PLOS SUSTAINABILITY AND TRANSFORMATION

RESEARCH ARTICLE

Continuing recovery of wolves in Europe

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Abstract

The recovery of wolves (*Canis lupus*) across Europe is a notable conservation success in a region with extensive human alteration of landscapes and high human population densities. We provide a comprehensive update on wolf populations in Europe, estimated at over 21,500 individuals by 2022, representing a 58% increase over the past decade. Despite the challenges of high human densities and significant land use for agriculture, industry, and urbanization, wolves have demonstrated remarkable adaptability and increasing

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population trends in most European countries. Improved monitoring techniques, although varying in quality and scope, have played a crucial role in tracking this recovery. Annually, wolves kill approximately 56,000 domestic animals in the EU, a risk unevenly distributed and differently handled across regions. Damage compensation costs 17 million EUR every year to European countries. Positive economic impacts from wolf presence, such as those related to reducing traffic accidents with wild ungulates or supporting wildlife tourism, remain under studied. Wolf recovery in Europe is supported by diverse policy and legal instruments such as LIFE programs, stakeholder platforms, as well as the EU Habitats Directive and the Bern Convention. Coexisting with newly established wolf populations in Europe entails managing impacts on human activities, including livestock depredation, competition for game, and fear of attacks on humans, amidst varying social and political views on wolf recovery. Sustainable coexistence continues to operate in evolving and complex social, economic, and political landscapes, often characterized by intense debates regarding wolf policies.

Author summary

We report that wolves are continuing to make a remarkable comeback across Europe, with their population growing to over 21,500 individuals by 2022–a 58% increase in a decade. This is a notable conservation success, particularly in a region heavily shaped by human activity, from agriculture to urbanization. Improved monitoring methods have helped us track their recovery, although these tools vary in quality and extent across countries. Annually, wolves kill around 56,000 domestic animals in the EU, leading to annual costs of about 17 million EUR for damage compensation. Yet, wolves may also bring potential benefits, such as reducing car accidents with wild ungulates and creating opportunities for ecotourism, though these positive impacts are often overlooked. Legal protections, including the EU Habitats Directive and the Bern Convention, along with conservation programs, such as the LIFE programs, have been key to supporting wolf recovery. However, the coexistence of wolves with human activities, notably farming and hunting, remains a challenge and requires navigating complex social, economic, and political contexts.

Introduction

While large carnivores and biodiversity are declining worldwide [1], an exception has been the recovery of large carnivores in Europe [2]. This positive trend is remarkable because Europe appears at first as an unlikely place for a large carnivore to recover. In Europe, wildlife has to share space with a human population of roughly 450 million people in a highly anthropized landscape where people grow crops, raise livestock, hunt wild game, and more broadly shape the landscape through urbanization, energy production, industries, and transport infrastructures [2–4]. Even more remarkable is that the predatory species recovering the most is the wolf (*Canis lupus*), which many people perceive as belonging to wilderness areas and which is often embroiled in conservation conflicts and political controversies [5].

An earlier continental overview revealed that permanent wolf ranges were characterized by a mean density of 36.7 human inhabitants/km² [2], which suggests a high degree of adaptation to human presence. This raised the question of whether Europe had found a recipe to

sustainably coexist with large predatory mammals [6], which could provide relevant insights for the conservation of many other species worldwide in the 21st century [7]. Here we provide an update of numbers, trends, monitoring methods, and conservation status of wolves across the European continent and discuss the ongoing conservation issues and challenges that will likely shape the future direction of wolf population development in Europe.

More than twenty thousand wolves in Europe

Our estimate based on monitoring reports and expert assessments in 34 countries (S1 Appendix) reveals that by 2022 at least 21,500 wolves inhabit Europe, 19,000 of which are found in the European Union (EU) [8], an increase of 58% from the 12,000 estimated 10 years ago [2]. In the EU, wolves share the landscape with millions of wild ungulates [4], 279 million head of livestock and 449 million people [9,10]. In most countries, wolf populations have continued to increase (Fig 1) and are now found in all but the smallest countries of mainland Europe (Fig 2). Several countries – Bulgaria, Greece, Germany, Italy, Poland, Spain, and Romania – now have more than 1,000 individuals each. For a variety of reasons including management goals (i.e., population caps) or the relatively recent recolonization of the species after a long absence, some countries have fewer than 100 individuals (Austria, Belgium, Denmark, Hungary, Luxembourg, Norway, and the Netherlands). The three microstates of Monaco, San Marino and The Vatican remain the only countries in mainland Europe not having experienced wolf recolonization.

Some countries that had very few wolves a decade ago now have large populations and continue to experience high growth rates. For example, wolves in Germany increased from 1 pack in 2000 to 184 packs and 47 pairs in 2022 [11]. Assessing wolf population dynamics in their respective countries, authors of the current paper reported that, during the last decade, wolf numbers increased in 19 countries (Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland,

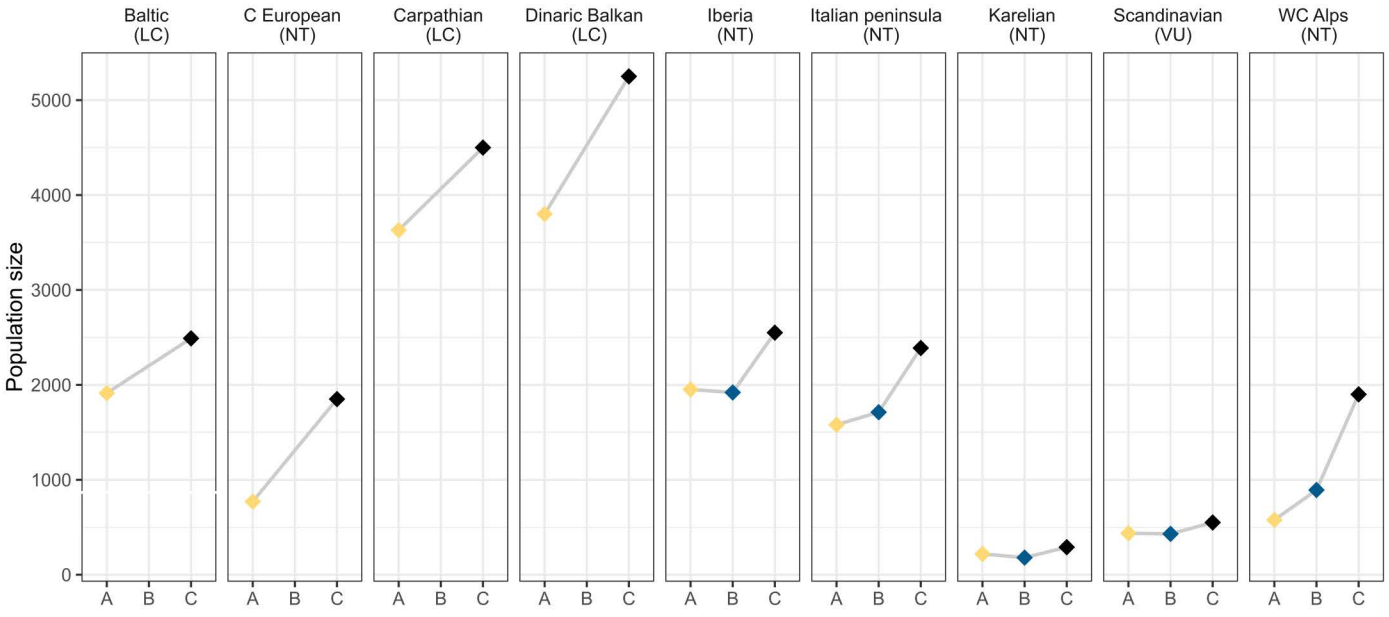

Fig 1. For the 9 European wolf populations defined by the Large Carnivore Initiative for Europe (LCIE), three population size estimates are shown, respectively for A) 2012–2016 from the LCIE [118] (in yellow), B) 2013–2018 from country reports in 2018 under Article 17 and Resolution No.8 [119] (in blue), and C) 2020–2022 from the LCIE [59] (in black). Red List categories from the assessment at the population level conducted by the LCIE are shown in brackets [59], where LC stands for Least Concern, NT for Near Threatened, VU for Vulnerable. A 10th population in Sierra Morena (Spain) is now extinct [17].

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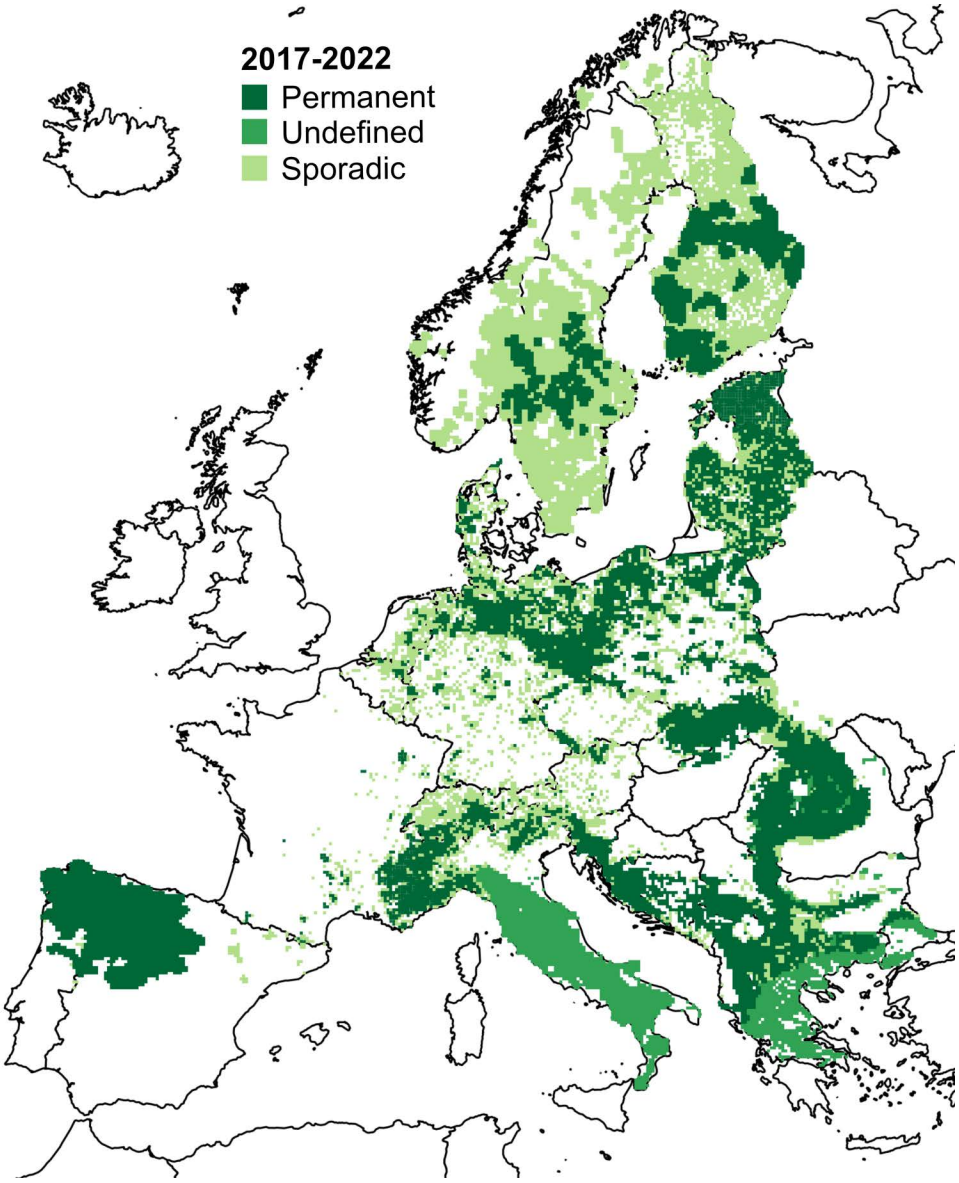

Fig 2. Wolf distribution in Europe reported for the period 2017–2022/23, as published by [120]. Permanent cells: established and reproducing populations, also including cells with continuous presence in the absence of documented reproduction. Sporadic cells: only occasional presence of dispersers or lone individuals. Undefined cells: confirmed presence but without distinction between permanent or sporadic presence, see [121] for details on, e.g., the use of an integrated spatial model for Italy [18]. Basemap is world map from QGIS (data source: Natural Earth 1:10 m detail level Cultural vectors https://www.naturalearthdata.com/downloads/10m-cultural-vectors/).

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France, Germany, Greece, Hungary, Italy, Lithuania, The Netherlands, Poland, Slovak Republic, Slovenia, Sweden, Switzerland and the European part of Türkiye), remained broadly stable in 8 countries (Albania, Croatia, Luxembourg, Norway, Portugal, Romania, Spain, Ukraine), fluctuated in three countries (Estonia, Latvia, Serbia) and decreased in three countries (Bosnia & Herzegovina, Montenegro, North Macedonia) while the situation in Kosovo is unknown.

When assessing trends at the population level (sensu [12]), we find that the largest populations (Dinaric Balkan, Carpathian) are increasing, with smaller populations (e.g., Central

European, Western Central Alps) displaying even larger growth rates [13,14]. Some populations (i.e., Scandinavian and Karelian) have experienced slower growth, and even stagnation, because of intensive management actions (lethal control and hunter harvest). Only the Nordic countries (Finland, Norway, and Sweden) and Austria appear to have limited their recovering wolf populations (Fig 1). A small, isolated population in southern Spain is the only European wolf population to become extinct in recent years [15–17]. Overall, wolves have shown an ability to recover in highly-altered, multi-use landscapes on a continental scale when they are permitted to do so, confirming the extraordinary adaptability of this species [6].

Wolf monitoring has improved, but is still far from perfect

The methods used to estimate wolf numbers across Europe are diverse (S2 Appendix) and vary in quality and scale but have generally improved over the years. In 21 countries, the most recent wolf abundance estimates were based on a complete survey (most of the known wolf distribution area was surveyed), while in 13 countries the estimate was based on partial surveys (i.e., only in parts of the known wolf range). Typically, smaller or recently recovered populations are monitored more thoroughly (e.g., in the Alpine countries, Belgium, Denmark, Germany, the Netherlands, Norway, Slovenia, Sweden), while some larger populations are less intensively monitored (e.g., Bulgaria, Romania). However, it is worth noting the recent nation-wide estimate in Italy based on state-of-the-art methods combining systematic field surveys and integrated population modeling [18] that demonstrated the application of robust statistical methods across large scales. Some countries have very detailed monitoring, where almost every individual wolf is known and the genetic pedigree of the population is available (Denmark [19], Finland [20], Germany [21], the Italian Alps [22] and Scandinavia [23–25]). Genetic monitoring methods are diverse and serve a variety of goals: assignment of individuals to source populations, population size estimation, determining genome-wide inbreeding and diversity or detecting hybridization with other canids [26–28].

Monitoring is performed by a diversity of actors in different countries, including government agencies, research institutes, hunters, conservation NGOs and the general public. Funds for wolf monitoring are allocated for multiple reasons: wolves are a conflict-prone and controversial species, sometimes intensively hunted, potentially vulnerable to the impacts of some infrastructure development, so management agencies, interest groups and the broader public want to know how many wolves there are and where. In addition, within the EU, the wolf is a protected species and Member States have obligations to survey and report its status every 6 years under Article 17 of the Habitats Directive. A challenge typical of recovering wolf populations will be to maintain monitoring at a level that allows the reliable detection of trends in abundance and distribution as populations increase, while dealing with limited budgets. Moreover, considering that some wolf populations are regularly hunted and that the species' protection may soon be downgraded in EU law [29], it will be difficult to detect possible local decreases in wolf population density without annual and state-of-the-art monitoring. Furthermore, to avoid double counting individuals in populations shared between countries [30], monitoring would need to be coordinated among countries, with good examples being Norway and Sweden [24,31], the Alpine countries [13] and some countries sharing the Central European population (e.g., Belgium, Denmark, Germany, Luxembourg, The Netherlands [11,32]).

Challenges for coexistence

Wolf recovery in human-dominated landscapes implies accepting and managing a certain level of impact that wolves might have on people's livelihoods and the potential for conflicts among people over their differing views on how to manage wolves [33]. In Europe, conflicts

about wolves generally relate to depredation on domestic animals, competition for wild game, fear of attacks on humans, as well other socio-political issues of which the wolf has become the symbol [34–36].

Our data reveal that ca. 19,000 wolves in the EU killed ca. 56,000 domestic animals per year [8] out of a total of 279 million head of livestock, corresponding to ca. 3 killed livestock per wolf per year. From a population perspective, an average head of livestock in the EU faces a 0.02 percent annual risk of being killed by wolves. However, there is large spatial variation in this risk which considers the total number of livestock and not only those in areas inhabited by wolves. Sheep and goats accounted for roughly two thirds of losses but, locally, depredation also affected cattle, horses, semi-domestic reindeer and dogs (Fig 3). A few countries, such as Croatia, France, Greece, Italy, Norway, and Spain, had significantly more absolute losses than others (Figs 3, 4), possibly linked to different husbandry practices and/or different compensation systems. Most damage is caused to free-ranging livestock [37]. In some contexts, high levels of depredation do not automatically lead to widespread social conflicts, for example regarding depredation on horses by wolves in northwestern Spain [38] or in Albania [39], because in some cultures a certain level of depredation can be accepted as being "normal". However, in other areas even low levels of depredation are the focus of intense social conflicts, for example with around 10 hunting dogs annually killed by wolves in Sweden [40–42]. The link between the number of wolves and the level of livestock depredation is not straightforward other than that, stating the obvious, there is no wolf depredation in the absence of wolves. No clear relationship was found when comparing either across countries [37,43] or longitudinally within a country, i.e., Germany [44]. A recent analysis of depredation in Europe found that damage typically increased as wolves recolonised new areas but subsequently decreased in association with the use of protection measures [45]. Regarding the connection between lethal control and levels of livestock depredation, different studies have produced contrasting findings (cf [46,47].) while research employing an experimental protocol is lacking, which precludes definitive answers.

Another challenge that wolves pose to human activities regards hunting of both wolves and other game species. This is also a complex issue due to multiple cultural, social, and political factors, rooted in concerns over competition for game, potential changes in behavior of game, interference with supplementary feeding of game during winter, concerns for hunters losing their status and role as regulators of wildlife populations [48–50], as well as the loss of hunting dogs [33,51]. The extent and character of wolf hunting differ widely among European countries, from full bans to regular license hunts or unregulated pest control (e.g., in North Macedonia), as a result of the local practices of wildlife management, the legal status of wolves and how it is translated into practical management, as well as the broader socio-political context.

Third, there is the fear of attacks by wolves on humans. Although wolf attacks are extremely rare in Europe [52] and reported cases were often found to be committed by human-habituated and food-conditioned individuals [53], many people fear the possibility of being attacked and their concerns are amplified by sensationalized and inaccurate media reports of wolf-human interactions [54–56]. For example, reported attacks on people in Italy [57] and Greece [58] were most likely by domestic dogs, not wolves. In some populations, hybridization with dogs is becoming a threat to wolf conservation with reported estimates possibly even including some hybrids [59–61]. Research has found limited evidence of jackal-wolf hybrids in Europe [62,63], but see [64] for putative gene flow between the species in the Caucasus. Wolf-jackal hybridization might become a future source of concern as wolf populations recover in human-dominated environments that jackals have already or will colonize as part of their ongoing, continental range expansion [65].

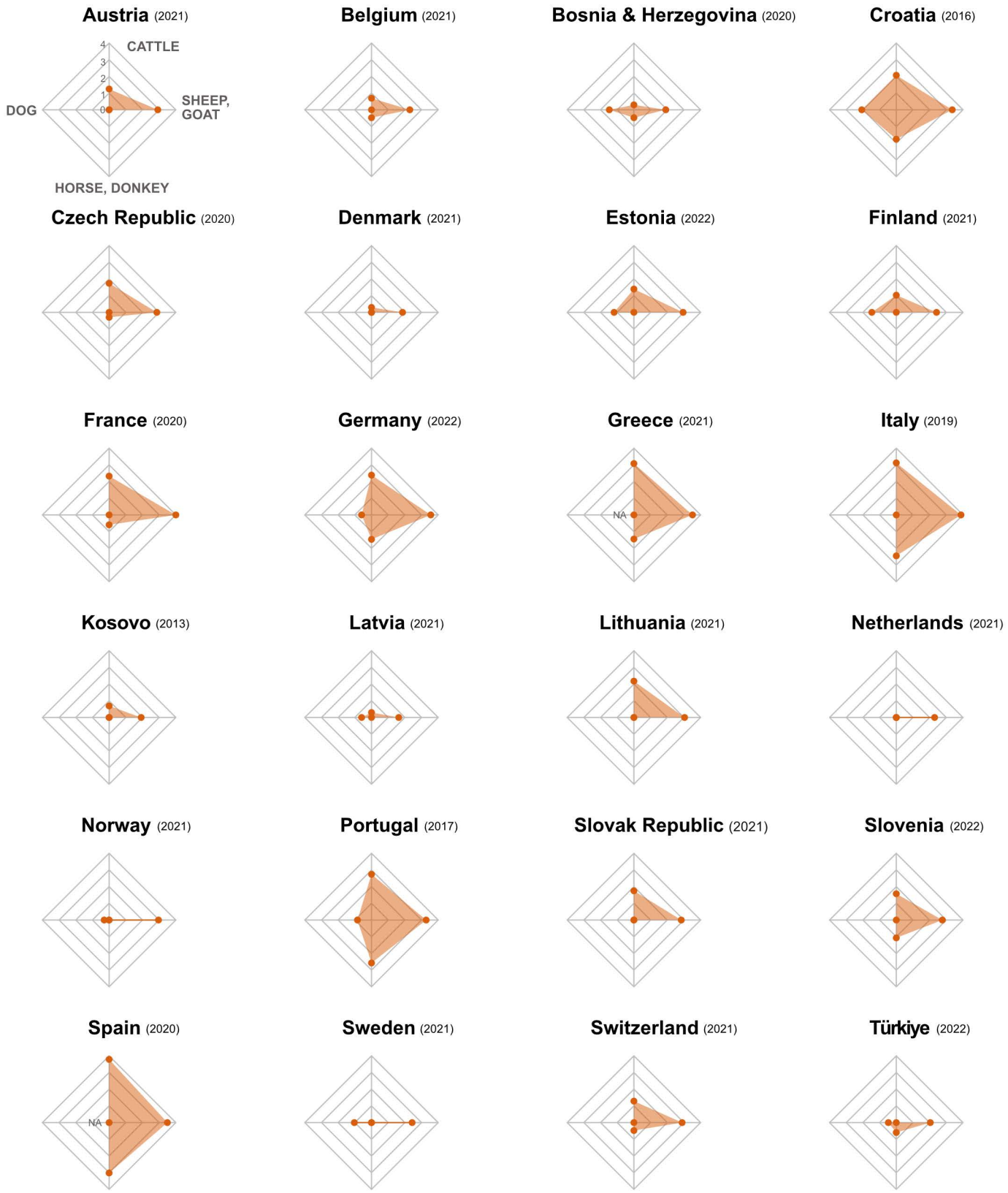

Fig 3. Depredation recorded in the most recent year (in brackets) for 24 countries, reported as the number of animals killed by wolves. The numbers in the graph are presented at the log10 scale, i.e., 1 stands for 10 animals, 2 for 100 animals, 3 for 1,000 animals, and 4 for 10,000 animals. Depredation on semi-domestic reindeer is not presented and is only reported by Norway (134 animals killed) and Finland (1,516 animals killed).

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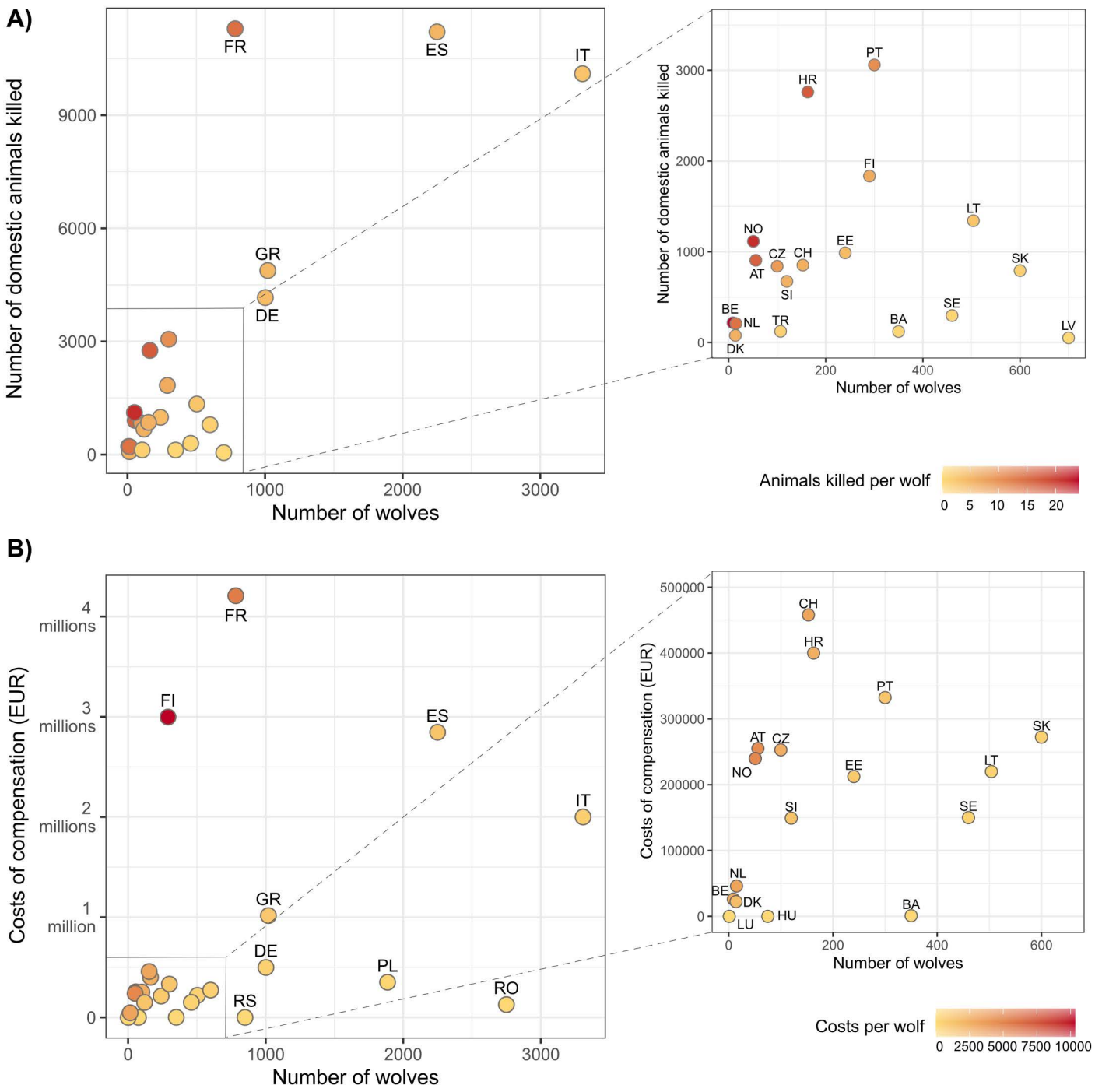

Fig 4. Number of A) domestic animals killed (depredation) and B) costs of compensation for livestock losses, according to the number of wolves from the latest annual update for each of the 23 countries reporting depredation data and 26 countries reporting compensation data (left: for the whole dataset, right: zoomed in) and wolf numbers. Each point is a country with country codes from ISO-3166 Alpha-2 classification (see S3 Appendix).

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Complex socio-political conflicts regarding wolves stem from disagreements between diverse interest groups, stakeholders or segments of the public, where controversy about wolf management becomes symbolic for deeper divisions around value systems, power, influence,

class, knowledge, education, human activity and the very nature of the human-nature relationship [33,66,67]. Wolves are also increasingly symbolic for a range of wider social and political issues especially framed as a rural-urban divide in Europe [68]. For example, the far-right parties Alternative für Deutschland (AfD) in Germany and Dansk Folkeparti (DP) in Denmark have actively opposed wolf recovery by framing it as a threat to rural inhabitants abandoned by their governments [68,69].

Finally, like many other species, wolf conservation can also be affected by unrelated but complex political issues, often through unrelated geo-political events. For example, while wolves in France kill several thousand sheep per year, the decline of sheep farming in the country has been influenced by France's cessation of protective measures against New Zealand lamb imports to the European Union, a consequence of political fallout from the 1985 bombing of Greenpeace's boat in Auckland by the French special forces to prevent anti-nuclear protests in the French Pacific [70]. When the wolf came back to France in 1992, it served as a political scapegoat to highlight the decline of sheep farming without addressing the root economic issues. A second example of wolf conservation being linked to unrelated political issues is the recent construction of thousands of kilometers of border fences due to the human migration crises and military conflicts in eastern and southern Europe, which may in the future affect the size, dynamics, and genetic diversity of the Baltic and Dinaric Balkan wolf populations [71,72].

The economics of wolf recovery

One proxy for the economic costs of coexisting with wolves is the amount of money spent annually by countries for compensation of damages, although this is a rough way of estimating the overall costs of such coexistence (e.g., damage prevention, monitoring, law enforcement, and conservation projects can add significant costs). In total, European countries spent 17 million EUR annually on compensation for damage attributed to wolves. France paid the largest amount of any country (4.2 million EUR/year), although Finland paid the most per wolf (10,300 EUR/year) (Fig 4). As with wolf density and damages, when comparing across countries there does not appear to be a clear relationship between the number of wolves and the resulting economic costs, with larger or denser wolf populations not necessarily implying higher economic costs (Fig 4). Although compensation costs may be tolerable at the national level, the concentration of damages at a local level may put high pressure on individual livestock owners, local communities, or local activities, especially when combined with other sources of financial hardship. This underlines the importance of reducing damages with a diverse set of instruments that need to be adapted to local needs [73]. In general, electric fences, shepherding and livestock guarding dogs are the most commonly implemented damage prevention measures. In three quarters of European countries, mitigation measures are financially supported to different degrees by government authorities, NGOs, or in the framework of time-limited conservation projects (e.g., LIFE projects).

On the other hand, positive socio-economic impacts of wolf recovery include, for example, the reduction of ungulate damages on forestry (e.g., in Poland [74,75]). Recent studies have argued that the return of the wolf may reduce traffic accidents involving collisions between ungulates and vehicles [76]. For example, one study [77] suggests that wolves consuming roe deer and wild boar prevented between 2.4 and 7.8 million EUR in road collision-related injuries and property damage annually in France. Other positive aspects include wildlife tourism and commercial activities that directly or indirectly benefit from large carnivore presence [78,79]. However, potential economic benefits from wolf presence have been poorly investigated and quantified in Europe.

European policy instruments and controversies

The recovery of wolves in Europe has been made possible by broader social, economic, and historical processes, such as reforestation, rural-urban migration, and sustainable ungulate management [80], combined with generally favorable public opinion [81]. This recovery would, however, not have happened without a substantial institutional and political investment of European countries. Specifically, wolves have benefited from various degrees of legal protection at national and European levels [82]. The wolf has been listed in Appendix II (strictly protected) of the Bern Convention in most European countries, with the exception of some countries, mainly in the east, having made reservations (in December 2024, the Standing Committee of the Bern Convention approved a proposal by the EU to move the species to Appendix III (protected) [83]). EU Member States are obliged by the Habitats Directive (HD) to ensure that the wolf reaches and remains at a so-called Favorable Conservation Status (FCS) [84,85]. They must transpose the HD into their national laws. In most EU countries, the wolf is listed in HD Annex II (obligation to designate protected areas for the species) and Annex IV (killing allowed only under limited exceptions, referred to as derogations) although the wolf is listed in Annex V (hunting allowed) in several countries (Bulgaria, Estonia, northern part of Finland, northern part of Greece, Latvia, Lithuania, Poland, Slovakia, and northern part of Spain). Following the change of Appendix in the Bern Convention, the European Commission has announced it will implement a similar change in the HD to have the wolf no longer listed in Annex IV but instead in Annex V [29].

To facilitate achieving FCS, the EU has developed a portfolio of policy instruments. It has awarded substantial funding to promote wolf-human coexistence, through the LIFE program [86], although the program's effectiveness remains difficult to measure [87]. Properly implemented prevention measures, especially electric fences, have however demonstrated their efficacy [73,88], although more evidence is needed [89,90]. There is a need to invest in such measures, with a constant evaluation of their performance, to reduce the impact of wolf depredations to economically acceptable and socially tolerable levels. In parallel, the European Commission has also launched a unique initiative in the form of platforms for coexistence where stakeholders meet, debate and share best practices [67]. Initially launched at the European level, the idea has now expanded to include regional platforms [91]. Furthermore, Member States are able to avail themselves of substantial financial resources available within agricultural and rural development funds to cover the costs of livestock protection and compensation activities [92].

Conflicts over wolf management have regularly sparked intense political debates, in many countries and at the European level, especially regarding the long-term goal of wolf recovery, whether more liberal use of lethal control or hunting should be permitted [93] and also about the downgrading of wolf legal protection, as often demanded by farmer or hunter representatives [94]. The European Parliament passed a resolution in 2022 calling for more flexible wolf management and greater consideration of agricultural and rural interests [95]. In September 2023, the European Commission announced its intention to reassess the protection status of the wolf in Europe [96,97]. In December 2023, it filed a proposal to amend the legal status of the wolf in the Bern Convention from strictly protected to protected [98], which was voted by a majority of Member States in September 2024 [99] and approved by the Standing Committee of the Bern Convention in December 2024 [83]. Non-EU countries, which are not bound by the Habitats Directive, have experienced similar debates [100], with Norway adopting extremely limited population goals [101] and Switzerland aiming at reducing its wolf numbers through preventive regulation [102].

Conflicts about wolves have been litigated and there have been numerous court cases regarding wolves in national jurisdictions [103]. The Court of Justice of the European Union has also issued several rulings on what the Habitats Directive mandates regarding wolf conservation [104–108] and further rulings about wolves are pending [109,110]. In addition, there is a 12-year-old ongoing infringement case by the European Commission against Sweden and its annual wolf hunt [111].

Conclusions

The recovery of the wolf in Europe demonstrates that a large predatory species can successfully share landscapes with high densities of humans. There are other examples of such coexistence, notably the case of leopards (*Panthera pardus*) occurring and breeding at the edges of large urban and in densely populated agricultural areas in India [112,113]. Wolves in Europe have come back across a wide diversity of land uses. Their recovery has certainly benefited from their opportunistic ecology (in contrast, the Eurasian lynx (*Lynx lynx*) and brown bear (*Ursus arctos*) have not experienced the same extent of recovery). Favorable social, legal and institutional contexts have also contributed to this recovery. Among the predators listed in the EU Habitats Directive, the wolf has possibly experienced the strongest population growth [2]. This shows that, with appropriate policy instruments, land-sharing models can work, even for apex predators, on continental scales [6,114,115]. However, as controversies escalate, the challenge will be to adapt conservation policies as they transition from saving endangered populations to sustaining success [116]. An emerging but no less critical aspect will be to avoid wolf, and nature conservation at large, becoming embroiled in "culture wars" and being perceived as wedge issues that sharpen the divide between progressive versus conservative ideologies [68,69,117].

Supporting information

S1 Appendix. Material and methods.
(DOCX)

S2 Appendix. Estimates of the percentage of wolf range/ population covered by each monitoring method for 34 European countries. Empty cells indicate that the method was not considered relevant.
(DOCX)

S3 Appendix. Country codes based on the ISO-3166 Alpha-2 classification.
(DOCX)

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