Virtual Fence: a Tool to Improve Precision of Conservation Strategies for Livestock Management*

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Abstract

Conventional livestock grazing relies on physical fencing to manage animal movements. Physical fences are effective but can require significant initial investment, maintenance, and can undermine conservation efforts by interrupting landscape connectivity, causing wildlife entanglements, and concentrating grazing pressure on sensitive areas. Virtual fencing (VF), which uses GPS-enabled collars to deliver auditory cues followed by electrical cues, allows producers to dynamically control the distribution of livestock without the use of physical fences. This paper evaluates the potential environmental benefits of using VF in lieu of or in conjunction with physical fence. We highlight the potential advantages of VF as a tool that includes redistributing grazing pressure to avoid rangeland degradation, creating virtual exclusion zones around sensitive areas, and enhancing wildlife mobility and connectivity by replacing physical fences. By addressing the limitations of traditional fencing, VF represents a promising tool and strategy to improve conservation strategies on rangelands while still allowing for livestock grazing. Further trials of VF's long-term effectiveness will strengthen its role as a sustainable grazing management solution.

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1 Introduction

Rangelands cover approximately 40% of Earth's terrestrial surface and provide essential resources such as forage, wildlife habitat, and critical ecosystem services that support the livelihoods of millions of people (FAO, 2025). North American grasslands, a significant subset of rangelands, rank among the most endangered ecosystems worldwide (Silber et al., 2025). Livestock grazing can benefit rangeland ecosystems by stimulating plant productivity, enhancing nutrient cycling, and maintaining habitat diversity (Byrnes et al., 2018; Teague & Kreuter, 2020; Dong et al., 2020; Ren et al., 2024). However, grazing can also lead to environmental threats and landscape degradation if livestock management, including stocking rates, animal density, and grazing duration, is not appropriately matched to the ecological conditions of the rangelands (Byrnes et al., 2018; Niu et al., 2025; Ren et al., 2024).

Conventional livestock grazing relies on physical fencing to manage animal movements. Physical fences are effective, but require significant initial investments and maintenance, and can undermine conservation efforts by interrupting landscape connectivity, leading to wildlife entanglements, and concentrating grazing pressure on sensitive areas (Murray et al., 2025). These limitations raise an important question: Can virtual fencing (VF) be used as a tool for conservation to improve sustainability of livestock grazing?

We address this question by examining the current scientific literature on how VF can be used as a tool to achieve conservation goals. Previous research on VF has focused mainly on its technical capabilities and initial applications (e.g., Campbell et al. 2018, 2020; Jeffus et al. 2025; Mayer et al. 2025; Gerhardt et al. 2025; Murray et al. 2025; Silber et al. 2025). Some of these papers discuss certain environmental benefits, with a focus on the exclusion effect of VF in environmentally sensitive areas (e.g., Campbell et al. 2018, 2020; Murray et al. 2025; Silber et al. 2025), but to our knowledge, no existing paper comprehensively evaluates its broader environmental implications and its integration into USDA conservation programs.

Our study contributes to the VF and USDA conservation literature by providing a comprehensive assessment of how VF incorporates into the USDA conservation and cost-share agreements in a manner that meets both producer and program objectives. Given the likelihood of VF product evolution and potential adoption by producers nationally, evaluating VF can inform USDA conservation plans and its long-running programs. This paper proceeds as follows: Section 2 introduces the fundamentals of VF technology. Section 3 details how VF can be used as a tool to improve conservation management. Section 4 outlines the pathways for adoption of VF through USDA conservation programs, and Section 5 concludes with future research and recommendations.

2 Background on Virtual Fencing

VF is an innovative technology that enables remote management of livestock movements. Originally commercialized for companion animals, it has recently advanced and begun to be used within livestock systems. It offers simplified grazing management and allows producers to adjust the distribution of livestock quickly and efficiently (Schillings et al., 2024).

At its core, VF relies on GPS-enabled collars that first deliver auditory cues as a warning to animals that they are approaching the user defined virtual boundaries. If animals continue to advance, they will receive an electrical cue as a deterrent to continue past the virtual boundary. This allows producers to control the distribution of livestock without having physical fences and the flexibility to rapidly build, adjust, and turn off and on virtual fences from a computer or mobile phone platform. These lightweight collars record the location of the animal at approximately 15-30 minute intervals (Chopra et al., 2025; Lamanna et al., 2025), allowing producers to know where their animals are within the landscape they are grazing. Figure 1 demonstrates the components of a VF system. Virtual boundaries are defined using a smartphone app or web-based platform app and transmitted to the collars. When animals approach these invisible boundaries, they receive an auditory cue, which

they learn to associate with the boundaries through training. If they continue crossing the boundary, a mild electrical cue is delivered (Mayer et al., 2024). Audio and electrical cues have been shown to cause minimal distress to animals; in fact, animals generally learn to respond solely to auditory cues, minimizing their exposure to electrical cues (Dozler et al., 2025; Ranches et al., 2025).

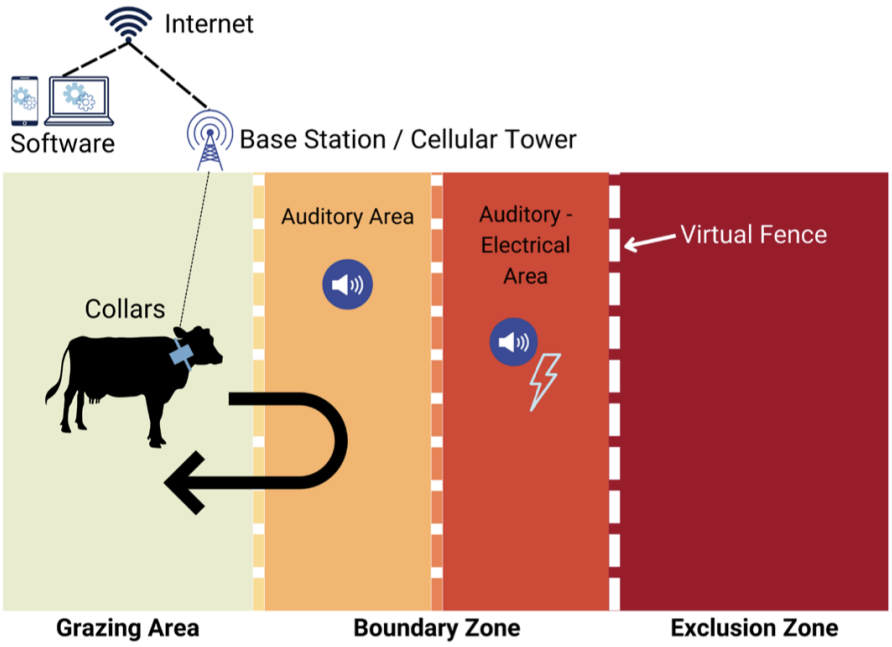


Figure 1: Components of a VF System. Source: Mayer et al. (2024)

While VF is emerging in the US, initial adoption rate remains low (Melo-Velasco et al., 2024). This is similar to other precision livestock farming technologies in the cow-calf sector, most of which have experienced slow adoption due to uncertainties about their economic benefits and the inability to translate the substantial data generated by these technologies into actionable insights for decision making (Kamphuis et al., 2015). Harris (2025) found that ranchers are most willing to adopt VF when they can try it on a small scale and see clear benefits, and that outside factors like wildfire-damaged fences or cost-share programs can tip the balance toward adoption, especially now that the environmental benefits and efficiency gains of the technology are more widely recognized.

3 VF as a tool to improve landscape and habitat conservation

VF technology is a tool that can offer flexibility for grazing management while providing opportunities for achieving conservation and environmental stewardship goals. The environmental benefits of VF can include the following:

I. Enhanced Rangeland Health and Biodiversity:

- **Targeted Grazing for Vegetation Management:** VF allows for more precise control of livestock distribution, enabling targeted grazing to achieve specific vegetation management objectives at different spatial scales across a landscape. For example, enclosures can be created on relatively small areas (e.g., 5 to 10 acres) to increase grazing pressure on targeted species. In contrast, VF can be used at large scales (<1,000 acres) to allow portions of a rangelands deferment in a given grazing season to allow non-target species recovery. This includes:
  - **Invasive Species Control:** With VF, ranchers can fence off zones for treating invasive plants or keep their animals away from toxic weeds such as tall larkspur, which can otherwise kill livestock (Jablonski et al., 2020). Toxic plants present a major risk to livestock health and livestock profitability, resulting in annual losses of approximately 250 million dollars through animal deaths, miscarriages, and reduced productivity (Abdisa & Dinbiso, 2024). VF can help control invasive species by directing animals towards desired areas where these species grow (Schillings et al., 2024).
  - **Changing Fine Fuel Loads:** Strategic grazing can be used as a tool to modulate or reduce fine fuels in fire-prone landscapes, such as creating wildfire fuelbreaks to help reduce wildfire risk in arid and semi-arid rangelands (Boyd et al., 2023),

Utilizing targeted grazing with VF can also help modulate fine fuels biomass to improve containment lines of prescribed fires.

- **Prevention of Overgrazing and Promotion of Rest Periods:** By creating dynamic paddocks, VF facilitates rotational grazing systems that allow adequate rest and recovery periods for pastures. This prevents overgrazing, which can lead to soil degradation, erosion, and reduced plant diversity (Donovan & Monaghan, 2021). Recent trials by Murray et al. (2025) and Campbell et al. (2017) demonstrated the effectiveness of VF in rotational grazing by successfully excluding cattle from designated pasture areas.

- **Protection of Sensitive Ecological Areas:** VF allows producers to create "exclusion zones" around ecologically sensitive areas without physical fences. This includes:

  - **Riparian Zones and Waterways:** Keeping livestock out of stream banks and wetlands protects water quality, reduces erosion, and preserves aquatic habitats (Murray et al., 2025; Silber et al., 2025).

  - **Wildlife Habitats:** Protecting specific wildlife nesting sites, critical breeding grounds, or migration corridors from livestock disturbance (Murray et al., 2025; Silber et al., 2025).

  - **Recently Burned Areas:** Preventing livestock from grazing in areas recovering from wildfires allows natural regeneration and targeted grazing on non-uniform burn patches. Boyd et al. (2022) demonstrated that VF was effective, reducing forage utilization in a prohibited burned area to less than 3%, compared to 70% utilization in pastures without fencing in the sagebrush grasslands of southeastern Oregon.

II. Wildlife Connectivity and Reduced Fence Impacts:

- **Elimination of Physical Barriers:** One of the most significant conservation benefits is the potential to remove traditional barbed wire fences. These fences can be significant barriers to wildlife movement, causing:
  - **Migration Impairment:** Obstructing the seasonal migration of large ungulates like pronghorn, deer, and elk, limiting their access to vital foraging and breeding grounds (de Avila et al., 2025)
  - **Entanglement and Injury:** Wildlife, especially birds and mammals, can become entangled in barbed wire, leading to injury or mortality (Stevens et al., 2012; Jones et al., 2018).
  - **Habitat Fragmentation:** Traditional fences can fragment large landscapes, isolating wildlife populations and reducing genetic diversity (Jakes et al., 2018; Jones et al., 2019).

By replacing physical fences with virtual boundaries, VF promotes the connectivity of seasonal habitats, allowing reduced restrictions in migratory and general wildlife movement across rangelands (Jakes et al., 2018; Jones et al., 2019), which is crucial for maintaining healthy populations. However, its benefits regarding wildlife connectivity have not yet been demonstrated in trials.

III. Water Quality and Soil Health Improvements:

- **Reduced Sedimentation and Nutrient Runoff:** Excluding livestock from waterways directly improves water quality by reducing sedimentation, nutrient loading, and pathogen contamination (Murray et al., 2025; Silber et al., 2025). However, because of difficulties in measuring such benefits, most VF trials have focused on quantifying direct exclusion efficacy rather than measuring the indirect environmental benefits that

arise from this exclusion.

- **Enhanced Soil Health:** Healthier rangeland soils can be managed through precision grazing facilitated by VF. With VF's ability to directly manage livestock distribution on rangelands there is the potential to utilize forage more uniformly and provide ample rest for rejuvenation of perennial grasses (Boyd et al., 2022; Mayer et al., 2025). The management of animal distribution allows for creating heterogeneity in rangelands and improved utilization of forage, which can lead to more incorporation of litter into the soil for increases in soil organic matter content (Stanley et al., 2024). As soil organic matter content increases so does the water holding capacity of the soil. Given the success of VF in rotational grazing[1], the technology is a promising tool for implementing complex grazing strategies to enhance soil health on a large scale.

In the short term, VF offers the aforementioned environmental benefits through targeted livestock exclusion and rotational grazing. In the long term, expanded adoption can significantly enhance ecosystem health at a broader landscape scale, providing widespread conservation benefits.

These conservation benefits often represent societal gains rather than private benefits to producers, which can limit adoption unless supported by incentive programs. Integrating these benefits into policy and incentive programs can further incentivize VF adoption and promote sustainable land management practices.

4 Integration of VF with USDA Conservation Programs

The successful adoption of VF will depend not only on its effectiveness, but also on its integration into economic and policy frameworks. Its potential as a widespread conservation

[1]Studies show that cattle remain within VF boundaries more than 99% of the time (Campbell et al., 2017; Harland et al., 2025)

tool is hinged on its eligibility for financial support through USDA conservation programs. These programs are managed by Natural Resources Conservation Service (NRCS) and Farm Service Agency (FSA), and they offer incentives that can bridge the gap between the private costs of adoption and the societal environmental benefits.

For any practice to receive financial assistance from USDA conservation programs, it must align with conservation practice standards (CPS) developed by NRCS (NRCS, 2025a). Currently, rather than creating a new CPS for VF, a long and complex process[2], NRCS has authorized funding for this technology by integrating it within two existing standards: Fence (CPS 382) and Prescribed Grazing (CPS 528) (NRCS, 2025b).

This pairing ensures that funding is tied to environmental stewardship, not simply the acquisition of technology. While CPS 382 sets the criteria for the funding mechanism for the fence itself, the required pairing with CPS 528 ensures its application for conservation purposes, including enhancing soil health, protecting water quality, improving wildlife habitat and reducing wildfire risk (NRCS, 2022a). VF directly supports these goals by enabling dynamic grazing management through virtual paddocks and exclusion zones, facilitating adaptive grazing strategies that are economically and operationally unfeasible with traditional fencing.

Despite these clear benefits, some administrative barriers remain. The primary barrier is a conflict between VF's dynamic, virtual boundaries and certain program rules requiring continuous, physical fences. This discrepancy, combined with the comprehensive planning required by the paired standards, would complicate program participation, potentially reducing adoption, unless addressed by adapting program rules to accommodate VF.

While these administrative challenges require long-term solutions, the current integrated framework offers financial assistance through payment scenarios that combine CPS 382 with CPS 528 (NRCS, 2025b). Once the fencing standard is met, the prescribed grazing plan provides upfront cost-share assistance for VF collars or base stations to support implemen-

[2]National CPS are updated every five years, but can be revised sooner to address technological changes (NRCS, 2025a), thus leaving room for revisions to integrate VF.

tation (NRCS, 2024). Because the Farm Service Agency (FSA) delineates farms by continuous physical boundaries such as physical fences or permanent waterways (FSA , 2006), a practical strategy is to keep a conventional perimeter fence and use program funds to install VF within that boundary for internal paddocks. Table 1 summarizes the major USDA conservation programs that can incentivize VF adoption.

Table 1: VF Eligibility Across USDA Conservation Programs

Program	**Type**	**How VF Fits**
ACEP	Easement + grazing plan	VF supports grazing aligned with wetland protection and working land conservation.
CIG	Competitive grant	VF qualifies as an innovative technology for grazing management and habitat protection.
CRP/CREP	Rental payment + cost-share assistance	VF can be funded under Grassland CRP or integrated into CREP for regional conservation objectives.
CSP	Stewardship payments	VF eligible as advanced grazing management, qualifying producers for supplemental payments.
EQIP	Cost-share assistance	VF eligible for cost-share specifically for internal cross-fencing.
RCPP	Partnership agreement	VF applicable as a key strategy in regional projects addressing rangeland health or wildlife corridors.

- **Agricultural Conservation Easement Program (ACEP)** protects wetlands, working farms and ranches through conservation easements (NRCS, 2025c). VF enables

grazing practices that align with wetland protection and maintaining working lands while enhancing natural resources.

- **Conservation Innovation Grants (CIG)** is a competitive grant program that supports the development and adoption of innovative technologies to address water quality, soil health, and habitat for wildlife while improving agricultural operations on private lands (NRCS, 2025c). VF aligns well with CIG by offering an innovative approach to manage livestock grazing, and supports conservation practices on private lands. Reflecting this fit, the NRCS has funded national CIG projects such as an Oklahoma State University initiative focused on evaluating the efficacy of VF technology and developing guidelines for its successful implementation, and another by the Eagle County Soil and Water Conservation District in Colorado to test the effectiveness of VF in challenging terrain and teach ranchers how to design appropriate grazing rotations (NRCS, 2022b).

- **Conservation Reserve Program (CRP)** provides payments for taking sensitive land out of production for conservation or enrolling working grasslands under Grassland CRP that provides cost-share assistance for approved practices and can cover costs up to 50 percent in establishing approved practices (NRCS, 2025c). VF aligns well with Grassland CRP, as the program is designed to protect existing grasslands from conversion to cropland while allowing for sustainable livestock grazing. Because VF helps producers meet Grassland CRP objectives in an easier and less labor-intensive way, it can encourage greater enrollment in the program. This flexibility offered by VF is crucial, as studies on CRP programs show that ranchers often resist mandatory rotational grazing requirements within program contracts (Kabir et al., 2025). Beyond Grassland CRP, VF also aligns with the Conservation Reserve Enhancement Program (CREP), where it can enable conservation efforts at a large, regional scale.

- **Conservation Stewardship Program (CSP)** offers financial assistance for existing conservation efforts and encourages the adoption of new technologies (NRCS, 2025c).

VF can be a relevant "enhancement" under CSP. Enhancements are management activities that exceed the minimum requirements of a CPS, allowing producers to achieve a higher level of conservation practice (NRCS, 2025c). VF technology enables a wide range of enhancements for grazing management and wildlife habitat. It enables producers to meet the complex requirements of enhancement practices like Advanced Grazing Management (E528G) by managing livestock movements based on plant growth, maintaining cover on sensitive areas, or deferring grazing during critical periods. Furthermore, by eliminating physical barriers, VF aligns with the Wildlife friendly fencing (E382A) enhancement, providing passage for species like pronghorn and allowing for seasonal migrations. Adopting VF will qualify producers to receive supplemental payments for implementing such enhancement practices.

- **Environmental Quality Incentives Program (EQIP)** stands as the primary funding source for the adoption of VF (NRCS, 2025c). It provides financial and technical assistance to agricultural producers for conservation practices. It functions as a cost-share program, providing partial reimbursement to producers for the cost of implementing approved practices. VF is now eligible for cost-sharing under EQIP, but it is allowed only for cross fencing. Through the prescribed grazing (528) plan, effective October 1, 2024, producers can receive significant financial support for the implementation of VF. This includes cost-share rates of 50-60% for the initial system, with rates increasing to 90% for historically underserved producers and beginning farmers. Furthermore, the program may provide payments in years 2-5 to cover ongoing subscription costs (NRCS, 2024). NRCS scores EQIP applications in competitive pools based on how effectively they address national, state, and local environmental priorities. Therefore, a successful application must clearly link the VF system to solving a priority environmental issue.

- **Regional Conservation Partnership Program (RCPP)** provides the ideal frame-

work for scaling up VF from single-ranch use to coordinated, landscape-level solutions, such as protecting wildlife corridors or entire watersheds (NRCS, 2025c).

The aforementioned fit of USDA programs suggests a potential framework for the broad adoption of VF. While the technology's benefits for exclusion and adaptive grazing are promising, moving from pilot projects to widespread use is a significant step. The pathway from CIG testing, to EQIP cost-share, to RCPP landscape projects is logical, but its success will ultimately depend on efforts to refine policy and remove the administrative barriers currently faced by producers.

5 Conclusions

This paper systematically evaluates VF as a tool to create opportunities for conservation management and improving environmental conditions while providing flexibility within livestock management. We summarize how effective VF can be at improving environmental conditions and ecosystem services within grazable rangelands. VF has the potential to promote ecological integrity of rangelands through maintaining or increasing biodiversity, reducing soil erosion and water contamination, and improving rangeland soil health. Recent VF trials underscore the environmental benefits and flexibility in livestock management that this technology can provide.

Our assessment comes with several limitations. First, long-term effectiveness of VF remains uncertain. Also, economic viability and adoption rate might be constrained by the initial investment in base stations. Additionally, practical implementation of VF requires producer education, and cell phone access which might be challenging in under-developed regions.

From a policy standpoint, including VF in conservation incentive programs could increase adoption rates by aligning producer incentives with societal environmental benefits. Policymakers should consider subsidizing initial investment on base stations and providing

education.

Future research should focus on the economic viability of VF and trials to assess broader environmental benefits. Ongoing research coupled with enabling policy frameworks that help to reduce costs and improve VF technology, and provide producer education can fulfill its promise as a cornerstone technology for conservation-minded livestock systems.

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