COVID-19 could accelerate the decline in recreational hunting: a natural experiment from Northern Italy

Running title: COVID-19 can accelerate hunters decline

Jacopo Cerri[1,*], Carmela Musto[2], Marco Ferretti[3], Mauro Delogu[2], Sandro Bertolino[4], Adriano Martinoli[5], Francesco Bisi[5], Damiano Preatoni[5], Clara Tattoni[5], Marco Apollonio[1]

[1]Department of Veterinary Medicine, University of Sassari, Sassari, Italy
[2]Department of Veterinary Medical Sciences, University of Bologna, Bologna, Italy
[3]Regione Toscana, Firenze, Italy
[4]Dipartimento di Scienze della Vita e Biologia dei Sistemi, Università degli Studi di Torino, Torino, Italy
[5]Dipartimento di Scienze Teoriche e Applicate, Università degli Studi dell'Insubria, Varese, Italy

*corresponding author; jcerri@uniss.it

Keywords: Sars-CoV2; Italy; recreational hunting; wildlife management; INLA

Abstract

Although many studies highlighted the potential of COVID-19 to reshape existing models of wildlife management, empirical research on this topic has been scarce, particularly in Europe.

We investigated the potential of COVID-19 pandemic to accelerate the ongoing decline in an aging population of recreational hunters in Italy. Namely, we modeled spatiotemporal trends between 2011 and 2021 in the number of recreational hunters in 50 Italian provinces with a varying incidence of COVID-19, and temporally delayed waves of infection.

Compared to projections from 2011-2019 data, we detected a lower number of hunters who enrolled for the hunting season, both in 2020 (14 provinces) and in 2021 (15 provinces). The provinces with the highest incidence of COVID-19 in the Lombardy and Emilia-Romagna regions were also those experiencing the most marked decrease in hunting participation.

Our findings revealed that a wildlife management system based on recreational hunting can be rapidly destabilized by epidemics and their associated public health measures, particularly when the average age of hunters is high, like in Italy. Considered the high incidence attained by COVID-19 in many European countries, where hunters are pivotal for the management of large ungulates and where they were already declining before the pandemic, our findings call for further large-scale research about the impact of COVID-19 on hunting participation.

Introduction

Between early 2020 and early 2023, Sars-CoV-2 infected over 655 million people globally, leading to more than 6 million official deaths (WHO, 2023) and a much higher excess mortality (Wang et al., 2022). Millions of people experienced long-term physical and mental harm and COVID-19 caused temporary global reductions in human mobility (Bates et al., 2020).

In conservation science, the COVID-19 pandemic was studied from multiple viewpoints (Bates et al., 2021; Gibbons et al., 2021). Some studies explored how changes in human mobility affected the ecology (e.g., diet, Gilby et al., 2021; Vez-Garzón et al., 2023), demographics (Lopes Costa et al., 2022) and behaviour of wildlife (e.g., movement, Corradini et al., 2023; Schrimpf et al., 2023; Tucker et al., 2023). Other research quantified changes in human-nature relationships (Soga et al., 2021) and explored the potential effects of the pandemic on existing management models for wildlife and ecosystems (Lindsey et al., 2020).

Some other studies suggested that the sustained impacts of COVID-19 pandemic on outdoor activities (Schweizer et al., 2021; Venter et al., 2021, Hansen et al., 2022), could potentially result in long-lasting changes in patterns of outdoor recreation (Pröbstl-Haider et al., 2023), including recreational hunting. This consequence is plausible from both demographic and behavioural viewpoints. In facts, COVID-19 resulted into a significant increase in the death rate or health complications among people above 65 years of age (Yanez et al., 2020; Sorensen et al., 2022). Consequently, the pandemic may have prompted many hunters to prematurely end their hunting career due to health problems, caregiving responsibilities for older relatives, or even higher mortality among older hunters (Fusar Poli et al., 2021; Messina et al., 2022). Moreover, many countries repeatedly enforced restrictions to human mobility, whenever they experienced peaks in SARS-CoV2 incidence and deaths from COVID-19, and some even halted the hunting season (e.g., Portugal, see Garcia et al., 2023). This could have increased the uncertainty of hunters about the upcoming hunting seasons in 2020 and 2021, potentially leading them to not renew their licenses.

While both mechanisms are possible, and despite some research has been conducted about recreational angling (Britton et al., 2023), empirical research on the impact of COVID-19 on hunting licenses has been limited to two studies, carried out in North America. Namely, Chizinski et al. (2022) found a decrease of approximately 90% in permits for non-resident turkey hunters across the US in 2020 compared to the previous three years. Conversely, Danks et al. (2022) reported an increase in participation in turkey hunting across the US in 2020, aligning with grey literature that indicated an overall increase in hunting licenses across the US in 2020 and 2021 (CAHSS, 2021).

Given the critical role that hunters plays in the management of wildlife in Europe, the lack of studies in this continent is cause for concern. The monitoring (Cretois et al., 2020; Pokorny et al., 2022), control (Gortázar et al., 2022) and epidemiological surveillance (Cardoso et al., 2022) of wildlife populations are among the many tasks that hunters are responsible for in many nations.

In this study we investigated the potential of COVID-19 pandemic to accelerate the ongoing decline in recreational hunting, using Italy as a natural experiment. In this country ungulate hunters are responsible of extensive monitoring to gain data necessary to produce management plans and COVID 19 prevented these activities during 2020 and 2021. Northern Italy was the first epicentre of 2020 COVID-19 outbreak in

Europe (Remuzzi & Remuzzi, 2020) and Italian regions differed in the temporal progression of the pandemic (https://www.epicentro.iss.it/coronavirus/sars-cov-2-dashboard), as well as in the implementation of restrictions on crowding and human mobility (Pelagatti & Maranzano, 2021). This allowed us to: *i*) model spatiotemporal trends in the number of recreational hunters (2011-2019) across 50 Italian provinces with varying incidence of SARS-CoV2, and temporally delayed waves of infection, *ii*) detect discrepancies between the observed and predicted number of hunters in 2020 and 2021 and *iii*) correlate these discrepancies with spatial differences in the evolution of the COVID-19 pandemic.

Materials and methods

The study area encompassed 50 provinces across the regions of Emilia-Romagna, Friuli Venezia-Giulia, Lombardy, Piedmont, Veneto, and Tuscany in Central and Northern Italy (Fig. 1). Overall, these regions housed 28.4 million residents in 2020, accounting for 47.7% of the Italian population.

In Italy, professional hunting does not exist, and hunting is a recreational activity. Wildlife is considered a public property and falls under the ownership of the state (Bertolino et al., 2023). During each hunting season, which typically spans from September to January, hunters are required to pay a tax for hunting license to the Italian government and the region where they reside and then a tax to the hunting area/s (i.e. Ambiti Territoriali di Caccia and Comprensori Alpini) where they hunt. While recreational hunting has focused in the past on small game and migratory passerines (Sharp & Wollscheid, 2009), there has been a consistent rise in the abundance and exploitation of wild ungulates since the early 2000s (Apollonio et al., 2010). The annual hunting bags for these species are nowadays considerable exceeding 500.000 heads (ENETWILD, 2022).

Over the past four decades, Italy has experienced a considerable long-term decline in recreational hunting. In 1980 there were 1,701,853 hunters (https://www.istat.it/it/archivio/48261), whereas in 2017 the Ministry of the Interior estimated a total of 678,970 hunting licenses (Ministry of the Interior, private communication). The overall number of hunters in the study area fell by 37.8% in Emilia-Romagna, 29.1% in Friuli Venezia-Giulia, 33.2% in Lombardy, 36.9% in Piedmont, 44.6% in Tuscany, and 29.2% in the Veneto region, between 2004 and 2019. In urbanised areas, this loss was more noticeable (Cerri et al., 2018). In addition, recreational hunters had been aging. In 2010 the percentage of hunters above 60 years of age was approximately 52% in Tuscany and Emilia-Romagna region (Regione Toscana, 2012; Regione Emilia-Romagna, 2018), and 43% in the Lombardy region (Regione Lombardia, 2022).

In 2020, the evolution of COVID-19 varied across the five regions in the study area. The initial wave, occurring in spring 2020, predominantly affected Lombardy and parts of the Emilia-Romagna and Piedmont regions, with no significant excess deaths observed in Friuli Venezia-Giulia, Veneto, and Tuscany regions (Blangiardo et al., 2020; Henry et al., 2022; Konstantinoudis et al., 2022). The spread of the virus was mitigated by the nationwide implementation of non-pharmaceutical measures (Bezzini et al., 2022), from March to May, possibly influenced by the progressive increase in air temperatures (Balboni et al., 2023). However, a second wave of COVID-19 emerged in autumn 2020, affecting the entire study area, and excess deaths became widespread throughout 2021

(https://www.istat.it/it/files//2022/03/Report_ISS_ISTAT_2022_tab3.pdf). Despite the imposition of various restrictions on human mobility throughout 2020 and 2021, the hunting season was regularly opened in September during both years.

To assess the impact of COVID-19 on hunting participation, we gathered data on the number of hunting licenses issued by each province from 2011 to 2019. Hunting licenses were employed as a proxy for hunting participation, recognizing that some hunters may have renewed their licenses without actively participating in the season. In Italy the hunting season starts in September; consequently, we quantified the number of licenses for the 2020/2021 season (hereinafter "2020") and the 2021/2022 season (hereinafter "2021").

We used Bayesian Generalized Linear Models to capture spatiotemporal variations in the number of hunters in the study area. Specifically, we used a negative binomial distribution to model the annual number of hunters in each province. Model selection was based on leave-one-out cross validation, and diagnostic assessment followed the approach outlined by Zuur et al. (2017). Overall, we tried multiple spatio-temporal structures to account for different potential spatiotemporal patterns, as suggested by Blangiardo & Cameletti (2015). Model selection retained a best candidate model where the number of hunters was modelled according to a non-linear random walk term, with a random intercept assigned to each region, to account for differences in the total number of residents across provinces. We also accounted for temporal trends between 2011 and 2019 through a linear term.

Finally, we compared the total number of hunters in each province, during 2020 and 2021, against predicted values from the posterior distribution of our model, trained on 2011-2019 data. We considered anomalies those values that exceeded the boundaries of the 95% credibility interval. Additionally, we compared the number of hunters in 2020 and 2021 against the median value of the posterior distribution, which in Bayesian models represent the most likely predicted value (Kruschke & Liddell, 2018). Regarding the Veneto region, we could only test for anomalies for the 2020/2021 season, because the number of hunting licenses for 2021 was not available at the time of the study.

Statistical models were implemented using INLA (Lindgren & Rue, 2015) and the "inlabru" package in R (Bachl et al., 2019). A reproducible dataset and software code are available at https://osf.io/j25cr/

Results

Our findings indicate that the number of hunters who enrolled for the hunting season was lower than expected based on the 2011-2019 trend in 14 Italian provinces during 2020 and in 15 provinces in 2021. Anomalous decreases were observed specifically in provinces within the Lombardy, Emilia-Romagna, and Tuscany regions (Fig. 2).

Lombardy exhibited the most pronounced decrease in both 2020 and 2021. By comparing the observed number of hunters in Lombardy with the median value of the posterior distribution, it was found that there were 3,904 (2,936-4,911, compared to the upper and lower bound of 95% Credibility Interval) fewer hunters in 2021 and 2,720 (1,790-3,688) fewer in 2020. There were 808 fewer hunters in the Emilia-Romagna region in 2020 (255–1,382) and 682 in 2021 (138–1,249). There were 538 fewer hunters in the Tuscany region in 2020 (259–828) and 741 fewer in 2021 (213–1,291), however only two out of ten regions in 2020 and three

provinces in 2021 were affected by these anomalies. A complete overview of the decrease in hunters for each province is shown in Table 1.

The province of Milan exhibited the most significant decrease overall (396-756 fewer hunters in 2020 and 284-638 in 2021), followed by Cremona (399-619 fewer hunters in 2020 and 286-503 in 2021), Lodi (402-570 fewer hunters in 2020 and 377-541 in 2021) and Bergamo (175-774 fewer hunters in 2020 and 101-691 in 2021).

Discussion

Although many studies highlighted the potential of the COVID-19 pandemic to reshape socio-ecological systems (Kadykalo et al., 2022), the amount of empirical research quantifying its implications on wildlife management models has been relatively limited. Through an examination of regional differences in COVID-19 progression in Northern Italy, we found that areas of the country experiencing the most immediate and pronounced impacts from COVID-19 also exhibited an anomalous decline in the number of hunting licenses in 2020 and 2021. We believe our study holds important implications to understand how wildlife management in Italy and Europe can be impacted by large scale epidemic events, and it calls for further large-scale collaborative research on trends in recreational hunting across Europe.

Our findings revealed that a wildlife management system where recreational hunters are aging, can be rapidly destabilized by epidemics and the associated public health measures. According to the Italian Institute for Statistics, the provinces of Cremona, Lodi, and Pavia exhibited the highest death rates during the 2020 pandemic (https://www.istat.it/it/files//2022/03/Report_ISS_ISTAT_2022_tab3.pdf). Interestingly, these areas also showed the most significant negative anomalies in hunting licenses, suggesting a potential decrease in hunting activity related to COVID-19. We believe this pattern to have resulted from at least four different mechanisms.

On the one hand, since COVID-19 predominantly affected people above 60 years of age (Mannucci et al., 2023), older hunters could have died from COVID-19, or from consequence of the lack of health care deriving from it (e.g., from missed diagnoses, Angelini et al., 2023). The Lombardy and Emilia-Romagna regions were characterized by an impressive number of excess deaths and recoveries in intensive care units, particularly during spring 2020. Consequently, a higher-than-usual number of hunters may have perished from COVID-19 as they were in the most affected demographic segment. Despite the current estimates of COVID-19 incidence are subject to debate, these areas likely experienced a higher total burden of COVID-19 in terms of incidence (https://www.istat.it/it/files//2022/03/Report_ISS_ISTAT_2022_tab3.pdf). Hunters may have refrained from the hunting season to provide assistance to their relatives (Fusar Poli et al., 2021; Messina et al., 2022) or because affected by long-COVID symptoms that could persists for months after the infection (Davis et al., 2021). In turn, these two dynamics may have been mutually reinforcing, leading to the rapid dissolution of established social networks within the hunting community: as some hunters died, and others quit hunting, more hunters could have simply not renewed their licenses as their social circle was destroyed. A particular case could have been represented by collective hunting, implying the presence of hunting teams of a given number of hunters to be practiced, like wild boar drives with hounds, the most

popular ungulate hunting in Italy (Apollonio et al., 2010). Here the contrasting impact of the prescription not to group as a consequence of COVID-19 and the need to reach at least some tents of hunters in a team might have influenced even more negatively this practice, Finally, hunters might have ceased hunting due to uncertain about the opening of the hunting season, especially during 2020, as sanitary restrictions caused a confused situation where no firm decision were anticipated. The relative weight of these mechanisms is open to debate. In Italy restrictions, such as the lockdown in spring 2020, were implemented at the national level and therefore, if uncertainty had really played a major role, we should have observed an anomalous decrease across the entire study area. Future studies, carried out through structured questionnaires administered to a representative sample of hunters (Vaske, 2019), will be crucial for delving into the ways in which COVID-19 affected the quality of the hunting experience. These investigations will help elucidate how each one of these four mechanisms could have affected the behaviour of hunters. Moreover, future studies should also replicate our analyses with long-term data, whenever these are available from regional offices: it is possible that the observed trends in 2020 and 2021 could have reversed in 2022, with some hunters renewing their hunting licenses.

However, we believe that the anomalies we observed in 2020 and 2021 should raise an alarm regarding the potential long-term consequences of COVID-19 for wildlife management in Italy and perhaps other parts of Europe, particularly where COVID-19 had a high incidence and mortality since late 2020 (https://cohesiondata.ec.europa.eu/stories/s/The-regional-impact-of-COVID-19/24gj-n8r2/). In these areas, where hunters are already declining (Massei et al., 2015), a further decrease in recreational hunting could undermine the management of wild ungulates, whose populations have expanded (Apollonio et al., 2010) and nowadays require intensive culling (Valente et al., 2020, Carpio et al., 2021), as well as the integrated management of African Swine Fever (EFSA, 2018). To better understand the severity of this risk it is urgent to create a pan-European dataset about hunting licenses in Europe, to model large-scale trends in recreational hunting. This initiative will be fundamental to navigate potentially rapid changes in existing models of wildlife management and to design policies aimed at minimizing social conflicts related to wildlife.

Supplementary information The reproducible dataset and software code are available at:
https://osf.io/j25cr/

Acknowledgments We express our gratitude to the people and the institutions that provided us with access to data on hunters: Alessandra Berto and the Piedmont Region “Settore Conservazione e Gestione Fauna Selvatica e Acquicoltura”, CSI Piemonte, Dario Colombi (Friuli Venezia-Giulia Region), Guido Lavazza and Stefano Omizzolo of the Veneto Region and the staff of the “Territorial Services for Agriculture, Hunting and Fishing” (STACP is the Italian acronym) of the Emilia-Romagna Region.

Funding The co-author Carmela Musto was partially supported by a research grant funded by the Vienna Science and Technology Fund (WWTF) [10.47379/ESR20009].

Declarations

Conflict of interests The author declares no competing interests.

References

Angelini, M., Teglia, F., Astolfi, L., Casolari, G., & Boffetta, P. (2023). Decrease of cancer diagnosis during COVID-19 pandemic: a systematic review and meta-analysis. *European Journal of Epidemiology*, *38*(1), 31-38. https://doi.org/10.1007/s10654-022-00946-6

Apollonio, M., Andersen, R., & Putman, R. (Eds.). (2010). European ungulates and their management in the 21st century. Cambridge University Press.

Bachl, F. E., Lindgren, F., Borchers, D. L., & Illian, J. B. (2019). inlabru: an R package for Bayesian spatial modelling from ecological survey data. *Methods in Ecology and Evolution*, *10*(6), 760-766. https://doi.org/10.1111/2041-210X.13168

Balboni, E., Filippini, T., Rothman, K. J., Costanzini, S., Bellino, S., Pezzotti, P., ... & Vinceti, M. (2023). The influence of meteorological factors on COVID-19 spread in Italy during the first and second wave. *Environmental Research*, *228*, 115796. https://doi.org/10.1016/j.envres.2023.115796

Bates, A. E., Primack, R. B., Moraga, P., & Duarte, C. M. (2020). COVID-19 pandemic and associated lockdown as a "Global Human Confinement Experiment" to investigate biodiversity conservation. *Biological conservation*, *248*, 108665. https://doi.org/10.1016/j.biocon.2020.108665

Bates, A. E., Primack, R. B., Biggar, B. S., Bird, T. J., Clinton, M. E., Command, R. J., ... & Parmelee, J. R. (2021). Global COVID-19 lockdown highlights humans as both threats and custodians of the environment. *Biological conservation*, *263*, 109175. https://doi.org/10.1016/j.biocon.2021.109175

Bezzini, D., Schiavetti, I., Manacorda, T., Franzone, G., & Battaglia, M. A. (2022). First wave of COVID-19 pandemic in Italy: data and evidence. In *Coronavirus Therapeutics–Volume II: Clinical Management and Public Health* (pp. 91-113). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-85113-2_6

Blangiardo, M., & Cameletti, M. (2015). *Spatial and spatio-temporal Bayesian models with R-INLA*. John Wiley & Sons. http://dx.doi.org/10.1002/9781118950203

Blangiardo, M., Cameletti, M., Pirani, M., Corsetti, G., Battaglini, M., & Baio, G. (2020). Estimating weekly excess mortality at sub-national level in Italy during the COVID-19 pandemic. *PloS one*, *15*(10), e0240286. https://doi.org/10.1371/journal.pone.0240286

Britton, J. R., Pinder, A. C., Alós, J., Arlinghaus, R., Danylchuk, A. J., Edwards, W., ... & Cooke, S. J. (2023). Global responses to the COVID-19 pandemic by recreational anglers: considerations for developing more resilient and sustainable fisheries. *Reviews in Fish Biology and Fisheries*, 1-17. https://doi.org/10.1007/s11160-023-09784-5

Cardoso, B., García-Bocanegra, I., Acevedo, P., Cáceres, G., Alves, P. C., & Gortázar, C. (2022). Stepping up from wildlife disease surveillance to integrated wildlife monitoring in Europe. *Research in Veterinary Science*, *144*, 149-156. https://doi.org/10.1016/j.rvsc.2021.11.003

Carpio, A. J., Apollonio, M., & Acevedo, P. (2021). Wild ungulate overabundance in Europe: contexts, causes, monitoring and management recommendations. *Mammal Review*, *51*(1), 95-108. https://doi.org/10.1111/mam.12221

Cerri, J., Ferretti, M., & Coli, L. (2018). Where the wild things are: urbanization and income affect hunting participation in Tuscany, at the landscape scale. *European journal of wildlife research*, *64*, 1-9. https://doi.org/10.1007/s10344-018-1183-0

Corradini, A., Peters, W., Pedrotti, L., Hebblewhite, M., Bragalanti, N., Tattoni, C., ... & Cagnacci, F. (2021). Animal movements occurring during COVID-19 lockdown were predicted by connectivity models. *Global Ecology and Conservation*, *32*, e01895. https://doi.org/10.1016/j.gecco.2021.e01895

Chizinski, C. J., Gruntorad, M. P., Lusk, J. J., Meduna, L. R., Inselman, W. M., & Fontaine, J. J. (2022). The influence of the COVID-19 pandemic on spring turkey hunting. *The Journal of Wildlife Management*, *86*(3), e22202. https://doi.org/10.1002/jwmg.22202

CAHSS - Council to Advance Hunting and the Shooting Sports (2021). Hunting licence sales 2020-2021. https://fishwildlife.org/mscgp/application/files/2016/8691/8549/MicroSite_F22AP00350_2021_CAHSS_LIC_Report_Digital.pdf

Cretois, B., Linnell, J. D., Grainger, M., Nilsen, E. B., & Rød, J. K. (2020). Hunters as citizen scientists: Contributions to biodiversity monitoring in Europe. *Global Ecology and Conservation*, *23*, e01077. https://doi.org/10.1016/j.gecco.2020.e01077

Danks, Z. D., Schiavone, M. V., Butler, A. B., Fricke, K., Davis, A., & Cobb, D. T. (2022). Effects of the COVID-19 pandemic on 2020 spring turkey hunting across the United States. *Wildlife Society Bulletin*, *46*(2), e1294. https://doi.org/10.1002/wsb.1294

Davis, H. E., Assaf, G. S., McCorkell, L., Wei, H., Low, R. J., Re'em, Y., ... & Akrami, A. (2021). Characterizing long COVID in an international cohort: 7 months of symptoms and their impact. *EClinicalMedicine*, *38*. https://doi.org/10.1016/j.eclinm.2021.101019

EFSA - Panel on Animal Health and Welfare (AHAW), More, S., Miranda, M. A., Bicout, D., Bøtner, A., Butterworth, A., ... & Gortázar Schmidt, C. (2018). African swine fever in wild boar. *EFSA Journal*, *16*(7), e05344. https://doi.org/10.2903/j.efsa.2018.5344

ENETWILD-consortium, Illanas, S., Croft, S., Smith, G. C., López-Padilla, S., Vicente, J., ... & Acevedo, P. (2022). New models for wild ungulates occurrence and hunting yield abundance at European scale. *EFSA Supporting Publications*, *19*(10), 7631E. https://doi.org/10.2903/sp.efsa.2022.EN-7631

Fusar-Poli, L., Surace, T., Meo, V., Patania, F., Avanzato, C., Pulvirenti, A., ... & Signorelli, M. S. (2021). Psychological well-being and family distress of Italian caregivers during the COVID-19 outbreak. *Journal of Community Psychology*, *50*(5), 2243-2259. https://doi.org/10.1002/jcop.22772

Garcia, F., da Silva, A. A., Freitas, H., Sousa, J. P., & Alves, J. (2023). The effect of COVID-19 confinement on the activity behaviour of red deer. *Global Ecology and Conservation*, *45*, e02525. https://doi.org/10.1016/j.gecco.2023.e02525

Gibbons, D. W., Sandbrook, C., Sutherland, W. J., Akter, R., Bradbury, R., Broad, S., ... & Ockendon, N. (2021). The relative importance of COVID-19 pandemic impacts on biodiversity conservation globally. *Conservation Biology*, *36*(1), e13781. https://doi.org/10.1111/cobi.13781

Gilby, B. L., Henderson, C. J., Olds, A. D., Ballantyne, J. A., Bingham, E. L., Elliott, B. B., ... & Schlacher, T. A. (2021). Potentially negative ecological consequences of animal redistribution on beaches during COVID-19 lockdown. *Biological Conservation*, *253*, 108926. https://doi.org/10.1016/j.biocon.2020.108926

Gortázar, C., & Fernandez-de-Simon, J. (2022). One tool in the box: the role of hunters in mitigating the damages associated to abundant wildlife. *European Journal of Wildlife Research*, *68*(3), 28. https://doi.org/10.1007/s10344-022-01578-7

Hansen, A. S., Beery, T., Fredman, P., & Wolf-Watz, D. (2023). Outdoor recreation in Sweden during and after the Covid-19 pandemic–management and policy implications. *Journal of environmental planning and management*, *66*(7), 1472-1493. https://doi.org/10.1080/09640568.2022.2029736

Henry, N. J., Elagali, A., Nguyen, M., Chipeta, M. G., & Moore, C. E. (2022). Variation in excess all-cause mortality by age, sex, and province during the first wave of the COVID-19 pandemic in Italy. *Scientific reports*, *12*(1), 1077. https://doi.org/10.1038/s41598-022-04993-7

Kadykalo, A. N., Beaudoin, C., Hackenburg, D. M., Young, N., & Cooke, S. J. (2022). Social–ecological systems approaches are essential for understanding and responding to the complex impacts of COVID-19 on people and the environment. *PLOS Sustainability and Transformation*, *1*(4), e0000006. https://doi.org/10.1371/journal.pstr.0000006

Kruschke, J. K., & Liddell, T. M. (2018). The Bayesian New Statistics: Hypothesis testing, estimation, meta-analysis, and power analysis from a Bayesian perspective. *Psychonomic bulletin & review*, *25*, 178-206. https://doi.org/10.3758/s13423-016-1221-4

Konstantinoudis, G., Cameletti, M., Gómez-Rubio, V., Gómez, I. L., Pirani, M., Baio, G., ... & Blangiardo, M. (2022). Regional excess mortality during the 2020 COVID-19 pandemic in five European countries. *Nature communications*, *13*(1), 482. https://doi.org/10.1038/s41467-022-28157-3

Lindgren, F., & Rue, H. (2015). Bayesian spatial modelling with R-INLA. *Journal of statistical software*, *63*(19). https://doi.org/10.18637/jss.v063.i19

Lindsey, P., Allan, J., Brehony, P., Dickman, A., Robson, A., Begg, C., ... & Tyrrell, P. (2020). Conserving Africa's wildlife and wildlands through the COVID-19 crisis and beyond. *Nature ecology & evolution*, *4*(10), 1300-1310. https://doi.org/10.1038/s41559-020-1275-6

Lopes Costa, L., Machado, P. M., de Moura Barboza, C. A., Soares-Gomes, A., & Zalmon, I. R. (2022). Recovery of ghost crabs metapopulations on urban beaches during the Covid-19 "anthropause". *Marine Environmental Research*, *180*, 105733. https://doi.org/10.1016/j.marenvres.2022.105733

Manfredo, M. J., Teel, T. L., Don Carlos, A. W., Sullivan, L., Bright, A. D., Dietsch, A. M., ... & Fulton, D. (2020). The changing sociocultural context of wildlife conservation. *Conservation Biology*, *34*(6), 1549-1559. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7754113/

Manfredo, M. J., Teel, T. L., & Henry, K. L. (2009). Linking society and environment: A multilevel model of shifting wildlife value orientations in the western United States. *Social Science Quarterly*, *90*(2), 407-427. https://doi.org/10.1111/j.1540-6237.2009.00624.x

Mannucci, P. M., Galbussera, A. A., D'Avanzo, B., Tettamanti, M., Remuzzi, G., Fortino, I., ... & Nobili, A. (2023). Two years of SARS-CoV-2 pandemic and COVID-19 in Lombardy, Italy. *Internal and Emergency Medicine*, 1-7. https://doi.org/10.1007/s11739-023-03315-7

Massei, G., Kindberg, J., Licoppe, A., Gačić, D., Šprem, N., Kamler, J., ... & Náhlik, A. (2015). Wild boar populations up, numbers of hunters down? A review of trends and implications for Europe. *Pest management science*, *71*(4), 492-500. https://doi.org/10.1002/ps.3965

Messina, A., Lattanzi, M., Albanese, E., & Fiordelli, M. (2022). Caregivers of people with dementia and mental health during COVID-19: findings from a cross-sectional study. *BMC geriatrics*, *22*(1), 56. https://doi.org/10.1186/s12877-022-02752-x

Pavone, S., Iscaro, C., Dettori, A., & Feliziani, F. (2023). African Swine Fever: The State of the Art in Italy. *Animals*, *13*(19), 2998. https://doi.org/10.3390/ani13192998

Pelagatti, M., & Maranzano, P. (2021). Assessing the effectiveness of the Italian risk-zones policy during the second wave of COVID-19. *Health Policy*, *125*(9), 1188-1199. https://doi.org/10.1016/j.healthpol.2021.07.011

Pokorny, B., Cerri, J., & Bužan, E. (2022). Wildlife roadkill and COVID-19: A biologically significant, but heterogeneous, reduction. *Journal of Applied Ecology*, *59*(5), 1291-1301. https://doi.org/10.1111/1365-2664.14140

Pröbstl-Haider, U., Gugerell, K., & Maruthaveeran, S. (2023). Covid-19 and outdoor recreation–Lessons learned? Introduction to the special issue on "Outdoor recreation and Covid-19: Its effects on people, parks and landscapes". *Journal of Outdoor Recreation and Tourism*, *41*, 100583. https://doi.org/10.1016/j.jort.2022.100583

Regione Emilia-Romagna (2018). Piano Faunistico Venatorio Regionale 2018-2023. https://agricoltura.regione.emilia-romagna.it/caccia/temi/normativa/indirizzi-pianificazione/piano-faunistico-2018/piano-faunistico-venatorio-regionale-2018-2023

Regione Lombardia (2022). Piano Faunistico Venatorio Regionale. https://www.regione.lombardia.it/wps/portal/istituzionale/HP/DettaglioRedazionale/servizi-e-informazioni/cittadini/agricoltura/fauna-selvatica-e-caccia/piano-faunistico-venatorio-regionale/piano-faunistico-venatorio-regionale

Regione Toscana (2012). Piano Regionale Agricolo Forestale 2012-2015. https://www.regione.toscana.it/documents/10180/71336/PRAF/63dd2550-00e3-4002-b98e-b7bf126e5d4c

Remuzzi, A., & Remuzzi, G. (2020). COVID-19 and Italy: what next?. *The lancet*, *395*(10231), 1225-1228. https://doi.org/10.1016/S0140-6736(20)30627-9

Schrimpf, M. B., Des Brisay, P. G., Johnston, A., Smith, A. C., Sánchez-Jasso, J., Robinson, B. G., ... & Koper, N. (2021). Reduced human activity during COVID-19 alters avian land use across North America. *Science Advances*, *7*(39), eabf5073. https://doi.org/10.1126/sciadv.abf5073

Schweizer, A. M., Leiderer, A., Mitterwallner, V., Walentowitz, A., Mathes, G. H., & Steinbauer, M. J. (2021). Outdoor cycling activity affected by COVID-19 related epidemic-control-decisions. *Plos one*, *16*(5), e0249268. https://doi.org/10.1371/journal.pone.0249268

Sharp, R., & Wollscheid, K. U. (2009). An overview of recreational hunting in North America, Europe and Australia. *Recreational hunting, conservation and rural livelihoods: science and practice*, 25-38. https://doi.org/10.1002/9781444303179.ch2

Soga, M., Evans, M. J., Cox, D. T., & Gaston, K. J. (2021). Impacts of the COVID-19 pandemic on human–nature interactions: Pathways, evidence and implications. *People and Nature*, *3*(3), 518-527. https://doi.org/10.1002/pan3.10201

Sorensen, R. J. D., Barber, R. M., Pigott, D. M., Carter, A., Spencer, C. N., Ostroff, S. M., ... & Murray, C. (2022). Variation in the COVID-19 infection-fatality ratio by age, time, and geography during the pre-vaccine era: A systematic analysis. *The Lancet*, *399*(10334), 1469-1488. https://doi.org/10.1016/S0140-6736(21)02867-1

Tucker, M. A., Schipper, A. M., Adams, T. S., Attias, N., Avgar, T., Babic, N. L., ... & Stacy-Dawes, J. (2023). Behavioral responses of terrestrial mammals to COVID-19 lockdowns. *Science*, *380*(6649), 1059-1064. https://doi.org/10.1126/science.abo6499

Valente, A. M., Acevedo, P., Figueiredo, A. M., Fonseca, C., & Torres, R. T. (2020). Overabundant wild ungulate populations in Europe: management with consideration of socio-ecological consequences. *Mammal Review*, *50*(4), 353-366

Vaske, J. J. (2019). *Survey research and analysis*. Sagamore-Venture. 1807 North Federal Drive, Urbana, IL 61801. https://eric.ed.gov/?id=ED605453

Venter, Z. S., Barton, D. N., Gundersen, V., Figari, H., & Nowell, M. S. (2021). Back to nature: Norwegians sustain increased recreational use of urban green space months after the COVID-19 outbreak. *Landscape and urban planning*, *214*, 104175. https://doi.org/10.1016/j.landurbplan.2021.104175

Vez-Garzón, M., Giménez, J., Sánchez-Márquez, A., Montalvo, T., & Navarro, J. (2023). Changes in the feeding ecology of an opportunistic predator inhabiting urban environments in response to COVID-19 lockdown. *Royal Society Open Science*, *10*(4), 221639. https://doi.org/10.1098/rsos.221639

Viesti, G. (2021). Centri e periferie: Europa, Italia, Mezzogiorno dal XX al XXI secolo. Gius. Laterza & Figli Spa. https://www.laterza.it/scheda-libro/?isbn=9788858143889

Wang, H., Paulson, K. R., Pease, S. A., Watson, S., Comfort, H., Zheng, P., ... & Murray, C. J. (2022). Estimating excess mortality due to the COVID-19 pandemic: a systematic analysis of COVID-19-related mortality, 2020–21. *The Lancet*, *399*(10334), 1513-1536. https://doi.org/10.1016/S0140-6736(21)02796-3

WHO - World Health Organization (2023). COVID-19 Epidemiological Update - 29 September 2023. https://www.who.int/publications/m/item/covid-19-epidemiological-update---29-september-2023

Yanez, N. D., Weiss, N. S., Romand, J. A., & Treggiari, M. M. (2020). COVID-19 mortality risk for older men and women. *BMC public health, 20*(1), 1-7. https://doi.org/10.1186/s12889-020-09826-8

Zuur, A.F., Ieno, E.N., & Saveliev, A.A. (2017). Spatial, temporal and spatial-temporal ecological data analysis with R-INLA. Highland Statistics Ltd, 1. https://www.highstat.com/index.php/books2?view=article&id=11&catid=18

Figures

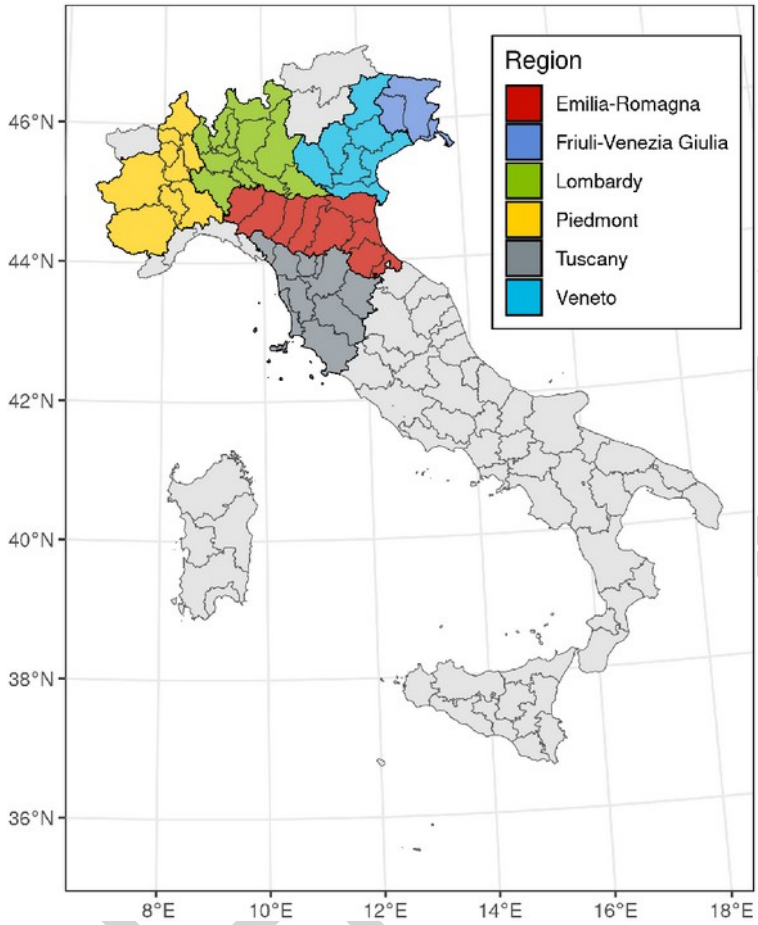

Fig. 1. Map of the study area, representing the 50 provinces, divided between the 6 different regions.

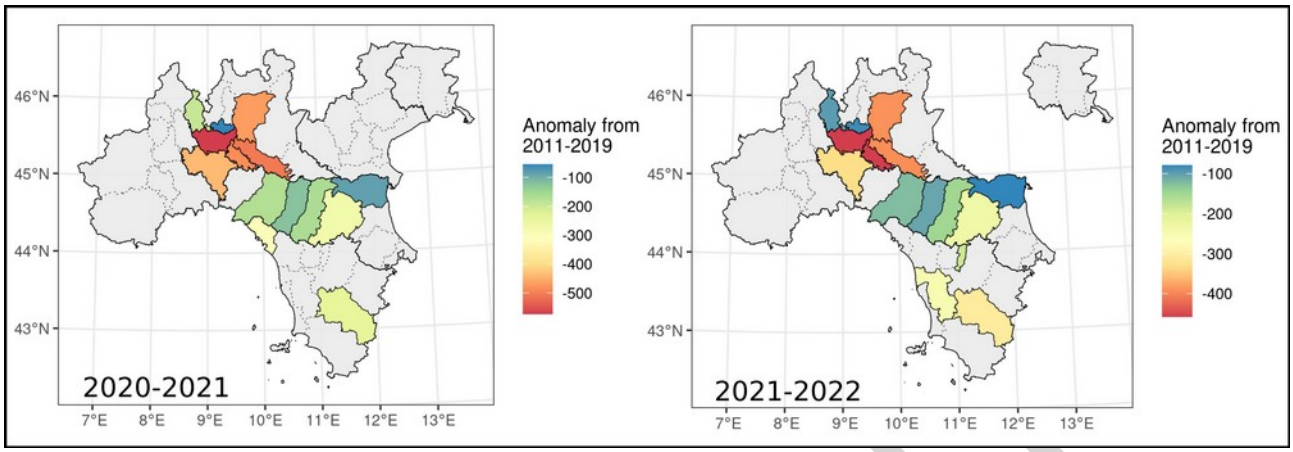

Fig. 2. Difference between the observed number of hunting licenses and predictions from 2011-2019 data, during the 2020-2021 season (left) and the 2021-2022 season (right). Anomalies are expressed as the difference between the median value of the posterior distribution, which in Bayesian models represent the most probable value, and observed values. Provinces in grey did not have any anomalous variation.

Tables

Table. 1. Overview of predicted and observed number of hunters in the 2020/2021 and 2021/2022 hunting season. Only provinces with an anomalous decrease are included in the table.

Hunting season: 2020/2021								
Province	Region	Number licences (observed)	Number licences (predicted, most likely)	Number licences (predicted, min-max)	Anomalous decrease (compared to the median)		Anomalous decrease (min-max)	
					Number	Percentage	Number	Percentage
Milan	Lombardy	5067	5640	5463 - 5823	573	-10.20 %	396 - 756	-7.20% / -13.00%
Cremona	Lombardy	2879	3386	3278 - 3498	507	- 5.00 %	399 - 619	-12.20% / -17.70%
Lodi	Lombardy	1176	1660	1578 - 1746	484	-29.20 %	402 - 570	-25.50% / -32.60%
Bergamo	Lombardy	9061	9530	9236 - 9835	469	-4.90 %	175 - 774	-1.90% / -7.90%
Pavia	Lombardy	3726	4166	4034 - 4303	440	-10.60%	308 - 577	-7.60% / -13.40%
Massa Carrara	Tuscany	1490	1792	1732 - 1854	302	-16.90%	242 - 364	-14.00% / -19.60%
Bologna	Emilia-Romagna	4882	5152	4990 - 5320	270	-5.20%	108 - 438	-2.20% / -8.20%
Siena	Tuscany	6824	7060	6841 - 7288	236	-3.30%	17 - 464	-0.20% / -6.40%
Varese	Lombardy	2460	2653	2567 - 2742	193	-7.30%	107 - 282	-4.20% / -10.30%
Parma	Emilia-Romagna	3274	3444	3330 - 3563	170	-4.90%	56 - 289	-1.70% / -8.10%
Modena	Emilia-Romagna	3496	3659	3543 - 3780	163	-4.50%	47 - 284	-1.30% / -7.50%
Reggio Emilia	Emilia-Romagna	2924	3045	2947 - 3146	121	-4.00%	23 - 222	-0.80% / -7.10%
Ferrara	Emilia-Romagna	1811	1895	1832 - 1960	84	-4.40%	21 - 149	-1.10% / -7.60%
Monza and Brianza	Lombardy	1519	1573	1520 - 1629	54	-3.40%	2 - 110	-0.10% / -6.80%

Hunting season: 2021/2022								
Province	Region	Number licences (observed)	Number licences (predicted, most likely)	Number licences (predicted, min-max)	Anomalous decrease (compared to the median)		Anomalous decrease (min-max)	
					Number	Percentage	Number	Percentage
Milan	Lombardy	4991	5449	5275 - 5629	458	-8.41%	284 - 638	-5.38% / -11.33%
Lodi	Lombardy	1147	1604	1524 - 1688	457	-28.49%	377 - 541	-24.74% / -32.05%
Cremona	Lombardy	2879	3271	3165 - 3382	392	-11.98%	286 - 503	-9.04% / -14.87%
Bergamo	Lombardy	8817	9207	8918 - 9508	390	-4.24%	101 - 691	-1.13% / -7.27%
Pavia	Lombardy	3694	4025	3895 - 4160	331	-8.22%	201 - 466	-5.16% / -11.20%
Siena	Tuscany	6514	6821	6605 - 7046	307	-4.50%	91 - 532	-1.38% / -7.55%
Pisa	Tuscany	7160	7408	7174 - 7651	248	-3.35%	14 - 491	-0.20% / -6.42%
Bologna	Emilia-Romagna	4749	4977	4818 - 5143	228	-4.58%	69 - 394	-1.43% / -7.66%
Prato	Tuscany	2186	2372	2294 - 2454	186	-7.84%	108 - 268	-4.71% / -10.92%
Modena	Emilia-Romagna	3387	3536	3421 - 3655	149	-4.21%	34 - 268	-0.99% / -7.33%
Parma	Emilia-Romagna	3205	3328	3215 - 3445	123	-3.70%	10 - 240	-0.31% / -6.97%
Reggio Emilia	Emilia-Romagna	2838	2942	2846 - 3042	104	-3.54%	8 - 204	-0.28% / -6.71%
Varese	Lombardy	2467	2563	2479 - 2651	96	-3.75%	12 - 184	-0.48% / -6.94%
Monza and Brianza	Lombardy	1437	1520	1468-1574	84	-5.53%	31-137	-0.02% / -8.70%
Ferrara	Emilia-Romagna	1752	1830	1769 - 1895	78	-4.26%	17 - 143	-0.96% / -7.55%