



## **Fencing the future: enhancing livestock management and wildlife conservation with virtual fencing**

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### **Abstract**

Virtual fencing technology presents a potentially transformative approach to livestock management across extensive rangeland systems with significant implications for wildlife conservation. Virtual fencing enables remote and dynamic management of livestock movement, offering solutions to mitigate the adverse impacts of traditional physical fencing on landscape connectivity, reduce wildlife-livestock conflicts, and exclude grazing in sensitive habitat areas. In this paper, we present a framework outlining the diverse applications of virtual fencing to conservation efforts and present insights from several pilot case studies from the North American Great Plains and Greater Yellowstone Ecosystem, USA. We examine the operational approaches, and adaptive strategies employed to integrate virtual fencing into existing rangeland management practices, and their potential impact in achieving wildlife conservation goals as part of a working livestock operation. Despite the promising potential of virtual fencing, pilot applications have encountered a range of technological, social, and policy barriers. The findings from the case studies underscore the necessity for continued innovation, stakeholder engagement, and policy reform to harness the full potential of virtual fencing. We argue that, by addressing these considerations, virtual fencing technology can substantially contribute to the co-objectives of livestock production and wildlife conservation. By enhancing landscape connectivity, reducing human-wildlife conflicts, and minimizing habitat impacts, virtual fencing represents a pivotal step towards more sustainable rangeland management.

### **Introduction**

Livestock grazing is the most extensive land use globally, occupying approximately 25% of the Earth's terrestrial surface (Asner et al., 2004). Physical fencing is a key grazing management tool to control the spatiotemporal distribution of livestock (Bailey, 2004) and plays a large role in human socio-ecological interactions worldwide (Xu and Huntsinger 2022). While nearly universally associated with grazing, traditional fencing has only recently received widespread conservation attention (McInturff et al., 2020), including the recognition that fencing can have considerable ecological and economic drawbacks.

Traditional fencing can create social conflicts by reducing human mobility and weakening social relationships, fragment landscapes that reduce wildlife mobility, cause direct mortality due to collision and entanglement, facilitate the spread of invasive species, and reduce native plant diversity, leading to potential widespread ecological consequences (Harrington and Conover, 2006, Jakes et al., 2018, McInturff et al., 2020, Xu et al., 2021, Xu and Huntsinger 2022). From an economic perspective, fencing is a major input and expense for livestock producers. For instance, new fencing in the western USA can be upwards of \$25,000/mile and requires significant physical and financial maintenance once erected. Given these challenges, there is a need and demand for new ways to contain livestock while offsetting some of the potential negative effects of traditional fence.

There is a growing interest in technological solutions that can meet the needs of livestock management while minimizing negative ecological impacts and reducing costs for producers. Virtual fencing provides a potential win-win solution that can enhance livestock operations while providing significant conservation benefits that extend beyond simply reducing physical fencing. Below, we provide an overview of emerging virtual fencing technology, detail the specific functions virtual fencing can provide to realize conservation benefits, and provide insights from initial pilot applications.

### **Methods**

We employed two complementary approaches to identify conservation opportunities and implementation challenges associated with virtual fencing technology: an expert stakeholder workshop and semi-structured interviews with key stakeholders involved in pilot projects. In June 2024, we convened a three-day workshop in Bozeman, Montana, that brought together over 40 experts from across technology, agriculture, government, and conservation sectors. Expert workshops have been shown to be effective for synthesizing diverse knowledge and identifying priorities in conservation planning (Sutherland et al., 2011). The workshop, co-hosted by the Property and Environment Research Center and the Beyond Yellowstone Program, with support from multiple conservation organizations, focused on understanding the current state of virtual fencing technology, evaluating its conservation potential, and identifying barriers to adoption. Participants included virtual fencing technology developers, ranchers with direct experience implementing the technology, conservation professionals, researchers, and government agency representatives. Through facilitated discussions and working sessions, participants identified key functions of virtual fencing that enable conservation benefits and developed strategies for scaling adoption.

To complement the workshop findings, we conducted 15 semi-structured interviews with key stakeholders involved in four pilot projects implementing virtual fencing technology for conservation benefits (Young et al., 2018). Interview subjects included ranchers operating the technology and conservation professionals involved in project implementation. Semi-structured interviews are particularly valuable for understanding complex social-ecological systems and documenting stakeholder experiences with new conservation technologies. These interviews explored practical challenges encountered during implementation, documented early conservation outcomes, and identified opportunities for improving virtual fencing applications. The interviews provided detailed insights into the real-world application of virtual fencing technology and helped validate the functions and challenges identified during the expert workshop. Together, these methods provided a comprehensive understanding of both the theoretical potential and practical realities of using virtual fencing to achieve conservation outcomes.

## Results

### ***Key Functions and Potential Conservation Benefits***

Based on the expert workshop, we identified five key functions of virtual fencing that provide significant conservation benefits. First, virtual fencing can reduce the need for physical infrastructure, helping restore landscape connectivity by removing barriers that fragment habitats, impede wildlife movement, and cause wildlife mortalities through entanglement and collisions (Jakes et al., 2018; Harrington and Conover, 2006). Second, virtual fencing enables precise livestock exclusion from sensitive areas through dynamic, remotely adjustable boundaries. This capability allows managers to protect critical habitats such as riparian zones (Belsky et al., 1999), breeding areas, and post-fire restoration sites (Boyd et al., 2022), with the flexibility to modify exclusion zones based on seasonal needs or changing environmental conditions.

The third function involves the strategic concentration of livestock, which can serve multiple conservation purposes. Operators can focus grazing pressure to control invasive species, create fuel breaks for wildfire management (Boyd et al., 2022), and reduce predation risk by grouping cattle away from areas that provide cover for predators (Kluever et al., 2009). The fourth function utilizes the technology's precise livestock tracking capabilities to aid in predator conflict mitigation. Real-time monitoring can detect abnormal herd movements indicating predator presence and enable rapid carcass removal to reduce predator attractants (Morehouse and Boyce, 2011).

Finally, virtual fencing provides unprecedented flexibility in timing grazing rotations, enabling sophisticated management strategies such as high-density, short-duration grazing. This approach can create habitat heterogeneity that benefits various wildlife species (Fuhlendorf et al., 2010; Krausman et al., 2009) while allowing for more strategic rest periods that promote ecosystem recovery (Briske et al., 2008). The technology's adaptability is particularly valuable in the context of climate change, as managers can rapidly adjust grazing patterns in response to changing environmental conditions, contributing to the overall resilience of grazed landscapes.

### ***Challenges and Promise in Pilot Efforts***

Based on the interviews with stakeholders involved in pilot virtual fencing projects, we identified several implementation challenges during early adoption phases. Initial efforts were often more ambitious than what could be realistically achieved in the first few years of deployment, with participants encountering technical obstacles such as collar retention issues and limited battery life. The learning curve for adopting the technology proved steeper than anticipated, requiring significant time investment from operators to become proficient with the system. Additionally, effective communication between conservation organizations and ranchers emerged as a critical factor for success. In one pilot project, misaligned expectations regarding timelines, funding arrangements, and technology deployment created challenges that could have been avoided through more structured communication protocols.

Despite these initial obstacles, stakeholders universally expressed optimism about the technology's potential and demonstrated strong commitment to continuing their virtual fencing programs. While documented conservation benefits have been limited thus far, largely due to implementation challenges that shifted focus away from specific conservation objectives, participants identified numerous promising applications for future deployment. Stakeholders emphasized that achieving conservation outcomes would require patience as operators progress through the learning curve and technical improvements enhance system reliability. The need for more durable collar designs was consistently highlighted as a priority for advancing the technology's effectiveness. As these pilot projects mature, participants plan to expand their focus on specific

conservation applications, building on the operational experience gained during initial implementation phases.

### **Discussion and Conclusions**

Virtual fencing represents a transformative technology for both livestock management and conservation, but realizing its full potential requires addressing several key challenges. While innovative producers are successfully implementing virtual fencing systems across large operations, widespread adoption faces three primary barriers. First, ongoing technological improvements are needed, particularly in areas of battery life, collar retention, and system reliability across diverse landscapes. Second, the significant learning curve for both operators and livestock requires substantial time investment and may initially disrupt established routines. Third, cost remains a critical factor, especially where existing physical infrastructure is functional. Although virtual fencing can be cost-competitive when compared to new fence installation or intensive range riding operations, the initial investment and ongoing maintenance costs can be prohibitive for many operators without external support or clear evidence of return on investment (Umstatter, 2011).

Conservation organizations can play a crucial role in accelerating adoption of virtual fencing technology through strategic partnerships and targeted support. Cost-share programs focused on critical conservation areas, such as migration corridors or sensitive habitats, could help overcome financial barriers while ensuring implementation achieves meaningful conservation outcomes. The success of such programs is evident in existing conservation initiatives, such as the USDA's investment of over \$290 million in wildlife-friendly fence modifications since 2014 (USDA-NRCS, 2021). Similar programs could be adapted or developed specifically for virtual fencing adoption. However, these initiatives must be coupled with research to demonstrate conservation effectiveness and identify best practices for implementation.

Looking forward, the implications of successful virtual fencing adoption extend beyond individual ranch operations to landscape-scale conservation outcomes. The technology's ability to create dynamic, adaptable boundaries while reducing physical barriers could fundamentally reshape how we approach grazing management and wildlife conservation in working landscapes. However, realizing these benefits requires proactive engagement with the agricultural community and careful attention to both technical and social aspects of adoption. Strategic partnerships between conservation organizations and livestock operators, supported by targeted research and policy initiatives, will be essential for capitalizing on virtual fencing's potential to advance both agricultural productivity and biodiversity conservation goals.

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