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Use of radio frequency identification (RFID) technology to record grazing beef cattle water point use

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ABSTRACT

Current recommendations for the provision of water points for grazing beef cattle in northern Australia are based on effective grazing distribution rather than cattle water point use. Scientific examination of cattle watering behaviour under varying conditions of climate, pasture and water availability (i.e. distances between water points) is required to inform water infrastructure development recommendations and maximise cattle productivity. This study assessed the potential of Radio Frequency IDentification (RFID) reader data from remote weighing technology to examine cattle visit times and time intervals between cattle visits to water points. Data from three cattle stations in northern Australia was used. Daily weather data (temperature, humidity, wind speed, cloud cover, solar exposure and rainfall) were obtained from official weather stations located at or near each experiment site. Linear mixed-effects models were used to detect variation in cattle behaviour within and between stations. The RFID reader data showed that most cattle visits to water points occurred during daylight hours (between 06:00 and 19:00 h) and within 48 h of a previous visit. The time of day that cattle visited water points did not differ between stations ($P > 0.05$) but varied according to month ($P = 0.001$), period of day ($P < 0.001$), time since last visit ($P = 0.013$) and cloud cover ($P = 0.043$). Time intervals between cattle visits to water points differed considerably between stations ($P < 0.002$) and appeared to reflect seasonal conditions and water availability at each station. Time intervals between visits to water points also varied according to month ($P < 0.001$), period of day ($P < 0.001$), temperature-humidity index ($P = 0.035$) and cloud cover ($P = 0.029$). The results of the study show that RFID reader data is able to detect behavioural differences according to climate and water availability and is a suitable tool to study cattle water point use. Cattle water point use data could be used to aid mustering and trapping cattle, identify animals that fail to visit a water point, better understand pasture conditions, predict the amount and consistency of weight data collected from remote weighing technology, improve decision making by graziers and inform recommendations for the optimal number and distribution of water points.

1. Introduction

In northern Australia artificial water points (e.g. dams or bores) often provide the only source of drinking water to grazing beef cattle (Freer et al., 2007). Cattle have a high rate of water turnover and regular access to drinking water is essential (Yeates and Schmidt, 1974; Lardner et al., 2013). A minimum of one water point per 30 km^2, with a maximum spacing of 6 km between water points, is currently recommended (James et al., 1999; Thrash and Derry, 1999; Meat and Livestock Australia, 2013; Hunt et al., 2014). The current recommendation considers cattle grazing distance from water points, grazing impact around water points and evenness of grazing. It does not consider water point use by cattle (e.g. regularity of visits) or water availability (e.g. distances between water points) effects on cattle production, reproduction and survival.

Most graziers have some practical knowledge of how cattle use water points in their own operations (Morrish, 1984). However, knowing how many water points to install and how far apart they should be to meet cattle water needs is difficult to determine. Few studies have attempted to understand grazing beef cattle watering

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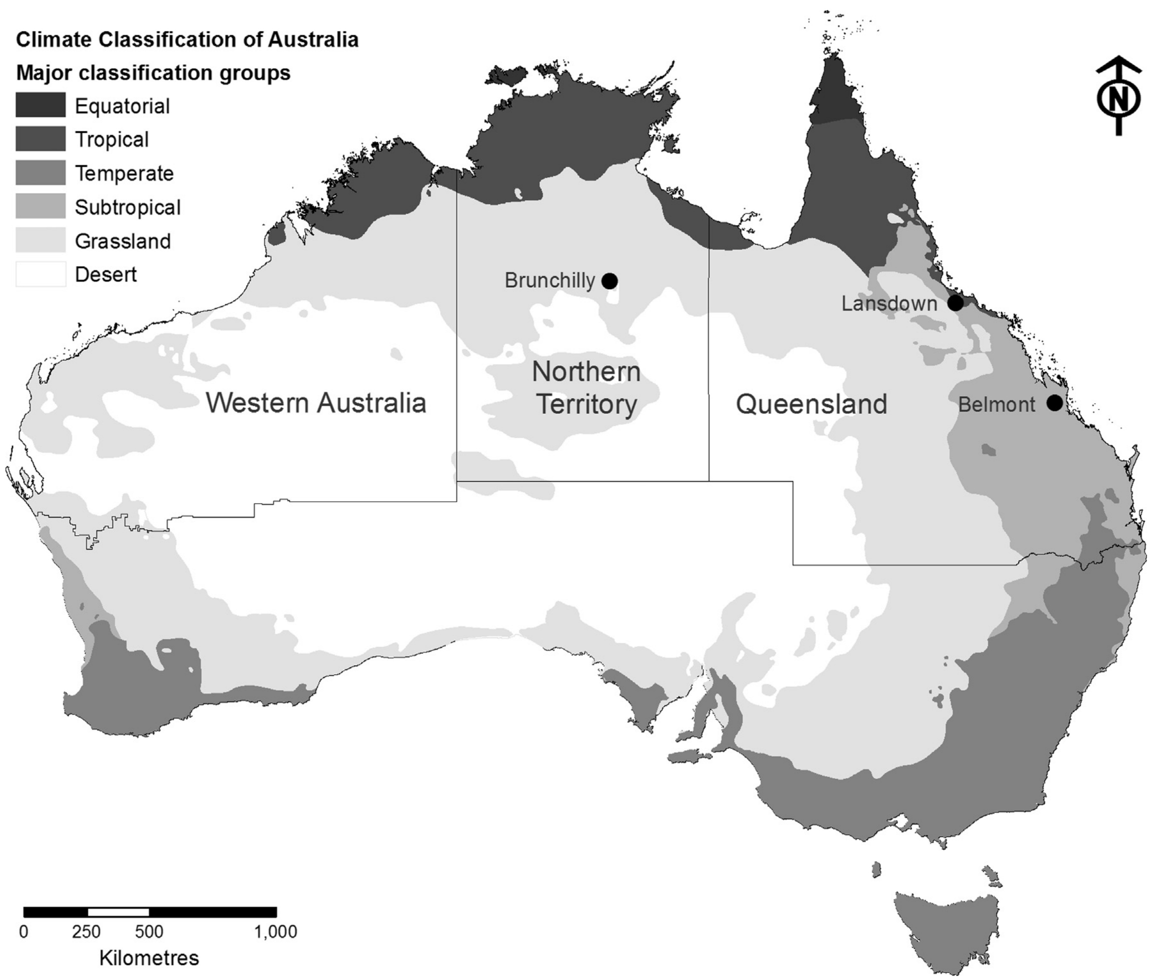

Fig. 1. Map of Australia showing the location of three stations where Radio Frequency IDentification (RFID) reader data from remote weighing technology was used to examine cattle water point use.

behaviour. Thus, basic facts about how much water cattle consume and how often cattle drink under varying conditions of climate, pasture and water availability are not well understood by graziers or scientists (Williams et al., 2017). In northern Australia only three studies have documented grazing beef cattle watering behaviour. Schmidt (1969) undertook a detailed study of walking, watering and grazing behaviour of a Shorthorn breeding herd on the Barkly Tableland, Northern Territory, during the 1966 and 1967 dry seasons. A team of CSIRO scientists observed the watering behaviour of British breed cattle on three stations located around Alice Springs, Northern Territory from late 1969 to early 1973 (Low et al., 1978, 1981). Morrish (1984) recorded long term observations of mixed Braford cattle on a property located near Windorah, Queensland. Only a small number of studies from other parts of the world contribute more information on grazing beef cattle watering behaviour (Rollinson et al., 1955; Wilson, 1961; Lampkin and Quarterman, 1962; Rouda et al., 1994; Coimbra et al., 2010; Lardner et al., 2013).

In a recent review, Williams et al. (2017) showed that cattle drinking frequency influences the quantity of water cattle consume and can affect other performance attributes. The review reported that dairy cows with *ad libitum* access to water drank 12–13% more than cows with restricted access to water (once or twice daily) and had higher milk yields and milk fat. Beef cattle with access to water once daily drank 15–25% more than cattle with access to water once every second or third day and had higher feed intakes. The review also highlights that water intake and grazing beef cattle performance has not been studied in response to voluntary drinking regimes. Scientific examination of beef cattle watering behaviour under normal grazing conditions, which involves complex interactions between animals, management and their environment, is essential to inform water point distribution recommendations for graziers and maximise cattle productivity.

Remote weighing technology, which is linked to automatic Radio Frequency IDentification (ig) recording, could be exploited to study grazing cattle water point use. Remote weighing of grazing cattle was first introduced in the 1960s to negate disadvantages of conventional weighing practices such as stress and costs associated with mustering and drafting (Martin et al., 1967). The technology is strategically installed at the entrance of an enclosed water point to entice cattle to walk through the system (Martin et al., 1967). Each time an animal accesses water its RFID equipped ear tag is scanned as it walks past an RFID reader and the date and time is recorded. The animal's weight is also measured as it walks over an electronic weighing platform (Charmley et al., 2006; Brown et al., 2014). Remote weighing technology has primarily been used to monitor beef cattle live weight and weight gain (Anderson et al., 1980; González et al., 2014b; Hegarty, 2015; Menzies et al., 2017). However, the RFID recording component can also be used to autonomously collect behavioural data as an alternative to traditional time-consuming and expensive observation methods. In a recent study, Menzies et al. (2018) successfully used RFID data from remote weighing technology to determine calf maternal parentage. The number of times a cow and her calf walked through remote weighing technology within a predefined time period correctly identified over 90% of maternal cow-calf pairs. Because remote

Table 1
Summary of the stations and animals used to assess remote weighing technology as a suitable tool to examine beef cattle water point use.

Station	Paddock size (ha)[a]	No. of water points	Max. distance to water (km)	Class	No. of animals present[b]	No. of animals used	Age (± SD)	Body weight (± SD)	Breed
Brunchilly	6600	2	6.5	Steers	80	24	1 ± 0	326 ± 28	Brahman (*B. indicus*), Charbray (*B. indicus* × *B. taurus*)
				Cows	544	212	7 ± 5	475 ± 64	Brahman, Charbray, Santa Gertrudis (*B. indicus* × *B. taurus*)
				Bulls	~17	0			
Belmont	22	1	1.3	Cows	40	39	8 ± 2	575 ± 62	Tropical composite (*B. taurus*)
				Bulls	1	0			
Lansdown	15–45	1	0.75	Steers	20	20	2 ± 0	429 ± 33	Brahman, Belmont Red Composite (*B. indicus* × *B. taurus*)

[a] A block of three 15 ha paddocks were used in a rotation. Gates between the paddocks were opened throughout the experimental period to allow the animals' simultaneous access to two or three paddocks.
[b] Young calves were also present at Brunchilly and Belmont but were not equipped with RFID ear tags.

weighing technology is installed at water points, the RFID recording component essentially registers the date and time of cattle visits to water points and could be used to study water point use by grazing cattle.

The aim of the study was to assess whether RFID reader data from remote weighing technology could be used to examine cattle water point use. The hypothesis was that the technology would be able to detect behavioural differences according to climate and water availability and thus, be a practical tool to study cattle water point use.

2. Material and methods

2.1. Experimental design

The study was conducted as a retrospective analysis of RFID data from three separate experiments that had installed remote weighing technology to monitor cattle live weight. The experiments were conducted between 2011 and 2016 at three cattle stations in northern Australia (Fig. 1). Each station was located in a different grazing region and represented varying climates and water availability conditions. The first experiment was conducted at the Brunchilly outstation of Helen Springs Station, hereafter referred to as Brunchilly (134°29′E, 18°52′S, elevation 238 m). The experiment ran from October 2011 to May 2013 with approval from the Charles Darwin University Animal Ethics Committee (Quigley et al., 2014). The second experiment was conducted at Belmont Research Station, hereafter referred to as Belmont (150°22′E, 23°13′S, elevation 17 m). The experiment ran from August 2015 to March 2016 with approval from the Central Queensland University Animal Ethics Committee (Menzies et al., 2017). The third experiment was conducted at the CSIRO Lansdown Research Station, hereafter referred to as Lansdown (146°50′E, 19°39′S, elevation 65 m). The experiment ran from February 2013 to February 2014 with approval from the CSIRO Animal Ethics Committee (González et al., 2014a, 2014b).

A subset of RFID data from the spring-summer period (October to February) from each experiment was used. The data subsets were created so that the time period was consistent across the three stations. The spring-summer period also encompassed the late dry season (hot ambient conditions) and early wet season (rainfall) and would accentuate behavioural changes in cattle water point use according to weather conditions. The data subsets consisted of RFID records from 18 October 2011 to 29 February 2012 for Brunchilly (135 days), 1 October 2015 to 28 February 2016 for Belmont (151 days) and 1 October 2013 to 13 February 2014 for Lansdown (136 days). Unfortunately, equipment malfunction due to failing electrical components was experienced during the second spring-summer period at Brunchilly (October 2012 to February 2013). The RFID data for this period was not used.

2.2. Remote weighing technology

A cattle yard was built at each experiment site to enclose a permanent water point so that cattle entered the water point through a one-way spear gate and exited through a separate spear gate. The remote weighing technology was set up at the entrance to the water point and was equipped with an electronic RFID panel reader (Brunchilly; Allflex Australia Pty Ltd, Capalaba, Australia, Belmont; Aleis Pty Ltd, Capalaba, Australia, Lansdown; Tru-Test Ltd, Pakuranga, New Zealand). All cattle wore an RFID equipped ear tag in the right ear and had *ad libitum* access to the water point at all times. Each time an animal came within range of the RFID reader's antenna i.e. upon each visit to the water point, its RFID number and live weight was recorded along with the date and time. The live weight data was not used in this study.

2.3. Study sites and animals

The characteristics of the experimental paddock and cattle at each station are summarised in Table 1. The paddock at Brunchilly was 6600 ha in size and was comprised of 66% Barkly1 (black soil) and 34% Wonorah (red soil) land types. The red soil areas of the paddock had scattered trees that provided shade. The paddock contained two water points located approximately 6 km apart. One water point (No. 19 bore) was located close to the centre of the paddock and the other water point (Stud bore) was located in the northwestern corner of the paddock. Remote weighing technology was installed at both water points. The maximum distance between the water points and the furthest point in the paddock was approximately 6.5 km. A herd of 80 yearling steers and 544 pregnant, non-lactating cows that calved between October 2011 and April 2012 grazed the paddock. The steers had a mean live weight of 326 kg (August 2011) and were of Brahman (*Bos indicus*) and Charbray (*B. indicus* × *Bos taurus*) breeding. The cows had a mean age of 7 years and a mean live weight of 475 kg (August 2011) and were of Brahman, Charbray and Santa Gertrudis (*B. indicus* × *B. taurus*) breeding. Bulls were present at all times but were excluded from this study. The cattle had *ad libitum* access to a loose lick phosphorus supplement (Rumevite, Ridley Agri-products, Melbourne, Victoria, 3000) from troughs placed in both water enclosures.

Remote weighing technology was relatively new in Australia at the time of the experiment at Brunchilly and had not previously been used in extensive grazing conditions. The technology that was installed at Stud bore was an older prototype and regularly broke down during the experiment. The technology that was installed at No. 19 bore was fitted out with newer equipment and updated designs and was much more reliable (Quigley et al., 2014). Fortunately, the herd showed a strong preference for No. 19 bore over Stud bore during the experiment. The majority of RFID reader records were collected from No. 19 bore and supplement intake records for the selected spring-summer period show that the majority of supplement was consumed at No. 19 bore (2880 kg at No. 19 bore compared to 250 kg at Stud bore). The dataset from Stud bore was small and unreliable and was excluded from this study. To ensure the excluded data did not affect the integrity of the study, a cohort of 236 cattle (38% of the herd) that were only ever recorded to visit No. 19 bore during the selected spring-summer period were used. It was assumed that minimal, if any, visits to Stud bore by these cattle would have coincided with equipment downtime and the missing data would have no effect on the results. The cohort of cattle included 24 steers and 212 cows.

The paddock at Belmont was 22 ha of alluvial plains with scattered Brigalow trees that provided shade. One water point was located at the northeastern corner of the paddock. The maximum distance between the water point and the furthest point in the paddock was 1.3 km. A herd of 40 tropical composite (*B. taurus*) cows, with a mean age of 8 years and a mean live weight of 575 kg (20 August 2015) grazed the paddock. All cows were pregnant and not lactating at the start of the experiment and calved mid-October 2015 to January 2016. One cow died during calving and was excluded from the study. A bull joined the herd on 8 December 2015 and was excluded from the study. A*d libitum* access to a liquid protein supplement (AniPro Natural, Performance Feeds Pty Ltd, Kingsthorpe, Queensland, Australia) was provided from August until mid-November (when the wet season commenced) from a trough placed in the paddock.

The grazing area at Lansdown comprised of a block of three 15 ha loamy alluvial paddocks that were used in a rotation. Scattered trees provided shade. One water point was located in the central paddock. A 20 m wide alleyway was created for cattle to access the water point from the paddocks on either side. Gates between the paddocks were opened from mid-November and onwards to allow cattle to graze two or three paddocks simultaneously. The maximum distance between the water point and the furthest point in the block of paddocks was 0.75 km. A group of 20 steers grazed the paddocks. The steers were of Brahman and Belmont Red Composite (*B. indicus* × *B. taurus*) breeding and had a mean age of 2 years and a mean live weight of 429 kg (21 August 2013). Ad libitum access to a liquid protein supplement (AniPro, Performance Feeds Pty Ltd, Kingsthorpe, Queensland, Australia) was provided from 1 December 2013 from a trough placed in the water enclosure.

2.4. Weather

Daily weather data were collected from the Australian Bureau of Meteorology website (Australian Bureau of Meteorology, 2010). The daily weather variables collected were minimum temperature (Tmin, °C), average ambient temperature (Tav, °C), maximum temperature (Tmax, °C), average relative humidity (RH, %), average wind speed (WS, km/h), average cloud cover (CC, eights), average solar exposure (SO, MJ m^2) and rainfall (RF, mm). Temperature-humidity index (THI) was calculated using the equation developed by Thom (1959): THI = 0.8 * Tav + [(RH/100) * (Tav – 14.4)] + 46.4. Rainfall data was available from weather stations located at each experiment site and the remaining weather variables from the nearest weather station. Rainfall data for Brunchilly was collected from the Brunchilly weather station (015123) and the remaining weather variables from the Tennant Creek Airport weather station (015135). The weather stations were located 5 km and 95 km from the experimental paddock, respectively. Rainfall data for Belmont was collected from the Belmont weather station (033229) and the remaining weather variables from the Rockhampton Airport weather station (039083). The weather stations were located 3 km and 20 km from the experimental paddock, respectively. Rainfall data for Lansdown was collected from the Lansdown weather station (033226) and the remaining weather variables from the Townsville Airport weather station (032040). The weather stations were located 1 km and 45 km from the experimental paddock, respectively. All weather stations were located in the same climatic zone as the corresponding experiment sites. Daily sunrise and sunset times were calculated using the Australian Government's Geoscience Australia website (Geoscience Australia, 2010).

2.5. Data processing

The RFID reader data was acquired as text files with three columns of data: RFID, date and time. Each row of data represented one recorded visit to a water point by one animal. The data were imported into Microsoft® Excel® (version 14.0, Microsoft Corporation, Washington, USA) and processed using R (R Core Team, 2016). The data were cleansed by removing rows without electronic identification and removing data outside of the selected time periods (Aldridge et al., 2016; CQUniversity, 2018). Rows of data that had the following attributes were then removed: (1) An erroneous RFID (i.e. the RFID number was inconsistent with animals included in the study), (2) A date that corresponded with animal handling, as human interference could have impacted cattle behaviour. Time intervals between cattle visits to water points were calculated on a per animal basis by subtracting the date and time of each record from the date and time of the subsequent record. The first recorded interval after periods of missing data (due to animal handling or equipment failure) were removed as the missing records could bias the data. Records that were within 30 min of a previous record were also removed as they were more likely generated by cattle loitering around the water point rather than cattle making separate visitations to the water point to drink.

2.6. Data analysis

Daily weather variables were compared between the three stations. All data appeared to be normally distributed on a quantile-quantile (Q-Q) plot except for RF, which had a positively skewed distribution. The weather variables with normal distributions (Tmin, Tav, Tmax, THI, RH, WS, CC and SO) were analysed using a Welch's analysis of variance (ANOVA) due to heterogeneity of variances according to Levene's test ($P < 0.05$). Differences among means were obtained using the Games-

Howell post-hoc test in the 'userfriendlyscience' R package (Peters, 2018). Rainfall was analysed using the Kruskal-Wallis (non-parametric) test followed by Dunn's Post Hoc test in the 'PMCMR' R package (Pohlert, 2018).

The RFID reader data was analysed using a non-parametric bootstrap procedure. The non-parametric bootstrap is a resampling technique used to overcome modelling problems such as interdependence, simultaneity, nonlinearity, instability, non-normality, heteroscedasticity, small datasets and missing data (Vinod, 1993). In this case, the bootstrap was applied to manage unequal sample sizes caused by the different number of animals at each station. The steps in the bootstrap procedure were as follows: (1) An even number of records per month were randomly selected with replacement from each station to create a balanced bootstrap sample (2) A linear mixed-effects model was fitted to the bootstrap sample using the 'lme4' R package (Bates et al., 2016) and summary statistics were calculated (3) Steps 1 and 2 were repeated 100 times (4) Summary statistics were averaged across the 100 models to generate parameter estimates. Two aspects of cattle water point use were examined: cattle visit times to water points and time intervals between cattle visits to water points. Cattle visit times to water points were the time of day (hour and minute) that cattle entered a water point. Time intervals (hours) between cattle visits to water points were the duration of time between successive visits to a water point. Separate models were used to analyse each facet of water point use. The R model syntax used to analyse cattle visit times to water points was:

```
lmer(Time ~ (1|RFID) + Station + Month + Period of
    day + log(Int) + THI + WS + CC + SO + RF)
```

Time (time of day) was the dependant variable. The variable RFID (RFID ear tag number) was a random effect. The remaining variables were fixed effects. Period of day was the daytime period (morning or afternoon) during which a visit occurred. Log(Int) was the log transformed time interval since the previous visit. Tmin, Tav, Tmax and RH were not included in the models because multicollinearity was detected between these weather variables and THI (Variance inflation factor (VIF) values > 4.0). THI was considered the best indicator of ambient conditions across the three stations. The remaining weather variables (RF, WS, CC and SO) had VIF values < 3.0. In a subsequent analysis, cattle visit times were related to sunrise times. The time difference between sunrise and cattle visit times was calculated and 'Time' was replaced with 'Hours after sunrise'. The R model syntax used to analyse time intervals between cattle visits to water points was:

```
lmer(log(Int) ~ (1|RFID) + Station + Month + Period of
    day + THI + WS + CC + SO + RF)
```

Log(Int) was the dependant variable, RFID was a random effect and the remaining variables were fixed effects. Time intervals between visits were log transformed because model residuals on bootstrap samples of untransformed data showed a highly skewed (positive) distribution.

3. Results

A summary of the RFID reader data is shown in Table 2. The final dataset for Brunchilly No. 19 bore comprised of 131 days and 18,239 records. Equipment failure occurred during four days (3% of the study period), between 3 and 6 January 2012, due to a hardware fault. Two-thirds of the dataset (38, 661 records) had an erroneous RFID (e.g. excluded cattle). Less than 5% of the dataset was within 30 min of a previous record (2573 records). The data from Stud bore comprised of 2152 records. Equipment failures occurred during 60 days (45% of the study period) due to some or all of the older system components breaking down in the harsh environment. The data from Stud bore was excluded due to the high occurrence of equipment failure. The final dataset for Belmont comprised of 136 days and 5073 records. Five days were removed due to animal handling (215 records). Equipment failures occurred during 10 days (7% of the study period). Between 15 and 23 October 2015 (9 days) a cable connection between the panel reader and the indicator became loose and on the 14 December 2015 temporary power loss was experienced. About 3% of records had an erroneous RFID (171 records) and less than 2% of the dataset was within 30 min of a previous record (76 records). The final dataset for Lansdown comprised of 133 days and 5135 records. Three days of data were removed due to animal handling (163 records). No equipment failures were experienced during the study period. Less than 2% of the dataset was within 30 min of a previous record (90 records).

3.1. Weather

All weather variables were different at each station except for SO (Table 3). The ambient temperature (Tav) was highest at Brunchilly (29.3 °C) and lowest at Belmont (26.2 °C). The RH was highest at Lansdown (67.8%) and lowest at Brunchilly (44.3%). The THI was similar between Brunchilly (76.2%) and Lansdown (76.6%) and lower at Belmont (75.1%). Higher RF was experienced at Brunchilly compared to Belmont and Lansdown. Total RF at Brunchilly was 506 mm, which was well above average for the study period (October to February). RF occurred on 35 days during October (8 mm), November (210 mm), December (93 mm), January (26 mm) and February (169 mm). Total RF at Belmont was 275 mm, which was close to half the average RF for the study period. Rain occurred on 14 days during November (131 mm), December (46 mm), January (20 mm) and February (78 mm). Total RF at Lansdown was 222 mm, which was about one third of the average RF for the study period. Rain occurred on 13 days during November (81 mm), January (55 mm) and February (86 mm).

3.2. Cattle visit times to water points

The RFID data showed that most cattle visits to water points occurred during daylight hours (Fig. 2). Approximately 83%, 98% and 96% of visits to the water point were recorded between 06:00 and 18:59 h at Brunchilly, Belmont and Lansdown, respectively. Very few nocturnal visits (i.e. prior to 06:00 h and after 19:00 h) were recorded.

There were no significant differences in the time of day that cattle visited water points between stations (Table 4). The median daily visit times were 11:16 h at Brunchilly, 12:22 h at Belmont and 11:15 h at Lansdown. Behavioural variation was detected according to month, period of day, time since last visit and CC. There were no behavioural differences between the cows and steers at Brunchilly ($P > 0.05$). Time differences between sunrise and cattle visits to water points were detected between the stations ($P < 0.05$). The median time interval between sunrise and cattle visits to water points was 5.3 h at Brunchilly, 6.9 h at Belmont and 5.7 h at Lansdown. Variation was detected according to period of day, time since last visit and CC but not according to month. There were no behavioural differences between the cows and steers at Brunchilly ($P > 0.05$).

3.3. Time intervals between cattle visits to water points

The RFID data showed that most cattle visits to water points occurred within 48 h of a previous visit (Fig. 3). At Brunchilly, approximately 71% of visits occurred within 24 h of a previous visit and 85% within 48 h of a previous visit. At Belmont, approximately 60% of visits occurred within 24 hrs of a previous visit and 96% of visits occurred within 48 hrs of a previous visit. At Lansdown, approximately 95% of visits to the water point occurred within 24 hrs of a previous visit and 98% of visits occurred within 48 hrs of a previous visit. Differences in the time intervals between cattle visits to water points were significant between the stations (Table 4). The median time interval between cattle visits to water points at Brunchilly was 45.8 hrs, which equated to

Table 2
Summary of RFID data from remote weighing technology at three stations in northern Australia.

	Station			
	Brunchilly (No. 19 bore)	Brunchilly[a] (Stud bore)	Belmont	Lansdown
Days				
All data	135	135	151	136
No. animal handling days	0	0	5	3
No. equipment failure days	4	60	10	0
Total	131	75	136	133
Records				
All data	59,473	2152	5536	5388
No. with erroneous RFID	38,661	2152	171	0
No. on animal handling days	0	0	215	163
No. on equipment failure days	0	0	1	0
No. within 30 min of previous visit	2573	0	76	90
Total	18,239	0	5073	5135

[a] The data from Stud bore was not used in this study because of the high occurrence of equipment failure. The technology at Stud bore was an older prototype and regularly broke down in the harsh environment.

Table 3
Means ± SD of daily weather conditions observed at the three stations. Daily rainfall data were obtained from weather stations located at each station and the other variables from the nearest official weather station.[1] Tmin, minimum temperature; Tmax, maximum temperature; Tav, average temperature; THI, temperature-humidity index; RH, relative humidity; WS, wind speed; CC, cloud cover; SO, solar exposure; RF, rainfall.[2]

	Tmin (°C)	Tmax (°C)	Tav (°C)	THI (%)	RH (%)	WS (km/h)	CC (eights)	SO (MJ m[2])	RF (mm)	Sunrise (h)	Sunset (h)
Brunchilly	23.7 ± 2.2^{a}	35.8 ± 3.2^{a}	29.3 ± 2.5^{a}	76.2 ± 2.8^{a}	44.3 ± 18.7^{b}	14.0 ± 3.3^{b}	3.7 ± 2.1^{ab}	25.1 ± 5.9	3.9 ± 2.5^{a}	$6{:}02 \pm 0.25^{a}$	$19{:}00 \pm 0.22^{a}$
Belmont	21.4 ± 2.4^{b}	32.9 ± 2.7^{b}	26.2 ± 2.1^{c}	75.1 ± 3.1^{b}	66.0 ± 7.2^{a}	13.2 ± 3.4^{b}	3.6 ± 2.0^{b}	23.9 ± 5.3	2.0 ± 2.1^{b}	$5{:}22 \pm 0.26^{c}$	$18{:}30 \pm 0.27^{c}$
Lansdown	23.6 ± 2.1^{a}	31.4 ± 1.6^{c}	27.0 ± 1.4^{b}	76.6 ± 2.8^{a}	67.8 ± 6.7^{a}	18.9 ± 4.7^{a}	4.2 ± 1.8^{a}	23.8 ± 5.3	1.7 ± 1.4^{b}	$5{:}39 \pm 0.20^{b}$	$18{:}36 \pm 0.27^{b}$
P value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.05	> 0.05	< 0.001	< 0.001	< 0.001

[1] Means with different superscript letters in the same column differed between experimental sites ($p < 0.05$).
[2] Average daily RF is shown. Total RF during the study period was 496 mm at Brunchilly, 275 mm at Belmont and 222 mm at Lansdown.

approximately one visit every two days. The median time interval between visits at Belmont was 24.5 hrs, which equated to approximately one visit per day. The median time interval between visits at Lansdown was 12.5 hrs, which equated to approximately two visits per day. Variation in the time intervals between cattle visits to water points was also detected according to month, period of day, THI and CC. The negative relationship between THI and time intervals between visits suggests that as the THI increased the cattle visited the water points more regularly. Time intervals between visits to the water point were not different between the cows and steers at Brunchilly ($P > 0.05$).

4. Discussion

Beef industry interest in using remote weighing technology to monitor cattle live weight and weight gain is growing. With this growing interest there is an associated opportunity to automatically record cattle behaviour at water points using the technology's RFID recording component. This study demonstrates the use of RFID reader data to examine cattle water point use. The study was conducted as a retrospective analysis of RFID reader data collated from three previous experiments. The experiments were carried out at different cattle stations in northern Australia that had varying climates and water availability conditions. The analytical methods applied to the data identified variation in cattle visit times and time intervals between cattle visits to water points within and between the three stations. The results are broadly consistent with expectations and satisfy the hypothesis; that the technology would be able to detect behavioural differences according to climate and water availability. The authors consider RFID reader data from remote weighing technology a suitable tool to study cattle water point use. The following section compares the characteristics of cattle water point use in this study to observations in the literature and offers some recommendations for the future use of RFID reader data in field experiments and industry application.

The RFID reader data in this study showed that most cattle visits to water points occurred during the day. Many reports in the literature show that grazing beef cattle (Rollinson et al., 1955; Lampkin and Quarterman, 1962; Herbel and Nelson, 1966) and dairy cattle (Castle et al., 1950; Campbell and Munford, 1959; MacLusky, 1959; Jago et al., 2005) are diurnal and mostly drink during daytime.

The time of the day that cattle visited water points did not differ between the three stations. The cattle at each station varied in their age, body weight, physiological status and genetics and were exposed to different environmental conditions such as shade and water availability, pasture availability and quality, supplementation, weather, herd dynamics and grazing range. The similarity in cattle visit times between the three stations indicates that the behaviour was regulated by the diurnal cycle. Many studies on the diurnal behaviour of grazing cattle report a characteristic pattern of movement and activity (Lampkin and Quarterman, 1962; Schmidt, 1969; Low et al., 1981; Roath and Krueger, 1982; Morrish, 1984). With great regularity daily cattle activity begins with a high intensity grazing period at sunrise. The grazing period can vary in length but usually lasts between two and five hours. Cattle seek water after the morning grazing period and spend the middle of the day resting at or near a water point. Drinking typically occurs upon arrival to the water point and intermittently throughout the day between periods of resting, ruminating and grazing. Late in the afternoon another high-intensity grazing period is commenced and continues into the night. The majority of the night is then spent resting until sunrise. The distributions of times during which cattle visits to water points occurred in this study align well with this diurnal activity pattern.

Time intervals between sunrise and cattle visits to water points were different between the three stations. The differences suggest that there was variation in the timing of diurnal activities between stations. A number of environmental variables can influence the timing and duration of cattle activity including ambient conditions, grazing range,

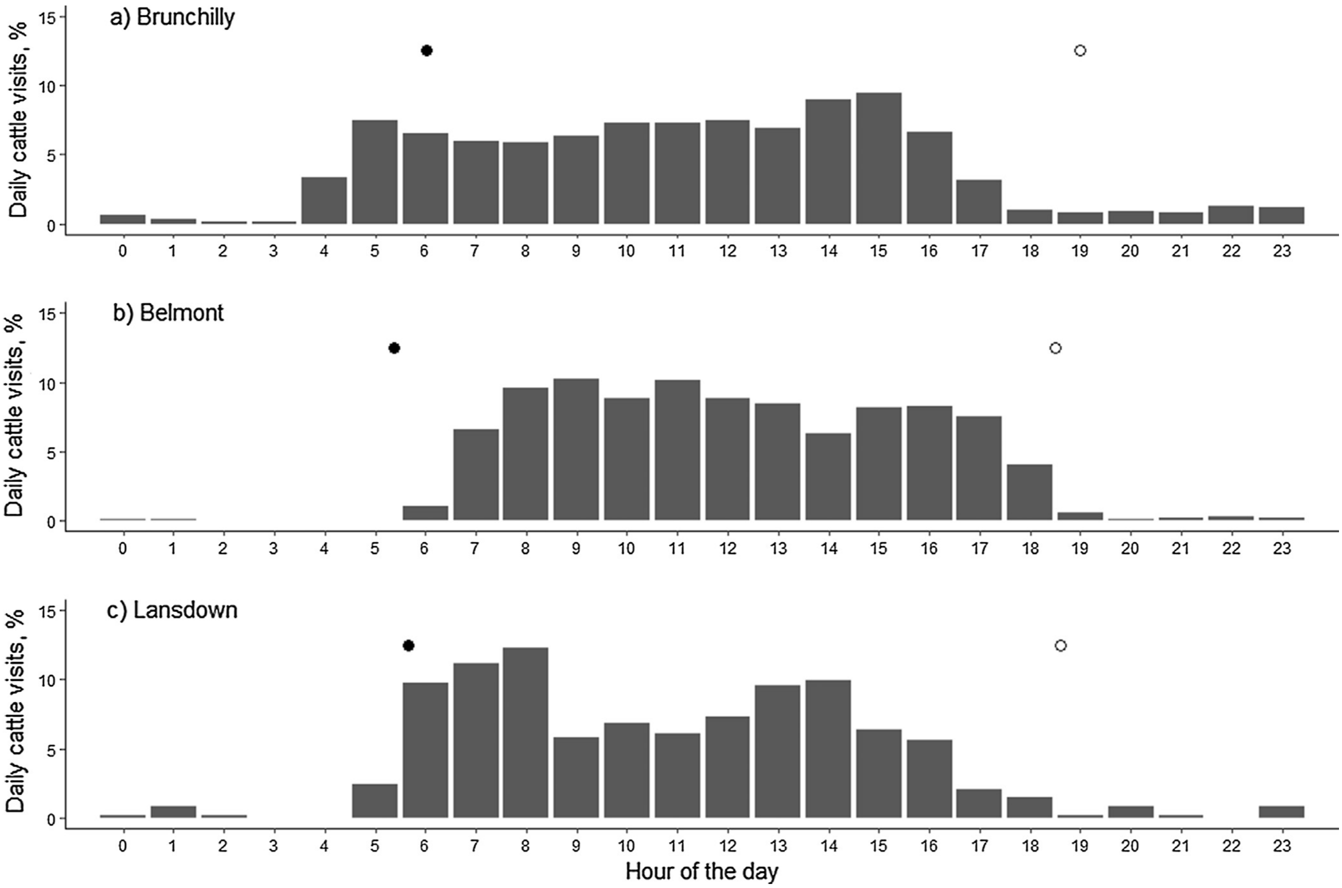

Fig. 2. Frequency distribution of average daily visit times of grazing beef cattle to water points in hourly intervals during spring-summer. Nocturnal visits (i.e. prior to 04:00 h and after 20:00 h) accounted for a small percentage of total daily visits and were not included in the mixed-effects models. The open circles indicate sunrise times and the solid circles indicate sunset times.

Table 4
Average parameter estimates (+SE) and variance components (± SD) associated with fixed and random effects for the mixed-effects models fitted to 100 bootstrap samples to explain cattle visit times and time intervals between cattle visits to water points at three stations.

	Cattle visit times to water points						Time intervals between cattle visits to water points		
	Time of day			Hours after sunrise			Hours		
Random effects	Average bootstrap variance	Average bootstrap SD		Average bootstrap variance	Average bootstrap SD		Average bootstrap variance	Average bootstrap SD	
RFID	0.002	0.008		0.005	0.018		0.029	0.116	
Residual	5.738	2.395		5.750	2.397		1.189	1.090	
Fixed effects	Average bootstrap estimate	Average bootstrap SE	Average bootstrap p-value	Average bootstrap estimate	Average bootstrap SE	Average bootstrap p-value	Average bootstrap estimate	Average bootstrap SE	Average bootstrap p-value
(Intercept)	7.213	3.209	0.043	0.897	3.218	0.246	5.100	1.457	0.006
February	1.070	0.263	0.001	0.438	0.264	0.104	0.764	0.119	< 0.001
January	0.076	0.261	0.251	−0.289	0.262	0.168	0.007	0.120	0.287
November	0.067	0.258	0.250	0.040	0.258	0.266	0.293	0.118	0.029
October	−0.205	0.289	0.235	−0.422	0.289	0.118	0.010	0.132	0.280
Period of day	6.783	0.171	< 0.001	6.779	0.172	< 0.001	−0.328	0.078	< 0.001
Time since last visit	0.213	0.070	0.013	0.226	0.071	0.008			
Belmont	0.280	0.255	0.194	0.603	0.257	0.030	0.752	0.123	< 0.001
Brunchilly	−0.236	0.225	0.170	−0.572	0.227	0.020	0.385	0.110	0.002
THI	−0.014	0.039	0.256	−0.008	0.040	0.251	−0.046	0.018	0.035
RF	−0.014	0.015	0.181	−0.013	0.015	0.200	0.007	0.007	0.186
WS	0.025	0.023	0.184	0.027	0.023	0.153	0.011	0.011	0.167
CC	0.160	0.072	0.043	0.178	0.073	0.028	0.083	0.033	0.029
SO	0.028	0.028	0.184	0.038	0.028	0.139	0.009	0.013	0.233

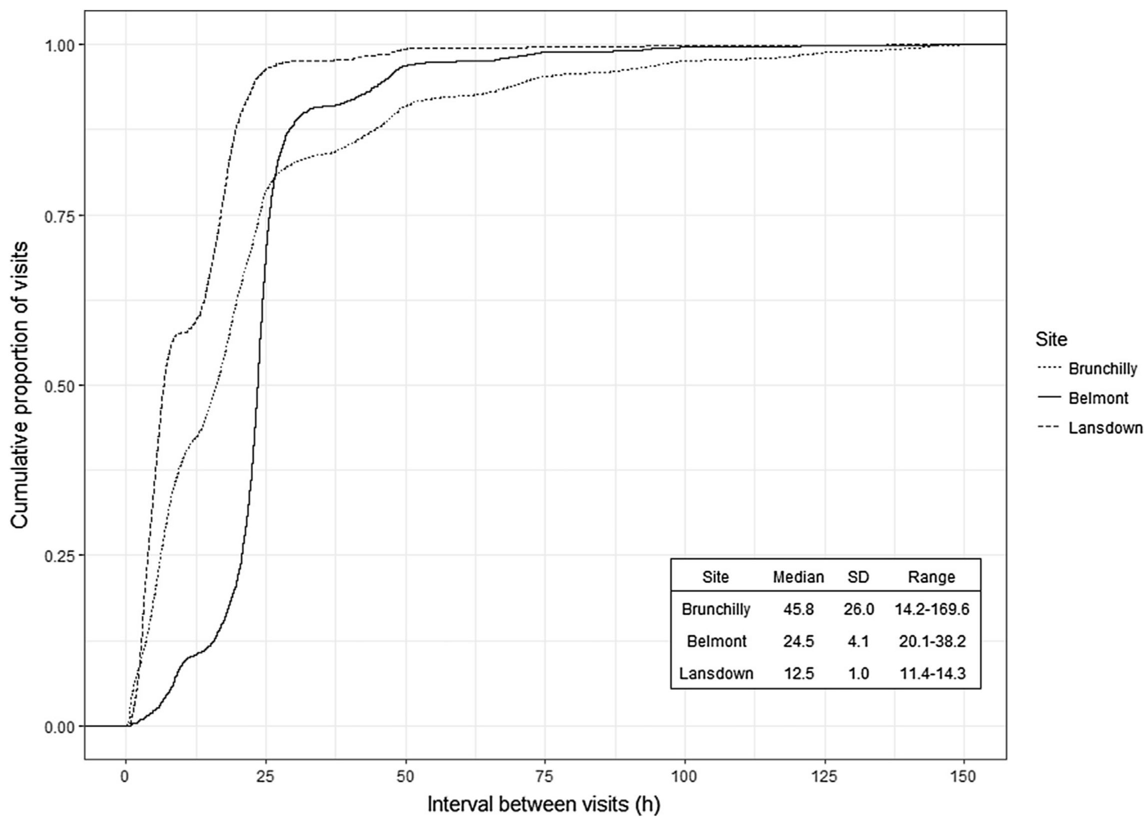

Fig. 3. Cumulative proportion for time between visit to water points of grazing beef cattle at three stations in northern Australia.

herd dynamics and pasture conditions (Schmidt, 1969; Low et al., 1981; Roath and Krueger, 1982). Sunrise times were different at each station and could have influenced the commencement time of morning grazing. Morning grazing periods could also have varied in duration due to any of the aforementioned variables.

Cloud cover was the only weather variable that showed some influence on cattle visit times to water points. A positive relationship was detected and indicates that as CC increased the cattle visited water points later in the day. Cattle activity is highly sensitive to ambient conditions (Lainez and Hsia, 2004) and watering behaviour is subject to modification (Schmidt, 1969; Low et al., 1981; Lainez and Hsia, 2004). During hot weather, cattle have been observed to walk to water early in the morning or late in the afternoon to avoid walking during the hottest part of the day. However, when ambient conditions are reduced by clouds, rain or a cool change cattle walk to water later in the morning or earlier in the afternoon. The results of this study indicate that CC has more influence on cattle watering times during hot weather than other weather variables such as THI, WS, SO and RF.

The time of the day that cattle visited water points was later during February compared to the other months. However, relationships between cattle visits to water points and hours after sunrise were not different between months. Sunrise times were considerably later during February compared to the other months and could be reason for the difference in the times of cattle visits to water points but not the timing of the activity.

The time intervals between cattle visits to water points differed considerably between the three stations. The RFID data showed that the cattle at Lansdown visited the water point about twice per day, the cattle at Belmont about once per day and the cattle at Brunchilly about once every two days. Many variables have the potential to influence grazing cattle water requirements and the regularity of cattle visits to water points (Winchester and Morris, 1956; Low et al., 1978; Agricultural Research Council, 1980; Sexson et al., 2012). Ambient conditions, the presence of alternative water sources (e.g. surface water, pasture moisture) and grazing distance from a water point are considered to have the most influence on the frequency of cattle visits to water points (Youngblood, 1927; Schmidt, 1969; Low et al., 1978; CQUniversity, 2018). Unfortunately, surface water and cattle spatio-temporal movements were not monitored during the experiments used in this study. However, data for THI, RF and a measure of water availability (maximum possible grazing distance from the water point) were collected. The THI was highest at Landsown and was identified as a significant influence on time intervals between visits. Water availability (max. 0.75 km) was also highest at Lansdown and RF during the study period was lowest (223 mm). Water availability (max. 1 km) and RF (275 mm) at Belmont were similar to Lansdown but the THI was lower and could explain the longer time intervals between visits to the water point compared to Lansdown. The THI at Brunchilly was similar to at Lansdown but water availability was lower (max. 6.5 km) and RF was higher (496 mm) compared to the other stations. Water availability and/or the presence of alternative water sources are likely reasons for the longer time intervals between visits to the water point at Brunchilly.

Cloud cover showed some influence on time intervals between cattle visits to water points. The positive relationship indicates that as CC increased so did the time intervals between visits. The presence of cloud cover likely reduced ambient conditions, cattle water requirements and cattle visits to the water point (Agricultural Research Council, 1980). Rainfall, WS and SO did not appear to influence the frequency of cattle visits to water points.

The time intervals between cattle visits to water points were longer during November and February compared to the other months. The longer time intervals coincided with the months during which the highest RF was experienced at each station. Although a relationship between daily RF and cattle visits to water points was not detected, it is possible that surface water was present during these months and the cattle were able to partially meet their water requirements without visiting the water point. There were no notable differences in THI, WS, CC or SO during November and February compared to the other months.

There are a number of potential applications of cattle water point use data moving forward: (1) Aid mustering and trapping cattle (2) Identify sick, injured, deceased, displaced or missing animals that fail to visit a water point (3) Better understand pasture conditions (4) Predict the amount and consistency of weight data that will be collected from remote weighing technology (5) Improve decision making by graziers (6) Inform recommendations for the optimal number and distribution of water points. Ideally, future field experiments should be designed to consider animals, management and the environment and how variables influence cattle watering behaviour at various temporal scales (e.g. daily, weekly, monthly). It is recommended that RF and surface water availability are monitored concurrently to better understand how these variables interact to influence cattle visits to water points. Cattle spatio-temporal behaviour should also be monitored to approximate grazing distances from water points and better understand water availability effects on cattle watering behaviour. Tracking technologies (e.g. GPS and accelerometers) could be used to collect this data (Bailey et al., 2018).

The placement of supplements at water points when monitoring cattle watering behaviour should be carefully considered. Although water usually has the strongest influence on cattle spatio-temporal behaviour (Martin et al., 1967; Bailey et al., 1996), supplements may alter cattle grazing and watering habits and encourage cattle to preferentially visit water points (Hunt et al., 2007; CQUniversity, 2018). The phosphorus supplement placed at the two water points at Brunchilly during the experiment was unlikely to affect cattle water point use. Supplement intakes during the study period were much lower than targeted (approx. 50 g/head day compared to the targeted 100 g/head day) and evidence collected during the experiment indicated that the cattle were not phosphorus deficient (Quigley et al., 2014). The protein supplement placed at the water point at Lansdown was highly palatable and may have contributed to the regular visits made by the steers during the experiment.

Equipment failure is a risk associated with the use of any technologies in research or industry applications. A challenge with using RFID technology in a grazing environment is maintaining continuous operation under harsh environmental conditions of dirt, dust, wind, moisture and extreme temperatures (Ruiz-Garcia and Lunadei, 2011; Quigley et al., 2014). Significant equipment failure (45% of the study period) was experienced at one water point (Brunchilly Stud bore) in this study due to malfunction of older technology in the harsh grazing environment. The newer technology at the other three water points demonstrated a large improvement in reliability. Equipment failures still occurred due to hardware faults, lost connections between the panel reader and the indicator and power loss, but were much less frequent and only lasted for a short period of time (< 7% of the study periods). Other common causes of temporary equipment failure include loose or damaged communication cables, weak or lost signal between the antenna and tags and a full memory (CQUniversity, 2018; Tru-Test Limited, 2018). Equipment failures can be moderated by using the latest RFID technology and performing routine checks and maintenance. In a remote sensing application, the use of real-time telemetry is also recommended for prompt fault detection (Quigley et al., 2014; CQUniversity, 2018). The locally stored data can then be automatically transferred to a computer and monitored regularly (hourly or daily).

In conclusion, RFID reader data from remote weighing technology is considered a suitable tool to autonomously record cattle visit times and time intervals between cattle visits to water points. The practical nature of the technology makes it suitable for field experiments and industry application. Future experiments on cattle water needs, cattle watering behaviour and water availability effects on cattle production, reproduction and survival are required to improve decision making by graziers. Cattle watering behaviour is complex and many variables are likely to interact to influence how cattle use water points. Customised recommendations for the placement of water infrastructure may be required for individual situations. Future experiments on cattle water point use will enable water infrastructure to be developed with more direct benefits for cattle production alongside the current focus on grazing distribution.

Conflict of interest

None.

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