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Behavior of cattle in pens exposed to ±500 kV DC transmission lines*

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ABSTRACT

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The general hypothesis tested was that groups of cattle (*Bos taurus*) kept in pens under a ±500 kV DC transmission line and in control pens 550 m away would exhibit similar patterns of activity and distribution. Identical facilities, consisting of four pens under the line and four pens in the control area, were stocked with 2 groups of 50 cow/calf pairs in the exposed area, and 2 groups of 50 cow/calf pairs in the control area (a total of 200 pairs). The extra pens in each area allowed rotation of cattle to a clean environment when manure accumulations became excessive. Exposed and control groups were paired with paired groups maintained and rotated through corresponding pens throughout the study. Exposed cattle could move as far as 55 m from the line. Paired designs with simultaneous monitoring of exposed and control groups were used to compare livestock distributions when animals were feeding, resting in mid-afternoon, bedded for the night, and over 24-h periods. Cattle activities were monitored for one 24-h period each month. A significant ($P<0.01$) but weak ($R^2=0.11$) correlation indicated 6.9% fewer exposed than control cattle were observed in the central areas of pens when afternoon, night and 24-h data were combined. When time periods were analyzed separately, a similar trend for afternoon data was found for 1 of the 2 paired groups (11% fewer cattle, $R^2=0.55$). This trend was not detected in the night or 24-h data. Feeding positions and activity patterns were similar between treatments. Variation in feeding and afternoon distribution patterns of exposed cattle did not appear to be correlated with fluctuations in electric fields and detectable noise generated by the line. Owing to the overall similarities of cattle behavior; a lack of effects on conception rates, birth rates, birth dates and calf growth; and the fact that greatest densities of both exposed and control animals occurred in the central areas of pens during afternoon and 24-h observations; no adjustments in management are necessary when cattle are kept under or near ±500 kV DC power lines.

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INTRODUCTION

High voltage transmission lines traverse thousands of kilometers of range and crop lands throughout the world. Because the consequences of their presence on animals and crops are often questioned, this research was conducted to examine behavioral aspects of long-term exposure of penned beef cattle (*Bos taurus*) to a ±500 kV DC transmission line. The overall objective was to test the hypothesis that cattle in pens under high voltage DC (HVDC) lines and cattle in pens without high voltage lines would exhibit similar behavior patterns. The study was designed to simulate a "worst case" in terms of exposure to an electrical environment, in that half of the cattle were confined year round to large pens traversed by DC lines. Cattle are not normally this confined under rangeland circumstances, but this study has wider application because it addresses conditions where livestock may be pastured near DC lines for extended periods or during feedlot confinement.

American interest in the possible environmental effects of high voltage DC conductors initially arose over construction of a ±400 kV DC line in Minnesota (Lee et al., 1985). After these lines were energized in 1978, surveys of nearby land owners revealed concerns that wildlife, livestock and people may be adversely affected (Genereux and Genereux, 1980). A science advisory committe in Minnesota concluded the survey was inadequate, there was no scientific evidence to indicate short-term exposure to high voltage DC lines posed a risk to human health (Bailey et al., 1982), and later (Bailey et al., 1986), that evidence of biological effects of air-borne ions generated by the lines was inconsistent and that further studies of crops and livestock near DC lines should be conducted. Examination of several aspects of dairy herd records, before and after the Minnesota line was energized, found no effects on cattle which could be attributed to the line (Martin et al., 1986). Griffith (1977) studied wheat growing at various distances from the Pacific Intertie when it was operating at ±400 kV prior to 1985 and detected no disparities in height, quantity, or quality of grain at harvest time. In a recent review on air-ions, people, and animals Charry (1987) concluded that effects are typically small in magnitude and do not persist after exposure has ceased. An abundance of controversial literature exists regarding laboratory studies of people, animals and plants exposed to high voltage DC electric fields and air-ions. Most of this research, however, does not specifically address the possible effects of high voltage DC transmission lines.

ANIMALS, MATERIALS AND METHODS

Facilities and livestock management

A 130-ha study site was constructed on the Crooked River National Grassland approximately 19 km southeast of Madras, OR. The area lies 1060 m above sea level and has a north-facing aspect with a mean slope of 4%. The climate of the region is characterized by mean high and low temperatures in January and June of 4 and -7, and 31 and 7 °C, respectively; mean annual precipitation of 23.9 cm (National Oceanic and Atmospheric Administration, 1987), and winds from the west ~70% of the time (Raleigh, 1988). Two spans (supported by three towers) of the 1360 km Pacific Intertie ±500 kV DC transmission line cross the site in roughly a north–south direction. The lines extend from the Dalles, OR to Sylmar, CA. A classification of land use along the initial 275-km portion of the system in Oregon revealed approximately 91% rangeland and 9% cropland (Raleigh, 1988).

The two transmission line conductors are suspended from lattice steel towers with towers spaced 350 m apart. Each conductor, or pole, of the system consists of a pair of 4.6-cm-diameter aluminum cables with spacers maintaining a 46 cm horizontal distance between cables. Horizontal distance between the positive and negative conductor is 12.2 m with the positive conductor suspended from the west side of the towers and the negative conductor from the east side. Polarity of the system may be reversed, but this did not occur during the project. Respective midspan to ground clearance for north and south spans was 15.8 and 12.5 m. Thermal expansion of the cables, a product of line current and ambient conditions, can allow north and south midspan clearances to range between 14.4–16.7 and 11.3–13.4 m, respectively.

Four approximately square shaped treatment pens were established under the powerline (Fig. 1). Three pens were 1.3 ha each (122×104 m) with their long axes perpendicular to and centered under the lines. Owing to topographic constraints in the northeast corner, Pen 1 was trapezoidal and only enclosed 0.73 ha. The maximum distance cattle could move from the transmission lines was 55 m. Four control pens of identical size, configuration, and orientation were built 550 m west of the powerline to minimize exposure to air-borne ions generated by the lines. Electric fields and ion densities in the treatment area were one to two orders of magnitude greater than the control. Pens were fabricated from wood posts and galvanized iron mesh. Feedbunks for cattle, 58.5-m long, made up the central portion of the south side of each pen with feed access provided through slant-bar feeder panels. Calf feeders (29.3-m long) were centered under the powerline along the north boundary of each pen, and a water tank was placed under each conductor in the middle of the pen. All structures associated with the pens were grounded.

Each pen was visually subdivided into 16 equal sized cells (Fig. 1) by using brightly colored placards on fences, and mineral supplement containers and water tanks as mid-pen reference points. Cells were indexed alphabetically with subdivisions A–H constituting the north half and I–P the south half of each pen. Dimensions of the number one pen in both the treatment and control areas resulted in elimination of Cell H and reduced areas in Cells F, G and P.

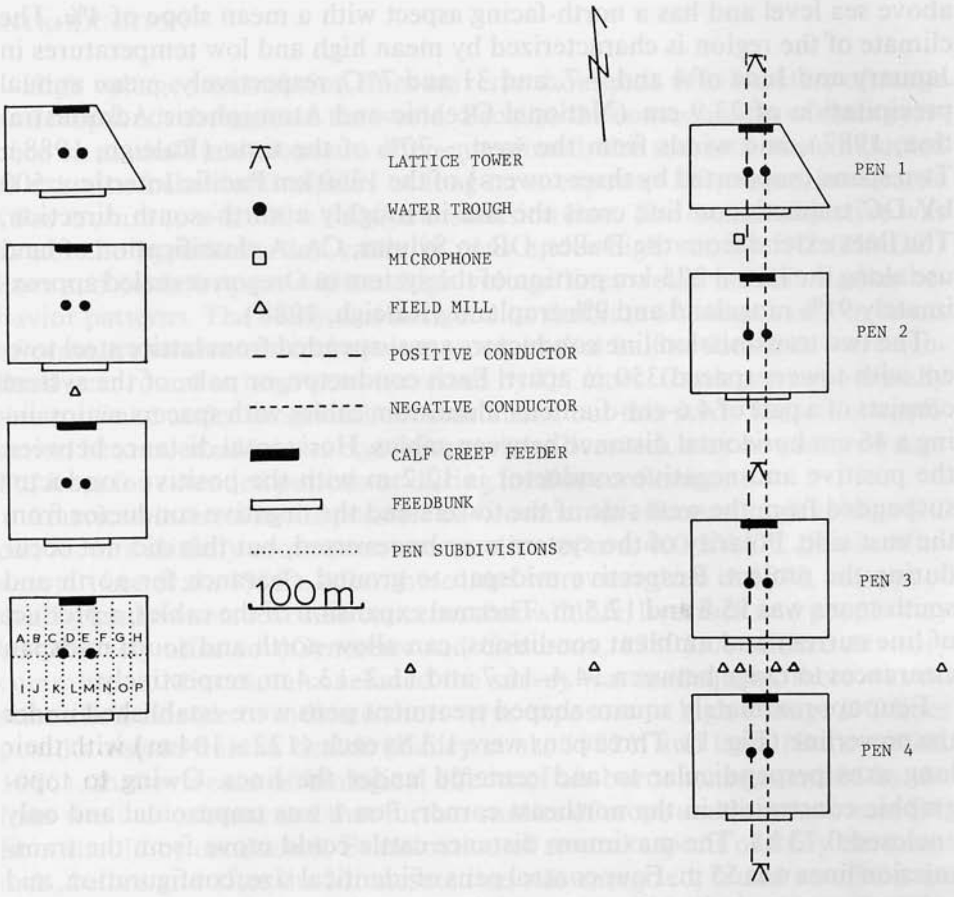

Fig. 1. Configuration of livestock facilities traversed by ±500 kV DC transmission lines.

To elucidate the spatial distribution of cattle while feeding, graduated scales, incremented in 0.3-m units, were painted on the outside of feedbunks. The zero point was centered directly under and between the two conductors in the treatment pens, with the scale extending 96 units east and 96 units west of zero.

Two hundred mixed breed (Hereford×Angus×Charlois) cow–calf pairs were brought to the site in late April 1985 and initially maintained for 3 weeks in control pens before the study began. Cows were 2–7 years old. They were randomly divided into 2 herds (treatment and control) and each herd further subdivided into 2 groups (A and B). Twelve bulls were similarly allotted among the 2 treatment and 2 control groups. Treatment and control cattle were moved to their appropriate areas and respective groups were assigned to corresponding pens. Generally each group was kept in a single pen with two treatment and two control pens in use at any one time. The two extra pens in each area allowed rotation of cattle to a clean environment when manure accumulations became excessive, usually at 2–3 month intervals. Treatment and control cattle were dispersed among all four pens, except when cows were calving during February, March and April. Bulls were with cows from 25 days after the first calf until 90 days after the last delivery and kept in separate pens for the rest of the year. Calves left the study each year when they were weaned in mid-October. Cows and bulls were under treatment for 29 months with three breeding and two calving events occurring in that period. Cattle were marketed to slaughter where they were pregnancy checked at the end of the project.

To minimize behavior differences among treatment and control groups, activities such as feeding, pen rotations, and behavior monitoring were performed concurrently on corresponding groups of exposed and control animals. Data were not recorded on days when typical activity patterns of the facility were disrupted. This excluded months when cows were calving and days when unusual facility maintenance or livestock handling occurred.

Electrical variables

The two electrical variables correlated with livestock behavior were electric field (kV m^{-1}), measured by field mills (Maruvada et al., 1983), and detectable noise (dBA between 20 and 20 000 Hz) sampled by a stationary microphone. Both of these phenomena can be perceived by mammals above certain thresholds.

Voltage on HVDC lines produces an electric field in the space around the conductors. The electric field at the conductor surface causes ionization of the air near the conductors. This phenomenon, known as corona, generates charged atoms, molecules, molecular clusters and particles, in addition to audible noise. Because HVDC conductors have a constant polarity, ions having the same polarity as the originating conductor move away from the source creating a net electric charge in the surrounding air. This charge and the accompanying conductor voltage contribute to electric fields at ground level. Fields produced by conductor voltage are constant, but environmental conditions (wind, humidity, precipitation etc.) substantially alter the space around the conductors. Accurate assessment of electric fields, therefore, requires monitoring for extended periods at different distances from the source and under diverse weather conditions. Within the study area, ground level electric fields are typically strongest just outside the conductors $\sim$8 m from the centerline (Fig. 2). Owing to movement of air ions, a wind blowing predominately from the west tends to decrease field strength on the positive side of the line and increase strength on the negative side.

Electric fields were monitored on each side of transmission lines at 8, 23,

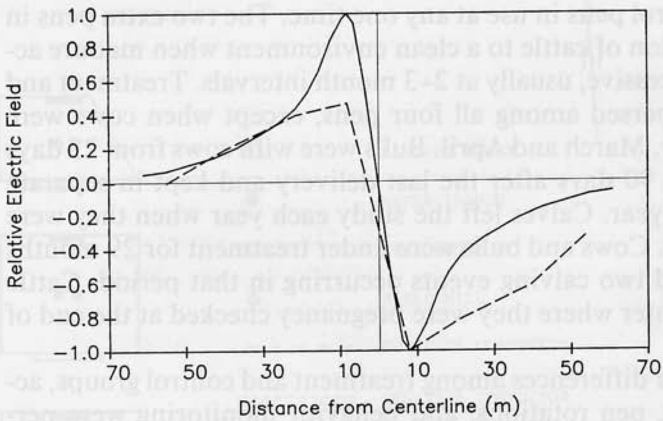

Fig. 2. Relative intensity of electric fields at ground level in pens under ±500 HVDC transmission lines during calm, dry weather conditions (solid line) and mean relative electric fields measured for 30-month period (broken line) of project.

152, 305 and 609 m from the centerline. A portable electric field measuring system was used for short-term measures and validation of predicted values at intermediate distances. Measurements closest to the lines were made between Pens 3 and 4 (Fig. 1). Electric field in the control area was monitored by a single instrument between Pens 2 and 3. A single unit was used because field variation in the control pens that far from the line was less than instrument resolution. Measurements of electric field and other electrical attributes were recorded at 1-min intervals by an automated system established by personnel of the Bonneville Power Administration. Wind speed and direction, humidity, temperature and precipitation were monitored at a central point with the same resolution as electrical data. Environmental and electrical data were integrated to predict electric fields accurately for any study area location. A detailed description of instrumentation, procedures and analyses for electrical and environmental data has been given by Raleigh (1988) and Chartier et al. (1988a,b).

Detectable noise, also monitored at 1-min intervals, was measured 15 m west of the positive conductor in the exposed area. Noise in the control area was only monitored for a 2-month period from 22 June to 27 August 1987.

Livestock behavior

Data were recorded on positions of cattle at feedbunks twice each week, except when cows were calving. Cattle were fed at roughly 07:00 h each morning with deliveries being made simultaneously to both exposed and control treatments. After cattle scattered themselves along the full length of the feedbunks (~30 min after feed delivery) technicians were dispersed to both treatments to record the positions of feeding animals. Data included numbers of cattle feeding on the east and west halves of feedbunks, mean positions of cattle on east and west halves of feedbunks, and mean position of cattle along the entire feedbunk. Data did not include individual identification numbers of the cattle. All variables denoting numbers of animals were converted to percentages to compensate for unequal numbers in exposed and control groups (mortality over the study was 2.6%, one bull, five cows and 14 calves) and the fact that some animals were not at the feedbunks when data were recorded. Exposed and control data were paired by group and day of observation with the assumption that environmental influences specific to a given day (i.e. wind or rain) would similarly affect both herds. Hypotheses of zero mean differences (null hypothesis) and nonzero mean differences (alternative hypothesis) between exposed and control groups were examined using paired t-tests. Separate analyses were conducted for Groups A and B. Differences for this and all other paired analyses are expressed on an "exposed minus control" basis.

To examine further hypotheses that cattle would respond to fluctuations in electrical environment while feeding, the mean position of exposed cattle along the east and west halves of feedbunks were related to simultaneous measures of electric fields 8 m to the east (negative side) and west (positive side) of the centerline. Regression analyses and visual examinations of scattergrams were used in an effort to correlate the positioning of the cattle to fluctuations in the electric field or detect some threshold of exposure which might stimulate movement of the animals.

Distributions of cattle were also monitored during periods when they were not being drawn to the central areas of the pen by feed. Two days each week, between 14:00 and 15:00 h when cattle were generally inactive or ruminating, the spatial distribution of treatment and control animals was documented by recording the number of cattle occurring in each subdivision of the pen. The hypothesis of zero mean differences between exposed and control distributions was examined with Hotelling's t^2 procedure (Hotelling, 1947), which is basically a multivariate paired-t test.

Hotelling's t^2 requires generation of a variance covariance matrix derived from a table of differences of paired observations. When data are expressed as percentages or equal numbers of animals occur in paired pens, sums of differences between paired observations equal zero, and the variance covariance matrix is indeterminant. Omission of one or more corresponding columns (pen subdivisions) from each data set will rectify this problem. By omitting subdivisions with the least number of observations, data were only slightly affected. Omissions typically withdrew $< 5\%$ of total observations of cattle. Degrees of freedom associated with this analysis equal p and $n-p$, where: n is the total number of observations and p is the number of paired entities (subdivisions) compared.

To convey the degree to which exposed and control treatments were alike or different in their occupancy of pen subdivisions, a similarity index (S) was calculated for each line:control pair (Renkonen, 1938).

$$S = \sum M_{i(\mathrm{e,c})}$$

where i is the particular subdivision in question (Cells A–P); e and c designate exposed and control, respectively; and M is the minimum of the two corresponding values associated with Cell i. Similarly indices may range between 0 and 100, with a value of 100 indicating perfect agreement in distributions of exposed and control animals and 0 indicating no overlap or no similarity.

When significant differences in distribution patterns of exposed and control animals were detected, scattergrams and regression analyses were employed to detect systematic patterns in disparities possibly related to the presence of the powerline. Mean differences between exposed and control cattle in each pen subdivision (dependent variable) were related to distance of the 16 subdivisions (independent variable) from the centerline of the conductors. Midpoints of the eight subdivisions on each side of the line were 7.6, 22.8, 38.1 and 53.3 m east or west of centerline.

To test the hypothesis that exposed cattle responded to fluctuations in electrical environment, measures of positive and negative electric fields 8 m from the centerline and measures of audible noise (independent variables) were correlated with percentages of cattle in pen Subdivisions D, L, E and M which were directly under the conductors (Fig. 1). Data from Subdivisions D and L (under positive conductor) and E and M (under negative conductor) were pooled to serve as dependent variables.

Positions of bedded cattle were recorded one night each week (19:00–23:00 h) with actual time of observation varying seasonally. Bedding positions were recorded by a single observer because most cattle were lying down, and movement among subdivisions was minimal. Night vision was aided with a vehicle-powered spotlight which caused no disturbance to the animals after their initial exposure at the beginning of the project. Analyses of these data included Hotelling's t^2, to test for differences between exposed and control groups, and regression analysis relating mean differences among exposed and control groups in each subdivision to distances of subdivisions from centerline.

Distribution patterns and activities of exposed and control cattle were monitored simultaneously for one 24-h period each month. Numbers of cattle within pen subdivisions were recorded beginning at 10:30 h, with sampling continuing on an hourly basis through 09:30 h the subsequent morning. Data for each of the 16 subdivisions were totaled for a 24-h period and totals were viewed as single observations in the final analyses. Analyses included Hotelling's t^2 and regression analysis relating mean differences between exposed and control groups to distances the subdivisions were from centerline.

Because data from the three different samplings of distribution (afternoon, night and 24 h) shared a common format, mean differences derived from each group and sampling period were combined in a common matrix and further examined for patterns possibly related to the HVDC conductors. Because this was a table of means with only six observations, degrees of freedom were insufficient to use Hotelling's t^2. Regression procedures relating differences exhibited between each cell to distances of cells from the centerline were the only analyses conducted on pooled data.

Activities of exposed and control cattle were monitored by the same observers documenting 24-h distribution patterns. Observations were recorded at 15-min intervals, beginning at 10:00 h and continuing through 09:45 h the subsequent morning. Activities included: nursing, drinking, walking, eating, lying and standing. Data were totaled for each 24-h period and converted to percentages. Nursing percentages were based on the number of calves in each pen, with the remaining activities based on number of mature animals. This distinction was used because cattle could nurse their young and simultaneously be involved in another activity. Means from each 24-h period were considered a single observation in the final analyses. Hypotheses of zero mean differences and nonzero mean differences between exposed and control groups were evaluated with paired *t*-tests, and analysis of each group and activity was conducted separately.

RESULTS

When cattle were observed feeding, ~40% of the available space along the feedbunks was unoccupied. Dispersal patterns of feeding livestock were similar ($P > 0.05$) among pens within treatments and between treatments with nearly equal percentages (49–51%) of cattle detected along east and west halves of feedbunks. Mean positions of exposed and control cattle along east and west halves were also similar, but when data from both halves of the feedbunk were pooled to derive an average cow position, a significant difference was detected between exposed and control cattle in Group A but not Group B. Because the mean exposed:control difference for Replicate A was only 0.88 m, a distance roughly equalling the width of a mature cow, this disparity was considered to have no biologic or management significance. In all treatments and groups the average cow was positioned within 1 m of the feedbunk center.

No significant ($P > 0.05$) relationships or trends were detected in regression analyses or observed in visual examination of scattergrams relating variation in positioning of exposed cattle to measures of electric fields at feedbunks. During observation periods electric fields ranged between -3.3 and 24.7 kV m^{-1} ($\bar{x} = 7.0$ kV m^{-1}, $n = 101$) 8 m west of feedbunk centers under the positive conductor, and 6.9 to -35.3 kV m^{-1} ($\bar{x} = -10.1$ kV m^{-1}, $n = 108$) 8 m east of feedbunk centers under the negative conductor. Positive or negative values measured under a conductor of the opposing polarity resulted from wind movement of ions. The mean electric field in the control area was 0.2 and ranged between 0.04 and 0.4 kV m^{-1}. During brief periods when transmission lines were off for routine annual maintenance (November 1985 and October 1986) mean electric fields in the control area were recorded at 0.1 ± 0.6 kV m^{-1}.

Cattle were typically ruminating or inactive when afternoon distributions were recorded. Across treatments and groups highest densities (67%) of cattle occurred in the four central subdivisions (K, L, M and N) which were bounded by feedbunks (Table 1). Forty-six percent of the exposed and 51% of the control cattle occurred in Subdivisions D, L, E and M, which were traversed by HVDC conductors in the treatment pens. Exposed:control similarity indices averaged 87% across the 2 groups. The null hypothesis of a zero mean difference between exposed and control treatments was rejected ($P<0.01$) for both replicates, indicating exposed and control cattle were not identically distributed among subdivisions. Mean differences between exposed and control subdivisions ranged from -3.5 to 5.3% for Group A and -3.0 to 5.0% for Group B (Table 2). Negative disparities indicate fewer exposed than control cattle in a specific subdivision.

Regression analyses relating differences between respective exposed and control subdivisions to distances of subdivisions from centerline yielded significant linear and quadratic models for Group B but not Group A (Table 3). The Group B quadratic model predicted differences of -2.7, 0.4, 1.6 and 0.8%, respectively, as one moved from subdivisions under the conductors to those at extreme ends of the pens. Expansion of these values by a factor of four, the number of subdivisions at each distance, suggests we will find 11% fewer exposed than control cattle in the central 25% of the pens with 1.6, 6.2 and 3.6% of these animals displaced to subdivisions 22.8, 38.1 and 53.3 m, respectively, from the centerline. This model further implies that if cattle were sensitive to the transmission lines, the majority of sensitive animals elected to move only a short distance (38.1 m) away from the center and not to the extreme ends of the pens.

Regression analyses relating numbers of exposed cattle in the afternoon in subdivisions under conductors to simultaneous measures of electric fields and noise produced no significant relationships. Examination of scattergrams similarly revealed no response patterns or thresholds of tolerance by cattle to higher levels of exposure. Mean electric fields measured under the positive conductor during observation periods ranged between -1.9 and 18.7 kV m^{-1} ($\bar{x}=5.7$ kV m^{-1}, $n=70$) and under the negative conductor between -0.05 and -35.6 kV m^{-1} ($\bar{x}=-14.2$ kV m^{-1}, $n=93$). Noise levels, measured on the west side of the line only, ranged between 31.8 and 65.5 dB ($\bar{x}=44$ dB, $n=103$) during observations of afternoon distributions. In the 2 months that

TABLE 1

Mean percentage of A and B groups of exposed and control cattle within subdivided pens (A–P) reflecting the similarity of their spatial relationships during afternoon, night and 24-h observations of cattle distribution. Centers of adjacent subdivisions within a row were approximately 15.2 m apart

Sample period and number	Treatment	Group A Pen subdivisions								Similarity index (%)	Group B Pen subdivisions								Similarity index (%)
		A I	B J	C K	D L	E M	F N	G O	H P		A I	B J	C K	D L	E M	F N	G O	H P	
Afternoon	Exposed	1.7	2.8	3.9	(3.2)	[3.2]	2.3	0.7	0.2		3.1	2.8	4.1	(3.2)	[4.2]	3.5	1.5	0.5	
		3.4	5.5	15.7	(19.4)	[18.8]	14.0	3.7	1.5		1.3	5.0	14.8	(18.5)	[18.8]	13.8	4.0	1.0	
$n = 158$										88									86
	Control	4.8	6.4	4.8	3.7	3.4	1.8	0.3	0.1		0.8	1.4	2.8	5.5	5.5	2.2	0.9	0.2	
		3.8	7.1	15.2	21.3	17.0	8.7	1.0	0.3		1.4	3.9	17.9	23.5	21.1	10.9	1.8	0.3	
Night	Exposed	10.5	9.5	9.1	(2.8)	[4.1]	7.9	7.1	5.2		4.9	6.0	7.9	(2.6)	[2.4]	7.0	10.8	8.2	
		5.5	6.1	6.1	(4.5)	[4.6]	6.2	5.6	5.1		6.5	7.9	7.3	(4.6)	[4.2]	6.3	7.5	6.1	
$n = 83$										69									77
	Control	1.1	1.9	3.1	3.0	8.1	12.1	6.1	3.6		1.8	2.7	3.5	3.7	7.9	8.5	7.7	5.6	
		2.9	3.9	6.3	4.4	6.7	10.5	10.1	16.3		3.8	4.6	8.7	4.8	4.8	6.0	7.3	18.5	
24-h	Exposed	4.5	4.8	5.9	(2.8)	[3.8]	6.9	4.3	3.5		5.6	4.9	6.0	(1.8)	[2.2]	4.5	5.8	4.6	
		2.4	4.2	11.3	(12.2)	[12.8]	11.5	6.0	3.6		3.3	5.9	11.4	(12.5)	[11.8]	10.8	5.5	4.1	
$n = 23$										86									83
	Control	1.6	1.3	2.6	3.1	6.0	8.2	4.0	2.3		1.6	1.8	2.4	3.3	5.0	5.4	4.0	2.6	
		1.1	2.6	11.1	14.3	14.2	11.5	5.7	10.5		2.6	3.7	12.7	14.0	14.8	11.3	5.1	9.9	

Numbers in parentheses, subdivisions of exposed pens directly under positively charged transmission line.
Numbers in brackets, subdivisions of exposed pens directly under negatively charged transmission line.

TABLE 2

Mean differences between percentage of cattle in subdivisions of pens exposed to ±500 kV DC transmission line and cattle in corresponding subdivisions of control pens for Groups A and B during afternoon, night and 24-h observations. Negative differences indicate fewer exposed than control cattle in a specific subdivision

Sample period	Group	Pen subdivisions A / I	B / J	C / K	D / L	E / M	F / N	G / O	H / P
Afternoon	A	−3.1	−3.5	−1.0	(−0.6)	[−0.2]	0.5	0.4	0.1
		−0.5	−1.6	0.5	(−1.9)	[1.8]	5.3	2.7	1.1
		Sample Hotelling $t^2=51.4$; $P<0.01$; 12 and 146 d.f.							
	B	2.3	1.3	1.3	(−2.3)	[−1.3]	1.3	0.6	0.3
		−0.1	1.1	−3.0	(−5.0)	[−2.3]	2.9	2.2	0.7
		Sample Hotelling $t^2=51.27$; $P<0.01$; 14 and 144 d.f.							
Night	A	9.5	7.6	6.0	(−0.2)	[−4.1]	−4.2	1.0	1.6
		2.6	2.3	−0.2	(0.1)	[−2.1]	−4.3	−4.4	−11.3
		Sample Hotelling $t^2=166.2$; $P<0.01$; 15 and 68 d.f.							
	B	3.0	3.4	4.4	(−1.1)	[−5.5]	−1.5	3.1	2.5
		2.6	3.3	−1.4	(−0.2)	[−0.6]	0.2	0.2	−12.4
		Sample Hotelling $t^2=137.2$; $P<0.01$; 15 and 68 d.f.							
24 h	A	2.9	3.4	3.4	(−0.3)	[2.2]	−1.4	0.3	1.1
		1.2	1.6	0.2	(−2.1)	[−1.4]	0.0	0.2	−6.9
		Sample Hotelling $t^2=474.2$; $P<0.01$; 14 and 9 d.f.							
	B	4.0	3.1	3.6	(−1.5)	[−2.8]	−0.9	1.8	1.9
		0.7	1.9	−1.3	(−1.5)	[−3.0]	−0.5	0.4	−5.9
		Sample Hotelling $t^2=88.0$; $P<0.05$; 13 and 10 d.f.							
Total negatives		3	2	5	11	11	6	1	4
Total positives		9	10	7	1	1	6	11	8

Numbers in parentheses, subdivision in exposed pens directly under positively charged transmission line.
Numbers in brackets, subdivision in exposed pens directly under negatively charged transmission line.

noise was measured in control pens, values averaged 30 dB ($n=28\,660$) and ranged between 27 and 69 dB.

When cattle were bedded for the night, they were more uniformly distributed among pen subdivisions than during the afternoon (Table 1). Unlike afternoon hours when cattle tended to concentrate in central portions of the pens, no individual cell or group of cells served as a universal focal point at night. The exposed and control treatments did tend to concentrate in higher densities in one or two subdivisions, with control animals showing the most obvious concentrations, but no biologic explanation can be offered for these observations.

Night-time exposed:control similarity indices averaged 73%. The null hypothesis of zero mean differences in distribution patterns between exposed and control animals was rejected ($P<0.01$) for both replicates (Table 2), but efforts to correlate disparities with distances from the centerline failed to establish any statistically significant relationships.

Because 24-h monitoring of cattle distributions involved a compilation of day and night activities, dispersal patterns of livestock were less clustered than afternoon data and more clustered than night-time observations (Table 1). Exposed:control similarity indices averaged 84.5%, and null hypotheses of zero mean differences in distribution patterns were rejected for both groups (A ($P<0.01$) and B ($P<0.05$)). Visual examination of scattergrams relating exposed:control differences (Table 2) to distances of the subdivisions from centerline suggested 1–3% fewer exposed cattle were found in the pens' central areas. Variation was substantial, however, and no significant relationships were detected with regression analyses for either group (Table 3).

When signs (+ or −) of mean exposed:control differences for afternoon, night and 24-h observations were viewed together (Table 2), a preponderance of negative signs in the subdivisions directly under the conductors was noted. Only two of 24 exposed minus control differences had positive values for subdivisions under the lines. At 22.8, 38.1 and 53.3 m from centerline positive:negative ratios were 13:11, 21:3 and 17:7, respectively. Because

TABLE 3

Regression analyses of mean differences in distribution of exposed and control cattle to distances of pen subdivisions from the centerline for afternoon, night and 24-h observations, as well as pooled observations of all three sampling periods

Sample period	Group	Model	χ Coefficient	χ^2 Coefficient	Intercept	R^2	P value
Afternoon	A	Linear	−0.017		0.52	0.02	0.611
		Quad	0.077	−0.0015	−0.47	0.05	0.728
	B	Linear	0.074		−2.25	0.35	0.016*
		Quad	0.325	−0.0041	−4.88	0.55	0.005**
Night	A	Linear	0.058		−1.77	0.04	0.465
		Quad	0.183	−0.0021	−3.08	0.05	0.732
	B	Linear	0.030		−0.90	0.02	0.645
		Quad	0.409	−0.0062	−4.88	0.14	0.369
24 h	A	Linear	0.027		−0.82	0.03	0.492
		Quad	0.284	−0.0042	−3.52	0.19	0.255
	B	Linear	0.056		−1.72	0.14	0.157
		Quad	0.317	−0.0043	−4.44	0.28	0.113
Compiled afternoon, night and 24 h	A and B	Linear	0.038		−1.16	0.04	0.052
		Quad	0.266	−0.0037	−3.55	0.11	0.005**

$^*P<0.05$; $^{**}P<0.01$.

TABLE 4

Percentage of exposed cattle penned under a ± 500 kV DC transmission line and percentage of control cattle monitored in various activities during 24-h observations and associated paired-*t* statistics

Group	Activity[1]					
	Nursing	Drinking	Walking	Eating	Lying	Standing
A						
Exposed	2.4	0.5	1.0	23.7	44.6	30.0
Control	2.2	0.4	1.3	23.9	43.4	30.8
Mean difference	0.2*	0.1*	−0.2	−0.2	1.2	−0.8
SE difference	0.1	0.0	0.1	0.5	0.8	0.8
B						
Exposed	2.3	0.3	1.1	20.4	43.0	34.9
Control	2.5	0.4	1.3	21.6	42.1	34.4
Mean difference	−0.1	−0.0	−0.1	−1.1	−0.9	0.5
SE difference	0.1	0.0	0.1	0.7	0.7	0.8

[1]Drinking, walking, eating, lying and standing activities sum to 100% ($n=25$). Nursing percentages ($n=14$) were based on number of calves and calculated separately, because cows could nurse their young and concurrently be involved in other activities.
*($P<0.05$).

negative values indicate fewer exposed cattle compared with control cattle in a given locale, a movement of the exposed cattle from the pens' central areas is implied. Regression analyses of these data yielded a significant quadratic effect (Table 3), however, the R^2 was only 0.11. This model predicted total emigration from the central area of 6.9%.

Activity patterns were relatively similar between exposed and control cattle. The greatest proportion of time was devoted to lying (Table 4) with successively smaller amounts of time devoted to standing, eating, nursing, walking and drinking. Small but significant ($P<0.05$) differences of < 1% between exposed and control cattle in Group A were detected for nursing and drinking activities, but no explanations of biologic significance are apparent.

DISCUSSION AND CONCLUSIONS

Activity pattern and feeding position data provided no evidence that HVDC transmission lines altered the behavior of cattle. From significant relationships between exposed:control disparities in livestock distribution and distance of pen subdivisions from the centerline, we conclude that at least a small proportion of exposed cattle (5–11%) choose to occupy areas a short distance (38–53 m) away from overhead conductors. Variation in afternoon distribution patterns of cattle in the central areas of pens exposed to HVDC conductors was not correlated with fluctuations in electric field or audible noise.

Five possible interpretations are offered. Only a small proportion of cattle (5–11%) were sensitive to the electrical environment, and behavior of the majority masked responses when analyses focused solely on exposed animals. Disparities between exposed and control cattle were established quickly when the study began and became habit with no further adjustments by exposed animals as the study progressed. Exposed:control disparities were related to structural differences (support towers outside the pens and overhead lines) between treatments and not the electrical environment. Claiming of the most desirable sites by dominant animals may have moved animals either toward or away from the line. Significant relationships were due to Type 1 errors (erroneous rejection of a true null hypothesis). Most likely, Interpretations 1 and 2 are applicable, but additional study with control of independent variables and intensive documentation of individual animals would be required to substantiate this speculation.

Despite slight distribution differences and some movement of exposed cattle from subdivisions under lines, greatest densities of both exposed and control animals still occurred in the central areas of pens during afternoon and 24-h observations. Evaluations of conception rates, calving dates and rates, and calf growth rates found no effects attributable to the line (Angell et al., 1990). This, coupled with no biologically significant disparities in feeding positions and activities of the cattle suggests that no adjustments in management are necessary when cattle are confined under or near ±500 kV DC transmission lines.

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