African swine fever vs. COVID-19: only one virus mattered for wild boar hunting bags in Europe

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Abstract

Wild boar (*Sus scrofa*) populations have been steadily increasing across Europe in the last decades, due to the synergy between landscape modifications, the ecological plasticity of the species and global warming. However, since 2014, an increasing number of these populations have also been affected by African swine fever (ASF) and have experienced increased mortality. Moreover, in 2020 and 2021, wild boar hunting regimes were temporarily changed due to restrictions in response to COVID-19. There is therefore a need for a pan-European assessment of the long-term trend in wild boar populations. We analysed wild boar hunting bags from 21 European countries, as a proxy of population abundance, to estimate long-term trends between 2000 and 2022. We also identified possible changes in harvests due to COVID-19. Finally, we summarized changes in the number of hunters between 2018 and 2023 in 19 European countries. Wild boar harvest has increased steadily over the last two decades, peaking at over 3.6 million harvested individuals in 2019. Since the appearance of ASF in Europe, hunting bags in most affected countries decreased, i.e. either immediately after the first outbreak or following a short-term increase of the harvest after the outbreak. Restrictions due to COVID-19 did not have any clear impact on the total number of harvested wild boar. Over the past six years, in spite of mixed trends between the countries, the overall number of hunters has decreased across Europe.

Keywords: ASF; hunting management; mortality; population trend; SARS-CoV-2; *Sus scrofa*; ungulates

Highlights

- Wild boar harvests increased 2.25-folds across Europe for two decades until 2019.
- ASF outbreaks caused harvest declines in affected countries.
- COVID-19 restrictions did not measurably affect wild boar harvest levels.
- The overall number of hunters in Europe is decreasing (≈3.9 million), although some countries show slight increases.
- In 2017, legal changes and the adoption of new hunting methods, such as night-vision devices and silencers, marked a key shift in hunting practices.

1. Introduction

Wild boar (*Sus scrofa*) is a highly adaptable species whose numbers have steadily increased throughout Europe in recent decades (Massei et al., 2015; Smith et al., 2025). This growth, along with the species' expansion into new areas, has made wild boar among the most widespread and commonly hunted ungulates in Europe (Jori et al., 2021). Hunting bag data further highlights this fact, showing an increase in the number of wild boar hunted, from almost 2.2 million in 2012 (Massei et al., 2015) to over 3 million in 2017 (Linnell et al., 2020), and almost 4 million in recent years (ENETWILD-consortium et al., 2024).

As wild boar populations have grown, conflicts with humans have also increased. Wild boar has high economic impact through damage to crops and forests, vehicle collisions, nuisance behaviour in urban areas, and disease transmission, with important consequences to public health (Šprem et al., 2013; Podgórski et al., 2018; Conejero et al., 2024). In addition, wild boar can also negatively affect other native species and biodiversity, sometimes leading to declines in the density and abundance of various plant and animal species (Barrios-Garcia and Ballari, 2012; Colomer et al., 2021). At the same time, wild boar are

important ecosystem engineers, positively affecting the environment by shaping soil structure, promoting seed dispersal, and influencing nutrient cycling in many habitats (Barrios-Garcia and Ballarí, 2012).

The increase of the wild boar populations can be attributed to a combination of environmental and socio-economic factors, interacting with the biological and ecological plasticity of the species. For example, global warming has benefited wild boar populations in Central and Northern Europe by decreasing winter mortality and increasing food availability of high-energy food such as acorns and other forest seeds due to more frequent masting (Vetter et al., 2015). Landscape changes have also increased environmental suitability for the species. The afforestation and rural abandonment that characterized many marginal rural areas of Europe in the second half of the 20th century (Levers et al., 2018) have additionally increased the availability of food, and the fragmentation of semi-natural forests due to their conversion to arable land created mosaic landscapes that provided wild boar with both refuges and abundant resources (Ferens et al., 2025). Moreover, landscape anthropisation offered considerable and rich anthropogenic food resources (Colomer et al., 2024), without affecting individual fitness due to the ability of wild boar to avoid human disturbance (Johann et al., 2020). Reduced winter mortality and increased resource availability and accessibility alongside with supplementary feeding and baiting allowed wild boar populations to boom, due to a high reproductive rate of the species, which is the highest among wild ungulates (Barrios-Garcia and Ballari, 2012). Landscape anthropisation also promoted hybridization with domestic pigs (*Sus scrofa* f. *domesticus*), which may have further enhanced the reproductive capacity of wild boar (Iacolina et al., 2019).

Wild boar populations are greatly influenced by hunting which is still the main cause of the species' mortality (Bassi et al., 2020). Hunting is also believed to shift reproduction of wild boar to an earlier age (Gamelon et al., 2011), alter physiological state (Kelava-Ugarković et al., 2025), and affect the species' spatial behaviour (Olejarz et al., 2024). In some countries, hunters have been responsible for deliberate releases, which accelerated the spread of wild boar across Europe (Jori et al., 2021), and for extensive supplementary feeding which affects wild boar behaviour (Muthoka et al., 2023) and potentially also its survival rates (Oja et al., 2014).

In recent years, wild boar populations across Europe have been affected by African swine fever (onwards ASF) (Drimaj et al., 2020). In its latest outbreak on the continent, ASF was first detected in the (north)eastern part of the European Union (i.e., Poland and Baltic states) in 2014 and has since spread across several other European countries (Dixon et al., 2020). ASF causes high lethality among suids and in the absence of any treatment or vaccination, the disease represents a major threat to pig production and wild boar populations. Wild boar and its habitats are the sole reservoir of ASF virus (Chenais et al., 2018) and thus it is important to reduce wild boar numbers to help constrain the disease (Drimaj et al., 2020). Hunters play a key role in population control, alongside natural mortality sources such as starvation, disease, and predation (Massei et al., 2015). As hunting management strategies in Europe vary from country to country and are typically implemented at the local level, effectively controlling the spread of ASF in wild boar remains a significant challenge (Linnell et al., 2020; Sauter-Louis et al., 2021a). Various European countries have used a range of measures to combat ASF, including zoning, restricting wild boar movement with fencing, banning hunting in infected areas that are not physically contained, modifying habitat management, and prohibiting access to infected zones (EFSA et al., 2024a). Additionally, efforts to reduce wild boar numbers through intensive hunting and trapping have been introduced (Jori et al., 2021). The use of night vision equipment and silencers during wild boar hunts is also already permitted by law in some countries or under consideration in others (Sauter-Louis et al., 2021a). Despite these management efforts, ASF continues to spread among wild boar populations across Europe (Sauter-Louis et al., 2021a; EFSA et al., 2025). In most cases, the spread of the disease is not due to animal-to-animal transmission, but rather due to human activity (Bergmann et al., 2021); indeed, humans are responsible for all known long-distance transmissions of ASF in Europe.

In March 2020, the World Health Organization (WHO) declared the COVID-19 pandemic prompting countries worldwide to implement various forms of lockdown (Allen, 2022). These restrictions led to “anthropause”, a period of reduced human activity which, in many cases, had a positive effect on wildlife (Rutz et al., 2020) with animals showing increased movement shortly after the lockdowns began (Pokorny

et al., 2022). However, the pandemic also affected hunting and wildlife management. The number of hunting licenses issued during this period was lower than in previous years, indicating a decline in hunting activity (Cerri et al., 2024). Driven hunts with hounds, which rely heavily on group participation, may have been significantly affected by the restriction on gatherings in pandemic. Consequently, COVID-19 may have further reduced the number of active hunters, resulting in a decline in recreational hunting and a subsequent reduction in the control of wild ungulate populations (Cerri et al., 2024).

Collecting and analysing hunting statistics is essential for effective hunting management and the development of wildlife policies (Jori et al., 2021; Colomer et al., 2024). Data on hunting bags, ideally used in conjunction with the number of hunters or hunting effort, are an excellent tool for monitoring wildlife populations trends and for detecting factors such as disease outbreaks, poaching, and environmental changes that might affect these trends. Hunting bag data are primarily used in ecological research and wildlife management as indicators of population density (Carvalho et al., 2024).

The most recent pan-European study that used hunting bags to analyse wild boar and hunter population trends in 18 European countries from 1982 to 2012 was conducted by Massei et al. (2015). Therefore, our overall objective was to continue this data series and analyse trends in wild boar populations in Europe over the past two decades, a period marked by two major events – ASF outbreaks and COVID-19 lockdowns – that may have affected wild boar population numbers across the continent. Understanding the impact of these events is crucial for the future development of wild boar population management.

The specific aims of this study were: *i*) to present trends of wild boar hunting bag (as a proxy of the abundance) over the last two decades in Europe; *ii*) to explore how ASF outbreaks (i.e., its presence in a country) influenced wild boar hunting bags by comparing trends in ASF-infected and ASF-free countries; *iii*) to quantify potential changes in hunting bags due to COVID-19 associated restrictions and changes in recreational hunting; *iv*) to evaluate changes in the number of European hunters over the past six years.

2. Materials and methods

We collected wild boar hunting bag data from the last two decades in 29 European countries. To maintain the reliability of the manuscript and ensure accurate results, we excluded countries with missing or incomplete data (n = 8) from the analysis, leaving the following 21 countries: Austria, Belgium, Bulgaria, Croatia, Czech Republic, France, Germany, Hungary, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and Switzerland (Figure 1). It is important to emphasize that: *i*) in different countries wild boar are hunted with different techniques, *ii*) in some countries, numbers of hunted wild boar are defined through hunting quotas that are decided at the beginning of each hunting season based on population monitoring and a discussion of management objectives, and *iii*) this situation has changed through time. Regarding the hunting method, in countries such as Germany (Keuling et al., 2021) or Sweden (Thurfjell et al., 2013) a significant proportion of wild boar are stalked and culled from hides by individual hunters, whereas in other countries, most wild boar are harvested through driven hunts (e.g. Spain: Fernandez-de-Simon et al., 2023). In some countries, hunting quotas limit the number of wild boar that can be hunted (e.g. Slovakia: Goračova et al., 2025). In other countries, particularly those where drive hunts are common, such as Croatia, Czech Republic, Poland, and Spain there is no real limit to the number of wild boar hunted; moreover, in recent years hunters may even be financially motivated by the state to shoot as many wild boar as possible (e.g. Croatia, Slovenia). It is worth mentioning that, in the two decades, management regimes sometimes considerably changed within the same country.

Additional data on the number of hunters, hunting management of wild boar (Supplementary file 1) and on the COVID-19 lockdown periods and hunting management during these periods (Supplementary file 2), as well as data on the occurrence of ASF and the number of positive cases and hunting bans due to ASF were also provided by all included countries (Supplementary file 3).

As different countries had very different numbers of wild boar (harvest), either due to their size and the different range of the species or different hunting efforts and hunting intensities, we made hunting bag

numbers between countries more comparable by calculating the hunting index, expressed as the total numbers of hunted individuals per km^2. Harvest densities (not population densities) represent the total number of wild boar that were hunted in each year, divided by the extension of the species range in 2022 in the respective country (ENETWILD-consortium et al., 2022). Although this value is an approximation, as the range of wild boar has likely expanded since 2000, we used data from 2022 as they were the only one with a pan-European coverage and an adequate resolution. We did not control for hunting effort, as data on overall hunting effort and the total number of hunters are not available for Europe over the study period. We used a Generalized Extreme Value distribution (Bali, 2003) for our response, and we used the year as a covariate. To account for country-specific trajectories, we fitted approximate Gaussian processes to each country (Wood, 2017). Moreover, we allowed the scale parameter of the Generalized Extreme Value distribution to vary between different countries (Bürkner, 2017a). The scale parameter captures the variability in the response; through this approach we managed to account for differences among countries in wild boar management, which could have resulted in higher or lower differences in the total number of wild boar that were harvested in different years. Models were fitted in STAN (Carpenter et al., 2017), through the brms package (Bürkner, 2017b) in R (R Core Team, 2025). Model selection was carried out through Bayesian leave-one-out cross validation (Vehtari et al., 2017) and posterior predictive checks and model residuals were used to assess the goodness of fit of the best candidate model. Continuous variables were standardized and centred before being included in the model.

To assess the variation in the number of wild boar that were hunted due to changes in hunting caused by COVID-19 restrictions, we used the approach proposed by Cerri et al. (2022; 2024). In this approach we: *i*) fitted a Bayesian Generalized Additive Model (GAM) to predict wild boar harvests between 2000 and 2019 in each country, *ii*) used the same model to forecast how many wild boar would have been harvested between 2020 and 2024, under the same temporal trend, and *iii*) compared the actual number of wild boar that were hunted between 2000 and 2024 against predictions for these five years from 2000-2019 data. We used a Bayesian Generalized Additive Model (GAM), because under the Bayesian inference framework

values from the posterior distribution, even when included in credibility intervals, are not equally plausible (Kruschke and Liddell, 2018). Therefore, we could compare the number of wild boar that were hunted in 2020-2024 against the most plausible predicted value for each year. However, from the initial 21 countries included in the previous analysis, we had to exclude Latvia and Lithuania because wild boar numbers and harvests in these countries plummeted after 2014 due to ASF. Therefore, we trained our model with data that also reflected a rapid, generalized decrease in these two countries. As a result, we observe that post-COVID-19 predictions for the number of wild boar shot per km² are unrealistic: the 2014-2019 trend continues even for 2020-2023/2024, and in some cases, we even have negative values. Therefore, we removed these predicted values because they were not reliable.

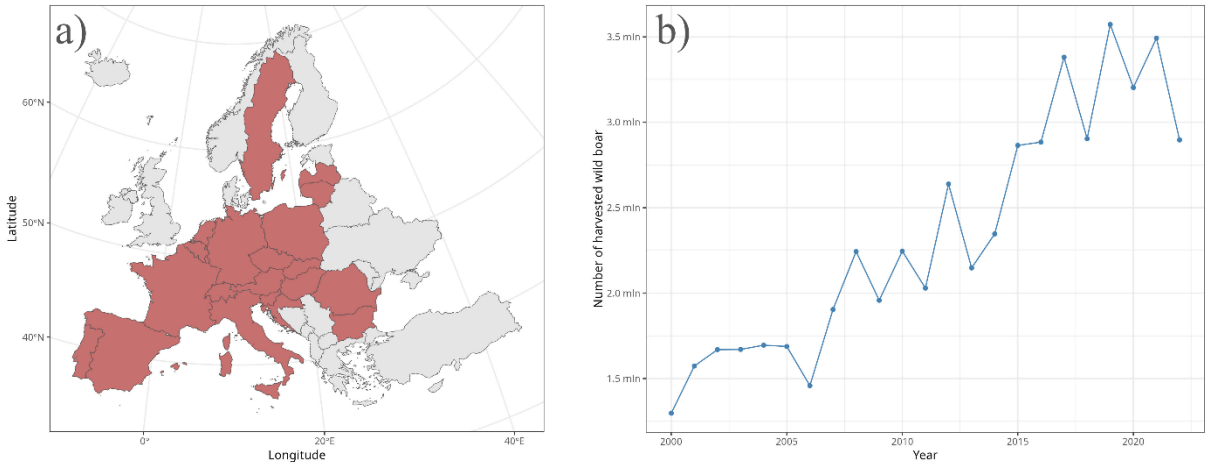
We analysed the percentage change in hunter numbers by country, as well as the overall trend during the past six years, in 19 selected European countries (Austria, Belgium, Bulgaria, Croatia, Czech Republic, France, Germany, Hungary, Italy, Latvia, Luxembourg, Montenegro, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden and Switzerland). Other countries were excluded from this analysis owing to incomplete data on hunter numbers.

3. Results

Our best candidate model showed that the Generalized Extreme Value distribution was a good approximation for wild boar harvest densities (Fig. S1) and explained a significant amount of variation in 2000-2019 data (Bayesian $R^2 = 0.95$). Model selection (Fig. S2) retained a model where the expected harvest density in each year was explained by a Gaussian process with 9 bases, and where variation in the harvest density differed between countries. Residuals (Fig. S3), the autocorrelation function (Fig. S4) as well as the exploration of country-specific trends showed that Gaussian processes were effective at capturing country-specific variation in wild boar harvests. However, the best candidate model still showed signs of overdispersion, when residuals were plotted against predicted values from the model (Fig. S3).

This probably depended upon the choice of quantifying hunting effort as the number of wild boar hunted, divided by the range of the species in each country, which did not entirely rule out differences among countries, in terms of the magnitude of hunting bags.

The total number of harvested wild boar in Europe has been steadily increasing over the last two decades, and in the period 2000-2022 total hunting bag in the 21 countries, included in our analysis, rose 2.25-folds, i.e. passing from approximately 1,297,500 individuals harvested in 2000 to 2,922,500 in 2022, with a peak of 3,663,500 individuals harvested in 2019. Data for 2023 and 2024 were not included in the analysis, as many countries had not yet published figures for those years. Moreover, for some countries included in the study, data were incomplete across the whole study period, although the number of harvested wild boar appears to be on the rise also there. Montenegro and Bosnia and Herzegovina have only recently begun recording wild boar hunting bag data, although the species has long been present and hunted in these two countries. Serbia publishes its official wild boar harvest data every two years, thus not providing reliable data. Finland and Norway have also only recently started to collect data on wild boar harvests following the species' recent expansion into these two countries. Greece and Russia had incomplete data, and Albania had no data recorded. To maintain consistency, these eight countries were excluded from the total harvest analysis, so only countries with continuous data from the year 2000 onward were included, as incorporating countries with shorter data records would distort the long-term trend (Figure 1). If the data from the eight countries with incomplete records are included, the number of harvested wild boar could potentially increase by approximately 177,000 individuals (see Supplementary file 4).



283

284 Figure 1. Complete datasets on wild boar hunting bags were available for 21 red-coloured countries (a) and
285 were used to calculate overall hunting bag trends across Europe between 2000 and 2022 (b).

286

287 Since the first recent outbreak of ASF in the European Union in 2014, 18 of the 28 countries included in
288 the study (i.e., those for which we collected any relevant data for this study, even when not included in the
289 above analysis of temporal trends) have been affected by the disease (for more details, see Supplementary
290 file 3). Hunting bags are showing different trends across 13 infected countries for which consistent data are
291 available, but with the same ultimate outcome of a decline in the number of harvested animals (Figure 2a).
292 In eight countries where ASF did not occur and for which relevant data are available, wild boar harvest
293 generally continued to rise. The only exception is the Netherlands, where the number of harvested wild
294 boar has declined sharply despite the absence of ASF (Figure 2b).

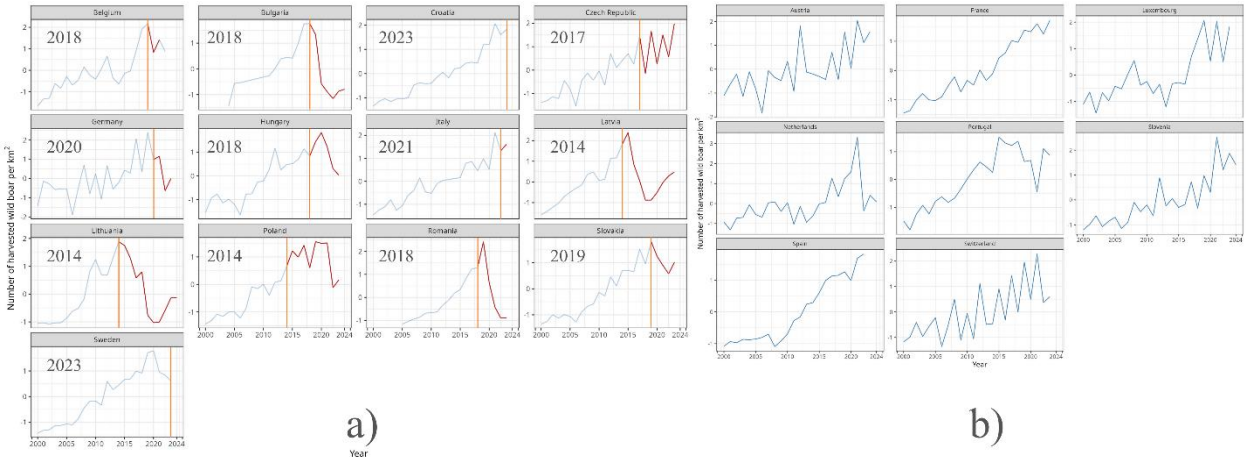
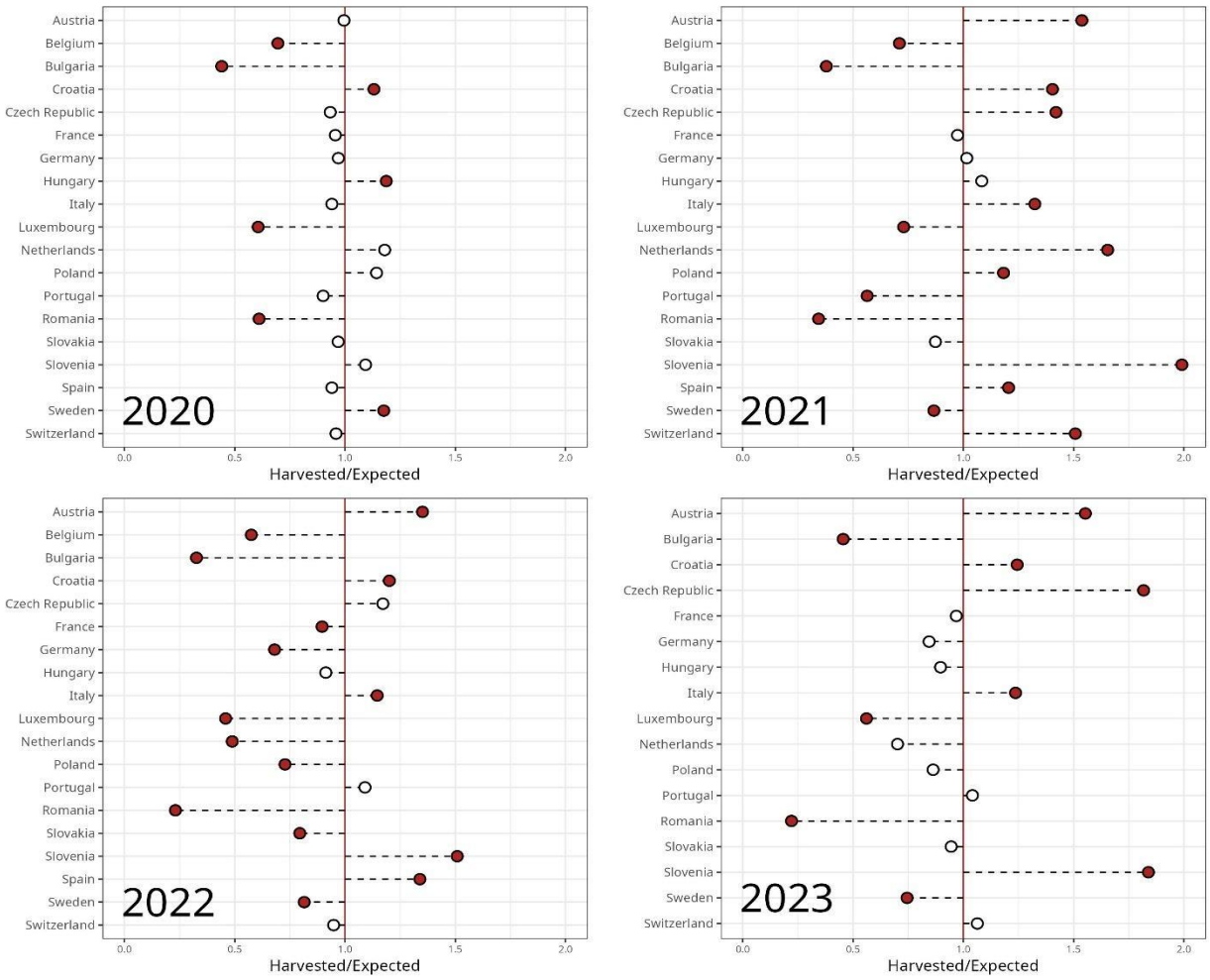


Figure 2. a) Wild boar hunting bags in 13 countries with African swine fever (ASF; years after outbreak in red lines, while vertical orange lines indicate the year in which ASF first appeared in each country; for more details, see Supplementary file 3). b) Wild boar hunting bags in eight countries without ASF. For Belgium and Spain, the dataset ends in 2022 as no official records for the last two years were published.

When assessing the impact of the COVID-19 lockdowns and the anthropause on the hunting activity through the total number of harvested wild boar, no clear pattern emerged, compared to the 2000-2019 period. When comparing the total number of wild boar that were hunted against the most likely values predicted by the posterior distribution of our candidate model, we found that in 2020, 13 out of 19 countries harvested a lower number of wild boar than expected, but 6 countries harvested more wild boar than expected. A similar pattern emerged in 2021 (8 and 11), 2022 (12 and 7) and 2023 (10 and 7), respectively. No clear pattern emerged even when considering values that fell outside of the 95% credibility interval (Figure 3). For 2023, Belgium and Spain are missing as we did not have data on wild boar hunting bags for that period in those two countries.



310

311 Figure 3. Impact of the COVID-19 restrictions on wild boar hunting bags in selected European countries,
312 i.e. comparison between real and expected numbers of hunted individuals. Dots on the left side of the
313 vertical lines indicate that the number of hunted individuals was lower than expected, while on the right
314 side the number of hunted wild boar was higher than expected. Red dots indicate values that fell outside of
315 the 95% credibility interval, reflecting harvests that deviated from the expected numbers, i.e. in scenario
316 that COVID-19 restrictions did not occur.

317

318 The trend in hunter numbers varies among 19 European countries. While some countries have recently
319 experienced an increase in the number of hunters, others have shown a marked decline (Figure 4). Overall,

the total number of hunters in Europe demonstrates a substantial decrease over the past six years (Figure 5).

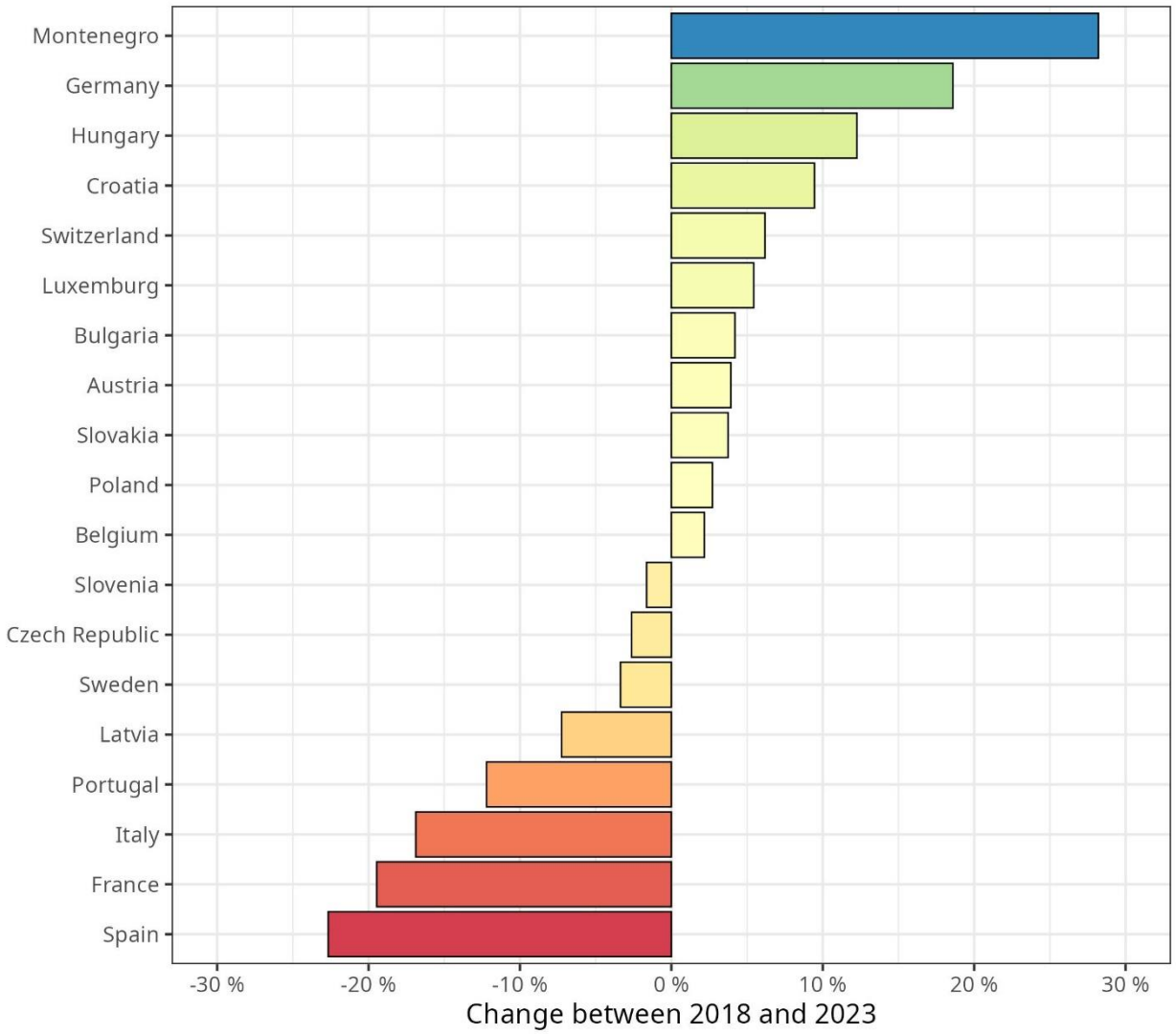


Figure 4. Percentage change between the number of hunters in 19 selected European countries that had the available data for the six-year period.

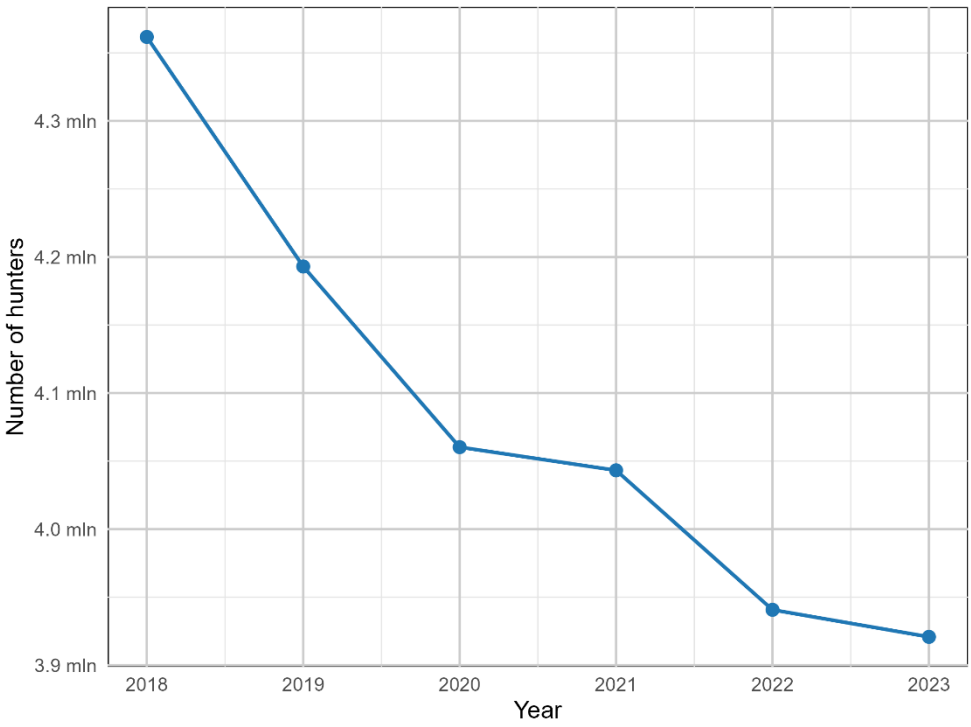


Figure 5. Overall trend in hunter numbers during the six-year period across 19 selected European countries.

4. Discussion

Accurate estimates of population abundance are essential for developing effective wildlife management strategies and for detecting changes in population trends (Soininen et al., 2016). In this respect, it is important to note that hunting data collection is not standardized across European countries, making it difficult to accurately estimate population densities and to precisely compare data among countries (EFSA et al., 2018). Nevertheless, in case of species such as wild boar, for which hunters are generally highly motivated to hunt and report the harvest, hunting data are good (and actually only broadly available) proxy/indicator for abundance as well as trends and interannual variability in population sizes (ENETWILD-consortium et al., 2018). Our analysis of wild boar hunting bag data reveals a significant increase in the number of wild boar harvested across Europe in the last two decades: since 2000, the number

of hunted wild boar has increased 2.25-folds (Figure 1), passing from approximately 1.3 million individuals harvested in 2000 to 2.9 million in 2022, with a peak of 3.6 million wild boar harvested in 2019. This upward trend, previously observed by Sáaez-Royuela and Telleriia (1986) up to 1975, by Massei et al. (2015) up to 2012, and later by Linnell et al. (2020) up to 2017, has clearly continued in recent years, with a peak in 2019 after which the number of harvested wild boar in Europe began to slightly decrease, at least on a short term (i.e., last three year) basis. The rise in the number of wild boar harvested reflects the ongoing general increase of the abundance of the species in Europe, which is in accordance with increasing reports on the occurrence of urban individuals, crop damage and traffic collisions with wild boar (Conejero et al., 2024). Moreover, several factors can lead to underestimate the true number of wild boar mortality even in the countries with hunting data across the whole study period, for example illegal hunting and unreported roadkill (Massei et al., 2015; Bíl et al., 2025). The harvest/mortality of these animals is not documented, therefore the recorded hunting bags often reflect a lower count than the actual mortality rate, deviating by more than 30% in some countries (Massei et al., 2015). In some cases, hunting bag records typically rely on self-reported statistics, and their accuracy may be compromised by either over-reporting or under-reporting, further distorting population assessments (Massei et al., 2015; Soininen et al., 2016). In addition, hunting statistics sometimes do not include animals which are killed during wildlife control operations by non-hunters, such as police officers, whose numbers can be significant in some countries (Banti et al., 2021).

Understanding the impact of ASF on wild boar populations is crucial for designing evidence-based population management to combat ASF (Morelle et al., 2020), and to forecast future population trends. A recent model of ASF epidemics showed a decrease of the wild boar populations after an ASF outbreak (Salazar et al., 2022), which is consistent with our findings showing evident decline in wild boar hunting bags across most countries affected by ASF (Figure 2). Given that the hunting bag data reflect population trends and interannual variability of local wild boar numbers, our results indeed suggest that wild boar numbers declined in several European countries due to mortality caused by ASF.

When analysing how the outbreak of ASF in 2014 affected the hunting bags (as a proxy of the abundance) of wild boar, we found a difference in hunting bags after the ASF appearance in Latvia, Lithuania, and to a lesser extent in Poland. In Poland, unlike in Latvia and Lithuania, the hunting bags continued to rise until 2021 before declining. In both Latvia and Lithuania, after a sever drop immediately after the ASF outbreak, the hunting bag started to rise again in 2020, which may indicate either a recovery of the population or increased hunting pressure to stop the disease spreading (Figure 2). However, the European Food Safety Authority (EFSA) suggests that the growing hunting bags in the Baltic states reflect a genuine population recovery (EFSA et al., 2024b). Since 2014, ASF has continued to spread and in the following years (until 2022) it appeared in Belgium, Bulgaria, Czech Republic, Germany, Hungary, Italy, Romania, Serbia, and Slovakia (EFSA et al., 2020; Sauter-Louis et al., 2021b). In Belgium, the ASF epidemic lasted only one year and affected only 5-10% of the wild boar range. In this country, high hunting bag in 2018 and 2019 is linked to increased pressure imposed at the regional level to stop spreading of ASF as well as to the important mast production in 2018. Belgium effectively controlled ASF, reporting 833 cases in wild boar in 2018 (Sauter-Louis et al., 2021a), but the disease had no lasting impact on Belgian hunting bags, thanks to swift containment measures and small proportion of the country which had been affected. EFSA reported that the Bulgarian wild boar population followed a stabilising trend, but there was a decline in the abundance after the ASF outbreak (EFSA et al., 2025), which is consistent with our data (Figure 2). In countries where hunting bag trends did not decline immediately after the ASF outbreak, this could be due to the low percentage of the country affected by ASF. Further research should account for the percentage of country territory affected by ASF, i.e. with restriction zones, as a proxy of ASF spatial coverage. In 2023 and 2024, the first ASF outbreaks were recorded in several previously unaffected countries, such as Croatia and Sweden. The number of positive cases in these countries remains low, and hunting bags have not yet shown significant changes. ASF has only recently appeared in Sweden, and it has regained ASF-free status (EFSA et al., 2025), but the number of wild boar hunted had already decreased before the appearance of ASF. The effect of ASF on hunting bag should be closely monitored as previous work has shown that the density and

abundance of wild boar decreased by 84% and 95%, respectively, within a year of the ASF outbreak (Morelle et al., 2020).

ASF poses a significant challenge for wildlife disease control (Jori et al., 2021). This is reflected in the fact that the number of reported ASF outbreaks in wild boar increased by 10 in 2023 in Europe compared to the previous year and remained at this level in the following year (EFSA et al., 2024b; 2025). In the inner zones of ASF occurrence, driven hunts were banned to contain the spread of the disease. In contrast, in the outer areas, targeted hunting for depopulation was promoted and intensified to reduce population density of wild boar (Sauter-Louis et al., 2021a). Many countries have also adopted sanitary culling and promoted the intensive harvesting of wild boar females whilst also revising regulations on wild boar hunting methods (see Supplementary file 3). Some studies argue that the decline in the wild boar population has been observed in the affected countries (Schulz et al., 2019; 2020), and the declines of the hunting bags confirmed by our results are a good indicator of this. However, from analysing solely the hunting bag data it is difficult to conclude whether the disease has affected the European wild boar populations due to its high mortality rate or whether the declines in hunting bags are rather due to the implemented hunting bans (Sauter-Louis et al., 2021a). Further research focusing on the impact of ASF on the demographic structure of wild boar populations could provide valuable insights into the resilience and long-term viability of populations as well as developing wild boar management strategies to combat ASF (Gočárová et al., 2025).

Due to the complexity of managing wild boar populations and the inability of hunters to achieve sufficient removal rates to control population growth, many countries have modified hunting regulations. These changes include the legalization of night hunting and the use of night vision or thermal imaging devices, with the year 2017 seemingly marking the starting point for making these changes legal (Supplementary file 1). Also, many countries have allowed the use of silencers, which has certainly contributed to better hunting success and a larger hunting bag. For example, a government decision in Sweden in 2019 to permit the use of movable lights and thermal imaging led to a significant increase in wild boar harvest and probably a decrease in population size. The observed up-following reduction in harvest is believed to result from this

414 population decline. In addition, changes in supplementary feeding and baiting have been reported. In many
415 countries where supplementary feeding used to be practiced, it has been banned in recent years. Following
416 the spread of ASF, restrictions on the amount of feed used for baiting have been established and vary from
417 country to country (Supplementary file 1). Moreover, monetary incentives for culling wild boar increased
418 the hunting effort, with bounties again varying from country to country (Supplementary file 1). All these
419 changes have influenced hunting effectiveness and may have affected hunting bag data, changing the
420 association between hunting bags and population abundance throughout the study period.

421 In 2020, during the COVID-19 pandemic, the associated "anthropause" was widely reported to have
422 positive impacts on wildlife due to reduced human activity and disturbance (Allen, 2022). Despite many
423 studies emphasizing the potential transformation of existing wildlife management models due to COVID-
424 19, little empirical research has been conducted on this topic (Cerri et al., 2024). Two studies examined the
425 impact of COVID-19 lockdowns on the wild turkey (*Meleagris gallopavo*) hunting season in North
426 America. One study observed an increase in hunting participation and effort in 2020 compared to previous
427 years, resulting in a higher total reported harvest (Danks et al., 2022). The other study found no difference
428 in harvest success compared to previous years despite an increase in the number of resident hunters
429 (Chizinski et al., 2022). Our findings indicate that potential changes in wild boar hunting that could have
430 followed COVID-19 restrictions did not significantly affect wild boar harvest (Figure 3). Indeed, analysis
431 of the hunting bag data shows no major change in wild boar harvests during the COVID-19 lockdown
432 period. This may be explained by the timing of lockdowns, which predominantly occurred in spring, a
433 season that typically falls outside the main (driven) hunt period for wild boar, which in most European
434 countries takes place in late autumn and winter. Furthermore, driven hunts on wild boar were not prohibited
435 in most countries during the COVID-19 lockdowns and high alert periods, but were rather regulated with
436 some restrictions, i.e. with the prescribed minimum distance and the maximum number of participants in
437 the driven hunt varying from country to country (see Supplementary file 2). Due to the restrictions

introduced during COVID-19 pandemic, many hunters may have shifted to single hunts, resulting in no significant changes in wild boar yields.

Controlling of the growing populations of wildlife can be achieved through recreational hunting (Šprem et al., 2024), and hunting is currently one of the widely employed tools for controlling overpopulated wildlife species, including wild boar (Gortázar and Fernandez-de-Simon, 2022). However, a significant shift from rural to urban lifestyles has contributed to a decline in the number of hunters across many European countries (Massei et al., 2015; Gaspar et al., 2025). One of the main challenges that the hunting communities are facing is the aging of the hunter population. Reports from the Iberian Peninsula and Denmark indicate that the hunting population is aging rapidly, with most hunters in the Iberian Peninsula falling between 61 and 70 years of age (Hansen et al., 2012; Gaspar et al., 2025). This older group of hunters is not being replaced by enough newcomers, leading to a demographic imbalance within the hunting community (Gaspar et al., 2025). It is also difficult to determine how many hunters specifically hunt wild boar, making it challenging to assess whether trends in wild boar hunters mirror those of the general hunting population (Massei et al., 2015).

Our findings indicate a heterogeneous situation about hunting in recent decades. In countries such as Czech Republic, France, Italy, Latvia, Portugal, Slovenia, Spain, and Sweden, hunter numbers are decreasing. On the other hand, several other European countries have seen growth in their hunting populations (Figure 4). Spain, for example, maintained a stable hunting population of around one million hunters for a decade until 2011, making it the largest in Europe at that time (Gaspar et al., 2025). However, this number has since declined dramatically, dropping by nearly half by 2022. Gaspar et al. (2025) reported that the Iberian Peninsula has experienced a 45% decline in its hunting population over the past 50 years. In contrast, Croatia has seen a recent increase in the number of hunters, possibly due to changes in education system (online lectures) and reduced licensing fees (80 euros), which have made hunting more accessible to younger generation. A similar trend was recorded in Bulgaria, where the cost of hunting permit was reduced to a symbolic 0.5 euros (see Supplementary file 1). Overall, the number of hunters during six-year period

across 19 selected European countries has declined since 2018 (Figure 5), falling from 4.3 million to 3.9 million in 2023, although trends vary by country. Massei et al. (2015) reported the total number of hunters in 16 European countries to be around 7 million in 2011. This considerable difference in the number of hunters in these two studies could be a result of the fact that data on hunter numbers in Russia (over 3 million) were included in the study by Massei et al. (2015), but not in our one. However, the number of hunting license holders does not always reflect actual hunting activity (Gočárová et al., 2025), neither it reflects the effectiveness of (different) hunting practices. Given that wild boar harvest in Europe continue to rise while overall hunter numbers decline, it is likely that hunters in some countries have intensified their efforts to become more efficient in wild boar hunting (Massei et al., 2015; Gortázar and Fernandez-de-Simon, 2022), or this may also be a consequence of the implementation of more efficient hunting methods such as night vision devices (see above).

As the hunting population is aging rapidly, maintaining the high hunting effort to efficiently manage the wild boar population might become a problem in the future. Additionally, the implementation of measures to prevent the spread of ASF may also be hampered by the reduced number of hunters, e.g. when searching for carcasses, which is one of the most important measures to prevent the spread of ASF. This could potentially be solved by the establishment of professional hunters. Some countries, such as Austria and Belgium, have already established professional hunting units to help manage problematic wildlife populations (see Supplementary file 1).

5. Conclusions

Despite the continued spread of ASF across Europe, the overall wild boar population in the continent continues to grow until 2019. In several countries, however, the number of harvested animals has decreased following ASF outbreaks. This decline may be attributed either to the high mortality associated with the disease or to hunting bans and restrictions implemented as part of disease control measures. Other factors that may have reduced the number of animals harvested are the climate with occasional poor mast years and the spread of large predators such as wolves. In countries where ASF has only recently emerged, it is

still too early to determine the long-term effects on wild boar harvests and population dynamics, which needs to be monitored in the future. As ASF continues its gradual expansion throughout Europe, many countries are adopting a range of control measures aimed at containing the disease and preventing its spread to unaffected regions. Our data suggest that COVID-19 had no impact on wild boar harvests. Given that (recreational) hunting remains the primary method for wild boar population control, it is essential to ensure a stable and active population of hunters or to implement additional options (i.e., activation of professional hunters, implementation of capturing/trapping) as well as to potentially explore alternative methods such as fertility control that might complement culling. Importantly, in countries experiencing a decline in hunter numbers, systemic changes to the registration and training processes for new hunters should be considered. Additionally, establishing and supporting professional hunting units could be an effective strategy for managing overabundant or problematic wildlife species, thereby enhancing disease control efforts and contributing to sustainable wildlife management.

CRediT authorship contribution statement

Valentina Barukčić: Writing – original draft, Data curation, Visualization; **Boštjan Pokorny:** Conceptualization, Writing – review & editing, Data curation; **Jacopo Cerri:** Writing – original draft, Formal analysis, Visualization; **Klaus Hackländer:** Investigation, Data curation; **Ferdinand Bego:** Writing – review & editing**,** Investigation, Data curation; **Alain Licoppe:** Writing – review & editing, Investigation, Data curation; **Jim Casaer:** Writing – review & editing**,** Investigation, Data curation; **Dalibor Ballian:** Investigation, Data curation; **Stoyan Stoyanov:** Investigation, Data curation; **Miloš Ježek:** Investigation, Data curation; **Mervi Kunnasranta:** Writing – review & editing**,** Investigation, Data curation; **Elmo Miettinen:** Writing – review & editing**,** Investigation, Data curation; **Eric Baubet:** Investigation, Data curation; **Oliver Keuling:** Writing – review & editing, Investigation, Data curation; **Konstantinos Papakostas:** Investigation, Data curation; **András Náhlik:** Writing – review & editing, Investigation, Data curation; **Andrea Monaco:** Investigation, Data curation; **Jānis Ozoliņš:** Writing –

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Declaration of generative AI use

During the preparation of this manuscript, the author(s) did not use AI tools.

Conflict of Interest Declaration

The authors declare no conflict of interest.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Funding

This work was supported by the Croatian Science Foundation, project HRZZ: IP-2022-10-7502, “Wild boar fear of hunting: effects on space use, stress, and meat quality.”.

Supporting information

Supporting information may be found in the online version of this article.

Acknowledgments

This study was supported by the Croatian Science Foundation, project IP-2022-10-7502, “Wild boar fear of hunting: effects on space use, stress, and meat quality.” This trilateral project (Croatia-Slovenia-Switzerland) was also supported by the Slovenian Research and Innovative Agency (project N4-0350), which supported the study also through the programme group P4-0107 and the project V4-2223, cofounded also by the Ministry for Agriculture, Forestry and Food of the Republic of Slovenia. Thanks to the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Agreement on financing the scientific research work of NIO in 2025, registration number 451-03-137/2025-03/200169), the Hellenic Hunters Confederation and all institutions of data providers, from each country.

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