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Monitoring cattle behavior and pasture use with GPS and GIS¹

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Turner, L. W., Udall, M. C., Larson, B. T. and Shearer, S. A. 2000. **Monitoring cattle behavior and pasture use with GPS and GIS.** Can. J. Anim. Sci. **80**: 405–413. Precision agriculture is already being used commercially to improve variability management in row crop agriculture. In the same way, understanding how spatial and temporal variability of animal, forage, soil and landscape features affect grazing behavior and forage utilization provides potential to modify pasture management, improve efficiency of utilization, and maximize profits. Recent advances in global positioning system (GPS) technology have allowed the development of lightweight GPS collar receivers suitable for monitoring animal position at 5-min intervals. The GPS data can be imported into a geographic information system (GIS) to assess animal behavior characteristics and pasture utilization. This paper describes application and use of GPS technology on intensively managed beef cattle, and implications for livestock behavior and management research on pasture.

Key words: Livestock behavior, electronics, grazing, forage, global positioning system, geographic information system

Turner, L. W., Udall, M. C., Larson, B. T. et Shearer, S. A. 2000. **Surveillance continue du comportement des bovins et de l'utilisation du pâturage au moyen des systèmes GPS et GIS.** Can. J. Anim. Sci. **80**: 405–413. L'agriculture de précision est déjà utilisée pour améliorer la maîtrise de la variabilité dans les cultures en lignes. La compréhension des effets de la variabilité spatio-temporelle qui affecte les animaux, les fourrages, le sol et le paysage sur les comportements au pâturage et sur l'utilisation des herbages permettrait de modifier la conduite du pâturage, en plus d'en améliorer l'utilisation et de maximiser les profits. Les progrès récents dont bénéficie la technologie du système de positionnement global (GPS) nous ont valu la mise au point de colliers receveurs de GPS autorisant la surveillance des déplacements des animaux à intervalles de 5 minutes. Les données GPS peuvent être intégrées dans un système d'information géographique (GIS) pour évaluer les caractères du comportement animal et de l'utilisation du pâturage. Nous décrivons l'application et l'utilisation de la technologie GPS dans la gestion intensive des bovins à viande et nous en examinons les incidences pour la recherche sur le comportement et sur la gestion des animaux au pâturage.

Mots clés: Comportement, électronique, pâturage, fourrage, système de positionnement global, système d'information géographique

Global positioning system monitoring can provide researchers with efficient and accurate information on grazing behavior. Previous research focused on tracking animals using data gathered by observation. Recent advances in GPS technology have allowed the development of lightweight collar receivers suitable for monitoring animal position at 5-min intervals. Data can be imported into a GIS to assess animal behavior characteristics and pasture utilization. Precision animal location recording allows researchers to evaluate pasture utilization, animal performance, and behavior. Researchers may assess the merits of pasture or paddock shapes and sizes, fence designs, grazing systems, forage

composition and availability, location of shade, water, and supplements, and other variables that affect beef cattle operations.

The objectives of this article are: 1) to review previous tracking technology; 2) to explain GPS animal monitoring; 3) to describe GPS tracking collar application for beef cattle; and 4) to discuss pasture livestock behavior and management research implications.

Cattle Grazing Behavior and Pasture Distribution

Significant investigation of cattle behavior, grazing distribution, and forage utilization has been conducted previously. Research has focused on cattle preferences, improving grazing efficiency by various management techniques, and grazing consequences in riparian zones.

Abbreviations: CEP, circular error probable; DGPS, differential GPS; GIS, geographic information system; GPS, global positioning system; PTT, platform transmitter terminals; VHF, very high frequency

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Hart et al. (1993) [15-minute intervals during daylight hours, colored collars, locations on a 100-m grid] evaluated grazing systems (continuous and rotational) and pasture size (24 vs. 207 ha) effects on cattle behavior, distribution and weight gain. Langbein and Nichelmann (1993) visually observed behavior of free-ranging Holstein-Friesian and Siboney de Cuba breeds in a tropical climate. Proportions of time spent grazing, lying, standing, and using shade were evaluated between breeds. Heat stress effects such as reduced feed intake, increased water intake, increased respiration rate, decreased conception rate, and increased body temperature have been studied by Buffington et al. (1983), Collier et al. (1981), and Blackshaw and Blackshaw (1994). Smith et al. (1992), using binoculars, observed cattle during daylight hours at 15-min intervals in a continuously grazed pasture and recorded time spent in channel, floodplain, and upland areas to assess riparian grazing. Marlow et al. (1987) proposed pasture rest or rotation and limiting riparian vegetation cattle use to reduce stream bank degradation. Stream bank degradation resulted from combinations of soil moisture, stream flow, and cattle use, but not solely cattle presence. Owens et al. (1991) identified green herbage availability, grass quantity, brush abundance, remoteness from roads and water, and proximity to fences as major factors affecting utilization of pasture in a continuous grazing system. Radio telemetry tracking has been used to record cattle rangeland distribution effects by water availability and terrain slope (Pinchak et al. 1991).

This research enhanced the understanding of cattle behavior/distribution and utilization in various pasture systems. Pasture design and management improvements have led to greater efficiencies and higher returns. However, gathering data is the most difficult aspect in all studies. Automation of data gathering and accuracy improvement continue to be major goals of research in this field

Previous Tracking Methods

Free-ranging animal tracking has previously shown low animal-location-per-time predictability. Early methods relied on human observation of natural (color patterns) or artificial features (colored collar or tag). Problems included observer fatigue and associated error, study area accuracy and physical limitations, external factors (weather and light), and observer proximity effects on animals.

VHF Radio Signal Tracking

Very high frequency (VHF) technology (battery-powered transmitter, receiver, and recorder) has been commercially available since the late 1950s (Rodgers et al. 1996). A radio transmitter attached to the sought-out animal generates a unique signal to identify, remotely locate, and home-in on the animal for observation. Modern transmitters are small and versatile, which has allowed the tracking of many small animals like mice, birds and ghost crabs (Mech 1983). Gibb et al. (1998) have monitored bunk attendance of feedlot cattle. Location fixes and accuracy depend on mobile researcher (ground or air), terrain, visibility, discomfort, and fatigue. Without a visual sighting, errors have exceeded 500 m (Rodgers et al. 1996).

ARGOS Data Collection and Location System

The ARGOS Data Collection and Location System records environmental data including ecological, meteorological, hydrologic, and oceanographic information (Argos 1984). ARGOS consists of: 1) earth-based platform transmitter terminals (PTT); 2) polar orbiting Tiros-N satellites; and 3) ground-based satellite tracking station network and; 4) communication links that transfer data to processing centers. All weather, wide-range location collars (with battery-powered PTT, 1.5 kg) may support simultaneous measurements (temperature, motion and pressure sensors). Animals studied include wolf and bear (Ballard 1997); polar bear, caribou, musk oxen, brown bear, gray wolf, moose, pacific walrus, Dall sheep, elk, and mule deer (Harris et al. 1990); elephant (Tchamba et al. 1995); whale [Mate et al. (1983), cited by Harris et al. (1990)]; and small birds [Fuller et al. (1984) cited by Harris et al. (1990)]. The average location error of wolf and bear was 577 m and 1110 m, respectively (Ballard 1997). ARGOS system errors equal VHF methods, where errors can exceed 0.5 km (Rodgers et al. 1996). Animal-attached PTT collar location information is provided without human intervention. The position is fixed regardless of weather conditions, season, or time of day. Data are available in remote locations within 8 h of satellite overpass (Tchamba et al. 1995) and PTT are less labor intensive than VHF tracking methods. Ballard (1997), in a 3-yr study of wolves, reported obtaining location fixes with relatively high frequency (once every 2 d) at one-third the cost of VHF telemetry.

Global Positioning System (GPS) For Animal Monitoring

Navstar GPS (Navigation System with Timing and Ranging) is operated by the US Department of Defense. Initially designed for the military, users obtain position fixes via a constellation of carefully monitored earth-orbiting satellites. The GPS system components are: 1) space segment – 24 satellites arranged in orbits where five to eight satellites are visible from any point on earth at any time and generate/transmit precisely timed radio signals (Dana 1997); 2) control segment – network of ground-based stations to monitor satellite information (health status and time, and satellite location) to ensure correct operation of the system; 3) user segment – user-community receivers that convert satellite signals into location estimates. Apart from receiver cost, processing equipment or software, there is no subscription cost involved with using basic GPS signals.

Accuracy of GPS Technology. While GPS uses extremely accurate timing mechanisms and state-of-art electronics, it is subject to errors, notably:

- Satellite clock errors – system depends on accuracy of satellite clocks.
- Satellite position errors – known as ephemeris errors.
- Receiver errors – accuracy of clock.
- Atmospheric errors – propagation rates of radio waves change as they move through ionosphere and troposphere.
- Multi path errors – radio signal reflection off large objects.

- Selective availability (SA) errors – degraded accuracy of clock and ephemeris correction information is biggest component of error for civilian users.

This deliberate and unpredictable waver of the satellite clock (controlled by the military) can be switched on or off at will. The SA results in decreased accuracy of location and is intended to prevent more accurate positioning capabilities from falling into enemy hands. This inaccuracy can be vastly improved with differential GPS (DGPS) correction procedure. A stationary receiver (base station) is placed at a surveyed mark and takes position readings simultaneous with a roving receiver. The stationary receiver calculates location positions that will not correspond exactly to the surveyed mark due to the error sources. However, since the stationary marker has known coordinates, the receiver can calculate the magnitude of errors involved. If the roving receiver is relatively close to the base station (within approximately 50 km), many of the same errors also apply to the roving receiver and can be removed from location fixes. In this way, an accuracy of at least 5 m horizontal is readily obtainable.

Absolute errors are expressed as radial distance of error location from true location. Circular error probable (CEP) is circle radius that contains the stated percentile of points around a true location (Rempel et al. 1995; Moen et al. 1997; Rempel and Rodgers 1997). The 95% CEP value is determined by graphically locating all data points located in the 95th percentile.

GPS Location Accuracy on Animals. Most studies conducted on new-technology GPS collars have examined location accuracy, two-dimensional (2D) versus three-dimensional (3D) locations, factors affecting accuracy and success rate, and performance under various cover types. Evaluation and testing are important because researchers require some level of confidence in a new system before general technology adaptation.

Moen et al. (1997) reported that for open canopy conditions, uncorrected readings from a GPS collar had a 50% CEP of 28.2 m and a 95% CEP of 73.7 m. These same readings with DGPS gave values of 4 m at 50% CEP and 10.6 m at 95% CEP. They also noted that accuracy was not affected by heavy rain. Rempel and Rodgers (1997) found that under open canopy 95% of uncorrected readings had errors less than 125.6 m. With DGPS, the 95% CEP was reduced to 7.5 m.

Moen et al. (1996b) showed increased time-to-location fix with increased density of forest cover. Rempel and Rodgers (1997) verified decreased accuracy of both DGPS and non-DGPS locations with increased canopy cover. They also demonstrated a reduced rate of successful GPS location fixes with increased density of tree cover. The overall success-rate of signal acquisition has increased from 71% to 89% (Rempel et al. 1995).

Moen et al. (1996b) studied moose movement and habitat use on collar performance to assess the effects of a GPS receiver collar being worn by an animal. They found no correlation between moose movement and any of the following: proportion of 2D, 3D or failed location attempts; time to location fix; and higher dilution of precision for either 2D

or 3D locations. They observed that fix success rate was related to ambient temperature where moose use cooler, denser vegetation in warmer weather.

GPS and GIS Applications in Domestic Animal Research

Limited studies have examined GPS receiver performance on animals, mostly wildlife in the field. One study in Wales tracked sheep with GPS to correlate higher cesium levels in carcasses of animals that had grazed in specific areas (Roberts et al. 1995; Rutter et al. 1997). Success in tracking was obtained at the expense of a bulky pannier pack on each animal. Before DGPS, 95th percentile errors were 57.8 m. After DGPS, errors were within 3.9 m of true location. The authors commented that “GPS with differential correction... is the only existing tracking/navigation system which has the potential to meet (horizontal accuracy) requirements.” Hulbert et al. (1998) reported that 8 of 16 Scottish Blackface ewes were fitted with GPS collars weighing 863 g, representing 2.2% of body weight. No differences between circadian rhythm and bite rate were found between the two sets of animals.

Geographic information systems have been used to map range usage (Beaver and Olson 1997). Beaver and Olson (1997) used GIS to map locations of thermal protection and compared extensive range use for older versus younger cattle through visual tracking. Wade et al. (1998) used GIS to model spatial distribution of beef cattle.

Beef cattle have been monitored using GPS collars in a grazing setting (Udal 1998; Udal et al. 1998). Assessment of GPS collar suitability with post-processed DGPS to track grazing cattle has been a focus of this research. Differentially corrected GPS technology and a lightweight unit suitable for grazing beef cows were required for this research application. Tracking requirements specified a system that would provide:

- Pasture location tracking of a mobile grazing cow;
- 5 m horizontal accuracy in locating true cow position;
- Continuous location fixes for a 5-d period;
- Frequency of location fixes to accurately track and map cow movement in pasture;
- Location fixes obtained regardless of weather, season, temperature, time or resources;
- Flexible and accessible parameter settings to optimize system, and;
- Convenient data access and easily analyzed.

MATERIALS AND METHODS

The goals of this project were to: 1) gather GPS data from grazing beef cows; 2) differentially correct; 3) spatially reference; 4) query the database; and 5) analyze data to allow interpretation.

Project resources included paddock, beef cattle, seven GPS tracking collars, and supporting software. The rectangular paddock (Fig. 1) was 6.07 ha (221 by 274 m). Forage was predominantly endophyte-infected tall fescue, with white clover, bluegrass, and alfalfa, but few weed species. Eight mature Angus and Angus-cross cows weighing up to 680 kg and nursing calves were used. Varying numbers of grazing steers (up to 16) were present at different times dur-

Fig. 1. Diagram of paddock layout.

ing the grazing season, depending upon forage availability. All data collections were initiated with seven collared cows. *GPS Collars.* Collars were GPS_2000 small animal location system units (Lotek Engineering Inc., Newmarket, ON). Collars used a Motorola GPS engine in an eight-channel receiver, allowing signal lock on eight satellites simultaneously. Location information (latitude and longitude) was stored cumulatively in on-board RAM sufficient in size for 4400 position fixes. Each fix record contained corresponding height estimate, GPS date and time, dilution of precision value, fix status (2D or 3D), ID numbers of satellites used, ambient temperature, plus vertical and horizontal activity sensor counts. User-selectable position fix interval times available were 5, 10, 15, 20, and 30 min or 1, 2, 3, 4 and 6 h. The non-rechargeable power supply was a battery pack of high-density lithium cells that supports data collection up to 10 d at 5-min fix intervals. Collar units were compact, robust, and weighed less than 1 kg. Figure 2 illustrates a GPS collar on a cow in the paddock.

Collars were fitted with two additional sensor types: 1) a temperature sensor records ambient temperature ($\pm 1^\circ\text{C}$) per GPS location fix. The sensor is not directly exposed and may display lag time in response to rapid temperature changes. 2) dual axis motion sensors record animal movement, and are sensitive to horizontal and vertical movements of the head and neck. They record activity in movement counts (255 counts maximum) that are stored with other

information when GPS position fix is taken, then are reset to zero. The time period during which sensors record movement during each fix interval are user defined, but have an upper limit of 1 min less than the associated GPS fix interval setting. Two-way data transfer between THE collar unit and THE personal computer was facilitated by a hardware download link unit and associated proprietary software (Lotek Engineering Inc).

Collar attachment was accomplished within a few minutes per cow while the cow was confined in a squeeze chute. Animals were uniquely marked with non-permanent luminous ink marker to aid distant visual identification.

Differential GPS. Data collected from GPS collars were manipulated using a proprietary program designed to differentially correct position fix data for increased accuracy. A Trimble Community base station (Ag Data Weather Center, University of Kentucky) provided data at 5-s intervals in Trimble proprietary format (*.ssf). Files were converted to RINEX format (Receiver Independent Exchange) with a Trimble program (*SSFRNX.exe*) that gave position in latitude and longitude. A program (*CORPSCON.exe*, v4.12, U.S. Army Topographic Engineering Center, internet free-ware) was used to convert latitude and longitude values to the UTM (Universal Transverse Mercator) coordinate system. All GIS display and analyses were performed using ArcView GIS v3.0.

Fig. 2. Cow with GPS collar in paddock.

Static Accuracy. Data were collected from a collar (April 1997) to assess static accuracy. The collar was placed on a wooden cradle with antenna centered 1 m above a known longitude/latitude benchmark. Readings were taken at 5-min intervals for 24 h (1100 h, 16th – 1100 h, 17th). Statistical analysis (CEP) was applied to determine the error-of-location estimates. Rayleigh's test was used to check for angular bias of error locations (Zar 1984).

GPS Data Collection and Analysis. Three cattle data collections were conducted: 1) November 1997 (1500 h, 21st – 1300 h, 25th); 2) May 1998 (1500 h, 14th – 1200 h, 21st); and September 1998 (0000 h, 11th – 0800, 18th). The GPS fix interval was set at 5 min for each data collection. Data from five of seven collars were available for analysis from each collection. Reasons for incomplete data collection included failure of the collar to initiate and collect data, collar malfunction during collection and inability to download data.

The paddock was divided into a 16-cell (four $\times$ four) symmetrical grid (55.3 by 68.5 m, 0.378 ha each, Fig. 3). Pasture utilization, measured by time spent in each paddock grid section, was used as comparative measure between different collar strategies. Utilization per cell was indicated by number of locations (GPS fixes) within cell multiplied by GPS fix interval. Cell utilization was determined for period and expressed as a percentage of total paddock occupancy time. This percentage was used to compare among cells the effect of different GPS fix intervals or optimum number of animals collared.

Fig. 3. Cow locations for collar 9, September 1998.

Five-minute fix interval utilization percentages were considered the control value against which other fix intervals were compared. Effects on pasture utilization by increasing GPS fix interval from 5 to 10 min was simulated by considering every second data record. Simulated 10-min records of location were selected and analyzed for distribution within the cells of the grid. The difference between the 5 and 10-

Table 1. Percentage error for single animal and herd (5 head, in bold) paddock cell use with increasing GPS fix intervals

Test date	GPS fix interval, min				
	5	10	15	20	30
November 1997	0	2.9	4.5	5.7	7.3
	0	1.4	2.3	2.8	3.8
May 1998	0	2.4	3.4	5.0	5.6
	0	1.7	1.7	2.5	4.3
September 1998	0	1.9	3.8	4.1	6.6
	0	0.6	2.7	2.2	3.9
Average	0	2.4	3.9	5.0	6.5
	0	1.2	2.2	2.5	4.0

min utilization was considered the error introduced by increasing the interval. Similar analyses were conducted for simulated GPS fix intervals of greater length.

Data analysis to represent the optimum proportion of collared herd was similar to GPS fix frequency analysis. Utilization per cell was known for the complete set of five collars. Four collars to represent data from the original five were simulated by removing all records for one collar in all possible combinations and weighting the remaining collar records by 5/4. The resulting change was interpreted as the error introduced to pasture utilization by using the four-collar model instead of five collars. Errors within cells were weighted according to time of cell occupancy, which recognized greater effect of error in heavily utilized cells and lesser importance of error in cells less-utilized. A similar procedure was used for each reduction in collars down to one collar of the original five.

Animal Activity Analysis. Accurate prediction of animal activity for collared periods may enhance interpretation of animal forage utilization/intake relative to pasture location. Previously, collar capabilities were limited to animal location without indication of active grazing. A companion investigation was conducted to validate animal activity (grazing, standing, lying) based upon analysis of data from collar activity sensors. The success of this approach was limited in a study on moose (Moen et al. 1996a).

The GPS location fixes were taken every 5 min for 7 d where the activity-sampling window was set at 4 min between fixes. Cows were distantly observed on four occasions, each lasting up to 8 consecutive hours. At each GPS location fix, the general behavior of each cow during the preceding 5 min was classified as active (grazing) or inactive (standing or lying). Counts from horizontal and vertical activity sensors were summed for respective 4-min observation windows and data were analyzed for differences between collars and observed activity per period. An activity counter cutoff value was determined via trial and error that classified the activity of animals. These data were checked against observed data to evaluate the accuracy of this approach.

Table 2. Average percentage error associated with paddock cell use as number of collars/herd (5 head) is reduced

Number of collars	Error	Range ($\pm$)
Five	0	0
Four	9.7	5.4
Three	14.9	13.0
Two	22.4	19.5
One	38.9	21.7

Computer Animation of GPS Data. Behavioral information may remain hidden in static representation of animal positions. Therefore, sequential maps of animal locations for a time period may contain useful information about animal and herd behavior or response to external stimuli. For example, animal observations may include time of day, ambient temperature, and their interactions related to shade presence, grazing pattern and social interaction. A script was developed in MATLAB (Udal 1998) to sequentially animate the location of animals, updating animal position on command. This allowed halting animation and visually assessing data at any point. The script animated ambient temperature data for corresponding GPS location fix, which correlated time of animal movement with temperature change.

RESULTS AND DISCUSSION

Static Test

Collar static testing showed that location fixes over a 24-h period were accurate at approximately 8 m 95% of the time after differential correction. Errors had no directional bias, which is consistent with the findings of other studies.

Fix Interval

Increasing GPS fix interval from 5 to 30 min introduced proportionally increasing errors compared with original 5-min results (Table 1). However, errors were small (approximately 7%) for a GPS fix interval of 30 min with a single animal. Errors introduced for multiple animals collared (4%), are approximately two-thirds that of a single animal. The proposed study objectives should be carefully reviewed when choosing the length of the fix interval. Any interval greater than 5 min may overlook data apart from pasture utilization, such as discrete watering events or interpreting animal activity.

Collar Number

Significant errors were introduced when fewer collars were used to model locations of more animals (Table 2). These errors ranged from 10% when four of five cows were collared compared to nearly 40% when only one of five cows was collared. The range of error was approximately 70% of the average error values, indicating large animal variability. When fewer collars were used, average error and range of error increased. Expressed animal individuality yielded unique individual tracking patterns in the relatively small, intensively managed paddock. The researcher must ultimately determine the acceptable error in the research.

Fig. 4. Active (grazing) cow locations for collar 9, September 1998.

Fig. 5. Inactive (non-grazing) cow locations for collar 9, September 1998.

Grazing versus Non-Grazing Behavior

Differences were found between collars for activity sensor counts for the same observed behavior. This implies that mounting of collars per animal should be standardized (freedom of movement) and that individual collars may need to be calibrated. However, observed active versus inactive sensor count means were different ($P \leq 0.0001$), suggesting that successful classification of activity counts occurred. A cutoff value of 200 was determined for sums of horizontal and vertical activity sensor counts. Animal sensor count sums (during 4-min periods between GPS fixes) less

Table 3. Estimated percentage of time spent grazing for each collar – September 1998

Collar number	Percentage of time spent grazing (%)
19	31.6
18	33.4
17	33.5
9	32.9
4	19.7

than 200 were classified as inactive, while sums equal to or greater than 200 were regarded as active.

This system correctly classified 94.8% (128/135) of active (grazing) data records, and 91.2% (1092/1196) inactive (not grazing) data records for an overall performance of 91.7% (1220/1331) of records correctly classified. This high percentage of correct classification imparts confidence that accurate prediction of animal activity was accomplished. The GIS database was queried to visually demonstrate total, active, and inactive points over the entire period of the September study (Figs. 3, 4 and 5). Grazing location fixes in active classification were relatively well distributed. Inactive fixes (lying and standing behavior) were clustered, located near water or in favorite resting places.

Active versus inactive classifications in data were used to estimate the amount of time of “grazing” for each animal (Table 3). Four of five collars have grazing estimates within two percent (± 0.9). These predictions correspond with literature estimates (McDaniel and Roark 1956). The Collar 4 estimate of grazing time was 60% that of other collars. This is most likely the result of misclassification of data points and not less time spent grazing, which illustrates the danger of applying activity classification to collars demonstrated to be different from each other. However, results for remaining collars display exciting potential for studies requiring identification of grazing behavior.

Animation of Animal Movement

Animation of data using MATLAB (The MathWorks, Inc., Natick, MA) is a useful approach to show time-related behavioral patterns. Figure 6 represents a traced illustration of three cows’ movements for 14 May 1998, from 1500 h to 0000 h, with location fixes taken at 5-min intervals. Initially, each animal was inactive and located near a watering point in the middle of the paddock. The corresponding ambient temperature for this time was 30 to 35°C. The temperature began to drop at approximately 1800 h, and cows sequentially moved from water within a half-hour, presumably to start grazing. The cows continued to graze as the temperature decreased to 17°C at 2145 h, when the temperature began to rise. All cows began a resting period that lasted until 0000 h. The patterns displayed in animation revealed interactions between individual cows and that individual cow movement may be influenced by ambient temperature. Similar patterns are found throughout the May data set. Beginning groundwork and methodology have been demonstrated for time-sequenced studies of behavioral response to environment, and potential exists for continuing research in this area.

Fig. 6. Cow movement for collars 19, 18, and 11. 14 May 1998, 1500 to 0000 h.

CONCLUSIONS

Animal tracking and monitoring technology has advanced dramatically the past 50 yr. Progress from visual observation, to VHF radio transmitters, to satellite-based systems such as ARGOS and Navstar GPS has been dramatic. Advantages and disadvantages are associated with the use of each system. However, the GPS system matches or exceeds the benefits of any other method, with few disadvantages. The cost of GPS collar technology will reduce as this technology evolves and is marketed to a wider audience. A second challenge will be to utilize "real time" GPS location fixes for management. This technology currently exists in non-differentially corrected form for animal tracking. Corrected, "real-time" methods need to be developed.

Information reported here (length of GPS fix interval, number of collars required to represent a herd of grazing animals, classification of animal activity, and sequential animation of cow GPS locations) was gathered from grazing beef cows to investigate the quality and properties of GPS-related data. These data suggested that there were definite grazing preferences exhibited by individual cows on pasture. Collar application parameters and performance characteristics have undergone preliminary investigation. Standardized collar mounting and calibration procedures will need documentation, allowing for effective data collection from future experiments in this research area.

IMPLICATIONS

Many environmental and management variables affect the distribution of grazing cattle on pasture. It will be necessary to understand the impact of these variables on cattle behavior

and subsequent performance to maximize efficiency of pasture systems. Important variables include composition, availability, and distribution of forage; strategic location of shade, water, and supplemental feed; and pasture soil type, slope, and aspect. Furthermore, manipulation of management variables such as paddock shape and size, fence design, and different grazing systems have potential to affect grazing cattle efficiency. The effect of pasture size upon GPS collaring technology should be investigated. Cattle in small, familiar, intensively managed paddocks may exhibit different herd behavior than those in extensive rangeland grazing situations. Extensive grazing systems may require different cow collaring protocols. Collared dominant or social cows may represent herd location adequately and herd behavior may be estimated. Fenceless paddocks employing "real time" GPS systems to guide animal behavior pose an exciting opportunity. Monitoring livestock with GPS technology offers meaningful data from which research-based results can be obtained to improve such efforts.

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