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Original Research

What's in a Name? Standardizing Terminology for the Enhancement of Research, Extension, and Industry Applications of Virtual Fence Use on Grazing Livestock

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ABSTRACT

Virtual fence (VF) is the use of a global positioning system (GPS) to dictate where on the landscape livestock can graze without relying on traditional physical fence such as barbed wire. The recent acceleration in the development and adoption of VF technology for grazing management has been characterized by the evolution of divergent terminology. Different research and commercial entities have adopted terms and definitions independently. Some terms and definitions are inherently problematic, while others are more aligned, and the simple fact that differences exist contributes to confusion in communication among scientists, producers, land managers, manufacturers, government agencies, and the public. In this paper, we propose a standard terminology determined during a 2-d in-service workshop at the annual meeting of the Society of Rangeland Management in February 2023. Standard terminology will aid in efficient and effective communication among all entities and interested parties.

Introduction

Virtual fence (VF) uses borders without physical boundaries to contain grazing livestock (Umstatter 2011), and is available for cattle, sheep, and goats. The idea behind VF for livestock originates from the Invisible Fence patented by Richard Peck in 1973 (Peck 1973). By 1990 researchers were using remote dog training collars on four Hereford steers (Quigley et al. 1990). The ability to manage livestock grazing through technology like VF has tremendous implications for the 798 million acres of grazing land in the USA (ERS 2017). Since VF is a relatively new technology in grazing lands management, it requires standardized terminology across both scientific and livestock producer communities. As might be expected, terminology among users is variable at this relatively early stage of VF development and adoption. For example, the terms geofence, invisible fence, and stakeless fence have all been used synonymously with "virtual" fence (Anderson 2001; Monod et al. 2009; Umstatter et al. 2015). Consistent terminology can improve the rate of learning and reduce confusion among users of new technologies in rangeland management. Menendez et al. (2022) described many challenges of implementing precision livestock technology into extensive grazing environments and recognized standardization as an important aspect of improving adoption and positive outcomes from these technologies. Standard terminology could in-

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crease the pace of VF technology adoption, and help users avoid costly miscommunication. This paper aims to provide a reference in the literature for suggested terminology and definitions for VF that are applicable to all devices currently available. The authors recognize that language and terminology are continuously changing and updates to this document may be needed periodically to accommodate future advances (Menendez et al. 2022). Below we outline how standardized terminology will benefit scientific communication and improve dissemination to livestock producers, land management agencies, and the public.

Impact of standardized terminology

Benefits to the scientific community

The development of a consensus regarding VF terminology will enhance scientific communication. Specifically, scientific disciplines—including rangeland ecology and management—tend to entrench themselves in specialized vocabulary, i.e., jargon. Jargon is beneficial when working with peer scientists where "each new term enriches the initial message with information, structuring and systematizing concepts into the corpus of science" (Hoyningen-Huene 2013). However, jargon can simultaneously limit scientific communication, both among and between disciplines, and ultimately lead to papers that are "less understood, remembered and ultimately cited" (Martinez and Mammola 2021). A case study using cave literature of over 21,000 articles documented a negative and nonlinear relationship between the number of jargon words and number of citations (Martinez and Mammola 2021); as the proportion of jargon words in the title and abstract increased, the number of citations decreased. This can be especially important considering that scientists skim over 1,100 titles and 200 abstracts per year but read only 97 full texts (Mabe and Amin 2002). Titles and abstracts serve as critical filters and having a clear understanding of terms can aid in the uniformity of the science (Franca and Monsterrat 2019; Freeling et al. 2019). Overall, the current use of jargon words in the scientific field can be both a benefit and a hindrance to communicating science among our peers and ultimately affect the impact of scientific advancements within and across disciplines.

Benefits to communication with stakeholders

Consensus on VF terminology serves the scientific community and will ideally lead to increased inter-disciplinary collaboration with increased visibility (e.g., papers being read and cited), and it will serve scientists and Extension professionals who regularly communicate with audiences who are not scientists. The typical methodology of Extension-based outreach and communication relies on the diffusion and dissemination of information to stakeholders. Diffusion is "the communication process through which an innovation travels or spreads through certain channels from a person, an organization, or any unit of adoption to another within a social system over time" (Kee 2017). Dissemination, in contrast, employs mass communication strategies versus interpersonal communication associated with diffusion (Kee 2017). Both methods of communication are critical to increasing producer adoption of VF, based on the diffusion of innovations theory ("diffusion theory") that classifies adopters of technology into five different types: innovators, early adopters, early majority, late majority, and laggards (Rogers 1962).

Diffusion theory is centered on a bell-shaped curve (Fig. 1) that demonstrates how some individuals, such as innovators (2.5%) and early adopters (13.5%) take little time to adopt new technology (start of the bell curve), in contrast to individuals in the early majority (34%) and late majority (34%, middle of the bell curve), as well as individuals who likely never adopt the technology (laggards, 16%, end of the bell curve; Kee 2017). The separation between the early majority and late majority is that the early majority adopts the new technology right before the average member of a system does, while the late majority is more cautious and adopts the new technology due to economic necessity or peer pressure (Kee 2017). Avoiding jargon and standardizing terminology is one method to reduce miscommunication, particularly among innovators and early adopters. This aligns well with one of the key attributes that influence the likelihood of adoption, which is how complex or difficult innovation is to use and understand (Rogers 1962; Kee 2017). The adoption of VF for the improvement of rangeland management must occur via the innovators and early adopters and trickle down to the early and even late majority. Thus, standardized terminology will facilitate understanding by livestock producers and land managers.

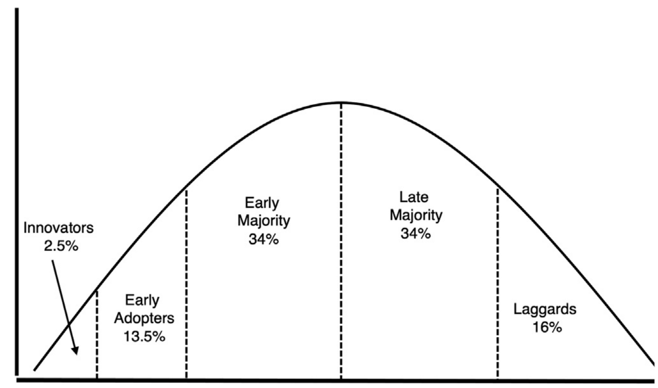

Figure 1. The diffusion of innovation theory (Rogers 1962; Kee 2017), that classifies adopters of technology into five different types, as noted in the figure. The diffusion of innovation theory is critical to the adoption of virtual fencing.

Benefits to VF development

Effective and clear communication with livestock producers and land managers that avoids jargon and instead uses standardized terminology also has direct benefits to VF developers. Moreland and Hyland (2013) expand on diffusion theory, meshing it with "technology-push" and "demand-pull" communication strategies. In essence, technology-push relies on the invention of new technology being "pushed" to end-users, which contrasts with demand-pull strategies where the end-user—in the case of VF, a producer or land manager—identifies an issue that can be solved with innovation (Camp and Sexton 1992; Moreland and Hyland 2013). While VF for livestock originated in a specialized setting, as a management technology for grazing livestock producers, it would greatly benefit from broader accessibility beyond the confines of technical jargon understood only by engineers and researchers. Instead, having the end-users (i.e., producers, and land managers) contribute to the product design and adoption of VF on meaningful scales requires that they can communicate and understand the associated terminology. Producer feedback and innovative ideas have been noted as contributors to design enhancements of several VF technologies (*Personal communication*). This is underpinned by Dahlstrom (2018) who emphasized several strategies to effectively communicate science, with one strategy being avoiding jargon.

Benefits to public perception

Aspects of VF (e.g., use of an electrical cue) may be concerning to some members of society, and avoiding inflammatory terminology may reduce negative emotional responses during discussions

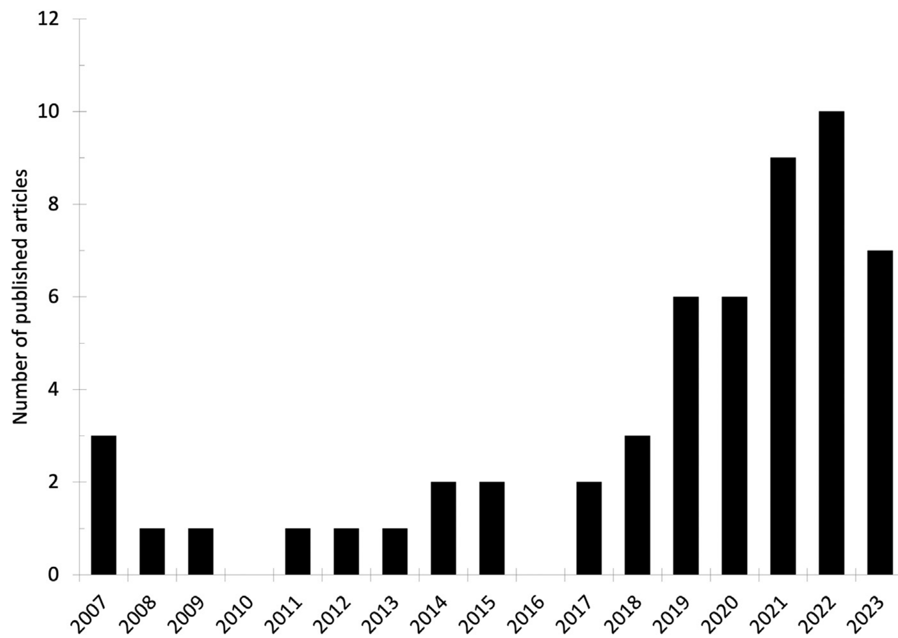

Figure 2. The number of articles published from 2007 to 2023 ($n = 55$) using a Web of Science search for peer-reviewed articles with "virtual fence" and "cattle" or "sheep" or "goat" in the title or "virtual fence" as a keyword with "cattle" or "sheep" or "goat" in the title. Note that the Web of Science query displayed results starting in 2007 and therefore does not account for earlier publications.

of animal welfare and livestock agriculture. Dahlstrom (2018) further states communicating science requires an understanding that facts—accurate and credible information—will always be filtered through a person's respective values and beliefs. While discord is inevitable, it is best navigated when both parties understand what the other is referring to, by avoiding jargon. For example, most VF systems available at the time of publishing rely on an auditory cue followed by an electrical cue. Sometimes, the latter is referred to as a "shock," which carries a connotation that the animal is being physically hurt. In this example, terminology can be inflammatory to groups that seek to regulate livestock production in the name of animal welfare. Instead, we suggest that "electrical cue" be used to describe the low-frequency electrical signal sent through a VF device when triggered by the animal crossing the boundary zone. Once all current parties understand and agree to the definition of what is happening to the animal they can then filter and interpret the proposed terminology through their value system (Dahlstrom 2018).

This paper suggests terms and their associated definitions and provides evidence from associated literature of how variable terminology has been. The need for clear terminology in this space was first highlighted by Anderson et al. (2007), where it was suggested that terms were inadequately documented and incompletely understood because VF research continued to evolve and be shaped by researchers and practical users. VF research has rapidly advanced, especially in the last 5 yr (Fig. 2), we recognize that the suggested terminology and definitions are not exhaustive; however, we strive to provide a foundation of terminology that can be used by experts, producers, and land managers moving forward.

Further, standardizing terminology is not novel, even in range and animal science. Allen et al. (2011) published an international terminology for grazing lands and grazing animals. The methodology used by Allen et al. (2011) consisted of a task force/working group that came together because of a resolution passed by the International Grassland Congress and International Rangeland Congress, centered largely on discussions with members of the working group. This was an update to the terminology published in 1991, providing evidence of "a living language." Our efforts and methods outlined below mirror those of Allen et al. (2011), who had the intention of fostering clear communication across international boundaries and improving communication within and among education, science, industry, and production, such that it becomes the standard for use in publications.

Methods

VF working group

Approximately 10 researchers and extension specialists from land-grant institutions across the USA and the USDA convened virtually as the VF Working Group in the summer of 2021, with the intent to foster interdisciplinary research and extension efforts across state lines. The University of Arizona (UA) became the coordinating institution for the VF Working Group, supported by South Dakota State University (SDSU). Participating institutions in the VF Working Group currently include UA, SDSU, University of Nebraska—Lincoln, Oklahoma State University, University of Nevada—Reno, Colorado State University, Oregon State University, Montana State University, Kansas State University, North Dakota State University, and the USDA-Agricultural Research Service. The VF Working Group began meeting monthly to share research updates and generate ideas for grant proposals. A result of these meetings was a grant effort sponsored by a USDA-NIFA Agricultural Genome to Phenome Initiative (AG2PI) Seed Grant that sponsored an in-person meeting focused on standardizing data management and terminology for increased adoption of VF systems. The cumulation of these efforts was a VF in-service workshop at the 2023 Society for Range Management (SRM) Annual Meeting in Boise, ID.

VF in-service workshop—SRM annual meeting 2023, boise

The VF in-service workshop was held for two full days prior to the SRM Annual Meeting. With approximately 75 participants in attendance, the goal of the workshop was to bring together individuals and research teams working on VF systems to share

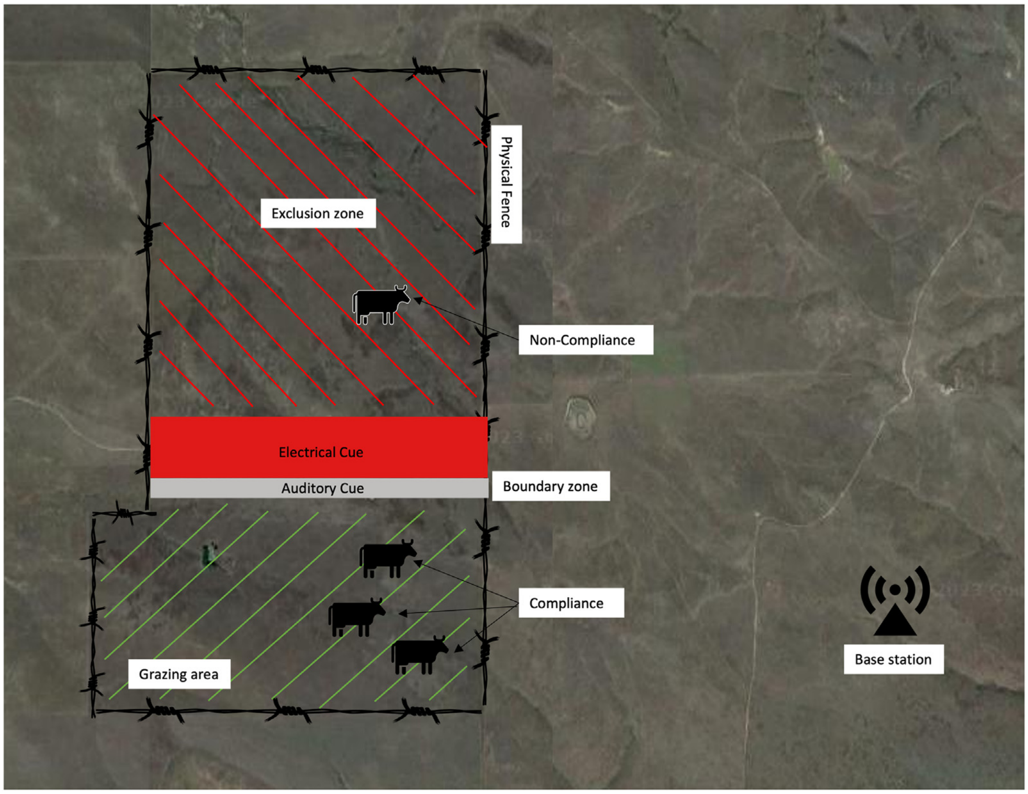

Figure 3. A schematic of a virtual fence (VF) system on the ground, providing a visual representation of the proposed terms, specifically the difference between the grazing area and the exclusion zone, with the components of a VF system: electrical and auditory cues, compliance and non-compliance, base station(s), and boundary zone. Note that the boundary zone encompasses only the auditory cue.

knowledge of ongoing projects, and lessons learned, and provide a framework for how VF systems are discussed, analyzed, and reported. Many groups were represented, with individuals from state and federal agencies, universities—extension and research, livestock producers, industry—including different VF companies, and non-government organizations (NGOs). Some of the discussions centered on developing a consensus on VF terminology that both researchers and extension specialists agreed upon. A table of terms associated with VF was presented, and participants in the workshop were given time to discuss the terms in small groups followed by a larger group discussion about changes to both the terms and definitions. Those changes have been incorporated into the terms and definitions presented below and represent the collective agreement of the VF Working Group and the participants in the workshop.

Terminology consensus

Table 1 presents proposed terms, definitions, variations in previously published work and/or VF Working Group discussions, and other rationale that was the result of discussions among members of the VF Working Group and workshop participants. Terms relate to how VF works—that is, explaining how the system works to another scientist, land manager, or producer. Literature cited under "Term Variation" represents papers that have conducted VF experiments. Figs. 3 and 4 represent the use of the proposed terms in application.

For example, a VF is established such that the animals with active VF devices can enter and remain inside the *grazing area.* This contrasts with an *exclusion zone,* where animals with VF devices are not allowed to enter for a specified time period. Riparian (Campbell et al. 2018, 2020) or burned areas (Boyd et al. 2022) are common examples of exclusion zones. Variations in terminology for both examples elicit animal welfare concerns, with the former being previously referred to as a "containment area" (Fay et al. 1989) and the latter called an "aversion zone" (Quigley et al. 1990). Similarly, we propose an *auditory cue* to describe the high-pitched sound emitted by a *VF device*, such as a collar, when the animal enters the boundary zone and an *electrical cue* to describe the low-frequency electrical signal sent through the device when the animal crosses the boundary zone. The latter contrasts with variations in previously published literature, with terms used of "shocking" (Fay et al. 1989) or "electrical stimulation," (Bishop-Hurley et al. 2007) both of which have direct, and negative implications associated with them for animal welfare.

There are other terms in Table 1 that do not have copious variations in the literature with respect to the term itself, but rather lacked clarity on the definition. *Compliance* and *effectiveness* are such terms. *Compliance* has been alternatively described as "untrainable" (Fay et al. 1989) and "penetration" (Anderson et al. 2004). We propose that *compliance* be defined as the ability of an animal to learn the boundary zone through the negative reinforcement associated with the auditory and electrical cues and to stay within the grazing area and not enter any exclusion zones. *Effectiveness* has previously been described by "time in the grazing zone" (Anderson 2007) and "percent of daily locations" (Boyd et al. 2022). We propose that the term used is *effectiveness*, with the definition: the percent time an animal is contained within a grazing area; it may be represented by the percent of global positioning system (GPS) points within a grazing area. Note that this combines the concept alluded to by Anderson (2007) and Boyd et al. (2022) and synthesizes it under one proposed term. We refer the reader to Table 1 for additional proposed terms and definitions.

Table 1
Proposed and previously published virtual fencing (VF) terminology use, alphabetized by the proposed term, with term variations alphabetized and included from the literature that conducted VF experiments, where applicable.

Proposed term	Proposed definition	Term variations	Other rationale
Active move	A VF is moved toward a particular goal (e.g., new paddock, corral, etc.), forcing the animals to move toward that goal.	■ Mustering or herding (Campbell et al. 2021)	
Grazing area	The area in which the animals with active VF devices can enter and remain inside without receiving auditory or electrical cues. The opposite of an exclusion zone.	■ Accessible area (Hamidi et al. 2022) ■ Allowable grazing area (Quigley et al. 1990) ■ Containment area (Fay et al. 1989) ■ Containment zone (Nyamuryekung'e et al. 2023) ■ Grazing zone (Tiedemann et al. 1999) ■ Inclusion zone (Vence Merck Animal Health; Lomax et al. 2019; McSweeney et al. 2020; Verdon et al. 2020) ■ Virtual paddock (Anderson et al. 2004);	
Auditory cue	A high-pitched sound that is sent by the VF device when triggered by the animal entering the boundary zone, as a warning and negative enforcement that the animal is about to cross the boundary zone.	■ Actuators (Palmer et al. 2004) ■ Auditory or audible cue or sound (Bishop-Hurley et al. 2007; Lee et al. 2009; Vaintrub et al. 2021) ■ Audio cue signal or audio tone (Campbell et al. 2019; Marini et al. 2018; Verdon et al. 2020) ■ Audio stimulus (Quigley et al. 1990) ■ Audio tone, audio cue, neutral stimulus vs aversion stimulus (Campbell et al. 2019) ■ Audio electrical stimulus (Quigley et al. 1990; Tiedemann et al. 1999) ■ Audio warning (McSweeney et al. 2020; Tiedemann et al. 1999; Umstatter 2011) ■ Cue and consequence/sensory stimulus (Bishop-Hurley et al. 2007) ■ Electromechanical cue (Anderson 2007) ■ "Pressure" ■ Warning tone (Fay et al. 1989)	The combination of the auditory and electrical cues in some literature (e.g., "audio electrical stimulus" (Quigley et al. 1990) or "electromechanical cue" (Anderson 2007) suggest that these two cues from the VF device occur simultaneously when for most systems, the auditory cue is given as a warning, followed by the electrical cue.
Base station	The device that acts as a transmitter/receiver using long-range radio (LoRa), cellular network, and/or satellite. Needed by some systems to transmit the VF to VF devices and to gather information from the VF devices (locations, status, cues delivered, error messages, etc.)	■ Base station (Boyd et al. 2022; Campbell et al. 2019) ■ Ground-based transceivers (Anderson 2001) ■ Transmitter (Tiedemann et al. 1999)	An alternative term, "gateway," could also be confused with a ranch gate, to an unfamiliar person. Another alternative, "tower," evokes images of a large cell phone tower, and has permitting implications on public lands.
Boundary zone	A set amount of space is associated with the VF. Acts as a warning buffer to the animals to not proceed any further, preventing "fence" crossover. The boundary zone only contains the auditory cue.	■ Auditory zone (Boyd et al. 2022) ■ Signal boundary (Tiedemann et al. 1999) ■ Virtual barrier (et al. 2018) ■ Virtual boundaries (Anderson et al. 2004; Jachowski et al. 2014) ■ Virtual fence boundary (Colusso et al. 2020; Lee et al. 2009; McSweeney et al. 2020; Verdon et al. 2020) ■ Virtual fence line (Hamidi et al. 2022) ■ Warning zone (Confessore et al. 2022)	
Device (VF device)	A device—e.g., a collar or ear tag—that transmits/receives GPS, LoRa, or both.	■ Platform (Anderson 2007)	
Compliance	The ability of an animal to learn the VF through the negative reinforcements (i.e., auditory, and electrical cues) and stay within the designated area (i.e., grazing area) and not enter any exclusion zones.	■ Penetration (Anderson et al. 2004)	
Effectiveness	The percent time an animal is contained within a grazing area; it may be represented by the percent of GPS points within a grazing area.	■ Effectiveness (Campbell et al. 2020; Ranches et al. 2021; Hamidi et al. 2022) ■ Time in the grazing zone (Anderson 2007) ■ Percent of daily locations (Boyd et al. 2022) ■ Percent of successful interactions out of total interactions; successful interactions classified as the animal being held inside the boundary during the interaction (Jero 2022)	

(continued on next page)

Table 1 (*continued*)

Proposed term	Proposed definition	Term variations	Other rationale
Electrical cue	Low-frequency electrical signal that is sent through the VF device when triggered by the animal crossing the boundary zone. Varies in exact frequency, intensity, duration, etc. by VF manufacturer.	■ Audio electrical stimulus (Quigley et al. 1990; Tiedemann et al. 1999) ■ Cue and consequence/sensory stimulus (Bishop-Hurley et al. 2007) ■ Electromechanical cues (Anderson et al. 2007) ■ Electrical pulse, electrical stimuli (Campbell et al. 2019; Lee and Campbell 2021; Lomax et al. 2019; Verdon et al. 2020) ■ Electric stimulus (Marini et al. 2018; Quigley et al. 1990; Umstatter 2011) ■ ELECTRICAL stimulation (Bishop-Hurley et al. 2007) ■ "Pressure" ■ Shock (Boyd et al. 2022) ■ Shocking or electric shock (Aquilani et al. 2022; Fay et al. 1989; Lee et al. 2009; McSweeney et al. 2020) ■ Vibration cues (Anderson 2007)	See note above about the combination of the auditory and electrical cues in some literature.
Exclusion zone	The area in which the animals with VF devices are **not** to enter. The "outside" area of the VF, opposite or away from the grazing area. It may also include areas where animals are actively excluded such as riparian zones.	■ Aversion area (Quigley et al. 1990) ■ Electrical stimulus zone (Boyd et al. 2022); ■ Exclusion zone (Colusso et al. 2020; Lee et al. 2009; Lomax et al. 2019; Marini et al. 2018; McSweeney et al. 2020; Tiedemann et al. 1999; Umstatter et al. 2015; Verdon et al. 2020) ■ Management zone (Ranches et al. 2021) ■ Nonaccessible area (Hamidi et al. 2022) ■ Restricted zone (Nyamuryekung'e et al. 2023) ■ Standby zone (Monod et al. 2009)	
Noncompliance	The inability or unwillingness of an animal to learn and accept the VF through the negative reinforcements (i.e., auditory, and electrical cues) and stay within the designated area (i.e., grazing area). The animal enters the exclusion zone.	■ Untrainable (Fay et al. 1989)	
Passive move	A VF appears "invisible" to an animal until after the animal naturally crosses it, and then the VF becomes active, thereby preventing the animal from returning to the previous area.	■ One-way gate ■ Passive capture	
Physical fence	A permanent or temporary fence constructed of physical material (e.g., barbed wire, wood, metal, electrified wire, etc.).	■ Conventional fences (Marini et al. 2018; Umstatter 2011) ■ Hard fence ■ Traditional fence (Lee et al. 2018)	
Physical herd	Animals in a pasture, rangeland, or field that are managed as a group.		
Trained animals	The portion of a herd that effectively responds to VF. These are animals for which VF is expected to be successful at containing the animals to the allowable grazing area. Various training protocols exist. Successfully trained animals stay within the grazing area X% of the time, with X dependent on management objectives.		
Virtual herd	A group of animals/VF devices represented in the software/application/online platform to which VF are assigned/managed.		
Virtual fence (VF)	An invisible boundary that is electronically generated (Anderson 2007) and controls animal behavior using auditory and electrical cues.	■ Boundary without a physical border (Umstatter 2011) ■ Directional virtual fencing (Anderson et al. 2004) ■ Fenceless livestock control (Markus et al., 2014) ■ Geofence ■ Invisible barrier (Quigley et al. 1990) ■ Invisible fence (Anderson 2001; Fay et al. 1989; Umstatter et al. 2015) ■ Virtual fence (Anderson 2007)	

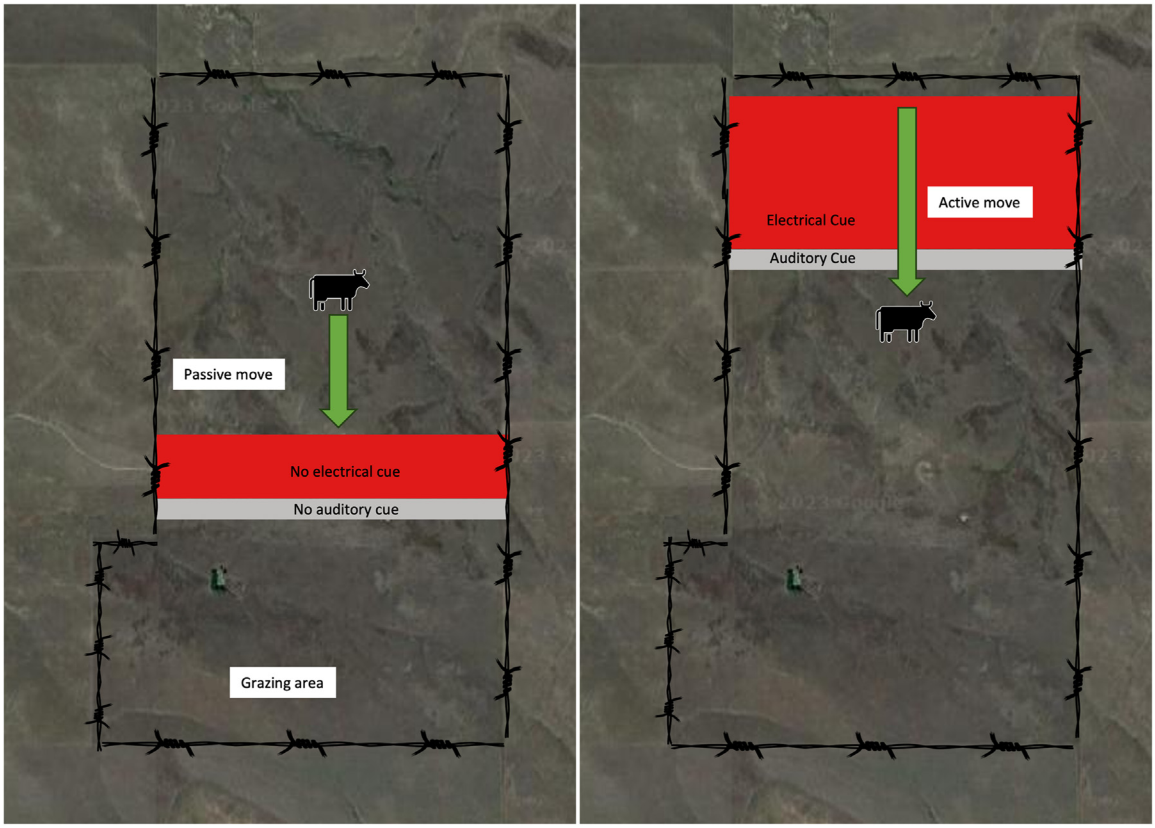

Figure 4. A schematic of a virtual fence (VF) system on the ground, provides a visual representation of the proposed terms, specifically the difference between a passive and active move. Note that in an active move, the electrical cue and auditory cue "move" behind the animal, moving it toward a new area of pasture.

Discussion

The lack of standardized terminology with respect to VF leaves terms and definitions open for interpretation. The suggested terms and definitions outlined in this paper are a starting point to foster both communications between and among scientists and dissemination to producers, land managers, and the public. To our knowledge, there has been no other effort to standardize VF terminology. This is despite several tools that currently exist for terminology. First, the Rangelands Gateway is a website developed by The Rangelands Partnership—a consortium of 20 land-grant institutions within the USA that creates and assesses rangeland ecology content for rangeland professionals. Within the Rangelands Gateway is a Glossary of rangeland terms; "virtual fencing" and its associated derivatives are not found within the Glossary (Rangelands Gateway 2023). This Glossary is the same one that is linked to from the SRM website. Additionally, a second tool called RangeDocs developed by several research institutions with support from The Rangelands Partnership, is a website with both collections of rangeland literature and a glossary. A search in both resources for "virtual fencing" yields no results (RangeDocs 2023). Taken together, these examples are further evidence that VF is a newer technology such that it has not yet been incorporated into literature databases and glossaries.

Overall, there are several advantages to standardizing VF terminology. First, it will increase communication and understanding across the globe as scientists from different regions, speaking different languages, can quickly understand each other. Second, specialists and those in Extension roles can more effectively relay the benefits and challenges of VF adoption to producers and land managers. Third, livestock producers and land managers themselves will have the same terminology as the researchers, thereby facilitating user feedback to VF developers to assist them in overcoming applied challenges in product design and implementation that producers and land managers face. Lastly, standardized terminology can enhance conversations where viewpoints based on value systems conflict. Additional benefits may accrue when governmental agencies must communicate precisely about VF in regulations and conservation programs.

Implications

Standardized terminology and the absence of jargon in scientific communication will foster collaboration and knowledge sharing across the globe, furthering research efforts and applications of VF. Landscape-scale impacts of VF will only be achieved with widespread adoption, following the diffusion of innovations theory. This requires clear communication with livestock producers and land managers, who will then benefit from standardized terminology and easier facilitation of feedback and barriers to adoption. Standardization also provides a base for opposing viewpoints to start from. While we have successfully achieved the task set forth by Anderson et al. (2007), it is essential to acknowledge that the terms and definitions presented in this paper are subject to future review as VF technology and research continue to evolve.

Declaration of Competing Interest

None.

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