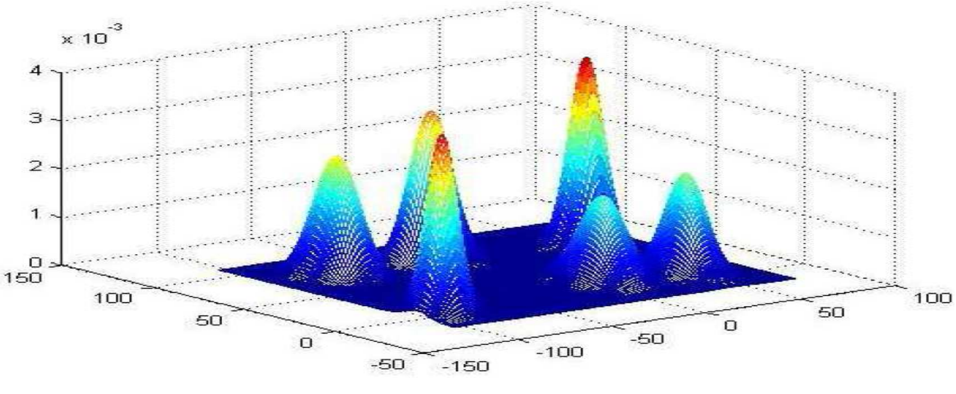
PROCEEDINGS
OF THE
SPATIAL GRAZING BEHAVIOUR WORKSHOP



JUNE 2006
J M RENDEL LABORATORY
ROCKHAMPTON

This workshop funded by the
"Water for a Healthy Country National Research Flagship"

Water for a Healthy Country is a national research program focusing on water, its uses and values. Our scientists are developing the technologies and information needed to protect Australia's rural and urban landscapes and ecosystems, provide safe and clean drinking water, manage our rivers, wetlands and estuaries, and ensure the sustainable use of our water resources.

CSIRO

Workshop organised by Dave Swain, Ed Charmley and Greg J. Bishop-Hurley, CSIRO, Livestock Industries, Rockhampton, QLD 4701, Australia. Proceedings of the Spatial Grazing Behaviour Workshop held on the 14th and 15th June 2006 at J M Rendel Laboratory, Rockhampton, QLD 4701, Australia. Articles published in these proceedings were invited presentations at the workshop. Text and figures were edited for style and content. The proceedings were edited by G. J. Bishop-Hurley, Autonomous Livestock Systems Group, Livestock Industries, CSIRO, J M Rendel Laboratory, Rockhampton, Queensland 4701, Australia.

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Program

Start time	**Day 1**
8:00 am	Registration
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	Session I: Livestock monitoring
8:45 am	Doug Veira, Agriculture and Agri-Food, Canada. Meeting livestock water requirements on the Canadian prarie
9:30 am	Leigh Hunt, CSIRO – Sustainable Ecosystems. Monitoring cattle movement in northern Australia using GPS
10:15 am	Morning tea
10:45 am	Introduction by breakout session facilitator
11:00 am	Breakout session: Livestock monitoring
12:00 pm	Summary of livestock monitoring breakout session
12:30 pm	Lunch provided
	Session II: Livestock modelling
1:30 pm	Julian Derry, University of Edinburgh. Modelling in Northern Queensland
2:15 pm	Ying Guo, CSIRO – Information & Communication Technologies. Modelling livestock movement and behaviour
3:00 pm	Afternoon tea
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3.45 pm	Breakout session: Livestock modelling
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	Day 2
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8:30 am	Andrew Fisher, CSIRO - Livestock Industries. Towards automated animal control through understanding animal behaviour
9:15 am	Dean Anderson, USDA-ARS. Virtual fencing – concept into reality
10:00 am	Morning tea
10:30 am	Introduction by breakout session facilitator
11:00 am	Breakout session: Livestock management
12:00 pm	Summary of livestock management breakout session
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	Session IV: Belmont tour
1:30 pm	Depart for tour of Belmont Research Station
4:30 pm	Back to JM Rendel Laboratory

Virtual Fencing – A Concept into Reality

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Abstract

Virtual fencing is a method of controlling animals without ground based, natural or man made structures. Control occurs by altering an animal's behaviour through one or more sensory cues administered to the animal after it has attempted to penetrate an electronically generated 3-dimensional boundary. This boundary can be any geometrical shape and though unseen by the eye, is detected by an electronic computer system worn by the animal. Autonomous programmable systems use an electronic signal, most commonly from the Global Positioning System (GPS) of satellites that emanate electronic signals in the radio frequency (RF) range. Algorithms within a Geographic Information System (GIS) use these data to determine if a cue should be applied and if so what cue(s), where on the body the cues should be applied and for how long. The first commercial virtual fencing system, patented in 1973 for controlling domestic dogs, was successfully used in 1987 to contain goats in the first experiment to control livestock using virtual fencing. Since then researchers using commercial as well as custom designed systems have successfully demonstrated proof-of-concept that virtual fencing can successfully hold as well as move livestock over the landscape. Commercial virtual livestock control systems do not yet exist; however, research in Australia and the United States continues toward this goal. Pending research needs relating to this method of animal control are discussed in light of currently available technologies.

Background

Fencing is designed according to the animals being controlled. Fences encompass a variety of materials (Pickard 1992) ranging from natural to man made, but are always built with the same purpose - to control animal ingress or egress. With the longest conventional fence in the world, Australians were attempting to control dingos (Glen and Short 2000). In America, fences were the single greatest item of expense in production agriculture in the 19th century (Simmons 1935) and remain a substantial expense today (Mayer and Olsen 2005). However, today fencing costs extend far beyond simple economics and include social and environmental concerns (Ben-Shahar 1993; Boon and Hobbs 2004).

Though smooth wire dates to 400 AD, it was not until the 1870’s that wire was successfully used to control animals once points or barbs were added. Over a period of six years and nine patents ending with Joseph Glidden’s patent No. 157,124 issued November 24, 1874, life in the American West was reshaped with the invention of barbed wire (Ray and Schamel 1997; Trew 2005). It is impossible to affix an exact name, date and location as to when the concept of virtual fencing was first conceived.

Surely it must have evolved early in the antiquity of pastoralists (Galaty and Johnson 1990) as herdsmen went about their daily routine to control livestock, or possibly when humans began to think of ways to reduce labour and time required to control animals in lieu of growing hedges, cutting timber, gathering stones, or moulding mud into barriers.

I would like to believe it may have originated during a scenario similar to the following.

> The story involves a polled bull, some cows, an exact number not given and a rather drowsy, rotund young lad living near Laggan. This was a part of Scotland where fences were scarcely known. The lad had been hired by the owner of the stock to keep watch and prevent them from entering and destroying a nearby corn field. Unfortunately the young lad was often found asleep and therefore was severely chastised whenever he would awake and it was found the cattle had trespassed. In his "unsparingly revenged" response to his chastisement he would use a "long switch" to return the cattle to the area from which they "trespassed." Apparently this routine was observed by the bull and he eventually was found to take a threatening stance between the cows and the boundary and use his large forehead to strike cows if they approached and attempted to cross the boundary. Soon this "honest and vigilant" behavior on the part of the bull became so obvious the lad's services in controlling the cattle were no longer needed and he was "re-employed in weeding and other business" without fear of the cattle straying from the area to which they had been assigned (Instinct Displayed, Letter 34 page 6 in Youatt 1836).

Nearly 47% of the world's land surface, approximately 13 x 10^9 ha (32 x 10^9 ac; FAO 1987), consists of marginal lands (rangelands) that are too rocky, too droughty, too steep, too poorly drained or too inaccessible for conventional row crop agriculture (Williams *et al*. 1968; Stoddart *et al*. 1975). Furthermore, the world's population is expected to reach 9.4 x 10^9 by 2050 (United Nations 1998). Therefore, it becomes obvious that free-ranging animal management will of necessity increase in importance as demand for food and fibre increases throughout the world (Heitschmidt and Taylor 1991).

This paper focuses on one particular type of fencing that has been generically termed virtual fencing. Virtual fencing uses electromechanical cues to make the animal aware of a boundary and subsequently elicit behaviours to alter the animal's direction of movement in a manner similar to conventional sight based fencing. In this paper cue and stimulus are used interchangeably and refer to any event perceived by the animal that subsequently produces a noticeable change in the animal's behaviour.

This paper will attempt to coalesce the current state of virtual fencing and present some of the unresolved challenges that must be answered before virtual fencing becomes an alternative for resource managers to consider when controlling free-ranging animals.

Virtual fencing

Richard Peck is credited with turning the concept of virtual fencing into reality. He filed for a U.S. patent in December 1971 and received a patent describing a method and apparatus for controlling an animal (Peck 1973). Pet containment systems are big business in the United States with sales of electronic fences growing from $8 million in 1990 to $150 million in 2000 (Salmon 2000). Radio Systems Corporation research indicated U.S. pet owners in 2001 purchased more than 2 million remote training devices, pet containment systems and bark collars with unit sales of electronic training devices projected to reach 4 million annually by 2007 (Brudecki 2004).

Equipment manufactured by Peck’s Invisible Fence® Company provided the first virtual control device used on domestic livestock (Fay *et al*. 1989). Since this initial research in 1987 in which virtual fencing was successfully used to contain meat-type goats on leafy spurge (*Euphorbia esula* L.), research has focused on attempting to control cattle using various prototype devices to establish proof-of-concept that virtual fencing is a viable method of animal control (Quigley *et al*. 1990; Markus *et al*. 1998a and b; Tiedemann *et al*. 1999; Anderson 2001; Butler *et al*. 2004; Bishop-Hurley *et al*. 2005). Other virtual fencing devices have been proposed, but to date have not been built or extensively field tested (Rose 1991; Rouda 1999; 2003; Rouda *et al*. 2000, Ravsten Farms, Bonham, Texas, personal communication, 2004). The web contains advertisements from companies in South Africa (http://www.geoft.co.za/home.htm) and North America (http://www.agritechelec.com) that claim to be developing virtual fencing devices for free-ranging animals.

Prior to the proof-of-concept research by Anderson (2001), ground-based transceivers were used to define the perimeter of the virtual fence polygon. The first recorded control of a free-ranging cow using the concept of virtual fencing combined with Global Positioning System (GPS) technology was recorded on April 2, 2001.

Global Positioning System (GPS) and animal location

When satellites are used to determine an object’s location on a landscape, it is conceptually a short step to automating control of the object. The most recent utility (Hurn 1993) available to mankind for this type of automation is the Global Positioning System (GPS; Hurn 1995; Herring 1996; Eng 2004). Technically, GPS is simple in concept but incredibly complex in implementation. Developed in the late 1960's and early 1970's for precise timing and space-based navigation by the US Navy and Air Force, respectively, it was not fully operational until the 1990's (McNeff 1999). Since that time, GPS has evolved into a utility used daily by tens of millions throughout the world (Rizzo 2006). GPS technology relies on a constellation of approximately 24 operational satellites managed by the National Space-Based Positioning, Navigation and Timing (PNT) Executive Committee, supported by the PNT Executive Secretariat (http://pnt.gov/); U.S. Coast Guard Navigation Center 2005). GPS satellites circle the earth twice daily (11 hr 58 min/orbit) at an altitude of about 20,000 km (12,927 miles) in one of six orbits at an inclination of 55^{o} (Krüger *et al*. 1994). To obtain very precise and accurate locations, a minimum of four satellite signals must be available (Hurn 1993). Other satellite systems, including Galileo, which launched its first satellite on December 28, 2005 and the Global Navigation

Satellite System developed by the Russians in 1983 and fully functional in December 1995, will help to alleviate the threat of a single system failure (Ashjaee *et al*. 2006; Space Today Online 2006). The most useful practical modification of GPS technology for locating objects was the elimination of selective availability (SA) at midnight on May 1, 2000, allowing civilian users to pinpoint locations up to ten times more accurately ± 20 m (65 ft) than the ± 100 m (328 ft) previously advertised accuracy (Divis 2000). Recent research by the author showed measurement error accuracies (standard deviations) of 1 to 3 m are possible using low cost Trimble® receivers without special processing during periods of cattle inactivity. However, to insure a further refinement in accuracy, Differential Global Positioning System data (DGPS; Hurn 1995; Moen *et al*. 1997) can be used.

The first study that employed GPS to locate animals began in March 1994 using collars designed and manufactured by Lotek® Engineering Inc. (Newmarket Ontario, Canada; Rodgers and Lawson 1997). To date, GPS systems have been used successfully to track domestic sheep (Roberts *et al*. 1995; Rutter *et al*. 1997; Hulbert *et al*. 1998) and cattle (Udal *et al*. 1998; Udal *et al*. 1999; Turner *et al*. 2000; Schelecht *et al*. 2004; Ungar *et al*. 2005; Ganskopp and Bohnert 2006) as well as numerous wildlife species (Austin and Pietz 1997) with accuracies never before possible (Tomkiewicz 1997; Hulbert and French 2001). Recently shock collars for training dogs (Files 1999) and devices to control large animals (Marsh 1999; Anderson and Hale 2001; Bishop-Hurley *et al*. 2005; Butler *et al*. 2006) have incorporated GPS technology.

With satellite technology have come devices that can control both animal location and direction of movement (Manning 1998; Anderson and Hale 2001). Though ground-based transceivers are not required, other challenges arise with satellite generated radio frequency (RF) signals, including, e.g., forest vegetation canopy which may (Spruce *et al*. 1993; Rempel *et al*.1995) or may not (Bennett *et al*. 1997; Biggs *et al*. 1997) affect RF reception.

What we already know

The most obvious ecological goal that will be realized with virtual fencing involves managing animal distribution (stocking density) in a temporal context. However, virtual fencing will impact the life style of those who choose to adopt it. Dairy farmers in The Netherlands, Australia and New Zealand apparently embrace the concept of virtual fencing not only to optimize their "bottom line" but also because it promises a life-style more like those with a nine to five job (Kees Lokhorst, Agrotechnology and Food Innovations, personal communication 2004; Tom Davison, Dairy Australia, personal communication 2005).

However, if absolute animal control is required, virtual fencing should not be chosen. The reason is simple, animal behaviour is never 100% predictable. If health or safety of either humans or animals would be compromised, then virtual fencing should be avoided. Frequently in range animal ecology, ecosystem health rather than safety issues are the focus of paramount concern and virtual fencing offers many exciting possibilities to enhance ecosystem health.

Directional Virtual Fencing (DVF™)

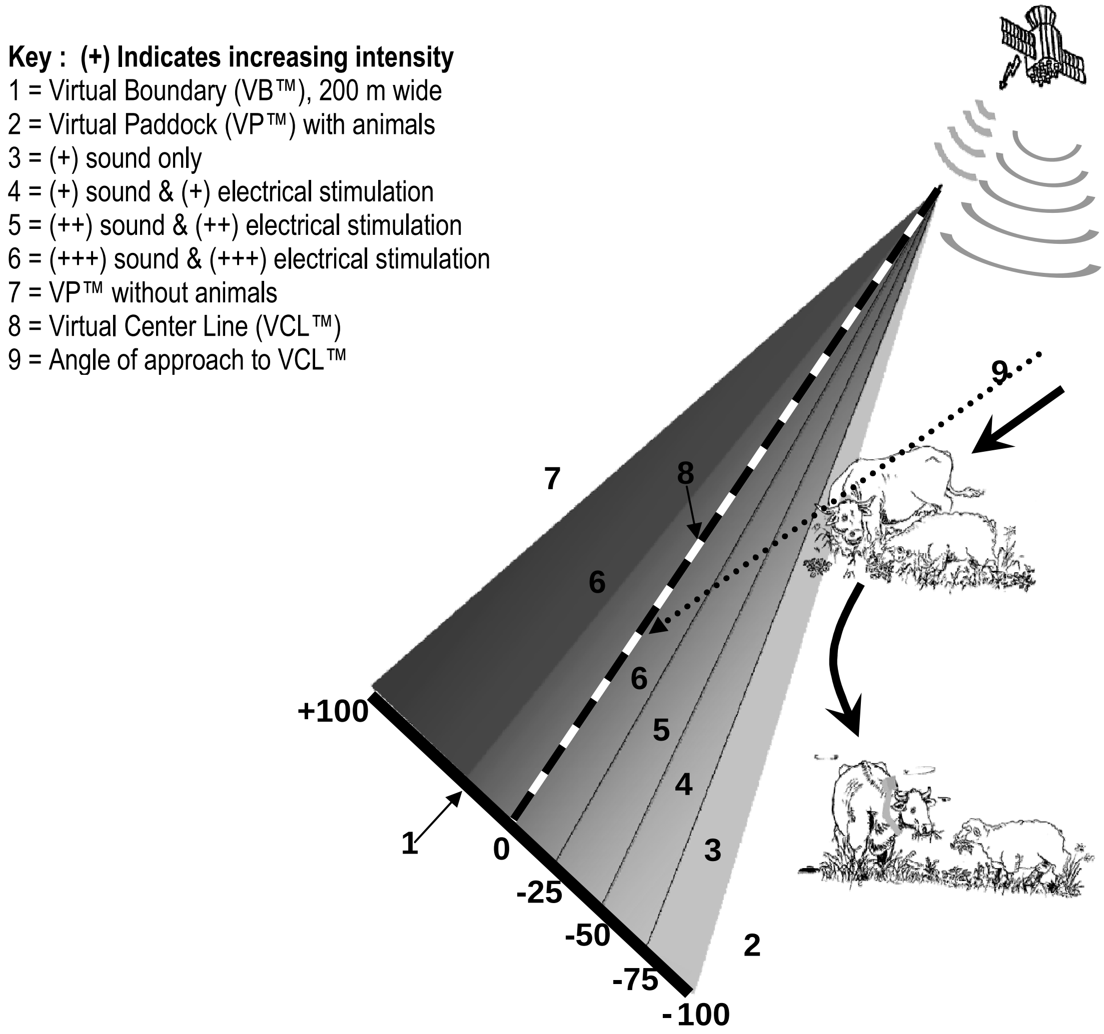

Figure 1. Schematic representation of how Directional Virtual Fencing (DVF™) operates. A magnetometer located in the DVF™ device worn on the animal’s head or neck determines the animal’s angle of approach to the Virtual Center Line (VCL™). Once the animal penetrates the Virtual Boundary (VB™), determined with the systems Global Positioning System (GPS), algorithms in the unit’s Geographical Information System (GIS) use these data to determine to which side of the animal and how intense the electromechanical stimulation (cues) should be to cause the animal to turn away from the VCL™ and return to the Virtual Paddock (VP™) in the shortest distance and time. The VCL™ represents where a conventional fence would be constructed. (Adapted from Anderson *et al.* 2003)

Directional Virtual Fencing (DVF™; Comis 2000; Anderson and Hale 2001; Anderson 2001) is a patented method to autonomously control an animal’s location and subsequently its direction of movement on a landscape by applying bilateral cues that capitalize on innate behavioural responses; i.e., animals will initially move away from an irritating sensory cue. The current DVF™ design has successfully held animals behind a static boundary (Anderson *et al.* 2003; 2004) as well as within a paddock programmed to move in time and space across the landscape (Anderson *et al.* 2004). This methodology involves the use of Virtual Boundaries (VB™) to make a Virtual Paddock (VP™) in which the instrumented animal is to remain using sensory cues. These cues are administered to either the animal's left or right side depending on the angle of approach to a Virtual Center Line (VCL™) located within the VB™ (Anderson *et al.* 2003; Rango *et al.* 2003; Anderson *et al.* 2004). The angle of approach is determined by an electronic magnetometer that is part of the DVF™ hardware. In the current DVF™ design, location data are recorded approximately every minute while the animal is in the VP™ and once per second when the animal enters the VB™. A VCL™ can be thought of as the physical location on a landscape where a conventional fence would have been constructed. Note also that VB's™ discussed in this paper were symmetrical around the VCL™, however, the VB™, VCL™ and zones within the VB$^{\text{TM}}$ and are fully programmable and need not remain symmetrical around the VCL™ (Figure 1).

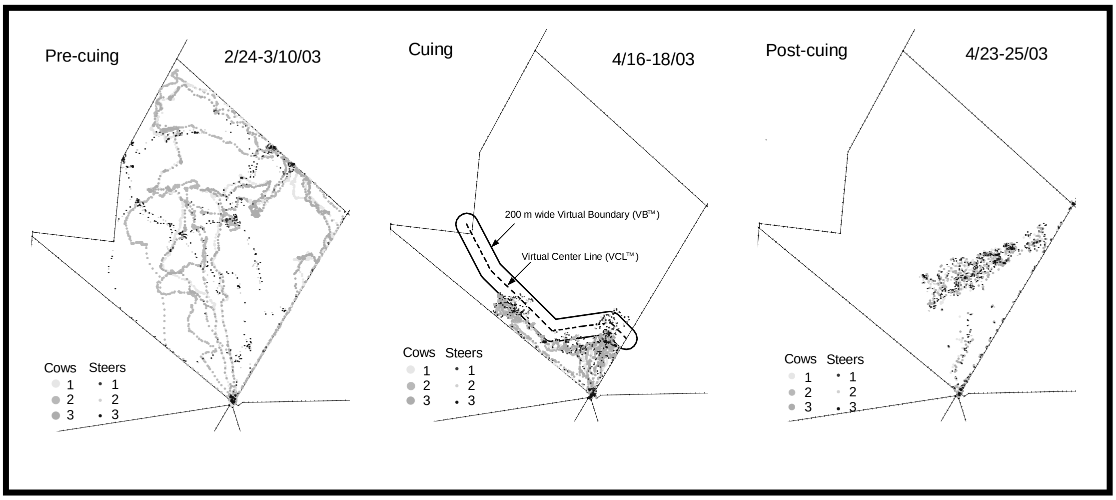

Figure 2. The spatial location of six cattle within the 466 ha Jornada Experimental Range Paddock 10B between February 24 and April 25, 2003 prior to, during and following three of the cattle (cows = large dots) having their location controlled by Directional Virtual Fencing (DVF™) devices on April 16 – 18. Throughout the trial the three steers (smaller dots) wore Lotek® collars that provided no cues. Location data from the DVF™ devices and collars were recorded every 1 minute and 5 minutes, respectively. Precipitation received during the trial caused growth of herbaceous vegetation on a red sand sheet landform giving the false appearance there was an activated VB™ during the post-cuing period.

With DVF™, cuing can be stopped based on either distance or time. In the proof-of-concept research cuing was stopped based on the animal's distance from and angle to the VCL™. As the animal left the VP™ and entered the VB™, cuing continued until the animal's direction of movement was at an angle of $\geq 3^{o}$ away from the VCL™ and when this occurred, cuing immediately stopped. If the animal passed through the VCL™ and continued walking away from the VCL™, cuing ceased as soon as the animal's distance from the VCL™ exceeded 100 m. However, if the animal at any time decided to return, it could walk back through the VB™ and into the VP™ without receiving cues.

The terms used with DVF™ have been given trade marks (Anderson *et al*. 2004) to encourage those who will eventually license or adapt bilateral cuing to use this methodology within a total ecosystem management package designed to optimize husbandry and stewardship in a spatial and temporal context. This framework should embrace low-stress animal handling techniques (Smith 1998) and monitor animal performance (Jameson and Holechek 1987) and plant and soil components of the ecosystem (Herrick *et al*. 2005) to foster proactive, ecologically sound management.

Table 1. Area (ha) occupied by cattle and sheep that had previously been bonded to cattle (Anderson 1998) in Paddock 10B on the Jornada Experimental Range between April 26 and May 17, 2004. The mixed species group termed a flerd (Anderson *et al*. 1988) remained together when controlled by three mature cross bred cows wearing Directional Virtual Fencing (DVF™) devices programmed to provide bilateral electromechanical cues to the cattle only if they attempted to cross a Virtual Boundary (VB™) during the cuing phase of the trial. The mature white-faced sheep and single calf wore commercial Global Positioning System (GPS) equipment unable to provide electromechanical cues.

Dates in 2004[a]	Treatments[b]	Number		Available area (ha)	Polygon Area[d] (ha)		Path Area[f] (ha)	
		Cattle[c]	Sheep		Cattle[e]	Sheep[e]	Cattle[e]	Sheep[e]
April 26-28	Pre-cuing	3	3	466	37	27	1.3	0.6
May 2-5	Cuing	4	2	58	40	37	2.4	0.9
May 5-7	Cuing	4	7	58	50	47	1.5	0.6
May 10-12	Cuing	4	7	108	75	62	1.3	0.6
May 12-14	Cuing	4	14	108	70	68	1.7	0.6
May 17-19	Post-cuing	4	14	466	82	73	1.1	0.6

[a] Consecutive days of data missing between April 28 and May 17 are the result of malfunctioning in one or more of the three Directional Virtual Fencing (DVF™) devices used to control animals behind the Virtual Boundary (VB™).

[b] During pre- and post-cuing only location data were obtained from all animals using Global Positioning system (GPS) data while during cuing the DVF™ devices were activated to give location data in addition to animal control within the confines of a Virtual Paddock (VP™) composed of three conventional fences and one VB™.

[c] Three cows and one calf were used. On April 26-28 the calf was not instrumented with a GPS unit.

[d] Area enclosing the smallest polygon that would include all animals of the same species without excluding areas from within these polygons in which animals were not found.

[e] Garmin Legends® and a Geiko® were used to collect GPS data at a rate of one location per minute for the calf, all the sheep and cow 4127 during post-cuing. All other GPS data were obtained using DVF™ devices.

[f] Area based on a band 1m wide x the total distance traveled (m) for each animal species excluding the calf.

The ability of animals without DVF™ devices to be controlled by animals wearing DVF™ devices was demonstrated by Anderson in 2003. Three cows with DVF™ devices controlled three steers wearing only GPS collars on a 466 ha (1,103 ac) arid rangeland paddock (Figure 2 and again in 2004 Table 1). In the later study, a small mixed species group termed a flerd (Anderson *et al*. 1988) was controlled by cattle instrumented with virtual fencing devices. The sheep had previously been bonded (Anderson 1998) to cattle and consistently stayed near cattle under free-ranging conditions allowing the flerd to be controlled using DVF™.

Commercial collars and ear tags

Beginning with the research of Fay *et al*. (1989), commercial shock collars (Invisible Fence®) designed for dog control were the first virtual fencing devices successfully used to control livestock. Shock collars were deployed on randomly selected Spanish meat-type goats of mixed age and sex during two separate 12-day trials (6 collared goats each). To insure skin contact with the electrodes, hair around the goat's neck was shaved before applying and tightening the collar. Within 30 minutes of training, goats were controlled with the cue package consisting of a beeping tone (37 Hz) followed in 2 s with a mild shock (65 V at 45 mA). Most of the goats adapted quickly and though they received five or six shocks during the first 5 minutes of a 30 minute training interval, no shocks were necessary thereafter. Other research supports these findings that animals learn quickly what acceptable behavioural responses when using virtual fencing are.

Tiedemann *et al*. (1999) noted that heifers learned where the exclusion zone was after receiving as few as one or two cuing packages. Anderson (unpublished data) also observed that beef cattle learn quickly to avoid irritating cues. Cattle in a paddock were found to remain just out of range of an observer carrying a hand activated device capable of delivering audio and electrical stimulation cues when the animal had experienced the cue package just a few times previously. In a replicated study, Bishop-Hurley *et al*. (2005) determined mean rate of travel of 5 steers per treatment through an alley approximately 40 m x 6 m decreased following the application of irritating sensory cues. In this research, a single cue package consisting of either a vibration (1 s) followed by electric stimulation (1 KV for 1 s) or sound (1 s) followed by electric stimulation (1 KV for 1 s) was found to cause steers to hesitate during movement through the alley to approach feed and peers located at the opposite end. What was surprising was the rapid rate at which animals appeared to learn. On the third trial through the alley steers hesitated (4 to 8 times longer) after receiving just the audio or vibration cues and did not require electrical stimulation to prevent them from moving rapidly through the alley.

Though animals appear to learn quickly how to avoid sensory cues, not all animals react in an identical fashion. Two goats (17%) in the study by Fay *et al*. (1989) were replaced with trainable animals. One goat termed "untrainable" remained motionless during shocking, while the other goat, when alone inside a 70 m x 70 m enclosure would not endure the pain associated with the electric shock to join peers outside the enclosure. Furthermore, none of the six collared goats in the Fay *et al*. (1989) study left the containment area during the initial trial. As a result, the non-collared control goats never wandered more than 50 m from the confined animals. The animals began to demonstrate anxiousness if their nearest neighbour distances exceeded 20 m. Tiedemann *et al*. (1999) reported this same behaviour during several occasions; when animals wearing ear tags moved back into the grazing zone the control animals moved with them.

Quigley *et al*. (1990) used Tri-tronics® A1-90 remote dog training collars set at a level four electrical stimulation to cause four Hereford steers to turn 90 degrees and jump. Over a four day trial designed to keep steers out of a polygon within a corral and pasture, correct responses to audio-electrical stimulation were 83, 93, 97 and 100%, respectively. Furthermore, when two steers were grazing relatively close to each other and one received a cue, the other steer moved in tandem with the cued steer. By day four, steers were responding to an audio cue (buzz) only in a manner similar to that of audio-electrical stimulation in which electrical stimulation lasted ≤ 5 s and never exceeded 10 s. While on pasture, grazing resumed in as few as 10 s following audio-electrical stimulation, suggesting this type of control was not producing noticeable stress. A similar response by cattle has been observed numerous times on the Jornada Experimental Range following cuing from the DVF™ equipment (Figure 3).

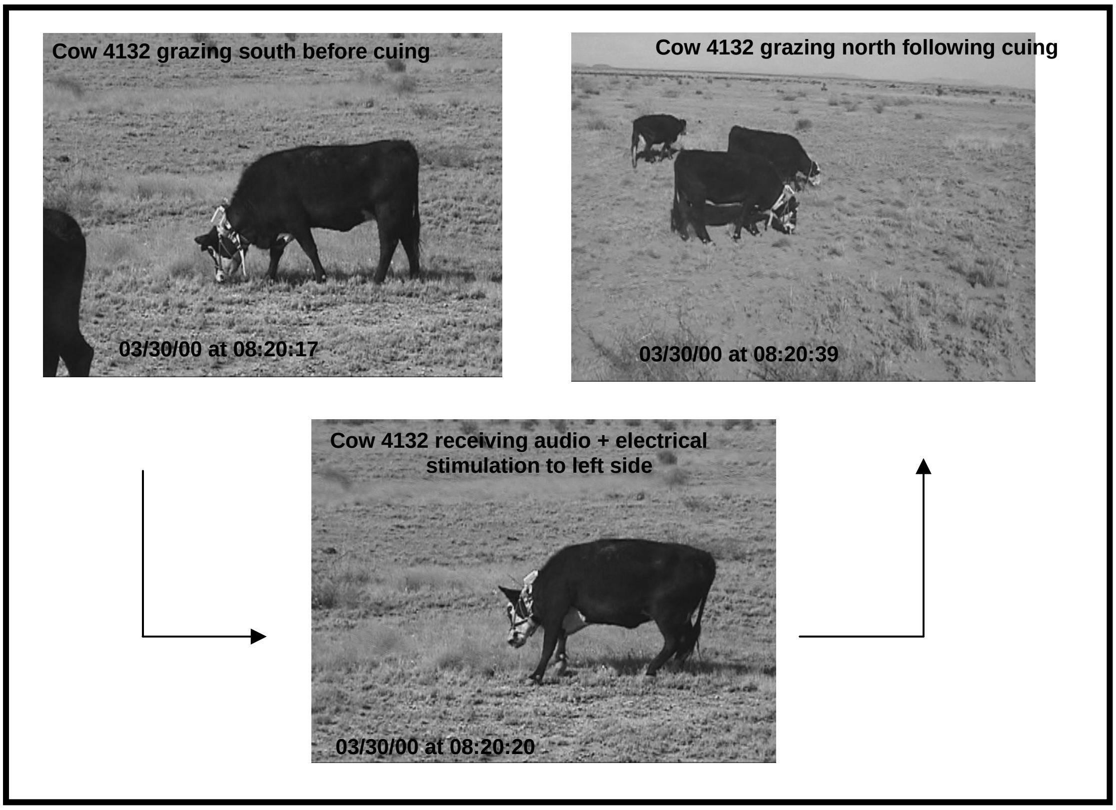

Figure 3. Behavior of a cow before, during and after receiving an audio + electrical stimulation cue to the left side of its head while foraging. Note the change in foraging direction took only 22 s with little noticeable stress to the animal.

The longest virtual fencing study to date was conducted in the United States in response to riparian stewardship concerns using prototype electronic ear tags approximately 7.6 cm (3 in) x 15.2 cm (6 in) and weighing about 113 g (4 oz). These electronic ear tags were about twice the length of commercial ear tags. The circuit was a six layered fused circuit board about 0.2 cm (0.06 in) thick with logic provided by 25 integrated circuits powered by two 1.5 V AAA batteries. The tags were manufactured by Schell Electronics (Chanute, Kansas) as the platform from which sensory cues were administered. A hand-held unit was built to allow the observer to manually lock and unlock ear tags, provide an electrical stimulus and test signal strength of the transmitter. The research was conducted on private ranches using 90 steers in Texas for eight weeks and 90 yearling replacements Hereford-Angus crossbred heifers in Nevada for 5 weeks, respectively (Tiedemann *et al*. 1999).

In the Texas trial, a short period of training was necessary. A transmitter was located in the area of desired exclusion that emitted a continuous coded signal of designated strength defining the area from which animals were to be excluded. Animals wore an electronic ear tag containing a receiver, an audio warning emitter near the top of the ear tag and a device capable of producing a small electrical stimulus to the ear through four electrodes mounted on the post of the ear tag. If the animal moved into the exclusion zone, the signal emanating from the transmitter activated the audio and electrical stimulation modules in the ear tag. An audio warning always preceded the electrical stimulation. Once cuing stopped the animal left the exclusion zone.

The Texas test occurred in June 1992 and used 15 steers in each of six irrigated coastal Bermuda isosceles trapezoid shaped paddocks delineated using electric fencing. The six paddocks were approximately 488 m (1,600 ft) in length, 243 m (800 ft) at the wide end and 9 m (30 ft) at the narrow end. Cattle were placed in these paddocks two weeks before the test to train them to electric fencing. For the test, three transmitters were placed across the paddock between the two longest sides of the trapezoid at a distance approximately 61 m (200 ft) from the narrow end of the paddock. Water and minerals were supplied at one of the longest fence lines near the narrow end of the paddock while water was also located towards the wide end of the paddock on the longest fence line. An observation point was established approximately 91 m (300 ft) from the paddocks. Initially upon release, the naïve steers passed through the virtual fence zone and into the zone of exclusion. The responses from the steers as they passed through the virtual fence zone were variable; some moved in circles while others shook their heads as they ran through. For the remainder of the test, the signal boundary was moved approximately 183 m (600 ft) closer to the wide end of the paddock.

Bolting and entering the zone of exclusion as recorded by Tiedemann *et al*. (1999) was also observed by Anderson (unpublished data) during initial testing of the DVF™ method of animal control. In these initial trials, the original VB™ was programmed to be 65 m wide. If an animal in a VP™ was at the interface between the VP™ and a VB™ when the GPS fix was recorded and continued moving towards the VCL™, at the next GPS fix (approximately 1 minute later) the animal would have travelled within a few meters of the VCL™. At this location, the system would immediately begin delivering cue packages and GPS fixes would be recorded on a second by second basis. Because of the close proximity to the VCL™, this initial cue would be quite severe, causing the animal to lunge forward through the VB™ rather than turning away from the bilaterally applied cue and back into the VP™. To correct this situation, the width of the VB™ on either side of the VCL™ was arbitrarily increased to 100 m, which placed the animal in a zone having lower cue intensity initially (Figure 1). Another option would have been to keep the narrower VB™ and record data at a ≤ 1 s rate continually. This was not possible with the original DVF™ equipment because of power and memory storage limitations.

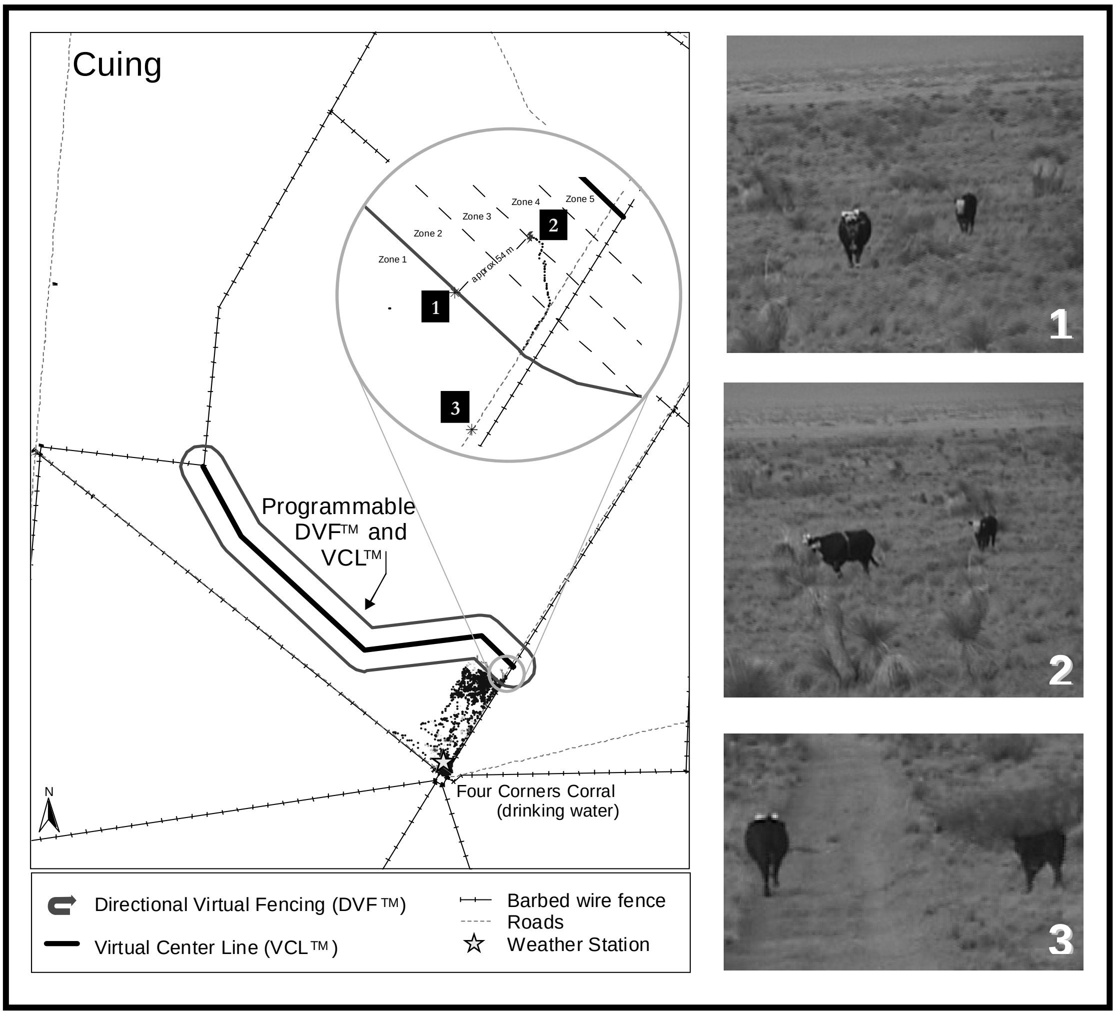

Figure 4. Locations of a free-ranging 8 year old cross-bred beef cow with her un-instrumented calf in a 466 ha (1,103 ac) paddock located on the Jornada Experimental Range (106^{o} 43.263’ W, 32^{o} 34.297’ N) between June 26 and June 28, 2002 (lighter colour dots) and June 28 and July 1, 2002 (darker dots) while held behind a programmable Virtual Center Line (VCL™). The cow was filmed on the morning of June 27 prior to an attempt to enter a Virtual Boundary (VB^{TM}) (1), at 0653 hours when it received an initial audio + electrical stimulation approximately 42 m from the VCL™ (2) and after having left the VB™ delineated by the programmable DVF™ system (3).

Data from a staged scenario on June 27, 2002, illustrates how an operating DVF™ device can elicit a proper behavioural response from bilateral cuing even if a cow is walking at a rate approaching 1 m/s. This scenario was staged by enticing a cow to cross a VCL™ using cottonseed supplement by shaking a bucket containing cubes (sound/odor cue) while standing approximately 50 m to the north of the VB™ (Figure 4). It is desirable to have the animal receive a less severe cue initially to act as a “warning” of things to come rather than being unnecessarily startled with a severe cue initially. Radio Systems suggest electrical stimulation should be more startling than painful and should impart the sensation of an electric current rather than produce muscle contraction, which are many magnitudes more severe than the electric stimulation produced by most dog training collars (Brudecki 2004). Most commercial electronic training devices have eliminated the “one –size fits all” approach and allows from five to 18 modes of operation (Thoms 2004).

The cue package used by Tiedemann *et al*. (1999) lasted 1 s. In some cases, this was too long and the animal turned 360^o and ended up moving toward the exclusion zone after being cued. With DVF™, when an instrumented animal moves away from the VCL™ $\geq 3\ ^0$ (based on data from an electronic magnetometer in the device; (GPS data also contains magnetometer information but an animal’s normal rate of travel is too slow for it to be useful in determining to which side of the animal the bilateral cues should be applied) cuing immediately ceases on the side that formed an acute angle with the VCL™. If the animal does not turn back toward the VP™ but passes through the VCL™, cuing continues on the same side of the animal but now forms an obtuse angle with the VCL™. Algorithms in the device’s GIS system use this angle information to insure the animal receives cues on the side that will move the animal back into the VP™ over the shortest distance and in the least amount of time with the least amount of cuing.

There will always remain a time lag between determining animal location on the landscape and implementing an external cue. Internal cuing using brain micro-stimulation as has been demonstrated in rats from a brief train of stimulus pulses of 80 μA; typically 10 biphasic pulses, each 0.5 ms, 100 Hz, per train directed at the somatosensory cortical (SI) and medial forebrain bundle (MFB) can autonomously produce directed animal navigation (Talwar *et al*. 2002; Xu *et al*. 2004) it may be possible to further reduce the width of a VB™ using a similar technique in herbivores. However, it seems reasonable to assume VB’s™ will always be wider than conventional fencing.

Tiedemann *et al*. (1999) decided the steers needed training to prevent them from moving into the exclusion zone, accomplished by establishing an electric fence across the paddock near the three transmitters for 1.5 days. As the animals approached the visual cue (electric cross-fence), technicians stood up and waved their arms in an effort to turn animals away and stop the cues. It was assumed the training was successful because once the electric fence was removed, most animals turned away from the virtual fencing cues when the exclusion boundary was encountered.

With every experience an animal is learning. Though no formal training was used with the animals controlled with DVF™, they quickly learned to respond correctly to cues programmed into the DVF™ devices as they encountered the VB™ while foraging. Over numerous studies it was found that some animals learned rapidly with minimal cuing to turn and leave a VB™ while other animals required more time to learn the routine or required a more severe cue package to leave a VB™. This can be seen in Figure 5 from the “worm-like” trails penetrating into the east VB™. Though both cows were experienced with DVF™, at the onset of this experiment cow 4130 (darker lines) never moved past zone 2 (audio sound only) before returning to the VP™ while cow 4132 appeared to consistently require more irritation in the form of audio and electrical stimulation before returning to the VP™.

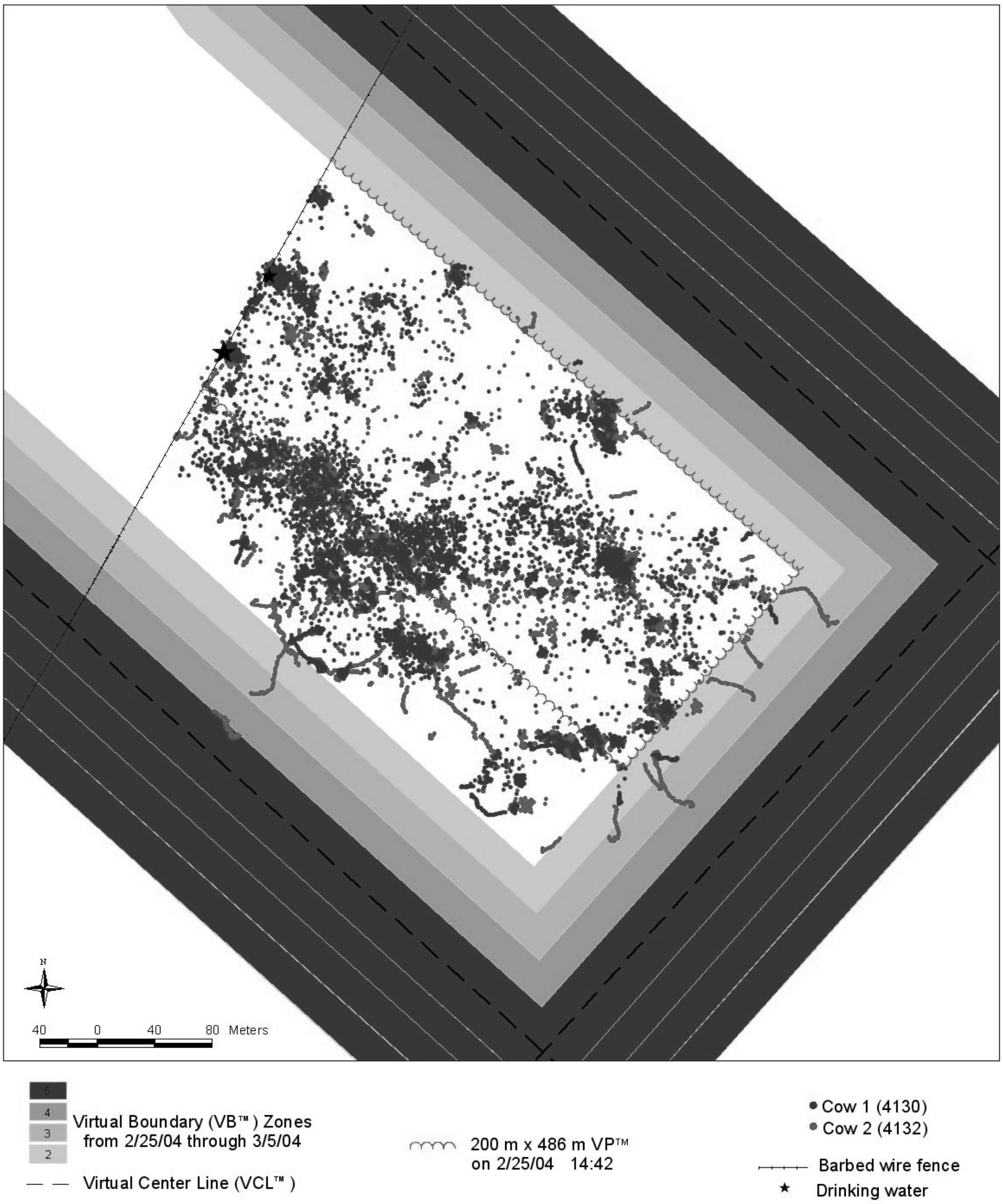

Figure 5. Spatial occupation of a 200 m x 486 m Virtual Paddock (VP™) stocked with two free-ranging mature, cross-bred beef cows instrumented with Directional Virtual Fencing (DVF™) devices between February 25 and March 05, 2004 during which time the north and south Virtual Boundary (VB's™) were programmed to move in a southerly direction at a rate of 1.1 m per hour between 0700 and 1700 hours, thus moving the rectangular VP™ ≈ 100 m south during the nine consecutive day trial. Though neither cow escaped from the rectangular VP™ both cows "tested" the VB™ a number of times as clearly shown by the "worm-like" lines penetrating into the east VB™. Each VB™ consisted of four 25 m wide zones on either side of a Virtual Center Line (VCL™). Data from the east VB™ shows cow 4130 was always returned to the VP™ after receiving only bilateral audio cues (Zone 2) while cow 4132, though never reaching the most severe cue package (Zone 5), did require both audio + electrical

stimulation in the form of bilateral cues before returning to the VP™. The east VB™ remained static throughout the trial and the west boundary was a wire fence to allow for orientation while observing the animals from outside the VP™. Drinking water and salt were maintained in the “centre” between the north and south VB’s™ on the west side of the VP™, beginning at an initial location (small star) and subsequently moved to a second location (large star) on March 01, 2004. (Adapted from Anderson *et al*, 2004).

In the initial trial described by Tiedemann *et al*. (1999), not all ear tags were found to receive a signal at the same distance from the transmitters. Distance varied diurnally and increased at night, apparently due to higher humidity. This variability in cuing location that took place among the herd apparently caused some confusion among the steers. Even with these challenges, they reported a 93% correct response among the 23 observations.

In this Texas trial beginning June 22, ear tag failure and length of time cues were administered caused movement in the wrong direction even though more observations were recorded than in the first trial (Tiedemann *et al*. 1999). In this trial, the transmitters were hard wired together so they could be activated remotely. Animals were trained to an electric fence for two days by establishing a zone behind a cross-fence approximately 122 m (400 ft) from the narrow end of the isosceles trapezoid shaped paddocks. The steers learned quickly the signal boundary location and made an overt effort to avoid that area.

Overall, the Texas trials revealed: 1) training may be necessary before attempting to control animals using virtual fencing; 2) animals should not be agitated when released into an area to be controlled by virtual fencing, especially if they run, because they are likely to run through the virtual fence when they encounter it for the first time; 3) identifying lead animals and controlling them appears essential because if its ear tag ceased to function and it left the zone of inclusion, other animals would endure the audio-electrical stimulus to follow; 4) the 8,500 Hz audio cue was too similar to insect sounds and animals reacted to insect sound and moved as if in response to the audio cue; 5) the 1 s audio cue was considered too long; 6) the cuing sequence was a single audio warning signal (length of delivery not given) followed by 4 s of silence and then an electrical stimulation (intensity and time not given). If the steer did not move appropriately following another 4 s of silence a second electrical stimulus was given. If a third electrical stimulation was required, the system locked up after it was delivered; 7) the ear tag attachment stud was too short, causing physical damage to the ear. The Texas trials revealed animals without virtual fence ear tags were in the grazing zone and the transition plus exclusion zone 52% and 48% of the time, respectively. In contrast, steers wearing virtual fence ear tags spent 93% and 7% of the time in the grazing zone and transition plus exclusion zone, respectively (Tiedemann *et al*. 1999).

The Nevada test evaluated 90 yearling Hereford-Angus cross heifers for a 5 week trial while foraging along a riparian area about 1.6 to 2.4 km (1 to 1/1/2 mi) long and 0.4 to 0.8 km (¼ to ½ mi) wide (Tiedemann *et al*. 1999). Electromechanically, the Nevada test differed from the Texas test in two major ways; the audio cuing frequency was lowered by a factor of 10 to 850 Hz and the period of electrical stimulation lasted only about 12% as long as in the Texas test. Also the ear tag attachment stud was increased from 2.54 cm (1 in) to 3.81cm (1.25 in) and holes were drilled through the nylon washer placed between the ear pinna and the hardware to eliminate physical damage to the ear. Furthermore, to unlock ear tags, transmitters were set up at the water troughs in the treatment paddocks.

The six rectangular shaped paddocks ranged in size from 152 m to 244 m (500 ft to 800 ft) by 76 m to 122 m (250 ft to 400 ft). The longest fence line was oriented north of a stream which ran through the southern end of each paddock. Though the animals had received training to an electric fence prior to being trucked to the experimental paddocks, during the first test the treatment herd (n=15) breached the three wire electric fence and joined the control herd. This resulted in an unplanned 2-day trial with both the treatment and control herds combined into one group. This group was gently herded toward the exclusion zone on four separate occasions. Transmitters were set up between the riparian area and the grazing zone. Each time, animals were reluctant to move toward the exclusion zone because there was adequate forage in the grazing zone. However, of the 16 encounters with the signal boundary 13 were correct (81%) and in three of the four trials, the treated animals moved back into the grazing zone and control animals moved with them.

Tiedemann *et al*. (1999) intensified training of a group of 17 heifers to an electric fence for a second trial by placing alfalfa hay silage on the opposite side of an electric fence, such that they received a shock as they reached across to obtain the feed. The training took place in an area that provided a grazing zone of about 46 m (150 ft) separated from an exclusion zone with transmitters and an electric fence. During one full day of training, 23 of 25 observed responses were correct. After only one or two stimuli, the animals seemed to know where the exclusion zone was.

The following day, the two groups of instrumented and control heifers were randomly allocated to the six repaired rectangular paddocks built of three strand electrified wire. Drinking water was provided in the north portion of the paddock termed “the grazing zone.” Animals selected to wear the ear tags were not trained to the virtual fencing devices prior to beginning the trial due to time constraints caused by ear tags damaged during transport that required repair. The cue package was as follows: 850 Hz audio stimulation (0.125 s), 4 s of silence, electrical stimulation (time and intensity not provided) and 4 s of silence. This package was repeated four consecutive times before the unit locked up.

Transmitters were placed across the rectangular paddocks approximately 61 m (200 ft) to the north of the riparian zone. On day 1, none of the treatment group attempted to enter the exclusion zone during daylight hours (transmitters were off at night because previous experience revealed signal strength changing diurnally). Over the next three days, animals appeared to have received a cue from the virtual fence ear tags 36 times and in only four of these observations did the heifers move incorrectly toward the riparian zone. However, there appeared to be equipment failure for some tags, since on several occasions, heifers passed through the virtual fence without any sign of having received a cue and these tags could not be activated with the hand-held transmitter. This situation tended to cause “follower type” animals to endure the irritation of the audio-electric stimulus and enter the exclusion zone.

To attempt a more rigorous test of the transmitter signal boundary to hold animals, a second trial with new animals trained to electric fencing was conducted. Animals wearing virtual fence ear tags (n=17) were separated from control animals by an electric fence. Animals were trained to virtual fence control by placing transmitters along an electric fence and confining the animals to an area behind the transmitters/electric fence. If the animals approached within 12 m (40 ft) of the electric fence, they received a cue. During one-day training, 23 correct responses and two incorrect responses were observed.

The animals were then moved to the large rectangular paddocks in the riparian area. Transmitters were set up about 61 m (200 ft) from the riparian zone. The boundary was never challenged by heifers the first day of the trial and again transmitters were shut off at night. Over the next three days, 32 of 36 observed encounters (a noticeable response of the animal to the cue was observed) resulted in heifers turning back into the grazing zone. However, in several instances animals moved through the boundary without showing any sign of having been cued. Further investigation into tag malfunctions suggested they had been damaged, presumably during transport to the trial location.

In this second trial, 44% of the control animals spent time in the exclusion zone while 0% of the animals wearing virtual fencing ear tags entered the exclusion zone during the day. The overall conclusion was that virtual fencing has a strong potential for excluding livestock from specific areas.

Several conclusions were drawn from the Nevada test: 1) the shorter interval of the cue from 1 s to 0.125 s was beneficial; 2) for a more robust design, the ear tag must be smaller and weigh ≤ 28 g (1 oz); 3) audio stimulation may be adequate to elicit animal movement without electrical stimulation; 4) training may be an essential part of implementing this technology.

Virtual fencing and animal stress

Reducing stress when handling animals benefits both husbandry and economics (Smith 1998; Durham 2006). Stressors affect many systems in animals (Dantzer and Morméde 1983); however, heart rate (HR) is one of the easier traits to monitor in free-ranging animals. Values of 48 to 84 beats per minute (bpm) have been reported for dairy cattle (Dukes 1970; Aiello 1998) with peaks of 186 bpm recorded by Rometsch and Becker (1993) for Simmental oxen during exercise. The cues delivered with a DVF™ device do not appear to cause undue stress to HR based on data recorded on June 27, 2002 (Figure 6) in which HR peaked at 94 bpm following an initial audio plus electrical stimulation cue package ranked at a moderate level of irritation (Figure 4). Overall, this cow had a mean HR of 56 ± 7 bpm over approximately 8 hours, preceding and following the 94 bpm spike. The animal’s HR returned to the mean value in about 13 minutes after the initial cue. The 94 bpm spike was recorded at 0653 hours from a Polar® Accurex Plus Heart Rate Monitor attached using a girth strap (Hopster and Blokhuis 1994). A second spike > 90 bpm was recorded about an hour later when the cow was being observed standing near drinking water.

What we need to know

Terminology and uniformity

The word virtual when used with fencing has been described in different ways and a common definition currently does not exist (Anderson 2001; Palmer *et al*. 2004). For objectivity and understanding to be common when conducting virtual fencing research, some common definitions to foster communication are needed. Furthermore, some items remain inadequately documented or incompletely understood, partly attributed to the evolving nature of virtual fencing research.

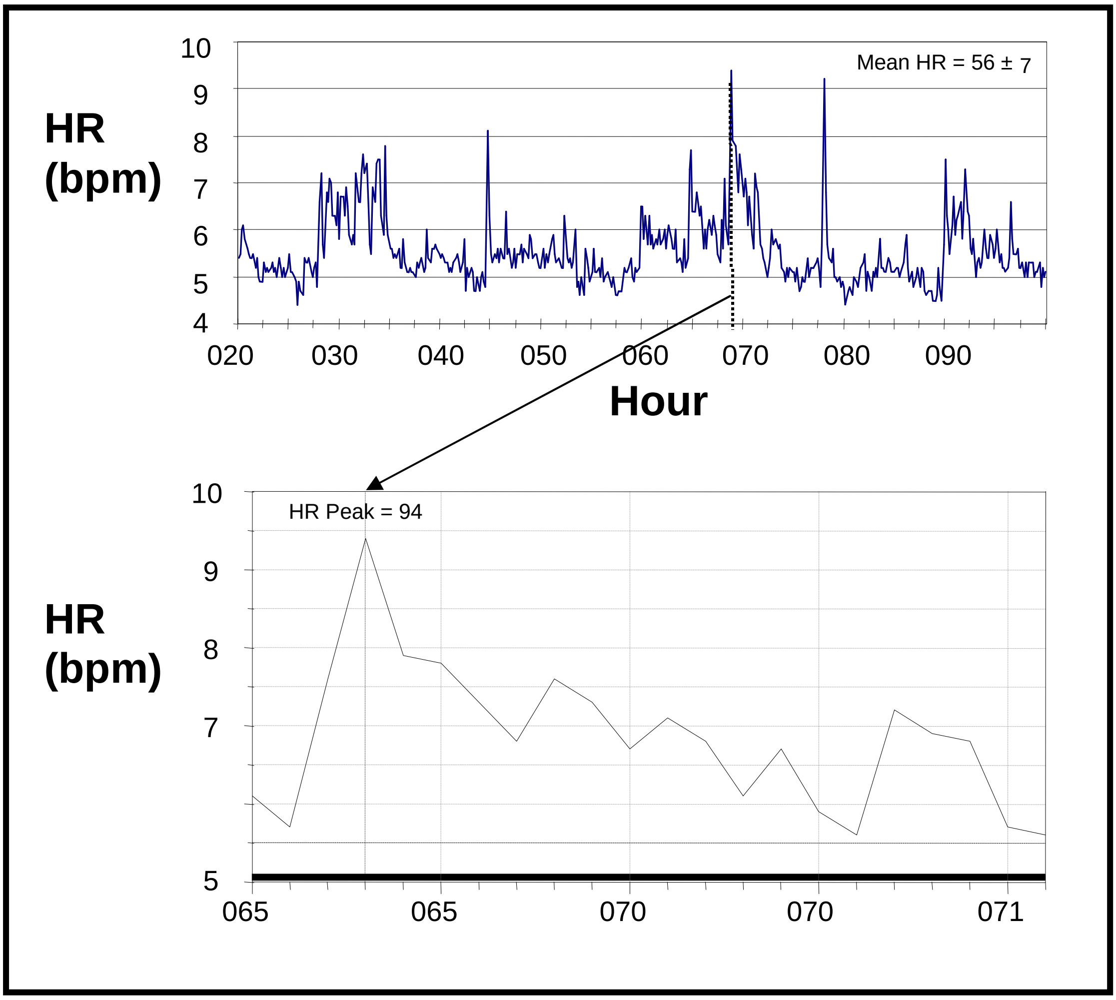

Figure 6. Heart rate (HR) profile of an 8 year old free-ranging cross-bred beef cow expressed in beats per minute (bpm) on June 27, 2002 between 0200 and 1000 hours while being monitored with a Polar® Accurex Plus Heart Rate Monitor prior to, during and following an audio + electric stimulation cue from a Directional Virtual Fencing (DVF™) device delivered at 0653 hours. The second spike in HR > 90 bpm was not due to electromechanical cues as the animal was observed to be standing during this time.

Expressing, producing and storing power (example, electrical stimulation)

How should electrical stimulation be expressed? Currently cuing intensity is either determined by a manufacturer for controlling pets, primarily dogs, or "tested" and deemed appropriate by the designers of the equipment. Designer tested equipment has literally been a "hands on (off)" experience by a technician touching "energized" electrodes and verbally indicating when the recipient believed they were experiencing a stimulus adequate to cause the animal's behaviour to change appropriately if "animals" received the electrical stimulation. This setting then became what was used in the experiment. Though not totally inappropriate, this approach lacks an objective evaluation and may not represent what the actual free-ranging animal will experience.

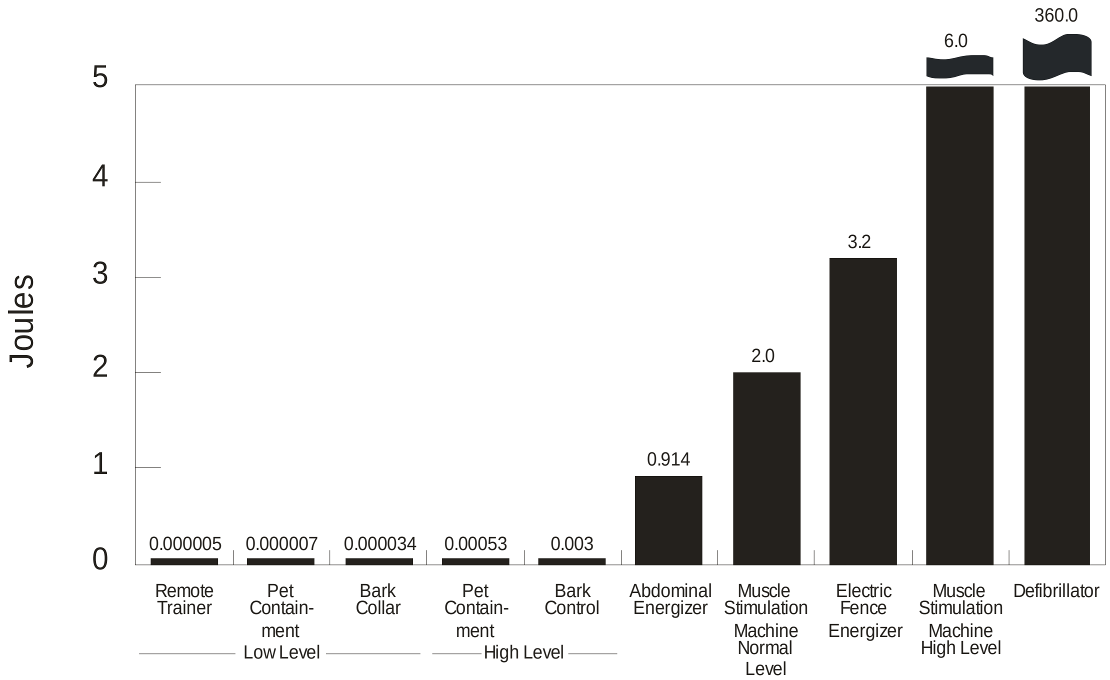

Figure 7. The relative energy comparison of electronic training devices from common sources of static impulses prepared by Philips Testing Services a division of Philips Consumer electronics Company. (Adapted from Radio Systems Corporation 2004 white paper available at: http://www.petsafeoutreach.com/white_paper.pdf).

The various ways previously used to describe the "amount" of electrical stimulation have not been uniform, making conversion to a common standard impossible. Radio Systems Corporation, manufacturers of Petsafe® containment systems, expresses stimulation level in Joules (Figure 7). Fay *et al*. (1989) indicated the Invisible Fence Co system used a shock pulse of 65 V at 45 mA. Bishop –Hurley *et al*. (2005) used an electrical stimulus level of 1 kV s^{-1}. It is difficult to accurately express what the animal actually experiences in the way of an electric stimulus. Electrode placement and contact with the skin, physiological state of the animal and ambient weather conditions are just some of the factors that affect what an animal actually "feels" upon receiving the stimulus. This same lack of uniformity in terms for any of the other sensory cues that have been used also needs to be addressed. A commonly accepted way to express the intensity of the various types of cues does not currently exist but is needed to make comparisons among future virtual fencing studies possible.

Figure 8. A grazing cross-bred beef cow wearing a battery (1) powered Directional Virtual Fencing (DVF™) device equipped with spring loaded electrodes (only left side pair shown 2) for providing electrical stimulation and left (3) and right (4) piezo speakers housed inside Poly Vinyl Chloride (PVC) pipe for audio stimulation. A Global Positioning System (GPS) antenna (5) is located in the centre of a panel of solar cells (6). This prototype platform may appear clumsy but was remarkably robust during numerous field trials conducted between 2001 and 2005.

Most studies have simply described the hardware used to produce the stimulus rather than the physiological impact the stimulus has on the animal. In stress physiology, studies the effect of ambient temperatures on an animal are more accurately expressed as black globe temperature than simple wet or dry bulb temperatures (Yousef 1990).

Possibly, developing an appropriate “pain” scale for an animal’s response to a physical description of a cue might be one approach to solving this challenge.

Solar panels have successfully been used to generate adequate power for DVF™ devices (Figure 8) with the most recent configuration being a flexible solar panel attached to a neck belt (Rango *et al*. 2003). However, solar panels may not work everywhere if solar energy is not consistent enough to charge an on board battery.

It may be possible to generate energy from animal motion. If the concept of a “cow boot” described by Horn (1981) were combined with the electronics described in a patent by Le *et al*. (2001), it might be possible to convert animal movement into power in quantities adequate to keep an on board battery charged, allowing the virtual fencing device to operate for extended periods without changing batteries. Regardless of the approach, power needs to be generated on board the animal to avoid frequent human intervention.

Once power has been generated, the most likely storage device is a battery. Where battery contact is required, a dielectric compound has been found useful (Tiedemann *et al*. 1999). However, battery life expectancy tends to be the most limiting factor affecting how long electronically instrumented animals can be successfully deployed (Clark *et al*. 2006). New technology such as the all-polymer batteries developed at Johns Hopkins University may someday prove to be the storage source of choice because they are efficient in heat and cold, contain no liquids and can be formed to take any configuration the user desires (Strümpler and Glatz-Reichenbach 1999). Even though polymer batteries currently cost more than other batteries, polymer technology is currently available through Ultralife® (http://www.ultralifebatteries.com/).

A better understanding of how to motivate an animal to respond to virtual fencing in an optimum manner coupled with the use of the most efficient cuing hardware should reduce the concern over power. Lastly, assuming the moral and ethical issues can be adequately addressed, the use of brain micro-stimulation as a cuing approach has some very interesting possibilities (Talwar *et al*. 2002; Xu *et al*. 2004) not only because of reduced power requirements but also due to size and mass reduction of the hardware itself.

Electronics and equipment platforms

As confirmed by the research of Tiedemann *et al*. (1999), the actual device to be worn by the animal must be lightweight if it is to hang from the ear and robust, especially in its ability to withstand reasonable impact, moisture and dust. Collars remain the platform of choice for pet containment systems and have been used on free-ranging cattle (Butler *et al*. 2004). However, collars offer many challenges as a virtual fencing hardware platform. If electrical stimulation is used as one of the cues collars will not work unless they are maintained tightly around the animal’s neck to keep electrodes in constant contact with the animal’s skin. A loose collar can rotate, resulting in intervals when electrodes lose skin contact and may cause harm to the animal if its foot is caught in the collar during body grooming (Fraser 1985) or if caught on obstacles in the environment. Furthermore, if collars rotate, antennas move for capturing the GPS signal and signals for wireless communication (Wang *et al*. 2006) from the optimum location on top of the animal’s neck. Rotated antennas can cause signal interruption due to attenuation from bodies of nearest neighbours (Bishop-Hurley *et al*. 2005; D’eon and Departe 2005; Butler *et al*. 2006).

Neck saddles (Anderson 2001; Rango *et al*. 2003) of varying designs have been satisfactorily used for experiments, but are too bulky (Figure 8) for commercial application. Though a combination of a halter and collar worked well in an experimental venue (Bishop-Hurley *et al*. 2005), it also is not the platform of choice for long term field studies or commercial application because of exposed wires between the collar and halter. Mass of the electronics and power required to implement virtual fencing has made ear tags unsatisfactory in early trials (Tiedemann *et al*. 1999). Furthermore, if an accurate magnetometer reading is essential to make the hardware operate correctly as in DVF™, even light weight ear tags are probably not the answer due to the near constant movement of an animal’s ears in response to environmental sounds.

In an attempt to address many of these challenges of conventional hardware platforms, Anderson (2005) developed a platform called Ear-A-Round (EAR™). This platform looks much like a donut and fits over the animal’s ear. Depending on the requirements of the virtual fencing device chosen, either single or pairs of EAR™ devices could be deployed on an animal. The outer ring can be manufactured to contain all of the hardware necessary for virtual fencing. Because it is positioned next to the animal’s head at the base of the ear pinna, mass of electronics no longer is a significant issue. Furthermore, because the EAR™ moves with the animal’s head, the magnetometer reading is consistent with the direction the animal is normally moving if it is true that “as the eyes are looking so shall the body follow.” The position over the ear places this platform in an optimum location for receiving radio frequency (RF) signals. The only consistently higher position is the backbone and though used in earlier studies (Petrusevics and Davisson 1975) a girth strap to hold an equipment saddle on the animal has the same challenges as neck belts and collars in addition to changing gut fill that must be accounted for in a girth belt design. Field tests are currently underway to determine the EAR’s™ suitability and limitations for housing virtual fencing electronics.

Safety and security for both animal and manager

Virtual fencing relies on altering animal behaviour and therefore, equipment must be designed with fail-safe features to prevent excess cuing (especially cues that elicit physiological long term stress). Excess stress has yet to be defined since it is not a constant from animal to animal (Stricklin and Mench 1990). Because excess stress varies among individuals it may be most appropriate to allow the animal to choose the “irritation” level it will not tolerate before changing its behaviour, e.g., cues ramped from least to most severe in a manner similar to those designed into DVF™. This safety feature is absolutely necessary because animal behaviour is dynamic and not 100% predictable. In reality, not all animals will adjust to virtual fencing. These animals should be removed from the group. Virtual fencing electronics must be designed to ensure that if an animal escapes from the polygon, it can return on its own without receiving unwanted cues. Tiedemann *et al*. (1999) accomplished this by providing electronics to unlock ear tags at drinking water or a similar site that animals frequent with some periodicity, while Anderson and Hale (2001) used the animal's distance from and angle of approach to a VCL™.

Laws do not insure good husbandry practices, people do. Animal welfare issues began as ethical issues but have frequently evolved into political and animal rights controversies (Howard 1990) and often result in legislation based on extreme opinions, e.g., Bill No. 57 banning the manufacture, sale or use of electric shock collars on animals introduced into England's House of Commons (Rendel *et al.* 2003). If electrical stimulation is necessary in virtual fencing, should it take place on the animal's skin or in its brain? All previous research as well as that projected into the near term will most likely apply to external stimulation. However, recent research using rats demonstrated that brain micro-stimulation can autonomously produce directed animal navigation (Talwar *et al*. 2002; Xu *et al*. 2004). This opens up a completely new set of ethical as well as practical questions that will need to be resolved in light of its potential use with virtual fencing. Most producers and research animal scientists know low-stress animal husbandry practices make practical and economic sense (Smith 1998). Proper guidelines for the care and use of agricultural animals used in research and teaching are in place (Curtis 1999; Anonymous 2004; Fisher 2006). Most animal research locations have in place an Institutional Animal Care and Use Committee (IACUC) and details about its role and links to similar organizations throughout the world can be found at (http://www.iacuc.org). Common sense coupled with reasonable and fair legislation and proactive management should ensure virtual fencing will be safe for the user as well as the animal.

The livestock industry has been catapulted into the computer age and with it has come security and theft issues. When virtual fencing and individual electronic animal identification (http://idcattle.com/) are combined the potential use of computers for theft exists and may be made easier, if animals are not managed with good husbandry that requires quality human animal interactions.

Australian statistics for 2005 suggest 5% of livestock producers reported theft of animals (http://www.aic.gov.au/publications/facts/2005/facts_and_figures_2005.pdf). Statistics released in May 2006 for the US indicate theft of cattle and calves in 2005 amounted to more than \$13.9 x 10^6 (http://usda.mannlib.cornell.edu/reports/nassr/livestock/non-amb-catt/naccan06.pdf). These statistics present a unique set of practical, legal and ethical issues that should be addressed before virtual fencing becomes commercially available.

Monitoring and management

With virtual fencing, monitoring must be rapid and accurate because of the speed at which it will be possible to bring about ecological changes on the landscape. Satellite technology will probably form the basis from which virtual fencing will be administered and provide the data required for monitoring (Rango *et al*. 2003). Research to determine standing crop quantity (Thoma *et al*. 2002) and quality is progressing (Tueller 2001). With virtual fencing, it will be possible to reduce the time lag between observing a condition on the landscape and moving animals to or away from the situation. The effect of poisonous plants on livestock production is an example. Nielsen and James (1991) estimate poisonous plants account for death and abortion in livestock in excess of $340 million annually in the 17 western states of U.S.A. With optical techniques such as fluorometry (Anderson *et al*. 2006), it is possible to identify different forages in a rapid manner. Within a few hours of determining animal diets, they could potentially be moved using virtual fencing. Anderson *et al*. (2004) demonstrated that DVF™ has the potential to move animals over the landscape. What remains to be investigated is determining the optimum rate(s) of movement based on management goals.

Virtual fencing differs from conventional fencing in that a transition or buffer zone can develop between the foraging zone and the exclusion zone if the virtual fence remains static (Tiedemann *et al*. 1999; Anderson *et al*. 2004). These “transition corridors” may prove to have ecological benefits to birds and wildlife (Edminster 1938; O’Conor and Shrubb 1986; Demers *et al*. 1995). In addition, these “transition corridors” may serve as areas where desirable trees or herbaceous plants can be protected from browsing until they are of adequate size and age to supply forage for the animal species being controlled (Reid and Ellis 1995).

Animal behaviour and production

As with all emerging technologies, virtual fencing is fraught with challenges. No written protocol exists for training animals to virtual fencing control and the preliminary data are divided as to how much training may be warranted. No data currently exist to indicate if periodic retraining is necessary or how frequently it might be required. Furthermore, deciding which animals among a group should be instrumented and the number of animals the group should contain for optimum control awaits investigation. Extrapolating from what Stricklin and Mench (1987) say about gregarious animals that herd or flock, it probably will not be necessary for the entire group to be instrumented for virtual fencing to be effective. However, topography will certainly be a factor because line of sight affects behaviour of animal groups. On relatively flat to gently undulating landscapes, it will probably not be necessary to instrument all animals based on the preliminary results of several studies.

However, the most efficient way to attain consistent control will be to instrument leader animals and develop a test for identifying leaders. Among the questions that will need to be addressed concerning characteristics of a leader will be effect of prior experience, age, gender and breed on virtual fencing leadership. These characteristics have been shown to affect other animal behaviours. An Australian stockman commented to the author in 2005, “my leaders are those cows that get up first and start foraging following periods of inactivity.” Because leadership changes with group size and structure (Albright and Arave 1997; Phillips 2002) such a test, though challenging to develop, will be worthwhile and should be attempted. To ascertain animal information to select leaders, individual electronic animal identification (Anderson and Weeks 1989) may prove to be helpful.

No definitive studies currently exist on how virtual fencing may influence animal production. Though Tiedemann *et al*. (1999) found steers controlled using virtual fencing lost weight compared to the controls they did not attribute this to the method of control, but rather to the training method used to prepare the steers to virtual fencing control.

Conclusion

Virtual fencing, when commercially available on a worldwide basis, will provide rangeland managers the opportunity to manage natural landscapes proactively with all the advantages and challenges real-time decision making provides. Even though it holds great potential for management and stewardship of natural landscapes, it also holds the ability, if mismanaged, to compress the effects of temporal and spatial management and potentially destroy landscapes at a rate faster than possible using conventional methods to control free-ranging animals.

Proof-of-concept that virtual fencing is an option for controlling free-ranging herbivores has been established through the melding of many different disciplines. What remains to be accomplished includes: 1) reducing size of the equipment platform worn by the animals, 2) developing the best source of power and 3) determining how to store power in order to operate the electronics and 4) developing an optimum suite of sensory cues to elicit behaviours that are humane, efficient, reproducible and provide only a low stress impact on the animal’s physiology. A “one size fits all approach” is definitely not appropriate with virtual fencing. Ethologically, this method will require additional research to understand individual as well as group behaviours, especially the rate at which animals learn and the range of behaviours animals express when exposed to a particular stimuli.

Because of the potential of virtual fencing to elicit changes on the landscape in a rapid manner, virtual fencing should only be used in conjunction with proper rangeland management practices. Monitoring (with feedback) linked to decision making involving soils, plants and animals must be practiced rather than applying virtual fencing in a thoughtless and cavalier manner as just another management tool. Virtual fencing should free up labour from the menial tasks of conventional animal control while increasing the intellectual demands of those charged with the responsibility of managing animals within virtual fences.

Humans are not infallible; therefore, the devices they build are certainly not. Therefore, the properly trained eye of a resource manager who understands the ecological implications and solutions to over-stocking as well as under-stocking should never be replaced by algorithms or electronics regardless of how sophisticated computer software may become. When considering virtual fencing, potential users should not dwell on what technologies are not yet available but rather on understanding the challenges arising from human nature and how they will apply to this new methodology of animal control.

The practical studies that remain to be conducted are trials with large numbers of animals ($n \geq 50$ animals) in replicated studies conducted in a number of different ecosystems in order to determine where, if any, the weak links to this methodology lie and more importantly, how they can be corrected.

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