CSIRO PUBLISHING
www.publish.csiro.au/journals/trj *The Rangeland Journal*, 2009, **31**, 267–276

Determining the effect of stocking rate on the spatial distribution of cattle for the subtropical savannas

N. W. Tomkins[A,D], *P. J. O'Reagain*[B], *D. Swain*[A], *G. Bishop-Hurley*[C] *and E. Charmley*[A]

[A]CSIRO Livestock Industries, PO Box 5545 Rockhampton MC, Qld 4702, Australia.
[B]Queensland Department of Primary Industries and Fisheries, PO Box 976 Charters Towers, Qld 4820, Australia.
[C]CSIRO, ICT Centre, PO Box 883, Kenmore, Qld 4069, Australia.
[D]Corresponding author. Email: nigel.tomkins@csiro.au

Abstract. With the commercial development of the global positioning system (GPS), it is now possible to monitor the distribution of free ranging cattle and derive measures to describe landscape use. Animal GPS data can be integrated with a geographic information system (GIS) detailing topography, vegetation, soil type and other landscape features. Combining GPS and GIS information is useful for understanding how animals respond to spatial variability. This study quantified land-type preferences for Brahman cross steers over three time periods, from October 2004 to March 2006 in a replicated trial, under heavy (4 ha/AE; animal equivalent of ~450 kg steer) and light (8 ha/AE) stocking in four, ~105 ha paddocks of subtropical semi-arid savanna near Charters Towers, Queensland, Australia. The grazing trail was conducted at a scale much less than would be found in commercial situations. Consequently, the spatial pattern of cattle reported here may not represent what occurs at a commercial scale and implications are discussed. Results were analysed in terms of the spatial distribution of steers fitted with GPS devices in each of the four paddocks and for each stocking rate to provide insight into cattle distribution and land-type preferences. Steers walked in excess of 6 km per day, regardless of stocking rate, and exhibited diurnal patterns of movement, with peak activity around dawn (0500–0700 hours) and dusk (1800–2000 hours). The spatial distribution of the collared steers was not uniform and appeared to be strongly influenced by the prevailing drought conditions and location of water points within each paddock. A hierarchy of drivers for distribution was identified. With the exception of drinking water location, land subtype based on soil-vegetation associations influenced animal distribution. Preference indices ($\hat{w}_i$) indicated that steers selected sites associated with heavy clay and texture contrast soils dominated by *Eucalyptus coolabah* Blakely & Jacobs ($\hat{w}_i = 5.33$) and *Eucalyptus brownii* Maiden & Cambage ($\hat{w}_i = 3.27$), respectively, and avoiding *Eucalyptus melanophloia* F.Muell. ridges ($\hat{w}_i = 0.26$) and *Eucalyptus cambageana* Maiden ($\hat{w}_i = 0.12$) on sodosols. The results suggest that spatial variation in cattle distribution within a paddock may be more critical than overall stocking rate in influencing the pattern of biomass utilisation. However, to quantifying the effects of different grazing land management practices on animal distribution on a commercial scale, additional studies in extensive paddocks are required.

Additional keywords: foraging, GPS, landscape, selection indices, rangelands.

Introduction

Commercial paddocks in northern Australia are inherently large, often in excess of 120 km^2 (Hunt *et al.* 2007), and can contain a heterogeneous mix of native and improved grasses, forbs and legumes (Ash *et al.* 1997). Spatial heterogeneity in soil type, drinking water location and rainfall across paddocks result in pronounced differences in the quality and quantity of available forage. Optimal forage utilisation is critical for cattle productivity and pasture sustainability, yet our ecological knowledge base at the paddock/landscape scale is limited (Ash *et al.* 1997).

Spatial selection by foraging animals is well documented, and can result in overuse at the patch and landscape scale (Vallentine 1990). Selected areas may degrade through consistent over-use and become less attractive to livestock. The cycle of over-use is then repeated elsewhere, resulting in a loss of landscape integrity and, ultimately, paddock degradation (Mott 1987; Ash and Stafford Smith 1996).

Water is the single most important determinant of livestock distribution at a paddock scale and can influence landscape selection. Significant geographic features such as ridges, rivers and steep terrain also act as physical barriers affecting livestock distribution (Stuth 1991). Given equal access to drinking water, foraging animals generally spend the greatest proportion of their time in areas offering the greatest rate of digestible energy intake (Langvatn and Hanley 1993; Wilmshurst *et al.* 1995). However, landscape selection is also influenced by predation risk, weather and the physiological state of the animal (O'Reagain 2001). As a result of the interaction of these factors, livestock may spend a proportion of their time in apparently suboptimal areas. Intensity, timing and spatial location of plant defoliation will also be affected by the animal's need to travel through suboptimal or non preferred landscapes.

The current understanding of key factors driving spatial selection of areas by livestock is limited, and largely restricted to

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10.1071/RJ07070 1036-9872/09/030267

predictions from coarse, broad-scale patterns of utilisation (O'Reagain and Schwartz 1995). This can be partly attributed to the difficulty in monitoring landscape selection by free ranging animals. Direct observation of cattle has provided comprehensive data on foraging behaviour and distribution in large paddocks (Low *et al*. 1981*b*; Pickup 1994), but the procedure is time consuming and biased (Low *et al*. 1981*a*). Similarly, indirect, paddock-based methodologies using grazing enclosures (Milner and Elfyn Hughes 1970) or surveys of pasture utilisation (Roth *et al*. 2003) are extremely tedious and relatively imprecise.

With the commercial development of GPS, a relatively efficient method for continuously monitoring the distribution of livestock has become available (Rodgers 2001). Positional data using GPS can be integrated with topography, vegetation, soil type and other features of the landscape to infer interactions between cattle and their environment (Tomkins and O'Reagain 2007). Quantification of these relationships is crucial to the development of sustainable management systems for heterogeneous landscapes (Turner *et al*. 2000; O'Reagain 2001). Sustainable land management strategies are increasingly dependent on the combination of GIS data with spatially explicit models to provide the basis for animal–habitat management (Wade *et al*. 1998; Parsons *et al*. 2001; Rushton *et al*. 2004).

The problem of selective foraging has long been recognised as a rangeland management issue in northern Australia, particularly in the rangelands of the Burdekin River catchment. Landscape selection by cattle has been addressed previously in the Burdekin rangelands, but was limited to direct observation and paddock surveys (Roth *et al*. 2003). Our study was conducted to; determine the patterns of landscape selection by steers in heterogeneous paddocks using GPS devices, identify the major edaphic and environmental factors associated with landscape selection and determine how stocking rate influences paddock utilisation.

Materials and methods

Study location

The study was conducted from October 2004 to March 2006 on a long-term, replicated grazing trial located on Wambiana Station (20°34′S; 146°07′E) near Charters Towers, Queensland (O'Reagain and Bushell 1999). Mean annual rainfall is 650 mm, with most falling during the summer (wet season) months (Clewett *et al*. 2003; O'Reagain and Bushell 2003). The landscape is an open *Eucalyptus–Acacia* savanna dominated by an *Aristida–Bothriochloa* pasture (Tothill and Gillies 1992). The soils are derived from tertiary sediments, and range from low fertility red/yellow kandosols to texture contrast sodosols and relatively fertile vertosols (Isbell 1996).

Site description

The Wambiana trial consists of 10 rectangular shaped paddocks (five treatments × two replicates) varying in size from 93 to 117 ha. Paddocks were fenced to contain a similar proportion of the main soil vegetation associations. Two permanent drinking water points located on fence lines were present in each paddock. Only the heavy and light stocking rate treatments were evaluated in the present study. All stocking rate treatments are described in detail by O'Reagain and Bushell (2003).

The main soil/vegetation associations (O'Reagain and Bushell 2003) consisted of a *Eucalyptus brownii* (box) community on brown sodosols and chromosols (55%); a *Eucalyptus melanophloia* (silver-leafed ironbark) community on red/yellow kandosols (23%) and an *Acacia harpophylla* F.Muell. ex Benth. (brigalow) community on grey vertosols (22%). These main soil–vegetation associations were subjectively subdivided into 11 land subtypes based on variation in soil, pasture and woodland vegetation associations (P. J. O'Reagain, pers. comm.; Table 1).

Animals and management

Brahman cross steers [initial mean ± s.e.m. live weight (LW) of 330 ± 4.6 kg] were randomly assigned to each replicated treatment group. Stocking rates were 4 and 8 ha/AE (AE: animal equivalent of ~450 kg steer) for the heavy (HSR) and light stocking rates (LSR), respectively. Paddocks were stocked with similar sized cohorts of 2- and 3-year-old steers for each of the subsequent years. In May 2005 stocking rates in the HSR were reduced to ~6.2 ha/AE because of the prolonged drought conditions and shortage of forage.

Each steer was implanted with a commercially available growth promotant (Compudose 400; Elanco Animal Health, NSW, Australia) and supplemented with a urea based dry mineral supplement in the dry season (April–September) and a phosphorus lick in the wet season (October–March) (Phos Wet Season Custom stock supplement, Stocklick Trading, Qld, Australia). In the HSR, a molasses-8% urea (M8U) supplement was fed in the dry season because of the extreme forage shortage resulting from low rainfall and heavy grazing pressure.

GPS protocols and GIS management

Approval to use GPS devices on animals was obtained from the Queensland Department of Primary Industries and Fisheries Animal Ethics Committee (#TSV/05/99).

Three steers, randomly selected from each HSR and LSR paddock, were fitted with archival GPS units (L400, BlueSky Telemetry Ltd, Aberfeldy, Scotland) mounted on neck collars. The units were fitted and retrieved during routine musters and remained on the animals for periods of up to 6 weeks on four different occasions in October/November (2004 and 2005) and February/March (2005 and 2006). These periods represented the dry and wet seasons, respectively. The GPS receiver unit was a μ-Blox 16 channel receiver with 2 Mb of flash memory. Receivers were programmed to obtain a 3-dimensional position from a minimum of four satellites every 60 min for the first two deployments and every 30 min for the third and fourth deployment. Each record included unit number, date, time, longitude and latitude, a horizontal dilution of precision value (HDOP; an index of satellite geometry indicating positional accuracy), a 3-dimensional fix status (success in locating individual units dependent on number of satellites available) and number of satellites accessed for each recorded location (Tomkins and O'Reagain 2007). Positional data were downloaded using a wireless interface.

Environmental variables

Soil types and detailed soil/vegetation associations within each paddock were determined from a ground based survey of the

Table 1. Land subtypes, soils, landscape features, estimated pasture production, subjective grazing preference and predominant pasture species of the Wambiana study site

Land subtype	Soil group	Soil type	Landscape	Estimated pasture production (kg/ha)^A	Subjective grazing preference^B	Predominant pasture species
Coolabah	Heavy clay	Grey sodosol/ dermosol	Open *Eucalyptus coolabah* on heavy clays, seasonal water logging common	High >2000	Moderate, avoided when rank	*Dicanthium sericeum*, *Eulalia aurea* and *Bothriochloa ewartiana*. Abundant sedges in wet years
Black clay	Heavy clay	Grey vertosol	*Acacia harpophylla* and/or *Eucalyptus brownii* on heavy clay soils	High >2000	Moderate, avoided when rank	*Dicanthium sericeum*, *Eucalyptus aurea*, *Bothriochloa ewartiana* and annuals (e.g. *Iseilema vaginiflorum*)
Ironbark	Kandosol	Yellow/brown kandosol	*Eucalyptus melanophloia*	Low <1500	Low-variable	*Aristida* spp., *Chrysopogon fallax*, *Heteropogon contortus*, annual grasses (e.g. *Schizachyrium fragile*) and forbs
Box annuals	Texture contrast	Grey/black sodosol	*Eucalyptus brownii* with *Fimbristylis* spp. and *Chloris* spp. lawns	Very low <1000	Low-moderate	*Fimbristylis* spp., *Chloris* spp., *Chrysopogon fallax*
Box brigalow	Texture contrast/clay	Grey vertosol/ sodosol	*Acacia harpophylla* and/or *Eucalyptus brownii* on heavier duplex/clay soils	High >2000	Moderate	*Bothriochloa ewartiana* and *Chrysopogon fallax. Paspalidium caespitosum*
Box *Eremophila*	Duplex	Brown sodosol-yellow kandosol	*Eucalyptus brownii* with understorey of *Eremophila mitchelli* and *Carrisa ovata*	Medium >1500	Moderate	*Bothriochloa ewartiana* and *Chrysopogon fallax*
Wet box	Heavy clay	Grey earth	*Eucalyptus brownii*, subject to water logging	Medium >1500	Low-moderate	Sedges, *Eriachne obtusa*, *Dicanthium fecundum*, some *Bothriochloa ewartiana*
Box	Duplex	Brown/grey sodosol	*Eucalyptus brownii* with understorey of *Carrisa ovata*	Medium >1500	Moderate	*Bothriochloa ewartiana* and *Chrysopogon fallax*
Blackbutt	Duplex	Grey sodosol	*Eucalyptus cambageana* on shallow sodosols	Low–medium >1500	High	*Enteropogon acicularis*, *Chloris* spp., *Fimbristylis*, *Chrysopogon fallax*
Ironbark ridge	Kandosol	Yellow brown kandosol	*Eucalyptus melanophloia* on *Eriachne mucronata* ridges	Low <1500	Very low	*Eriachne mucronata* and annual grasses (e.g. *Schizachyrium fragile*), annual forbs
Box blackbutt	Duplex	Grey/black sodosol	*Eucalyptus brownii* and *Eucalyptus cambageana* on sodosols	Medium >1500	Moderate	*Bothriochloa ewartiana*, *Chrysopogon fallax* and *Enteropogon acicularis*

Nomenclature follows Isbell (1996), ^AO'Reagain *et al*. (2008), ^BObservational data (P. J. O'Reagain, unpublished).

study site in 1997. Soil N, P and K concentrations were determined from representative top-soil samples collected from two, 1 ha monitoring sites located within each major soil type in 2000 (P. J. O'Reagain, unpubl. data). Pasture total standing dry matter (TSDM) and composition were determined annually in May and October (wet and dry seasons, respectively) along two transects in each paddock using the BOTANAL procedure (Tothill *et al*. 1992). Landsat satellite imagery was used to calculate a normalised difference vegetation index (NDVI; Townshend 1994) for each paddock. The Statewide Landcover and Trees Study (SLATS) project was used to provide data on woody vegetation cover (Kuhnell *et al*. 1998). Tree foliage cover (%), based on visual assessment of crown type (McDonald *et al*. 1998) was estimated at 34 randomly selected sites along a single transect in each of the four experimental paddocks.

Rainfall was measured from a network of rain gauges across the study site.

Data processing

Spatial analyst tools in ArcMap™ 9.1 (ESRI, Redlands, California, USA) were used to overlay spatial data from each GPS device and independent GIS layers. A grid based on 25 × 25 m rasters was established across each paddock with respect to a known reference point. Bio-physical determinants obtained from soil and paddock surveys together with independent GIS layers were assigned to each cell and grouped according to; (i) paddock characteristics (herbaceous yield, ground cover, NDVI), (ii) soil and vegetation type (soil type, soil/vegetation class, soil N, P, K concentrations) and (iii) woody vegetation cover (SLATS).

A binary approach; present (1) or absent (0) was used to indicate the existence of a fence line or water point for each cell. Occupancy rate was calculated by counting the number of times an animal frequented each cell. Data were exported to an ASCII file that represented the heterogeneity and steer positional data for each raster. Minimum convex polygons (MCP; the smallest polygon that contained 95% of GPS positional data) were calculated for each steer. Temporal relationships were derived from 24 h datasets. Euclidean distances travelled by collared steers were based on consecutive positional data and summed to determine total distance travelled over 24 h.

Preference and standardised indices (Hobbs and Bowden 1982; Manly *et al*. 2002) were calculated for each of the 11 land subtypes and for each of three main soil-vegetation associations (brigalow, box and ironbark). Location preference ratios were calculated based on the number of counts for collared steers in a given land subtype divided by the proportional area of that land subtype. Values >1 suggested preferential selection for an area while values <1 indicated that animals used that particular land subtype proportionally less than its availability would suggest (Bowyer and Bleich 1984).

Statistical analysis

A 2 × 2 factorial experimental design was used with treatment (light and heavy stocking) and paddock as the factors with four repeated-measures over time. Limited paddock replication in this study necessitated using the individual steers and the association with resources measured for each as the primary sampling unit (Manly *et al*. 2002). Availability of a resource was measured at the population, or herd, level. Distances travelled by steers were log-transformed to satisfy normality assumptions.

To overcome the unbalanced nature of the locational data, the data relating to temporal locations of individual steers were analysed using residual maximum likelihood (REML; GENSTAT 8.2, VSN International, Hertz, UK). Stocking rate effects were tested using a Wald test. Pair-wise comparisons of the means were made using a least significant difference (l.s.d.) test.

A conditional model, based on resource selection functions (RSF; Boyce *et al*. 2002) was used to describe the animal-landscape associations. This approach combined a model to accommodate the binary (presence/absence) nature of the data; and then a second distribution, Poisson with a Log-link function, conditional on their presence. It was assumed that all continuous variables (SLATS, NDVI, pasture yield and ground cover) had linear relationships with each other. These generalised linear models were used to evaluate the probability of animal-landscape associations and were parameterised by a reference level based on land subtype selected in the model (GENSTAT, VSN International).

Results

Rainfall and pasture yield

Rainfall during 2004–05 (470 mm) and 2005–06 (469 mm) was below the long-term mean (650 mm) with both years being close to the lowest 20% of rainfall years recorded (Clewett *et al*. 2003). Approximately 80% of the total annual rainfall received was recorded between January and March (wet season) with the majority falling in a small number of relatively large events (Fig. 1).

Pasture TSDM declined sharply over the duration of the study between April 2004 and April 2006 (Fig. 2). Mean pasture TSDM over the study period was markedly higher in the LSR (965 ± 161.6 kg/ha) than in the HSR (236 ± 68.9 kg/ha). Ground cover also varied markedly between treatments (Table 2). There was some variability among land subtypes in TSDM and ground cover in the LSR, but in the HSR all land subtypes exhibited extremely low TSDM and ground cover. Grazing conditions were particularly severe in the late dry season of 2004–05 when TSDM declined to <100 kg/ha in the HSR forcing steers to subsist on poor quality stubble, browse and leaf litter. Consequently, M8U supplementation was provided late in the dry season, in 2004–05 and 2005–06, to steers in the HSR treatment due to rapidly declining body condition which was assessed on a herd basis.

Animal distribution and land subtype selection

Season (wet or dry) and stocking rate (heavy or light) had no effect on cattle distribution patterns among land subtypes and these factors were accordingly removed from further analysis. Animal positional information from the fourth deployment (February–March 2006) was incomplete to such an extent that it could not be used to determine spatial patterns of activity and was not included in the results.

The mean (±s.e.m.) initial LW of steers for the first three deployments were 304 ± 4.8 kg, 307 ± 4.1 kg and 410 ± 5.8 kg, respectively. Mean horizontal dilution of precision of the GPS units for the first three deployments was 8.1 ± 0.01. Tree foliage cover, based on visual assessment of crown type, was sparse to moderate (10–30%) in all paddocks and was considered not to have had a negative effect on acquisition of GPS positional data (Rempel *et al*. 1995).

Hourly or half-hourly GPS locational data allowed a coarse temporal pattern of distribution to be mapped that indicated collared steers were not uniformly distributed across the study site. The mean (±s.e.m.) MCP among all collared steers accounted for 85 ± 2.0% of the available paddock area regardless of stocking rate.

Land type (specific vegetation and soil type association) was identified as contributing to the presence or absence of steers and the frequency of return visits to individual rasters within each experimental paddock. Five of the 11 biophysical determinants (land subtype, SLATS, NDVI, pasture yield and soil type) made a significant ($P < 0.05$) contribution to the binary model used to describe steer positional data for each cell (Table 3). Land subtype, SLATS and NDVI significantly ($P < 0.001$) contributed to the Poisson distribution model when the relationship between

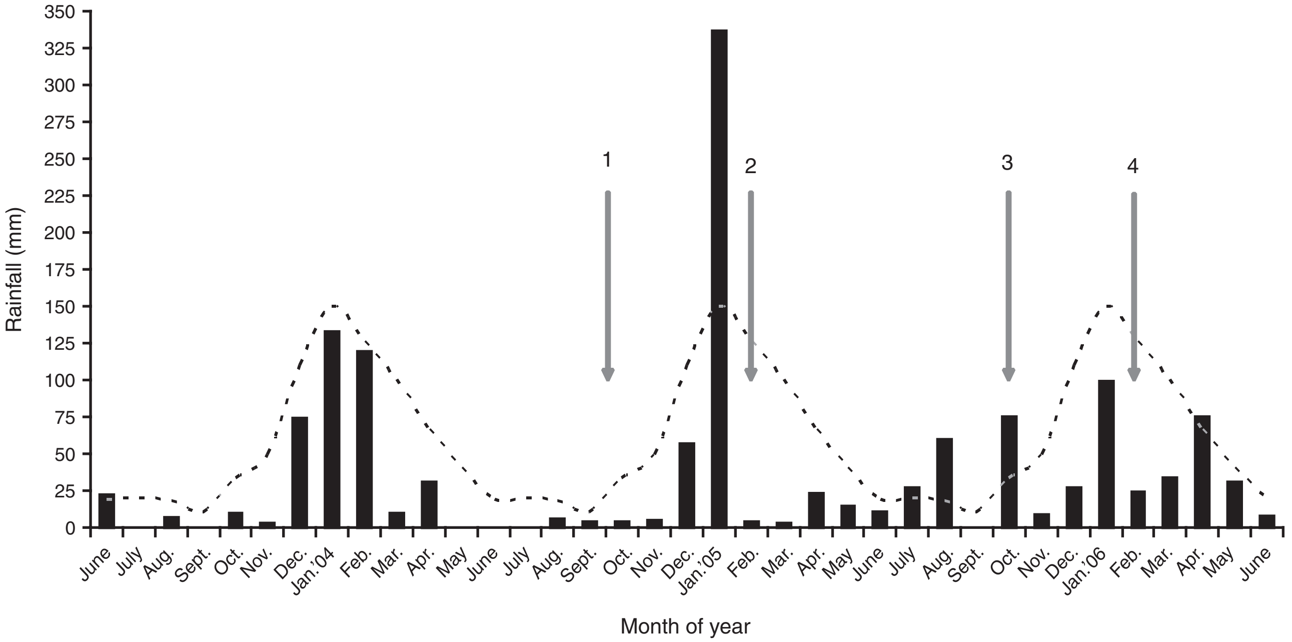

Fig. 1. Total monthly rainfall (■) at the Wambiana study site (June 2003 to June 2006) and 30 year mean rainfall (- - -) for Charters Towers (1971 to 1992). Arrows indicate the four deployments of GPS collars on steers.

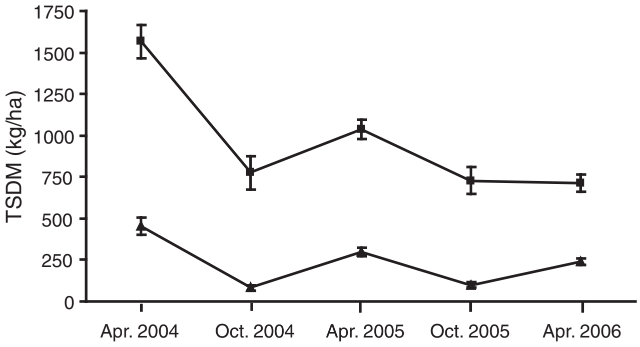

Fig. 2. Mean (±s.e.m.) total standing dry matter (TSDM) between April 2004 and April 2006 in the light, (■) and heavy (▲) stocking rate paddocks at Wambiana.

Table 2. Mean (±s.e.m.) total standing dry matter (TSDM, kg/ha) and estimated projected ground cover (%)^{A} based on land subtype for light (8 ha/AE) and heavy (4 ha/AE) stocked paddocks from October 2004 to October 2005, Wambiana

Land subtype	Stocking rate			
	Light		Heavy	
	TSDM (kg/ha)	Ground cover (%)	TSDM (kg/ha)	Ground cover (%)
Coolabah	–	–	677 ± 177.8	29 ± 11.6
Black clay	920 ± 156.1	39 ± 2.5	140 ± 50.0	27 ± 4.3
Ironbark	686 ± 150.4	37 ± 4.4	172 ± 64.0	27 ± 4.1
Box annuals	–	–	120 ± 52.0	26 ± 4.4
Box brigalow	571 ± 130.3	35 ± 7.1	180 ± 68.8	38 ± 11.1
Box *Eremophila*	995 ± 132.8	41 ± 7.6	140 ± 48.7	31 ± 7.8
Wet box	765 ± 232.1	36 ± 5.8	89 ± 76.2	28 ± 4.3
Box	1010 ± 156.1	29 ± 7.0	158 ± 44.5	29 ± 2.2
Ironbark ridge	–	–	178 ± 97.2	22 ± 5.1
Box blackbutt	437 ± 216.7	17 ± 3.4	99 ± 34.8	25 ± 5.0

^{A}See text for details. Missing values indicate land subtype is not present.

frequency of animal location and the five defined attributes of that raster were investigated. Only land subtype and soil type were useful predictors of animal location. Both drinking water points and fence lines significantly ($P < 0.001$) contributed to the binary and Poisson models when the relationship between frequency of animal location and infrastructure attributes of each raster were investigated.

Preference indices ($\hat{w}_i$), calculated for each land subtype indicated that the steers selected for distinct land subtypes (Table 4). For box and ironbark ridge, which comprised 68% of the paddock area, preference indices were <1 indicating that steers tended to avoid these areas. For box annual, wet box and coolabah subtypes, which comprised less than 10% of the available area, preference indices were 3.00, 3.27 and 5.33, respectively, indicating selection for these areas. Black clay, ironbark and box–*Eremophila* land subtypes had preference indices ~1.0. Overall, the preference indices suggested that steers selected land subtypes associated with heavy clay soils while ironbark ridge and box blackbutt land subtypes were less preferred.

In all paddocks there was a significant ($P < 0.001$) probability that steers would be associated with rasters that contained a drinking water point (Table 3).

Daily activity patterns

Mean distance travelled per day was not significantly ($P > 0.05$) different between high and low stocking rates

Table 3. The significance of biophysical determinants in Binary and Poisson models used to describe animal distribution in experimental paddocks, Wambiana

Biophysical determinant	Binary model	Poisson model
Land type[A]	$P < 0.001$	$P < 0.001$
SLATS	$P < 0.001$	Significant, but range too narrow for analysis
NDVI	$P < 0.001$	Significant, but range too narrow for analysis
Soil type[B]	$P < 0.001$	$P > 0.05$
Pasture yield[C]	$P < 0.001$	$P > 0.05$
Ground cover[D]	0.523	$P > 0.05$
Soil N[E]	$P > 0.05$	$P > 0.05$
Soil P[E]	$P > 0.05$	$P > 0.05$
Soil K[E]	$P > 0.05$	$P > 0.05$
Drinking water[F]	$P < 0.001$	$P < 0.001$
Fence line[G]	$P < 0.001$	$P < 0.001$

[A,B] As described in Table 1, SLATS (statewide landcover and trees study) used to provide a measure of woody vegetation cover, NDVI (normalised difference vegetation index).

[C] TSDM (kg/ha).

[D] Ground cover (%).

[E] Soil concentration (mg/kg).

[F] Association between animal positional data and water point within the same cell.

[G] Association between animal positional data and existence of a fence within the same cell.

(6967 *v.* 6262 m, ± s.e.m. = 681.8 m, respectively). A marked diurnal movement pattern was apparent for all collared steers (Fig. 3). Two peak travel periods were identified: 0500–1000 hours and 1400–2200 hours based on a low (<250 m/h) or high (>250 m/h) travel rate. Preference indices were best described if land subtypes were aggregated into their respective broader soil groups (Fig. 4). Steers rested overnight in areas associated with clay or texture contrast soils, but then migrated predominantly to areas of heavy clay soil and out of areas associated with red/yellow kandosol soils around dawn. Cattle were found to remain in areas associated with clay soils throughout the mid-day period, a time characterised by minimal activity. By mid afternoon (1400 hours) steers again became active and were found distributed between clay and red/yellow kandosol soil types. Steers generally displayed a greater preference for texture contrast soils, compared with red/yellow kandosols during daylight hours.

Discussion

Rainfall and pasture yield

Pasture TSDM was relatively low across all paddocks due to the drought conditions during 2004–06. Positional data indicated that in general steers accessed 85% of the paddock area. This extensive distribution may have been predominantly due to the low pasture biomass (<800 kg DM/ha) across the study site as steers were forced to forage widely to maintain intakes. In addition, the small size of experimental paddocks (93–117 ha) facilitated relatively easy access across most of the paddocks and distribution was not necessarily influenced by land subtype selection alone or the provision of dry mineral or M8U supplements.

Determinants of cattle distribution

Preference indices for the 11 land subtypes, characterised by soil and dominant vegetation, indicated that steers selected sites on

Table 4. The proportions of each land subtype, proportion used by collared steers, preference and standardised indices and the probability of selection for drinking water points, fence lines and land subtypes based on soil/vegetation classes, Wambiana

	Proportion Land subtype[A]	Proportion Used[B]	Preference index[C] ($\hat{w}_i$)	Standardised index[D] (B_i)	Log linear regression model estimate
Drinking water point/s					0.98
Fence line					0.55
		Land subtype			
Coolabah[E,F]	0.006	0.032	5.33	0.32	1.00
Black clay	0.168	0.179	1.07	0.06	0.41
Ironbark	0.216	0.200	0.92	0.05	0.36
Box annuals[G]	0.010	0.029	3.00	0.18	0.61
Box brigalow	0.027	0.019	0.70	0.04	0.47
Box *Eremophila*	0.083	0.077	0.93	0.06	0.40
Wet box	0.011	0.036	3.27	0.19	0.54
Box	0.468	0.420	0.89	0.05	0.44
Ironbark ridge[F]	0.019	0.005	0.26	0.02	0.30
Box blackbutt	0.026	0.003	0.12	0.01	0.27

[A] Size of land subtype/total size of study area.

[B] Count of animal positional data per land subtype/total count for all land subtypes.

[C] Proportion of used/proportion land subtype (Hobbs and Bowden 1982).

[D] $B_i = \hat{w}_i/(\sum_{i=1}^{I}\hat{w}_j)$ (Manly *et al.* 2002).

[E] Reference land subtype for log linear regression model.

[F] Heavy stocked animals only.

[G] Light stocked animals only.

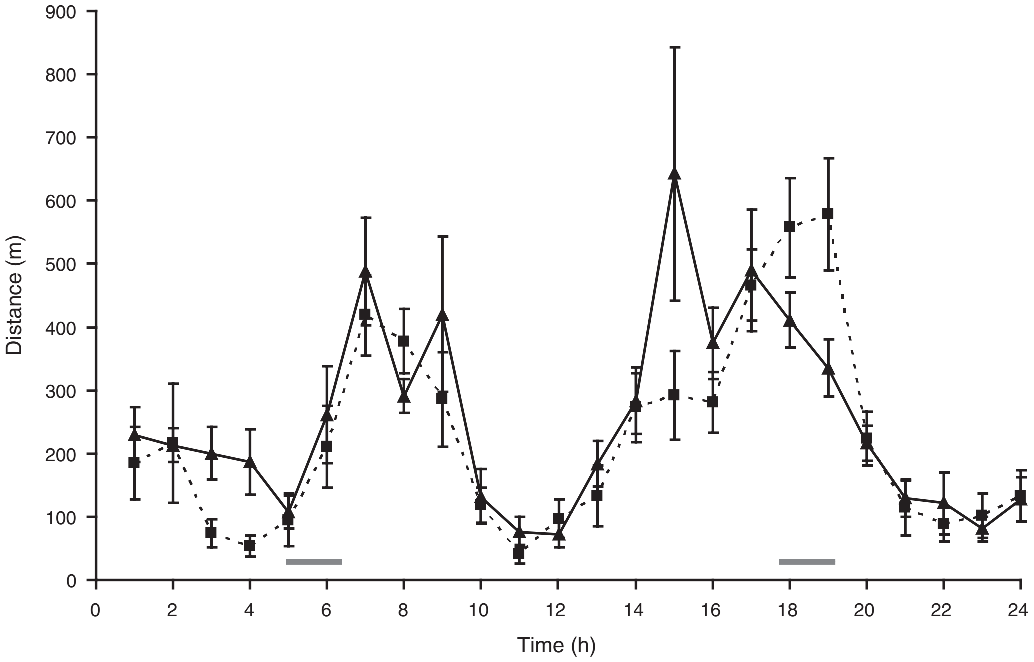

Fig. 3. Mean (±s.e.m.) distance travelled per hour over 24 h, for steers fitted with GPS units, for light, (–■–) and heavy (–▲–) stocking rate treatment paddocks over four deployments in successive wet (February 2005 and 2006) and dry (October 2004 and 2005) seasons, Wambiana. The grey horizontal bars along the *x*-axis indicate dawn and dusk, respectively.

heavy clay and texture contrast soils, but avoided ironbark ridges and box blackbutt on sodosols. The sodosol soils have a lower soil moisture storage capacity compared with the deeper kandosols and vertosols and consequently dry out relatively rapidly leading to low forage yields and rapid leaf senescence (P. J. O'Reagain, pers. obs.). The apparent selection against box blackbutt was unexpected as these areas are relatively fertile, generally produce high quality forage and are generally strongly selected by grazing cattle (O'Reagain *et al*. 2008). At the time the GPS devices were deployed, the box blackbutt areas had possibly been previously preferentially grazed. In addition, preferential grazing in paddocks <500 ha, has been shown to occur independent of stocking rate and be a function of the number of animals and their selection for specific patches (Mott 1987). The wet box and coolabah subtypes are associated with heavy clay soils, and are often dominated by relatively palatable, perennial grasses such as *B. ewartiana* and *Dichanthium sericeum.* Both *Bothriochloa* spp. and *Dicanthium* spp. are selectively grazed by stock with the latter generally being one of the most palatable and productive of the native grasses (Tothill and Hacker 1983).

The preferred land subtype, box annuals, occurred on shallow texture contrast soils with *Fimbristylis* spp., *Chloris* spp. and some *Chryspogon fallax. Chrysopogon*, an increaser species, has value as fodder, but is generally less preferred by cattle compared with other perennials like *B. ewartiana*. Grasses and sedges on these box annual areas generally respond rapidly to rainfall and are strongly selected early in the season for their green leaf despite their relatively low total dry matter production. In three out of four locations, these shallow texture contrast soils were associated with drinking water points. Consequently, it was not possible to ascertain if preference for these areas was due to land subtype or the availability of drinking water. However, the presence of steers at drinking water in other soil types suggested that the main driver influencing the movement of cattle between locations was water, not land subtype.

The interpretation of the current data to identify biophysical determinants driving patch and land subtype selection must be exercised with some caution given the nature of the data and the conditions under which it was collected. Because GPS points could not be associated with actual grazing behaviour (as opposed to simply 'presence') and visual observations were not conducted, apparent selection for an area did not necessarily equal grazing preference.

Forage availability throughout the study was extremely low and to maintain intake the steers would have been forced to graze unselectively compared with an environment where selective grazing would be inevitable (Bailey *et al*. 1996; Pringle and Landsberg 2004). Positional data alone is insufficient to make behavioural interpretations, especially regarding foraging, as the steers could equally be travelling through an area or select an area for reasons other than grazing, such as resting, seeking shade or breeze or accessing water/supplement. In general, cattle preferentially graze areas close to water (Lange 1969; Graetz and Ludwig 1978), but have been reported to travel between 2 and 10 km/day from a water source (Hodder and Low 1978; Ganskopp 2001).

Daily activity patterns

Individual steer locations were evaluated over four periods (2200–0500, 0501–1000, 1001–1400 and 1401–2200 hours). Marked diurnal changes in preferred location over the study site

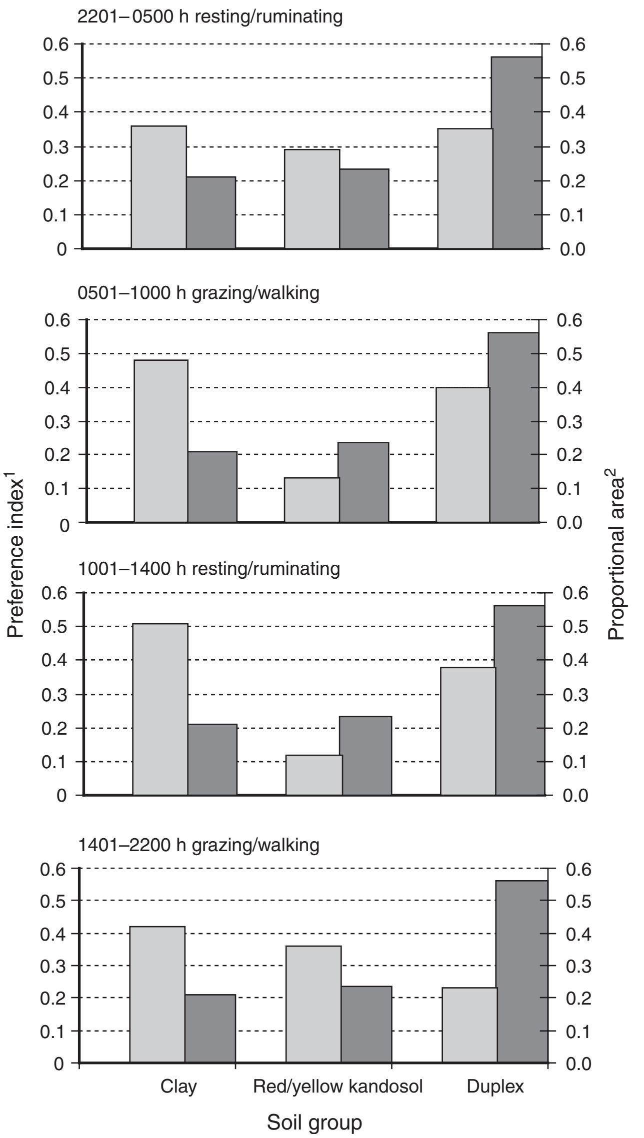

Fig. 4. The diurnal preference index (☐) for cattle fitted with GPS devices, for grazing/walking and resting/ruminating, based on the proportion of the total area (■) associated with each soil group over four deployments in successive wet (February) and dry (October) periods, Wambiana. [1]Derived from Manly's standardised selection ratio (Manly *et al.* 2002). [2]Proportional area = area associated with each soil group/total area.

were apparent. The diurnal pattern of activity indicated that steers were most active 4 h after sunrise and for a similar period around sunset compared with other periods. These were probably the main times when foraging was taking place. Similar foraging periods have been identified over 24 h for cattle in other rangeland environments (Arnold and Dudzinski 1978; Tomkins and O'Reagain 2007).

Collared steers appeared to have spent much time walking and generally travelled between 6000 and 7000 m over a 24-h period. Animals in HSR paddocks generally travelled further, on an hourly basis, compared with LSR animals, although this was not significantly ($P > 0.05$) different. Pasture biomass in the HSR was extremely low (183 ± 27.9 kg DM/ha) resulting in an almost complete absence of forage in some areas. Under these conditions, land subtype selection could have been influenced by foraging for browse or leaf litter rather than pasture characteristics.

Steers generally avoided ironbark areas dominated by unpalatable *Aristida* spp. on yellow/brown kandosols which are among the least fertile on the site. Ironbark 'ridges' on red kandosols were particularly selected against: these areas are largely dominated by the tough, unpalatable grass *Eriachne mucronata* which is seldom grazed except under severe drought conditions.

Steers predominantly used areas associated with clay soils during night time periods of inactivity (2200–0500 hours) and around midday (1000–1200 hours). This may have been a consequence of their preference for the associated land subtype during the morning period (0501–1000 hours) or related to particular camp sites that were used during the hottest part of the day. Only one permanent drinking water point was associated with clay soil.

Limitations to grazing studies using GPS units

Our results indicate that land subtype selection by steers can be quantified using GPS units at a paddock scale. However, it was difficult to elucidate the underlying relationships driving this selection, principally because of the prolonged drought conditions during the study that resulted in less than average rainfall during the wet season months and general loss of paddock heterogeneity in terms of pasture TSDM. Further work is required to collect sufficient spatial data to accommodate these seasonal variations.

The major advantage in tracking livestock with GPS is the ability to record consecutive locations per animal autonomously (D'Eon and Delparte 2005), but the calculation of straight line paths between successive GPS positions can under estimate actual walking distances (Schlecht *et al.* 2004; Schwager *et al.* 2007). This is likely in the current study given that locational data was collected at 30 and 60 min intervals. More recently, results from similar experiments have confirmed that increasing the frequency of obtaining positional data to every 10 or 15 min provides a more accurate measure of distance travelled by cattle in paddocks up to 500 ha (N. Tomkins, unpubl. data).

Conclusions

This study confirmed that land subtype selection by cattle can be quantified using GPS units at a trial paddock scale. However, the trial paddocks were small (~105 ha) and atypical in terms of the close spacing of drinking water compared with the large commercial paddocks commonly found in Australian rangelands (Pringle and Landsberg 2004). Rainfall during the study was below the long-term mean, and quantity and quality of available forage was generally low. Nevertheless, preference indices based on GPS positional data, clearly indicated land subtypes that were avoided or selected by steers. This study was conducted with small herds and the spatial pattern of foraging steers reported here may not represent what occurs at a commercial scale. Studies in extensive paddocks using GPS units, in addition to the work reported by Hunt *et al.* (2007), will be important in evaluating the effects of different grazing land management practices (location of water points, paddock size, stocking rate practices) on animal distribution and relate patch selection within land-types to the temporal processes of land degradation. Such work has the potential to develop strategies that will result in more even paddock utilisation, or at least ameliorate patch selection as a result of burning or spelling, thereby ensuring sustainable use of the rangelands.

Acknowledgements

This work was funded in part by Meat and Livestock Australia (MLA). We are grateful to the Lyons family, Wambiana for allowing the work to be conducted on their property. The authors would like to thank John Bushell, Chris Holloway and the late Peter Allen who provided valuable assistance with collar deployments. Sam Williams programmed collars and processed data. We are indebted to Christina Playford for statistical advice and data analysis. Dave Masters, David Wilcox and two anonymous reviewers provided constructive comments on the manuscript.

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Manuscript received 12 December 2007; accepted 10 November 2008