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Original Article

Indirect Costs of Sheep Depredation by Large Carnivores in Sweden

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ABSTRACT Carnivore depredation gives rise to direct costs for killed and injured animals as well as indirect costs due to productivity losses and additional labor requirements. Our aim was to investigate indirect costs to sheep farmers in Sweden due to carnivore depredation and presence. We estimated these costs using survey data describing conditions in 2013. Reproduction and time spent on fence maintenance and taking care of animals were analyzed to isolate effects of carnivore exposure from other factors that affect these variables. Results indicate that both high carnivore densities and attacks are associated with comparatively lower sheep reproduction. Farmers who experienced an attack spent much more on labor for maintaining fences, searching for lost animals, and bringing the animals in for the night. Results suggest that the indirect cost per adult female sheep is EUR23 for nonattacked herds in areas with high carnivore densities; EUR71 in herds that were attacked and where sheep are kept on fenced grazing land; and EUR100 on attacked summer-pasture farms, where free-range grazing is applied. A flat rate compensation per adult female sheep, differentiated between herds in areas with high carnivore density that have not been attacked and herds that have been attacked could be used to compensate sheep farmers for these costs.

KEY WORDS brown bear, direct and indirect costs, lynx, sheep, wildlife compensation, wolf.

Economic losses due to carnivore predation on livestock have been a worldwide concern for livestock producers (Kaczensky 1999, Naughton-Treves et al. 2003, Treves and Karanth 2003, Bulte and Rondeau 2007). Direct costs occur as a result of killed and injured animals, but there can also be indirect costs in terms of decreased productivity and additional labor required to prevent attacks and manage the consequences of attacks. In many countries all over the world, compensation is paid for costs associated with killed and injured animals, while compensation for indirect costs is rarely granted (Nyhus et al. 2003, Bulte and Rondeau 2005, Sommers et al. 2010).

Carnivore presence and attacks are known to reduce productivity because of the secondary stress imposed on livestock. Stress has a negative effect on animal health and reproduction, leading to reduced fertility, fewer offspring, lower birth mass, and greater susceptibility to virus and bacterial infections (Doney et al. 1976, Faries and Adams 1997, Dobson and Smith 2000). Further, carnivore presence and attacks can affect grazing behavior of livestock negatively, with indirect effects on animal conditions and reproduction (Howery and DeLiberto 2004, Kluever et al. 2008). Several studies have attempted to estimate the magnitude and value of predator effects on productivity. For example, Ramler et al. (2014) found that the slaughter mass of calves from farms that experienced gray wolf (*Canis lupus*) attacks was 3.5% lower compared with other farms, implying a revenue loss of approximately EUR6,000/year (euros/year) for an average cattle ranch. In contrast, they found that wolf packs having a home range that overlaps with the ranch has no significant effect on calf mass, suggesting that carnivore presence alone is not sufficient to account for a negative effect of slaughter mass. Sommers et al. (2010) showed that, when calves are killed by grizzly bears (*Ursus arctos*) and gray wolves, mortality of other calves in the herd also rose considerably, implying that the compensation for a killed animal should be 4 and 6 times its value for grizzly bear and gray wolf depredation, respectively, if additional calf losses were considered. Steele et al. (2013) simulated the aggregate economic effects of predation, including costs of dead and injured animals, reduced growth and reproduction, and reduced animal health, and concluded that total costs to farmers are 2–3 times larger than paid compensation. None of the above studies accounted for the role of farm production technology in the size of the indirect costs.

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Farmers exposed to large predators also incurred costs for additional labor for prevention of carnivore attacks. For example, additional labor costs were incurred for bringing animals in for the night, enforcing fences, early weaning, lambing or calving delay, and grazing limits, followed by increased forage costs (Shelton 2004). Existing studies used expert judgements to estimate increases in labor costs due to carnivore attacks and presence. For example, Steele et al. (2013) accounted for increased labor time for managing the consequences of an attack, and Asheim and Mysterud (2004) estimated that one-tenth of the total carnivore-related costs to sheep farmers was due to additional work with fence maintenance and repair.

Our purpose was to estimate indirect costs of carnivore predation and presence for sheep farmers in Sweden. We viewed this as an issue that is not confined to Sweden alone and a study such as this has applicability elsewhere. To estimate productivity and labor-related farm costs of carnivores, we make use of data from a survey of Swedish sheep farmers describing conditions in 2013. We hypothesized that the indirect costs differ depending on the level of exposure to carnivores.

There are approximately 600,000 sheep in Sweden, and 500–600 are killed by carnivores each year (Elofsson et al. 2015). Gray wolves have attacked approximately 400 sheep/year in recent years, while brown bears (*U. a. arctos*) have attacked approximately 100, and lynx (*Lynx lynx*) between 40 and 100 sheep/year since 2001 (Elofsson et al. 2015). There have only been a few instances of wolverine (*Gulo gulo*) attacks on sheep. Annual compensation to farmers for livestock killed or injured by these species is approximately EUR150,000 in total. Compensation is mainly paid for income losses due to verified killings and injuries. Regulations do not exclude compensation of indirect costs, but between 1997 and 2013 indirect costs (for increased labor and forage, and reduced production) were only compensated in one-tenth of the cases (Elofsson et al. 2015). A likely reason is the difficulties in verifying productivity decreases and internal labor time. Limited compensation of indirect costs has been questioned by farmers exposed to carnivores, who argue that the negative effects on productivity and increased labor are very costly (Wolf Committee 2013, Hedén 2014). We identified the labor-related costs associated with carnivore attacks, based on farm-level data, and by comparing consequences of carnivore attacks for 2 different sheep production systems: 1) conventional, fenced sheep farms; and 2) free-range grazing ("summer-pasture") farms.

STUDY AREA

There were no areas in Sweden, except the islands of Gotland and Öland, which did not host any wolves, brown bears, or lynx. Wolves were mainly present in the inland parts of mid-Sweden. The population approximated 350 individuals in the winter 2012–2013 (Svensson et al. 2013). Brown bears occurred mainly in mid- and north Sweden, where the total population was approximately 2,800 individuals in 2013 (Kindberg et al. 2014). Lynx were present in most parts of the country and the population was estimated to be $\geq$840 individuals (Zetterberg 2014). Sheep production was present throughout country, where the density was greatest in the southern parts, especially in the coastal areas (Widman and Elofsson 2018).

For the purpose of our study, we sought to identify farm categories that differed with respect to carnivore exposure. First, 2 farm categories of interest were those that were not attacked, but located in areas with high and low carnivore density, respectively. To identify such areas, we used data on carnivore inventory from the Environmental Protection Agency's database Rovbase (www.rovbase.se). Using these data, we selected 15 municipalities with high carnivore density and 15 with low carnivore density, out of 290 municipalities in the country. We defined municipalities as having a high carnivore density if they had a documented presence of family groups of wolf and lynx, and individual brown bears. All municipalities with high densities of carnivores were located within the core area for wolves in Sweden and, hence, located inland in mid-Sweden. They could all be characterized as mainly rural. Municipalities located inland with similar economic structure and presence of sheep farms were selected for the control group in areas with low carnivore densities. Municipalities with low carnivore density had no stable presence of wolf or brown bear for at least the past 5 years, but had a possible, occasional presence of lynx. These municipalities were found further south in the country, which could, hypothetically, imply that sheep production conditions were different, and context was needed when evaluating results. We listed municipalities with high and low carnivore density in the Supporting Information. Second, we included all conventional sheep farms that were attacked in 2013. Information on attacked farms was available in Rovbase, which is a Swedish–Norwegian database on carnivore inventories and compensation. Attacked farms were located across the country, albeit more attacks occurred in carnivore- and sheep-dense regions (Widman and Elofsson 2018). Finally, we included all summer-pasture farms. Those were exclusively located in areas with high densities of carnivores (i.e., the inland parts of mid-Sweden).

METHODS

Survey

We conducted a survey with livestock producers in Sweden. Our purpose was to identify quantifiable indirect costs for farmers from carnivore attacks and interference. From this survey, we obtained a cross-sectional data set that described sheep farms and their activities in 2013.

Sampling of farmers for the survey took into account that sheep farms differ with respect to whether the herd 1) has been subject to interference or attacks by carnivores; 2) is located in an area with high or low densities of carnivores; and 3) is kept on fenced or unfenced grazing land. We identified 5 different groups of farmers as follows. First, conventional farmers in areas with high densities of large carnivores that had not been attacked. Second, conventional farmers in areas with low densities of carnivores that were not attacked. The third category of interest was conventional farmers who have experienced carnivore attacks. Finally, the fourth and fifth categories of interest were summer-pasture farms ("fäbod" in Swedish) that have and have not experienced carnivore attacks, respectively. Unlike other sheep farms, where sheep are kept fenced, the summer-pasture farms apply free-range grazing, implying that the risk of carnivore attacks was larger. We allocated each farm only to a single farm category. It was not possible to allocate farms to several categories (e.g., classifying a farm as being both attacked and located in an area with high [or low] carnivore density). This was because most municipalities do not fit these criteria for either high or low carnivore density, while it also was not feasible to exclude all attacked farms outside the $15 + 15$ selected municipalities because the attacked group would be too small for statistical analysis. Hence, we used a quasi-experimental approach, similar to Ramler et al. (2014). The purpose of the stratification was to allow for comparisons of productivity and labor time across farm types and locations that differ with regard to the risk for, and actual attacks from, predators.

For the survey, we included only farms with >21 animals. We set this limitation to avoid inclusion of hobby farms, where production practices can differ from commercial farms. In municipalities with large densities of carnivores, there were 140 sheep farmers in total, all of which were included in the survey. We randomly selected 200 sheep farmers in municipalities with low carnivore densities from the Swedish Farm Register. We included all sheep farmers who received wildlife damage compensation in 2013 for the group that has experienced an attack, for a total of 113 farmers across Sweden. We included all 201 farmers receiving summer-pasture support through the Rural Development Program. They were all located in areas with large carnivore densities. We designed this survey in a web-based survey instrument. We sent letters with login information to 563 sheep farmers in October 2014, with 2 follow-up reminders in December 2014 and early January 2015, respectively. We provided telephone support or paper version of the survey to farmers on demand.

The survey included questions in 5 areas: 1) general information about sheep production; 2) health and reproductive status of the animal stock; 3) grazing areas and agri-environmental support for natural grazing land; 4) labor time for different tasks and future business prospects; and 5) attacks and interference by large carnivores. Questions were developed based on the literature, complemented by a postal enquiry to farmers' organizations; the Federation of Swedish Farmers, the Swedish Association for Sheep Breeding (Svenska fåravelsförbundet), the Swedish Transhumance and Pastoralist Association (Föreningen Sveriges Fäbodbrukare), and a regional pastoralist association (Gävleborgs fäbodförening), on their members' experiences with the consequences of carnivore attacks that aimed to identify possible effects not described in the literature. The survey can be found in the Supporting Information.

From the different types of effects on animal health and productivity so obtained, we restricted survey questions to effects that could be identified by the farmer and valued in monetary terms. Survey questions on labor time spent on different tasks asked for number of person-days, defined as 8-hr days, spent on each task. Tasks included were typically performed by all livestock producers, but depredation or interference by large carnivores can imply additional time spent on them. Questions were asked about tasks in which additional labor could be the consequence of an attack, including time spent on searching for and retrieving lost animals, repairing fences damaged either by predators or fleeing livestock, care of injured and sick animals, and time spent on contacts with public authorities. Questions were also asked about activities to prevent carnivore attacks, such as the time spent bringing the animals in for the night and for monitoring. In addition, there were questions concerning instances where farmers have set up so-called "carnivore fences", which are a reinforced type of electric fence requiring additional labor for installation and regular cutting of vegetation underneath the fence.

We requested responses to questions on production, animal health, and labor time for 2013. The survey also asked about carnivore attacks and interference of large carnivores in both 2012 and 2013 to account for possible delays in the effect of an attack on reproduction, delays in compensation payments, and the possibility that not all farmers apply for compensation.

In terms of validity, there was a potential risk that farmers may overstate consequences of carnivore attacks to signal the importance of the problem to policy makers (Pearson et al. 1992). To identify such a possible bias in their responses, we sent out 2 different letters, such that two-thirds of the survey recipients, randomly selected, received an accompanying information letter saying that the purpose was to investigate the costs of carnivore attacks, and one-third received a similar letter saying that the purpose was to analyze productivity in farming. Survey questions were identical for all respondents.

We pretested separate elements of the survey on representatives from the different farmer organizations and researchers in farm business management and wildlife damage management. Subsequently, we piloted the full online survey on a few sheep and cattle farmers. Based on their responses and feedback on the survey, we clarified a few questions and added a few response alternatives.

Data Analysis

First, we used a *t*-test to identify variables that were potentially affected by carnivore attacks and density. We chose to further analyze variables for which the *t*-test indicated significant differences at $P < 0.10$ across farmer categories, which was found for reproduction and labor time for 3 of the tasks: 1) fence maintenance; 2) bringing the animals in for the night; and 3) searching for and fetching lost animals. There were not any significant differences in the prevalence of mastitis (which was used as a proxy for udder health), time spent on care of damaged and sick animals, or time spent on contacts with public agencies. We used multiple regressions to preliminarily test for the prevalence of mastitis, time spent on care of damaged and sick animals, or time spent on contacts with public agencies, and did not find any significant effects by farm category ($P > 0.10$). We therefore proceeded with analysis of reproduction and labor time for the 3 above-mentioned tasks. We regressed reproduction and labor time variables against farmer category and other relevant explanatory variables with an aim to determine whether farmer category had a significant effect. We identified the effect of farmer category by comparing each category with the reference category, defined as farmers in areas with low carnivore densities.

Reproduction, measured as the number of live-born lambs per adult female sheep (hereafter, "ewe"), can depend on the breed (Löfquist 2006). The dependent variable was obtained from a survey question, where we asked farmers about the number of live-born lambs. This was divided by the stated number of ewes in the herd. We controlled for sheep breed categories, according to standards of the Swedish Association for Sheep Breeding (Elitlamm): meat breed, native breed, Gotland sheep (fur breed), and cross-breed. Further, we controlled for whether the production was organic or conventional. Organic production could be associated with fewer lambs per ewe because they are brought up solely on the ewe's milk (Johnson et al. 1998). We also controlled for whether the herd had been infected by the Schmallenberg virus, which was spread in 2012 and implicated in an increased risk of stillbirths and aborted fetuses (Afonso et al. 2014). We defined breed, organic production, and Schmallenberg virus as dummy variables. In addition, we included the total number of sheep in the herd as a control to capture potential scale effects. We used a generalized linear model, which was estimated in the statistical software Stata (StataCorp LLC, College Station, TX, USA). We excluded outliers with >3 lambs/ewe. Due to data limitations, we did not include summer-pasture farms in the estimations for reproduction.

To investigate whether farmers' labor time was affected by carnivore presence and attacks, we compared reported workloads for the 3 different labor tasks across all 5 categories of livestock producers. Our aim was to identify whether there were significant differences in labor time across categories when control variables were included. We used separate models for all 3 different work tasks where the t-test suggested a significant effect of farmer category. Distribution of data for time spent on fence maintenance has an exponential shape. We therefore took the logarithmic value of the number of days reported for this task as the dependent variable, hence using a log-linear regression, estimated using ordinary least squares. This model performed better than did alternative specifications, such as the Poisson regression and negative binomial regression, which were applicable with overdispersed data. We did not include outlier values >50 days (5 observations) in the analysis because of possible errors in reporting. We used robust standard errors, as recommended by Cameron and Trivedi (2009), to control for mild violations of underlying assumptions.

In the second model, the dependent variable was the time spent searching for and retrieving lost animals. Here, 59% of the respondents reported this time to be zero. There is a large difference between the mean value of the variable (2.7 days) and standard deviation (6.8). With this type of distribution, and when the dependent variable is count data (i.e., no. of days), either a Poisson, a zero-inflated Poisson, or a negative binomial regression model was suitable. We ran the countfit test in Stata to compare these models and concluded that the preferred model was the negative binomial regression, although results were similar for the different estimations. We estimated the model using maximum likelihood, with a log-likelihood function, and robust standard errors.

In the third model, the dependent variable was bringing sheep in for the night. The survey asked for the number of person-days spent on the task. However, the time necessary for bringing animals in for the night could vary substantially with farm-specific conditions such as land consolidation and location of buildings. For the regression, we therefore used a dummy variable, taking the value 1 if the farmer has performed the task at least once during the year, and 0 if the task has not been carried out. Given the binary dependent variable, we used a probit model for the analysis.

In all 3 labor-time models, we controlled for total number of animals because it was impossible to disaggregate the labor input data for each type of livestock. We created a cattle dummy to represent farmers who have both cattle and sheep. It was included in the models for fence maintenance and searching for lost animals because fencing requirements as well as the propensity to flee could differ between cattle and sheep. Further, we controlled for the percentage of carnivore fences. Such fences can require additional maintenance time, and may reduce the risk of livestock escaping as well as the need for taking sheep in at night. Data were obtained from a survey question where farmers could state the share of fences that were carnivore fences. Finally, we controlled for whether sheep were organically produced because organically produced sheep have a greater economic value (e.g., HKScan Agri 2018). The economic incentive for their protection could, therefore, be larger. For each model, we estimated an alternative formulation, in which we added a dummy variable indicating whether the respondent received a letter indicating that the survey would be used to explore carnivore costs.

Cost Calculations

We calculated all costs in euros (EURs) in 2015 year value, using the average exchange rate from the Swedish Riksbank. We used econometric analyses to calculate the average effect of farm category on the dependent variables. This approach directly estimated the effect of farm category on the number of live-born lambs per ewe, labor time spent on searching for and retrieving lost animals, and labor time spent on fence maintenance. To obtain the effect of farm category on labor time for bringing the animals in for the night we proceeded as follows. To calculate the expected prevalence of bringing the animals in for the night, we first calculated the marginal effects for each farm category, expressed in percentage terms. We calculated the difference between categories as the expected prevalence in a category minus the expected prevalence in areas with low carnivore densities. We then calculated additional time-use for each farm category by multiplying the expected additional prevalence of the task by the yearly median number of days used for that task by all farmers who reported performing it.

We then estimated cost of reduced fertility for an average herd by multiplying the estimated decrease in fertility rate, compared with the fertility rate in herds in areas with low carnivore density, with the number of ewes in an average herd and the net revenue of one unborn lamb. We assumed the net revenue of an unborn lamb to be EUR43, which equaled the wildlife damage compensation recommended in 2015 by the Wildlife Damage Center, Swedish University of Agricultural Sciences, for an unborn lamb killed by a predator.

We finally calculated costs for additional labor for an average herd by multiplying the additional labor time required for a farm category, compared with farms in areas with low carnivore density, by labor costs. We assumed labor costs to be EUR27/hr, which equaled the compensation for labor recommended in 2015 by the Wildlife Damage Center. We then associated an 8-hr day of additional labor with a cost of EUR216.

Table 1. Effects of independent variable characteristics of sheep farms in Sweden during 2013 ($n = 139$, $F_{10,128} = 5.59$, $P = 0.005$; pseudo $R^2 = 0.18$) on the number of live-born lambs per ewe as the dependent variable, estimated number of live-born lambs evaluated at the means of the other variables, and the difference in the number of live-born lambs per ewe for different farm categories, as compared with those reported in farms in areas with low carnivore density.

Variable	Coefficient (SE)	Mean no. of lamb/ewe, estimated at means	Difference compared with farms in areas with low carnivore densities
Low carnivore densities		2.149	
High carnivore densities	–0.529* (0.173)	1.620	–0.53
Experienced carnivore attack	–0.401* (0.164)	1.748	–0.40
Intercept	2.856* (0.525)		
Schmallenberg virus	–0.002 (0.271)		
Sheep of meat breed	–0.420* (0.160)		
Gotland (fur) breed	–0.094 (0.180)		
Cross breed	–0.252 (0.152)		
Other sheep breed	–0.585 (0.270)		
Organic production	0.209 (0.144)		
Total no. of sheep in herd	–0.001 (0.001)		
Ram in herd	–0.166 (0.167)		

*$P < 0.10$.

RESULTS

A total of 214 sheep farmers replied to the survey, for a response rate of 38%. Out of the 214 farmers, 58 were conventional farms located in carnivore-dense areas, but not subject to attacks; 73 were conventional farms located in areas with low carnivore density; 54 were conventional farms that were subject to an attack; 15 were summer-pasture farms that had experienced an attack; and 14 were summer-pasture farms that had not experienced an attack. Respondent characteristics such as herd size, age of the farmer, and distribution over the different types of farms were similar to the national averages. Five farmers located in municipalities with low densities of carnivores reported to have experienced carnivore attacks, and were categorized as such, while none of the farmers in areas with low densities reported interference by large carnivores. It was judged that the few farmers in areas with low carnivore densities who had experienced attacks were exceptions, in which the attack was made by wandering wolf or brown bear individuals. Descriptive statistics can be found in Table S1 of the Supporting Information.

Impact of Farmer Category on Sheep Reproduction

Statistical analysis revealed differences in the number of live-born lambs per ewe between herds in areas with high densities of carnivores and herds that have been attacked compared with herds in areas with low densities of carnivores. Sheep of meat breed had, on average, 0.42 fewer lambs per ewe ($F_{10,128} = 5.59$, $P = 0.01$; Table 1) than did the native breed (reference category in our estimations), which was an expected result (Löfquist 2006).

Estimated number of lambs for each farm category was evaluated at the means of the other variables. The number of live-born lambs per ewe was 0.53 units lower in herds in areas with high carnivore densities ($F_{10,128} = 5.59$, $P = 0.003$; Table 1), and 0.40 units lower in herds that have experienced an attack ($F_{10,128} = 5.59$, $P = 0.016$; Table 1), compared with herds in areas with low carnivore densities. Notably, we have not found any effect of carnivores on slaughter mass ($F_{9,91} = 2.42$, $P = 0.85$ for herds in areas with high carnivore density; $F_{9,91} = 2.42$. $P = 0.46$ for herds that have been attacked). However, sheep producers typically compensate for a reduced mass gain by delaying slaughter, implying that slaughter mass could be unaffected. We found indications of delayed slaughter in our data, but could not establish an effect ($F_{2,142} = 1.43$, $P = 0.12$).

Impact of Farmer Category on Labor Time

Regressions on labor-related tasks showed the expected result: time spent on the 3 analyzed tasks was greater in herds experiencing a predator attack, compared with herds in areas with low carnivore density, which was used as reference category. Farmers with herds having experienced a predator attack spent 1.9 days more on fence maintenance ($F_{8,142} = 5.45$, $P = 0.08$; Table 2); 3.2 days more on searching for and retrieving lost animals ($\chi^2_8 = 28.9$, $P = 0.001$; Table 2) and 2.6 more days on bringing the animals in for the night ($\chi^2_7 = 16.70$, $P = 0.018$; Table 2) compared with herds in areas with low carnivore density. When control variables were included, there was no difference in labor time for fence maintenance between areas with high and low carnivore densities ($F_{8,142} = 5.45$, $P = 0.61$; Table 2). The share of carnivore fences was significant in the fence maintenance model ($F_{8,142} = 5.45$; $P = 0.04$; Table 2), but all other control variables were

Table 2. Effects of independent variable characteristics of sheep farms in Sweden during 2013, on labor-time spent on different tasks as a dependent variable. Farms in areas with low carnivore densities were used as a reference category. Coefficients with robust standard error are in parentheses.

Variable	Fence maintenance (log of no. of days)[a]	Searching for and retrieving lost animals (no. of days)[b]	Bringing animals in for the night (dummy)[c]
High carnivore density	−0.093	−0.842	−0.454
	(0.181)	(−0.548)	(0.413)
Attacked herd	0.311*	1.478*	0.750*
	(0.177)	(−0.459)	(0.357)
Summer-pasture no attack	0.630*	1.101*	1.154*
	(0.353)	(0.653)	(0.618)
Summer-pasture attack	1.020*	2.518*	1.624*
	(0.258)	(0.593)	(0.662)
Total no. of animals	0.001	0.007*	−0.007*
	(0.001)	(0.004)	0.004
Cattle	0.119	−0.214	
	(0.149)	(0.501)	
Organic production	−0.150	−0.620	−0.258
	(0.147)	(0.421)	0.328
Carnivore fence share	0.004*	−0.011*	0.004
	(0.002)	(0.005)	0.005
Constant	1.358*	0.166	−0.550*
	0.157	0.145	0.332
n	151	117	106
P	$F_{8,142} = 5.45$[d]	$\chi^2_8 = 28.9$[d]	$\chi^2_7 = 16.70$[d]
	<0.001	<0.001	<0.002
F/Wald χ^2	4.05[e]	33.69[e]	21.11[e]
P	<0.001	<0.001	0.004
R^2	0.13	0.06	0.22

[a] Model used: OLS with logged dependent variable.
[b] Model used: Negative binomial regression.
[c] Model used: Probit.
[d] Test of the significance of the difference between the different categories of farmers.
[e] Test of the model.
$^*P < 0.10$

insignificant (Table 2). Error terms were approximately normally distributed, which indicated that the model was correctly specified (see Fig. S1 in the Supporting Information available online).

There was a positive effect of herd size ($\chi^2_8 = 28.9$, $P = 0.08$; Table 2), and a negative effect of carnivore fences ($\chi^2_8 = 28.9$, $P = 0.04$; Table 2), on time spent searching for and retrieving lost animals. Further, results revealed an effect of the attacked farm category ($\chi^2_7 = 16.70$, $P = 0.02$; Table 2) and both categories of summer-pasture farms ($\chi^2_7 = 16.70$, $P = 0.01$ for those not having experienced an attack; $\chi^2_7 = 16.70$, $P = 0.008$ for those having experienced an attack; Table 2) on the propensity to bring animals in for the night. Summer pasture farms not having experienced an attack spent on average 3.3 days more on the task than farms in areas with low carnivore density. For summer pasture farms having experienced an attack the additional number of days was 3.6. Total number of animals had a small negative effect ($\chi^2_7 = 16.70$ $P = 0.03$; Table 2) on the probability of bringing the animals in for the night, which might be explained by a larger herd being more time-consuming to bring in at night.

The median number of days that animals were taken in for the night was 10, corresponding to 80 hr/year in total. This can be related to the length of the grazing season, which varied between 60 and 150 days. In addition, although we found no effect of farmer category on the time spent on cutting and clearing under fences, data showed that respondents that had carnivore fences spent, on average, 5 more days/year on this task. Marginal effects for labor tasks, the number of days per year for fence maintenance, searching for and retrieving lost animals, and additional prevalence of bringing animals in for the night can be found in the Supporting Information (Table S2).

Impact of Information on Responses

The inclusion of a dummy variable for whether the respondent received a letter indicating that the survey will be used to explore carnivore costs did not reveal any effect of the type of information provided. However, the response rate was 45% among sheep farmers who were informed about the true purpose of the survey, compared with 23% for those that did not receive that information.

Cost Differences Across Farmer Categories

All results were calculated for a sheep herd with 31 ewes, which was the average for the sample as well as for national statistical data. Compared with a farmer in a municipality with low carnivore density, estimated average additional cost for a farmer in a municipality with high densities of carnivores exceeded EUR700/year (EUR23/ewe), while the additional cost for a farmer whose herd has been attacked by predators was approximately 3 times greater, EUR2,200 (EUR71/ewe; Table 3). The additional cost for summer-pasture farms that have not experienced an attack, compared with farms in areas with low carnivore densities, can be due to both carnivore presence and different production methods, implying that no firm conclusions can be drawn regarding the size of the carnivore-related costs for summer-pasture farms that have not been attacked. In contrast, the difference between the 2 groups of summer-pasture farms can be attributed to carnivore attacks. Hence, summer-pasture farms that have suffered an attack have an additional labor cost of >EUR3,100/year (EUR100/ewe) compared with other summer-pasture farms (Table 3). This could be interpreted as a lower bound because some differences between summer-pasture farms that have not suffered an attack and conventional farms located in areas with low carnivore density were potentially due to the greater carnivore abundance in areas where summer-pasture farms were located. More than half the additional cost for summer-pasture farms that have experienced an attack, compared with other summer-pasture farms, was due to more time spent on searching for and retrieving lost animals.

DISCUSSION

Our results show that the additional costs for a farmer in a carnivore-dense municipality with an average-size sheep herd, compared with a farmer in a municipality with low carnivore density, exceeded EUR700/year. This was due to the negative effect of carnivore abundance on sheep reproduction. A similar cost due to reduced reproduction,

Table 3. Additional labor days and reduced number of live-born lambs in Sweden during 2013, and associated costs in euros (EURs) in 2015 year value, for an average sheep farm with 31 adult female sheep, compared with a farm in an area with low carnivore density[a].

Labor type	High carnivore densities		Herd attacked		Summer-pasture, no attack		Summer-pasture, attack	
	Additional days	Cost	Additional days	Cost	Additional days	Cost	Additional days	Cost
Fence maintenance	–[b]	–[b]	1.9	406	3	644	7.9	1,706
Search for and retrieving lost animals	–[b]	–[b]	3.2	691	1.9	410	10.8	2,332
Bringing animals in for the night	–[b]	–[b]	2.6	562	3.3	713	3.9	842
	Reduction (no.)	Cost	Reduction (no.)	Cost	Reduction (no.)	Cost	Reduction (no.)	Cost
Live-born lambs	16.7	722	12.7	549	–[c]	–[c]	–[c]	–[c]
Total cost for an average herd		722		2,208		1,767		4,882

[a] The table shows 1) the no. of additional 8-hr days/yr for different labor tasks (fence maintenance, search for and retrieving lost animals, bringing animals in for the night) across the different farm categories, compared with farms in areas with low carnivore density; 2) the reduction in the no. of live-born lambs per year for different farm categories, compared with farms in areas with low carnivore density; and 3) the additional cost per year, measured in EUR, due to increased labor time and reduced reproduction, for different farm categories, compared with farms in areas with low carnivore density.
[b] No statistically significant effect of farm category was found at the $P < 0.10$ level.
[c] The effect was not estimated because of data limitations.

approximately EUR550/year, was found for farms that had experienced a carnivore attack. However, results regarding reproduction should be interpreted with some care, given that we were unable to fully control for all differences between farms located in areas with high and low carnivore densities. Farms located in municipalities with high carnivore densities were concentrated inland in central Sweden, while municipalities with low densities were found further south. This could, hypothetically, imply that production conditions were different. However, we have not found any evidence that the number of lambs per ewe differs across Sweden. Typically, the shorter grazing season further north is compensated for by additional purchased feed; thus, the location should not significantly differ for reproduction (Thellenberg 2009). We have not found any indication that reproduction should vary with latitude, and standard farm business-calculation programs assume constant reproduction across the country for given sheep breeds (Agriwise 2015). As a result of data limitations, we were unable to estimate whether there was a corresponding effect on sheep reproduction on summer-pasture farms. Our results on productivity contrast with Ramler et al. (2014), who could not confirm any effect of carnivore abundance on productivity in the absence of attacks.

Whereas Ramler et al. (2014) established a significant relationship between carnivore attacks and slaughter mass, we could not establish such an effect. This could be due to sheep farmers compensating for lower growth by delaying slaughter. However, we were unable to establish an effect of farm category on slaughter time. Thus, although the net effect of a predator attack could be both reduced mass and delayed slaughter, the effect on each of those might be too small to be significant. This suggests that future studies on the topic should consider compensatory measures by farmers that could reduce productivity impacts. Our study showed considerably greater labor costs for farms that had been attacked, compared with other farms—approximately EUR1,650 for the average conventional farm and ≥EUR3,110 for summer-pasture farms. For those 42% and 62%, respectively, of the additional labor cost was due to increased time spent on searching for and fetching lost animals. This type of cost typically occurs after an attack. Increased labor time spent on preventive efforts for bringing animals in for the night explained 34% and 4% of the additional labor costs at the attacked conventional and summer-pasture farms, respectively. Increased time spent on fence maintenance could be due to preventive efforts and efforts to manage consequences of an attack. Thus, costs to manage consequences of attacks are larger in both absolute and relative terms for summer-pasture farms. This seems plausible given that sheep kept on unfenced land could flee more easily than sheep on fenced land. In contrast, the additional costs for bringing the animals in for the night are lower for the summer-pasture farms than for conventional farms, both in absolute and relative terms. This is likely to be explained by a large share of all summer-pasture farmers bringing their animals in for the night, which could be due the summer-pasture farms being located in carnivore-dense areas. As mentioned, it was not possible to calculate the indirect costs for summer farms that were not attacked. Lower costs for bringing the animals in at night should be interpreted with this in mind.

Our results on the effect of carnivore attacks on labor costs can be compared with results in Asheim and Mysterud (2004), where it was concluded that additional labor accounted for approximately half of the indirect costs for Norwegian sheep farmers. In our study, additional labor time accounted for approximately 75% of indirect costs for farmers that had experienced a predator attack. Swedish and Norwegian sheep farming differ considerably. In Sweden, almost all sheep graze on fenced land, whereas sheep in Norway typically graze unattended on unfenced land in the summer and the share of killed sheep is approximately 10 times greater than Sweden (*cf.*, Ross et al. 2016, Skonhoft 2016). This raises the question of the relationship between indirect costs for labor spent on preventive activities and direct costs, related to kill rates, which should be further researched. For a comparison of Sweden and Norway it would, for example, be necessary to account for the larger size of the Norwegian sheep industry, and the relatively more frequent attacks by bears in Norway compared with wolves (Wolf Committee 2013).

It should be noted that there can be other indirect costs of carnivore presence and attacks, which have not been addressed in our study. These include secondary effects on value-added activities, such as the production of own brands of cheese or on-farm meat sales, and time for the farmer to plan and administer their business. Further, the risk of carnivore attacks can discourage farmers from letting sheep graze all of their land, which can lead to lost agri-environmental subsidies for the farmer. Also, the risk of carnivore attacks can be a source of concern to the farmer for reasons other than purely economic ones, and can contribute to severe distress (Naughton-Treves et al. 2003).

MANAGEMENT IMPLICATIONS

Our results indicated that there are additional costs associated with sheep farming in areas with high densities of carnivores and for carnivore attacks, as compared with sheep farming in areas with low densities of carnivores. Estimated indirect costs can be compared with the average compensation for an attack for the period 2003–2013, which was approximately EUR950 for all farms, and EUR1,600 for summer-pasture farms. Our results then suggest that, on average, indirect costs for an attacked herd are 2.3 and 1.9 times the compensated costs for conventional and summer-pasture farms, respectively. If indirect costs occur for both livestock producers who have experienced a predator attack, and those who have not but whose farm is in a carnivore-dense area, it is not sufficient to increase the compensation per killed and injured animal. Instead, a government-financed flat-rate compensation per ewe in the sheep herd could be better. The use of a flat-rate compensation would reduce transaction costs compared with the current practice, with individually determined compensation for indirect costs. A flat-rate compensation, set at the level of the average indirect cost, would also compensate the sheep industry in proportion to its overall costs. Evidently, this could lead to a too high or too low compensation of individual farmers compared with their actual costs; however, actual costs are not easily verified, implying few other alternatives. A flat-rate compensation could then help avoid a reduction in the sheep industry in carnivore-dense areas. This is advantageous if there is a policy goal set at the national level to maintain sheep production in these areas, motivated by the importance of sheep production for the local economy or because sheep grazing benefits biodiversity. On the other hand, if there is no such goal, introduction of compensation for indirect costs would imply that the number of sheep and wildlife damage costs have become greater than would be socially optimal (Bulte and Rondeau 2005). A further disadvantage of flat-rate compensation is the reduced incentives for livestock producers to undertake preventive measures (Rollins and Briggs 1996). This effect can be partly counteracted if compensation is conditioned on the use of preventive measures. An alternative could be to provide support for fence maintenance. Currently, there is support for investment in carnivore fences, but not for their maintenance. Such support would only partly compensate for the indirect costs, but is potentially easier to implement than a flat-rate compensation. Similarly to the flat-rate compensation, it would provide incentives for suboptimally high numbers of sheep if there is no target for the sheep industry size, but it is not evident that predation and, hence, wildlife damages costs would increase, which is an advantage compared with the flat-rate compensation.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's website.

Table S1. Descriptive statistics for the whole sample, and survey questions used to obtain data on factors affecting productivity of sheep farms in Sweden, 2013.

Table S2. Marginal effects for labor tasks, the number of days per year for fence maintenance and search for and retrieving lost animals, and additional prevalence of bringing animals in for the night.

Survey. Data collection survey instrument used to investigate factors affecting productivity of sheep farms in Sweden, 2013.

Figure S1. Distribution of residuals for fence maintenance.