

The Effect of Topography, Vegetation, and Weather on Cattle Distribution at the San Joaquin Experimental Range, California¹

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Abstract

In this study livestock distribution on the landscape was mapped during two seasons, summer and winter, for two years to determine where livestock congregate and to model factors that influence livestock distribution. Two small herds of cows were observed in separate range units on the San Joaquin Experimental Range for a total of twenty-four 24-hour observation periods to ascertain daily movements and activities. Treatments involving water placement and the use of supplemental feeding sites were implemented to judge the effects of these management techniques on cattle distribution. Animal distribution during daylight hours was determined by videotaping all visible animals in the herd every 15 minutes, then positioning cows on rectified digital orthophotographs. The location of the videographer was determined to an accuracy of one meter using a differential global positioning system (DGPS) to facilitate placement of animals. During nighttime hours, the location of the herd was determined every 15 minutes using the DGPS. Night animal activities were observed using night-vision binoculars and recorded for each time period. Our study identified topographic, vegetative and environmental forces that affected cattle distribution patterns. The effects of these factors varied between seasons and years. Water treatments varied in effect with seasons and size of range unit. They showed little effect in winter when free water was available on the forage. The feeding of supplement also had a variable effect. Animals consumed some supplement at all times, but the amount of supplement consumed varied with supplement placement, as well as with the quantity and quality of available forage. Thermal environment was an important factor in determining cattle location and activity. The social interactions of individual animals were important in determining subgroups that formed the herd units. A probabilistic model was developed from this research and will be tested in future studies.

Introduction

The way an animal uses the landscape is affected by many factors. For domesticated livestock, abiotic factors (i.e., slope and distance from water) and biotic factors (i.e., forage quality and quantity, species composition, plant morphology and canopy cover) act in combination to determine distribution patterns (Senft and others

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1987, Smith 1988). Animals also possess spatial memory that allows them to return to areas with high quality forage (Bailey and others 1996, Laca 1998). Social interactions between individual animals also act to influence animal distribution. Subgroups of animals use different areas of the landscape than other subgroups that form herd units (Howery and others 1996, Roath and Krueger 1982).

The areas that cattle graze without active management and the areas that land managers want them to graze are usually not the same (Bailey and others 1996). For example, riparian zones often receive more use than upland areas because they provide water, shade, thermal cover and a productive source of high quality forage (Ames 1977). Therefore, land managers need tools that can help them modify animal distribution. Two of these tools are the placement of water sources and the use of supplemental feed (Valentine 1990). Off-site water has been used to reduce the time that livestock spend in or near streams (Miner and others 1992). McDougald and others (1989) found that the strategic placement of supplemental feed was effective in reducing grazing in riparian areas during periods when the riparian zone is most attractive. Bailey and others (2001) found that supplemental feed had a zone of influence extending for 600 m from the supplement site.

Bentley and Talbot (1951) developed a range site classification (10 classes) for the San Joaquin Experimental Range (SJER) based on topography, aspect, soils, and tree/shrub cover. This classification reflected differences in animal use as well as forage production. Wagnon (1968) found that cattle grazed swale sites heavily in most seasons. After swales, cattle preferred to graze the gentle slope classes. In winter and spring, animals used predominantly south facing slopes and shifted in late summer and fall to north facing slopes.

The objectives of our study were to 1) map the distribution of livestock in a pasture setting on California foothill rangeland in different seasons, 2) develop a predictive model of animal use, and 3) map changes in distribution in response to management actions (i.e., changing water locations and adding supplement sites).

Methods

Our study used range units 1, 6-2, and 72 on the SJER (*fig. 1*). Range units 1 and 6-2 were combined into one unit by allowing cattle free access through open gates. The SJER (UTM zone 11N, Easting 257600, Northing 4109300) is located along State Highway 41 approximately 30 km north of Fresno, California. The SJER encompasses 1,837 hectares and has been a research facility since 1934. The SJER is located on the east side of the San Joaquin Valley within the oak savanna vegetation type of the Sierra Nevada foothills. The elevation of the SJER ranges from 213 to 518 m above sea level. Soils are shallow (less than 0.76 m deep), coarse, sandy loams derived from granitic rocks. The Ahwahnee series (Mollic Haplustalf) covers about 96 percent of SJER. The Visalia series (Cumulic Haploxeroll) is found on alluvial or swale sites.

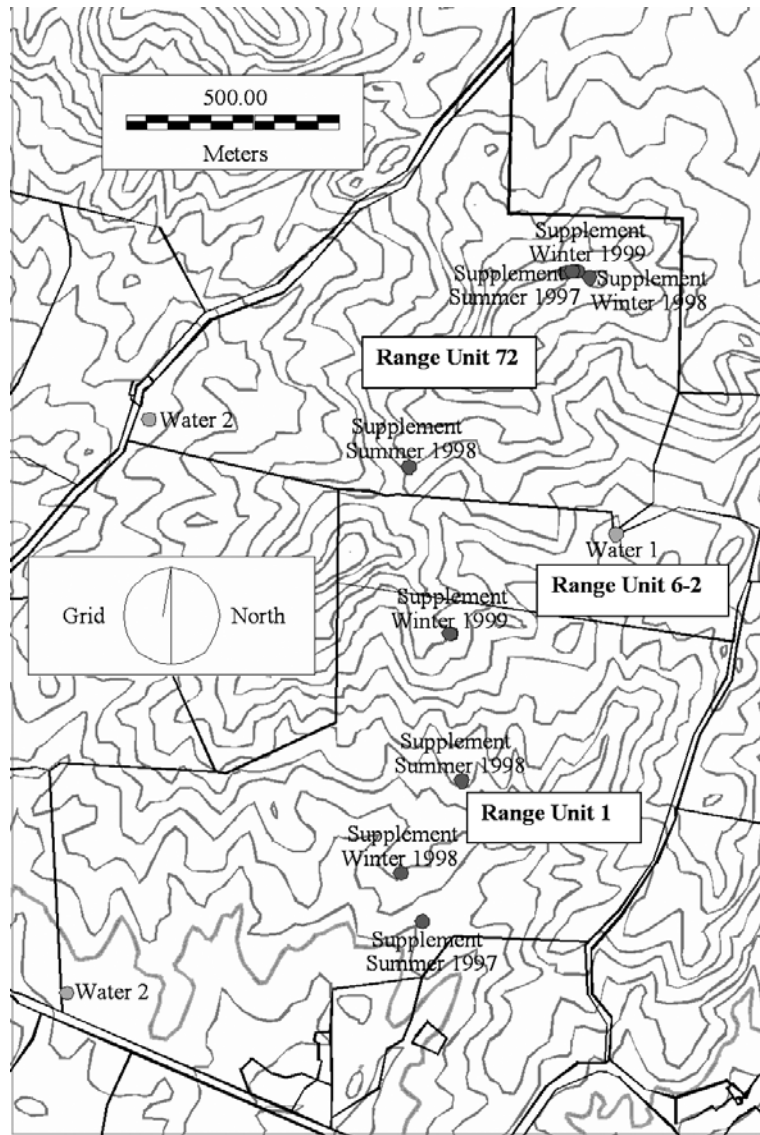


Figure 1—Arrangement of study area showing locations of water and supplement. Contours are 40-foot elevation changes. Fences are shown as broad black lines.

The SJER has a Mediterranean climate. Long-term average annual precipitation (65 years) is 48 cm. However, annual precipitation varies between 23 and 95 cm with most occurring as rain. Snowfall is rare. Rainfall usually occurs between the months of October and March, but may commence earlier in the fall or persist later in the spring. Forage production varies considerably with the amount and timing of precipitation and temperature. Monthly mean air temperature ranges from 6°C in January to 27°C in July.

The annual grasses, soft chess (*Bromus hordeaceus* L.) and foxtail fescue (*Vulpia myuros* [L.] C. Gemlin), and two types of broadleaf filaree (*Erodium* spp.) constitute between 75 and 95 percent of annual herbaceous production. Some of the more productive Visalia soils (approximately 7 percent of the study area) support large populations of bur-clover (*Medicago polymorpha* L.) and Bermuda-grass

(*Cynodon dactylon* [L.] Pers.). The dominant shrubs are two species of ceanothus: wedgeleaf (*Ceanothus cuneatus* [Hook.] T. & G.) and whitethorn (*Ceanothus leucodermis* E. Greene). The evergreen, interior live oak (*Quercus wislizeni* A. DC.), the deciduous, blue oak (*Quercus douglasii* Hook & Arn.) and the conifer, California foothill pine (*Pinus sabiniana* Douglas) compose approximately 98 percent of the tree canopy. Oaks are an important source of shelter for cattle. Trees and shrubs cover about 20 percent of the total surface of the study site.

Standing crop was measured in the middle of each observation series. Forage was sampled at twenty-two locations throughout the two range units. At each location, two 0.093 m² (1 ft²) plots were clipped. Twenty-two plots were also clipped from under the tree canopies located within 10 m of the other sample sites. Vegetation was weighed, dried in an oven at 55° C for 24 hours, and reweighed. Samples were pooled within range sites and canopy locations, ground to pass through a 1 mm screen, and sent to a laboratory for analysis of crude protein and acid-digestible fiber (ADF).

Cattle distribution patterns were mapped using direct observation and videography supplemented by global positioning system (GPS) technology. The timing of observation/treatments was planned to correspond to phenological and physiological stages of the forage referred to in the California literature (Bentley and Talbot 1951, George and others 1996) as the inadequate green (usually October through January) and dry-forage periods (mid-June through September). Supplemental feeding of livestock is common in late dry-forage and inadequate green periods. Observations began in June of 1997 and ended by February 1999. Two teams of observers followed two herds, one in unit 1 and another in unit 72, simultaneously. This approach identified responses to abiotic factors, such as temperature and solar exposure, occurring across units.

Herds of mixed-breed cattle were randomly selected from a large breeding herd of approximately 250 cows. Observation herds usually contained 15 animals and were the only animals in each study range unit. All animals had previously grazed in the study range units, thus were familiar with the parcels. Animals ranged from 2 years to 16 years, with a mean age of 7 years. Ninety-eight different cows were part of the study. Color-coded, reflective tags were attached to their ears to assist in locating animals at night. Bells were placed on two randomly selected cows from each herd to facilitate tracking during night and in dense fog.

Our experiment changed the position of water and supplement in range units 1 and 72 in the pattern shown in *table 1* and *figure 1*. Two existing water troughs in each range unit were selected as water sources; all other water troughs were drained for the study periods. Unit 1 troughs were located 1,657 meters from each other, while unit 72 troughs were 1,120 meters apart (*fig. 1*). Because water sources were alternated as part of the treatments, float valves were periodically wired shut and troughs were pumped dry (*table 1*). Similarly, a high protein (20 percent) supplement was placed or removed from each unit (*table 1*). Supplement sites were located in areas visited by animals but underutilized for grazing purposes. The sites were chosen for each range unit at the start of each series of observations.

Table 1—*Experimental design used for the SJER Cattle Distribution Study. A series of six patterns of water and supplement were presented to animals in each range unit (pasture) during each trial. In the table below, X denotes the treatment was present; a 0 denotes it was absent or unavailable to livestock. See figure 1 for position of water and supplement in each pasture for each observation period.*

Observation	Supplement	Water source 1	Water source 2
1	0	X	0
2	X	X	0
3	X	X	X
4	X	0	X
5	0	0	X
6	0	X	0

Two 250-pound barrels of supplement were placed in each range unit. This placement provided one barrel per seven or eight cows. Adequate supplement was maintained during supplemented observation periods. Animals were led to the supplement sites when the barrels were placed in the range units to show them supplement locations. All animals had previously been fed supplement as a normal part of herd operations.

Animals were allowed three to seven days to adjust to treatment changes, then were observed for a 24-hour period. Observers then followed the herds continuously for a 24-hour period. Two types of observations were recorded at 15-minute intervals (scan sampling) depending on whether it was day or night. During daylight hours, observers videotaped all visible animals every 15 minutes to record animal identity, spatial location, and activity. Observers used a Trimble Pathfinder Pro XRS[®] GPS unit to obtain a positional fix of the videographer.⁵ This positional fix, coupled with objects visible in the video and a rectified orthophotograph, allowed individual animals to be accurately mapped on the landscape ($\pm 2\text{m}$). Videotapes also recorded weather conditions and captured verbal notes from the observers. At night, observers located animals using flashlights and/or night-vision scopes every 15 minutes and obtained a GPS positional fix of their location. Because individual animals could neither be identified nor accurately positioned, herd position was outlined on transparent overlays on an orthophotographic base map. Observers also recorded the total number of animals in the group and the number of animals engaging in each activity (i.e., grazing, walking, laying, standing, drinking, browsing, and eating supplement), air temperature, and weather conditions.

Statistical Analyses

Forage and supplement data were analyzed by analysis of variance (SAS 1998) using two models. Tukey's studentized range tests (SAS 1998) were used to separate means. The model used for analyzing forage parameters included year, season, range site, sampling location (under tree canopy or open exposure) and interactions. Supplement consumption was analyzed using a model that included year, season, temperature, period in range unit and interactions. In both of these models, the residual was used as the error term for statistical tests.

⁵ Mention of trade names or products is for information only and does not imply endorsement by the U.S. Department of Agriculture.

Statistically, the position of cows within a herd or subgroup is autocorrelated because animals tend to move together. Thus, positions of individual animals are not independent observations. This precluded the use of cows as replicates in parametric statistical tests. Analysis of variance was therefore applied to data of only one cow for each observation series. The model used for this analysis included distance from supplement, distance from both water sites, distance from fences, distance from swales, and interactions. As with forage and supplement analysis, the residual was used as the error term.

Stepwise linear regression (SAS 1998) was used to explore and analyze selection of range sites mitigated by forage and time effects. Significance levels to enter and stay in the model were set at $P=0.10$.

Positional data were expressed as preference indices since each class of independent variables did not contain an equal proportion of the landscape. The preference index was calculated as the ratio of the percentage of total animals observed within a particular class (distance-based or landscape-based) to the percentage of the total accessible landscape within that class (Gillen and others 1984). An index value greater than one indicated that more cattle were observed within a class than would have been expected by random use and was considered to imply positive animal preference for that class. Index values near one are neutral; those less than one indicate avoidance.

Results and Discussion

Our study supported other cattle distribution studies in emphasizing the importance of forage quality and slope as determinants of animal position. Forage quality, as measured by protein and fiber content, (*table 2*) was dependent on season, while forage quantity was dependent on weather factors (amount and timing of precipitation and temperature) throughout the year. The major difference between seasons, winter and summer, was in the crude protein content of forage. Winter levels were significantly ($P<0.0001$) higher than in the summer, 12.2 ± 1.9 percent versus 6.1 ± 1.4 percent. Forage standing crop differed significantly between years. For summer 1997-winter 1998, the standing crop was significantly ($p=0.0001$) less than for summer 1998-winter 1999. Standing crop for the first year was 60 percent of the second year's production. During both summers, the forage in the swale sites had significantly more crude protein ($P=0.018$) than forage on any other range site. However, in 1997 swale vegetation was closely cropped (less than 3 cm stubble height) before the observation series, while in 1998, swale vegetation was over 25 cm in height when the animals were put in the range units. While the protein content (>7.5 percent) of the swale forage was adequate for maintenance, the forage on the uplands was inadequate. Therefore, our observations for summer 1997 occurred during the dry-forage period when the protein content of the forage was inadequate for cattle to maintain weight. Although the forage quality figures did not accurately reflect it, our observations during summer 1998 occurred at the end of the adequate green forage period as a result of a *la Niña* weather pattern. In the winter, there were no significant forage differences between range sites. In the winter of 1998, the standing crop was 816 kg/ha. Huston and Pinchak (1991) state that, generally, standing grass crops below 1,000 kg/ha restrict forage intake by sheep and cattle on temperate native grasslands of North America. This would indicate that these observations occurred during the inadequate green forage stage. Furthermore, this

was reflected in the activities of the cows as they grazed for 12.8 hours a day. In winter 1998, the standing crop was 1,785.5 kg/ha. For all observation periods the cattle preferred to graze swale sites during daylight hours (*table 3*). A similar pattern was exhibited for all nighttime observations, except for the winter of 1998, when the animals showed a preference for gentle south slopes for nighttime grazing.

Table 2—Mean forage standing crop and quality available for cattle in each observation series. DM stands for dry matter and ADF stands for acid digestible fiber.

Observation series	Standing crop kgDM/hectare	Water percent	Crude protein percent	ADF percent
Summer 1997	1690.3	10.1	6.2	50.1
Winter 1998	816.0	77.5	13.4	46.2
Summer 1998	2387.0	16.9	6.1	49.4
Winter 1999	1785.5	74.9	11.1	51.4

Table 3—Relative preference indices of range sites for grazing during daylight hours.

Range site	Summer 1997	Summer 1998	Winter 1998	Winter 1999
Swales	5.15	9.68	1.57	3.23
North gentle slope	0.85	0.47	0.72	1.11
South gentle slope	0.64	0.96	1.31	1.03
North open rolling slope	2.33	0.30	1.21	0.19
South open rolling slope	0.97	0.35	1.56	1.01
North brushy rolling slope	0.64	0.16	0.37	0.61
South brushy rolling slope	0.30	0.26	0.53	0.62
North brushy steep slope	0.00	0.00	0.00	0.00
South brushy steep slope	0.97	0.23	0.33	0.79
Steep rocky bluff	1.21	0.03	0.29	0.63

The effect of slope (*table 4*) was also consistent throughout the observation periods, with cows preferring gentle slopes of less than 10 percent. In the winter of 1998, the animals also grazed slopes between 10 and 15 percent. This was a time when very little forage was available, and above average rainfall made the ground in the swales so soft that the animals would sink into it as they walked across.

Table 4—Relative preference indices of the slope classes for daylight observations only.

Slope classes Percent slope	Summer 1997	Summer 1998	Winter 1998	Winter 1999	Average
0 to 5	2.9	2.1	1.6	2.3	2.2
5 to 10	1.9	2.5	1.3	1.7	1.9
10 to 15	0.5	0.3	1.5	0.5	0.7
15 to 20	0.6	0.2	0.7	0.7	0.6
20 to 25	0.3	0.3	0.6	0.5	0.4
25 to 30	0.4	0.1	0.6	0.5	0.4
Over 30	0.4	0.3	0.3	0.6	0.4

The effect of water on livestock distribution varied with season. In the winter observations, water was not a factor influencing animal distribution when forage was succulent and covered with dew, or ephemeral streams contained water. In range unit 72, the distance between water sources (1,120 m) was close enough and/or the terrain gentle enough that no water effect was evident in summer observations. In range unit 1, the distance between water sources (1,657 m) was far enough and/or the terrain rugged enough that a water effect was evident (*table 5*) during summer observations. Water influenced animal distribution for a distance of 900 m in summer observations. The high preference indices for the zone 100 to 400 m from water were biased by the locations of large swales sites and an adjacent shade tree that animals rested under during morning hours.

Table 5—Relative preference indices for distance-to-water site 1 (range unit 1) when filled with water, for daylight observations only.

Distance class (m)	Summer 1997	Summer 1998	Winter 1998	Winter 1999	All observations
0 - 100	3.85	8.32	0.96	1.02	3.54
100 - 200	2.62	4.67	0.16	1.72	2.29
200 - 300	3.99	16.38	1.21	3.11	6.17
300 - 400	2.01	3.76	2.01	0.91	2.17
400 - 500	1.38	2.38	4.26	2.53	2.64
500 - 600	1.76	1.56	0.40	1.73	1.37
600 - 700	1.26	1.16	1.33	1.52	1.32
700 - 800	1.93	1.21	1.23	0.73	1.28
800 - 900	1.19	1.36	1.14	1.38	1.27
900 - 1,000	0.99	0.20	1.06	1.16	0.85
1,000 - 1,100	0.96	0.26	0.56	0.33	0.53
1,100 - 1,200	0.38	0.49	0.76	0.30	0.48
1,200 - 1,300	0.74	0.19	1.51	0.96	0.85
1,300 - 1,400	0.10	0.00	0.52	0.00	0.16
1,400 - 1,500	0.00	0.00	0.31	1.10	0.35
1,500 - 1,600	0.00	0.00	0.10	0.54	0.16
1,600 - 1,700	0.00	0.00	0.13	0.13	0.07

Supplement also had a variable effect on animal distribution that was dependent on forage conditions and supplement location (*table 6*). Animals consumed supplement anytime it was present. However, supplement consumption was higher when the supplement was located close to nighttime bedding grounds. In general, more supplement was consumed during the night than in the daylight hours. In most observations, the zone of influence for supplement was 100 m, but in winter 1998, the zone of influence in unit 72 was 500 m.

Table 6—*Supplement consumption and distances from supplement to water.*

Observation series	Range unit	Supplement consumed kg/animal/day	Distance to water site 1 m	Distance to water site 2 m
Summer 1997	1	0.118	1009.57	844.70
Summer 1997	72	0.748	622.11	1029.03
Winter 1998	1	0.354	936.48	826.69
Winter 1998	72	1.061	603.45	1078.98
Summer 1998	1	0.544	677.73	1045.01
Summer 1998	72	0.839	506.97	616.66
Winter 1999	1	0.680	452.46	1223.24
Winter 1999	72	0.508	622.24	1044.87

The actions of cattle to regulate body temperature are often mentioned in studies as being important in the distribution of animals on the landscape. On sunny summer days, the animals spent considerable time (8 hours) under shade trees near water. During the winter of 1999, the animals would also lay in the shade for a couple of hours on sunny days. However, in the winter of 1998 the cattle exhibited a heat seeking strategy of grazing south slopes during the day and not resting under shade trees. On clear winter days, the cattle would lay down at night on warmer ridges. This was also the pattern they exhibited on the hottest summer days. On rainy winter days, the animals would move to lower, more sheltered areas. During the coldest winter days (-3°C), cattle would move to higher, but still sheltered, areas that were warmer. Supplement was not a strong enough attractant to keep animals on exposed ridges during these times.

Analysis of associations between individual animals showed that the herds were composed of subgroups of animals. These subgroups usually consisted of three to six animals, with groups of five animals most common. Subgroup membership and dominance were age related in our study. Animals of similar ages stayed together, and older animals dominated younger animals.

Conclusion

Our study reached many of the same conclusions as other cattle distribution studies. Three of the factors often cited in the literature as influencing cattle distributions are slope, distance to water, and forage characteristics. Cattle distribution is greatly influenced by slope. Eighty percent of all observations occurred on slopes less than ten percent. In summer, cattle were usually found within 900 m of water. In winter, water was often not a factor. Forage characteristics, quality and quantity, were the single most important factor affecting cattle

distribution. Forage in swale areas was high in these characteristics and swales were the preferred landscape site for grazing in all observations.

While many studies have implicated thermoregulation as a factor influencing cattle distribution, this factor is largely undocumented and untested. Our study also implicated thermal environment as being an important factor in cattle distribution. During the hottest part of the day, the cattle were found lying under shade trees. Using solar insolation models, we noted differences between the winter of 1998 and the other three observation periods, indicating that animal were seeking warmer sites that winter. Comparison of our handheld temperature recordings to the USDA Forest Service weather station data indicated that cattle were utilizing warmer ridge tops during clear nights.

We developed a temporal/spatial model of cow movement using the information in this study. Our initial premise is that cattle seek to control their external environment via sensory awareness of the experiences of hunger, thirst, heat, cold, and fatigue, within a social/herding context. At any given moment, an individual will seek to maintain its internal environment by responding to stimuli and by engaging in stereotypic action patterns (grazing, drinking, walking, resting, etc.) at a position on the landscape. Stimuli vary in their intensity throughout the day. This model will be used to generate a probability map for each time period. The accuracy of the modeling technique will be assessed and problems identified. With this procedure, we will gain further insight into cattle behavior and how cattle move and use the landscape.

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