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ORIGINAL ARTICLE

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Wolves' contribution to structural change in grazing systems among swiss alpine summer farms: The evidence from causal random forest

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Abstract

The return of wolves to Swiss mountains and the damage they cause to sheep and goat herds in the region have raised concerns about a consequent wave of farm closures. In this paper, we examine the relationship between wolf attacks and the decline of Alpine summer farms, a specific high-altitude farm type. We collected farm structure data and monitoring data on wolf attacks between 2004 and 2021 and analysed them using a causal random forest method, enabling a detailed analysis of the relation between wolf attacks and the number of different types of Alpine summer farms at a regional level. The results show that the farming systems are unaffected by incidental and infrequent wolf attacks, but that a high number of wolf attacks in a region is related to faster decrease in number of grazing systems where sheep are most vulnerable to such attacks. In contrast, systems that allow for better herd protection tend to show an increase in areas with frequent wolf attacks.

KEYWORDS
Alpine summer farming, causal random forest, sheep and goat, Switzerland, wolf

JEL CLASSIFICATION
C12, C87, D22, O13, Q15

1 | INTRODUCTION

'Alpine summer farming is in danger' (Blunier, 2021)—this is one of many alarming wolf-related article titles found in rural and peasant magazines. The reason for this is that wolves occasionally prey on domestic sheep and goats in high-altitude pastures during the summer months. Wolves cause increased work for small ruminant farmers attempting to properly protect their livestock and great emotional distress when livestock are killed (Flykt et al., 2022; Zahl-Thanem et al., 2020). Due to the high wolf pressure and increasing workload, some farmers have given up farming (Mink & Mann, 2022), which is often coupled with land abandonment (Price et al., 2015), a decline in livestock and food production (see more about the sector in Aepli & Finger, 2013), negative consequences for biodiversity (Colombaroli et al., 2012; Koch et al., 2013) and a reduced attractiveness for tourism (e.g., Lindemann-Matthies et al., 2010). Moreover, the sense of tradition and security may be lost in rural areas, which is of particular importance for rural populations (Ashley & Maxwell, 2001).

The conflict between agriculture and wolves in Switzerland is not a marginal or regional phenomenon, and it has led to controversy between rural farmer representatives and conservationists. Multiple political initiatives have attempted to soften the protective status of wolves, or at least to detail the effect of wolves on the decline of agricultural farms (von Siebenthal, 2016; Stalder, 2020). Although the number of Alpine summer farms has decreased (Baur et al., 2007), which is often associated with wolves, no study has quantified this association. A connection between wolves and farm abandonment is difficult to determine because farms differ greatly in their sizes and types of management, and some are supported financially by the government to promote better conditions for herd protection. We attempt to fill this research gap. Our hypothesis is that the number of wolf attacks affects the change in the number of Alpine summer farms, while we also expect differences in effect between different farm types.

To test our hypothesis, we use data on the number of Alpine summer farms of different types in the districts of the Swiss Alps issued by the Agricultural Information and Intelligence System (AGIS) and monitoring data on the number of wolf attacks recorded and provided by Carnivore Ecology and Wildlife Management (KORA). We use a machine learning technique known as causal random forest (Lechner, 2019) to quantify the differences in changes of the number of farms treated by various numbers of attacks by wolves. The method has been shown to be effective for research questions with multiple treatment settings, but this study is the first to apply it for studying the structural change in the farming sector under wolf attacks.

Our study is structured as follows: Section 2 provides the background information on the phenomena in Switzerland. Section 3 describes the data and the method used in the study. Section 4 presents the results of the study, and Section 5 concludes the study.

2 | LITERATURE

2.1 | Wolves in Switzerland

At the beginning of the twentieth century, wolves were exterminated in most parts of Europe (Breitenmoser, 1998). Some residual populations were preserved (Boitani & Ciucci, 1992; Promberger & Hofer, 1996) in a few retreat areas, such as the Italian Apennines (Zimen & Boitani, 1975). International protection efforts by nature conservation agencies have been successful, as the number of wolves has increased significantly, and they have returned to their ancestral geographical ranges (Chapron et al., 2014; Salvatori & Linnell, 2005). Since 1995, wolves originating from the Italian population have been regularly sighted in Switzerland (Glenz et al., 2001; Valière et al., 2003).

With the appearance of the first wolves in Switzerland, the serious potential for conflict emerged (Glenz et al., 2001). Although wolves feed mainly on wild animals, many livestock, mainly sheep and goats, also fall prey to them.[1] The number of identified wolf individuals has

[1]Several studies observed and investigated that wolves prey on livestock (Newsome et al., 2016), specifically in the United States (Ramler et al., 2014; Woodruff & Jimenez, 2019), Greece (Iliopoulos et al., 2009), Portugal (Pimenta et al., 2017), Slovenia (Van Liere et al., 2013), Poland (Gula, 2008) and mainly in Italy (Berzi et al., 2021; Gervasi et al., 2021; Meriggi & Lovari, 1996; Russo et al., 2014, 2020).

increased exponentially, up to 150 in 2021, mainly in the Swiss Alps, with a few found in the Jura mountain range (KORA, 2020; Figure A1). The number of livestock killed by wolves has also increased over the years, reaching a peak in 2020, when more than 900 sheep and goats were killed (KORA, 2022). During an attack, a single farmer can lose many livestock. For farmers, killed livestock are not only an economic loss but also a source of emotional distress (Vittersø et al., 1998; Zahl-Thanem et al., 2020). Despite the strong increase in the wolf population, the strict protection status of wolves has not been reduced. As a result, farmers are needing to engage in expensive and time-consuming herd protection measures,[2] which only rarely include culling of particularly voracious wolves. As in other countries with similar problems (e.g. Schroeder et al., 2022; Sjölander-Lindqvist, 2009), the attitude of Swiss farmers towards wolves has remained negative (Hunziker et al., 2001). A recent study by Mink and Mann (2022) has shown that the exits of Swiss farmers from farming are weakly correlated, among other factors, with the burden caused by wolves. An increased exit of farmers, however, does not imply that the number of farms will decrease if, at the same time, other farmers take over the farms, land and livestock. Also in Norway, Strand (2020) observed a rapid decrease in the number of sheep kept by farmers in wolf areas. Swiss agricultural structures differ from those in Norway, and thus the effect of wolves on the decrease in the number of Swiss farms remains unknown.

2.2 | Alpine summer farm types

Alpine summer farms represent a special type of livestock farming in which vertical transhumance pastoralism is practised, meaning that livestock are brought to high altitude pastures during the summer months (May to September; see Herzog & Seidl, 2018) when the farmers stock fodder for winter months in the valley. Alpine summer farms generate more than 10% of Switzerland's total agricultural income on average but 30% in the mountain areas (Mack et al., 2008). Consequently, these farms are important for the economy and food production. In 2021, 5572 Alpine summer farms were operating within the Swiss Alps, one-third of which kept sheep or goats ($N=1781$). For sheep farming, three types of grazing systems are used: permanent shepherding, rotational grazing and permanent grazing (Table 1). These systems differ by management and thus by the level of livestock protection. No distinct pasture systems exist for goat farms, which are mostly characterised by small numbers of goats among large cattle herds. After a change in agricultural policy in 2014, direct payments from the government for Alpine summer farms drastically increased (Flury et al., 2012, who previously evaluated the new policies). Existing contributions were increased by an average of 20%, whereas contributions for permanent grazing have remained unchanged. In addition, farmers of all systems could apply for further direct payments contributions for preservation of cultural landscape and biodiversity. This financial incentive slowed the decline in the number of farms, but the wolf population and amount of killed livestock continued to increase. Accordingly, whether regional wolf attacks are causing a decline in the number of Alpine summer farms and which farm types are most affected are the central questions of this study.

Many sheep farms with permanent grazing do not have enough capacity (stocking possibility or workforce) to change the pasture system to rotational grazing or permanent shepherding. Therefore, they have fewer possibilities to apply herd protection measures due to smaller herds and the lowest direct payment contributions (see Table 1). Hence it appears that farms that use permanent grazing are particularly threatened by the presence of wolves. Goat pastures are very rarely protected with herd protection measures due to their small size. In addition, goats find protection in the midst of

[2]Livestock depredation by wolves can be reduced by using herd protection measures (Khorozyan & Waltert, 2019; Linnell et al., 2012; Potet et al., 2021), such as livestock guardian dogs (Andelt & Hopper, 2000; Smith et al., 2000; Van Bommel & Johnson, 2012) and electrified fences (Hansen & Leitinger, 2018). The purchase and maintenance of fencing material and dogs is expensive and time-consuming (Moser et al., 2019). Farmers often lack these means for effective herd protection. In addition, even good herd protection is no guarantee that wolves will not prey on livestock (Bruns et al., 2020; Eklund et al., 2017).

TABLE 1 Grazing systems in Switzerland.

	Grazing systems in Switzerland			
Animal	**Sheep**			**Goats**
Type	**Permanent shepherding**	**Rotational grazing**	**Permanent grazing**	**Goat farms**
Management	**Shepherd is with the herd all the time**	**The herds are led from one fenced pasture to another in a weekly schedule**	**Livestock are moved to pastures without being managed or fully fenced**	**Mainly small herds, complementary to large cattle herds; rarely bigger herds without cattle**
Number of farms in 2004	89 [3.84%]	221 [9.53%]	743 [32.06%]	1264 [54.55%]
Number of farms in 2014	168 [8.96%]	203 [10.83%]	452 [24.11%]	1052 [56.11%]
Number of farms in 2021	223 [12.52%]	194 [10.89%]	384 [21.56%]	980 [55.02%]
Annual change before 2014	+6.5%	−0.8%	−4.8%	−1.8%
Annual change after 2014	+4.1%	−0.6%	−2.3%	−1%
Direct payment per NST[a] in CHF[b] since 2014	400 CHF	320 CHF (with LGDs[c] ➔ 400 CHF)	120 CHF	400 CHF + 40 CHF if used for dairy production
Pasture biodiversity	More sustainable (Boggia et al., 2012; Meisser & Chatelain, 2010; Stadler & Wiedmer, 1999) due to optimised use of sensitive Alpine pastures		Less sustainable due to selectively over- and under-grazing	Goats are able to feed on wooden plants, which can restore biodiversity-rich pastures (Pauler et al., 2022)
Possibilities for herd protection	Daily close herd management by shepherds allows for increased efficiency in the optional use of LGDs; night pens and (electrified) fences can be maintained	Electrified fences are regularly maintained and also help to increase the efficiency in the optional use of LGDs due a compact herd	Due to irregular control of the herd and non-compact herd management, efficient herd protection measures are difficult to apply	Goat pastures are generally defined as unprotectable. With shepherds present, night pens and stabling are possible, with natural protection also provided by the cow herds that are often present
Costs	Salary for shepherd(s), material costs maintenance for optional fences, night pens and LGDs	Material costs of fences, labour work for frequently maintenance of fencing and costs for optional use of LGDs	Very low but optional costs for use of herd protection measures (for example LGDs)	Dispersed around the herd types
Minimum herd size to cover costs	400 sheep (Mettler et al., 2014)	100 sheep (Eiselen, 2012)	100 sheep (Eiselen, 2012)	Undefined

Note: The values in quadratic brackets are the shares in total number of Alpine summer farms.

[a]NST (Normal stock) = 1 LSU /100 days. 1 LSU (livestock unit) is equivalent to one cow, 4 dairy sheep or 6 ewes, 5 dairy goats or 6 normal goats and serves as a reference unit that simplifies the aggregation of livestock of different species. An NST still includes the grazing duration to define the optimal grazing use on Alpine summer farms.

[b]1 CHF (Swiss franc) = 1 dollar.

[c]LGD is an abbreviation for a livestock guardian dog.

cattle herds. Because goats are attacked much less frequently compared to sheep, we assume that the influence of wolf attacks on the annual change of goat keeping farms is rather small.

3 | DATA AND METHOD

3.1 | Data

We aim to quantify the relation between wolf attacks and the decrease in the number of Swiss Alpine summer farms. We investigated the period from 2004 to 2021, which reflects the availability of data on Alpine summer farms and on the number of attacks of livestock by wolves. We used data on the number of wolf attacks collected and provided by KORA (2022) and on Alpine summer farms issued by AGIS. We focused only on Alpine summer farms keeping at least one sheep or goat. The study area was restricted to the area of the Swiss Alps, as this region holds almost all Swiss Alpine summer farms with sheep and goats and is also the area in which almost all attacks by wolves have occurred.

Linking wolf attacks to individual farms was not possible due to spatial definitions of the data. Although GPS data were available, they did not match with the patchy GPS data on Alpine summer farms. The smallest spatial unit for wolf attacks was the municipal zip code. Even though the number of farms, which is the basis for the dependent variable in our study, could also be aggregated on a municipality level, we decided to use a larger spatial aggregation, since many municipalities are too small to have any Alpine summer farms. In addition, the number of attacks was strongly unbalanced at the municipality level.

Given the properties of the available data, we aggregated the number of farms and the number of attacks by district (59 districts with an average size of 434 km^2) and year (18 years from 2004 to 2021), which resulted in a balanced panel that included 1062 observations. During this period and in these districts, 1140 wolf attacks on sheep or goats were recorded. However, for 74% of observations, the number of attacks was zero, as wolves did not attack in most of the studied district/years.

The permanent shepherding and rotational grazing sheep farm types were grouped together as guided pastures due to their common advantage of controlled herd management, similarities in the use of herd protection measures as well as individually low frequency per district. The second farm type was permanent grazing, likely to be most affected by wolf attacks. Goat farms served as the third group.

3.2 | Method

To quantify the relation between wolf attacks and the annual change in the number of farms, we employed a modified causal forests (MCFs) approach that estimates heterogeneous causal effects (2019; mcf package in Python, version 0.2.4. issued in 2022). MCFs (Lechner, 2019) build on the causal tree introduced by Athey and Imbens (2016) and further developed by Wager and Athey (2015). The causal random forest method works with causal trees, a type of a decision tree based on a difference-in-difference approach instead of ordinary least squares. This method has been applied in, for example, Cockx et al. (2020, pp. 18–19) where they summarised the method as follows: (i) improves the splitting rule for individual trees; (ii) penalises splits that do not reduce selection bias; (iii) estimates group average treatment effects (GATEs) and individualised average treatment effects (IATEs) with low computational costs; (iv) suggests and performs unified inference for all aggregation levels; and (v) is applicable to a multiple, discrete treatment framework. The technical and practical details were described best by Lechner (2019), Cockx et al. (2020) and the MCF-Tutorial (2022).

The main benefit of causal random forest compared to other models (Appendix B) is the capacity for causal inference. The name of the method and the corresponding terminology stem from the similarity between data processing and a biological forest. As the trunk of each tree is divided into different (random) branches, the data is split into (random) fractions, which are used for model assessment. The collection of such (random) trees forms a forest (random forest by Breiman, 2001). In causal tree, the assessment of a model happens on different fractions of data using a causal model, for example a difference-in-difference approach. The MCF package adds to this technique by allowing a comparison between different treatment effects, reducing the standard errors and computational costs. To the best of our knowledge, this is the most accurate model for causal estimation of various treatment effects, and is also packed in a user-friendly statistical package. However, we remain cautious in interpreting the results causally as the debates and the models on causal estimation are actively developing and are still being discussed.

Table 2 summarises the definitions and assumptions for MCF estimation. For our research question, the outcome $\boldsymbol{Y}$ should quantify the change in summer Alpine farming; treatment variable $\boldsymbol{D}$ should reflect the activity of the wolves; and covariates $\boldsymbol{X}$ should ensure the comparability between observations under different treatments. We discuss each of these variables in Section 3.3. Moreover, the data should fit the main assumptions of MCF, that we discuss in more detail in Section 3.4. We only used the average treatment effect (ATE) and the average treatment effect on treated (ATET) estimates in our study.

3.3 | Specification

We define the ranges in the number of attacks by wolves in district i and year $t-1$ as treatment types $d \in \boldsymbol{D}$. The number of attacks $\left(a_{i,t}\right)$ was used to define which treatment d the district i experienced in a year t. The districts that experienced a different number of attacks (or no attacks) are potential control groups. This understanding of treatment is plausible based on the assumption that the farmers of the district are a group of people randomly assigned to participating in a social experiment, that is, farming under the risk of financial loss and psychological pressure due to the unknown number of attacks on their livestock by wolves. The district aggregates these farmers territorially. In order to balance the number of observations by treatment, we grouped the number of attacks $a_{i,t}$ into our treatment variable d as follows:

$$d_{i,t} = \left\{ \begin{array}{c} 0, \text{if } a_{i,t} = 0 \\ 1, \text{if } 1 \leq a_{i,t} \leq 2 \\ 2, \text{if } 3 \leq a_{i,t} \leq 6 \\ 3, \text{if } a_{i,t} > 6 \end{array} \right\}. \tag{1}$$

In classic difference-in-differences over time, we would have to define the pre-treatment and post-treatment phases with another variable T and further clarify all four combinations of $\boldsymbol{T}$ and $\boldsymbol{D}$ for the estimation (e.g., Loginova et al., 2021). In MCFs, this is not necessary, as the treatment types are compared between each other as well as within themselves in different years. The best area for a control group is selected by propensity score matching. Therefore, we needed to use socioeconomic characteristics of the farmers and a political period as a covariate X. Since our dataset was rather small, we only used the year, canton (Swiss member states and superior to the districts), as a categorical spatial variable and the change in agricultural policy in 2014 as a temporal variable. In other words, we compared the farms only within 1 year, canton, and considered the means before and after the change in agriculture support policy in 2014.

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TABLE 2 Definitions and assumptions regarding effects in a modified causal forest.

Definitions		**Assumptions**
Y	Outcomes, each is y or $Y_{i,t}$	(1) Conditional independence assumption (CIA)
X	Covariates, each is x or $X_{i,t}$, the selected are χ	$\left\{Y^0, \dots, Y^m, \dots, Y^{M-1}\right\} \coprod D \mid X = x, \forall x \in \chi$
Z	Groups of observations, each is z	(2) Stable-unit-treatment-value assumption (SUTVA)
D	Treatment, integer $\{0, \dots, M-1\}$	$Y = \sum_{d=0}^{M-1} \underline{1}(D = d) Y^d$
Δ	Treatments of interest to compare $\{m, l\}$	$\underline{1}(\cdot)$ denotes the function, which is one if its argument is true
Y^d	Outcomes under treatment d	
Effects		(3) Common support (CS)
$ATE\ (m, l, \Delta) = E\left(Y^m - Y^l \mid D \in \Delta\right)$		$0 < P(D = d \mid X = x) = p_d(x), \forall x \in \chi$ $\forall d \in \{0, \dots, M-1\}$
$ATET\ (m, l, \Delta) = E(Y^m - Y^o \mid D \in \{0, m\})$		
$IATE\ (m, l, x, \Delta) = E\left(Y^m - Y^l \mid X = x, D \in \Delta\right)$		(4) D is randomly assigned
$GATE(m, l, z, \Delta) = E\left(Y^m - Y^l \mid Z = z, D \in \Delta\right)$		(5) Exogeneity (X is not influenced by the treatment)

Source: Modified causal forest assumptions by Lechner (2019), summarised in this table by the authors of the present article. All the symbols are the same as in the source material. Lechner (2019) used Rubin's (1974) potential outcome language to describe a multiple treatment model under unconfoundedness, or conditional independence (Imbens, 2000; Lechner, 2001).

To ensure stationarity of the dependent variable $Y_{i,t}$ (see Callaway & Sant'Anna, 2021 and stationarity tests in Appendix C, Table C1), we related the number of farms in the selected district $b_{i,t}$ to the number of farms in the same district in the previous year under a logarithm. We calculated this variable as follows[3]:

$$Y_{i,t} = \ln\left(\frac{b_{i,t}+1}{b_{i,t-1}+1}\right) = \ln(b_{i,t}+1) - \ln\left(b_{i,t-1}+1\right) \tag{2}$$

To measure the effect of wolf attacks on different farm types f, we also calculated the logarithmic annual change in the total number of farms of the particular type $f \in \{guided\ pastures; permanent\ pastures; goat\ farms\}$:

$$Y_{f,i,t} = \ln\left(b_{f,i,t}+1\right) - \ln\left(b_{f,i,t-1}+1\right) \tag{3}$$

We chose this measure because, among other alternatives (see, e.g., Loginova & Mann, 2022), it allows for (a) both cross-district and cross-year comparisons of the observations, (b) gains stationarity, (c) keeps zeroes in the data and (d) handles highly skewed non-negative data. The log transformation has also helped us to weigh the decreases and increases equally. For example, a halving of the number of farms on the log scale is −0.69 and a doubling is +0.69, instead of 0.5 and 2 if not logged. The shortcoming of this measure is that it reduces our data on the number of observations in 2004. Therefore, we had 1003 observations for each farm type, which is one observation for each of 59 districts during the 17 years from 2005 to 2021.

The ATE for $d = \{m, l\}$ appears in $Y^{d=l}$ in addition to cantonal, time and agricultural policy factors and can be called a *wolf effect*, which is our focus. The estimates of *wolf effects* are taken from MCF (Lechner, 2019) with the same best-performing (among the alternatives tested) input features of the forest proposed and tested by the developers. This package allowed us to compare data under different treatments. If the assumptions of the causal random forests do not hold, we do not get an estimate.

3.4 | Model assumptions

The high spatial resolution on the area used in this study and homogeneity of Alpine summer farmers within cantons enhanced the plausibility of the CIA. SUTVA was also plausibly fulfilled, as the farms that participated in the statistical survey represented a small yearly subset of the total number of Swiss farmers. We did not detect any common support problems with the final specification. However, the low number of observations with $d > 0$ was a limitation with regard to including more covariates and using narrower treatment type windows. Finally, the exogeneity of the confounding and heterogeneity variables was ensured by using the explanatory variables that the farms cannot change over time, except for farms abandoning or changing their farming type. Therefore, we concluded that the main assumptions for understanding our research design as an experimental setting are plausible.

The model considers the number of wolf attacks as random (Table 2, Assumption 4), based on two main reasons. First, the attacks per district and year are hardly correlated with time (Pearson correlation coefficient is 0.19), despite the total number of wolf attacks per year on small ruminants increasing gradually over the years (Pearson correlation coefficient is 0.82). Second, the spatial distribution of wolf attacks can also be considered random throughout the districts within the Swiss Alpine region as Appendix A, Figure A2 visualises (online). To check this statistically, we calculated the correlations between the numbers of attacks over years for all combinations of districts (without repetitions and self-correlating). Only 10% of all correlations

[3]It is common to apply this linear transformation (adding a constant) under a natural logarithm when the data are non-negative but keep zero values that are important.

were above 0.6 and only 5% of all correlations were above 0.72, so there are not many arguments against randomness (see Appendix A, Figure A3). For corelations on a cantonal level, these figures stood at 0.64 (for 10%) and 0.77 (for 5%), respectively.

We did not use the matrixes of neighbouring districts because of issues of their implementation and reliability for mountain areas: some districts have impassable borders due to high mountains and glaciers, while other districts' borders run in the valley plain, where wolves can cross them easily. This problem may be partially solved by using the shortest paths between the centres of the districts; however, we are still unable to include this information into a causal forest estimation. In this respect, our study leaves two main areas for improvement for further studies: (1) inclusion of spatial components into the causal random forest assessment, and (2) the developing of the accurate matrixes of neighbouring districts in the mountain areas. In this study we only control this issue by including the canton as a covariate.

Although we had only 1003 observations, they fitted nicely to the assumptions of causal random forests, suggested by the developers. Even with possible estimation inaccuracy, the design identifies the specifics of structural change that happens in the Swiss Alps.

3.5 | Descriptive statistics

We present the descriptive statistics of studied data in Table 3. Between 2004 and 2021, the total number of Alpine summer farms with small ruminants decreased from 2307 to 1777 farms, the number of guided pastures increased from 300 to 413, the number of farms with permanent grazing decreased from 743 to 384, and the number of goat farms decreased from 1264 to 980 farms. In 2004, a district had 39.1 farms (5.1 guided pastures, 12.6 permanent grazing and 21.4 goat farms) on average. In 2021, the average farm number per district decreased to 30.1 farms (7 guided pastures, 6.5 permanent pastures and 16.6 goat farms). Out of the 1003 observations in the studied districts and years, 781 had zero attacks ($d = 0$), 132 had 1 or 2 attacks ($d = 1$), 76 had 3 to 6 attacks ($d = 2$) and 73 had more than 6 attacks ($d = 3$). With 4 exceptions, each district was attacked at least in one of the studied years (Appendix A, Figure A2). The average number of attacks per attacked districts did not increase over time (6.6 attacks per attacked districts in 2004 and 6 in 2021), only the number of affected districts increased.

As Equation (2) describes, we took the natural logarithm of the annual change in number of farms, whereby negative values indicate a decrease in number of farms, positive values an increase in number of farms and zero means no change.

4 | RESULTS

4.1 | The wolf attacks and the number of alpine summer farms

The relation between the number of wolf attacks and the change in the number of Alpine summer farms was quantified using modified causal random forests (Lechner, 2019), as outlined above. Table 4 presents the results regarding the total number of farms with sheep or goats and for the three defined farm types separately. For each farm type, we present the results in the format of a matrix, where the treatments $d \in \{1 \dots 3\}$ in the first column are compared with the treatments $d \in \{0 \dots 2\}$ in the other columns. Therefore, the effect estimation for the treatment $d = m$ compared with treatment $d = l$ means the difference between the outcomes under treatment $d = m$ and $d = l$.

The annual change in the number of sheep and goat Alpine summer farms was significantly more negative when wolves attacked. The sharpest decrease was when more than three attacks occurred (-0.04 and -0.04 in the logarithmic annual change of number of farms for $d=2$ and $d=3$, respectively). The results differ between different farm types, demonstrating the propriety of their distinction.

TABLE 3 Descriptive statistics.

Variables	Subgroup	Symbol	Min.	Max.	Mean	Obs.
Logarithm of annual change in total number of farms[a]	All data	$Y_{total,i,t}$	−1.1	0.87	−0.02	1003
	Treatment 0	$Y\mid d=0$	−1.1	0.87	−0.01	726
	Treatment 1	$Y\mid d=1$	−0.29	0.39	−0.01	131
	Treatment 2	$Y\mid d=2$	−0.56	0.22	−0.03	74
	Treatment 3	$Y\mid d=3$	−0.45	0.29	−0.03	72
Logarithm of annual change in a number of guided pastures farms[a]	All data	$Y_{guided,i,t}$	−1.61	1.61	0.02	1003
	Treatment 0	$Y\mid d=0$	−1.16	1.1	0.01	726
	Treatment 1	$Y\mid d=1$	−0.61	1.1	0.01	131
	Treatment 2	$Y\mid d=2$	−0.69	1.1	0.02	74
	Treatment 3	$Y\mid d=3$	−0.69	1.61	0.09	72
Logarithm of annual change in a number of permanent grazing farms[a]	All data	$Y_{\mathrm{permanent},i,t}$	−2.2	1.95	−0.04	1003
	Treatment 0	$Y\mid d=0$	−2.2	1.61	−0.04	726
	Treatment 1	$Y\mid d=1$	−1.39	1.96	0.03	131
	Treatment 2	$Y\mid d=2$	−0.69	1.96	−0.03	74
	Treatment 3	$Y\mid d=3$	−0.85	0.51	−0.11	72
Logarithm of annual change in a number of goat farms[a]	All data	$Y_{goat,i,t}$	1.2	1.39	−0.01	1003
	Treatment 0	$Y\mid d=0$	−1.2	1.39	−0	726
	Treatment 1	$Y\mid d=1$	−1.1	1.23	−0.02	131
	Treatment 2	$Y\mid d=2$	−0.69	0.51	−0.02	74
	Treatment 3	$Y\mid d=3$	−0.92	1.1	−0.02	72
The number of attacks by wolves[b]	Treatment type	D	0	3	-	1003
Year	Covariate 1	X_1	2005	2021	-	1003
Canton	Covariate 2	X_2	1	15	-	1003
Policy period	Covariate 3	X_3	0	1		1003

[a]Calculated by authors based on AGIS.

[b]Calculated by authors based on KORA.

The number of farms with permanent grazing decreased significantly faster when the district experienced more than six attacks in a year ($d = 3$). Compared to no attacks, more than six attacks in a year resulted in a decrease in the number of farms with permanent grazing next year (−0.1). The effect estimates for permanent grazing were twice as high as the estimates for the total group and more significant compared to those for any of the other farm types. Thus, it can be concluded that *permanent grazing* are the most sensitive farms to wolf attacks.

Guided pastures (the group of permanent shepherding and rotational grazing) and Alpine summer farms with goats showed no significant differences in the annual change under variations in wolf pressure. Nevertheless, there was a positive annual change in the number of farms with guided pastures in districts with a higher number of attacks, which means that the number of farms increased faster compared with less-attacked districts (Figure 1). Our results indicate that wolves cause structural changes in Alpine summer farming. If we could have found at least one significant positive estimate, we could argue that the structural change is just a redistribution between farming types. For example, our estimations for the guided pastures are very close to showing positive significance. However, of the few significant impacts we found, all were negative. Therefore, we conclude that the wolf attacks have led to a significant decrease in a number of Swiss Alpine summer farms in total, with the sharpest decrease in farms that use permanent grazing.

TABLE 4 The effect estimations for different farm types.

	Compared with treatments (l)		
Total number of farms			
Treatments (m)	$d=0$	$d=1$	$d=2$
$d=1$	−0.02 (0.02)		
$d=2$	−0.04 (0.02)*	−0.02 (0.03)	
$d=3$	−0.04 (0.03)*	−0.03 (0.03)	−0.01 (0.03)
Guided pastures			
Treatments (m)	$d=0$	$d=1$	$d=2$
$d=1$	0.05 (0.03)		
$d=2$	0.07 (0.05)	0.03 (0.06)	
$d=3$	0.09 (0.06)	0.04 (0.07)	0.02 (0.08)
Permanent grazing			
Treatments (m)	$d=0$	$d=1$	$d=2$
$d=1$	0.02 (0.05)		
$d=2$	−0.05 (0.04)	−0.07 (0.06)	
$d=3$	−0.1 (0.04)**	−0.11 (0.06)**	−0.05 (0.05)
Goat farms			
Treatments (m)	$d=0$	$d=1$	$d=2$
$d=1$	−0.09 (0.06)		
$d=2$	−0.02 (0.05)	0.07 (0.08)	
$d=3$	0.01 (0.06)	0.09 (0.00)	0.02 (0.08)

Note: **, * denote p-values smaller than 0.01, 0.05 and 0.1, respectively. If $a_{i,t}$ is the number of attacks by wolves in municipality i in year t, then $d_{i,t} = 0, if\ a_{i,t} = 0; 1\ if\ 1 \le a_{i,t} \le 2; 2\ if\ 3 \le a_{i,t} \le 6; 3\ if\ a_{i,t} > 6$. The indices i and t are reduced for better readability. The values in parentheses are standard errors. The number of observations for all treatments is 1003; for $d_{i,t} = 0$ is 726; for $d_{i,t} = 1$ is 131; for $d_{i,t} = 2$ is 74; for $d_{i,t} = 3$ is 72.

4.2 | Discussion of the results

We studied the relation between the number of wolf attacks and the number of Swiss Alpine summer farms that keep sheep and goats. As hypothesised, we found that wolf attacks on livestock affect the number of Alpine summer farms negatively. The number of Swiss Alpine summer farms in the affected districts tended to decrease faster or at least to increase slower than in districts without any wolf attacks.

As expected, the number of Alpine summer farms that use permanent grazing as their pasture system decreased significantly after the number of wolf attacks increased. Nevertheless, at least six attacks were needed to significantly decrease the number of farms. Three or more attacks may be said to represent systematic attack behaviour by wolves that have learned to predate livestock. This leads farmers to assume that livestock will continue to be killed and to make the decision to change the pasture system or abandon the farm (Mink & Mann, 2022). Meanwhile, less than three attacks might be assumed to be negligible, as they can occur when a migrating wolf randomly attacks livestock.

Guided pastures, which consist of farms that use permanent shepherding or rotational grazing, do not show a faster decline in numbers after increasing attacks. More likely, farms with guided pastures show a non-significant positive effect in districts with attacks compared to districts without any attacks. This result is plausible since these two grazing systems are considered suitable for herd protection. Originally, these two systems were funded to reduce pressure on biodiversity through optimised grazing management. Therefore, the number of these systems, especially permanent shep-

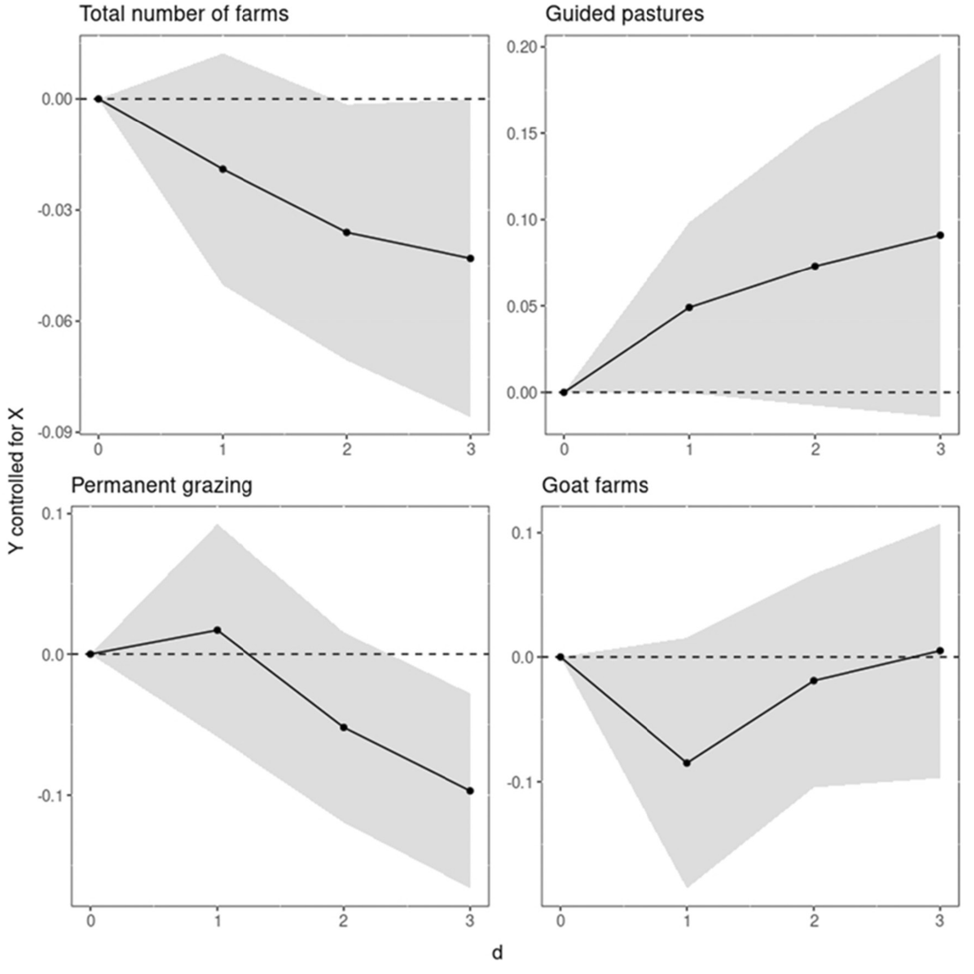

FIGURE 1 Estimated differences in changes in the number of farms experiencing different amounts of wolf attacks. Shaded area represents error bands (90% confidence interval). Y is a logarithmic relation between the number of farms in the selected district and the number of farms in the same district in the previous year. X are covariates, containing the canton, year and policy period. d is a treatment variable defined as $0, if\ a_{i,t} = 0; 1\ if\ 1 \leq a_{i,t} \leq 2; 2\ if\ 3 \leq a_{i,t} \leq 6; 3\ if\ a_{i,t} > 6$, where $a_{i,t}$ is a number of attacks in municipality i in year t. The indices i and t are reduced for better readability.

herding, has increased significantly since 2004. Our analysis shows, although not significantly, that in areas with high wolf pressure, additional farms with permanent shepherding or rotational grazing have emerged. On the one hand, this shows that farmers consider these systems help protect their flocks from wolf attacks, although these systems rarely offer 100% protection (Bruns et al., 2020). On the other hand, wolves indirectly encourage the preservation of the biodiversity of alpine pastures due to the increase in the number of guided pastures, which promote more sustainable pasture management. In addition, the sheep and goats in these systems are checked much more frequently by shepherds and owners, which helps to detect diseases and injuries earlier and ultimately increase the animals' welfare. However, some farmers point out that with rotational grazing and especially with permanent shepherding in combination with closely managed flocks in night pens, the health and weight gain of the sheep suffers because diseases are transmitted faster and the animals have less time to feed. Although a research report by Willems et al. (2013) was able to show that even better lamb weight gain was found in rotational grazing than in permanent grazing, we suggest that animal health and weight gain should be further studied and compared between all possible systems.

The decrease in permanent grazing and the increase in guided pastures indicate that, to some degree, permanent grazing is being replaced by permanent shepherding or rotational grazing. Almost all available pastures in this rocky and rough Alpine terrain are used as Alpine summer farms, and new farms with guided pastures don't emerge from nowhere; rather, they develop from existing farms. Because tradition also has a high value, the probability that cattle farms will become sheep farms is low. Thus, a decrease in the number of farms with permanent grazing does not necessarily mean that farmland is also being lost but that it is simply being managed under a different system. Some neighbouring farms also merge to increase stocking, which in turn provides opportunities for permanent shepherding or rotational grazing and thus better herd protection. Numerically, this has resulted in a decrease in the number of farms, while the managed areas and number of animals have remained the same.

If the agricultural policy remains as at present, the possibilities for changing the system from permanent grazing to guided pastures will decrease. As Mettler et al. (2014) showed, at least 400 animals are necessary for permanent shepherding to be economically profitable. Although rotational grazing does not require more animals than permanent grazing, it needs more working time for pasture management. Most of the farms that have fulfilled the requirements for guided pastures have probably already changed, since they receive more direct payments. For this reason, there is a need to determine the economic feasibility of a conversion from permanent grazing to other types of systems. In addition, studies are needed to ascertain whether the decline in the number of farms actually led to a decline of cultured areas and the role wolves played in this process.

In our study, so-called goat farms often keep few goats, and their economic emphasis relies mostly on cattle farming. These goat farms showed neither a significant effect nor a trend of annual change based on the number of attacks. Goats are attacked significantly less often than sheep in relation to their number. Most likely, this is because these goat herds are protected within the cattle herds. In addition, goats on Alpine summer farms are milked frequently and kept close to infrastructure (e.g., stables) or in fenced pastures, which prompts closer monitoring and control of the herd by the farmers. These are possible reasons explaining why the number of goat farms with increased wolf attacks in a district is not significantly affected.

Although cattle, suckler cow or dairy cow farms represent the majority of Alpine summer farms, we did not include them in our study because only a handful of cattle were attacked over the studied period. However, sheep or goat farms may potentially be replaced by cattle farms. The system most affected by wolves, permanent grazing, is usually not suitable for young cattle due to its remoteness, difficult terrain and very small size (Mettler et al., 2014). Nevertheless, we would like to add that cattle farming could be considered as a potential substitute for small ruminant farming, if the conditions on the pasture are appropriate. Since cattle and cow farms are also decreasing over time, it is possible, as promoted by Mettler et al. (2014), that small ruminants could switch from remote pastures to abandoned cattle pastures, where herd protection can be established due to better pasture conditions.

4.3 | Study limitations

The three analysed farm types constitute the total number of farms. However, their small numbers and changing proportion of the total number of farms might have created large variances in the annual changes and the estimates. In addition, the affected farmers might abandon their farms for other reasons that we did not examine (Mink & Mann, 2022). Therefore, the most important limitation of this study is the low number of treated observations, which could distort the estimates. Moreover, it limits the inclusion of more covariates and does not allow for narrower intervals for the number of attacks in our treatment variable. At the same time, the low number of treated observations means that the wolf attacks were not frequent in most of the Swiss districts in which summer Alpine farms are located. Although the low number of observations limits the power of models that split the data into training and testing datasets, we found significant effect estimations for districts in which the number of attacks exceeded six. Structural change in these districts may occur long after the sixth attack. However, as we cannot further improve the model with our data, we can conclude that for each significant estimate for $d = 3$ the seventh attack is the lower bound for observing a faster decrease in the number of farms. This does not mean that the effect estimates for more than six attacks follow the same logic, as the margin of each additional attack is likely to be lower than the margin of the previous attack.

5 | CONCLUSION

The causal random forests approach applied in this study shows a significant interrelation between wolf attacks and annual changes in farming in the Swiss Alpine region. In particular, farms engaged in permanent grazing appear to be the most challenged by the return of wolves to Switzerland. An accelerated decline in the number of farms with permanent grazing was observed during the study period, when the wolf attacks increased. Some of these farm managers gave up in response to the second or third wolf attacks, while others switched to guided pastures to better protect their animals. In contrast, farms with guided pastures were more resistant against wolves and increased in number faster in regions with many wolf attacks, although the increase was non-significant.

We recommend that policy-makers notice the structural change under increasing wolf pressure and seriously consider the effect of wolves on the decline in the number of farms with permanent grazing and support them with agricultural policy measures. However, we also point out as wolf attacks increase, the use of permanent shepherding or rotational grazing increases. This results in better control and protection of the animals as well as better pasture management, thus promoting sustainable biodiversity. Therefore, supporting this transition may also help in avoiding the loss of farms and herds.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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