Representing spatially explicit Directional Virtual Fencing (DVF™) data

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Abstract

Distributing free-ranging animals across a landscape to facilitate proper forage utilization is universally challenging to range livestock managers. By combining Global Positioning System (GPS) technology, Geographical Information System (GIS) methodology and a practical knowledge of animal behavior we have developed a device that autonomously controls animal distribution without conventional wire fencing or herding. Directional Virtual Fencing (DVF™) uses sensory cues administered at the proper time and in the correct location on the animal to keep animals within a Virtual Paddock (VP™) that can move in time and space using programmable Virtual Boundaries (VB™). Analyzing the resulting geospatial animal data obtained from the device using Tracking Analyst® Software, provides essential information for understanding and subsequently managing animal distribution.

Introduction

For over 90 years rotation of livestock across a landscape has been advocated as one of the most efficient methods for range improvement (Barnes 1913). Proper livestock distribution is the most important feature in range management once the correct stocking rate has been determined (Jardine and Anderson 1919, Stoddart and Smith 1943, Bell 1973, Squires 1981, Holechek et al. 2001). Therefore, controlling the frequency and intensity of defoliation remain the two most important challenges to be addressed when designing grazing systems (Beck 1980).

From a Scottish agricultural handbook published in 1777 Davies (1976) documents one of the earliest if not the first grazing system to simulate “natural rotation.” Grazing systems have been advocated in the US for over a century (Smith 1895) yet it was between the 1950’s and 1980’s that grazing system research flourished in the US (Holechek et al. 2001). Though studies have shown livestock production per animal may be the same or lower for many rotation systems when compared to continuous stocking (Herbel 1971), rotational grazing systems often provide improvements in the standing crop (Anderson 1981). Today the study of grazing systems remains focused not only on understanding how grazing systems impact standing crop and animal nutrition, but on how animal behavior impacts plant and animal productivity as well as how the animal impacts the system (Arnold and Dudzinski 1978, Briske and Kothmann 1982, Smith 1998).

Information is lacking on intensive grazing systems applied to xeric ecosystems, especially those that were originally developed for tame pastures in mesic regions (Voisin

1988). Current short duration grazing systems, as they are frequently referred to, use single animal groups and multiple paddocks through which the animals are rotated in an attempt to optimize production from both the plant and animal resources (Savory 1999). The major advantage of these intensive rotational stocking strategies is to improve livestock distribution and forage utilization when compared to continuous season-long stocking (Tiedeman 1986).

Fencing is the most common tool used to affect animal distribution (Semple 1970) and is pivotal in implementing intensive rotational stocking strategies. It provides for the intensive and effective management of grazing lands (Vallentine 1989) but is the most expensive component to implementing a grazing system (Conner 1991). Because of the costs (material, labor and maintenance) associated with conventional fencing rotational stocking strategies (Stoddart and Smith 1943) have often been deemed impractical (Bell 1973). Furthermore, with the exception of temporary electric fencing (Miles 1951) most conventional fencing is static on the landscape and can last for 20 to 30 years (Engle and Weir 2000). In contrast, plant and animal resources are diurnally dynamic in both time and space and thus require flexible management strategies in order to obtain optimum results.

Non-wire fencing has promise as an alternative for accomplishing the benefits of rotational stocking without many of the challenges of conventional fencing. Attempts to manage livestock using electromechanical cues to control free-ranging animals have shown to be successful (Fay et al. 1989, Quigley et al. 1990, Markus 1998 a and b, Tiedemann et al. 1999, Anderson et al. 2003, Anderson et al. 2004). This paper describes a methodology relying on Global Positioning System Technology (GPS; Herring 1996, Eng 2004) to control animals in the absence of conventional fencing. Directional Virtual Fencing (DVF™) has been shown to effectively contain animals within a Virtual Paddock (VP™; Anderson et al. 2003). This paper demonstrates that the VP™ can be moved across the landscape while containing free-ranging cattle.

Materials and Methods

Between February 25 and March 5, 2004, two bred, mature crossbred cows were equipped with DVF™ devices (Anderson 2001, Anderson and Hale 2001) and subsequently confined within a 200 m x 486 m VP™ located on the Jornada Experimental Range (JER) in southern New Mexico at approximately 32^0 37' N, 106^0 45' W. Mean annual precipitation for the JER is 245 mm (range 77 to 507 mm). The rectangular VP™ was delineated by a conventional barbed wire fence on the west side and a Virtual Boundary (VB™) on each of the three remaining sides (Figure 1). The north and south VB's™ were programmed to move in tandem each day in a southerly direction at the rate of 1.1 m/hr between 0700 hours and 1700 hours. This rate was determined in an entirely arbitrary manner to evaluate the potential of a moving VP™ to contain cattle without focusing on the physiological requirements of the plants or animals during dormancy. The eastern VB™, parallel to the barbed wire fence remained static throughout the trial.

Weather data obtained every 5 minutes during the trial was recorded approximately 3 km from the VP™. The weather station used solar powered Campbell Scientific (Logan, Utah) equipment. The R. M. Young Model 03001 anemometer and vane was used to measure wind speed and direction, respectively. Ambient air temperature and relative humidity were measured with a Model CS500 probe.

The 25 m wide Virtual Boundary (VB™) band shown in blue (Figure 1) defined the perimeter of the VP™. The remaining seven bands each 25 m in width made up the 200 m wide VB™ which was programmed into the DVF™ device. To locate the advancement of the perimeter of the blue band (defined as Zone 2 in Figure 1) one DVF™ device was periodically carried into the field and the audio cues were used to determine where the leading edge of the north VB™ was located. Once located, GPS coordinates were obtained using a Trimble® GeoExplorer (Sunnyvale, California) and survey flagging were placed at these locations to allow their locations to be relocated for future reference. A metric tape was used to measure distances among flags and calculate distances between successive flag locations.

To keep the animals within the VP™ cues were applied to either the animal's right or left side only if the animal penetrated a VB™. The side to which the cues were applied was determined entirely by the angle of the animal's head and neck with respect to the Virtual Center Line (VCL™). In order to move the animals out of a VB™ using the shortest route possible the DVF™ device's algorithm determined autonomously which side of the animal the cues would be applied.

Once in the VB™ the cattle were moved back into the VP™ with cues to elicit the least amount of stress, a long advocated husbandary principle (Watts 1936 p. 525). Therefore the cues were ramped from least aversive at the VP™ perimeter (Zone 2 the blue band) to most aversive as the animal approached the VCL™, dark red bands (Figure 1). Sound was the only cue administered if the animal penetrated only the blue band before returning to the VP™. However, if the animal penetrated deeper into the VB ™ an electric shock was administered immediately following an audio sound cue in each of the remaining seven bands. The most severe audio sound and electric shock were administered in the bands showing the darkest red (Zone 5 in Figure 1) on either side of the VCL™ and extending to the perimeter of the VB™ beyond which animals were to be excluded.

Drinking water and a mineral block were provided next to the barbed wire fence located on the west side of the VP™. The water trough was mounted on a two wheel cart that could easily be moved with a motorized all terrain vehicle. From its original location shown as a small star in Figure 1 the water and the mineral block were only moved one time (March 1, 2004) during the trial to the location of the larger star.

Data from the DVF™ devices were downloaded on Mondays, Wednesdays, and Fridays by removing the devices from the animals and using a hardwire connection to a laptop computer. Where appropriate means ± standard deviations have been calculated using the data base management system provided by Microsoft SQL Server 2000 Version 8.0 (Redmond, Washington). ArcView® 3.3 software was used to plot location data and an animated temporal presentation of the data was made possible using Tracking Analyst® Software, both products of ESRI (Redlands, California).

Results and Discussion

The weather during this trial was relatively dry and cool. A total of 10.7 mm of rain was recorded over a series of small rainfall events, the largest being1.0 mm. As a result of the precipitation, relative humidity ranged between 18.8 to 100 percent with a mean of 64.3 ± 25.2 percent. Ambient air temperatures ranged between -6.0^{o} C and 20.6^{o} C with a mean of 7.0^{o} ± 5.9 ^{o} C. Mean wind speed recorded was 3.8 ± 2.7 m/sec with a maximum of 12.9 m/sec recorded on Thursday, March 4, 2004, at 1830 hours.

In previous research a static VB^{TM} successfully restricted cattle to a specific area on the landscape (Anderson et al. 2003). In this proof-of-concept trial a VP^{TM} approximately 10 ha (24 ac) in size was shown to not only hold cattle, but when programmed to advance at 1.1 m/hr during daylight, could move the two cows over the landscape. Over the trial 34,379 locations were recorded (Figure 1) while the VP^{TM} moved approximately 100 m to the south of its original location.

The two cows differed in their behavior toward being controlled using DVF^{TM} devices. Cow 1 (red dots in Figure 1) penetrated the VB^{TM} 32 times and remained in the VB^{TM} 1,688 sec (28.1min) out of a total of 750,653 sec over the trial with a variable amount of time (Figure 2) and number of penetrations (Figure 3) into Zone 2 recorded for each day. In contrast, cow 2 (green dots in Figure 1) penetrated the VB^{TM} 83 times and remained in the VB^{TM} a total of 7,079 sec (2 hr) out of a total of 727,821 sec over the trial. Cow 2 penetrated Zone 2 more frequently on seven of the ten days compared to cow 1 (Figure 3).

Both cows attempted to leave the VP^{TM} a total of 115 times, however, neither animal was successful in escaping from the VP^{TM} during the trial. Cow 1 (Figure 1) was always (100%) turned back using only audio cuing (Zone 2, blue band) as evidenced by the fact that she never penetrated into Zones 3 – 5 (Figure 3). In contrast, cow 2 penetrated into all four zones (Zones 2 through 5) on March 4, 2004 (Figure 3). However, 93% of the time she was turned back into the VP^{TM} from VB^{TM} Zone 2.

The cows appeared to randomly orient themselves with respect to the VCL^{TM} once they had penetrated the VB^{TM}. Cow 1 spent 47% of the time with her right side closest to the VCL ^{TM} and 53% of the time with her left side closest to the VCL ^{TM}. The animal's side closest to the VCL ^{TM} is the side to which the cues would be applied. Cuing data from cow 2 was not reliable for the period March 5, 2004 01:32:57 to March 5, 2004 02:22:08. However, the remaining data indicate she spent 58% of the time in the VB^{TM} with her right side toward the VCL^{TM} and 42% of the time with it on her left side.

Non movement was detected for approximately 18 hrs out of every 24 hrs during the trial based on the criteria for walking/grazing (≥0.09 m/sec to ≤0.89 m/sec) and for non movement (0 m/sec to <0.09m/sec) shown in Table 1. These rates of travel were calculated using uncorrected GPS locations recorded every 46 ± 7.5 sec when the animals were in the VP™ and every 1 ± 0.7 sec when the cows were in the VB™. The difference in the frequency with which the data were recorded depended on where the animals were located and this was based on how the DVF™ device was designed to operate (Anderson and Hale 2001).

One would assume that the greatest number of VB™ penetrations would occur when the animals are moving and the literature suggests that the majority of movement occurs during daylight foraging according to Arnold and Dudzinski (1978) and Squires (1981). These data also show this trend, however, about 20% of the grazing/walking took place between 1701 and 0659 hrs (Table 1). This preliminary finding needs further evaluation using more animals and different seasons.

Table 1. Percent of walking/grazing (≥0.09 m/sec ≤0.89 m/sec) and non movement (0 m/sec-<0.09m/sec) from two cows between February 25, 2004 to March 5, 2004 on an arid rangeland Virtual Paddock (VP™) located on the Jornada Experimental Range within Paddock 10 B.

Cow	Behavior	No. of lines of data and (%)	0700 to 1700 hrs	1701 to 0659 hrs
			Percent	
1				
	Walking/grazing	3734 (24)	31	21
	Non movement	11987 (76)	69	79
2				
	Walking/grazing	4390 (25)	32	19
	Non movement	13383 (75)	68	81

It should come as no surprise that mean movement (m/sec) for both cows was faster inside the VB™ compared to the VP™. Most likely the 2.6 times faster movement of the cows when inside the VB™ was in response to the animals being cued (Table 2).

Table 2. Means ± standard deviations for travel (m/sec) for two cows between February 25, 2004 to March 5, 2004 while confined to a 200 x 486 m Virtual Paddock (VP^{TM}) surrounded by a Virtual Boundary (VB^{TM}) on three sides that moved at a rate of 1.1 m/hr between 0700 and 1700 hrs but remained stationary between 1701 and 0659 hrs.

Cow	Daily		0700 to 1700 hrs		1701 to 0659 hrs	
	VP^{TM}	VB^{TM}	VP^{TM}	VB^{TM}	VP^{TM}	VB^{TM}
1	0.19 ± 0.12	0.52 ± 0.19	0.18 ± 0.11	0.49 ± 0.19	0.19 ± 0.13	0.53 ± 0.19
2	0.21 ± 0.15	0.52 ± 0.20	0.21 ± 0.15	0.53 ± 0.20	0.20 ± 0.16	0.52 ± 0.20

Conclusions and the Future

This trial establishes proof-of-concept that cattle held within a VP^{TM} can subsequently be moved across the landscape. However, the individual differences in animal behavior with respect to penetrations into the VB^{TM} will require further testing using larger numbers of animals and different landscapes in order to determine the benefits and limitations of this methodology of free-ranging animal control to affect patterns of animal distribution. Using GPS data it is not only possible to control where animals forage on the landscape but also investigate aspects of their behavior such as intervals of non movement as well as travel.

The rate (1.1 m/hr) at which the VP^{TM} was programmed to move across the landscape was determined in an entirely arbitrary manner in order to evaluate the potential of a moving VP^{TM} to contain cattle. Using a rate of movement tied to optimizing the physiological needs of plants and animals must await studies specifically designed to address these most important questions.

Before DVF^{TM} becomes commercially available it will be necessary to download data remotely as well as upload changes to the VB^{TM}. This is currently being addressed using wireless technology (Butler et. al. 2004, Juang et. al. 2002) while miniaturizing the electronic footprint of the device and reducing its power consumption (Anderson 2004). Eventually knowing where on the landscape a VP^{TM} should be located will be determined using satellite imagery (Rango et. al. 2003).

Because direction and rate of movement of a VP^{TM} across the landscape is fully programmable Prescription Stocking (R_xS^{TM}) using DVF^{TM} may soon be a reality (Rango et al. 2003). The goal of R_xS^{TM} is to optimize the economic and ecological benefits offered by rotational stocking without the challenges of conventional fencing, especially those involving construction and maintenance costs. Holechek and Galt (2004) stated that "changing grazing intensity levels and deferment or rest periods in each pasture according to its specific rainfall, range condition, and plant community is a theoretically sound approach to grazing management." DVF^{TM} offers the potential for realizing this goal since a VP^{TM} can be programmed to move temporally and spatially to meet forage disappearance and plant re-growth optimizing both the plant's and the animal's nutritional requirements. In addition to optimizing the management of stocking density DVF^{TM} could be used to gather animals thus reducing the amount of time managers spend in this labor-intensive aspect of animal husbandry. However, because DVF™ relies entirely on modifying animal behavior to hold and move animals it should not be used if health or safety issues require absolute animal control.

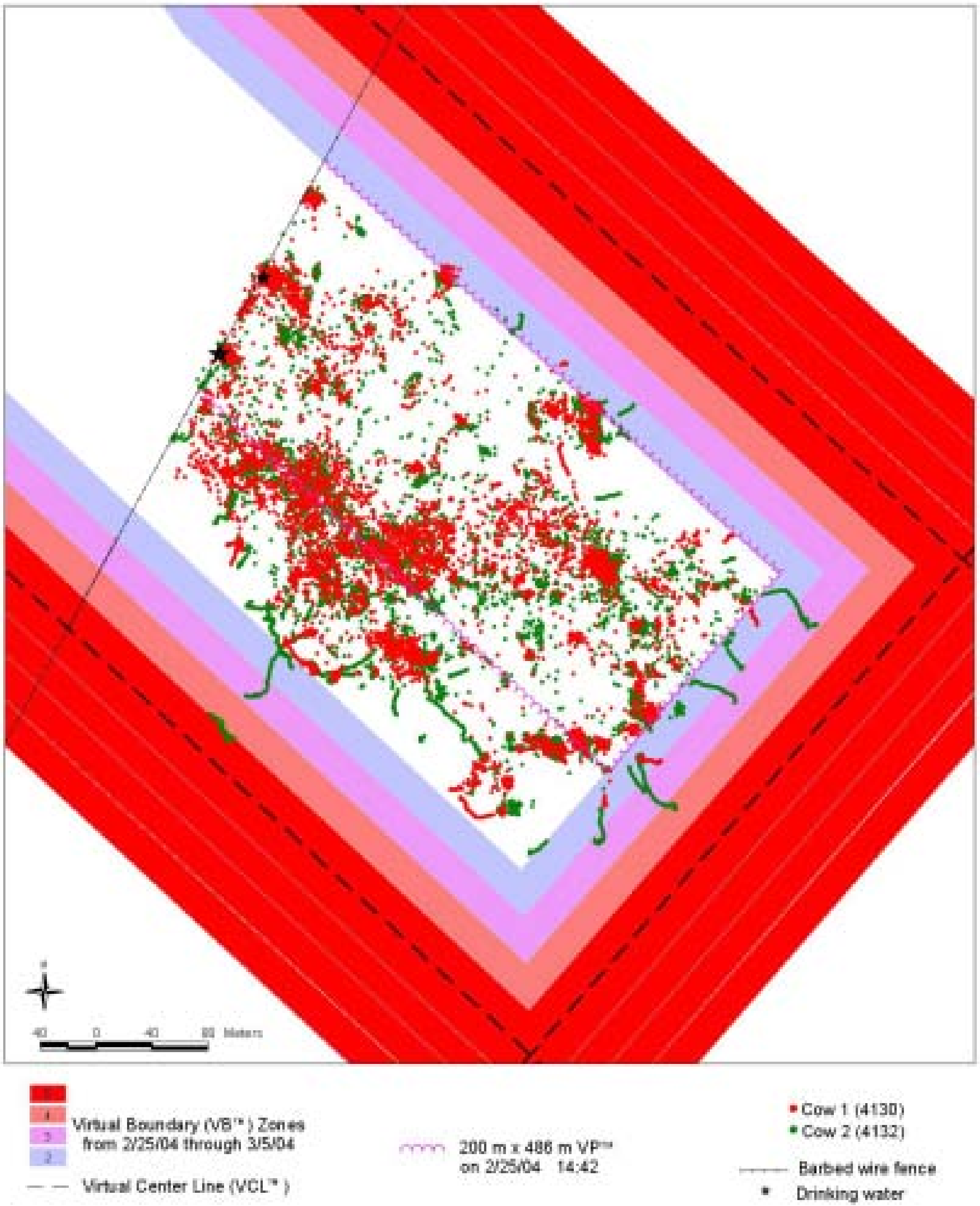


Figure 1. Location of two cows in a 300 m x 486 m area while wearing activated Directional Virtual Fencing (DVF™) devices. The animals were confined within a 200 m x 486 m Virtual Paddock (VP™) bounded on the north and south by a Virtual Boundary (VB™) that moved in a southerly direction at a rate of 1.1 m/hr between 0700 and 1700 hrs while the east VB™ remained static between February 25 and March 05, 2004. Neither animal escaped through the lines (crossed the Virtual Center Line; VCL™) of the moving VP™ over the trial. The "worm-like" lines, seen within the VB™, indicate locations where cues from the DVF™ device were sufficient to turn the animals back into the VP™. Each of the eight programmable zones comprising the VB™ were 25 m wide. Sound was the only cue in Zone 2 (blue band) while in the remaining zones both audio sound and electric shock cues were administered. Irritation from the sound and shock cues increased to a maximum level in Zone 5. Drinking water was moved from its initial location (small star) to its second location (large star) on March 1, 2004. This was done to keep the drinking water centered along the 200 m wide VP™ axis.

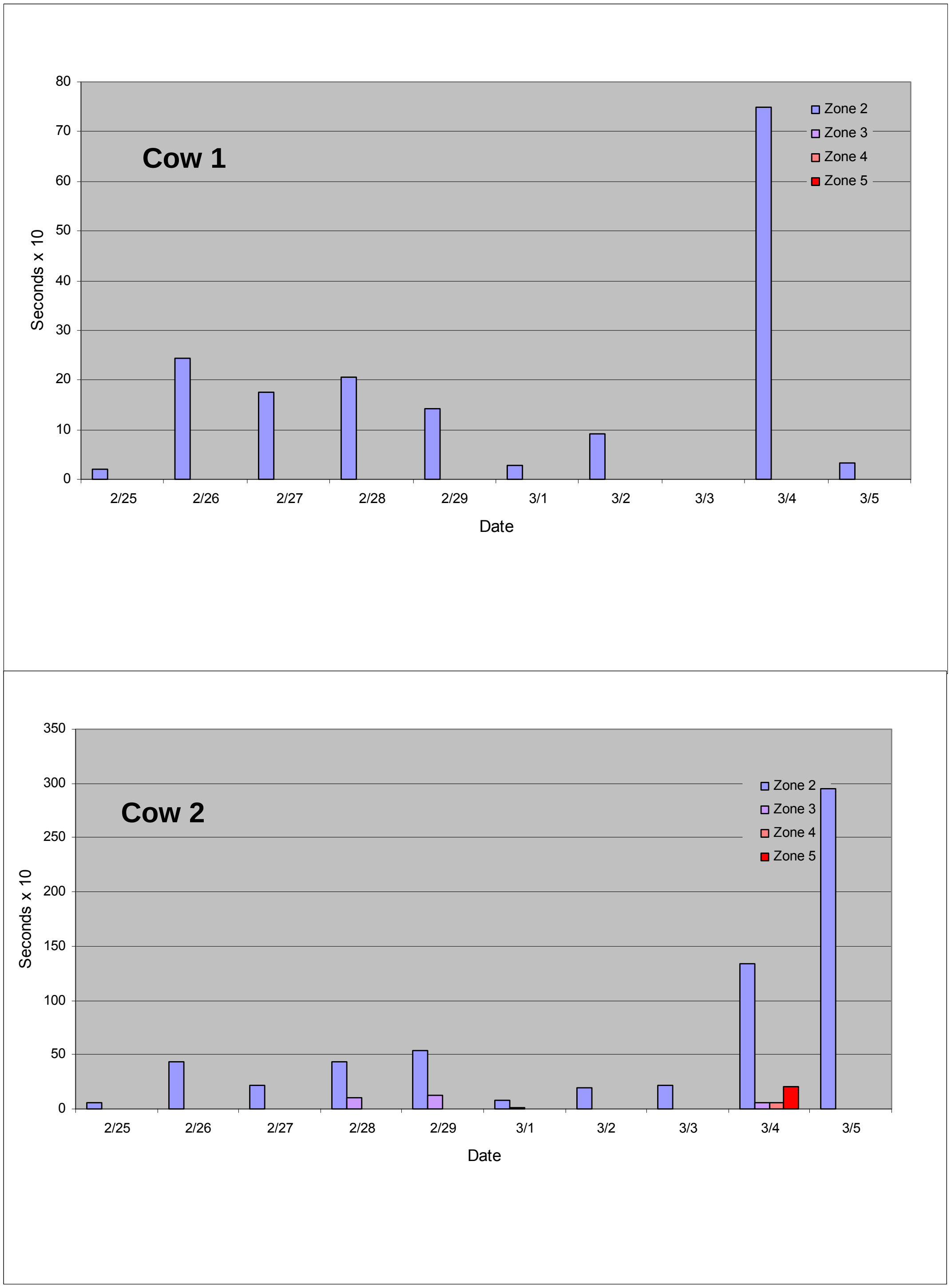
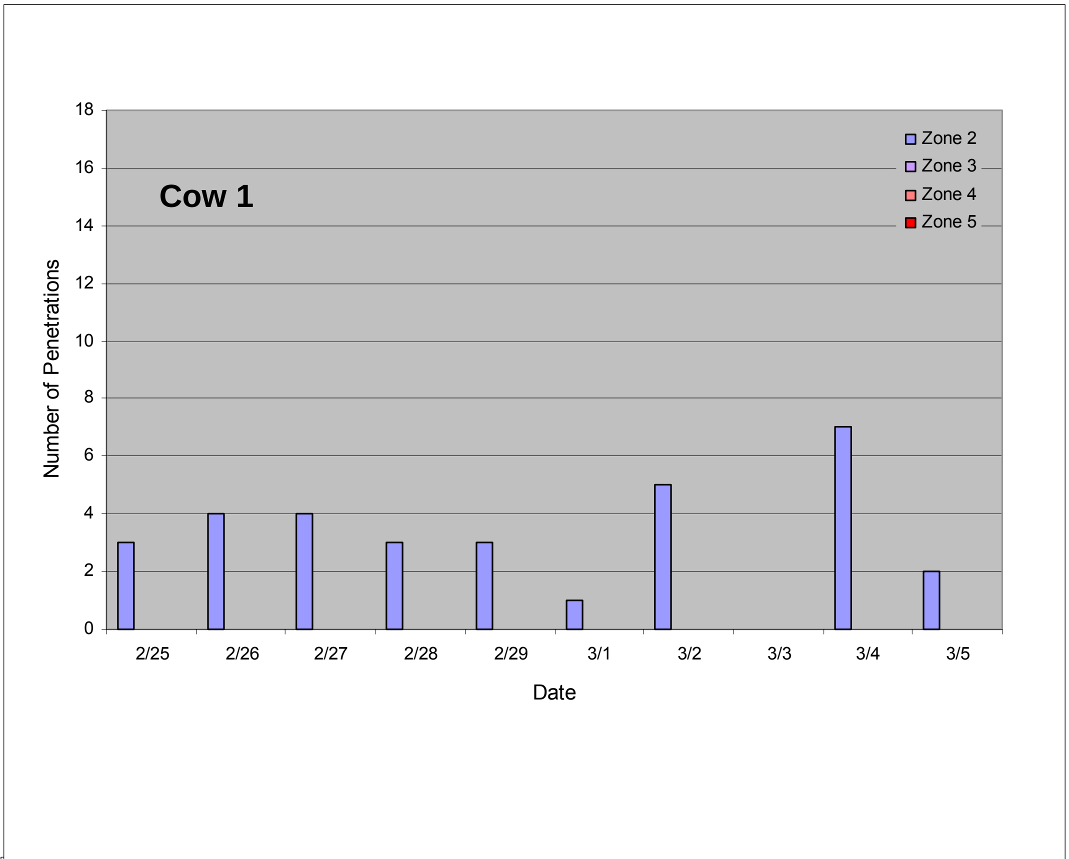


Figure 2. Time (seconds) cow 1 and cow 2 spent in the Virtual Boundary (VB^{TM}) Zones 2 through 5 between February 25, 2004 and March 5, 2004. Cue intensity increases between Zone 2 (audio sound only) and Zone 5 (highest level of audio sound and electric shock) with Zones 3 and 4 having intermediate levels of audio sound and electric shock.



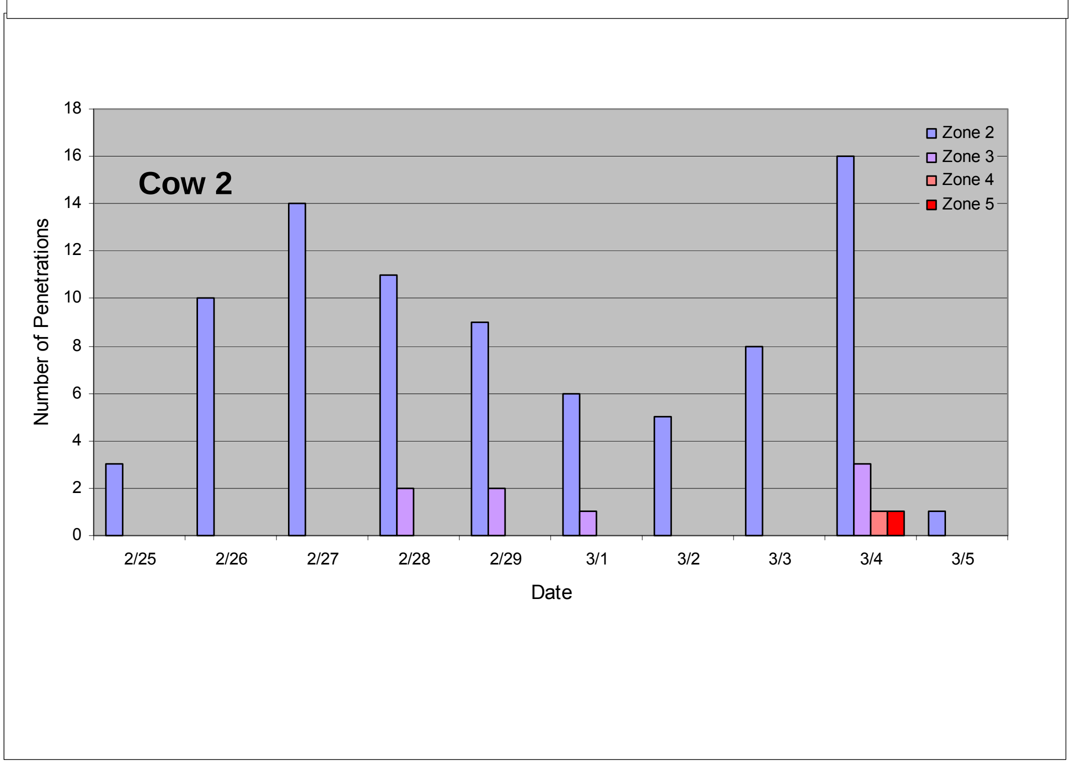


Figure 3. Number of penetrations of cow 1 and cow 2 into the Virtual Boundary (VB^{TM}) between February 25, 2004 and March 5, 2004. Cue intensity increases between Zone 2 (audio sound only) and Zone 5 (highest level of audio sound and electric shock) with Zones 3 and 4 having intermediate levels of audio sound and electric shock.

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End Notes

Trade names used in this publication are solely for the purpose of providing information. Mention of a trade name does not constitute a guarantee, endorsement, or warranty of the product by the U. S. Department of Agriculture over other products not mentioned.

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