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A scoping study to assess the precision of an automated radiolocation animal tracking system

Don Menzies[a,*], Kym P. Patison[a], David R. Fox[b,c], Dave L. Swain[a]

[a] CQUniversity, School of Medical and Applied Sciences, Precision Livestock Management Research Group, Rockhampton, Queensland 4702, Australia
[b] Environmetrics Australia Pty Ltd, Beaumaris, Vic 3193, Australia
[c] University of Melbourne, Parkville, Vic 3010, Australia

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ABSTRACT

The spatial precision of a new automated radiolocation animal tracking system (ARATS) was studied in a small-scale (~5 ha) trial site. Twelve static tags, in a four by three grid, transmitted for 28 days. The 12 tags recorded 36,452 transmissions with a mean transmission per tag of 3037. Each transmission included the tag number, date and time and the calculated longitude and latitude. The mean location and then the Euclidean distance from the mean location for each tag were calculated in order to derive location precision per tag. The overall precision for the 12 tags was ±22 m with a SD of 49 m with the most and least precise tags having precisions of ±8 m and ±51 m, respectively. As with other geolocation technologies, it would appear that structures in the environment cause signal propagation effects including multipath and non-line-of-sight, which result in errors in the derived locations.

The distance from the mean data was log transformed ($\log_{10}$) and summarised in order to present all data over a 24-h period. There was a statistically significant decrease in precision between 11:00 and 17:00 h. These data were correlated with meteorological parameters for the period of the trial, again summarised over 24 h, with temperature, humidity, wind speed and pressure all having significant correlations with the precision data.

The variance between individual tag transmissions were compared to see whether the distance between derived locations increased as time between transmissions increased. The means for each tag showed the same variance as the mean precision values, that is the more precise tags had lower means and the less precise tags had higher means. However, no tags showed a trend towards an increase in the distance between locations as the time between transmissions increased.

In order to assess whether there was any spatial variability in the derived locations, the variability in distance between tags was compared for all tag combinations. Tags that were proximal to each other had shorter distances between the mean derived locations and less variance, whereas tags farther apart had large distances and large variance in the mean derived locations.

The ARATS assessed in this static evaluation showed a lower level of spatial precision than commercially available global positioning systems. However the system could still have application when used to derive proximal associations between animals in low stocking-rate, extensive grazing situations such as are present in northern Australia.

1. Introduction

There has been an increase in the use of technologies to track domestic and wildlife animal location and movement, which commenced with wildlife ecologists using very high frequency (VHF) radio tracking in the 1960s (Cochran and Lord, 1963; Zerger et al., 2010; Swain et al., 2011). The early animal tracking systems relied on researchers using hand held receivers to locate animals fitted with radio transmitting collars (Cochran and Lord, 1963). More recently, the global navigation satellite system (GNSS), of which global positioning systems (GPSs) are the most common, have been used to monitor animal movement (Hulbert and French, 2001; Schwager et al., 2007; Anderson et al., 2013).

Within the livestock field, location based technologies have mostly been used to describe animal habitat and grazing selection preferences (Anderson et al., 2012; Swain et al., 2008a, 2008b) or for animal control (Ruiz-Mirazo et al., 2011; Bishop-Hurley et al.,

* Corresponding author.
E-mail address: d.menzies@cqu.edu.au (D. Menzies).

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2007) rather than monitoring animal proximity. Therefore, the focus has been on the derivation of accurate location rather than the monitoring of associations between animals.

Whether the location tracking technology uses land-based receivers or satellites often the issues are the same, namely location accuracy, cost and power requirements. Due to the cost, GPS collars have most frequently been used on a subset of animals rather than the whole population. In a review of 99 free-ranging cattle studies using GNSS, the number of cattle instrumented varied from 1 to 81 with the vast majority (>90%) of studies involving less than 20 animals (Anderson et al., 2013). The authors suggest that the high cost of GNSS units, which range from $500 to greater than $3000, exacerbate problems associated with inadequate sample size in experimental design. In the domesticated livestock industries, observations of every animal are required to derive proximity-based parameters, such as onset of oestrus and parturition events. Therefore, large scale animal monitoring requires a cost effective and long lasting device.

The development of a low powered automated radiolocation animal tracking system (ARATS) (e.g. http://taggle.com.au/applications/agriculture/livestock), using a series of fixed location receivers, is emerging as an alternative tracking option. It is claimed that the system can automatically monitor the location of large groups of animals (up to 30,000) using a small mobile transmitter that can be fitted to the ear of an animal. The transmitter sends a radio signal with a unique identity. A series of static receivers, which are located within the landscape and can cover an area of up to 15,000 ha, acquire the radio signal. These receivers are used to determine the individual animal transmitter location (Taggle Systems Pty Ltd, 2015). The transmitters are powered by a 1/2 AA Lithium Thionyl Chloride, 3.6 V, 1200 mA h battery, weigh 21 g and can remain active for several years using a 15-min transmission interval. This new location-based system may provide a potentially cost effective and practical solution for tracking free-ranging animals.

The effect of temporal and spatial influences and transmission/-fix rates on the derived location, have been studied extensively for other radiolocation technologies (Agouridis et al., 2004; Hulbert and French, 2001; Garrott et al., 1986; Swain et al., 2008b). For example, GPS has been shown to be more precise under certain environmental conditions such as low tree cover (Lewis et al., 2007) and enables more accurate speed calculations when there is a smaller time interval between fix locations (Swain et al., 2008a). To our knowledge, there is no published literature on the precision of low-powered fixed-receiver radiolocation devices.

Location accuracy, as defined by the derived position compared with the true location, is important (Swain et al., 2011), however relative temporal and spatial location data have also been shown to have value for understanding animal behaviour (Swain et al., 2011). Relative location is the difference between two location points in space or time and is used to calculate speed as well as association patterns. Animal interactions, especially within commercial livestock production systems, have be used to derive important commercial measures such as maternal parentage (Swain and Bishop-Hurley, 2007), reproductive status (O'Neill et al., 2014), date of calving (Finger et al., 2014) and grazing activity (Ungar et al., 2010). The absolute location, described as closeness to true location or accuracy, is not as important as precision, when using location measures to determine relative information. The value of relative location to determine movement patterns and associations is derived by the variance of the data. Understanding the overall variance or precision of the data is important in assessing how useful location based technologies might be for determining both movement and associations. Hulbert and French (2001) provide a detailed discussion of absolute (accuracy) versus relative (precision) information, and highlights the importance of considering these as separate but related error terms.

The aim of this study was to assess the precision, temporal effects and proximal associations of a low powered ARATS. More specifically the trial addressed the following objectives:

1. The spatial variance or precision of locations derived from static ARATS tags.
2. The relative variance or precision of distances between static ARATS tags.
3. The variance or precision of locations derived from static ARATS tags at different time intervals.
4. The effect of environmental variables on variance or precision of static ARATS tags.

2. Materials and methods

2.1. Measurement procedure

The study was conducted at the Central Queensland Innovation and Research Precinct (CQIRP) (150°51′E, 23°3′S), Central Queensland University, Rockhampton, Queensland, Australia. Twelve low powered radio transmitter tags (see Fig. 1), manufactured by Taggle Systems Pty Ltd, (Sydney, Australia) (Taggle) were placed at fixed locations within the trial site. The site comprised Ironbark woodland with a grassy ground layer of predominantly native grasses. The Ironbark trees and other species were well-established, mature trees with a maximum height of approximately 30 m. The tags were located in a four by three grid (see Fig. 2), with approximately 38.5–50 m spacing between the east–west rows and 51 m spacing between the north–south columns. Tags were attached to the top of wooden posts using plastic fasteners approximately 1050 ± 50 mm above ground level. The terrain of the paddock was undulating with a 10% slope from east to west and 2 non-flowing creeks that bisected the first and second rows and the third and fourth rows of tags in the paddock.

Four receivers with known positions were located at the boundary of the trial site (see Fig. 2). The receivers acquire the radio signal from each tag as it is transmitted. The Taggle device transmits between 917 and 927 MHz using electromagnetic radiation (EMR). The receivers send the Taggle device number, the date, time and the Taggle receiver number via the 3G network to a Taggle server. The Taggle server uses this information to calculate the time difference of arrival (TDoA) from at least three receivers to generate the location of each tag (Gordon Foyster, pers comms 10th November 2015). Time difference of arrival systems locate an emitting device by processing the arrival-time measurements and producing hyperboloids for each pair of receivers with the emitting-location estimated by the intersection of three or more hyperboloids from four or more receivers (Torrieri, 1984). The TDoA calculations do not rely on clock synchronisation at the point of transmission but rather the time difference the signal arrives at multiple receivers (Munoz et al., 2009).

2.2. Data processing

Once the data were processed at the remote server, the coordinates, with the date, time and tag number, were downloaded to a computer located in Rockhampton as a CSV file every 10 min, which were imported into a MySQL database. As the tags were programmed to transmit every 15 min and the CSV files were downloaded from the server every 10 min, there were some duplicate records in the imported data, which were deleted.

Data were collected over 28 consecutive days from 7:00 h on the 26 February until midnight on the 26 March 2014. The

Fig. 1. Taggle ear tag.

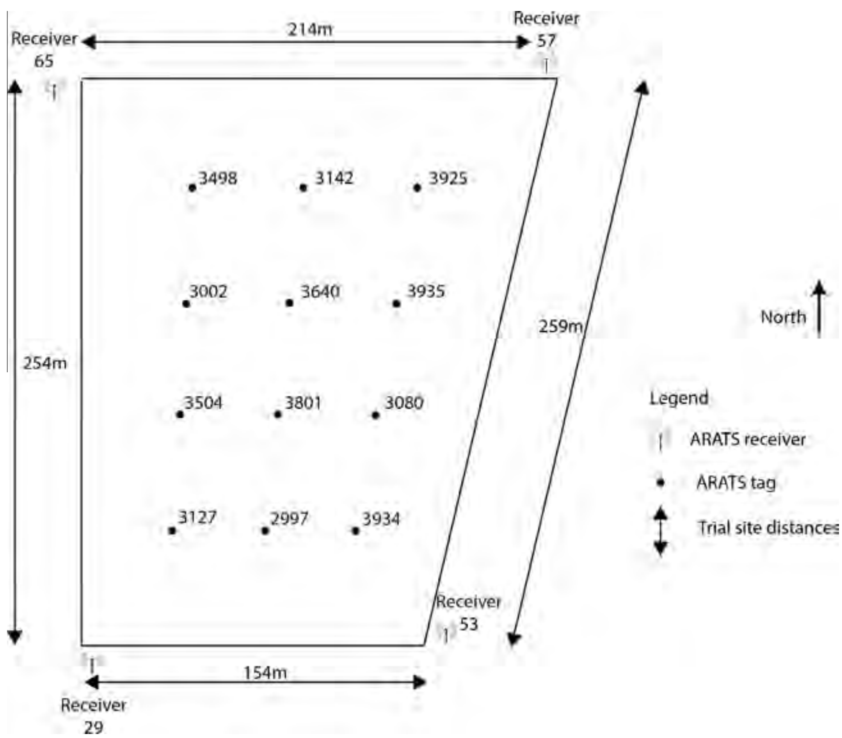

Fig. 2. Schematic representation of the four by three grid of the 12 ARATS tags.

longitude and latitude coordinates, which referenced the WGS84 datum, were converted with the MapInfo Geographic Information System software (version 12.5.2) (MapInfo, 2013) to Map Grid of Australia Universal Transverse Mercator (UTM) Cartesian coordinates which reference the Australian Geodetic Datum (GDA94) (Zone 56).

The Euclidean distance (d) from the mean location of each tag was calculated in Microsoft® Excel® 2010 (version 14.0.7132.5000) using:

$$d = \sqrt{(x_a - x_b)^2 + (y_a - y_b)^2} \quad (1)$$

where x_a is easting location, x_b is the mean easting location, y_a is the northing location and y_b is the mean northing location.

Data from the 28 days of the trial and the 12 tags was summarised to show daily fluctuations in precision. As the distance for each derived location from the mean location was not normally distributed, the data underwent log transformation ($\log_{10}$) before further statistical analysis. Results from the diurnal patterns were compared with meteorological data for the period of the trial, which was obtained from the Australian Government Bureau of Meteorology for the Rockhampton Airport Station (station number 039083) (Bureau of Meterology, 2015).

In order to assess whether the precision of the location derived for each tag drifts over time, data were subsampled at different time intervals. The Taggle derived locations could potentially be used to calculate animal speed and patch selection, as has been done with GPS (Swain et al., 2008a), but only if there was no effect of time interval between locations on precision. One thousand iterations were run to calculate the distance between transmission pairs, with the time between transmissions varying from 15 min to 28 days.

The distance between each tag was assessed by grouping transmission times into 15-min blocks and then comparing the distance between each tag against all other tags across the life of the project. If two transmissions for the one tag were recorded in the same 15-min period, the first transmission was used in the calculation. The distance between each tag for each 15-min period was then averaged to show the distance between tags over the period of the trial.

Code was written in R Foundation for Statistical Computing (version 3.1.1 (2014-07-10)) (R Core Team, 2014) to statistically analyse the data and provide graphical presentations.

3. Results and discussion

The Taggle technology relies on a transmiting ear tag to send a signal to land-based receivers. At least three Taggle receivers are required to receive the radio signal to derive a location. The effect of a fourth Taggle receiver attaining the radio signal was not evaluated in the current study, as the output from Taggle Systems does not show how many receivers were used to calculate the location.

There were 36,452 transmissions from the 12 tags, producing a minimum of 1993, a mean of 3038 and maximum of 3259 transmissions per tag. The tags used in this study were programmed to transmit every 15 min; however, the majority of tags had a mean transmission interval of 13.3 min. Tag ID 3142 only recorded data on 18 days of the trial, missing the first day and nine consecutive days at the end of the trial and thus only recorded 1993 transmissions. The mean number of transmissions collected for the 11 other tags was 3132 transmissions with a SD of 77.1.

The mean location for each tag, calculated using the UTM Cartesian coordinates, were imported into Google Earth (Version 7.1.2.2041) to show the derived location of each tag within the CQIRP landscape (Fig. 3).

3.1. Precision – distance from mean

The overall mean precision of the tags was ±22 m with a SD of 49 m. This variability is similar to that recorded for a static array of GPS collars (8.83 m) in an open field test (Agouridis et al., 2004). Fig. 4 shows the variation for each of the 12 ARATS tags as individual scatterplots.

Tag 3142 had the overall greatest variance (±58 m), followed by tag 3498 with a variance of ±51 m, both of which were located on the northern end of the trial site. The tag that showed the least variation was tag 3801, which was located in the middle of the trial site. Communications with Taggle Systems after the completion of the study has indicated that receivers should not be closer than 50 m to the tags (pers comms Gordon Foyster). Therefore, the increased precision in the middle section of the trial site may be a result of tags being an ideal distance from the receivers; however, this relationship was not consistent as some tags (3934 & 3925) close to the receivers still performed better than the mean precision.

Tag 3801 had considerably less variation in the distance from the mean, with the majority of data points within 20 m and all data points within 108 m. This contrasts with tag 3142, which had a much larger variance in the distance from the mean, with the maximum reading being 2653 m. All tags exhibited a positively skewed distribution from the mean.

The use of TDoA for geolocation relies on being able to measure the wave signature at each receiver and use phase synchronisation of the transmitted and received signals to determine the arrival time (Munoz et al., 2009). The radio signal from the transmitter is subject to a number of inaccuracies including reflection and refraction. In this study, the mobile devices were stationary to avoid the effect of changing environments associated with a moving transmitter. Despite the tags being stationary, it is clear that there are temporal and spatial factors that affected the precision of the tags.

Electromagnetic transmissions are subject to various propagation effects including multipath, non-line-of-sight, destructive interference and possibly others. The multipath effect causes the signal to reach the receiving antenna by two or more paths rather than solely through direct line-of-sight (Torrieri, 1984) and arrives at the receiver delayed, attenuated and phase-shifted (Gentile et al., 2012). The multipath effect is exacerbated if the signal cannot reach the receiver by direct line-of-sight, that is, the direct path is completely blocked by some structure in the environment. These non-line-of-sight issues, when combined with multipath effects, introduce biases in the algorithms that estimate the distance and locate the transmitting device (Gentile et al., 2012). Structures such as hills and buildings surrounding the trial area may result

Fig. 3. Google Earth image (37 m above sea level) of the trial site showing the mean locations for each of the 12 ARATS tags. Note the four receivers at the boundary of the site.

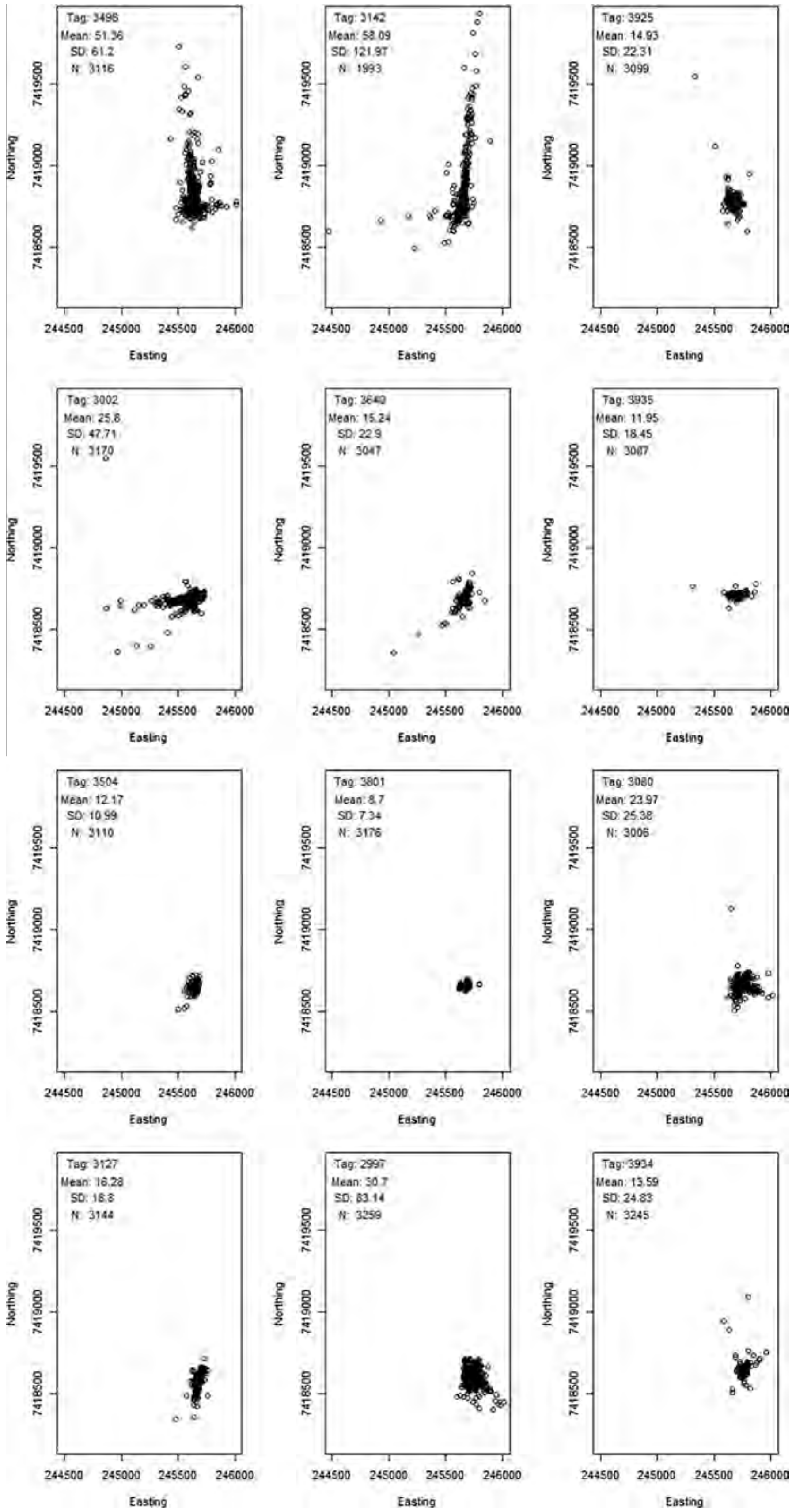

Fig. 4. Precision of the 12 ARATS tags over the life of the trial.

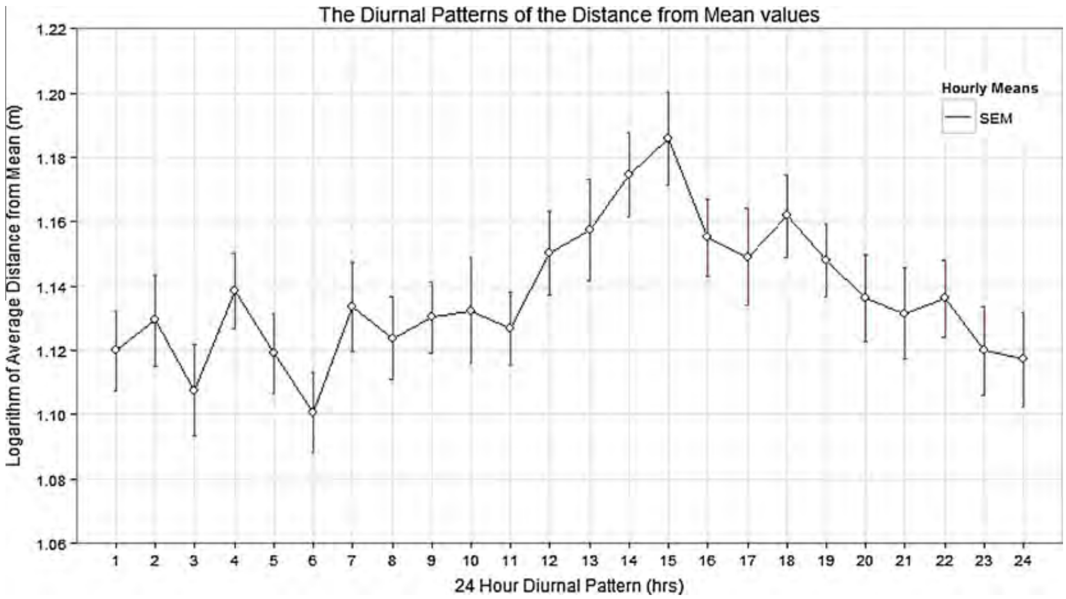

Fig. 5. Daily variation in precision of tags showing average distance from the mean per hour with standard error of the means shown in error bars.

in multipath effects generating erroneous locations for ARATS tags. Destructive interference is caused when two wavelengths are at the same frequency but approximately 180° apart in phase with the result being a wave of lesser amplitude. As mentioned, the phase-shifted signals are routinely attributed to multipath issues (Gentile et al., 2012) and result in a delay and distortion in the signal when compared with the line-of-sight signal (Ramírez, 2011).

There is a large body of research on signal propagation of radiolocation systems, historically with GPS but more recently with Ultra-wideband (UWB) systems used to track people and assets within indoor environments. Similar propagation effects have been observed in UWB signals when plotting position estimates and comparing the Euclidean distance from the mean position estimate, as was done in our study. Suski et al. (2012), in their study using Ubisense tags in a 13×10 m indoor facility, found that approximately 25% of locations showed a multi-modal distribution with as many as three possible data clusters. Their results showed the same elongated position plots as were exhibited by tags 3498, 3142, 3002 and 3640 in our study. Suski et al. (2012) found that the magnitude of the error vector, which is the distance from the actual location to the mean position estimate, in the locations that were poorly estimated, was twice that of those locations showing a Gaussian distribution. The authors attributed the error in the system to multipath and non-line-of-sight effects as well as some unknown measurement noise. Therefore, the errors in the tags located in the northern section of our trial site would appear to be because of multipath and non-line-of-sight effects between the tags and presumable the southern receivers.

The relative spatial variability in the precision of tags was assessed by analysing the data for diurnal fluctuations; drift in precision over time and differences in precision between tags. The absolute variability of each tag compared with a survey location was not assessed due to our focus on precision rather than accuracy.

3.2. Diurnal fluctuations in precision

The precision of location data showed a stable pattern from 1:00 through to 11:00 and from 17:00 to midnight of between ±20 and ±23 m but a pronounced increase in variance from between 11:00 to 17:00 h. Overall, the variance in precision, when summarised for all tags over 24 h, was approximately ±9 m from the most to the least precise period. Due to the positively skewed nature of the distance from the mean data, it was $\log_{10}$ transformed (see Fig. 5).

The 24-h diurnal data was further analysed to compare each hourly value against all other values. Due to the unequal variance in the data, the Welch two sample t-test was used, with results deemed significant at the $P < 0.05$ level. The period between 14:00 and 15:00 h was statistically significant compared to most other hourly values, as shown in the Table 1 below (other periods, such as 6:00 h, showed statistically significant differences from other times but for brevity the focus was given to the peak in variation at 14:00–15:00 h).

Table 1
Diurnal fluctuations in precision of Taggle tags.

Diurnal pattern (h)	Distance from mean	SEM
1	1.120[a,b]	0.012
2	1.129[a,b]	0.014
3	1.108[a,b]	0.014
4	1.138[a,b]	0.012
5	1.119[a,b]	0.012
6	1.101[a,b]	0.013
7	1.134[a,b]	0.014
8	1.124[a,b]	0.013
9	1.130[a,b]	0.011
10	1.132[a,b]	0.016
11	1.127[a,b]	0.011
12	1.150	0.013
13	1.157	0.016
14	1.175	0.013
15	1.186	0.014
16	1.155	0.012
17	1.149	0.015
18	1.162	0.013
19	1.148[b]	0.011
20	1.136[a,b]	0.014
21	1.131[a,b]	0.014
22	1.136[a,b]	0.012
23	1.120[a,b]	0.014
24	1.117[a,b]	0.014

[a] Values are significantly different ($P < 0.05$) from 14:00 h.
[b] Values are significantly different ($P < 0.05$) from 15:00 h.

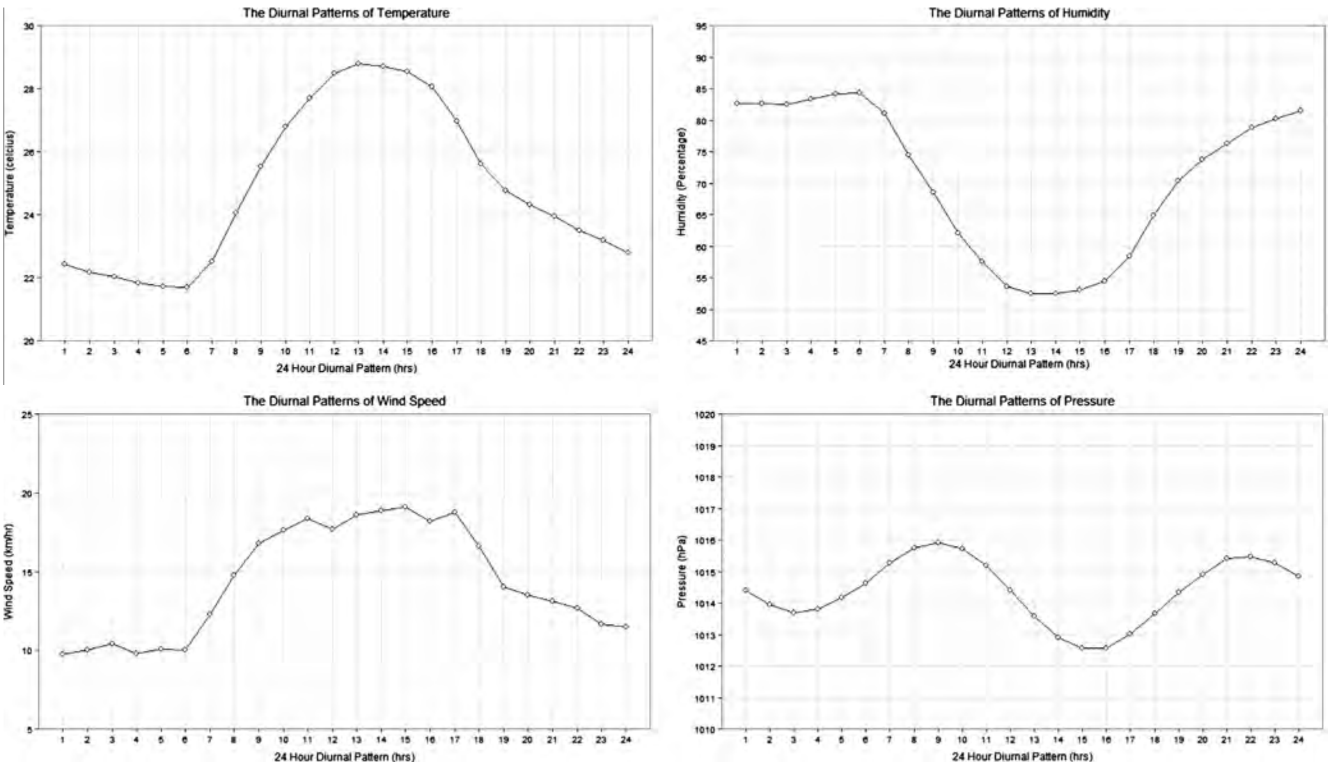

Fig. 6. Diurnal fluctuations in meteorological indices (temperature, humidity, wind speed & pressure) for the duration of the trial.

The diurnal pattern in the precision of the tags were compared with meteorological data for the same period which included temperature (°C), relative humidity (%), wind speed (km/h), mean sea-level pressure (h Pa) and precipitation (mm). The diurnal pattern for the first four of these meteorological indices are presented graphically in Fig. 6 below (rainfall was very sporadic during the trial with only 6 days registering more than 1 mm of precipitation).

Pearson's correlation coefficients were calculated for each of the meteorological indices compared to the precision data with the results presented in Table 2.

Temperature, humidity, wind speed and pressure all showed a statistically significant correlation to the precision of the diurnal distance from mean data.

The results suggest that variations in temperature, relative humidity, wind speed and barometric pressure are responsible for some of the inaccuracies. It is not clear whether these factors are directly affecting the EMR signal or whether the climatic factors are having a direct effect on the operation of the hardware, either the transmitters or receivers.

3.3. Drift in precision

Researchers have shown that GPS positional data is subject to drift when results from static units are compared over time (Swain et al., 2008a). GPS drift is defined as the drifting of position coordinates when the GPS receiver is stationary and is attributed to varying satellite configuration, satellite data errors and signal bounce off objects within the landscape (Mullenix et al., 2010). This has implications for the desired fix rate to use when assessing animal behaviour, which in turns effects the power consumption of the GPS device. The premise behind the drift in precision assessment is that two points that are close in time should have an equivalent distance between them as two data points further apart in time. If the distance between points increases with time, this would mean that precision drifts over time. For each tag, 1000 transmission pairs were randomly selected and the distance between transmission (mean & SD) were calculated. These data showed the same level of variance as the distance from the mean data with those more precise tags having less distance between transmissions and the less precise tags having a greater distance. Table 3 below shows each tag with the mean and SD.

Fig. 7 shows the distance between locations for the 1000 randomly selected transmission pairs for the least and most precise tags. Each graph has a regression line fitted to the data and although there are large differences in the distance between transmissions, illustrated by the much higher mean, SD and y-intercept of Tag 3142, the coefficient of Time, does not show a positive slope. All tags had the same result with none showing a trend towards an increase in the distance between transmissions as the time between transmissions increased, which would have been the case if there were a drift in precision over time. It should be noted that the Taggle ear tags transmit much less frequently than the fix rates used by the GPS collars that exhibited drift in accuracy. Swain et al. (2008a) showed, when using GPS collars that acquired two locations every second, that as fix rates increased from 1 to 5 min the distance between points increased, whereas the Taggle ear tag average transmission time was approximately 13.3 min.

3.4. Proximity – distance between tags

The study of animal associations, such as deducing maternal parentage (Swain and Bishop-Hurley, 2007) or oestrus activity (O'Neill et al., 2014), enables a biological event to be inferred based on the proximity of animals. In the current study, it was possible to use the static tag layout to determine the effect of location on proximal variance. In particular, it is determined herein that the nearest tags had smaller proximal variance compared to the tags that were furthest apart. In general, the tags that had the greatest distance between the mean derived locations also tended to have the greatest variance. As the mean distance between tags increased, the variation also increased, as shown in Fig. 8 below.

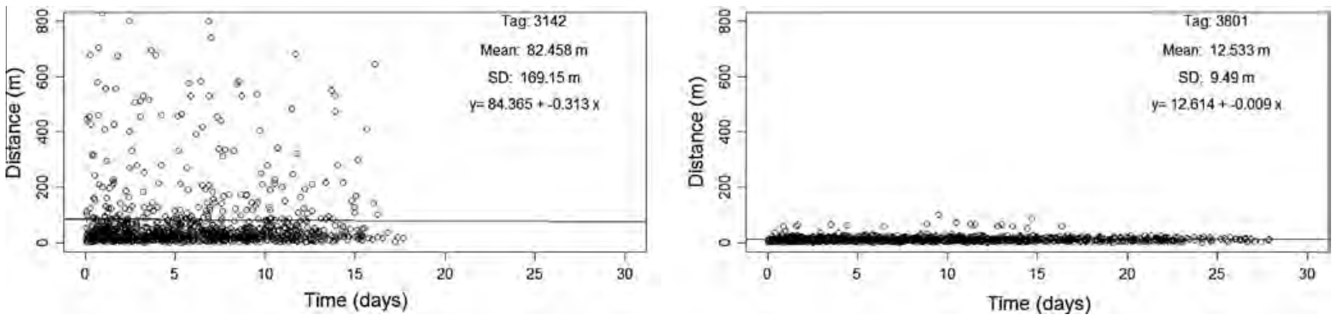

Fig. 7. Taggle distance between transmission pairs for the most and least precise tags.

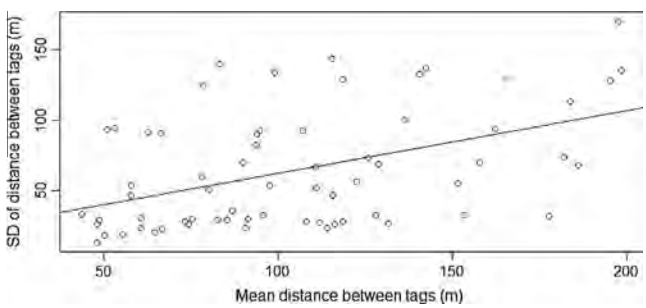

Fig. 8. Mean distance between tags V's SD of distance between tags for all tag combinations.

Table 2
Pearson's correlation coefficients between meteorological indices and diurnal precision.

Meteorological indices	Correlation coefficient
Temperature (°C)	0.766[a]
Relative humidity (%)	−0.780[a]
Wind speed (km/h)	0.733[a]
Pressure (h Pa)	−0.603[a]
Rainfall (mm)	−0.102

[a] Values are significantly correlated ($P < 0.05$) to the diurnal distance from mean values.

Table 3
Taggle tag with the mean and standard deviation of distance between transmissions.

Tag	Mean	SD
2997	41.748	36.398
3002	37.844	67.304
3080	34.720	31.232
3127	23.697	23.818
3142	82.458	169.150
3498	71.877	88.274
3504	17.588	17.146
3640	24.429	36.871
3801	12.533	9.490
3925	22.898	21.942
3934	20.206	29.637
3935	18.732	29.498

4. Conclusions

This scoping study provides the first documented information on the precision of automated radiolocation tags. The results show the overall precision of a static array of location tags was approximately ±22 m, although there was large variability between individual tags, with the most accurate having a variance of ±8 m and the least accurate being greater than ±51 m. The tags appear to be less precise than commercial GPS animal-tracking collars and susceptible to multipath and non-line-of-sight issues as is the case with other radiolocation technologies transmitting at similar frequencies.

Despite the variability in the derived locations, the automated location tags may still have value if used to address both animal behaviour research and commercial livestock applications, especially in the evaluation of large numbers of animals. The radiolocation system is both more cost effective and practical as the transmitter tags are both smaller and use lower power enabling longer deployment. An automated radiolocation system also enables more efficient data capture, as devices are not required to be removed from the animal to download the data.

The diurnal fluctuation in the precision of Taggle tags indicates that the derived location is effected by climatic parameters especially ambient temperature, wind speed, humidity and pressure. These metrics may account for an approximate ±9 m variation from the most accurate to the least accurate time of day. The effect of less precision in the mid-afternoon period may not be an issue if the time used to derive associations is more like days rather than hours. For instance, if a mating event could be assumed based on increased associations between a cow and a bull for a 24-h period within a 21-day oestrus cycle, the decrease in precision over a short time frame maybe in inconsequential. The Taggle system is commercially available and the user does not have access to the raw data or backend calculations. If the system was to include prevailing atmospheric parameters when calculating TDoA, potentially the precision of the derived location could be improved.

Due to the low transmission rate, compared to GPS technology, it would appear that the radiolocation precision is not affected by the time difference between transmissions. Previous work has indicated that GPS fix rates need to be less than 1 location per 10 s to ascertain grazing patch selection in an area of between 10 and 100^2 m (Swain et al., 2008b). It can therefore be concluded that these ARATS tags will only be able provide relatively low-resolution data on grazing preferences of domesticated livestock. In rangeland environments the data may still have value, however further work would be required to determine reliable measures of location accuracy.

The locations derived from the ARATS tags used in this study are not as precise as GPS data reported in the literature. The lower precision achieved with this radiolocation system would be most suited to tracking animals in extensive environments such as the grazing systems of northern Australia. The automated data transfer and low power requirements are also well suited to extensive animal monitoring. When animals are dispersed in the landscape, such as in low stocking-rate grazing systems, the precision and hence ability to derive animal associations from the system, may be adequate. Further work would be required to test whether the ARATS tags achieve the same level of precision in a dynamic test, as the results presented in this study.

Although this scoping study has provided initial results on the potential value of an automated radiolocation system, further work is required to determine what is causing the errors that lead to a lack of precision. These preliminary results indicate that there is an intrinsic error in the derived location when line-of-sight transmission is impeded and that there appears to be a correlation with weather parameters.

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