

RESEARCH ARTICLE

Sharing Landscapes with Wildlife: Conflict and Coexistence of Extensive Grazing Systems with Large Carnivores

Large, rugged and remote: The challenge of wolf–livestock coexistence on federal lands in the American West

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Abstract

1. The expansion of grey wolves (*Canis lupus*) across the western United States, including on public lands used for extensive livestock grazing, requires tools and techniques for reducing wolf–livestock conflict and supporting coexistence. We examined approaches used on forested lands managed by the U.S. Forest Service, which we characterize as large, rugged and remote (LRR) landscapes. Research on the spatial aspects of where tools and techniques are deployed and their effectiveness across geographic settings is scant.
2. We selected six national forests located in six western states where managers seek to mitigate ongoing wolf–livestock conflict and conducted semistructured qualitative interviews with stakeholders ($n = 69$) to discuss approaches to conflict mitigation and perceptions of the effectiveness of different tools and techniques.
3. We developed a three-part typology categorizing tools and techniques for conflict reduction: livestock husbandry, non-lethal deterrents and targeted lethal removal of wolves. Across these categories, interviewees noted that many approaches are challenging to scale up to the geographic context of Forest Service grazing allotments and LRR landscapes.
4. The techniques perceived by our informants to be most effective for mitigating conflict in LRR landscapes include: human presence (mobile range riders); flexibility in grazing management; husbandry practices to minimize livestock vulnerability; and targeted lethal removal of wolves (used in combination with non-lethal techniques).
5. Social, economic and political factors also influence the ability of producers to implement desired conflict mitigation tools in the national forest context. For example, the economic costs of implementation in LRR landscapes, and policies associated with grazing on federal lands, can limit mitigation options.
6. *Policy implications.* Geography matters! Efforts to address wolf–livestock conflict are more likely to be effective if they are designed to fit the local geographic context. Effectiveness may also increase if mitigation efforts go beyond technical approaches, considering the social, economic and institutional context in which conflict is embedded.

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human–wildlife conflict and coexistence, livestock husbandry, non-lethal deterrents, United States Forest Service, wolf management

1 | INTRODUCTION

Successful initiatives to conserve and reintroduce large carnivores around the world have prompted efforts to seek solutions to conflicts where growing predator populations and livestock co-occur (Moreira-Arce et al., 2018; van Eeden et al., 2018; Wilkinson et al., 2020). Such efforts and discourses of ‘coexistence with predators’ frequently emphasize *technical* innovations, implying that finding the right tool or technology will solve the coexistence questions raised by human–wildlife relationships. However, technical interventions are only one aspect of predator coexistence, which also includes complex *social*, *spatial* and *institutional* dimensions (Martin et al., 2021). In this article, we examine the *geography*, or spatial aspects, of predator–livestock co-occurrence and conflict, which is highly varied and influenced by both biophysical and social considerations. Predators and livestock roam across varied landscapes and jurisdictions, highlighting the importance of understanding where conflict mitigation tools are deployed and how local conditions influence their effectiveness.

The resurgence of wolves (*Canis lupus*) in the western United States makes an apt case study in the geography of predator–livestock conflict. Wolf return to the continental United States is an emblematic conservation success, but also a source of significant conflict, especially on landscapes used for livestock grazing (Ausband & Mech, 2023). Wolf habitat and livestock production in the American West both straddle a public–private land ownership mosaic. This study focuses on wolf–livestock conflict on United States Forest Service (USFS) lands, which are managed for ‘multiple use’ per the Multiple-Use Sustained-Yield Act of 1960.¹ Some 5400 livestock producers hold permits to graze livestock (mainly cattle and occasionally sheep) on USFS grazing allotments. Although some use them year-round, many move livestock seasonally from private lands to USFS allotments, which are typically at higher elevation, to take advantage of changing resource availability, allow home pastures to rest and facilitate hay production on the home ranch (Huntsinger et al., 2010). A high proportion of allotments also contain suitable wolf habitat; some national forests were sites of wolf reintroduction in recovery efforts under the Endangered Species Act (grey wolves in Idaho in 1995–1996, and Mexican grey wolves in Arizona and New Mexico in 1998). Whether through reintroduction or natural dispersal, wolf populations across the American West, including on national forests, have grown since the mid-1990s, with increasing wolf–livestock interactions (U.S. Fish and Wildlife Service, 2023).

Wolf–livestock conflict contributes to social tensions over wolves, affecting tolerance and support for wolf conservation (Miller et al., 2016; Muhly & Musiani, 2009; Treves & Karanth, 2003). In response, livestock producers and land managers turn to a diverse suite of tools for mitigating conflict. Lethal removal (targeted killing) of wolves has historically been the primary approach for managing predators and addressing predator–livestock conflict in the United States (Bangs et al., 2006) and remains widely used across much of the American West. However, non-lethal approaches to wolf–livestock conflict are growing in popularity, linked to social values prioritizing wildlife conservation and human–wildlife coexistence (Manfredo et al., 2021). While these are sometimes framed as alternatives to lethal removal, lethal and non-lethal tools are often used in combination.

Despite scientific research on the subject, the effectiveness of both lethal and non-lethal tools and techniques remains in many cases uncertain. The science on these tools is contested and is often highly politicized in the context of controversy over wolf return and wolf removal (Treves et al., 2019). In this context, choices about their use are often based on other factors including convenience, cost and individual experience and perception of effectiveness (Plotsky et al., 2024; van Eeden et al., 2018). Moreover, research on *where* tools and techniques for conflict mitigation are deployed, and the variation in their effectiveness across different landscape settings, is largely missing from debates over predator coexistence interventions. Significant wolf–livestock conflict in the western United States occurs on USFS grazing allotments that tend to be large, rugged and remote (LRR), in contrast to smaller, more accessible pastures on private lands. Thus, our research asks:

1. What are the tools and techniques currently in use for addressing wolf–livestock conflict on national forests in the western United States?
2. How does the geographical context of national forest grazing allotments affect the use and perceived effectiveness of these tools and techniques by stakeholders?

After describing methods, we present findings on the use and perceived effectiveness of three categories of conflict reduction tools and techniques on USFS lands: husbandry practices, non-lethal deterrence and targeted lethal removal of wolves. Although we focus on the spatial dimension of coexistence, we also draw attention to social, economic and institutional factors that influence producers' ability to implement these tools and techniques on USFS lands. Our discussion addresses findings on the use and effectiveness of these approaches in the LRR context and emphasizes the need to promote coexistence in ways that are more than technical. It also provides a comparison of wolf–livestock conflict and coexistence efforts across

¹The USFS is a federal agency that manages 193 million acres of public land (mainly in the western U.S.), including 154 national forests and 20 national grasslands located in 43 states and Puerto Rico.

the western United States (as illustrated in our research) with similar dynamics in Europe, the topic of this special journal issue. The conclusions summarize key contributions of our research and suggest its policy implications.

2 | METHODS

All research team members (the authors) were affiliated with the USFS Research and Development branch at the time this research was conducted. The study design, including research questions, was developed in collaboration with an advisory team that included USFS range managers from multiple affected national forests, whose interest in gathering insights into wolf–livestock coexistence from across the western United States was a key motivating factor for developing this research project.

2.1 | Study area

We investigated wolf–livestock conflict and mitigation approaches on six national forests located in six western US states: California, Idaho, Montana, Oregon, Washington and Wyoming (Figure 1). Selection criteria aimed to represent the diverse range of ecological, social and state policy contexts where wolf–livestock conflict occurs and the variety of management approaches to addressing conflict. We identified potential national forests for study that met these criteria by consulting with USFS Rangeland Management Program managers at both regional and national forest levels. Following consultation with rangeland managers and biologists from this subset of national forests, we selected final case study sites. An important additional criterion was interest and willingness of local managers to participate in the study.

2.2 | Data collection

Research team members (RA, JM, KE) gathered data from two national forests each using qualitative semistructured interviews (Patton, 2014) with stakeholders. We conducted 69 total interviews (9–15 interviews per study site). Interviewees included regional and forest-level range program managers and other USFS staff ($n=24$), other federal or state agency representatives involved in wolf management ($n=23$), livestock producers ($n=12$) and non-governmental organizations (NGOs) ($n=10$), with each of these categories represented at least once in each study site. Interviewees were purposefully selected based on their familiarity and experience with wolf management, wolf–livestock conflict and/or federal lands grazing. We identified interviewees at the recommendation of range programme managers and via snowball sampling (Patton, 2014).

We conducted interviews during 2021 over Zoom or via telephone (field data collection was prevented by the COVID-19 pandemic). Interviews lasted between 45 and 110min each and were

recorded and transcribed. Researchers followed guidelines for the ethical conduct of social science research with human subjects contained in the CITI Program training for human research, including taking measures to protect the anonymity of interviewees by redacting transcripts of any personal identifying information. In advance of interviews, we provided to interviewees a written document explaining our research objectives and protocols, our confidentiality practices and their rights as participants. We obtained verbal acknowledgment prior to the interview of their understanding of these rights and their informed consent to participate in the research, an approach consistent with ethical standards for human-subjects research posing limited risk to participants. Among other topics, we asked interviewees about the history and status of wolves on the national forest, wolf–livestock conflict dynamics, non-lethal tools and techniques used to mitigate conflict (who, when, where, how, why), tool effectiveness at reducing conflict and altering wolf behaviour, why some approaches are more effective than others and the role of lethal removal on the national forest.

Our interviews focused on interviewees' use and perceptions of the effectiveness of interventions to address wolf–livestock conflict based on their knowledge and lived experience, rather than direct testing or field observation. Although rigorous experimental testing of these interventions is valuable, we find that practitioners are highly attuned to the nuances of local ecological conditions and the complex combinations of tools and techniques in use. They can therefore offer valuable insights about tool efficacy, as well as the social and political dimensions of conflict mitigation, that complement and add to ongoing biophysical scientific research. Exploring these insights via qualitative research methods allows for the integration of place-based, practitioner knowledge alongside ecological research results (Wilkinson et al., 2007), representing an important addition to a literature on human–wildlife conflict reduction that often emphasizes ecological metrics at the expense of recognizing the important role of human perceptions in shaping conservation outcomes (McInturff et al., 2021).

2.3 | Data analysis

Each team member analysed interview transcriptions and data for the national forests where they collected data. Interview transcriptions were coded in ATLAS.ti using a codebook jointly developed by research team members (the authors). One interview was coded by all researchers and discussed to ensure inter-coder reliability. We drew on the coded interview data to develop individual summaries of each case study, and to examine significant themes and insights from across cases via a comparative spreadsheet. We also discussed findings from each case during monthly virtual meetings held throughout 2022–2023 and during a 2-day in person workshop in early 2023. Further discussion of the individual case studies, as well as additional information on research methods including the positionality of the authorship team, can be found in Martin et al. (in press).



FIGURE 1 Location of six national forests in six western states that served as study sites (Credit: Abigail R. Kaminski).

3 | RESULTS

3.1 | Tools and techniques for wolf–livestock conflict mitigation on U.S. national forests

We documented tools and techniques for mitigating wolf–livestock conflict that have been used on national forests in our study based on interview findings, and grouped them into three categories: livestock husbandry, predator deterrents (non-lethal) and wolf removal (typically lethal) (drawing from Martin, 2021b; Miller et al., 2016; Wilkinson et al., 2020) (Table 1). Husbandry includes proactive livestock management to reduce the attractiveness of livestock to predators and minimize their interactions, thereby reducing the likelihood of conflict. Non-lethal deterrence includes tools deployed to discourage wolves from preying on livestock via frightening stimuli (e.g. noises and lights; Gaynor et al., 2020). Lethal removal by shooting or trapping is also used across much of the American West, although state policy regarding its use is highly variable. As a conflict reduction tool, removal is primarily used in a targeted way to eliminate individual wolves or wolf

packs, typically ‘problem wolves’ that have been known to prey on livestock. As noted in the literature on predator–livestock conflict, predation is an ecological interaction shaped by the biophysical landscape, livestock management and carnivore ecology (Miller & Schmitz, 2019; Wilkinson et al., 2020). Human interventions to reduce conflict may target one or more of these aspects. This perspective is helpful to distinguish husbandry tools as those aimed primarily at affecting prey (livestock) behaviour and landscape use, while deterrence and removal aim mainly to influence predator behaviour (wolves).

The actors responsible for implementing these tools and techniques vary across the region. Husbandry techniques are generally the responsibility of producers, though they may require flexibility on the part of national forest managers when changes to grazing management are called for. Financial support may be available; for example, some states (e.g. Washington) or NGOs (e.g. Defenders of Wildlife) have assisted with range riding programmes by hiring or providing financial assistance to hire someone to accompany herds on horseback or all-terrain vehicle (see Table 1). Non-lethal deterrence measures are typically the responsibility of the producer or hired

TABLE 1 Three-part typology of tools and techniques for wolf–livestock conflict mitigation on national forests.

Category	Mechanism of conflict reduction	Tools and techniques used	Applicability to LRR context (based on interviews)
Husbandry	By changing livestock management practices, producers may be able to avoid wolves, reduce wolf attractants or reduce vulnerability of livestock, minimizing the likelihood of conflict	• Herding or range riding to patrol for wolves, protect livestock, increase human presence on allotment and move herds as needed, with or without use of guardian dogs • Reduce wolf attractants by removing livestock carcasses and bone piles • Protect calving/lambing areas • Prompt removal/treatment of sick or injured livestock • Change timing of turnout onto grazing allotments, change order of pasture use, reduce livestock numbers where wolves are present, or take temporary 'non-use' of allotments • Employ 'low-stress livestock handling' (Louchouart & Treves, 2023) to adapt livestock behaviour, making animals less vulnerable to attack	• Appropriate, but cost- and labour-intensive • Difficult in remote, rugged areas • Difficult in remote, rugged areas; may mean avoiding calving on LRR landscapes altogether • Difficult in remote, rugged areas • Appropriate, but constrained by grazing permit requirements and agency flexibility • May be appropriate, but cost- and labour-intensive
Deterrence (non-lethal)	Mechanisms for deterring wolves from attacking livestock include direct disruption of attacks, installation of physical or perceptual barriers to wolf movement and/or aversive conditioning to cause wolves to avoid areas they perceive as high-risk for human encounters	• Livestock guardian dogs • Fencing or fladry (sometimes electrified) • Harassment tools, such as noisemakers or non-lethal munitions • Automated scare devices, such as Foxlights or radio-activated guard boxes	• Most appropriate for sheep herding; not generally used for cattle • Not readily scalable to large areas • May be deployed by range riders; generally requires human presence • Not readily scalable to large areas
Removal (lethal, targeted)	Killing of wolves in areas where conflict occurs, usually targeted at removal of 'problem wolves' that have learned to attack livestock in order to reduce future predation. Removal may be incremental (one wolf targeted at a time) or full-pack removal	• Shooting (often from helicopter) • Trapping • Issuing kill permits to affected livestock producers	• Difficult in remote, rugged areas; cost- and labour-intensive; may be controversial • Difficult in remote, rugged areas; cost- and labour-intensive; may be controversial • Difficult in remote, rugged areas; cost- and labour-intensive; may be controversial

Abbreviation: LRR, large, rugged and remote.

range rider. Some states (e.g. Washington) require use of non-lethal deterrents before lethal removal can occur, underscoring the need to assess how effective and practical these are in the national forest context. Finally, lethal removal is often conducted by either the U.S. Department of Agriculture's Wildlife Services Division (a federal agency) or a state wildlife management agency. The USFS does not have authority to make decisions about, or conduct, lethal removal.

Other aspects of conflict reduction complement these three types of intervention. These include reconnaissance efforts to understand wolf presence and habitat use, as well as producer compensation programmes for livestock loss. As above, use of these approaches varies widely by state. They are not included in the analysis here because they do not directly target either prey or predator behaviour to reduce conflict. Instead, they inform the deployment of

other interventions or aim to alleviate the financial burden of livestock loss and stress on producers and to build social tolerance for wolves. Wolf hunting is a related intervention employed by wildlife management agencies primarily as a means to manage wolf population numbers. Recreational hunting of wolves may have impacts on livestock conflict or help prevent habituation of wolves to livestock predation (DeCesare et al., 2018). We do not include hunting in our typology because it is a function of state policies on wildlife management more broadly, rather than a tool used by local producers or managers for the express purpose of mitigating wolf–livestock conflict.

3.2 | Large, rugged and remote: The physical geography of national forests and tool effectiveness

Here, we examine how the geographical context of national forest grazing allotments affects the use and perceived effectiveness of the tools and techniques described above. The physical geography of USFS allotments raises unique challenges for wolf–livestock conflict mitigation (Figure 2). As one USFS range manager in Wyoming noted, ‘when they turn [livestock] out on the forest, it’s really a different situation... these allotments, they’re big, they’re rugged, the cattle might be well dispersed. It’s just more difficult to manage closely than... when they’re all down on the hay fields at the home place.’ An average grazing allotment in the American West is over 4000 ha in area, and larger allotments can be in the tens of thousands of hectares (US Forest Service, 2024). Even when subdivided into pastures, these remain in the hundreds or thousands of hectares, with livestock spread widely across the landscape. According to a staff member of a Washington NGO, ‘There’s one allotment that we’re riding that’s 59,000 acres [23,876 ha] ... There’s no way [to] get more human eyes on cattle every day.’ These landscapes are also rugged, often with steep topography and densely forested terrain, where ‘you can’t see the cows, and you can’t see the wolves’ (USFS manager, Montana), and ‘you wouldn’t know if one was there 50 feet [15 m] away’ (NGO staff, Washington) (Figure 3). Finally, many allotments are remote, far from human habitations and even road networks, so ‘to get infrastructure and people in place... is pretty labor intensive’ (USFS manager, Idaho).

The LRR context also makes it difficult to accurately know how much predation is actually occurring. It is difficult to detect livestock losses and to find carcasses in time to identify whether death was due to predation by wolves or another cause. A USFS manager from Montana observed: ‘they just don’t know where they went... If they find ‘em—that’s the key, if they find ‘em—they can’t tell what it was that killed ‘em... by the time they find ‘em, there’s not much left.’ Perceptions of conflict levels can thus vary significantly, with permittees often suggesting that many wolf-related livestock mortalities go uncounted. As one USFS manager in Washington noted, ‘some of our permittees are saying they might be missing 25 or more percent of their livestock.’ Additionally, livestock mortality is not the only impact of wolves on livestock. Another USFS



FIGURE 2 Terrain of grazing allotments on the Colville National Forest in northeastern Washington. The open, flatter areas in the distance (upper right) include some private rangelands (Photo credit: Robert Anderson).



FIGURE 3 Cattle grazing amid dense vegetation and rugged terrain on the Colville National Forest in northeastern Washington (Photo credit: Robert Anderson).

manager from Washington stated: 'Calves are comin' up with a lower weight,' which represents a 'larger economic loss than the few numbers of confirmed depredations.' A Washington permittee reported that, 'when you put wolves in with them [cattle], 20% don't breed.'

Thus, LRR factors limit stakeholders' ability to track where livestock and predators are on the landscape, and to move livestock, remove carcasses after predation events and implement conflict deterrents. Managers emphasized that the tools found to be most effective on smaller, more accessible areas (i.e. private lands), such as fladry, are either inappropriate (they don't work) or nonviable (they are too expensive) on LRR grazing allotments (Table 1). As one USFS manager in Washington put it, 'maybe you [can] deter 'em from a salt block, but you're not gonna deter 'em across [an entire] pasture.' These observations highlight the importance of examining conflict mitigation in the specific context of LRR landscapes, since tool efficacy does not necessarily translate across contexts, and 'proven' effectiveness in a research context means little if producers are unable (or unwilling) to adopt the technique under real-world conditions (see Volski et al., 2021).

3.2.1 | Husbandry practices

Interviewees described adaptations of *husbandry practices* as helping reduce conflict. These include close monitoring for any sick or injured livestock, delaying turnout onto national forest allotments until conflict is less likely and eliminating calving on allotments (a practice that just 'makes wolves look bad,' as one wildlife manager in Oregon put it, by inviting attacks). Some permittees have used low-stress livestock handling techniques (Louchouart & Treves, 2023) with the goal of modifying livestock behaviour to reduce their vulnerability to predators. For example, a permittee in Oregon described a 'paradigm shift' in their practices, emphasizing training livestock to gather together before turning them out onto their allotment: 'if you can keep cows herded up together, they're at less risk.'

Some managers also stated that adaptations in *how allotments are used*, such as changing the timing of livestock turnout or shifting grazing to different lands, can be helpful, so that 'cows would be less likely to be in the same pasture as [a known] den site' (USFS manager, Oregon). Many USFS managers described themselves as willing to let permittees adapt their practices to reduce conflict: 'anytime there is something within our authority that has the potential to reduce risk, we absolutely do that' (USFS manager, Washington). However, the same manager went on to add, 'there's two things we said we're unwilling to do. One is [to] close any allotment due to wolves, and the other is to cancel any permit, to tell a permittee they can't graze on their allotment. Other than that, everything's on the table, and we've done most things.' This tension between a desire to be flexible on the one hand and a statement of the limits of their flexibility (and of their own perceived authority to address wolf issues) on the other was typical of many managers' perspectives. Managers noted that they are constrained by regulatory processes associated with

grazing permits, such as National Environmental Policy Act (NEPA) analyses that dictate the dates when livestock are allowed on the allotment (discussed further below). Managers also frequently expressed that they would consider moving permittees to alternate, safer allotments if they could, but that they generally do not have such places available.

3.2.2 | Non-lethal deterrents

Some states require the use of *non-lethal deterrents* before resorting to lethal removal in response to livestock predation (e.g. Washington), while others do not allow lethal removal at all (California). Wolf advocates also strongly favour non-lethal deterrents, making the question of their effectiveness paramount. Deterrents such as fladry, sirens and lights are often fixed in place and generally cover relatively small areas. Several managers noted that scaling fladry up to the allotment level, for example, is 'totally unrealistic.' An Idaho Wildlife Services professional noted, 'the cattle are grazing in... a 50,000-acre [20,234 ha] Forest Service allotment... There's no way you could put fladry around all that.' Moreover, most deterrent tools need regular maintenance and must be rotated to avoid habituation, which is labour-intensive even at a small scale: 'none of [the tools] should just be kept in the field all the time because wolves and other carnivores do figure things out' (NGO staff, Idaho). Deterrents may also displace wolves to other areas, creating problems for neighbouring producers. As a result, many managers and producers are sceptical of success stories about non-lethal deterrence tools implemented elsewhere, noting that 'there are very few things that work well on public land' (USFS manager, Montana). One extension agent in California described some livestock producers as holding a 'nothing will work' mindset (except lethal removal), while a U.S. Fish and Wildlife Service manager in Oregon explained, 'you can't do it [non-lethal] up on a national forest allotment.'

Despite these challenges, some stakeholders described non-lethal approaches that they perceive as reducing unwanted interactions between wolves and livestock. The first is *human presence*. As one NGO interviewee from Idaho put it: 'The single best time-tested proven method... is having a human' on the range. This can mean livestock producers themselves, their family members, employees or professional range riders (government or NGO employees). One wildlife manager from Washington said that *range riding* is 'one of the best tools to minimize the chance that you will have livestock conflict.' Advocates of this approach highlight range riders' mobility, allowing them to cover large, remote areas, monitoring for both livestock and wolf presence, and deploying other tools (i.e. deterrents) where needed. One USFS manager in Washington thus described range riding as 'the mothership of tools.'

However, human presence is time- and labour-intensive to apply in the LRR context. One small-scale producer from Oregon reported that 'we basically live with our cattle' during the national forest grazing season to keep them safe. Many interviewees noted that it would be cost-prohibitive to scale up: 'we can't afford to

have a range rider everywhere throughout the entire state of Idaho' (Wildlife Services staff, Idaho); 'you'd need an army of range riders' (USFS staff, Washington). In some areas, range riding programmes funded by the state or NGOs help defray costs to the producer; however, many producers are hesitant to work with 'somebody strange... coming in and going through their cows' (Wildlife Services staff, California).

3.2.3 | Lethal removal

Finally, *lethal removal* of wolves was frequently cited by interviewees as a key component of successful conflict mitigation. However, in places where wolves have been federally delisted from the Endangered Species Act, wolf policy (including lethal management policy) falls to state wildlife agencies, leading to a highly fragmented policy landscape with divergent policies and practices from state to state. Removal is a 'tool that's being leaned on heavily' (Wyoming Game and Fish Department staff) and is commonplace in Idaho, Wyoming and Montana. As one manager noted, 'For the most part, [authorization is] given for lethal removal' whenever requested (Wildlife Services staff, Idaho). A state wildlife manager in Idaho described their approach as 'pretty aggressive [about] authorizing wolf control to be responsive to any wolf depredations.'

Other states such as Oregon and Washington try to minimize removal in favour of non-lethal tools, and California has prohibited removal entirely through state-level protections. Many interviewed permittees in states where removal is limited argued that more and faster removal would help, describing policy requirements around implementing non-lethal tools first as a 'song and dance' (permittee, Oregon) that delays the effectiveness of lethal action. Many also questioned the value of non-lethal approaches: 'I applaud people for trying to figure out different ways to do things, but the bottom line is, in the real world, the only thing that really works is just to remove wolves when they get into conflict' (Wyoming Game and Fish Department staff). At the same time, several interviewees acknowledged that lethal removal is only a temporary solution because wolves quickly repopulate or recolonize suitable habitat. As a USFS manager from Idaho stated, 'Give it two or three years... there'll be a new pack back... Animals continue to fill a void.'

Amid debates over the relative value of lethal and non-lethal approaches, some managers observed that they should not be seen as mutually exclusive, and in fact work best in tandem. Others suggested that removal is the basis of success for other techniques, as wolves learn to be wary due to the threat of removal (Anderson et al., 2023). These insights underscore the importance of considering the holistic effects of multiple tools and techniques in combination, both for understanding their effectiveness in real-world contexts and for potentially reducing polarizing debates over lethal versus non-lethal approaches to wolf–livestock conflict.

3.3 | Other factors influencing wolf–livestock conflict mitigation in LRR landscapes

Beyond the pros and cons of individual tools and techniques, our interviews identified other factors influencing wolf–livestock co-existence on USFS allotments. First, several interviewees pointed out that managing conflict on LRR landscapes requires a substantial investment of *labor, time and/or money*. Although NGO and/or state-based efforts to support adaptation and the implementation of new tools exist, these are unevenly available across states and locales. Lack of staffing is also often an issue: 'there's limitations in terms of number of people and capacity to be everywhere' (extension agent, California). Smaller producers, in particular, may have limited financial and labour resources to commit to conflict mitigation. Even permittees with larger operations were quick to note that their economic margins are small, and available resources limited. Those who have had success with proactive management techniques, such as one permittee from Oregon, noted that it would be 'cost prohibitive to really do it' on a larger scale.

Second, given diverse human values and broader political polarization around wolves and livestock grazing on federal lands, interventions are often aimed at producing *social tolerance* as much as reducing livestock predation and stress. Wolf removal can arguably be a tool for producing increased tolerance, with managers noting that 'some ranchers would say, "I could live with it a little more if I knew I could use lethal control when I had to"' (extension agent, California). Although some managers see routinization of lethal removal as a key tool for building tolerance, others worry that it amounts to appeasing anti-wolf actors and ultimately legitimizing what they perceive as an ineffective technique. Ongoing debates over the effectiveness of lethal versus non-lethal measures often reflect strong value differences in prevailing attitudes towards wolves across different geographies (e.g. rural versus urban), which can influence what tools and techniques are used on federal lands and contribute to political conflict over wolves in states with strong urban–rural divisions (Anderson, 2021).

A third important factor raised by interviewees relates to the *policy context* that governs livestock management on national forest lands. The terms of grazing permits and 'annual operating instructions' generally specify the allotment where grazing will occur; the period of use; the number, kind and class of livestock authorized to graze for the season; and the timing of pasture use within allotments. Several Forest Service range managers interviewed described the importance of flexibility in working with permittees to address wolf–livestock dynamics. However, different managers had varying perceptions of their own authority and capacity for flexibility, linked to the constraints created by prescriptive allotment management plans and grazing permit requirements. Some managers felt empowered to work creatively to take actions such as authorizing temporary use of vacant allotments, or allowing a period of non-use on an allotment beyond what is normally allowed. Others felt that such changes exceeded

their authority, and many pointed to the cumbersome, lengthy and resource-intensive environmental review process required by NEPA for formal modifications to allotment management plans and grazing permits. One USFS manager from Oregon noted: 'the two main tools... under the control of the Forest Service... are having vacant allotments to be able to move cattle around, and/or being able to change season of use and timing of grazing... but that flexibility would have to be written into the NEPA [analysis]... since we only renew the NEPA every 10 or 20 years, we don't have flexibility to change those dates... beyond two weeks in either direction.' This acknowledgement of the broader policy context, and the limited resources available to Forest Service managers to conduct NEPA analyses to change husbandry practices on allotments, is a significant limitation to the flexibility of managers to adapt practices under changing conditions.

4 | DISCUSSION

Our findings on the use and perceived efficacy of tools and techniques for wolf-livestock conflict mitigation on LRR landscapes highlight the need for attention to both the geography of conflict and the spatial dimension of coexistence. They also emphasize the importance of considering not only the biophysical setting in which efforts to reduce predator-livestock conflict take place and the livestock species involved but also the social, economic and policy variables that influence their use and efficacy.

4.1 | Effectiveness of tools and techniques for predator-livestock conflict mitigation in LRR landscapes

The LRR characteristics of USFS grazing allotments raise special challenges for wolf-livestock conflict mitigation. Our results indicate that some tools and techniques focus on 'doing something about the wolves' (deterrence and/or removal), while others emphasize 'doing something about the livestock' (husbandry). In some cases, preferences for one or the other may be aligned with pre-existing views on wolf conservation: those opposed to wolf return may lean towards 'doing something about the wolves' (including calling for more aggressive lethal removal), while critics of livestock grazing on federal lands may favour 'doing something about the livestock' (including limiting grazing access). Thus, the question of lethal versus non-lethal management approaches generally, and on federal lands in particular, can become a key terrain of conflict and polarization. Between these extremes, however, many livestock producers and land managers are actively working to combine strategic husbandry, non-lethal deterrence and targeted lethal removal approaches, and suggest that this integration may offer a middle ground for coexistence. The most effective examples of conflict mitigation from our case studies illustrate how practitioners can draw on multiple tools and techniques rather

than framing them as alternative or opposing approaches to the problem.

The effectiveness of different approaches in deterring live-stock predation by wolves is an essential question for producers seeking to adopt them and for wildlife managers encouraging their adoption. This is especially so where state restrictions on the use of lethal removal are predicated on demonstrated prior efforts at non-lethal deterrence. In the context of a significant degree of scientific uncertainty over the effectiveness of specific methods, practitioners generally agree that there is 'no silver bullet' for preventing wolf predation on livestock (Martin, 2021a), but that husbandry, non-lethal and lethal approaches do tend to be more effective in combination than alone (Bangs et al., 2006; Stone et al., 2017). Scientific studies of how and where tools are used in combination are lacking, however. Given this gap in scientific evidence (and recognizing that the topic is under active study by wildlife ecologists), the perceptions of practitioners and stakeholders with experience deploying these tools in the real-world context of LRR landscapes and public lands is a valuable contribution to the literature.

We found that there is no singular recipe for how husbandry, non-lethal and lethal tools and techniques should be combined in the LRR and national forest contexts, and indeed the exact combination is likely to vary from place to place based on local ecological and social dynamics. Nonetheless, we found commonalities across cases, including shared recognition of the value of: (1) combining the use of all three sets of tools (to varying degrees) in geographically informed ways, rather than using one alone; (2) using adaptable, mobile tools, generally deployed through increased human presence on the range, rather than relying on technologies fixed in place (e.g. fladry, fencing, Foxlights or RAG boxes); (3) emphasizing reducing livestock vulnerability (i.e. risk mitigation) rather than complete prevention of attacks; and (4) recognizing that both wolf and livestock behaviours can be changed through behavioural deterrents (see Anderson et al., 2023) and livestock husbandry (i.e. behavioural co-adaptation).

4.2 | Predator-livestock conflict mitigation is more than technical

Amidst ongoing debate over the effectiveness of husbandry, non-lethal and lethal approaches, stakeholders involved in wolf-livestock conflict increasingly recognize that mitigating conflict is not just a question of finding the best strategy for reducing wolf predation of livestock. The LRR nature of national forest grazing, which highlights the very material challenges of implementing wolf-livestock conflict reduction, requires substantial financial investment. The most effective tools on grazing allotments, such as human presence to guard herds, are labour-intensive, and the availability of workers or family members to implement such approaches is often limited. In the case of the former, wages, insurance and other costs (in addition to the costs of tools/technologies themselves) raise issues of feasibility,

especially for small operators and others who already struggle to maintain financially viable operations. This means that questions of scale of production, trends in the global political economy of livestock production and agricultural labour and environmental justice-tinged questions of 'who pays' and 'who benefits' (see McInturff et al., 2021) are all entangled in practices of predator–livestock coexistence.

Our findings emphasize the importance of what is frequently described as the 'social side' of conflict mitigation, including building tolerance for wolves and mutual understanding between stakeholders with very different perspectives (Anderson, 2021; Treves & Karanth, 2003). As Shivik argues, 'while technological advances may well lead to further improvement in predator management, ultimately some of the tools that are most desperately needed are social ones' (2006, p. 257). The effectiveness of tools and techniques for conflict mitigation can therefore be understood not only in ecological terms, such as their effects on wolf or livestock behaviour, but also in terms of their 'social effectiveness' (Volski et al., 2021). Building on the work of Volski et al., we consider social effectiveness to include not only the willingness of producers to adopt a given tool but also the role that tool may play in broader questions of tolerance for wolf presence or community willingness to cooperate with predator coexistence efforts. Thus, the question of 'what works' is as much about building effective collaboration and promoting cooperation across human divisions, as it is about determining what tool will best discourage a wolf from attacking livestock.

Our research focus on national forests located in six different western states also highlights the need to consider land ownership and jurisdiction as factors influencing the use and effectiveness of conflict mitigation approaches. States have very different policies towards the use of lethal removal. National forests are public lands with a multiple-use mandate. Therefore, USFS managers must be responsive not only to diverse public values around how wolf–livestock conflict should be managed but also to policy requirements that put sideboards on what they can do to help permittees mitigate conflict. The question of USFS responsibility and authority for addressing conflict is also important. Much of the work of deploying tools and techniques falls to livestock producers, with varying support from state or federal wildlife management agencies. However, adaptive management to enable husbandry techniques—such as changing grazing management practices on allotments under USFS management—can make a significant difference. Insofar as Forest Service lands are a key 'nexus of encounter' for wolves and livestock (Martin et al., 2021), USFS policies that support flexible and adaptive grazing management on federal lands are key.

4.3 | Sharing landscapes with wildlife: The western US and European contexts

Notable similarities exist between the US and European experiences of wolf return and wolf–livestock conflict and coexistence,

with broadly parallel timelines and socio-political dynamics. In both places, wolf eradication in many areas had been accomplished by the early 20th century, if not earlier. Nevertheless, wolves were never fully eradicated in some places (e.g. U.S.: Alaska, Michigan; Europe: Finland, Eastern Europe) owing to contiguity with neighbouring regions with significant wolf populations. Recovery has accelerated since the late 20th century in both regions, with new protections and growing populations across the western United States and northern and central Europe. Some areas have now experienced wolf return for decades, while others are just starting to contend with returning populations and debates over active reintroduction (e.g. California, Colorado in the United States; rewilding efforts in Scotland). Several of the tools and techniques for conflict mitigation used in the United States draw on European traditions. For example, fladry was developed from old wolf-hunting techniques used in Europe (Davidson-Nelson & Gehring, 2010), and livestock guardian dogs often draw on European breeds (Kinka & Young, 2019). Discourses surrounding wolf return in the United States and Europe also show remarkable parallels and cross-pollination, for example, in discussions of rewilding (compare Pereira & Navarro, 2015; Ripple et al., 2022; Soulé & Noss, 1998), and controversies over recovery (see Nie, 2003; Skogen et al., 2008).

There are also notable differences, however. Many European countries demonstrate policy support for agricultural activities and products (e.g. through national appellation systems and EU-level protections) that differ qualitatively from US agricultural subsidies, resulting in subsequent durability of so-called 'heritage landscapes' despite patterns of rural depopulation (Drenthen, 2018; Tokarski & Gammon, 2016). Yet many European livestock producers have much less experience contending with wild predators than their American West counterparts. Although wolves may be novel in the western United States, ranchers there often have experience with other predators (such as coyotes, bears and mountain lions), and are therefore accustomed to grazing livestock on rangelands that are less 'domesticated' than in Europe.

There may also be interesting comparisons to explore in future research between state-level policy towards wolves in the United States (and vis-à-vis federal regulations), and country-by-country variation in the EU. Furthermore, the public lands context—particularly the multiple use commitments of the USFS—may provide important insights for European policymakers and resource users adjusting to coexistence with wolves in shared landscapes. Finally, our findings about the use and effectiveness of tools and techniques for wolf–livestock conflict mitigation in LRR landscapes in the United States could be compared with those from LRR landscapes in Europe to explore their wider application.

5 | CONCLUSIONS

Federal lands in the western United States are a critical component of current regional grazing systems and also provide a substantial

proportion of suitable wolf habitat. In this context, extensive livestock production systems and the presence of large predators are not and arguably cannot be viewed as mutually exclusive land uses. Wolf-livestock interactions are nearly inevitable where they co-occur in these landscapes, highlighting the importance of fostering coexistence using appropriate tools and techniques alongside promoting social tolerance and collaboration in conflict reduction efforts.

Drawing on the perceptions and experiences of stakeholders, we examined how three categories of tools and techniques for addressing conflict (husbandry, non-lethal deterrents, targeted lethal removal) are used, and with what effect, in the LRR landscapes that characterize the majority of USFS lands. The key contributions of our research are several:

- We explore the spatial component of coexistence (see Martin et al., 2021);
- We offer a three-part typology of tools and techniques for mitigating wolf-livestock conflict and their relative advantages and disadvantages in LRR landscapes;
- We document approaches currently in use to mitigate conflict in the important but under-acknowledged context of national forest lands;
- By drawing on the experiences of practitioners around the effectiveness and limitations of different tools and techniques, we draw attention to the value of local knowledge and experience for complementing scientific studies; and
- We emphasize that predator-livestock conflict cannot be approached as only a technical problem to solve; tools and techniques cannot be divorced from the broader social, economic, institutional and biophysical dynamics that influence their use and effectiveness.

Improved understanding about what works, where, and why can help inform policy associated with wolf-livestock conflict mitigation and financial and technical assistance programmes. For example, we found either limited perceived effectiveness or a relatively high cost to producers of implementing husbandry and non-lethal tools and techniques in LRR landscapes where wolves and livestock overlap. This suggests that in states requiring use of non-lethal tools prior to considering targeted lethal removal, or that ban lethal removal, technical and financial assistance programmes to build capacity for non-lethal approaches might be directed towards producers dependent on grazing in LRR landscapes. In addition, on federal lands with prescriptive grazing management policies, increasing flexibility and fostering adaptive grazing management could facilitate husbandry practices that decrease encounters between wolves and livestock, minimizing livestock predation and stress caused by wolves. Finally, increasing social tolerance for wolves in these landscapes addresses the social dimension of coexistence, for a more holistic approach to the problem (Martin et al., 2021). Forest Service managers are in a unique position to serve as a conduit for communication and to help build collaborative working relationships among stakeholders, which

could help increase trust and ease conflict. Our research therefore highlights not only technical solutions to wolf-livestock conflict in LRR landscapes but also the complex social, economic and institutional dynamics that influence adaptation to wolf presence in these landscapes.

Importantly, the LRR context of predator-livestock conflict is not unique to USFS lands: wolves and livestock co-occur on federal, state, private and Tribal lands, some of which are likewise large, rugged and remote. They are also not unique to the United States context. Our findings about tools and techniques for conflict mitigation on national forests are likely applicable to LRR landscapes elsewhere, such as those found in Europe. Although physical geography matters, considering social factors associated with land ownership and jurisdiction is also important. In the United States, further research and experimentation are needed to better adapt extant mitigation approaches to the LRR, and federal lands, contexts.

AUTHOR CONTRIBUTIONS

All contributing authors were involved in the conceptualization, research design and implementation of the research project as a whole, under the leadership of principal investigator Susan Charnley. Robert M. Anderson, Jeff Vance Martin, and Kathleen Epstein collected and analysed data. Robert M. Anderson led the writing of this manuscript. All authors reviewed and edited the manuscript and gave final approval for publication. The findings and conclusions in this publication are those of the authors and should not be construed to represent any official U.S. Department of Agriculture or U.S. Government determination or policy.

CONFLICT OF INTEREST STATEMENT

The authors do not have any conflicts of interest regarding the article.

DATA AVAILABILITY STATEMENT

To protect the privacy of our research subjects, the interview data upon which this article is based is not publicly available.

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