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Characterising the spatial and temporal activities of free-ranging cows from GPS data

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Abstract. Electronic tracking provides a unique way to document behaviour by cows on a continuous basis. Over 2 years 17 beef cows with calves were fitted with global positioning system (GPS) devices programmed to record uncorrected GPS locations at 1-s intervals in a semi-desert rangeland. Each cow was periodically observed during daylight hours and foraging, walking and stationary (standing/lying) activity times were recorded across days and individual cows to calculate a mean travel rate for each activity. Data without observers present were collected immediately preceding and following the abrupt weaning of calves at between 223 and 234 days of age to evaluate the potential of classifying various travel rates into foraging, walking and stationary activity. The three activities were further characterised within a 24-h period based on the sun's angle with respect to the horizon. Only data from cows whose equipment acquired $\geq$90% of the potential GPS positional data among consecutive days were analysed. Due to problems with the equipment, data from two cows in 2009 and two cows in 2011 met these criteria. The interval evaluated consisted of four 24-h periods before abrupt weaning and seven 24-h periods following weaning. Results suggested that uncorrected 1-s positional GPS data are satisfactory to classify the behaviour by free-ranging beef cows into foraging, walking and stationary activities. Furthermore, abrupt weaning caused cows to change their spatial and temporal behaviour across and within days. Overall, travel by cows increased post-weaning with subtle within-day behavioural changes. Further research will be required to fully understand the biological importance of spatio-temporal behaviour to optimise cattle and landscape management goals.

Additional keywords: foraging, geospatial data, livestock, travel, weaning behaviour.

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Introduction

Attempting to understand 'where' and 'why' specific animal activities occur on a landscape probably began with hunter-gatherer cultures (Lee and DeVore 1968). Necessity continues to drive our quest for understanding because of today's multi-faceted demands placed on natural landscapes for new and evolving goods and services (Havstad *et al.* 2007). Behaviours involve a continuum of scale involving many motivational forces rather than a sequence of unrelated discrete activities (Farnsworth and Beecham 1999). Since animals appear to select habitats in a hierarchical manner (Sallabanks 1993), understanding at what spatial scales animals react to their habitat (Kotliar and Wiens 1990) is fundamental to pro-active management especially when recommendations combine both qualitative and quantitative data (Halbritter and Bender 2011).

Numerous tools (Anderson 2010) are being employed to assist manual observation of behaviours including video-taping (Ramseyer *et al.* 2009), cameras (Marshall *et al.* 2005; Moll *et al.* 2009) attached to an animal's head and even microphones (Clapham *et al.* 2011), to pick up sounds associated with foraging, all tools designed to minimise an observer's influence. The global positioning system (GPS; Herring 1996) is a revolutionary tool for obtaining animal location data every second that carries an accurate time stamp. The major challenge with positional sampling frequencies approaching continuous observations is the current requirement for battery power (Tomkiewicz *et al.* 2010).

The earliest authors who suggested that GPS data could be used to characterise cattle foraging behaviour were Schlecht *et al.* (2004). These authors recorded one positional 'fix' every 10 s. Swain *et al.* (2008) suggested it was possible to predict foraging by recording four GPS fixes s^{-1}. Recently, Cho *et al.* (2011) suggested that human walking can be accurately determined if the maximum elapsed time between consecutive GPS fixes is no greater than 180 s.

The frequency at which data are collected should always be driven by the question asked but is often dictated by requirements for battery power necessary for specific positional acquisition rates. This is especially true for currently available electronic equipment borne by free-ranging animals (Anderson 2011) although adaptive sampling algorithms have improved the efficiency of both energy and memory usage in GPS tracking equipment where auxillary software and hardware are combined into a hybrid system (Schwager *et al.* 2007; Youssef *et al.* 2010). For example, accelerometers, which classify movement and activity (Mathie *et al.* 2004; Scheibe and Gromann 2006; Gottardi *et al.* 2010), can be used in conjunction with GPS data to assist in classifying different behavioural categories in terrestrial (Löttker *et al.* 2009; Moreau *et al.* 2009) species. Adding auxillary sensors to GPS equipment, however, does not come without challenges. Consistent sensor placement (Wilson *et al.* 2008) is critical for obtaining meaningful accelerometer data especially if collars, the most common platform for carrying electronic equipment, are periodically removed and replaced (Venkatraman *et al.* 2007). Although instrumentation allows for more continuous recording of behaviour, observation still remains an essential component in data collection because of man's power to reason and give meaning to numbers (Anderson 2011). The biggest challenge when relying on electronics to provide data is not to lose a field-based understanding of animal behaviour (Hebblewhite and Haydon 2010).

The primary objective of the study was to determine if 1-s uncorrected GPS fixes, obtained from electronic devices fitted to free-ranging beef cows occupying a semi-desert rangeland, could be used to characterise the activities of foraging, walking and being stationary as a function of rate of travel (m s^{-1}). All observed behaviours in which a cow was either standing or lying with or without ruminating were considered stationary and observations of activities by cows were periodically recorded to characterise the GPS databased on the rate of travel.

This relationship was then used to characterise cow behaviour when observers were not present during two periods, one consisting of four 24-h periods preceding, and seven 24-h periods following abrupt weaning of calves at 7 months of age around midday in March 2009 and 2011. Abrupt weaning causes behavioural (Weary and Chua 2000; Price *et al.* 2003; Haley 2006; Enríquez *et al.* 2010) as well as physiological (Ste hulová *et al.* 2008) changes in both calves and their dams. Although walking appears to increase in both calves and cows following weaning, the majority of studies have only focused on calf travel rather than that of the dam yet management systems must also take into account effects on the dam (Weary *et al.* 2008). Overall, there is limited research evaluating the effects of weaning on the behaviour by beef cows (Bohnert *et al.* 2006; Merrill *et al.* 2008; Anderson *et al.* 2010).

Materials and methods

Description of cattle and rangeland, and weather measurements

During 2009 and 2011, a 433-ha mesquite-dominated area (Paddock 14A; 106°41′W, 32°34′N) was stocked with mature (>3 years of age) multiparous Hereford × Brangus cows weighing ~454 kg. The research was conducted on a Chihuahuan Desert-grassland, described by Peters and Gibbens (2006), and operated by the USA Department of Agriculture – Agricultural Research Service-Jornada Experimental Range (USDA-ARS-JER) near Las Cruces, New Mexico. Stocking was deferred before the start of each of the two studies to ensure an adequate herbage mass. The study in 2009 was conducted between 26 March and 6 April while the study in 2011 was conducted between 10 March and 21 March. Calves were abruptly weaned when they were between 223 and 234 days of age on 30 March 2009 at 1200 h and in 2011 on March 14, at 1410 h. Weaning took place in a corral located near drinking water. Immediately following separation of the cows from their calves, the calves were transported to JER Headquarters ~6.5 km to the north of the corral.

Except for three cows, the cows in the two herds differed between years. In 2009 the herd numbered 30 cows and five of the cows were fitted with electronic instruments while in 2011 all 12 cows constituting the herd were fitted with instruments. Calves were not fitted with instruments in either year because the stretch-halter/neck saddle equipment containing the electronic equipment (Fig. 1) was considered too heavy (3.2 kg) to be worn by unweaned calves.

Weather measurements were recorded (Campbell Scientific CR 10X Data Logger; Logan, UT, USA) ~2.5 km south-west of the study paddock. Sensors recorded ambient air temperatures, wind speed and precipitation every 15 s followed by calculation of 300-s means for these variables. In addition, the maximum relative humidity and wind direction were recorded over each 300-s interval. The land surface at the weather station and within the study paddock is continuous and characterised as being smooth to undulating with the presence of low-growing mesquite (*Prosopis glandulosa* var. *glandulosa* Torrey) and mesquite hummocks within a grassland matrix.

Training cows and electronic hardware

Prior to the study, each cow was trained to wear the GPS equipment (Fig. 1). Training involved working with individual cows in a small pen using cottonseed pellets as an incentive. This procedure was repeated over several days until each cow showed no reluctance to human contact, especially in the head and neck region.

The next step was to place the stretch-halter onto the cow's head. This was accomplished by placing the stretch-halter around the rim of a bucket containing cottonseed pellets and in one slow uninterrupted movement pulling the stretch-halter over the cow's muzzle and ears while she had her head in the bucket. The final step involved placing the neck saddle on the cow's neck and securing it to the stretch-halter with plastic zip ties. These steps led to a positive learning experience for both the cow and the technician. The cows did not appear to exhibit stress while wearing the stretch-halter/neck saddle equipment packages (Fig. 1) for extended periods of time lasting up to several weeks. The electronics package included a GPS ET-312 receiver manufactured by GlobalSat Technology Corporation (Taipei Hsien, Taiwan) programmed to record uncorrected GPS locations at a rate of one fix s^{-1} and other hardware previously described by Schwager *et al.* (2008).

Fig. 1. Cow wearing a stretch-halter/neck saddle electronics package. GPS hardware is housed inside the rectangular box equipped with solar panels. Continuous power is supplied from a battery located inside a box hanging below the cow's neck. A plastic ring below the left ear and two metal cylinders behind it, separated by a white insulator, can provide sound and electrical simulation cues, respectively, when activated (Directional Virtual Fencing; DVF™; Anderson 2007). No cues were activated in this study.

Data gathering and analyses

Manual as well as electronic methods were used to collect data in both years. Manual observational data were used as a training set to classify the GPS data. The manual method employed a modified sequence-sampling approach (Altmann 1974) for recording foraging, walking, and standing/lying (stationary) activities among the cows. To characterise the range in movement path speeds (m s^{-1}) obtained from the GPS equipment, two observers periodically went into the paddock and, after locating cows, followed them and recorded foraging, walking, and stationary activities and the time over which each took place. Movement would have been less in stationary cows if the GPS units had been positioned on the body rather than the head/neck location. No attempt was made to distinguish between head/neck and body movement during observations. In 2009, the five instrumented cows were watched for 20 h over 7 days during morning hours and in 2011 the 12 instrumented cows were observed during mornings for a total of 23 h over 10 days. Except for the first day of observations in 2009, observations in both years were done on Mondays, Wednesdays and Fridays before gathering the cows to check and service their electronic equipment. This protocol provided for optimum consecutive intervals of time when humans were not present in the paddock.

Manually recorded data of behavioural measurements with time/date together with GPS locations and associated files from both years were collated in Excel 2003 spreadsheets (Microsoft, Redmond, WA, USA). The GPS data were recorded in csv format as multiple files for each cow. These files contained occasional truncated records together with time stamp and header information. The data files were then concatenated and cleaned of all ill-formed records. The resulting files, one per cow, of 1-s records were processed to (1) convert latitude/longitude locations to Universal Transverse Mercator (UTM) coordinates, (2) convert GPS time to local time, and (3) determine distance and rate of movement. These files were then reduced to one record per minute by calculating a mean rate of movement along the path defined by the 1-s fixes. We called this path speed (m s^{-1}). With the advent of inexpensive GPS receivers, map users are adopting the UTM grid system for coordinates that are simpler to use than latitude and longitude.

In addition, the sun's angle was computed for each record based on time and location using the PyEphem python module (http://rhodesmill.org/pyephem/, accessed 22 April 2012), which is based on the XEphem (1990) software library of Elwood Downey. 'Time-of-day' attributes were defined as dawn, early am, late am, early pm, late pm, twilight and night, and this information was also added to each dataset. The time at the end of each minute was associated with the path speed for that minute. Behavioural observations were checked for transcription accuracy. Manual observations were merged with the 60-s GPS records by adding an 'observed behaviour' column in the spreadsheet and placing observed behavioural measurements in the column when data were available; otherwise the value was classified as unknown. GPS path speeds, representative of foraging, walking and being stationary among the five cows in 2009 and the 12 cows in 2011, were then calculated where simultaneously paired observational and GPS records were available. Behaviour observed any time during a 1-min interval were associated with the time at the end of that minute.

GPS data were downloaded every Monday, Wednesday and Friday mornings in both years by moving the cattle into a set of corrals located near the drinking water. Cows were worked on individually by moving individuals into a small pen as during the 'training phase.' There, the cow was provided with cottonseed pellets and visually inspected for abrasion or injury that could have been caused by the equipment saddles. Equipment saddles and electronics, especially connectors, were observed and, if found damaged, were immediately repaired or replaced. Power to the electronics was then shut off by disconnecting the power cord leading to the electronic box before it was opened and the 2-GB miniSD card (Transcend, Linthicum Heights, MD, USA) on which data had been stored was removed and replaced with a reformatted card. Once the reformatted miniSD card had been replaced, the 3.7-V, 17-Ah lithium polymer battery (Powerizer, Richmond, CA, USA) that hung beneath the cow's neck (Fig. 1) was replaced with a recharged battery before powering up the electronic equipment for the next period of data collection.

During the recording of behaviour in the field in 2009, a recorder filled out paper forms based on verbal communication from a second observer observing the five instrumented cows that were uniquely identified by large symbols painted on the cow's sides with white paint. A recorder indicated time in 1-min intervals (frequency deemed appropriate for the rate at which field observations could be accurately observed and recorded) and the observer then responded with cow ID and activity (i.e. foraging, walking and being stationary) for each of the five cows in no particular order. These three behavioural variables 'fit' the trimodal distribution that corresponded to the three general behaviour classes observed among the data (Fig. 2). These 1-min records were used to develop a behavioural model based on path speed used to characterise the autonomously recorded 2009 data.

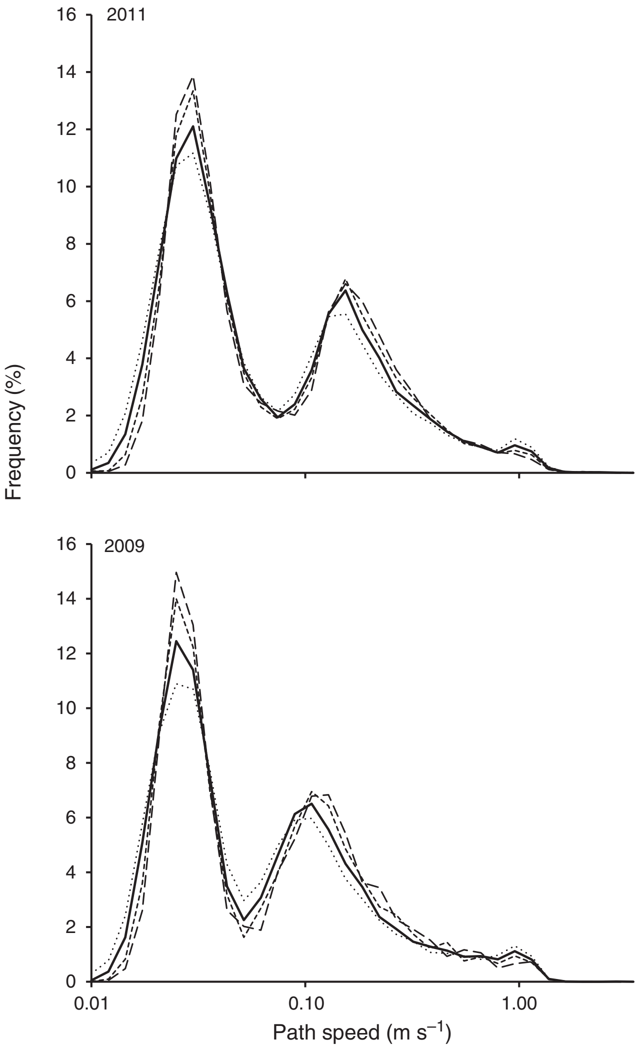

Fig. 2. Path speeds (m s^{-1}) for two cows, one from 2009, the other from 2011. Scale is geometric and starts at 0.01 m s^{-1} with a multiple of 1.1. The sampling periods were 30 s (····), 60 s (—), 120 s (- -) and 180 s (– –).

In 2011, with 12 instrumented cows, a slightly modified observation technique was used. Once the cows with symbols painted on their sides were located, each cow's behaviour (foraging, walking and being stationary) was indicated along with the time. The observer and recorder then began moving slowly and continuously among the cows observing when each cow's activity changed. When a change in activity was observed, the observer would call out the cow's ID together with its 'new' activity. The recorder manually recorded this information on field forms along with the time accurate to 1 s obtained from a hand-held GPS unit (Garmin Geko 201, Olathe, KS, USA).

Behavioural observations and 1-s GPS data were reduced to 60-s records that contained location, path speed, direction of travel and observed behaviour. Behavioural changes observed during a minute were recorded as the cow's behaviour at the completion of that minute. If multiple behavioural changes were observed during a given minute, the last behaviour recorded for the minute was used to characterise that minute's behaviour. Within a given minute, path speed was defined as the sum of Euclidean distances between each of the 1-s GPS fixes, divided by 60 s.

The dataset used to characterise GPS data, when observers were not present, involved several preparation steps. When observational and GPS fixes were concurrently available, the range in travel rate (m s^{-1}) among cows involved in foraging, walking and stationary activities was determined by computing the Euclidian distance between consecutive 1-s GPS fixes. Initial processing of the 1-s GPS data involved computing displacement, speed and direction relative to the prior fix. We observed that a frequency distribution of the mean path speed over an interval of up to several minutes produced a distinctly tri-modal distribution (Fig. 2). When the same distribution was computed for the subset of records corresponding to each of the three observed behavioural classes (foraging, walking and being stationary), we observed a clear association between each behaviour class and one of the three path-speed distribution models. This became the basis for the path speed behavioural models used.

A test was conducted to determine a suitable period over which to produce a mean path speed that would produce the most distinct path-speed frequency distribution. Figure 2 shows mean periods from 30 to 180 s. Averaging over longer periods produced more distinct, narrower peaks at low and middle speeds while the fastest speed peak tended to become flattened. This resulted from the abundant and extended behavioural activities occurring at the lower speed which tended to regress to a mean speed. The fastest movement (walking) tended to occur in short bursts; however, when the mean was calculated over several minutes, much of the high speed behaviour became 'diluted' because it did not last for the entire period. In both years the paired observational and GPS data were divided into intervals of 60 s. Mean rate of travel (m s^{-1}) was determined by calculating consecutive differences among 60 fixes. Records with both path speed and observed behavioural activities were used to develop two speed thresholds that constituted the behavioural model. The first threshold identified the transition from being stationary to foraging and the second identified the transition from foraging to walking (Fig. 3). These thresholds were set to optimise the proportion of

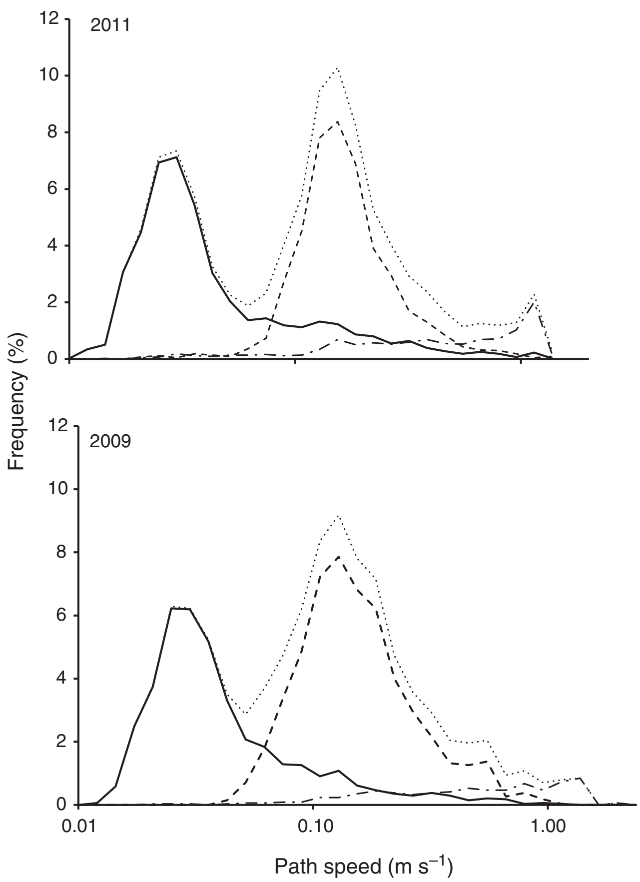

Fig. 3. Frequency distribution of path speeds (m s^{-1}) among all crossbred Hereford-Brangus cows for stationary (—), foraging (- -), walking (–·–) and combined (····) behaviours obtained from 1-s GPS fixes on a 433-ha Jornada Experimental Range paddock (14A); 26 March–6 April 2009 and 10–21 March 2011. In 2009, five cows were monitored over 7 days (20 h). In 2011, 12 cows were monitored over 10 days (23 h). The sampling period was 60 s.

correct behavioural activities identified among the records within that year's data.

To further quantify the temporal aspects of the GPS data, a 24-h period preceding and following abrupt weaning was partitioned into seven time intervals based on the sun's angle with respect to the horizon. Visually observed breaks in the relationship between the sun's angle and path speed were used to define the seven divisions within the 24 h. The path speed of each 60-s interval was plotted as a function of the sun's angle with respect to the horizon using one of seven colours and having each fix identified by one of three different symbols representing foraging, walking and stationary. In addition, the arrow symbols represent direction of movement. The symbols and colours provided several additional aspects of cow behaviour compared with simply plotting GPS data as only points.

The majority of GPS data were collected when observers were not present and it is these data that were used to describe pre- and post-weaning behaviour by cows. Even though the data used to generate travel rates among the three activities came from ~4.2×10^6 uncorrected 1-s GPS fixes in 2009 and 8.6×10^6 uncorrected 1-s GPS fixes in 2011, only data from four cows (two different cows in each year) had datasets that were ≥90% complete for 11 consecutive days covering both pre- and post-weaning periods.

All graphics were produced using ArcGIS 9.3 (Redlands, CA, USA) and Excel 2003 (Microsoft, Redmond, WA, USA). Images from 2003 QuickBird photography that included Paddock 14A were obtained from Digital Globe (Longmont, CO, USA) and used as the background on which to draw the locations and trails of cows, and their activities. Python 2.6 (Wolfeboro Falls, NH, USA; http://www.python.org, accessed 22 April 2012) was used to compile the GPS data and classify them into different behaviours. Behavioural data were analysed by ANOVA with individual cows as experimental units, and behaviour and year as fixed factors. Statistical analyses were carried out in SAS 9.2 (SAS Institute Inc. 2009).

Results

Characterising behaviour by cows using travel rates

Overall performance of the electronic equipment was low. Failure of the electronic hardware and software occurred not only during periods of observation but also when the cows were not being observed. We were unable to obtain complete 24-h GPS datasets over 11 days for all 17 instrumented cows. Incomplete datasets arose from several causes, the most serious being battery wire connectors breaking most frequently at the battery box that hung below the cow's neck (Fig. 1) and failures of the miniSD cards to consistently capture GPS data. Once in 2011 a cow lost the entire equipment saddle at the drinking water point but, otherwise, the saddle/stretch-halter proved a reliable platform for deploying the electronic equipment as configured. Even with these challenges, there were two cows in each of the 2 years with datasets that were ≥90% complete and these were used to characterise pre- and post-weaning cow movement.

It was possible to characterise cow travel rate (m s^{-1}) into foraging, walking and stationary activities by determining displacement between consecutive 1-s uncorrected GPS fixes summed over intervals between 30 and 180 s (Figs 2 and 3). In Fig. 3 it can be seen that the first peak of activity corresponded to data recorded when the cows were stationary, and this occurred at the lowest path speeds. Though stationary cows should show virtually no directional movement, the error associated with GPS technology always reflects some movement. Furthermore, because the stretch-halter/neck saddle is attached to the cow's head and neck, these body parts seldom remain motionless for extended periods of time. In both years, lying and standing were considered together. Stationary behaviour appeared spatially associated with areas where foraging took place rather than areas where walking was observed. In 2009, standing or lying among the five cows was calculated to have a travel rate of ≤ 0.060 m s^{-1} and in 2011 among 12 cows it was found to be ≤ 0.059 m s^{-1}. Of the four cows that had ≥90% continuous data, > 50% of their days were spent being stationary (Fig. 4).

Cows that were walking were moving at the highest speeds near the peak located near 1 m s^{-1} (Fig. 3). In 2009 the transition between being stationary and foraging took place at a travel rate of 0.060 m s^{-1} and in 2011 the rate was calculated to

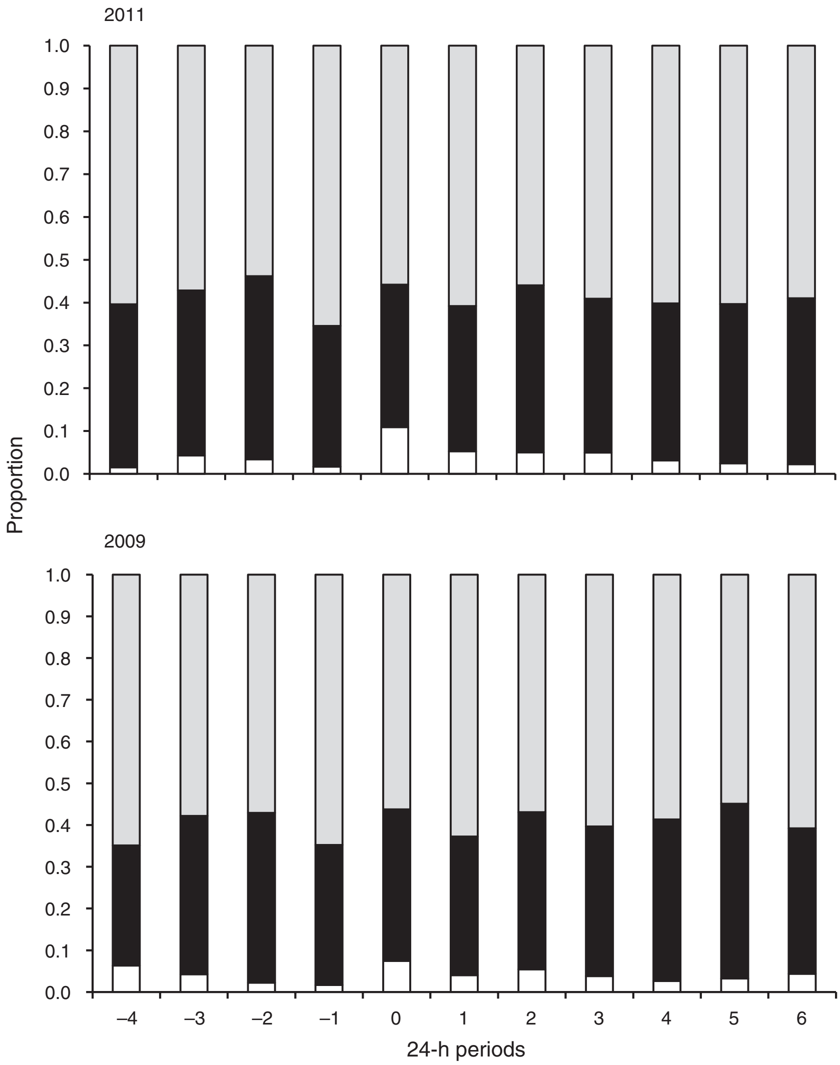

Fig. 4. Mean proportion of time two different cows in each of 2 years spent on being stationary (grey), foraging (black) and walking (white). Data were collected during four 24-h periods pre-weaning and seven 24-h periods post-weaning. A midday weaning took place immediately before the 24-h period designated '0' (30 March 2009 and 14 March 2011).

be 0.059 m s^{-1}. Likewise the transition between foraging and walking took place at travel rates of 0.55 m s^{-1} in 2009 and 0.50 m s^{-1}in 2011, respectively. In 2009, 95% of the foraging took place at path speeds between 0.060 and 0.55 m s^{-1}. In 2011 93% of the foraging took place between 0.059 and 0.50 m s^{-1}.

Pre- and post-weaning travel by cows

Weather conditions were within the cow's thermo-neutral zone thus their behaviour was unlikely to have been greatly impacted by weather during either 2009 or 2011. No precipitation was recorded during the measurement periods in either year. Ambient air temperatures ranged between 11 and 17°C while wind speeds ranged between 4 and 9 m s^{-1}.

Overall the mean rate of travel during the spring was similar across years but rate of travel varied among pre- and post-weaning periods following weaning ($P < 0.01$) (Fig. 5) with rate of travel increasing during the post-weaning period. The greatest increase in travel occurred during the 24-h following abrupt weaning (Fig. 4). GPS data provided spatial as well as temporal information concerning behavioural activities with drinking water apparently being a major focal point for cows throughout the study in both years. Overall, patterns were similar even though total numbers of cows and their ages were not identical in 2009 and 2011.

Post-weaning travel by cows increased in both years but not uniformly (Fig. 6). Between 1200 and 1800 h, overall travel was greater after weaning ($P < 0.05$) as was travel in the period between 2400 and 0600 h ($P < 0.05$), and 1800 to 2400 h ($P < 0.001$). This trend reversed for the 6 h between 0600 and 1200 h with the difference between pre- and post-weaning not statistically significant.

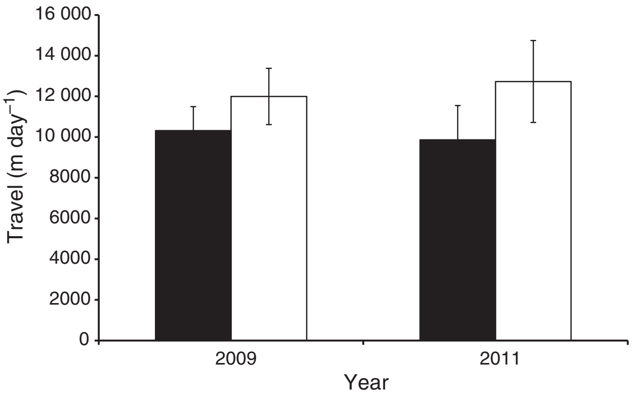

Fig. 5. Means ± standard errors for total travel distance (m day^{-1}) for two cows in the pre-weaning (black) and two cows in the post-weaning (white) periods on a 433-ha Jornada Experimental Range paddock (14A); between 26 March and 6 April 2009 and 10 and 21 March 2011.

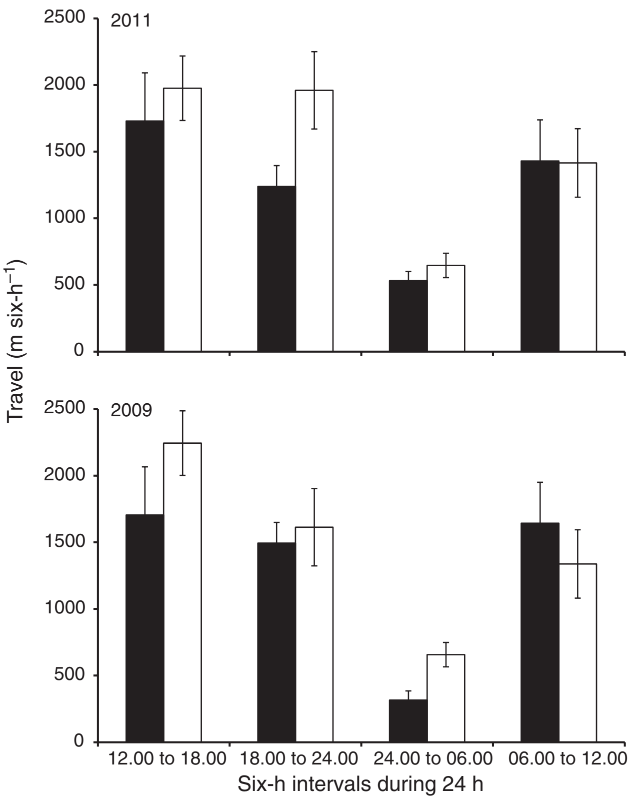

Fig. 6. Means ± standard errors for total travel in each of four 6-h intervals per 24-h period for four cows (two per year) in the pre-weaning (black) and post-weaning (white) periods on a 433-ha Jornada Experimental Range paddock (14A) between 26 March and 6 April 2009 and 10–21 March 2011.

Qualitatively, the area in the paddock where the cows spent time during the 4-day pre-weaning period appears quite similar between the 2 years (Fig. 7). Following weaning the locations where foraging, walking and standing/lying occurred appeared less similar between years (Fig. 8). Foraging by cows before weaning of calves was not concentrated near the drinking water in either year. Foraging tended to be associated with specific areas interconnected by paths/trails where walking took place. On closer inspection of the data, many of the paths appeared on or adjacent to previously existing trails.

There appeared more walking following weaning (Fig. 8) and the cow's overall spatial location was different compared with pre-weaning spatial patterns of use (Fig. 7). The overall increase in walking following weaning (Fig. 5) was throughout the paddock but especially near the drinking water (Fig. 8). Travel distances and foraging time among four 6-h intervals during 24-h showed no uniform pattern (Figs 6 and 9). The interval between 2400 and 0600 h contained the least number of minutes of foraging (Fig. 9) and travel (Fig. 6) in both years. Although weaning tended to decrease the number of minutes that cows spent foraging throughout the day in 2011, in 2009 two other patterns were observed (Fig. 9). Following the 2009 weaning foraging decreased between 0600 and 1200 h ($P < 0.05$) and again between 1800 and 2400 h but not significantly. The trend was for minutes spent foraging after weaning to increase though not significantly. The four cows tended to make unidirectional movements to and from drinking water based on the direction of the arrows in the 24-h period before weaning (Fig. 10). In contrast to this pattern, during the 24-h period post-weaning (Fig. 11) cows appeared to use the drinking water as a focal point (possibly because this was the location where weaning took place) while spending time making one or more 'loops' into the paddock as if searching for their calves. Furthermore, the frequency of walking (orange arrows) appears to take precedence over foraging (green arrows) and foraging appeared to be concentrated in a smaller proportion of the area of the paddock 24-h post-weaning (Fig. 11) compared with the 24-h pre-weaning (Fig. 10).

At the time corresponding to the angle of the sun being between 0 and –12° below the horizon, (designated as twilight), during the 24-h period pre-weaning in both 2009 and 2011 there appeared to be foraging (Fig. 10). During this same interval of time post-weaning in both years, walking appeared to be the dominant activity (Fig. 11).

Discussion

Characterising behavioural travel rates

By the end of the 20th century it was recognised that electronic sensor technology could rapidly provide large datasets that contain patterns of information applicable to pro-active management (Frost *et al.* 1997). This was particularly true of those datasets that contain animal movement patterns (Nams and Bourgeois 2004; Stephen *et al.* 2010). Although the electronically obtained data in this study showed variability throughout 24 h for travel (Fig. 6) as well as foraging (Fig. 9), similar patterns were recognised to occur among Aberdeen-Angus and Hereford cows long before electronic sensor technology was deployed (Johnstone-Wallace and Kennedy 1944).

We found that a model that used 'thresholds' to classify activities was better than a discriminant model that utilised only observational data. The thresholds were selected to optimise the number of correctly identified behavioural activity in records

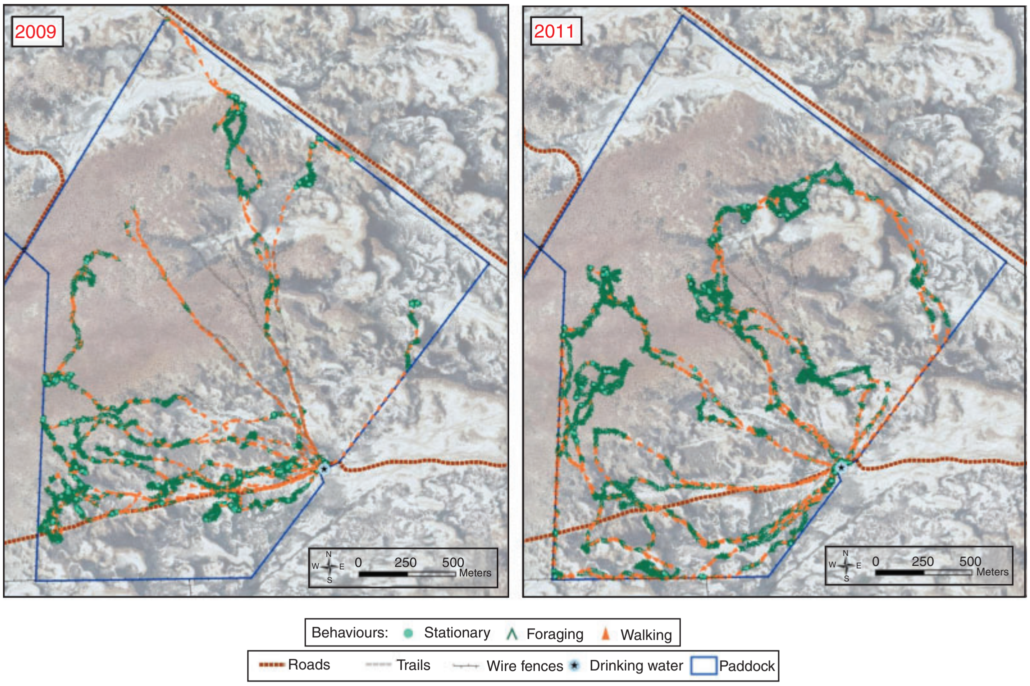

Fig. 7. Spatial pre-weaning activity was classified as; stationary <0.060 (m s^{-1}) in 2009 and <0.050 (m s^{-1}) in 2011, foraging 0.060 (m s^{-1}) to 0.55 (m s^{-1}) in 2009 and 0.050 (m s^{-1}) to 0.50 (m s^{-1}) in 2011, and walking >0.55 (m s^{-1}) in 2009 and >0.50 (m s^{-1}) in 2011 for two cows between 26 and 30 March 2009 and for two cows between 10 and 14 March 2011.

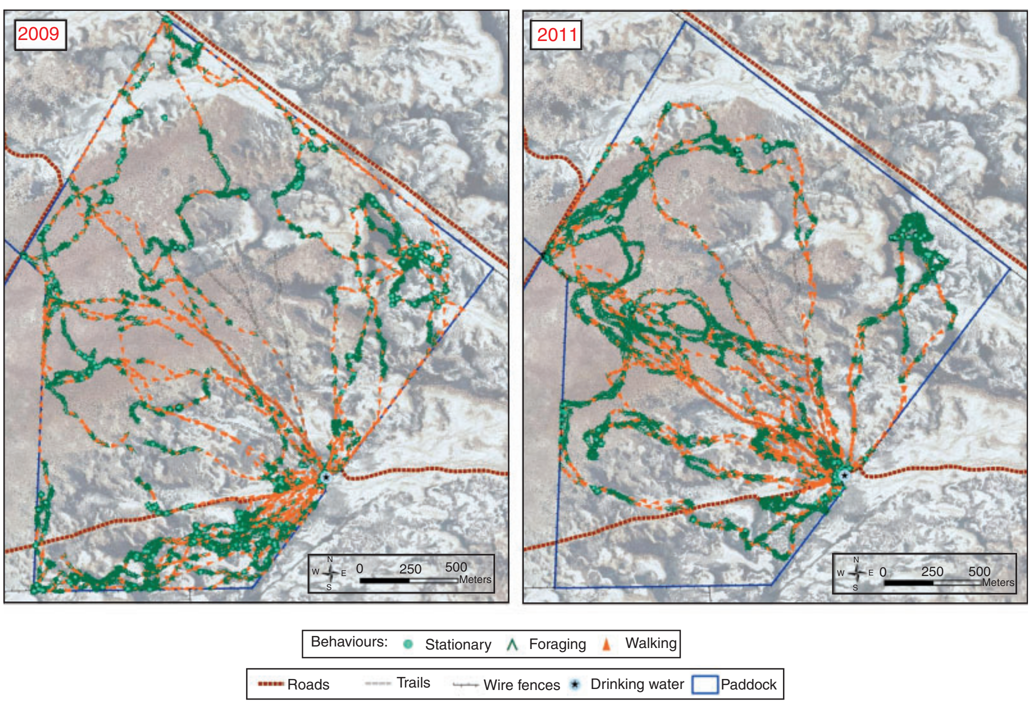

Fig. 8. Spatial post-weaning activity was classified as; stationary <0.060 (m s^{-1}) in 2009 and <0.050 (m s^{-1}) in 2011, foraging 0.060 (m s^{-1}) to 0.55 (m s^{-1}) in 2009 and 0.050 (m s^{-1}) to 0.50 (m s^{-1}) in 2011, and walking >0.55 (m s^{-1}) in 2009 and >0.50 (m s^{-1}) in 2011 for two cows between 30 March and 6 April 2009 and for two cows between 14 and 21 March 2011.

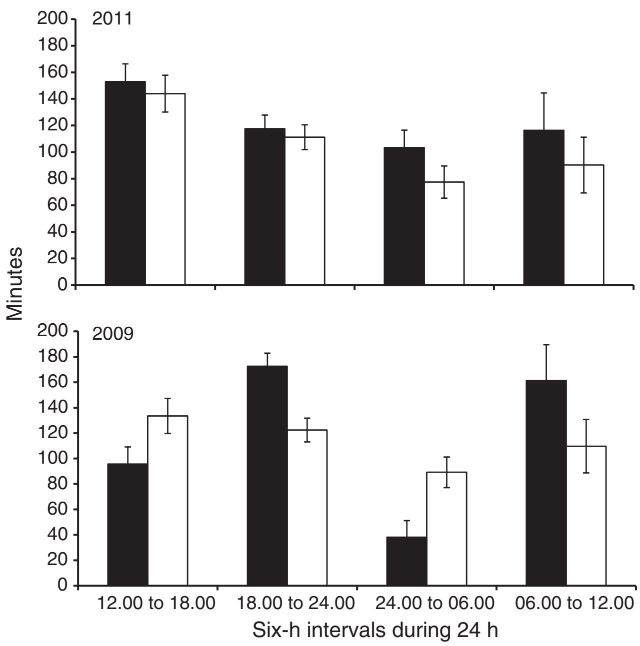

Fig. 9. Means ± standard errors for total minutes spent foraging in each of four 6-h intervals per 24-h period for four cows (two per year) in the pre-weaning (black) and post-weaning (white) periods on a 433-ha Jornada Experimental Range paddock (14A) between 26 March and 6 April 2009 and 10–21 March 2011.

with known observed behavioural activity. Any difference in behaviour by cows between years was probably not weather-related as the weather parameters recorded in 2009 and 2011 were similar.

The foraging rates in this study fall within reported ranges. Guo *et al.* (2009) suggested an upper rate of directional movement for foraging to be less than 0.2 m s^{-1} for cattle in 7-ha paddocks in Australia while the range that Putfarken *et al.* (2008) placed on rate of travel during foraging among a mixed-species group within a 180-ha paddock in Germany was between 0.02 and 0.33 m s^{-1}. In general, uncorrected GPS data should show a larger movement pattern than differentially corrected data (August *et al*. 1994; Rempel and Rodgers 1997). Unfortunately we were not able to evaluate this since the GPS recorded with the electronic equipment used could not be differentially corrected.

The low performance of the electronic equipment (data not being recorded on the miniSD cards) may have resulted from multiple causes. A common assumption is that natural landscapes may periodically shield GPS antennas due to canopy cover and, although habitat can reduce GPS fixes (Nielson *et al.* 2009), it is highly unlikely this was a problem since the majority of the woody plants were less than 2 m in height. However, shrubs were likely to have been responsible for the majority of the broken battery connectors as the cows moved through the paddock even though more than half of their day was spent being inactive (Fig. 4). Similar findings of inactivity among free-ranging cows have been reported for Hereford cattle (Moorefield and Hopkins 1951), mature Simford crossbred cows (Brosh *et al.* 2006), and lactating Friesian cows in open camps in South Africa (Muller *et al.* 1994). Merrill *et al.* (2008) found Angus × Hereford cows rested between 13.6 and 14.7 h day^{-1} based on when calves were weaned; early at ~130 days of age or traditionally at ~205 days of age, respectively.

Pre- and post-weaning travel by cows

Due to the intermittent electronic malfunctions of the GPS equipment, only data from four cows provided ≥90% of continuous data during each of the 2 years. As a consequence of this, behavioural implications revealed by these data can serve only as preliminary indicators of pre- and post-weaning behaviour among free-ranging beef cows occupying a semi-desert rangeland. Moreover not all factors that could have influenced travel by cows, such as the presence of coyotes (*Canis latrans*), prevent us from discussing pre- and post-weaning behaviour by cows in detail. The lack of observations during non-daylight hours prevents a complete interpretation of the qualitative data seen in Figs 7, 8, 10 and 11. Data showing cows walking along trails were expected since Ganskopp *et al.* (2000) documented cows tend to follow previously established routes, further supporting the research of Low *et al.* (1981) who suggested that patterns of activities have consistency and the sequence of activities a cow moves through will form a pattern of ‘transitional activities’ (Arnold and Dudzinski 1978).

The piosphere, or area surrounding drinking water, dictates behaviour patterns among free-ranging herbivores (Andrew 1988). This is definitely apparent in our data. Abrupt weaning took place at the drinking water and the cows may have been ‘searching’ for their calves (Haley 2006). Since behaviour by cows tends to return to normal levels ~96 h following abrupt weaning (Veissier *et al.* 1989), we chose to evaluate the first 24 h just before (Fig. 10) and following (Fig. 11) weaning to show the greatest difference. During this period we recorded ‘loops’ of walking that could possibly be explained as searching routines. Although previously not documented in the literature, we believe this detail may have been missed in earlier studies following weaning especially if locational data were acquired at infrequent intervals. Although suckling bouts tend to be initiated by calves (Lidfors *et al.* 1994) and may occur three times throughout a 24-h period at 8-h intervals (Johnstone-Wallace and Kennedy 1944), the build-up of intra-mammary pressure may have caused the cows to search for their calves. Bryant (1989) concluded that, although behavioural activities are never constant among individuals in a species, the general sequence or pattern of behavioural activities is consistent. The absence of suckling as an explanation for the ‘loops’ is only speculation since milk production from these cows should have been minimal based on lactation curves (García and Holmes 2001) as a function of time since parturition (223–234 days with our cow-calf pairs). von Keyserlingk and Weary (2007) point out that the behaviour by cows after weaning is associated with management and not cessation of milking (suckling in our case) *per se*. Regardless of the explanation, weaning is stressful to both cows and calves and reducing stress should be the paramount focus in dictating how weaning is conducted (Enríquez *et al.* 2011).

Although the interpretation of Figs 10 and 11 is strictly qualitative since it is based on the intervals we chose to divide

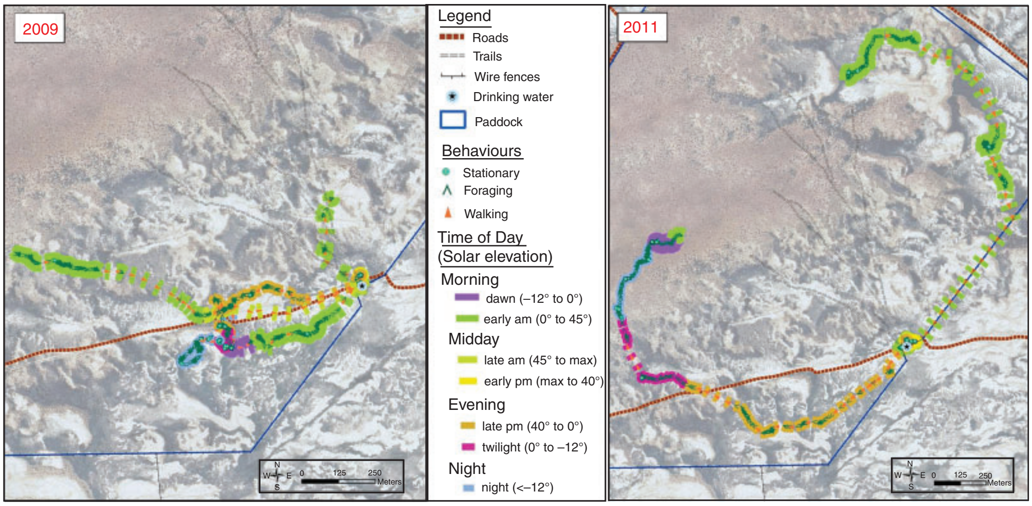

Fig. 10. Locations for one cow 24-h pre-weaning in 2009 and another cow in 2011 on a 433-ha Jornada Experimental Range paddock (14A) involved in three major behaviours: stationary <0.060 (m s^{-1}) in 2009 and <0.050 (m s^{-1}) in 2011; foraging 0.060 (m s^{-1}) to 0.55 (m s^{-1}) in 2009 and 0.050 (m s^{-1}) to 0.50 (m s^{-1}) in 2011; and walking >0.55 (m s^{-1}) in 2009 and >0.50 (m s^{-1}) in 2011. Daily behaviours were characterised based on the sun's angle above the horizon: morning, 0604–1042 hours (solar elevation –12° to 45° rising); midday, 1043–1607 hours (solar elevation 45° rising to 40° setting), evening, 1608–2019 hours (solar elevation 40° to –12° setting); and night, 2020–0603 hours (solar elevation <–12° no sun).

the 24 h into, Arnold (1985) suggests that the amount of night foraging is directly affected by daily maximum ambient temperatures, with less foraging taking place when temperature is < 15°C but increasing up to 70% of daily foraging time when maximum temperatures are > 25°C. Such divisions of a 24-h period may be extremely useful to study biological rhythms in livestock related to diagnostic as well as therapeutic applications (Piccione and Giovanni 2002). The key for optimising understanding of cause and effect relationships is that the time stamp used among all the measured parameters should be identical.

Methodologies for analysing geospatial data from GPS continues to evolve and offers management possibilities never before possible (Hulbert and French 2001). Classical statistics

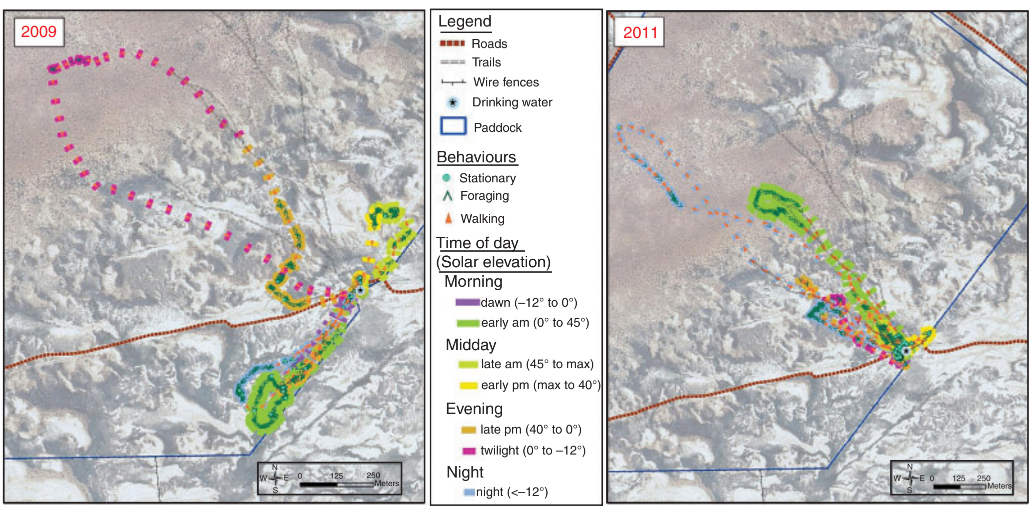

Fig. 11. Locations for one cow 24-h post-weaning in 2009 and another cow in 2011 on a 433-ha Jornada Experimental Range paddock (14A) involved in three major behaviours: stationary <0.060 (m s^{-1}) in 2009 and <0.050 (m s^{-1}) in 2011; foraging 0.060 (m s^{-1}) to 0.55 (m s^{-1}) in 2009 and 0.050 (m s^{-1}) to 0.50 (m s^{-1}) in 2011; and walking >0.55 (m s^{-1}) in 2009 and >0.50 (m s^{-1}) in 2011. Daily behaviours were characterised based on the sun's angle above the horizon: morning, 0604–1042 hours (solar elevation –12° to 45° rising); midday, 1043–1607 hours (solar elevation 45° rising to 40° setting), evening, 1608–2019 hours (solar elevation 40° to –12° setting); and night, 2020–0603 hours (solar elevation <–12° no sun).

assumes no autocorrelation among consecutive data points. GPS consecutive data fixes can be recorded in fractions of a second. Hence the use of classical techniques of statistics would require overlooking autocorrelation and this could lead to inaccurate biological interpretations (Johnson and Ganskopp 2008). Furthermore, assuming that recording more frequent GPS locations will necessarily provide a finer scale of movement resolution may also be a fallacy (Frair *et al.* 2010). More data does not necessarily yield greater knowledge (Hebblewhite and Haydon 2010). This is especially true in that errors in GPS positions are greater during static segments of a trajectory (Laube and Purves 2011). Furthermore, the trajectories of dominant cows may be shorter than subordinate cows and dominant cows may influence herd movement more than subordinate cows (Šárová *et al.* 2010). It is thus apparent that accurately describing movement by cows is not a simple task and will require not only more research but using the proper tools and techniques for accurate interpretation of the data.

Conclusions

Monitoring and accurately interpreting free-ranging behaviour of cattle within a spatial and temporal context remains challenging. Changes in husbandry practices, such as abrupt weaning, can bring about rapid changes in behaviour by cows that can be detected using GPS technology. GPS data collected independently of observational data revealed three peaks; each representing a different behaviour (foraging, walking and stationary) as determined during periods when GPS and observations were being made concurrently. This research suggests that a range in the path speeds by cows along a trajectory can be successfully used to characterise unique behaviours into foraging, walking and stationary when starting with GPS fixes recorded at 1-s intervals that were combined to produce 60-s mean fixes. Cows did not use the paddock uniformly either spatially or temporally before or following abrupt weaning with changes in the spatial and temporal pattern of use of the paddock reflected mostly in the activity of increased walking. During the first 24 h following weaning, at least a portion of the walking appeared to take place in 'loops' that began and ended from the location where the abrupt weaning took place. These patterns can only be obtained where intervals between GPS fixes are short. Our data suggest that foraging on desert rangeland in the spring takes place at a path speed or 'rate of forward movement' between 0.059 and 0.55 $m\,s^{-1}$. By integrating data such as the sun's angle with respect to the horizon with GPS fixes, it may be possible to accurately explain cause and effect relationships. This approach should provide a more complete understanding of how to manage cows in a proactive manner to optimise their wellbeing while sustainably utilising the foraging landscape.

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Mention of a trade name, proprietary product or vendor does not constitute a warranty of the product by the USDA or MIT or imply approval to the exclusion of other products or vendors that may also be suitable.

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