Biological Conservation 272 (2022) 109664

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Griffon vultures, livestock and farmers: Unraveling a complex socio-economic ecological conflict from a conservation perspective

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ARTICLE INFO

Keywords:
Farmer perception
Human-wildlife conflict
Restrictive sanitary regulations
Vulture attack
Vulture-livestock conflict
Wildlife damage compensation

ABSTRACT

An unexpected human-wildlife conflict between vultures and livestock has emerged in Europe during the last two decades. Farmers attributed changes in vulture behavior, due to food shortages caused by sanitary regulations, to increasing livestock interactions ('vulture attacks'). To disentangle this conflict, we analyzed 683 farmer complaints between 1996 and 2020 in Catalonia (northeastern Spain) and investigated the eco-anthropological factors driving their frequency. We also assessed farmers' perception through 127 interviews. Most complaints (80 %) occurred during the birthing season, mainly involving cattle (76.5 %), followed by horses (14.9 %) and sheep/goats (8.6 %). From 2008 to 2020, vulture-livestock conflicts cost the government €192,000 (~22 % of claims compensated). The frequency of complaints was positively associated with extensive livestock density, griffon vulture *Gyps fulvus* abundance (breeding and non-breeding), shorter distances to landfill sites and, to a lesser extent, to supplementary feeding stations. In contrast, there was a negative relationship between complaints and the number of griffon vulture breeding pairs, suggesting that long-distance foraging movements by both breeding and non-breeding individuals may play a major role in determining the occurrence of conflicts. Farmers (88 %) said that vultures attack livestock and that attacks had increased in recent years because of significant vulture population increases and food shortages due to sanitary regulations. They considered government policies and compensation ineffective. We highlight the critical need for mitigation in areas with high extensive livestock numbers, particularly during birthing times. Scientific assessments and interdisciplinary awareness campaigns on the coexistence of vultures and livestock are necessary to harmonize biodiversity conservation and agro-pastoral practices in rural economies.

1. Introduction

Human-wildlife conflicts (HWCs) are becoming more common and are of increasing concern to ecologists and managers because of their impact on biodiversity loss (Woodroffe et al., 2005; Treves et al., 2009; Nyhus, 2016). Wildlife attacks on livestock and damage to crops are major causes of HWCs worldwide (Torres et al., 2018) and are projected to increase due to climate change, increasing economic insecurity and retaliations against wildlife in agro-pastoral communities (Abrahms, 2021). Economic losses produced by HWCs, mainly due to endangered predators (carnivores and birds of prey) killing livestock, are considered the main driver of this conflict (Graham et al., 2005; Dickman, 2010; Redpath et al., 2013; Araneda et al., 2021). The resulting direct persecution of predator species can jeopardize conservation efforts (Peterson et al., 2010; Zimmermann et al., 2010). Torres et al. (2018) identified 263 terrestrial vertebrate species involved in HWCs worldwide, of which 53 were listed as threatened, such as vultures. Policy-makers therefore need evidence-based information to design sustainable management actions and policy tools to address this problem (Baynham-Herd et al., 2020).

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https://doi.org/10.1016/j.biocon.2022.109664
Received 26 April 2022; Received in revised form 1 July 2022; Accepted 12 July 2022
Available online 22 July 2022

Old World vulture populations are declining throughout their ranges, mainly due to anthropogenic pressures (Green et al., 2004; Ogada et al., 2012). However, in contrast, European vulture populations are stable, or even increasing. Nonetheless, over the past two decades critical threats to the conservation of European vultures have emerged (Safford et al., 2019). The main current threat, in the shape of new sanitary legislation (EC 1774/2002), appeared after the outbreak of bovine spongiform encephalopathy (BSE) at the beginning of 21st century. This controversial regulation prohibited the abandonment of dead extensively reared livestock in the countryside from 2006 to 2011 (Donázar et al., 2009). A collateral effect subsequently emerged; a widespread view, fueled by public and media misrepresentation, claimed a causal relationship between food shortages for scavengers and presumed attacks on livestock, leading to increasingly negative perceptions of vultures (Margalida et al., 2011).

Negative perceptions of wildlife can promote anthropogenic pressures such as lethal control. Indeed deliberate poisoning is considered one of the major causes of death in wildlife species in Europe (Guitart et al., 2010). Avian scavengers in general, and vultures in particular, are major victims of illegal poisoning, either intentionally or unintentionally (Pfeiffer et al., 2015; Ogada et al., 2016; Santangeli et al., 2016; Plaza et al., 2019; Safford et al., 2019). Laying the blame for livestock killing on Old and New World vultures has recently aggravated this situation (Margalida et al., 2011, 2014; Duriez et al., 2019; Plaza and Lambertucci, 2021). Generalized perceptions of vultures attacking livestock have increased in recent years, associated with the viral spread of partial and biased information through social media, despite the limited empirical support for these assertions (Margalida and Donázar, 2020; Lambertucci et al., 2021). In spite of the long-established mutual relationship between humans and vultures (Moleón et al., 2014), negative perceptions may drive discontent and incite vengeance from some farmers, creating a source of tension and the debate on vulture/livestock conflicts is increasing and remains open and controversial.

The study of public perceptions, "*the way an individual observes, understands, interprets, and evaluates a referent object, action, experience, policy or outcome*" (Bennett, 2016) has received growing attention in conservation biology because of increasing awareness of the critical role of the human dimension (i.e., perceptions, values, beliefs and attitudes) in improving conservation efforts (Bennett et al., 2017) and effectively resolving HWCs (Dickman, 2010). However, perceptions are not always objective since they are mediated by multiple contextual factors, including past experience, personal motivation or the reports of individuals, communities or social media (Naughton-Treves and Treves, 2005; Bennett, 2016; Ballejo et al., 2021). A person's perceptions can also be driven by contradictory governmental policies (e.g., when a species, such as vultures, is listed both as a livestock-predator and a protected species) requiring different mitigation and conservation measures. Therefore, making objective decisions can be challenging because human realities and perceptions may vary widely between and within the stakeholder groups involved (König et al., 2020).

A recent example of differing perceptions regarding the relationship between scavengers and livestock relates to farmers. Their perceptions, attitudes and values may change along a species geographical distribution (Ballejo et al., 2019), due to different local legislation (Gigante et al., 2021) or paradoxically, the same species and species within the same guild can be perceived as either beneficial or harmful, or a mixture of both (Morales-Reyes et al., 2018). Moreover, although farmers usually attribute severe damage to livestock as being due to scavenging birds, when the interaction is assessed it is often found to be minimal or even nonexistent (Margalida et al., 2014; Duriez et al., 2019). Indeed livestock losses to bird predation are often found to be less than those produced by other causes, such as disease, injury or poor nutrition (Graham et al., 2005). Recent research on the behavioral conflict between New and Old world vultures and livestock has focused on the human dimension (Ballejo et al., 2019; Gigante et al., 2021; Salom et al., 2021) and to a lesser extent on field observations (Ballejo et al., 2020). However, a complete examination of this phenomenon would require integrating the management/responses of local authorities, complaint assessments, farmer perceptions and broader assessments by technical experts and veterinarians.

Here, we try to disentangle the factors associated with increasing conflicts between vultures and livestock in Catalonia, a region of northern Spain inhabited by the four European vultures. We first assessed the complaints reported by farmers to the authorities and explored their temporal trend. Then, we investigated the influence of ecological and anthropic factors (e.g., global griffon vulture *Gyps fulvus* abundance, number of griffon vulture breeding pairs, extensive livestock density and the distances to the nearest landfill site and supplementary feeding stations 'SFSs') on the frequency of complaints. Finally, we interviewed farmers to analyze their perceptions and concerns regarding this emergent conflict, so as to assess the vulture/livestock interface from an ecological-economic-social perspective. Based on our results, we propose solutions and guidelines to manage this unexpected conflict and to harmonize vulture conservation with agro-pastoral practices.

2. Material and methods

2.1. Study area

Catalonia covers over 32,000 km^2, with altitudes ranging from sea level to >3000 m. The landscape is heterogeneous, dominated by forests (34.7 % of the total area), crops (30.1 %), shrublands (22.4 %) and grasslands (4.8 %), while urbanized areas cover 5.3 % of the surface (González-Guerrero and Pons, 2020). The region is characterized by a high population density (241.8 inhabitants/km^2) and powerful industrial and service sectors, while agriculture is less important (1 % of the regional GDP). Intensive farming of pork (54.9 %) and poultry (17.9 %) are the most important agricultural systems. Cattle (13.0 %), sheep/goat (1.8 %) and horse (0.4 %) rearing are economically less important (DARPA, 2018). Catalonia has at least 5457 extensive or semi-extensively farms of cattle (37.03 %), sheep/goats (34.9 %) and horses (28.07 %) (http://agricultura.gencat.cat/), which are present throughout the region, but especially in mountainous areas. Extensive livestock in mountainous zones graze on high summer pastures from June to October and remain stabled in the valley bottoms exploiting the surroundings of small hamlets for the rest of the year (García-Ruiz et al., 2020). Rural areas hold important populations of facultative and obligate scavenger species. At least 1628 breeding pairs of griffon, 20 of cinereous *Aegypius monachus*, 88 of Egyptian *Neophron percnopterus* and 49 of bearded vultures *Gypaetus barbatus* occur in the region (Del Moral, 2017; Del Moral and Molina, 2018a, 2018b; Margalida and Martínez, 2020).

2.2. Farmer complaints

We used an official database containing all complaints (n = 683) made by farmers from 1996 to 2020 relating to reported vulture 'attacks' on livestock. It is important to note that while farmers reported incidents as 'attacks', our study took the view that the precise nature of the interaction was still to be proven, so we additionally used the term 'interaction' to refer these conflicts. We used the complete database to assess the temporal trend, and the complaints reported from 2008 to 2020, for which more detailed information was available, to characterize the interactions (n = 616, 90.2 % of the total). A subset of this data (2008–2018, n = 573 claims, 83.9 % of the total) was considered for modelling the determinants of conflicts, as updated information of livestock density was not available for the latest period. For each complaint, the official data included: i) date of the interaction; ii) date of the assessment; iii) municipality and county; iv) livestock type (cattle, horses or sheep/goats) and category ('adult', 'female and new-born' or 'new-born'); v) the number of individuals affected; vi) validation (i.e., 'accepted' when the assessment considered that the animal was still

alive when vultures started to consume it, or 'rejected' when no evidence was found or when consumption by vultures was considered to be post-mortem); vii) financial compensation (€); and viii) UTM coordinates. To characterize the interactions, we recorded for each complaint: i) type of livestock involved; ii) livestock category; iii) seasonality (i.e., the month the claim was reported); iv) number of complaints 'accepted' (i.e., financially compensated) or 'rejected'; and v) total economic compensation by the authorities.

2.3. Frequency of complaints

We first recorded the number of complaints reported by farmers in a grid of 10 × 10 km UTM cells during 2008–2018, since each cell was considered as one single statistical observation in the analyses (n = 110 cells accounting for 573 complaints). Next, we calculated the following variables for each cell: i) 'number of griffon vulture breeding pairs'; ii) 'global griffon vulture abundance'; iii) 'extensive livestock density'; iv) 'distance to nearest SFS'; and v) 'distance to nearest landfill site'.

We estimated the 'number of griffon vulture breeding pairs' as the average of two censuses carried out in 2008 and 2018 throughout Catalonia (Del Moral and Molina, 2018a); and the 'global griffon vulture abundance', according to the values obtained by García-Ferré et al. (2011) following the methods described in Herrando et al. (2011). In brief, sampling was carried out through surveys performed in three consecutive winters (2006–2009) over the whole study area, and then was standardized by sampling effort. After that, all the data was processed statistically to achieve a value of abundance for each 1 × 1 km cell. Here, we averaged the 100 1 × 1 km cells to obtain a value of abundance for each 10 × 10 km cell. An advantage of this measure is that it accounts for the abundance of both breeding and non-breeding individuals. It is known that griffon vultures routinely perform movements at large distances from breeding sites (Delgado-González et al., 2022), so they can be abundant in areas located far from breeding sites. Moreover, non-breeding vultures may represent an important fraction of the population, which frequently exploit food resources far from the breeding grounds. Similar information on abundance does not exist for later years, although based on our personal observations we do not expect the spatial pattern of vulture abundances to have changed significantly during the period considered in the analyses.

The 'extensive livestock density' (e.g., extensive, mixed or transhumant farming systems) was estimated considering the potential capacity of the farms (i.e., maximum number of animals that a farm can raise) for each livestock type (cattle, sheep/goats and horses). We assumed that farm capacities are a good proxy of the number of livestock animals (information that was not yearly available) because farmers pay fees on this basis. To estimate the density of extensive livestock at the cell level, we first calculated for each year an average density of livestock heads for each municipality. Then, we calculated a weighted average for each cell according to the municipalities' surface within each cell. Lastly, we averaged the yearly estimates in each cell for the entire period. Farming information was extracted from the Livestock Information System (www.sir.gencat.cat). Geoprocessing analyses were performed using the ArcMap 10.5 program (ESRI, 2016). The distances (km) to the nearest landfill site and SFS from the nearest limit of each cell were estimated assigning a distance equal to zero for those cells containing a landfill site or SFS. Because some SFSs were not active in every year, an average distance value was obtained for the whole study period.

2.4. Farmer interviews

We assessed farmers' perception of vulture conflicts with livestock through face-to-face and telephone interviews from 2018 to 2021 (see Appendix S1 for the full list of questions). We surveyed 127 farmers from Pyrenean and adjacent regions, obtaining information on 166 farms with cattle (53.6 %), sheep/goats (30.1 %) and horses (16.3 %), since thirty-four respondents had mixed farms. We first recorded information regarding the farm characteristics (e.g., livestock type) and then asked both closed and open questions about conflicts between vultures and livestock. Some of the closed questions were in multiple-choice format (Appendix S2). Further, we asked if they had experienced vulture interactions on their livestock and if so, we collected information about the livestock involved (e.g., where and under what circumstances the dead livestock was found) as well as if they had recognized the species starting the interaction and how they detected it. Respondents were also asked a range of questions regarding their views on whether vultures could attack live livestock, the temporal trend of such conflicts, the type of livestock supervision during birthing times and the response of the local authorities and any financial compensations paid. Finally, we recorded farmers' views on the coexistence of vultures and livestock, the ecological relationships between them, and on measures that could be implemented to mitigate conflicts.

2.5. Statistical analysis

We investigated ecological and anthropic factors influencing the frequency of vulture/livestock interactions (i.e., number of complaints) using generalized linear models (GLM), where 'number of complaints' (per 10 × 10 km cell) was the response variable and 'number of griffon vulture breeding pairs', 'global griffon vulture abundance', 'extensive livestock density', 'distance to nearest landfill site', and 'distance to nearest SFS' were the explanatory variables. We used Poisson error distributions and logarithmic link functions. Models considering the main effects of the explanatory variables were evaluated. We used Akaike's information criterion for small sample sizes (AICc) to identify the most parsimonious model (i.e., the one with the lowest AICc) and to rank the remaining models. When there was more than one model competing with the best AICc model (those with $\Delta AICc < 2$), we performed conditional model-averaging across the candidate models (Burnham and Anderson, 2002) using the *MuMIn* package (Barton, 2013). This procedure averages parameter estimates across the set of selected models in which the respective parameter appeared, weighted by the relative importance of each model. The analyses were performed using the R Software for Statistical Computing program (R Development Core Team, 2020). We used Chi-squared analyses to look for differences in farmers' perceptions of the coexistence and ecological relationships between vultures and livestock, based on whether they had suffered attacks.

3. Results

3.1. Complaints assessment

We found three temporal trends in the 683 complaints reported from 1996 to 2020. Until 2006, the number of complaints was low and with little variability between years (mean ± SD = 1.8 ± 1.6 claims/year). From 2007 to 2011 complaints increased dramatically reaching a maximum in 2010 (86 complaints). After 2011 the trend diminished progressively until 2020 (Fig. 1). Complaints reported during 2008–2020 mainly involved cattle (n = 471, 76.5 %), followed by horses (n = 92, 14.9 %) and sheep/goats (n = 53, 8.6 %) (Appendix S3). Of these, 78.2 % were rejected. The proportion of accepted complaints (n = 134, 21.8 %) was similar: 77.6 %, 14.2 % and 8.2 % for cattle, horses and sheep/goats, respectively, and did not differ between species ($\chi^2_2 = 0.13$, $P = 0.94$). We identified a seasonal pattern (e.g., 80 % of complaints between February and July) associated with the birthing season: 76.4 %, 96.7 % and 83 % for cattle, horses and sheep/goats, respectively. Further, at least 68.3 % of the complaints occurred during birthing times (i.e., involving the female and new-born, or the new-born): 69 % for cattle, 83.7 % for horses and 35.8 % for sheep/goats, respectively (Appendix S3). The period March–June included 69.6 % of the total complaints. During this period, on average 8.3 claims were reported per

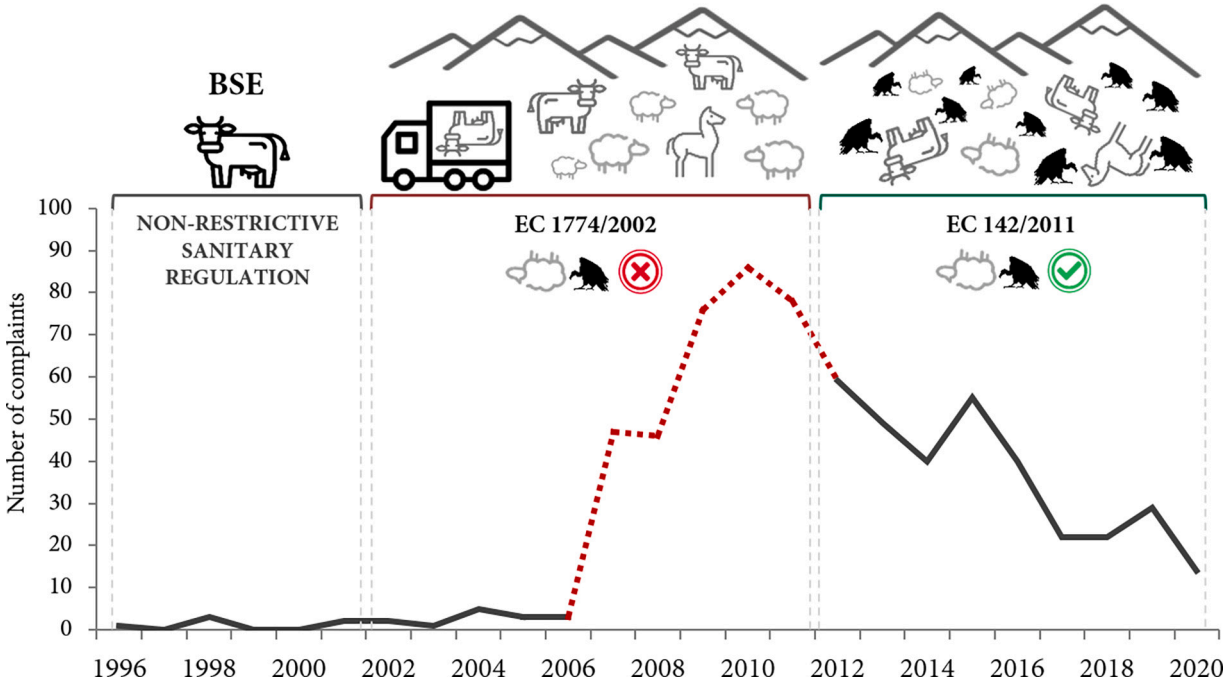

Fig. 1. Complaints regarding griffon vulture attacks on livestock from 1996 to 2020 in Catalonia. Three periods are highlighted: a) appearance of bovine spongiform encephalopathy (BSE) in Europe (1996) when no sanitary regulations were in force (e.g., livestock carcasses could be left in the countryside and available for scavengers); b) the approval of restrictive sanitary regulations (EC 1774/2002) prohibiting the abandonment of dead livestock in the countryside (2002–2011); and c) the approval of new regulation (EC 142/2011) allowing farmers to leave livestock carcasses in the countryside.
*The slow adoption of European environmental policies helps to explain the delay between regulation approval EC 1774/2002 and the increase in complaints from 2006 (López-Bao and Margalida, 2018).

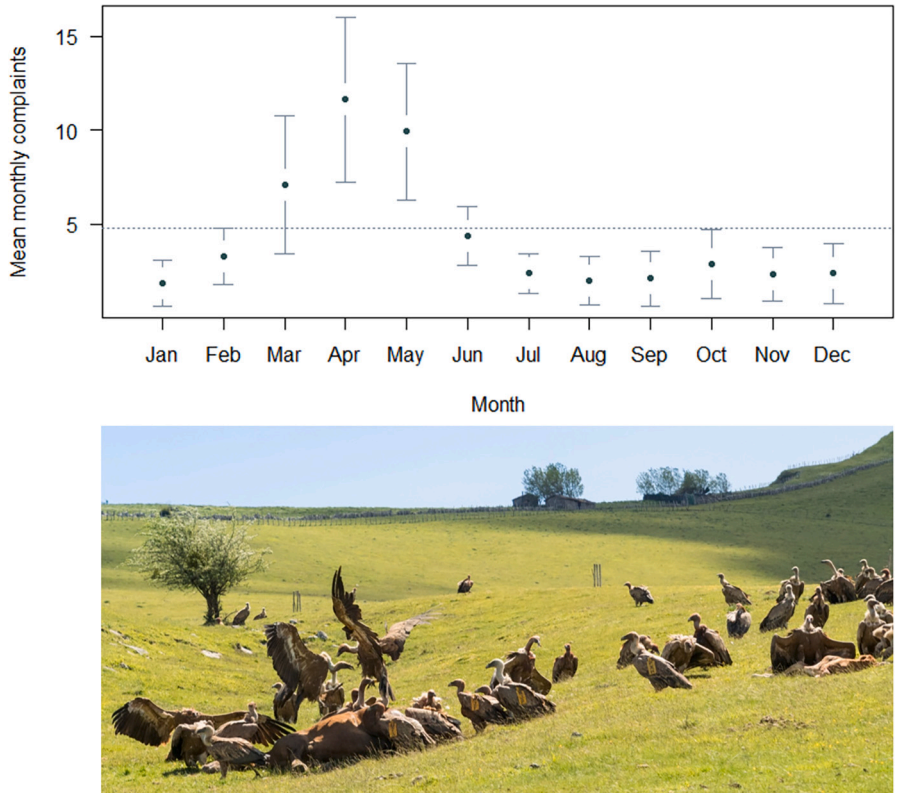

Fig. 2. Average number of monthly complaints (n = 616) from 2008 to 2020. The dashed line shows the average number of complaints reported during the entire period. The photograph shows a group of griffon vultures feeding on a dead mare and her new-born foal just after a problematic calving, which could be construed as an 'attack' (photo: Pilar Oliva-Vidal).

month, whereas for the rest of the year the mean number of monthly complaints was ≤3 (Fig. 2). Most accepted complaints (75.4 %) were made during the birthing season (65.7 % from March to June). The highest percentage of accepted complaints was in 2008 (56.6 %) and 2009 (61.8 %) and decreased in 2010 (39.5 %) and remained below 10 % until 2018. The estimated economic cost during 2008–2020 of the complaints assessed positively was €192,000.

3.2. Factors driving the frequency of complaints

We evaluated 32 models to investigate the factors influencing the frequency of complaints (n = 110 cells; Appendix S5). The averaged model included all of the predictors, of which four showed values of relative importance (i.e., > 0.8, Appendix S6). 'Extensive livestock density', 'distance to nearest landfill site', 'number of griffon vulture breeding pairs' and 'global griffon vulture abundance' were the predictors with the highest weights, although the averaged model also included the effect of 'distance to nearest SFS'. We found that higher densities of extensive livestock and shorter distances to both the nearest landfill site and SFS were associated with higher numbers of complaints (Table 1), although the effect of the distance to the nearest SFS was weak. In addition, our results showed that a higher abundance of griffon vultures (including both the breeding and non-breeding populations) was associated with higher numbers of complaints, but conversely, the number of griffon vulture breeding pairs was negatively associated with the number of complaints (Fig. 3).

3.3. Farmers' perceptions

Of 127 farmers interviewed, 67 (52.8 %) reported having suffered vulture attacks on their livestock, cattle being the most affected (71.9 %), followed by sheep/goats (21.1 %) and horses (7.0 %) (Appendix S4). Most interactions (75.9 %) described occurred during the birthing season. However, while most cases involving cattle (91.7 %) and horses (54.6 %) were associated with calving, interactions with juveniles and adults unrelated to parturition were more important for sheep (66.7 %) (Appendix S4). Farmers associated 72.2 % of the interactions on adult livestock with old, sick or dying individuals. The attacks described mainly occurred while livestock remained in open fields (48.6 %) or fields protected with electric shepherds (44.4 %), compared with cases in semi-open (5.6 %) or closed (1.4 %) farms. Most respondents (76.5 %) thought that griffon vultures had initiated the attack, followed by 'don't know' (10.5 %), ravens *Corvus corax*/foxes *Vulpes vulpes* (3.9 %) and cinereous vultures/bears *Ursus arctos* (2.6 %). However, none claimed to have seen the actual start of an attack. Farmers detected attacks because they were in the area and observed griffon vultures (42.9 %) while supervising livestock at the time (32.1 %), by their noticing a known (21.4 %) or unknown (1.2 %) person, or while supervising livestock on the following day (2.4 %).

Overall, farmers believed that vultures can attack live livestock (88.2 %) and most of them (77.2 %) said that attacks had increased in recent years, attributing them mainly to the population increase of griffon vultures and to the lack of food in the field due to sanitary regulations (Fig. 4A). Regarding farmers declaring attacks, 68.7 % (n = 46) had reported it to the authorities. Of these, 30.4 % were financially compensated and half had considered the economic compensation to be sufficient. However, considering all respondents, 86.1 % thought that the response of the authorities had not been favorable and 82.6 % believed that financial compensation did not satisfy farmers suffering attacks. Few respondents (5.4 %) considered that current economic compensations were sufficient. Farmers reporting attacks had a more negative perception of the coexistence of vultures and livestock (Fig. 5A) and the ecological relationships between them (Fig. 5B) than those who had not reported attacks. Further, 91.3 % of respondents said that it was necessary to apply management measures to mitigate the conflict (Fig. 4B) and 73.8 % believed that interactions would increase further otherwise.

Table 1
Generalized linear model (GLM) relating the frequency of vulture attack complaints to ecological and anthropic variables. The conditional model-averaged estimates and standard errors (SE) of models with ΔAICc < 2 are shown.

Variables	Estimate	SE
Intercept	1.050	0.137
Extensive livestock density (animals/km^2)	0.011	0.001
Distance to nearest landfill site (km)	−0.027	0.005
Number of griffon v. breeding pairs	−0.010	0.003
Global griffon v. abundance	0.872	0.334
Distance to nearest SFS[a] (km)	−0.004	0.005

[a] SFS: supplementary feeding station.

4. Discussion

Livestock and wildlife conflicts have occurred for millennia, mainly involving carnivores and birds of prey (Torres et al., 2018). However, recent widespread perceptions that vultures attack livestock threaten Old and New World vulture populations (Lambertucci et al., 2021). In southern Europe, claims that vultures attack livestock began in the mid-1990s but have increased since the mid-2000s, notably in Spain and southern France (Margalida et al., 2014; Duriez et al., 2019) and an unprecedented and complex socio-economic ecological conflict has emerged.

We identified three temporal trends in reported vulture attacks on livestock. From 1996 to 2006 the number of annual complaints was low but rose significantly from 2007 to 2011, followed by a progressive decline from 2012 to 2020. Certain policy decisions could explain these trends. First, changes in sanitary legislation (Regulation EC 1774/2002) prohibited the abandonment of livestock carcasses in the countryside, provoking general alarm among farmers and establishing a perceived causal relationship between food shortages and presumed vulture attacks (Donázar et al., 2009; Margalida et al., 2010, 2011). Second, the approval in Catalonia of a regulation (Decret 176/2007) including griffon vultures among potential livestock predators (listing them as compensating species with wolves *Canis lupus* and bears). This regulation coincided with a period of perceived vulture food shortage and growing alarm among farmers, leading to government compensation for most complaints (e.g., ~60 % of those reported in 2008 and 2009). In 2011, coinciding with the highest frequency of complaints, more flexible regulations were approved (EC 142/2011) allowing livestock carcasses to be left in the field to feed scavengers (Margalida et al., 2012). However, to date few farmers have requested permission to leave livestock carcasses in areas designated for this purpose. In fact, only 9.4 % of the farmers interviewed reported leaving carcasses in the field. Official collection and transport of dead livestock from farms to authorized processing plants is still the main means of dealing with carcasses following the BSE outbreak. Our results highlight a paradoxical lack of awareness since 'being able to leave carcasses in the countryside' was the second most frequent measure proposed to mitigate the conflict by the farmers interviewed. The steady fall in farmer complaints since 2011 may result from more rigorous assessments (e.g., accurate necropsies) verifying that livestock deaths were due to other causes (Dalmasso et al., 2012), increasing the percentage of rejected complaints and suggesting that the conflict had been overestimated.

Presumed vulture attacks were highest during the period of severest food shortage. However, Spanish griffon vulture populations increased 20.5 % during 2008–2018 (Del Moral and Molina, 2018a), suggesting that the severest food shortage had no demographic effects. Despite this, farmers continue to believe that vultures attack livestock when food is in short supply. Our findings showed that almost 90 % of farmers believe that vultures attack livestock and most of them thought that attacks have increased in recent years, mainly because of the drastic increase in the vulture population and a lack of food due to sanitary regulations.

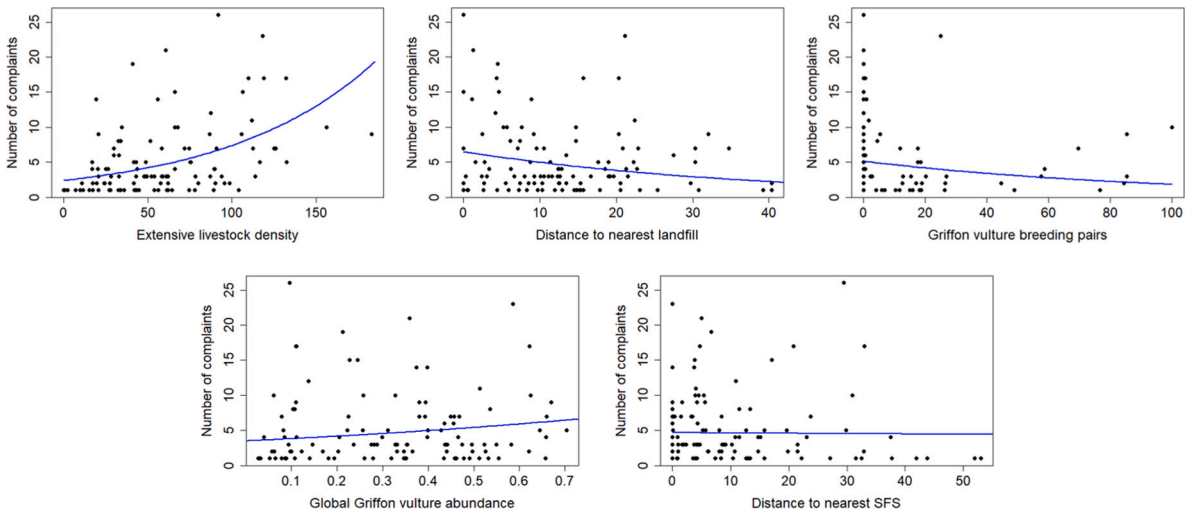

Fig. 3. Observed (black spots) and predicted (blue lines) values of the explanatory variables: 'extensive livestock density' (animals/km^2), 'distances to the nearest landfill site and SFS' (km), 'number of griffon vulture breeding pairs' and 'global griffon vulture abundance' considered in the generalized linear model determining the frequency of complaints of vulture/livestock interactions during the period 2008–2018. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

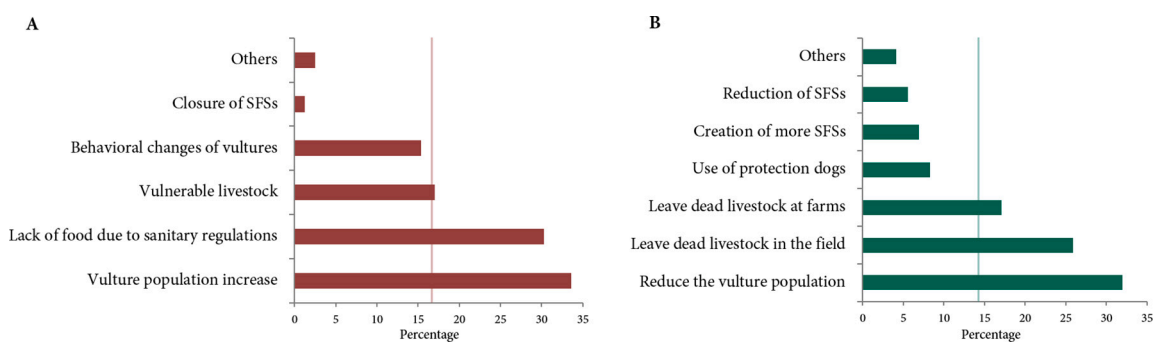

Fig. 4. A) Main causes of the increase in vulture/livestock interactions reported by the farmers interviewed (n = 241), and B) main management measures proposed to reduce this conflict (n = 216). Some farmers proposed multiple responses (Appendixes S1 and S2). The vertical line indicates the percentage of responses expected if the responses occurred equally frequently.

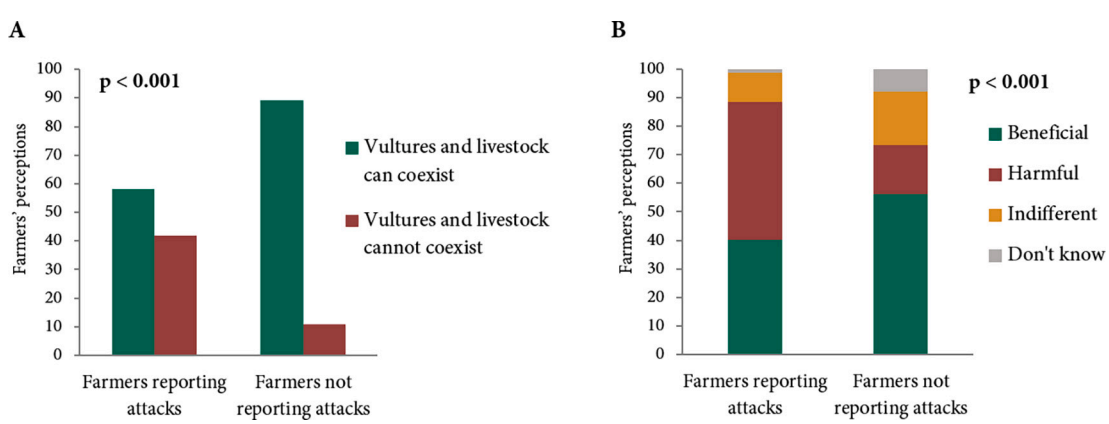

Fig. 5. Farmers' perceptions (in %) regarding the coexistence of vultures and livestock (A); and the ecological relationships between them (B). The significance of the Chi-squared tests are shown.

Nevertheless, no spatial relationship was found between the food availability and the frequency of complaints (Margalida and Campión, 2009). Further, 70 % of complaints in Spain and France were associated with post-mortem consumption and French shepherds were not present at 95 % of livestock deaths, so could not confidently attribute the death to vulture attack, suggesting that farmers' biased opinions led to perceived conflicts rather than any change in vulture behavior (Margalida et al., 2014; Duriez et al., 2019).

Our results showed that complaints were strongly associated with high extensive livestock densities and were influenced by shorter distances to landfills and, to a lesser extent, to SFSs. Griffon vultures and other scavenging birds commonly congregate at landfill sites to forage

(Donázar et al., 2010; Tauler-Ametller et al., 2017). The weaker effect of the distance to SFSs could be related to the type and management of the SFSs in our study area, most being specifically designed for target species such as the bearded vulture. The specialized resources provided at these SFSs may be less attractive to griffon vultures (Moreno-Opo et al., 2015). Although griffon vultures may visit SFSs, they seem to be less attractive than landfills, where both breeding and floating non-breeding individuals often gather (Arévalo-Ayala et al., 2022; Fernández-Gómez et al., 2022). Griffon vulture abundance was positively associated with the number of complaints while the number of breeding pairs showed the opposite trend. However, while most cells with higher complaint numbers harbored few or no breeding pairs, some cells with greater numbers of breeding pairs were associated with a high number of complaints. This suggests that the effect of vulture abundance on the number of complaints may be complex. In this sense, reports of conflict could vary greatly in time and space due to vultures' long distance foraging habits (Spiegel et al., 2015; Gutiérrez-Canovas et al., 2020). The foraging strategies of vultures (Ruxton and Houston, 2004) may explain why griffon vultures find it easier to detect vulnerable livestock (e.g., injured, sick, weak, or those suffering parturition problems) in rural and anthropogenic (e.g., close to landfills) landscapes, resulting in increased conflicts compared to areas less attractive to vultures. Conversely, the negative relationship between complaints and the number of vulture breeding pairs may be because a significant number of complaints were reported in areas far from their breeding sites, suggesting that breeding birds may perform longer foraging movements (Delgado-González et al., 2022), or that floating populations may play a major role in determining the appearance of conflicts.

We identified a strong seasonality in complaints associated with the birthing season, particularly from March to June (~70 % of the claims). However, while most complaints involving cattle and horses were associated with calving, most interactions involving adult sheep were not related to parturition. Similarly, farmers reporting attacks (52.7 %), declared that cattle were most affected and that attacks were mainly associated with calving. Further, farmers reported that attacks on sheep mainly concerned adult individuals. In our study area, cattle were most often reported as affected and interactions were more frequent in spring, demonstrating a seasonal, birthing time, pattern of vulture/livestock encounters. However, because of the patchy nature of the official data, cases involving calving cattle were probably underestimated. Therefore, it is imperative to establish a standardized protocol, supervised by qualified personnel (e.g., veterinarians and biologists), to assess and decide on official complaints.

Livestock management could explain the seasonal pattern we found regarding both official complaints and attacks described by farmers. In spring during birthing times, livestock are kept extensively in grazing pasturelands, often with minimal supervision. For instance, almost 37 % of the farmers interviewed recognized that livestock supervision during the birthing season is insufficient, regardless of whether they had suffered attacks. On the other hand, while sheep usually graze accompanied by shepherds and/or sheepdogs, and most herds spend the night at farms or remain protected by electric shepherds, cattle and horses usually remain at large for longer periods with minimal supervision. This could help explain why most interactions involving sheep were unrelated to parturition, since lambing difficulties are much less frequent compared to cattle (Jacobson et al., 2020). In fact, >90 % of vulture/cattle interactions described by farmers were associated with calving.

Although scavenging birds may cause some harm, especially during parturition, evidence of actual predation is exceptional (Ballejo et al., 2020). However, farmer's perceptions are different, and they usually attribute livestock death to vulture attack, often prompted by increasing numbers of false reports, even if they have never experienced this conflict (Margalida and Donázar, 2020; Ballejo et al., 2021). Nevertheless, media reports just suggest attacks showing vultures feeding on a carcass (Fig. 2) or people claiming livestock losses due to vultures without actual evidence (Lambertucci et al., 2021). Highly visible and potentially dangerous species are especially likely to generate disproportionate antagonism, being perceived as innately evil or harmful, so that even low levels of damage can still elicit harsh responses and even where conflicts are entirely mitigated, negative perceptions can perpetuate (Dickman, 2010). Some people consider vultures 'disgusting birds', associated with death and decay due to their obligate scavenging habits (Hla et al., 2011), despite their having cultural significance in some religions and the valuable contributions they make to public health and ecosystem services (DeVault et al., 2016). Education can reduce these negative perceptions, but such deep-seated preconceptions are difficult to overcome and must be considered in HWC assessments (Dickman, 2010).

We identified certain social factors that may contribute to the conflict. First, most farmers declaring attacks believed that vultures initiated the attack, but only because they had observed vultures or their signs (e.g., feathers). However, none confirmed observing the start of an attack. Second, 68.7 % of farmers reported interactions, and half of those compensated thought that the economic compensation was enough (Bauer et al., 2017). However, compensatory measures may not alleviate the problem because they rarely cover the total costs, are open to corruption, and are often expensive to administer (Sillero-Zubiri et al., 2004). Third, we found that sheep farmers complained much less often (8.6 %) than cattle (76.5 %) or horse (14.9 %) farmers. Complex bureaucratic procedures and livestock values can help explain these differences (e.g., in Catalonia, financial compensation for vulture interactions were ~€1200 for cattle, ~€1300 for horses and ~€150 for sheep; Decret 176/2007). Furthermore, 86 % of all farmers thought that the authorities' response was ineffective; 83 % said that financial compensations did not satisfy farmers suffering attacks; and only 5 % believed that compensations were enough – even though the compensation was considered fair by some farmers actually receiving it. Addressing these perceptions is crucial to alleviating this conflict. It is vital to improve administrative processes, and develop awareness campaigns and broader interdisciplinary approaches (e.g., to bring managers, scientists and farmers together) in order to move farmers away from a conflict mentality towards one of coexistence with vultures. The fact that we were able to interview 127 farmers on this topic highlights the opportunities to work together in future, and effectively resolve this complex conflict in the long term.

Farmers declaring attacks on their livestock had a more negative attitude towards the coexistence of vultures and livestock and considered vultures more often harmful than beneficial. This could be due to their lack of knowledge of vultures' behavior and the pivotal ecosystem services they provide, particularly in areas where vultures are scarce. In fact, we found that many interactions were reported in areas without breeding vulture pairs, suggesting that people's negative perceptions could be influenced by reports of others or the media (Margalida and Donázar, 2020). Finally, our findings illustrate that most farmers considered that reducing griffon vulture populations was necessary to mitigate the conflict. We argue that it is necessary to promote awareness campaigns to rural people that explain that if vulture numbers are reduced, may result in an increase in mesopredators and the spread of pathogens among livestock, wildlife and humans (Markandya et al., 2008; O'Bryan et al., 2019).

4.1. Management implications

To mitigate 'vulture attack' conflicts, ~22 % of claims were compensated between 2008 and 2020. However, financial compensation is not always the best way to minimize HWCs (Sillero-Zubiri et al., 2004). Instead, broader assessments of environmental and social risk factors affecting the frequency of interactions are critical to better understand the nature of this conflict and how it can be addressed (Dickman, 2010). Damage verification by veterinarians is crucial to clarify the real cause of death, avoid waste of public resources and obtain rigorous data to identify the real magnitude of the conflict (Dalmasso et al.,

2012). Further, improving livestock welfare is essential. This is critical in areas with high extensive livestock density, especially those with recurrent conflicts. Increased livestock protection is crucial to reduce livestock vulnerability, especially during the birthing season. As recognized by some farmers "*livestock calving has to be at home and not in the mountains, as was traditionally done*". Governments should enact regulations integrating livestock welfare and hold livestock owners accountable for providing adequate protection (López-Bao and Mateo-Tomás, 2021). The European Directive 98/58/EC on the protection of animals kept for farming purposes, states that "*all animals kept in husbandry systems in which their welfare depends on frequent human attention shall be inspected at least once a day*". Some farmers stated that livestock supervision was insufficient, and that regular inspections are essential, enabling farmers to recognize vulnerable or dead livestock, thus reducing the likelihood of an 'attack' or the uncertainty in verifying suspected attacks (López-Bao et al., 2017). Many complaints occurred in areas where no vultures breed, due to the large numbers of vultures congregating at nearby predictable food sources such as landfills (Arévalo-Ayala et al., 2022). Clearly, proper management of landfills is essential, particularly taking into account the expected drastic decrease of food available to wildlife at these sites over the coming years (Landfill Waste Directive 2008/98/EC; Circular Economy Action Plan). In addition, it is necessary to allow carcasses to be disposed of more widely than in the currently permitted high altitude (i.e., >1400 m) areas. Finally, because farmers perceive the arrival of vultures in newly colonized areas as a novel threat, it is crucial to implement educational campaigns to explain the importance of the ecosystem services they provide to society. Our findings demonstrate that scientific assessments and interdisciplinary awareness campaigns are urgently required to reconcile biodiversity conservation with rural economies.

CRediT authorship contribution statement

Conceptualization: A.M., P.O.-V., M.A.C., A.H.M., J.R.; Data curation: A.M., P.O.-V., D.G.; Formal analysis: A.H.M., J.R., P.O.-V., M.A.C.; Funding acquisition: A.M., M.A.C.; Project administration: A.M., M.A.C.; Writing original draft: P.O.-V., A.M., A.H.M., J.R.; Writing - review & editing: All authors.

Declaration of competing interest

The authors declare no conflict of interest.

Acknowledgements

We thank Ferran Miralles, Ricard Casanovas and Olga Lao (Generalitat de Catalunya), Gabriel Lampreave (Cos d'Agents Rurals), Roser Costa (Unió de Pagesos) for logistical support and all farmers interviewed for accepted to be interviewed and generously sharing their knowledge. R. Baraut, M. Comas, L. Pelayo and J. Subiron helped with the survey.The comments of B. Fisher, I. Zuberogoitia and an anonymous reviewer improved an earlier draft of the manuscript. This study was partially funded by the Generalitat de Catalunya and by the projects RTI2018-099609-B-C22 and PID2020-117909RB-I00 from the I+D+I National Plan funded by the Ministry of Science, Innovation and Universities. POV and AM were funded within the framework of the project RTI2018-099609-B-C22.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2022.109664.

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