 (± 0.37)	481.36	6.39	0.017	24.4
β_{int} = 2.404 (± 0.618)*** $\beta_{forestry[CV]}$ = -0.489 (± 0.646) $\beta_{forestry[DK]}$ = -2.851 (± 1.08)** $\beta_{forestry[DL]}$ = -0.654 (± 0.455) $\beta_{forestry[RR]}$ = -0.875 (± 0.636) $\beta_{forestry[S]}$ = -1.082 (± 0.599) $\beta_{forestry[ZA]}$ = -1.254 (± 0.486)** $\beta_{forestry[ZK]}$ = -3.046 (± 1.198)* $\beta_{forestry[ZV]}$ = -0.15 (± 0.508) β_{sheep} = -0.08 (± 0.321) $\beta_{wild[redd]}$ = 0.237 (± 0.096)* β_{wolf} = 0.007 (± 0.004)	2.025 (± 0.411)	482.19	7.22	0.011	36.9
β_{int} = 3.114 (± 0.121)***	1.241 (± 0.228)	482.53	7.56	0.01	43.8

4. Discussion

We found that, in Latvia, cumulative number of reported livestock depredation cases and affected sheep were correlated with estimated wolf density as most farms (88.4%), where wolf attacks had occurred, applied no or insufficient preventive measures against such attacks. In a survey on public attitudes towards large carnivores [15] most of the livestock farmers (73.4%) claimed that they do not use any preventive measures. Wolf hunting was deemed as an effective means to reduce depredation by 84.1% of surveyed farmers and 41.1% of farmers considered hunters to be responsible for the prevention and reduction of the wolf depredation. Only 29% of surveyed farmers claimed that they themselves are responsible for the prevention of depredation cases. Mostly some prevention is introduced only after the loss of livestock had been suffered due to the wolf attacks.

Most attacks were reported during summer and autumn. Similar timing of wolf attacks on livestock was observed in other countries [1, 5, 11, 14, 22-23, 33—36]. In Latvia, unlike in neighbouring Estonia [13] and Lithuania [37], wolf hunting season is opened considerably earlier on 15th July (compared to 1st November and 15th October, respectively), coinciding with the majority of the observed attacks on livestock. Nevertheless, we found no indication that wolf hunting in the current or in the following year decreased reported number of attacks or the number of affected sheep at SFS local forestry units. On the contrary, significantly more attacks were expected in current year at higher ratio between the number of culled wolves and estimated number of wolves, as the coefficient was positive and significantly different from zero. As seen in some studies, lethal predator control can be less effective than other preventive measures [18, 21], and appropriate livestock protection can be more significant than reduction of wolf numbers in decreasing the number of depredation cases [29, 38].

Sometimes hunting can have short-term positive effect on depredation reduction, however, it does not prevent attacks in long-term as harvested animals are soon replaced by dispersing individuals [22]. In some cases, wolf hunting can even increase the amount of depredation [17, 18, 24], as hunting impacts demographic, territorial and social structure of wolf population, thus leading to potentially higher reproduction rates [39] and possible changes in animal behaviour, including their hunting habits [17, 40—41]. As wolf hunting in Latvia begins when pups are still very young and will depend on adult animals for their survival for some time [42], loss of parents or other adult pack members might make it more difficult for the remaining adults to provide for the pups [41] and they may choose more vulnerable prey (e.g. livestock).

Theoretically, increase in livestock depredation may be associated with disrupted pack structure and accidental removal of adults due to intensive hunting [17]. However, our analysis revealed no significant relationship between cumulative number of attacks or affected sheep and the observed proportion of juveniles. In fact, juveniles are more likely to be removed from the population due to hunting than the adults [43]. Also having an abundant wild prey base decreases the possibility of depredation by juvenile wolves. The impact of culling on wolf pack structure is to be evaluated in further studies involving existing kinship data, as individual circumstances in packs, like the juvenile's age when losing adult pack members or early dispersal from the natal pack, might be important factors leading juveniles to depredation.

Another significant factor influencing number of reported depredation cases and affected sheep was the location at particular SFS forestry unit. Apart from regional variation of the analysed covariates (Tables 1–2), local differences in operation of the SFS and activity of farmers in reporting the cases may be relevant. However, at this point qualitative or quantitative assessment of such characteristics is problematic.

No correlation was found between sheep depredation and estimated numbers of most prey species. Although the numbers of roe deer and wild boar in Latvia have fluctuated [15, 25, 44], there is no reason to assume significant shortage at any point. However, cumulative number of affected sheep was related to estimated numbers of red deer, and according to estimated coefficients more affected sheep were expected at higher red deer densities. This may be associated with a competition between the two deer species [45—46] as roe deer is more common in wolf diet in Latvia [26], but may be affected by higher red deer density, consequently advancing opportunistic livestock depredation. In Europe, red deer is preferred in wolf diet [47], but may require advanced hunting skills or greater pack size.

In Latvian society, various opinions exist concerning wolves [48—49]. Generally, livestock farmers and herders are the most negative in their attitudes towards wolves [50—56] as their income and lifestyle is affected by the depredation. In addition, wolf is sometimes seen as a symbol of domination of urban population over the lifestyle and needs of rural inhabitants. Therefore, negative attitude towards this carnivore can come from the symbolic meaning of the animal and general social and economic reasons and not due to personal negative experience with wolves [57—58]. Although it is often considered that attitudes should be improved in order to improve species conservation condition, in case of livestock depredation, more important could be practical measures that would ensure successful coexistence. Ability to accept presence of wolves and coexist with them can be more important than having positive attitude towards these carnivores. Acknowledgement of existing conflicts, hearing out of farmers and their problems, objective evaluation of the situation and practical solutions for conflict mitigation might be more successful than attempts to improve knowledge and attitude towards predators [59]. As seen from this study, current wolf hunting practice in Latvia might not have the desired positive effect on depredation reduction, therefore use of effective preventive measures and subsidies for their implementation are significant for sustainable coexistence with these carnivores.

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