Evaluating Fact Claims Accompanying Policies to Liberalize the Killing of Wolves

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Abstract

Predators can support ecosystem health and diversity disproportionate to their numbers. Nevertheless, several U.S. state governments recently initiated killing grey wolves non-selectively and in large numbers. Among the justifications, governments claim that wolf-killing would: (1) increase human safety;(2) raise human tolerance for surviving wolves; (3) prevent livestock loss; and (4) increase wild ungulate populations. We reviewed the research into these assertions of fact and found scant evidence to support or refute fact claim (1). We found evidence against (2) from 6 regions (Wisconsin, Michigan, Minnesota, Arizona/New Mexico, North Carolina, U.S., and Finland) and weak support from 2 regions (Scandinavia and Montana, U.S.). For claims (3) and (4), we found evidence to suggest equivocal or no effects (either positive or negative) of wolf-killing. Several studies that present the best evidence in their subfields find that killing wolves likely led to counter-productive outcomes of intolerance in attitudes and wolf-poaching or higher livestock losses. We also summarized reported benefits associated with wolves, which might be lost if policies for widespread wolf-killing continue or spread. Here, we propose several hypotheses to explain the use of unsupported claims and the omission of

other fact claims such as benefits, which also help to explain expansion of wolf-killing recently. The 3 non-mutually exclusive hypotheses for unsupported claims refer to the reliability of trusted messengers, misinterpreting scientific uncertainty, and interest group politics. Finally, we summarize explanations for the partisan politics behind wolf-killing and the potential harms of unsupported fact claims to good governance and democratic policy formulation.

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INTRODUCTION

Worldwide consensus among ecologists provides strong evidence that predators can support ecosystem health and diversity out of proportion to their numerical abundances (Estes *et al.* 2011; Peterson *et al.* 2014; Ripple *et al.* 2014). For example, increasing evidence suggests that grey wolves (*Canis lupus*) play disproportionate roles in influencing deer (*Odocoileus* spp.) behavioral ecology, forest diversity and ecology, and perhaps even disease ecology and deer-vehicle collisions (Hebblewhite *et al.* 2005; Wild *et al.* 2011; Callan *et al.* 2013; Waller and Reo 2018; Tanner *et al.* 2019; Raynor *et al.* 2021), withstanding an ongoing debate over the strength of wolves' effects in Yellowstone National Park. Perhaps related, the U.S. public has become more positive about wolves over the past half century (George *et al.* 2016; Slagle *et al.* 2017). Nevertheless, in 2021 some U.S. state governments began pursuing rapid efforts to reduce wolf populations through programs that included incentivized hunting (e.g., bounties) and liberalized (even unlimited) hunting, trapping, and

hounding seasons. These policies differ from previous policies that balanced different interests in living and dead wolves, and which allowed wolves to maintain and sometimes increase their populations (Brown 2008; Bruskotter *et al.* 2010; 2011, 2013). For example, Wisconsin reduced its wolf population by >27% in <1 year and then proposed a second wolf-hunt in the same year (Treves *et al.* 2021a; Treves and Louchouarn 2022); Idaho, Montana, and Wyoming politicians articulated a goal to reduce their wolf populations even more; for Idaho by 90% (Oppie 2021) and enacted policies to help to reach that goal in 2021 and 2022 (Brown and Samuels 2021).

Here we address 4 fact claims (assertions of fact) commonly provided in policies for permitting or encouraging an increase in the legal killing of wolves and other large carnivores: (1) increasing human safety, (2) raising human tolerance for surviving wolves, (3) preventing livestock loss, and (4) increasing wild ungulate populations. We evaluate the fact claims (hereafter 'claims') by summarizing published scientific meta-analyses and systematic reviews in addition to reviewing >36 newer scientific studies on the social and ecological effects of killing wolves.

Claim 1: Killing wolves will increase human safety

Wolves can, and in rare circumstances have, attacked people (Linnell and Bjerke 2002; McNay 2002; Linnell *et al.* 2021). Thus, one justification governments provide for killing wolves has been to increase human safety. In Appendix 1, we present reports and statements by officials from the States of Michigan, Idaho, and Montana that show how claims about human safety have been used to raise fears or justify government funding and promotion of wolf-killing programs (including both the legalization and the liberalization of existing legal mechanisms, hereafter simply wolf-killing). Despite such warnings, no humans have been killed by wolves in the

Northern Rockies since their reintroduction and no humans have been killed in the western Great Lakes region since written records have been kept. Wolves pose so little risk to people that aggressive killing programs proposed by U.S. states are almost certainly unable to reduce risk further as the following reviews showed.

Linnell *et al.* (2002, 2021) compiled documented reports of wolf attacks on humans. The more recent study found evidence of 489 human victims of wolf attacks spanning 2002 to 2020 around the world, 26 of which were fatal, plus an equal number that were either too poorly documented to verify or almost certainly not caused by wolves. Rabies explained 77% of the above attacks and 59% of fatalities, and the geographic distribution of attacks correlated with rabies incidence across Eurasia. These researchers classified 14% of attacks as "predatory", which accounted for 36% of the fatalities. The remaining attacks were classified as "provoked/defensive". In Europe and North America, they "found evidence for 12 attacks (with 14 victims), of which 2 (both in North America) were fatal across a period of 18 years" (*Linnell et al.* 2021, p.3); however, there remains disagreement about the involvement of wolves in the Saskatchewan case, with investigating experts disagreeing with the provincial inquest, and a third opinion offered by independent investigators (P. Paquet report missing). Linnell *et al.* (2021) conclude "Considering that there are close to 60,000 wolves in North America and 15,000 in Europe, all sharing space with hundreds of millions of people it is apparent that the risks associated with a wolf attack are above zero, but far too low to calculate." (Linnell *et al.* 2021). Occasionally, wolf attacks may be precipitated by incidents of accidental or purposeful conditioning of wild wolves, whereby wolves learn to associate humans with food or lose fear of people via habituation (McNay 2002). However, there is no evidence that such behavior is now as widespread as it may have been before the 20th century when wild prey were more scarce

(Linnell and Bjerke 2002). Indeed, Linnell and Alleau 2016, p.364) wrote that recent and historical predatory attacks on people in Europe "…are all associated with a very specific set of circumstances… [including]… landscapes with very fragmented habitat, low densities of wild prey, wolf dependence on livestock and anthropogenic foods, and high human densities living poor rural lifestyles." Given the recolonization and repopulation of many wild prey populations eaten by grey wolves, the conditions for wolf attacks on people, such as hungry wolves or wolves habituated to feeding on carcasses of livestock or humans, have probably diminished. Therefore, they concluded, "Despite the need to recognize that the potential for wolf attacks on people is greater than zero and management plans and procedures should take these into account, it is still so small that it is impossible to calculate in a meaningful manner" (Linnell and Alleau 2016, p.365).

Finally, a rabid or threatening individual wolf might be seen as a hazard necessitating a law enforcement response. However, that situation bears no logical relationship to a policy that implements widespread wolf-killing to address perceived threats to human safety. The 2 North American fatalities cited above are alleged to have occurred in Alaska, U.S. and Saskatchewan, Canada, rather than the jurisdictions whose governments we referenced above that have recently enacted policies of widespread wolf-killing. Even if one adds human injury cases to the tally, the odds that non-selective, public hunting, trapping, or hounding methods to kill wolves over wide areas will remove the rare wolf that attacks a human seem too low to calculate. Because our purpose is to evaluate the governmental claims relating to human safety (Appendix 1) -- rather than the reality of fear of wolves or the possible rhetorical gains a politician might perceive from claiming to protect human safety -- we must conclude that this claim is unsupported by evidence.

Claim 2: Killing wolves will increase human tolerance for wolves

Governments often claim that killing wolves increases public tolerance (or decreases intolerance) for wolves and their conservation (Refsnider 2009; Bruskotter *et al.* 2013; Chapron and Treves 2017b; Epstein *et al.* 2019). For example, the U.S. Fish & Wildlife Service in federal court in 2005 tried unsuccessfully to convince a federal court that allowing some legal killing of wolves would benefit their recovery and slow illegal killing. Yet, scientific evidence indicates that policies that liberalize the killing of wolves generally have not improved public tolerance for wolves (Treves and Bruskotter 2014). At most, following legalization or liberalization of wolf-killing, some scientists documented a decrease in self-reported tolerance in small demographic groups, such as male residents of grey wolf range in Wisconsin who are familiar with hunting (Hogberg et al. 2015), or respondents' own forecasts of increased tolerance among livestock owners (Hogberg *et al.* 2015; Richardson 2022). The claims surrounding self-reported improvements in tolerance have rarely been tested objectively.

The best evidence for change in individual attitudes as a result of policy changes for wolf-killing comes from the U.S., where researchers assessed human attitudes using long-term, repeated measures (same individuals) before and after policy changes that legalized or liberalized wolf-killing or conversely, tightened protections for grey wolves. In total, 3 independent studies, from Wisconsin and Montana (Appendix 2), have addressed the issue. In the Wisconsin cases, tolerance for grey wolves declined after wolf-killing began or accelerated (Treves *et al.* 2013; Browne-Nuñez *et al.* 2015; Hogberg *et al.* 2015). In Montana, tolerance did not change pre/post the implementation of a public wolf-hunt but increased slightly from baseline several years later (Appendix 2). Although before-and-after comparisons lack the strength of inference of randomized, controlled trials, the Wisconsin research teams conducted both focus groups

(Browne-Nuñez *et al.* 2015) and mail-back questionnaires of the same individuals resampled periodically (Hogberg *et al.* 2015), both methods after policies for wolf-killing had changed.

Policies may fail to affect tolerance if they are perceived by the intended targets as insufficient to reduce risks or costs of the hazards, or there may be a lag between the time the policy is enacted and subsequent changes in tolerance. The Wisconsin studies show a 12-yr lag during which time tolerance for grey wolves declined among Euroamericans in the face of such policies. These factors could explain both the growing intolerance witnessed in Wisconsin and the lack of change witnessed in the 2012 and 2018 studies in Montana. Finally, the definition of 'public' in the hypothesis that wolf-killing improves public tolerance has not been systematically scrutinized. Again, studies in Wisconsin suggest different 'publics', or audiences, will have different tolerances for grey wolves (Naughton-Treves *et al.* 2003; Treves *et al.* 2009; Shelley *et al.* 2011). Indeed, studies that examined the nuances of attitudes among the intolerant reported small minorities (<25%) held extreme vies (Treves and Martin 2011; Montag *et al.* 2003), whereas the majorities in both Wisconsin and Montana heled intermediate attitudes to grey wolves. Given recent findings that majorities in every state disfavor killing grey wolves after livestock fell prey (Manfredo *et al.* 2020), liberalizing wolf-killing is likely to backfire with these groups that are numerous (e.g., urbanites or mutualists) or legally influential (e.g., Ojibwe). The minority who might be targeted by government seeking to improve tolerance for grey wolves, e.g., non-tribal male residents of grey wolf range with familiarity of hunting (Hogberg *et al.* 2015) or elk-hunting permit holders in Montana, have so far not shown the desired changes (Appendix 2).

A second way to examine the effect of policy on tolerance is to examine tolerance within a society across regions with different policies. To that end, Kaczensky *et al.* (2004) compared

attitudes toward brown bears (*Ursus arctos*) in a region of Slovenia where bears are protected and exhibit high conflicts with livestock to a region where bears are harvested as a game species and exhibit minimal conflict with livestock. They found no difference in attitudes toward bears across regions. Similarly, Bruskotter *et al.* (2018) found no differences in attitudes towards grey wolves across 3 regions of the U.S. with different wolf management policies and histories (Bruskotter *et al.* 2018). However, a follow-up study found lower levels of tolerance in areas with wolves among certain sub-groups (i.e., hunters, ranchers; Carlson et al. 2020). Research suggests that tolerance for wolves is strongly affected by social group and cultural group identity (Naughton-Treves *et al.* 2003; Shelley *et al.* 2011; Lute and Gore 2014), both of which are influenced by powerful social norms that change more slowly than policies (Marchini and Macdonald 2012; Kinzig *et al.* 2013). Researchers have proposed a variety of mechanisms that may cause attitudes to change both at the individual and societal level, e.g., (Ericsson, Bostedt, and Kindberg 2007; Karlsson and Sjöström 2007; Heberlein and Ericsson 2008; Bruskotter *et al.* 2017). A full review of these mechanisms is beyond our scope. However, a few findings are worth summarizing: (*i*) at the societal level, the U.S. public at large has become substantially more positive towards wolves over the past half-century (George *et al.* 2016; Slagle *et al.* 2017); and(*ii*) improving tolerance is strongly associated with changing social conditions, e.g., increased urbanization, education, income (Teel and Manfredo 2010; Bruskotter *et al.* 2017; Manfredo *et al.* 2019, 2020, 2021). While these findings raise intriguing hypotheses, experimental studies would be useful to better understand causal mechanisms, e.g., (Slagle *et al.* 2013). Collectively, however, existing evidence indicates that tolerance for grey wolves across society in general is largely unaffected by management policies.

Tolerance measured through poaching behavior

Other studies have assessed the effects of wolf-killing policies on tolerance more directly by examining hazard and incidence rates of poaching (illegal killing of grey or red wolves). In 3 populations of wolves, growth rates decreased, independent of the number of wolves killed legally, following liberalization of wolf-killing (Chapron and Treves 2016), withstanding challenges that presented no new data (Pepin *et al.* 2017; Stien 2017) or made errors (Olson *et al.* 2017). Indeed, the latter in particular was rebutted (Chapron and Treves 2017a,b), leaving the case stronger. Indeed, the latter authors' hypothesis that poaching would increase after wolf-killing was legalized or liberalized was corroborated by four independent studies using analyses for Mexican grey wolves (Louchouarn *et al.* 2021), Michigan grey wolves (Louchouarn 2023), Wisconsin grey wolves (Santiago-Ávila *et al.* 2020; Santiago-Ávila and Treves 2022), and North Carolina red wolves (Santiago-Ávila *et al.* 2022). Independently, Oliynyk (2023) showed that human-caused mortality in Minnesota's grey wolves rose long-term and apparently permanently after the state held its first public wolf-hunt. Therefore, an overwhelming body of evidence contradicts the suggestion that liberalizing wolf-killing would lessen poaching or intolerance.

Slower population growth was inferred to reflect a hidden cause of mortality, called "cryptic poaching" (Liberg *et al.* 2012). Failure to account for cryptic poaching – for example, discarding information on missing radio-collared wolves – can obscure the dynamics of poaching and bias population models (Treves *et al.* 2017; Santiago-Ávila *et al.* 2020; Agan *et al.* 2021; Santiago-Ávila and Treves 2022); contra (Hill *et al.* 2022). For example, research on radio-collared, grey wolves in Wisconsin, Mexican grey wolves in Arizona and New Mexico, and red wolves (*C. rufus*) in North Carolina, all revealed patterns of human poaching behaviour in relation to policy (Santiago-Ávila *et al.* 2020; Louchouarn *et al.* 2021; Santiago-Ávila *et al.* 2022; Santiago-Ávila and Treves 2022). Moreover, the latest studies follow new Open Science rules for registered

reports that reduce publication biases (Sanders *et al.* 2017), following current standards of evidence accepted by the global scientific community.

In summary, research to date has found that the ratio of reported poaching to cryptic poaching, and the sum of all poaching, varies with 1) policy on hunting bears, deer, and coyotes (*Canis latrans*); 2) U.S. federal policy on grey wolf protection; and 3) the methods used to census grey wolves. The relative increase in poaching rates and the ratio of reported ot cryptic poaching appear to vary by wolf population in ways not yet explained by theory. More policy and management variables are likely to surface when more teams investigate anthropogenic influences on the rates of both disappearance of marked carnivores and reported poaching. In short, liberalizing wolf-killing did not raise tolerance when tolerance was measured behaviorally, via poaching rates. Therefore, intention to poach is a behavioural measure of tolerance corroborating the attitudinal measures of tolerance in the previous paragraphs at least for U.S. populations.

Two studies from Nordic countries provided potentially credible research to suggest that grey wolf policy can reduce poaching albeit with unresolved shortcomings. In the first from Scandinavia, the investigators believe legalizing wolf-hunting reduced losses of breeding wolves (Liberg *et al.* 2020). However, that conclusion was questioned on statistical grounds for inappropriate survival analyses, and an unusual and possibly incorrect population-level model (Treves *et al.* 2020). Namely, the models ignored an apparent positive correlation between liberalizing killing and rising rates of illegal killing and disappearance, in favor of a claim about a negative correlation that did not seem to account for collinearity or autocorrelation (Treves *et al.* 2020). Also, Liberg *et al.* (2020) neither accounted for deaths of non-breeding wolves nor addressed the findings from the second Nordic study. In Finland, the number of wolves

poached diminished following seasons of higher legal wolf-killing (Suutarinen and Kojola 2017, 2018). Those authors hypothesized that the more legal killing occurred, the lower the risk of poaching because wolves were removed legally before they could be removed illegally (Suutarinen and Kojola 2017, 2018). Moreover, as Santiago-Ávila et al. (2020) and Louchouarn et al. (2021) pointed out, when the government pre-emptively removes grey wolves suspected of problems before they can be killed illegally, it is difficult to claim humans are exhibiting greater tolerance (Santiago-Ávila *et al.* 2020; Louchouarn *et al.* 2021).

Collectively, virtually all studies of grey wolf-poaching support the hypothesis that governments send a signal to would-be poachers that wolves are low in value, or that the government needs the support of poachers to control wolf populations (Chapron and Treves 2016). Most such policy signals seem to be unintentional but of late state governments have sent explicit signals to would-be poachers. For example, Idaho recently contributed funds to pay bounties for dead wolves (Bruhl 2021), which could inspire poachers in other states to draw on Idaho bounties. Also, in years past, the same agency defied federal regulations protecting wolves by announcing that they would no longer allow their own personnel to investigate reports of grey wolf poaching (Kramer 2010). Such signals encourage law-breaking and disrespect for democratic governance. Thus, we predict the recent state wolf policies have led and will continue to lower tolerance for wolves and increase wolf killing. We find no support for claim 2 and substantial evidence of a counter-productive effect on tolerance.

Claim 3: Killing wolves will prevent domestic animal losses

One of the long-standing reasons for humans to kill grey wolves and other threatening animals is to protect domestic animals (Treves and Bonacic 2016). For example, the U.S. Department of Agriculture's Wildlife Services division was created largely to kill offending animals

(Robinson 2005; USDA APHIS 2015), and local jurisdictions also do so in the U.S. and beyond (Bjorge and Gunson 1983; Fritts *et al.* 1992; Musiani *et al.* 2005; Epstein and Chapron 2018; Darpö 2020). Killing grey wolves or other predators perceived as a threat to domestic animals should be considered against the backdrop of the major causes of livestock death worldwide, i.e., weather, disease, accidents and in some cases, thefts. Hundreds of studies have shown that these factors in combinations that vary by site swamp losses to predators (Murray Berger 2006; Sillero-Zubiri *et al.* 2007).

In the case of determining whether the lethal removal of grey wolves increases livestock protection, the best evidence would come from before-and-after comparisons of interventions with random sampling (Khorozyan 2022) and other safeguards against research bias, such as crossover designs and open science protections against research bias and publication bias (Treves *et al.* 2016, 2019). No such studies exist for wolf-killing. To date, research on protecting livestock from wolves' ranges from before-and-after comparisons without randomization to lower standard, correlational analyses that leave numerous potentially confounding variables uncontrolled (Treves *et al.* 2016, 2019; Eklund *et al.* 2017; van Eeden *et al.* 2018b).

Studies with the highest (silver) standard for before-and-after comparisons of wolf-killing without randomization drew somewhat variable conclusions. From Slovenia, (Krofel *et al.* 2011) found no significant, annual reduction in livestock losses after years with high wolf-killing [also see reanalysis in (Treves *et al.* 2016, 2019). Studying 9 French sites with grey wolves, Grente (2021) reported that 5 showed no effect of killing grey wolves, 3 showed the desired decline in livestock losses, and 1 showed counter-productive increases in livestock losses (Table 1). The 2 U.S. studies disagree on the effects of wolf-killing on future livestock

losses (Bradley *et al.* 2015; Santiago-Avila *ert al.* 2018). Although many Northern Rockies wildlife agencies rely on the former study, it remains irreproducible for 3 reasons (Santiago-Avila *et al.* 2018a,b). Namely, the latter authors corresponded and conversed directly with the lead author and analyst of (Bradley *et al.* 2015), in an effort to repeat the methods. Bradley and Robinson were unable to recall a key step in the recurrence analysis. Second, the methods incorporated an inherent bias favouring the effectiveness of the lethal treatment by counting delayed grey wolf immigration into vacant territories as if these were delays to kill livestock (conservative decisions in intervention studies would favour the control condition or null hypothesis not the treatment); and finally the study by Bradley et al. (2015) remains irreproducible because the data were not shared originally nor upon request. Failures by state governments to share data transparently undermine claims about science-based management. By contrast, (Santiago-Avila *et al.* 2018a,b) made the recurrence methods reproducible, adapted the methods to the data for Michigan's grey wolf control program, and shared all data. That study found no net benefits for livestock or their owners from killing grey wolves (Table 1). They also reported a non-significant tripling of risk for cattle in neighboring townships after 1 or more wolves were killed at farms within 19.2 km of the farm that had received lethal management of wolves. Therefore, 3 of 4 studies suggest wolf-killing, as practiced in the U.S., France, and Slovenia, did not prevent future livestock losses reliably and can perversely raise such losses (Table 1). In every review thus far published on the effectiveness of lethal methods as a way to protect livestock from predators in general, authors from nearly 30 countries report occasional counter-productive effects resulting in higher livestock losses after predator-killing (Miller *et al.* 2016; Eklund *et al.* 2017; Lennox *et al.* 2018; Moreira-Arce *et al.* 2018; van Eeden *et al.* 2018a, 2018b; Khorozyan and Waltert 2019, 2020; Treves *et al.* 2019). Therefore,

the risk of raising livestock losses should be attached to government claims if they continue to be made – for reasons of transparency, scientific integrity, and public trust.

In contrast, the effectiveness of non-lethal methods and the standards of evidence used for their study have been higher than for lethal methods in situations involving grey wolves (Appendix 3). Although eradication of all wild predators might protect livestock from predation (Breitenmoser 1998; Riley *et al.* 2004; Nilsen *et al.* 2007), less drastic killing can produce variable and unpredictable results for grey wolves and other large carnivores (Elbroch and Treves 2023).

Killing one carnivore may leave survivors more prone to kill livestock thereafter. Survivors may be younger, less experienced or find themselves competing for food with immigrants for long periods—any of these situations may lead a hungry wolf to find the most predictable and vulnerable prey, often livestock; see review by (Elbroch and Treves 2023). Removing apex carnivores may also result in higher abundances of subordinate carnivores of the same species or other species (Newby and Brown 1958; Crooks and Soulé 1999; Elbroch and Treves 2023). Therefore, killing large predators like grey wolves may have varied effects on other animals including domestic ones (Krofel *et al.* 2007; Prugh *et al.* 2009; Allen *et al.* 2016; Minnie, Gaylard, and Kerley 2016; Newsome *et al.* 2017; Nattrass *et al.* 2019; Elbroch *et al.* 2020). For example, the eradication of the Tasmanian thylacine (*Thylacinus cynocephalus*) seems to have left niche vacancies for the smaller dingoes (*Canis familiaris dingo*) and red foxes (*Vulpes vulpes*) to become the dominant livestock predators of Australia and Tasmania (Greentree *et al.* 2000; Allen and Sparkes 2001; Sillero-Zubiri *et al.* 2007; Newsome *et al.* 2017). Or consider the expansion of range by coyotes (*C. latrans*) in the wake of extermination of red and grey wolves across many U.S. states and Canadian provinces (Gompper 2002; Hinton *et al.* 2016), and an associated increase in complaints of losses from sheep owners (Murray Berger 2006).

Furthermore, elimination of one or a few grey wolves can cause currently unpredictable behavioural consequences for survivors of the same species and members of other species including wild and domestic prey reviewed in (Elbroch and Treves 2023).

Claim 4: Killing wolves will improve wild ungulate abundances

Governments have for a century or more justified killing grey wolves to increase hunting opportunity for ungulates, such as elk (*Cervus canadensis*) and deer (Leopold 1933 reprinted 1986; 1949; Harbo and Dean 1983; Theberge and Gauthier 1985). Grey wolves are capable of reducing wild ungulate populations (Ripple and Beschta 2012); however the effect of grey wolves on ungulate abundances depends on other factors, such as ungulate vulnerability driven by winter severity (Vucetich and Peterson 2009; Peterson *et al.* 2014), local primary productivity (Melis *et al.* 2009), the abundance of ungulates relative to their carrying capacity (Ballard *et al.* 2001) , the diversity of the local carnivore guild and potential for multiple ungulate predators (Griffin *et al.* 2011), and the abundance of alternative prey (i.e. apparent competition (Wittmer *et al.* 2005). A recent meta-analysis of the outcomes of carnivore removal on geographically diverse ungulate populations estimated that predator removals resulted in increased juvenile survival and recruitment on average, but equivocal effects on average adult ungulate abundance, which should be the metric that determines if efforts to increase huntable population size or hunting opportunity succeeded (Clark and Hebblewhite 2021). Also, it was not uncommon for counter-productive effects lowering ungulate abundance after predator-killing (Clark and Hebblewhite 2021). A meta-analysis of female elk survival from western North America (Brodie *et al.* 2013) concluded that the best way to increase ungulate abundance was instead to decrease human harvest rather than predators. Indeed, the theory of density-

dependent growth of ungulate populations provides an explanation why killing a few predators could diminish ungulate numbers, “Female deer productivity is related to habitat quality. Habitat quality tends to decrease over time with increased deer density. As a result, it is entirely possible that a denser deer population will actually produce less young per year, and hence have a lower potential yield.” (Martin 2023). Indeed, the Isle Royale long-term study of moose and wolf dynamics seems to prove that habitat quality and climate are far better predictors of abundance than wolf numbers while we still lack strong theory to predict the short-term effects of any of those variables (Vucetich and Peterson 2009).

The exceptions to these general patterns are predator effects on small ungulate populations. Predation can harm rare ungulate populations via apparent competition. However, the underlying circumstances that lead to apparent competition are generally created by anthropogenic influences on ecosystems (Wittmer *et al.* 2005). Even in cases of rare ungulates, however, intensive grey wolf killing must be maintained to increase ungulate population growth rates. For example, Hervieux *et al. (*2014) in a controversial analysis claimed that killing 841 grey wolves over 7 years, (approximately a 45% reduction in mid-winter wolf abundance), was sufficient to increase population growth rates of endangered woodland caribou in their study area, but insufficient to increase caribou abundance. Critics of that study have questioned many aspects of that claim, particularly the mistargeting the major sources of caribou mortality or misidentifying the true causes of population decline (Proulx 2017a; 2017b).

Reports from all U.S. states with grey wolf populations indicate that opportunities to hunt wild ungulates have not been diminished statewide by increased wolf populations. Indeed, recent records from Idaho, Montana, and Wyoming indicate that the number of elk killed

by hunters in recent years is stable to increasing in those 3 states, as are elk populations. Data from Idaho, Montana and Wyoming were summarized here: (Center for Human-Carnivore Coexistence 2020). In Wisconsin, the 35-year period from 1975-2010 saw the state deer population grow from 600,000 to >1 million (Waller and Reo 2018), while the wolf population grew from 0 to 700 approximately (Wiedenhoeft *et al.* 2020). Also, hunters took 200,000 deer in the 1980s as compared to 500-600,000 in the 2000s (Waller and Reo 2018). Collectively, these data and the scientific studies suggest that the positive effects of killing wolves on wild ungulate abundance are slighte, may be negative in reality, and remain unpredictable.

A mismatch between goals of wolf-killing and approaches taken

Three of the 4 fact claims we have reviewed seem most commonly to be motivated by negative interactions with individual wolves or wolf packs, rather than populations of wolves. The exception may be the fourth relating to wild ungulates. Therefore, one should address policy interventions for 3 of the 4 claims in the most efficient and effective way to mitigate the costs and risks posed by individual wolves. This logic suggests that policies for targeted removal should be improved and tailored to specific individual grey wolves and local situations, rather than wolf-killing aimed at reducing the entire wolf population across wide areas. A return to policies and studies of targeted removal of confirmed culprits with a record of posing threats to humans and domestic animals seems reasonable. This strategy has long been understood as the most effective strategy for coyotes (Knowlton *et al.* 1999), and there is no scientific reason yet to a different outcome for grey wolves.

Our inference is especially important in instances when killing succeeds in reducing the wolf population but misses the individual wolves responsible for livestock loss or human safety

concerns; in such situations, the conflicts driving claims 1-3 are likely to continue unabated and calls for more killing may persist or escalate. Regarding claim 4, reducing wolves to increase ungulate abundance rarely works for any but the smallest ungulate populations for the reasons we describe in the previous section, Furthermore, any benefit of wolf-killing (to ungulate hunters) should be weighed against the benefits of maintaining or increasing grey wolf abundance.

Killing wolves reduces benefits of coexistence between humans and wolves

Ideal public policy maximizes the benefits (minus associated costs of) management interventions. Thus, having considered the various risks (i.e., to human safety, livestock, and wild ungulates), we find it appropriate to detail potential benefits to humans associated with coexisting with, rather than killing, wolves. In general, research shows that most audiences appreciate wolves and other carnivores, e.g., cougars (*Puma concolor*) and coyotes (Bruskotter *et al.* 2018; Manfredo *et al.* 2020), and that people report both financial and non-financial benefits of wildlife (Kellert 1985; Williams *et al.* 2002; Naughton-Treves *et al.* 2003). One subpopulation of wolves in Yellowstone National Park, for example, has produced net financial benefits beyond the boundaries of the park and revenues that far exceeded the costs of reintroduction (Duffield and Neher 1996; Duffield, Neher, and Patterson 2008). Findings from Wisconsin suggest that counties hosting 1 or more packs of wolves report fewer deer-vehicle collisions and reduced human injuries and fatalities, saving millions of dollars (Raynor *et al.* 2021). The studies of benefits of wolves have often grown out of an awareness that wolves were changing the behaviour of deer and elk and some evidence of broader ecosystem effects of wolves.

Many studies suggest grey wolves can benefit ecosystems through their effects on their prey and their ecological communities. For example, wolves may reduce the incidence or transmission of zoonotic and wildlife diseases (Wild *et al.* 2011; Tanner *et al.* 2019), increase scavenger diversity, reviewed in (Smith *et al.* 2003), and reduce deer damage to vegetation, reviewed in (Martin *et al.* 2020). Regarding the latter, rare understory plants fared better near the center of grey wolf pack territories in Wisconsin (Callan *et al.* 2013). Also, forests were more biodiverse, more mature, had higher tree volumes and regeneration rates, and resisted non-native plant invasions in the presence of wolves (Waller and Reo 2018). Though such effects may vary with conditions, research suggests wolves enhance biodiversity via direct and indirect pathways that begin with limiting ungulate herbivory, or by altering the competition between prey species. A persistent debate about Yellowstone's wolves notwithstanding, scientific consensus holds that top predators generally play such roles in ecosystem diversity, resilience, and health (Estes *et al.* 2011; LaBarge *et al.* 2022).

Killing grey wolves is not cost-free, and so we need to weigh the use of public funds for killing against the benefits minus the costs of maintaining wolves or expanding their ranges. It is not at all clear that aggressive killing of grey wolves will significantly reduce the real or perceived risks associated with living with wolves. Conversely, it is likely that the large-scale killing of grey wolves as proposed by some governments will substantially diminish the benefits associated with their presence. We highlight the need for formal comparisons between the benefits associated with apex carnivores and the economic costs long attributed to wolves (Gilbert *et al.* 2021), to set policies that optimize wolves' beneficial contributions to ecosystems and human communities.

Why do governments cite weak or unsupported claims for killing grey wolves and omit the benefits of wolves?

The scarcity of scientific evidence for the claims made to justify killing grey wolves leads to an obvious question: why are governments making such claims? Conversely, why don't more governments cite the human benefits and ecosystem advantages of grey wolf recolonization? To begin with, 3 non-exclusive explanations seem plausible.

1. Policy makers may believe their wolf-killing claims are true because of the source of their information or their existing belief system. The trusted messenger theory of communication sciences predicts that messages are believed or embraced more quickly, and that they shape behaviour more effectively when delivered by a trusted messenger (Dunwoody 2007; Kinzig *et al.* 2013). Further, people tend to filter information and retain what supports their existing belief and value systems (Kinzig *et al.* 2013; Bruskotter, Vucetich, and Wilson 2016; Antonelli and Perrigo 2018; Byerly *et al.* 2018; Kinka and Young 2019). That propensity has led at times to predator management that conflates value-based decisions with evidence-informed decisions (Mitchell *et al.* 2018; Koot *et al.* 2020; Santiago-Ávila 2020; Treves *et al.* 2021b). If a trusted messenger delivers inaccurate information, policy-makers may find themselves weighing apparently contradictory science and then selecting that which they trust more based on the identity of the messengers or their inherent biases and beliefs on the subject.

2. Policy-makers advancing wolf-killing with unsupported claims may not know the scientific evidence or may think the science is unclear enough to support their claims. We view this as unlikely because peer-reviewed scientific evidence has been presented repeatedly to debunk the claims via public comments, litigation, and official federal peer reviews, since 2013 (Bruskotter *et al.* 2013; Treves *et al.* 2021b). For example, the litigation and federal

agency peer reviews have addressed some or all of the claims surrounding grey wolf protection and wolf-killing in Wisconsin, the northern Rockies, and nationwide (Atkins 2019) and Humane Society of the U.S. (2014. 2017) respectively. Furthermore, the suggestion that scientific uncertainty about the 4 claims among scientists left policy-makers with equivocal recommendations, has a prerequisite of transparent debate between experts with diverse views. We know of no such policy review or debate. In general, hunting plans in North America lack the hallmarks of independent review and transparency, as revealed by a close reading of 666 such plans and a survey of the agency staff responsible for writing and carrying out such plans (Artelle *et al.* 2018a,b).

3. Policy-makers may know their claims are unlikely to be true, and these policies instead reflect internal values or external pressures acting on their decisions (Chapron and Lopez-Bao 2014; Darimont *et al.* 2018). This possibility finds circumstantial support in several other claims made by current governments to justify wolf-killing. One such value-based claim is that hunters, trappers, and hound-hunters should be given additional hunting opportunities, or that the reduction in the number of hunters requires agencies to create unlimited harvest to meet objectives previously achievable with limited take and more hunters. The value-based claim is that governments are creating more opportunities for these people via aggressive grey wolf policies. Although such justifications are not entirely in the domain of facts that scientists can evaluate, they are dubious on their face because of a logical flaw. Reducing carnivore abundance comes at the expense of carnivore hunters, who lose hunting opportunities over the long term (Mitchell *et al.* 2018). A more plausible political pressure for widespread wolf-killing comes from electoral politics. Recent research documenting the relationship between voting for the reintroduction of grey wolves (a Colorado ballot measure in the 2020 election)

and presidential voting may provide insights into the internal and external pressures that may be acting on policy makers and their constituents. That study found the strongest predictor of voting for grey wolf restoration at the precinct level was the proportion that voted for the Democratic candidate for president (Ditmer *et al.* 2022). Specifically, as Democratic voting increased, support for grey wolf restoration increased. Similarly, other research shows that political party affiliation and socio-political identity were strong predictors of attitudes toward carnivore policies in other jurisdictions (Hamilton *et al.* 2020; van Eeden *et al.* 2021), however, see (Carlson *et al.* 2020). Partisan politics also predicted rates of poaching of grey wolves in Michigan, U.S. (Louchouarn 2023).

Collectively, these data suggest that the general issue of how to manage wolves has become politicized precisely at a time when the U.S. electorate is extremely polarized as well (McCoy *et al.* 2018). In such environments, the wolf policies pursued by governments may not serve a clear purpose that can be defended scientifically. Wolf-killing policies align with the positions of interest groups that are themselves aligned with a conservative agenda, e.g., agricultural groups, hunting groups (Clark and Milloy 2014). Because these groups traditionally hold great sway with wildlife policy-making bodies, there is little risk for decision-makers in supporting such policies, e.g., (Chapron and Lopez-Bao 2014). In contrast, pursuit of policies viewed as supportive of wolves may carry substantial risk for policy-makers, wildlife commissioners, and wildlife managers. Indeed, research in psychology has long shown how pressure to conform to group settings can powerfully influence decision-makers (Asch 1951, 1952, 1956). Moreover, the dynamics of multiple individual decision-makers acting in concert may complicate the policy analysis.

Regardless of the underlying causal explanation for why governments are using unsupported claims about costs and ignoring claims of benefits, the effect is corrosive on a constitutional democracy like that of the U.S., particularly one whose environmental assets are held in trust for current and future generations (Geer 1896; Hughes 1979; USA 1989). Reliance on unlikely or false factual claims undermines both public policy and the authorities from which it emanates. As public trustees for wildlife under U.S. common law and sometimes statute, elected and appointed government officials have a professional, legal, and ethical duty to avoid unlikely or false claims about public interests. Such conduct misleads the sovereign public.

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Author contributions

All authors contributed equally.

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Table 1. Three studies comparing livestock losses before and after grey wolves were killed. See main text summary of Santiago-Ávila *et al.* (2018a) for explanation of why Bradley *et al.* (2015) was omitted as irreproducible.

Effect	France [a] (% of regions showing a given effect of killing wolves)	Slovenia [b] (entire country, % of years with the given effect of killing wolves)	Michigan U.P. [c] (change in hazard ratios %)
Desired reduction in livestock predation	33%	28%	-25% [c]
Undesirable increase in livestock predation	11%	65%	+75% [c]
No effect	55%	7%	Overall [c]

[a] France: 9 regions (Grente 2021), reporting the author's summary conclusions.

[b] Slovenia: nationwide (Krofel *et al.* 2011; Treves *et al.* 2016). The latetr reanalyzed the former using a non-randomzied before-and-after control-impact design. Neither study found an efefct of wolf-killing on subsequent livestock losses.

[c] Michigan, USA: (Santiago-Avila *et al.* 2018a,b). Although the overall effects of killing grey wolves was non-significant, we present the relative probabilities computed as changes in hazard ratios for target farms and non-target farms 19.2-28.8 km away (both -25% meaning lower risk) in contrast to non-target farms within 19.2 km (+75% meaning higher risk).

ABOUT THE AUTHORS

Adrian Treves is the founder and director of the Carnivore Coexistence Lab, and Professor of Environmental Studies at the University of Wisconsin–Madison. He earned his PhD at Harvard University in 1997. His research focuses on ecology, scientific integrity, public trust principles, and agro-ecosystems where crops and domestic animals overlap carnivore habitat. He and his lab http://faculty.nelson.wisc.edu/treves/ are best known for gold-standard experiments on non-lethal prevention of predation on domestic animals, estimates of illegal wolf-killing and cryptic poaching, risk maps to predict human-carnivore conflict sites, and public trust principles.

Appendix 1. Unsupported claims about threats to human safety.

Officials in 3 states alleged threats to human safety that did not materialize or were found inaccurate.

In 2016, Michigan state officials alleged grey wolf threats to human safety to justify wolf-hunting. A subsequent investigation uncovered that these stories were fabrications, leading 1 biologist to recant his story and a state Senator to apologize on the Capital floor for providing a misleading account (Barnes 2019).

Similarly, arguing against a proposed reintroduction of grey wolves into Yellowstone National Park in the mid-1990s, U.S. Senator Conrad Burns (R-Montana) predicted "there'll be a dead child within a year [of reintroduction]" , (Schullery 2003). Also, in 2011, Idaho's legislature declared: "The uncontrolled proliferation of imported wolves on private land has produced a clear and present danger to humans…dramatically inhibiting previously safe activities such as walking, picnicking, biking, berry picking, hunting and fishing."

Concerns about human safety in other grey wolf range in other areas have been tremendously exaggerated, apparently for political gain (Chapron and Lopez-Bao 2014; Darimont *et al.* 2018).

Appendix 2. Wisconsin and Montana studies of change in attitudes before-and-after wolf killing was liberalized.

Three independent studies measured changes in human attitude before and after changes in grey wolf-killing policies. Hogberg et al. (2015) used a mail-back survey to resample individuals in 2013, after the inaugural Wisconsin wolf-hunt in 2012, and compared their responses to those of the same individuals measured in 2009. She found the largest declines in individual tolerance for wolves among non-tribal men who lived in wolf range who self-identified as hunters, i.e., they hunted regularly in the past, or had hunted in the last 2 yrs (Hogberg *et al.* 2015).

Browne-Nuñez et al. (2015) convened focus groups of deer hunters, hound hunters, and livestock owners and analyzed anonymous questionnaires filled out by the same participants in a mixed-methods approach to understand attitudes to grey wolf-killing before and after changes in wolf policy that liberalized wolf-killing (Browne-Nuñez *et al.* 2015). Focus groups conducted after the change in policy showed increased calls for more wolf-killing via public hunts, little or no change in tolerance for wolves, and no quantitative change in the inclination to kill wolves illegally.

Multiple surveys conducted by Montana Fish Wildlife & Parks (MFWP) provide mixed evidence for the idea that liberalized killing can create tolerance (though, to our knowledge, these studies have not been peer reviewed). A report from 2012 compared data from surveys conducted before and after a 2011 wolf-hunt. That study used a single item to identify tolerance for wolves: "…how tolerant are you with wolves being on the Montana landscape" (Lewis *et al.* 2012). Researchers found that pre- and post-hunt responses did not differ across any of 4 sampled populations (i.e., Montana residents, private landowners, wolf license holders and deer/elk license holders) concluding, "…tolerance amongst survey respondents for each of the 4 survey [groups] was the same before and after the 2011 wolf hunt." (Lewis *et al.* 2012). This

survey was replicated with the same 4 groups in 2017 using identical methods, but different respondents. That study found increases in tolerance from the 2012 survey across all 4 survey groups (Lewis *et al.* 2018). However, a key group representing those holding wolf-hunting permits, changed least and it is unclear if the change exceeded the margin of error. The survey group that changed most were general Montana residents. Independent research, however, estimated that the majority of Montana residents (65.9%) opposed the statement, "Wolves that kill livestock should be lethally removed" and 84.6% were not active hunters defined as having hunted in the past and in the last 12 mo (Manfredo *et al.* 2020). Therefore, the subgroup in the Montana state survey that shifted most to become more tolerant of wolves was the subgroup least likely to kill wolves legally or illegally of the 3 subgroups. Regardless, the MFWP study did not address mechanisms of change, so it is unclear what role liberalized killing played or whether their responses reflected other widespread demographic changes in attitudes to wolves over time (George *et al.* 2016; Slagle *et al.* 2017). Moreover, the same study found that more than half of the MT residents sampled opposed wolf trapping (a primary means of reducing wolves), though a majority in all groups supported hunting generally (Lewis *et al.* 2018).

In summary, the longitudinal studies that resampled the same individuals before and after changes in policy or intensification of grey-wolf-killing policies did not find the desired outcome and instead, sometimes found the opposite pattern of attitudinal changes. Therefore, the policies followed by multiple U.S. state and federal agencies of legalizing or liberalizing grey-wolf-killing do not seem to have improved negative attitudes to grey wolves among the members of the public that were most negative (Treves and Martin 2011; Montag *et al.* 2003).

Appendix 3. Non-lethal methods proven effective for protecting livestock or deterring grey wolves in randomized, controlled trials

Randomized, controlled trials (RCT) indicate at least 4 forms of non-lethal interventions to protect livestock are more effective against grey wolves than lethal methods (Treves, Krofel, and McManus 2016; Treves *et al.* 2019; Bruns, Waltert, and Khorozyan 2020), including

(I) fladry, a Polish word for a visual deterrent, consisting of flagging hung from fence-lines (Davidson-Nelson and Gehring 2010) and in captive trials, was tested without livestock, and non-randomized before-and-after comparisons with and without electrification of the flagging, also see electrified fladry in (Lance *et al.* 2010);

(II) specialized dog breeds bonded to livestock (not people), and often used in combination with fencing or night-time enclosures (Gehring *et al.* 2010);

(III) low-stress livestock handling practiced by 'range riders' or specially trained herdsmen periodically visiting cattle on public, open-range pastures (Louchouarn and Treves 2023); and

(IV) Also note that shock collars seemed effective in deterring grey wolves from treated pastures (Rossler *et al.* 2012).

Indeed, many other non-lethal methods have proven effective against other predators and in other conditions (van Eeden et al. 2018; Treves et al. 2019), including methods that are likely to work on wolves such as electric fences but still awaiting unbiased RCT on grey wolves (Khorozyan 2021).