Ecological and economic assessments of native vertebrate pest control in France

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ABSTRACT

1.7 million foxes, mustelids and corvids are culled in France annually to reduce sanitary risks and economic losses to human activities and properties. The efficiency of the implemented lethal control strategy has never been assessed. We analyzed seven years of data reporting damage costs and lethal control effort across the country, and failed to find a link between control effort and change in reported damage costs, and reducing even cancelling control effort does not boost damage. We further report that the control effort does not drive breeding numbers in corvids. We also provide the first economic assessment of native vertebrate pest control in France. The monetary valuation of lethal control effort was estimated at 103–123 million euros annually, while official annual damage costs sum to 8–23 million euros. There is no evidence of any benefit from control effort. Lethal control does not drive population numbers, and possibly reduces ecosystem services associated with these species, including rodent predation and seed dispersal.

1. Introduction

Some native vertebrate birds and mammals are considered as pests because of their detrimental impacts on human economic activities and human or livestock health. Vertebrate pest control involves managing or controlling populations of animals that cause damage, mobilizing a range of strategies, from preventative measures to lethal control methods. Behind these lethal controls is the commonly accepted evidence that reducing the numbers of pest animals should reduce damage arising from these animals (Woodroffe et al., 2005; Tuyttens et al., 2000). Such belief is however challenged by multiple recent scientific results, first reporting that controls do not necessarily succeed in reducing animal numbers (Comte et al., 2017; Pépin et al., 2025) or in reducing damage (Pépin et al., 2025), second that controlling can be counter-productive and even increase the sanitary risks for human populations (Donnelly et al., 2006). Invoking a modern fable of the Fox and the Crow, Jiguet (2020) called for a timely moral for ecological, economic and ethical appraisals of pest control strategies. Here we propose ecological and economic assessments of native vertebrate pest controls as occurring in France during seven recent years.

French administration organizes regulatory vertebrate pest controls to face damage that mainly affect crop production and poultry. The

Environmental Code (the collection of environmental laws and regulations in France; here article R427–6) sets the conditions and lists of vertebrate animal species that can be declared as pest and then regulated at the spatial scale of the French administrative department. There are three categories of such pest species, each with dedicated control rules. Category 1 concerns six exotic invasive species: Coypu *Myocastor coypus*, Muskrat *Ondatra zibethicus*, Racoon *Procyon lotor*, Racoon Dog *Nyctereutes procyonoides*, American Mink *Neogale vison* and Canada Goose *Branta canadensis*. Category 3 are regulated by departmental decrees only and concern three native species: Wild Boar *Sus scrofa*, Wild Rabbit *Oryctolagus cuniculus* and Wood Pigeon *Columba palumbus*. Ten species can potentially be classified as native vertebrate pest of category 2 in France, and are regulated by a national decree: five carnivorous mammals and five passerine birds (Red Fox *Vulpes vulpes*, Beech Marten *Martes foina*, Pine Marten *Martes martes*, Polecat *Mustela putorius*, Least Weasel *Mustela nivalis*, Carrion Crow *Corvus corone*, Rook *Corvus frugilegus*, Eurasian Magpie *Pica pica*, Eurasian Jay *Garrulus glandarius*, Common Starling *Sturnus vulgaris*). The present study focuses on these ten species of category 2. Every three years, a national decree specifies, for each species, the departments in which lethal control is authorized for the upcoming triennial period. As a rule, a species can be classified by the national administration as a pest for three years (a triennial) in

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department if it is capable of causing damage and abundant (at least 500 individuals have been culled each year during the preceding triennial), or if it has been declared responsible for at least 10 k€ of damage in the preceding triennial. These thresholds (500 individuals and 10 k€) are jurisprudence arising from decisions made previously by the French Council of State in the context of legal disputes. If a species is designated as a pest within a French department, lethal control is permitted throughout the department at any time of year, irrespective of demonstrated new damages, for the duration of the triennial. This administrative process causes a potential gap between the damage being reported and action being taken against the animals, both in space and in time, since lethal control does not necessarily occur when and where the damage is reported (Plancke et al., 2023). Furthermore, there is little – if any – evidence that lethal control reduces population sizes of pest species and the damage they are deemed responsible for (Comte et al., 2017; Pépin et al., 2025). In addition, while overall economic costs of damage to crops or livestock are necessarily provided to justify whether or not a species should be controlled, the balance with control costs has been ignored. Quantitative results are thus needed to assess whether lethal control is ecologically and economically justifiable.

The administration of each department ($n = 96$ departments in continental France) provides the French national administration with data in order to inform the issuance of national decrees regulating pest species. This data is held in a national database, and consists of reported damage and the number of culls per species for each hunting season, defined as September to August, at the departmental level. Here we analyzed official data for seven consecutive hunting seasons (2015–16 to 2021–22) in order to test three predictions. First, since lethal control authorization during a triennial period is determined by the damage declared in the preceding triennial, it is expected to observe a positive relationship between the number of culled animals during a triennial and the declared damage in the prior triennial. Second, since lethal control should typically target areas and times where damage is reported, any department with authorized lethal control should exhibit a positive relationship between culled animals and declared damage within the same year. In addition, lethal control is expected to effectively reduce damage; we therefore tested whether changes in declared damage from one year to the next were directly predicted by control efforts in the initial year.

Furthermore, it could be hypothesized that lethal control effort, e.g. the extent of animal destruction, should reduce the regional abundance of the species. Breeding Bird Survey data were used to estimate the impact of lethal control on population dynamics for the five pest bird species. For these species, we could expect a negative relationship between the control effort and the year-to-year variations in spring numbers at the scale of the French department. The alternative of no link between control effort and spring abundance would suggest that control does not particularly affect mature breeding individuals.

Finally, this study proposes estimations of lethal control costs, enabling a comparison with reported damage costs. These estimates provide the first economic assessment of native vertebrate pest control in France. They should be considered as a potential investment to reduce the costs of damage, if there is an economic justification to vertebrate pest control.

2. Material and methods

2.1. Lethal control and damage costs data

In France, each administrative department collects official declarations of damage to wildlife, agricultural/livestock farming, citizens and other forms of property, using standard reports informing the involved species and a monetary estimate of damage in euros. Farmers, agricultural producers and private individuals can file a damage report, often online, in which they report the damage type, they propose an estimate of the economic cost and the species responsible of the damage. There is

no standardized form and no organized control of these declarations, which are stored and summarized by the departmental administrations, then transferred to the national administration. From these declarations, each French department produces an annual sum report of damage costs attributed to each vertebrate pest species (in euros), as well as the numbers of individuals culled per species, for a hunting season (from 1 September year 1 to 31 August year 2). Licensed trappers must keep a daily record of their catches, specifying, by municipality, the species and number of animals of each species captured. The same applies for hunters acting outside the usual hunting period as they need to obtain a special authorization and must report on the outputs. Reporting these data to the department administration is mandatory. All these data are then centralized by the ministry in charge of the environment. These official datasets, as used here, are not open access and were obtained from the ministry, with department level information, for seven successive hunting seasons (2015–16 to 2021–22). Table 1 reports the sums of culls for each animal species in each hunting season, while national damage costs (in euros) are reported in Table 2. There are potential flaws in the data, as there is no obligation to declare damage, and as the declarant estimates himself the economic cost and proposes the species concerned, with no further validation process beyond the declaration and its plausibility. Furthermore, as there is no compensation for the damage, they may not be reported when they are minor. Whatever, these data are unique and the only available for administrations, stakeholders and scientists to evaluate the public policy dedicated to pest regulation, and justify its implementation.

The data used in this paper corresponds to reports under two distinct ministerial decrees, resulting in two datasets. The first dataset covers the 2015–2016, 2016–2017 and 2017–2018 hunting seasons and corresponds to a ministerial decree covering this triennial. The second dataset covers the 2018–2019, 2019–2020, 2020–2021 and 2021–2022 hunting seasons, and correspond to a second ministerial decree covering this triennial period, which was extended by one hunting season following the COVID-19 pandemic. For understanding purposes, both will be referred to as triennials in this paper. We will also be using the term 'season' when referring to a 12-month hunting season, for example 2015–2016 starting 1st September 2015 and ending 31st August 2016. Both datasets were combined into a single 5690 rows dataset. Geographical coordinates of department centroids were extracted from the national IGN shapefile to provide spatial covariates (https://www.ign.fr/publications-de-l-ign/centre-departements/Centre_departement.xlsx).

2.2. Data filtering

Double zero reports, i.e. data from departments where a species had not been controlled and had not caused damage were excluded from the dataset. For instance, rooks do not breed in the southern half of France, so all southern departments reported zero culls and zero damages. Duplicates were detected within the data, which was when the same amount of damage was reported during successive seasons of a single reporting triennial. We hypothesized that these duplicates were generated when the assessment of damages was provided for the whole triennial, the total being divided by the number of seasons to obtain yearly values. As this precludes the study of seasonal variations, we deleted these duplicated values from the dataset. Five departments were affected by this problem: Indre-et-Loire, Maine-et-Loire, Marne, Haute-Saône and, to a lesser extent, Côte-d'Armor. Finally, we deleted one outlying value of damages attributed to rooks in Vienne department, representing an unrealistic increase related to a change in the methodology used to report damage in 2020–21 and 2021–22 (costs multiplied by 5 or 6 compared to the five previous seasons).

Polecat, Weasel and Jay were classified as pests in very few departments, and as a consequence culled numbers were low (Table 1), so that it was not possible to develop species-specific models of damage cost analyses for the three species; they were, however, considered in the

Table 1

Numbers of culled individuals per animal species and hunting season, as declared to the national administrative authorities. The grand total is 12,394,885 over 7 years. Data source: French administration.

Species	2015–2016	2016–2017	2017–2018	2018–2019	2019–2020	2020–2021	2021–2022
Red Fox *Vulpes vulpes*	462,879	345,993	396,353	402,294	355,943	364,170	355,462
Beech Marten *Martes foina*	4215	4220	4261	43,191	36,112	37,648	36,828
Pine Marten *Martes martes*	4890	4952	4388	16,219	14,248	14,179	14,527
Polecat *Mustela putorius*	2831	3008	2704	2266	1944	1783	251
Least Weasel *Mustela nivalis*	546	573	4583	4252	4008	3262	2975
Carrion Crow *Corvus corone*	553,262	556,780	504,830	605,628	567,043	653,348	572,864
Rook *Corvus frugilegus*	476,736	337,328	304,900	447,215	393,804	489,636	427,603
Eurasian Magpie *Pica pica*	302,163	282,728	263,172	243,275	209,482	217,867	196,953
Eurasian Jay *Garrulus glandarius*	17,481	15,828	14,806	3546	3908	3209	3500
Common Starling *Sturnus vulgaris*	105,331	105,026	110,200	134,505	111,209	101,106	100,655
Total	1,930,334	1,656,436	1,610,197	1,902,391	1,697,701	1,886,208	1,711,618

Table 2

Economic costs of declared damage and estimated costs of lethal control for seven hunting seasons in France (in €uros). Data sources: French administration for declared damage; authors' calculations for other estimates.

Hunting season	Sum of declared damage (in €)	Estimated costs of culling (in €)	Minimal estimates of culling costs (in €)	Estimates without salary cost (in €)
2015–2016	8,023,361	123,251,826	48,644,417	24,901,309
2016–2017	8,022,609	105,763,439	41,742,187	21,368,024
2017–2018	10,243,855	102,811,078	40,576,964	20,771,541
2018–2019	10,707,983	121,467,665	47,940,253	24,540,844
2019–2020	13,882,461	108,398,209	42,782,065	21,900,343
2020–2021	22,739,730	120,434,381	47,532,442	24,332,083
2021–2022	22,411,344	109,286,809	43,132,774	22,079,872
TOTAL	96,031,343	791,413,407	312,351,102	159,894,016

multiple-species models.

2.3. General features of data analyses

All analyses were based on generalized linear mixed-effects models (GLMM), fitted with the glmmTMB package (version 1.1.9, Brooks et al., 2017) with the R software (R Core Team, 2024). In all models, we included department latitude and longitude as fixed covariates to capture broad-scale spatial gradients in damage, control effort and species distribution (note that all results are robust to the omission of latitude and longitude variables). Except when analyzing triennial data, we included season fixed effects (categorical dummies for each hunting season from 2015 to 2016 to 2021–2022) to absorb nationwide year-to-year shocks in control effort and reporting. Department was treated as a random intercept, to account for repeated measurements within the same administrative unit and unobserved spatial heterogeneity in reporting or management practices. We performed separate models for each species as well as multi-species models, then adding species as a random intercept to pool information across taxa while allowing each species to have its own baseline level of damage cost and lethal control effort. For control effort and damage cost, we compared four candidate error structures: negative binomial (nbinom1), negative binomial with a constant zero-inflation term (zi ~ 1), Tweedie, and Tweedie with zero inflation. For each species and for the multispecies dataset, these four candidate models were ranked using AICc (R package MuMin). The best supported distribution was then retained for inference. For ΔDamage (log (Damage $_{t+1}$ + 1) – log (Damage $_t$ + 1)), which was approximately continuous, Gaussian GLMMs were used. For each response variable, the validation of residual hypotheses of the best-supported model was carried out using the DHARMa (v. 0.4.6, Hartig, 2024) and performance (v. 0.12.2, Lüdecke et al., 2021) packages. The significance level chosen in all analysis was $P = 0.05$. All continuous variables were centered and scaled prior to analysis. We assessed the temporal autocorrelation of residuals by department ($n = 92$) using annually aggregated simulated

DHARMa residuals (ACF lag-1 and Ljung–Box test). Before correction, six departments had $p < 0.05$; after Benjamini–Hochberg and Bonferroni correction, no department was significant. We conclude that there is no substantial residual autocorrelation and retain the main specification without additional temporal covariance structure. Sensitivity models with fixed season effects and random year slopes by department yield unchanged conclusions.

2.4. Damage costs during a triennial and control effort during the following triennial

The administrative process of classifying a species as a pest in a department is based on the amount of damage costs attributed to that species over the preceding three-year period. By construction, we expected to find a positive relationship between damage costs declared during a triennial and the control effort carried out during the following triennial. To verify this, we performed single-species and multi-species GLMMs to predict the summed numbers of culls during the second triennial by the summed damage costs declared during the first triennial, retaining the best supported error distribution (see above) and including department as a random factor, and species as a random factor in the multi-species model. The models were:

$$\sum \text{Control effort}(2019\text{--}2022) \sim \sum \text{Damage}(2016\text{--}2018) + \text{Latitude} \\ + \text{Longitude} + \text{random}(\text{Department}) [\\ + \text{random}(\text{Species})]$$

2.5. Control effort and damage costs in the same year

We hypothesized a link between control effort and current damage costs, given that, in some cases, culling occurs immediately after proven damage has occurred. For instance, when corvids consume seeds or seedlings in a crop field, trapping or shooting might scare individuals and limit further damage in the same season. To study such potential links, we developed single-species and multi-species GLMMs to predict the lethal control effort during a season by the damage costs during the same season. Alongside department latitude and longitude, we included the season as a fixed factor to capture interannual variation in control effort, department as a random factor, and species as a random factor in the multi-species model. The models were:

$$\text{Control effort}_t \sim \text{Damage}_t + \text{Season}_t + \text{Latitude} + \text{Longitude} \\ + \text{random}(\text{Department}) [+ \text{random}(\text{Species})]$$

2.6. Control effort and damage costs the following year

We might expect that control effort during one season in a department reduces the population size of the pest species, influencing the amount of damage during the following season. To test that, single-

species and multi-species GLMMs were used to predict damage costs in season $t + 1$ by the number of culls in season t. As in the previous model, department latitude and longitude and the season were entered as fixed effects, while department was treated as a random factor, and species as a random factor in the multi-species model. The models were:

$$\text{Damage}_{t+1} \sim \text{Control effort}_t + \text{Season}_t + \text{Latitude} + \text{Longitude} \\ + \text{random(Department)} \left[+ \text{random(Species)} \right]$$

For birds, we also repeated the models by controlling for initial species abundance, by considering as a fixed effect the average abundance of the species across all BBS squares surveyed in a department during the control season.

2.7. Control effort in one year and change in damage costs the following year

The objective of lethal control is to reduce damage, which could occur either immediately or in the short term. We could expect that control effort during one season reduces damage costs during the following season. We tested whether the number of culls during a season (September to August of year t) could predict a change in damage costs in the following season ($t + 1$). To do so, we computed a log-ratio of damage cost change, defined as.

$$\Delta \text{Damage}_{t+1/t} = \log (\text{Damage}_{t+1} + 1) - \log (\text{Damage}_t + 1)$$

for each species, department, and pair of consecutive seasons. This log-difference can be interpreted as a smoothed approximation of the proportional change in damage cost between two consecutive years, while avoiding division by zero and extreme ratios when damage costs are small. Adding 1 to the damage values means adding 1 euro, which is negligeable but allows to treat the problem of undefined logarithm of a zero. We then fitted single-species and multi-species GLMMs to predict this log-transformed change in damage cost by the number of culls during year t. As in previous models, department latitude and longitude were included as fixed covariates, and the season was included to capture interannual variability. Department was modelled as a random factor, with species added as an additional random term in the multi-species model. Gaussian error distributions were assumed after visual inspection of residuals. The models were:

$$\Delta \text{Damage}_{t+1/t} \sim \text{Control effort}_t + \text{Season}_t + \text{Latitude} + \text{Longitude} \\ + \text{random(Department)} \left[+ \text{random(Species)} \right]$$

2.8. Bird control and trends in population size

Data from the French breeding bird survey (STOC-EPS, hereafter FBBS) were obtained to assess population dynamics for the five pest bird species for the period 2016–2023.

The FBBS data are collected by volunteer skilled ornithologists counting birds following a standardized protocol (Jiguet et al., 2012). A 2×2 km square is randomly chosen and monitored by the volunteer, who selects 10 point-counts within this square, each separated by at least 300 m. The points are visited twice during spring (1 April – 8 May and 9 May – 15 June), in the morning. All birds seen or heard on the points are recorded during a 5 min session. Counts must be repeated every year at approximately the same dates (± 7 days), by the same observer. The maximum count of the two annual sessions per species and per point is retained as a measure of the relative abundance of the species on that point. We also retained per-point metadata on survey effort and timing (number of sessions and their within-season occurrences) for subsequent modelling. The raw data used in this study are the sum, over the 10 points, of these relative abundance measures within each plot.

We used GLMMs to predict annual variations in bird numbers using these data. The models included the following structural covariates:

counting session configuration (one early session, one late session, or two sessions in the spring), the latitude and longitude of the plot (square centroid), year (continuous), with a random effect of site (FBBS plot) nested within department. We further included species-specific culled numbers as predictors, taken either during the current hunting season (bird counts in April–June of year N, culled numbers from September of year N-1 to August of year N) or during the preceding hunting season (culled numbers from September of year N-2 to August of year N-1).

Both models were developed first for each species, then merging all species and adding species as a random factor. After checking the data for zero inflation, negative binomial distribution was used for crow, rook and magpie, and zero-inflated Poisson distribution for jay and starling. The best distribution for the data merging all species was a zero-inflated Poisson.

The models were:

$$\text{Abundance}_t \sim \text{Season}_t + \text{Session}_t + \text{Latitude} + \text{Longitude} \\ + \text{Control\_effort} \left(_{t \text{ or } t-1}\right) + \text{random}(1|\text{Department/Site}) \left[\\ + \text{random(Species)} \right]$$

2.9. Monetary valuation of control effort

We estimated the costs of control from separated sub-costs, including human resources (labor, based on time spent for controlling activities), transport, equipment depreciation, consumables, license cost and other costs.

2.9.1. Human resources

First, it was estimated that culling one animal would last on average one hour in total, from the start of material preparation to the return home. In some cases, one hour per animal is an overestimation. For example, when, beyond its installation and maintenance, visiting a corvid ladder trap reveals multiple simultaneous traps, or when bird shooting in a cropped field is highly successful. In other cases, one hour per animal is an underestimation, such as when a trapper has to visit a poultry farm to identify potential access points used by a mammal predator, install a trap and monitor it daily until a catch is made. Typical cost functions also assume larger costs to locate and remove individuals when density or abundance is low (Fischer et al., 2020; Olson and Roy, 2008). To account for these various cases, and overcome all potential biases, we determined that one hour per animal was a reasonable proxy. The balance between overestimates and underestimations should be ensured by rather equivalent numbers of culled mammals and birds (see Table 1). Hunters and trappers are qualified technicians, and in France, the gross hourly salary rate for scientific and technical activities, including all employer contributions, was estimated at 44.30€ (Insee, 2015). A second approach could consider the minimal gross hourly salary, named SMIC, i.e. 12,30€ (SMIC, "Salaire Minimum Interprofessionnel de Croissance"; https://www.service-public.fr/particuliers/vosdroits/F2300).

2.9.2. Transport

We estimated an average of 20 km (return journey included) to travel to and back from a control site. In some cases, 20 km per animal could be an overestimate, for the same reasons explained for human resources. In other cases, it would be an underestimation when for example a trapper has to visit a trap several days before a successful catch. Again, the balance between overestimates and underestimations should be ensured by rather equivalent numbers of culled mammals and birds. For comparison, in France, the average distance between home and work is estimated at 25.9 Km, for an estimated travel time of 32 min, which would sum at more than 50 Km and 1 h of travel time for a round trip (Hilal, 2020). We based the valuation of vehicle operating costs on the kilometric official scale of the French administration (https://www.service-public.fr/particuliers/actualites/A14686), depending on the fiscal horsepower of the vehicle, which we fixed at 6CV, as for typical

utilitarian cars in use in the country. The operating costs of these vehicles are of 0.665€ per kilometer, so we considered a travel cost of 0.665 × 20 = 13.30€ per culled animal. This calculation includes vehicle depreciation and maintenance.

2.9.3. Equipment depreciation

Control activities necessitate either rifles or traps. After reviewing various websites of companies providing such materials (such as www.ducatillon.com, www.chassemarket.com), we estimated an average price of 800€ for material cost, which corresponds to a hunting rifle or a set of three traps (two small traps for mammals or birds and one large ladder trap for corvids). As rifles are used not only for pest control but also for hunting, we will focus here on trapping material only, so providing a lower estimate of depreciation. The equipment cost has to be considered annually as a depreciation contribution of the initial investment. The standard depreciation period for equipment defined by the French tax authorities is 5 to 10 years. We retained the maximal period of 10 years for these materials, so the annual depreciation cost was estimated at 80€. There are approximately 50,000 formed trappers in France (https://www.chassons.com/chasse-en-france/action-des-chasseurs/piegeurs-francais-les-acteurs-dune-biodiversite-equilibree/413669/). Equipment depreciation for trappers represent 80 × 50,000 = 4,000,000 euros per year. The total number of culled animals during the seven studied seasons was 12,394,885, hence the average seasonal total is 1,770,698, so equipment depreciation can be estimated at 2.25€ per animal.

2.9.4. Consumables

Whether hunted or trapped, animals are put to death by gunshot. Based on data reported by some hunters on social media, we concluded than an average two ammunitions are necessary to shoot a bird, or a mammal (McLeod and Saunders, 2010). Ammunitions for foxes contain heavier and more numerous pellets, and costs 1.50€ each. Ammunitions for birds cost on average 0.50€ each. We retained a median value of 1€ per ammunition, so 2€ per animal. As numbers of culled mammals and birds are rather equivalent, this proxy should not be too much biased.

2.9.5. Other costs

We were not able to accurately estimate the following costs: (1) maintenance and feeding of potential live captive animals, used to attract wild conspecifics into traps (a common practice for corvids); (2) acquisition and maintenance of a hunting dog – used in some fox control activities; a hunting dog costs approximately 1000€; annual maintenance should include veterinary expenses (vaccines, cares, 100€), food (150€), accommodation, collar (15€), insurance (50€), so at least 315€; (3) training courses to obtain the initial hunting or trapping license; the cost of the national hunting license (a license is mandatory to shoot pest animals) was 244€ in 2024. We added a default 2€ for each culled animal to include a rough contribution of these costs.

2.9.6. Total control costs

We produced three valuations of lethal control costs. The first estimate summed all costs detailed above, providing a global estimate of the complete control cost for an animal. We also produced an estimate after halving transport costs and reducing the cost of human resources to SMIC. Finally, we produced a third estimation which did not include a monetary valuation of human resources, considering control activity as a volunteer work which is not valued.

3. Results

3.1. Damages during a triennial and control effort during the following triennial

Results of the GLMMs are reported in Table 3. We found a nearly – though not – significant positive relationship for two species only, Red

Table 3
Results of Generalized Linear Mixed-effects Models predicting the lethal control effort during the second decree period (2018–19 to 2021–22) by damage costs during the first decree period (2015–16 to 2017–18).

Species	Estimate ± s.d.	Z value	P value
Red Fox	0.194 ± 0.101	1.907	0.056
Beech Marten	0.355 ± 0.615	0.577	0.564
Pine Marten	3.122 ± 2.010	1.553	0.120
Carrion Crow	−0.010 ± 0.156	−0.062	0.951
Rook	0.016 ± 0.031	0.513	0.608
Eurasian Magpie	0.139 ± 0.186	0.750	0.453
Common Starling	2.023 ± 1.037	1.950	0.051
All species	0.032 ± 0.032	1.023	0.306

Fox and Common Starling. For the other species and for all species grouped together, we found no link between the control effort during the second triennial and damage costs during the first one. This means that control efforts do not increase where more species have been declared as causing damage during the previous triennial period.

3.2. Control effort and damage in the same year

Results of the GLMMs predicting the control effort by the damage costs in the same year are presented in Table 4. The multi-species model revealed a significant positive relationship between damage costs and control effort. A similar significant relationship was found in three single-species models, Carrion Crow, Common Starling and Rook.

3.3. Control effort and damage the following year

Results of the GLMMs predicting the declared damage in one year by the control effort in the previous year are reported in Table 5. We found a significant relationship for one species only, Eurasian Magpie, and this relationship was positive. When grouping all species, a significant relationship was found between the control effort in one year and the declared damages in the following year, and this relationship was again positive. The more pest animals were culled, the higher the damages in the next year. These results were robust to controlling for initial abundance in birds (Table 6).

3.4. Control effort and damage change the following year

Table 7 reports the results of the GLMMs predicting the change in damage from year t to year t + 1 by the control effort in year t. We found no significant effect of the control effort on the change in the amount of damage from a year to the next, neither at the species level nor for all species together (see Fig. 1).

3.5. Bird control effort and trends in population size

Results of the GLMMs are presented in Table 8. Three models revealed a significant effect of control effort on bird numbers, with positive estimates in all cases. Jays and starlings were more numerous

Table 4
Results of Generalized Linear Mixed-effects Models predicting the control effort in one year by damage costs in the same year.

Species	Estimate ± s.d.	Z value	P value
Red Fox	−0.005 ± 0.015	−0.336	0.737
Beech Marten	−0.002 ± 0.049	−0.036	0.971
Pine Marten	0.347 ± 0.195	1.780	0.075
Carrion Crow	0.031 ± 0.013	2.423	**0.015**
Rook	0.050 ± 0.020	2.485	**0.013**
Eurasian Magpie	0.028 ± 0.148	0.192	0.848
Common Starling	0.462 ± 0.230	2.008	**0.045**
All species	0.053 ± 0.013	4.127	**<0.001**

Table 5
Results of Generalized Linear Mixed-effects Models predicting damage costs in one year by the control effort in the previous year.

Species	Estimate ± s.d.	Z value	P value
Red Fox	0.224 ± 0.118	1.894	0.058
Beech Marten	0.465 ± 0.900	0.517	0.605
Pine Marten	3.768 ± 2.325	1.621	0.105
Carrion Crow	0.151 ± 0.098	1.533	0.125
Rook	−0.015 ± 0.063	−0.235	0.814
Eurasian Magpie	0.476 ± 0.199	2.389	**0.017**
Common Starling	0.145 ± 0.298	0.489	0.625
All species	0.323 ± 0.041	7.938	**<0.001**

Table 6
Results of Generalized Linear Mixed-effects Models predicting damage costs in one year by the control effort in the previous year, as in Table 5 but restricted to bird species and controlling for initial average species abundance in the control year.

Species	Estimate ± s.d.	Z value	P value
Carrion Crow	0.173 ± 0.099	1.740	0.081
Rook	−0.021 ± 0.066	−0.326	0.744
Eurasian Magpie	0.493 ± 0.208	2.370	**0.018**
Common Starling	0.114 ± 0.297	0.384	0.701

when the control effort was higher in the same year. When considering all 5 bird species together, we found higher abundances with increasing control effort either the same year or during the previous year.

3.6. Monetary valuation of control effort

Summing all estimated sub-costs, we obtained an average global cost of 63.85€ spent for each culled animal. The most important cost item is the human resources (69%), followed by the travelling costs (21%). The second valuation, with minimal hourly salary cost and halved travel cost, produced an estimate of 25.20€ per animal, representing 39% of the regular cost estimate. Outside gross salary, a third estimate was 12.90€ per animal. The final three estimations of overall costs associated with vertebrate pest control for each hunting season are reported for each hunting season in Table 2. Control efforts deployed in France are valued at 103–123 million euros annually (40–49 million euros with reduced salary valuation, 21–25 million euros if not valuing human resources at all).

4. Discussion

4.1. Control effort and damage costs poorly related to each other

The aim of this study was to produce an assessment of pest control in France. The first step was to test whether the number of culled animals during a triennial was linked to the costs of damages reported for the precedent triennial, since, at a department scale, the decision to list a species as a pest – then to control it – depends on the amount of damage

Table 7
Results of Generalized Linear Mixed-effects Models predicting the change in damage costs from one year to the next by the control effort in the first year.

Species	Estimate ± s.d.	Z value	P value
Red Fox	−0.056 ± 0.116	−0.480	0.631
Beech Marten	0.033 ± 0.132	0.250	0.802
Pine Marten	0.259 ± 0.156	1.662	0.097
Carrion Crow	−0.084 ± 0.230	−0.366	0.714
Rook	−0.113 ± 0.257	−0.441	0.659
Eurasian Magpie	0.051 ± 0.214	0.237	0.812
Common Starling	−0.040 ± 0.331	−0.120	0.904
All species	0.023 ± 0.069	0.332	0.740

attributed to that species during the previous triennial. However, we failed to find significant relationships between the amount of reported damage during one triennial and the numbers of culls during the following triennial. The relationship was borderline significant for two species, Red Fox and Common Starling, with positive coefficients. When considering all species together, no relationship was identified. Therefore, we found no statistical evidence that the control effort during a triennial is driven by and proportional to the amount of reported damage of the previous triennial. We also expected lethal control to occur locally right after damage reports, or control effort to increase locally if damage costs were particularly high in a department in a given year. Indeed, the control effort was globally proportionate to the reported damage during the same period for three bird species, namely Carrion Crow, Rook and Common Starling, with a positive coefficient. The culling of these three species therefore fits the hypothesis of a control effort adjusted to ongoing damage assessment. This pattern could arise from controls occurring shortly after damage to crop seedlings before resowing. Additionally, given the large numbers of culled rooks and crows, we suspect they are the drivers of the similar global pattern observed when grouping all species. Such a relationship was not found for Eurasian Magpie, and mammal species.

We found only two moderately significant relationships between reported damage costs in one year and lethal control effort during the previous year: for one species, the Eurasian Magpie, then for all species together. In both cases, the estimates were positive, meaning that reported damage costs were high where the lethal control effort was high in the previous year. This is possibly a structural information in the data, potentially arising from residual temporal autocorrelation, but it does not mirror the structural information found when investigating the same parameters (damage and control) in the same year. This probably reflects that reported damage costs were high in departments where the control effort was also high the previous year for magpie and species overall. Furthermore, these positive correlations may reflect unmodeled confounding factors rather than causal effects. To investigate the potential efficiency of lethal control to reduce damage costs, we conducted a final analysis trying to predict the change in reported damage costs from one year to the next by the control effort in the first year, but failed to find any significant effect at the species level and when considering all species together. An increase in control effort does not reduce damage reports, and a decrease or absence of lethal control does not boost damage reports as well.

Overall, we failed to find convincing evidence that lethal control effort reduced the economic amount of reported damage. There are various potential reasons for that. First, the available data may not be appropriate to detect such effects, because of the temporal and spatial scales of their collection. This would cause a regulatory issue, as the same data are used by the French authorities to justify the necessity and legality of culling – which should be efficient in reducing damage costs. If we consider the data as potentially informative, then the absence of link between control effort and change in reported damage costs has to be interpreted biologically, invoking potential demographic and/or behavioural processes. Most culled species are rapidly recovering in numbers even if the control effort is increased (see Comte et al. (2017) and Pépin et al. (2025) for examples in Red Fox in France), which is in line with the analyses on bird trends reported here. In any case, regardless of the underlying processes, the take-home message is that increasing control effort does not reduce damage costs, but also that reducing or even stopping the control effort does not increase damage. Another reason that may explain the lack of correlation between control effort and reported damage costs would be a non-linear relationship between population density and functional response (Robertson et al., 2022), which may explain the existence of non-linear relationships between local pest densities and damage (Mraicha et al., 2010; Paredes et al., 2022).

One potential limit of these analyses is the quality and reliability of the data used. The damage reports are based on self-declarations by
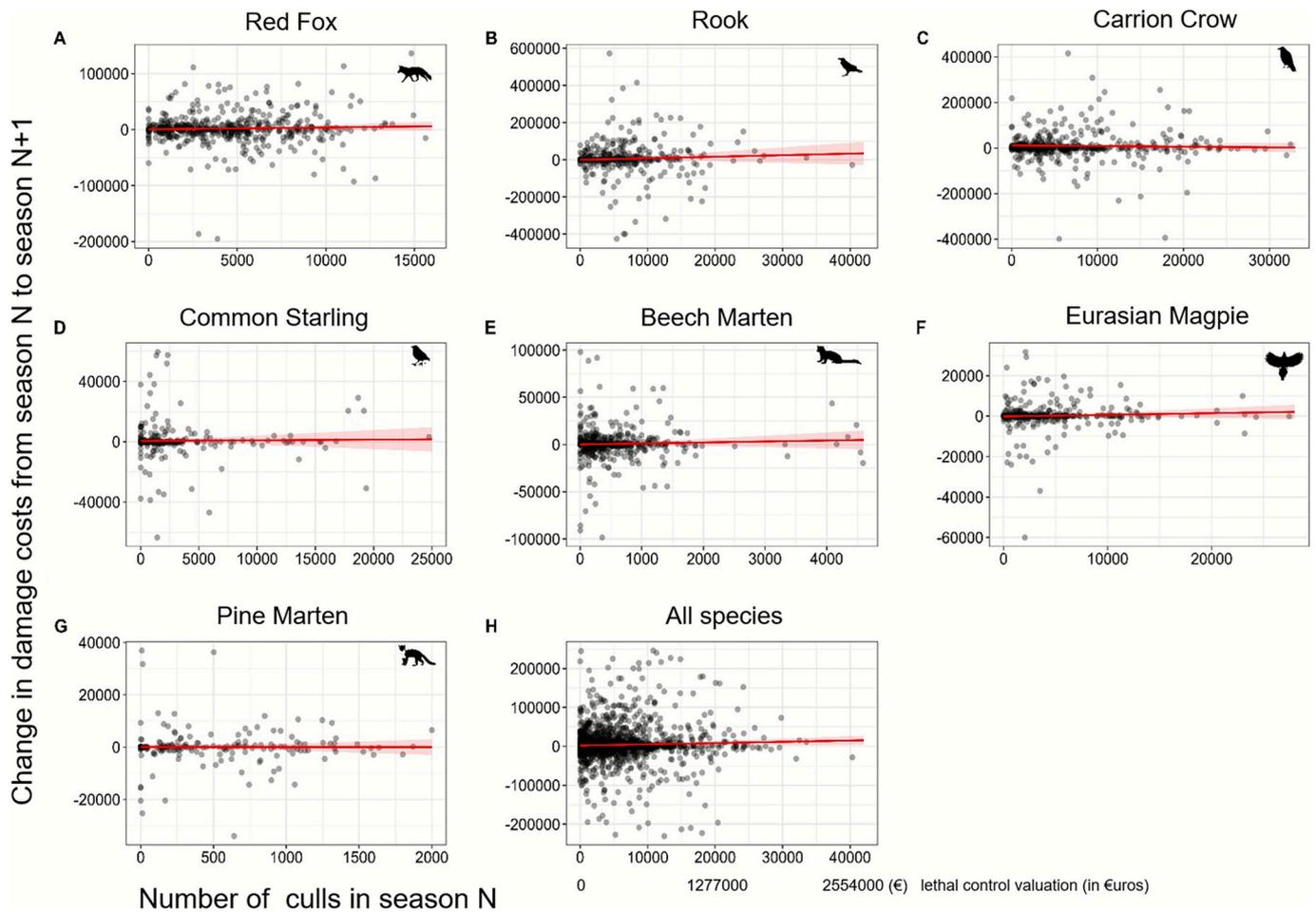
Fig. 1. Predicted change in damage costs from hunting season N to hunting season N + 1 according to the control effort in season N. The panel 'All species' includes a second graduation scale for the x-axis representing the estimated valuation cost of lethal control (63.85€ per cull).

Table 8

Estimates of the effect of lethal control effort (estimate ± s.d.) in Generalized Linear Mixed-effects Models analyzing variations in bird abundance using the breeding bird survey data, by considering (a) the control effort during the hunting season including the spring bird counts (season N) or (b) the control effort during the previous hunting season (season N-1).

Species	Estimate ± s.d.	Z value	P value
(a) control effort in season N			
Carrion Crow	−0.0300 ± 0.0155	−1.933	0.053
Rook	0.0784 ± 0.0426	1.839	0.066
Eurasian Magpie	0.0371 ± 0.0218	1.702	0.089
Eurasian Jay	1.8845 ± 0.7118	2.648	**0.008***
Common Starling	0.0658 ± 0.0178	3.705	**< 0.001***
All bird species	0.0973 ± 0.0035	28.118	**< 0.001***
(b) control effort in season N-1			
Carrion Crow	0.0023 ± 0.0144	0.161	0.872
Rook	0.0419 ± 0.0442	0.948	0.343
Eurasian Magpie	−0.0038 ± 0.0204	−0.188	0.851
Eurasian Jay	0.9419 ± 0.7050	1.336	0.181
Common Starling	−0.0011 ± 0.0189	−0.059	0.953
All bird species	0.0996 ± 0.0035	28.258	**< 0.001***

farmers and citizens, without standardized forms or independent verification, and minor damages may go unreported. This raises concerns about the accuracy and completeness of the dataset, potentially biasing the analyses. Additionally, the spatial and temporal aggregation of data at the departmental and triennial levels may mask local and short-term effects of control efforts, making it difficult to detect any real impact on damage or population dynamics. As a consequence, we call for more standardization, verification and transparency in the data collection and availability processes.

4.2. Bird culling does not regulate bird numbers

It has been shown that pest lethal control, even if increased in effort, is not necessarily regulating population numbers (see examples in the Red Fox: Baker et al., 2002; Comte et al., 2017). Using data from the French Breeding Bird Survey to provide an estimated index of abundance in spring, we failed to find any influence of lethal control efforts to drive the spring numbers of the five bird species. This predictor should capture a potential effect of lethal control in explaining annual variations in breeding numbers beyond a long-term trend which generally arises from major global changes (Devictor et al., 2008; Rigal et al., 2023). On the contrary, we found a positive effect for two species (Eurasian Jay and Common Starling), and an overall positive effect when analyzing all species together. A possible explanation is a rapid population recovery, and an increased breeding functionality in regions where control had temporarily depleted population numbers. Such a mechanism could also explain the larger numbers of young magpies in areas where the species was more culled (Chiron and Julliard, 2013). The absence of an effective regulation of spring numbers probably also illustrates that control does not affect the functional part of populations ensuring reproduction and population sizes maintenance, or that the movements of individuals at these spatial and temporal scales are sufficient to offset or overcompensate the effect of control. For example, in the Yellow-legged Gull *Larus michahellis*, it has been shown that control

does not reduce the breeding population at the metapopulation level, due to the emigration of birds to neighbouring colonies (Bosh et al., 2000). In the case of carrion crows, trapping occurs mainly in spring, when sensitive crops are sown, and most (up to 96%) of captured birds are young individuals dispersing at that period of the year (Jiguet and Gantin, 2025). Hence control does not regulate actual breeders. Since competition for food resources drives young crow survival (Lequitte-Charransol et al., 2024), reducing the numbers of young crows can induce an increased survival rate for surviving individuals, an increased brood size for breeders and a higher survival rate of fledglings, ensuring rapid population recovery. Indeed, understanding population dynamics of predators in the context of harvesting and culling is a complex exercise (Speakman et al., 2025). Yet, the analyses do not fully account for the complex ecological behavioural dynamics, but report on an output of these dynamics. Understanding mechanisms of population recovery, immigration, and compensatory reproduction could clarify the non-detection of short-term reductions in numbers. For example, the use of spring numbers from bird surveys may not capture mortality effects on the non-breeding segments of the populations.

4.3. An economic assessment

Lethal control would be economically justifiable if the estimated expenditures of control activities were lower than, or at least equal to, the monetary benefits corresponding to the reduction of damage costs caused by pests. This is not the case for native vertebrate pest birds and mammals in France, because we failed to find a relationship between the costs of lethal control and the costs of damages. Beyond that, control costs exceed reported damage by a factor up to 8, depending on the way control costs were assessed. An extreme scenario removing monetary valuation of human resources, e.g. time spent controlling, as well as travel costs, produced estimates still exceeding damage costs by a factor 1.66. In the United Kingdom, Badger *Meles meles* control also benefited from an economic assessment: financial costs of control exceeded savings achieved through reduced cattle tuberculosis by factors of 2 to 3.5 (Jenkins et al., 2010). In our study, the multiplicative factor is not related to savings but to gross damage costs; and we failed to find a link between lethal control effort and reported damage costs. The way it is currently conducted, there is no economic rationale to fox, mustelid, corvid and starling control in France.

It should be reminded that our estimates of some control costs rely on proxies for labor, transport, and equipment that may not reflect actual expenditures in all contexts. Some other important costs, such as training or dog maintenance, are only roughly approximated. Reported damages are lower than control costs, but the economic argument might be incomplete without a fuller consideration of potential long-term benefits and indirect ecosystem services provided by pest species (aside from the example of seed dispersal), avoided damages, eventual benefits from reduced disease transmission (but see Bielby et al., 2016; Comte et al., 2017), or societal values associated with pest management. These limitations should be released to provide a full economic picture of lethal control.

4.4. Future strategies to reduce damage costs

As currently implemented in France, the policy of native vertebrate pest control is justified as a solution to reduce sanitary risks and economic damage costs caused by the concerned species. Previous studies already reported that lethal control was not reducing, and even increasing, sanitary risks for humans (Comte et al., 2017; Hofmeester et al., 2017) and cattle (Donnelly et al., 2006; Vial and Donnelly, 2012; Bielby et al., 2016). Based on the official administrative data used by the government to build up decrees regulating lethal control, we failed to find a reduction in damage costs due to increasing control effort, and found no increase in damage costs when control effort is low. One hypothesis for the lack of effect of control on damage amounts is that

control effort is not enough to reduce damage, and that it would have to increase drastically to be efficient. However, this would also drastically increase the costs of lethal control, which are already higher than the costs of damage – there is no potential for getting significant reduction of damage costs at a reasonable price. As a conclusion, any further investment in lethal control would be an economic loss.

Lethal control is regulating neither fox numbers (Baker et al., 2002; Comte et al., 2017; Pépin et al., 2025) nor bird numbers, as variations in reproductive population sizes are not affected by the level of control. Corvid and starling populations are resistant to current control effort – although culling can affect population structure (Chiron and Julliard, 2013). French authorities are responsible for implementing pest control as long as it provides benefits to the economy or to the interest of the commons, which cannot stand anymore.

In addition to being costly and ineffective in limiting damage costs, lethal control has several drawbacks that should be further accounted for. Vertebrate animals that cause damage often have also positive economic impacts, such as rodent regulation by small carnivores (Jędrzejewski and Jędrzejewska, 1992) or seed dispersal by corvids (Green et al., 2019; Martínez-Baroja et al., 2019). As an illustration, Hougner et al. (2006) provided an economic valuation of oak seed dispersal by jays, estimated between 3200 and 14,600 euros per pair of Jay, or 1400 to 6100 euros per hectare of oak forest. Based on this valuation, France suffered a potential loss of 100 to 454 million euros of seed-dispersing services by culling 62,278 jays during the period we studied. Any control or recreative hunting schedule on jays and other seed-dispersing corvids should limit the impact on such services.

Warburton and Anderson (2018), who built on the experience of New Zealand in non-native predator control to propose a conceptual framework around sustainable or adaptive management, based on the so-called three Es: Ecology, Economics and Ethics. Lethal control is often negatively perceived by the public opinion, increasingly concerned by animal welfare, which should influence pest management strategies (Littin et al., 2004). Indeed, lethal pest control can induce injuries and animal suffering; Munro et al. (2014) reported that 6 to 19% of badgers are not recovered following a rifle shot, and are therefore at risk of experiencing marked pain. If there are no ecological and economical justifications for lethal control, the decision to perpetuate culling should be based on a global societal assessment mobilizing ethics.

Since lethal control is inefficient, economically unjustifiable and ethically questionable, we recommend that reducing the economic costs of damages should urgently focus on reducing and preventing damage, which does not require lethal control (Timm, 1982; Lorand et al., 2022). However, various social, cultural and cognitive rationale lead the farming community to remain attached to control trapping and shooting, assuming implicitly that it is effective, without scientific basis (Craplet et al., 2025). To succeed in getting farmers to abandon lethal control, Craplet et al. (2025) argued that three conditions must be met: awareness of the negative practical, economic and ethical aspects of control shooting, improved access to scientific knowledge on the subject in the farming world, and the emergence of a replacement innovation. This study aims at contributing to the first condition, while communicating the obtained results to the different stakeholders will contribute to the second. The development of alternative, efficient and potentially non-lethal solutions to reduce damage is the next priority. For corvids and crops, promising ongoing research focusses on seed repellents (Chantoufi et al., 2025a; Chantoufi et al., 2025b) and deterrent systems (Honda, 2018; Werrell et al., 2021).

We further encourage to replicate the same assessments in other countries, because different countries implement different processes to control damage. In most European countries, a financial compensation is preferred to animal control (IGEDD, 2024). The same report, produced by the French Environment General Inspection, called for a change of paradigm to controlling damage in France. In particular, it recommends not renewing the triennial decree when it expires in 2026, to implement a new collegial management system.

CRediT authorship contribution statement

Frédéric Jiguet: Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization. **Aïssa Morin:** Visualization, Methodology, Formal analysis, Data curation. **Héloïse Courtines:** Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Alexandre Robert:** Validation, Supervision, Methodology, Investigation, Conceptualization. **Benoit Fontaine:** Validation, Methodology, Data curation. **Harold Levrel:** Validation, Supervision, Methodology. **Karine Princé:** Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

FJ declares to be part of a national expert council advising the French minister in charge of hunting regulations since 2014. This council (Conseil National de la Chasse et de la Faune Sauvage) produces an opinion on the draft decree regulating native vertebrate pest. Otherwise, the authors declare that they have no actual or potential conflict of interest including any financial, personal or other relationships with other people or organizations within three years of beginning the submitted work that could have inappropriately influenced, or be perceived to influence, their work.

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Data availability

Data will be made available on request.

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