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Use of unmanned aerial vehicles (UAVs) and photogrammetric image analysis to quantify spatial proximity in beef cattle

¹Justin T Mufford, ²David J Hill, ¹Nancy J Flood, ³John S Church[□]

¹Department of Biological Sciences, Thompson Rivers University

²Department of Geography and Environmental Studies, Thompson Rivers University

³Department of Natural Resources Science, Thompson Rivers University

[□] Corresponding author at: Department of Natural Resource Science, Thompson Rivers University, 805 TRU Way, Kamloops, V2C 0C8, Canada. Email address: jchurch@tru.ca

Abstract

Spatial proximity is an important metric in cattle behaviour, which is used to study social structure, dyadic relationships, as well as grazing and maternal behaviours. We developed an efficient, novel, non-invasive method to quantify the spatial proximity of beef cattle by using UAV-based image acquisition and photogrammetric analysis. Orthomosaics constructed by images obtained from UAVs were used to measure, with an accuracy of ± 1.96 m (95% likelihood), the inter-individual distances between cows and calves. Aerial videos of the calves and their dams, held in a 5-ha pasture, were made over four days using UAVs. We used two UAVs to video-capture the following: (1) the location of all individuals (UAV flown at 100 m) and; (2) the identity of cow-calf pairs (UAV flown at 15–30 m). Still-images extracted from the UAV-acquired video screenshots were used to produce orthomosaics. The orthomosaics captured all the cows and calves in a single image, from which we measured the distance between related and non-related cow-calf pairs. This UAV-based orthomosaic method clearly showed that members of related pairs were closer than non-related ones, and that the distance was greater in the evening, demonstrating the utility of UAVs to accurately measure cattle spatial proximity.

Key words: Remote Sensing; Photogrammetry; Social Behaviour; Spatial Relationships; Unmanned Aerial Vehicle (UAV); Beef Cattle

Introduction

Understanding the social behaviour of cattle is important for optimizing production and maintaining animal welfare. Cattle (*Bos taurus*) are gregarious and exhibit a complex social structure, including the establishment of (Sowell et al. 1999) linear and/or triadic social hierarchies at herd and sub-herd levels (Schein and Forhman 1955). This structure plays a role in disease transmission (Laguna et al. 2018; Marquetoux et al. 2016; Bohm et al. 2009) and influences the efficacy of management practices such as animal grouping (Grant and Albright 2001; Phillips and Rind 2002), herding, selective culling, and supplemental feeding (Sowell et al. 1999). The social environment of cattle plays a significant role in animal welfare, productivity and behavioural and cognitive development (reviewed by Costa et al. 2016); for example, in calves, early social contact reduces post-weaning stress (Bolt et al. 2017). Poor management of animal groupings leads to an increase in social stress (Bøe and Faerevik 2003), especially for low-ranked individuals (Miranda-de la Lama et al. 2013), which may have restricted access to important resources; for example, displacement by dominants at feeding sites potentially slows their growth (DeVries and von Keyserlingk 2006; Katainen et al. 2005). Cattle also seem to develop affiliative relationships, as demonstrated by the existence of preferential feeding partners and behaviours such as allogrooming (Val-Laillet et al. 2009); this too should be an important practical consideration when managing groups.

Spatial proximity is an important metric of social behaviour in cattle. Inter-individual distances and spatial segregation has been used to study social structure (Finger et al. 2014; Harris et al. 2007) and dyadic relationships (Gutmann et al. 2015; Val-Laillet et al. 2008). The frequency and duration of close-proximity contacts has also been used to study dyadic relationships (Handcock et al. 2009; Swain and Bishop-Hurley 2007) and to provide the basis for social network analysis

(Bolt et al. 2017; Boyland et al. 2015). Spatial proximity is also useful for identifying cattle in estrus (O'Neill et al. 2014), studying maternal (Hirata et al. 2003) and grazing behaviours (Schauer et al. 2005), and monitoring inter-species interactions (Drewe et al. 2012).

The methods currently used to study spatial proximity are limited in reliability, accuracy and data-acquisition capability. For example, inter-individual distances have been quantified through visual methods (Val-Laillet et al. 2009; Harris et al. 2007; Hirata et al. 2003); however, the presence of observers in the field, whether stationary or moving, can affect cattle behaviour, and thus the validity of results (reviewed by Waiblinger et al. 2006). In addition, observers are limited in their ability to take notes quickly (Sueur et al. 2018; Finger et al. 2014; Patison et al. 2010), follow the animals (Boyland et al. 2015), and/or properly position their video cameras to capture every desired individual (Harris et al. 2007). Alternative methods, such as using overhead video cameras facilitate observation of cattle behaviour, but limit research sites to enclosed structures (Gutmann et al. 2015; Val-Laillet et al. 2008). Global positioning system (GPS) collars can obtain the locational position of cattle (Handcock et al. 2009), but measurements have time-dynamic positioning errors of up to 15 m. (Anderson et al. 2013). Radio-based transponders (Gygax et al. 2010; Gygax et al. 2007) can provide highly accurate location information (within 0.5 m); however, this technology is costly, requires expertise, and poses logistical challenges such as limited battery life, equipment malfunctions, and interference from built-up structures. Close-proximity contacts are typically recorded by radio-emitting contact collars (Bolt et al. 2017; O'Neill et al. 2014; Swain and Bishop-Hurley 2007), yet these devices miss information on key behaviours; some researchers thus choose to supplement this data with field or video observations (Boyland et al. 2015; Patison et al. 2010).

To address the challenges and limitations of current techniques, we developed an efficient, non-invasive method to simultaneously quantify the spatial proximity of cattle and collect aerial video of cattle using unmanned aerial vehicles (UAVs) and photogrammetric image analysis. This method was designed to measure inter-individual distances between cows and calves in a field setting.

Over the last decade, remarkable technological advances have been made in the development of UAVs in terms of battery life, data-collecting capability, and operation (Whitehead et al. 2014a; Whitehead et al. 2014b). UAVs have been successfully used for wildlife monitoring (reviewed by Linchant et al. 2015), cattle enumeration (Chamoso et al. 2014, Whitehead et al. 2014a) and in animal behaviour studies (UAF 2017; Hodgson et al. 2017; Nyamuryekung'e et al. 2016).

The next section details the UAV-based distance measurement method and the field study that was used to validate the method.

2. Methods

All the procedures used in our experiments were approved by the Animal Care Committee of Thompson Rivers University (Kamloops, Canada).

2.1 Field Site

Twelve Angus/cross beef cows (*Bos taurus*) and their single, 4-month-old calves were studied over a 7-day period during the month of June, 2016 at the Agriculture and Agri-Food Canada (AAFC) Lethbridge Research Centre, located on the outskirts of the city of Lethbridge, AB, Canada. The cow-calf pairs were held in a 5-ha fenced and treeless pasture throughout the study. Each cow-calf pair was uniquely identified with the use of penning tags (Wheel'n'Tree

Enterprises, www.penningsupplies.com) and coloured fabric squares (22.9 x 50.4 cm) glued to their backs with tagging cement.

2.2 Habituation to UAVs

Two DJI Phantom 4 quadcopters (Dà-Jiāng Innovations Science and Technology Co., Ltd, Shenzhen, China) with integrated 12-megapixel video cameras were used in the study. Three days prior to data collection, we allowed cattle to acclimatize to the UAVs hovering above and remaining stationary at an altitude of 10 m above ground level (magl), in front of, to the side of, as well as behind, them. In addition, we allowed cattle to acclimatize to the UAVs flying past them at speeds of up to 65 km/hr at an altitude of 30 magl. On the first day of the habituation period, each animal reacted when the UAV was within 10 magl; many raised their heads directly upwards to look at the UAV when it was hovering in front and above them. We also observed cattle raising their heads and turning their heads towards the side to look at the UAV when it was hovering behind them or at a lateral distance of up to 10 m and an altitude of 10 magl. After repeating this for three days, none of the cattle showed any observable behavioural responses to the UAVs when they were hovering within 10 m (in any direction). We did not observe cattle responding to UAVs flying past them at an altitude of 30 magl at any time during the habituation period.

2.3 Field Data Collection

Following the 3-day habituation period, the UAVs were used to acquire cow-calf proximity data over a 4-day period (Day1–Day4). Each day was divided into a daytime (Day: D) and an evening (Eve: E) data collection period. The Day period extended from 10:00 to 16:30 hours, while the Eve period extended from 17:30 to 21:30 hours. During each sampling period, aerial image

acquisition was attempted every 15 minutes, resulting in 26 and 16 possible image acquisition times during the Day and Eve periods, respectively. The images acquired during each of these flights were used to measure the distances between calves and their dams (i.e., their mothers), as well as the distances between calves and each of the other 11 cows in the herd. These measurements constitute a temporal sample of cow-calf proximities, which is comprised of 12 distance measurements for calf-dam pairs and 122 distance measurements for calves and non-related cows. This sample was analyzed to explore whether the proximities of cows and calves varied with kinship (i.e., Calf-Dam vs Calf-Other) or time period (i.e., Daytime vs. Evening).

Poor weather prevented the UAV from flying during 2 of the 8 possible sampling periods: Day1-E and Day3-E. Furthermore, episodic wind/rain prevented some flights on other days of the study. As a result, differing numbers of samples were acquired during each sampling period, as shown in Table 1.

At each of the 76 sampling points throughout the data collection period, we flew both UAVs simultaneously, but at different altitudes. One pilot flew at an altitude of 100 magl and the other pilot flew at 15 and 30 magl. Both pilots video recorded the herd at 4K resolution and 24 frames per second (fps).

We took screenshots of the video collected from the 100 magl flight to obtain jpeg images of the cattle herd at every sampling point. In most of the videos, the herd was too widely spaced to capture every individual in a single frame. Thus, we used multiple, overlapping screenshots to capture the entire herd. These images were processed using Agisoft Photoscan Pro (Agisoft LLC, St. Petersburg, Russia), a photogrammetric software package, to produce an orthomosaic of the entire region encompassing the herd (Figure 1a-d).

Figure 1a-d.

Agisoft Photoscan Pro uses a structure-from-motion algorithm to create a 3-D model of the land surface from these overlapping images. This 3-D model is then used to orthorectify the images and mosaic them into a single orthomosaic image that simulates an undistorted nadir perspective of the land surface, with consistent spatial resolution throughout the image. Due to the constant scale, and the relatively small spatial region represented within the orthomosaic, we then

assumed that straight-line distances within the image are good estimates of the corresponding real-world distances.

Cow-calf distances were calculated using ImageJ (Version 1.51j8), an open-source image processing program that is maintained by the US National Institutes of Health. First, an image scale for each orthomosaic was determined using a reference object of known length that was visible within the orthomosaic. The image scale relates pixel-based coordinates (i.e., row/column) into a coordinate system with real-world length units relative to the upper-left hand corner of the image and is necessary for calculating real-world distances based on the corresponding (scaled) distance within the image. The location of each animal within the orthomosaic was then approximated by retrieving the image coordinates of the image pixel at the centre of the penning tag on the back of each animal. Using these coordinates, and the image scale, the distances between calves and their mothers (Calf-Dam group) and the distances between calves and non-related cows (Calf-Other group) were then measured.

Depending on the location of the cattle within the research pasture, one of three different reference objects was used to calculate the image scale, based on which object was closest to the cattle: (1) a feeding trough that was 3.51 m in length, (2) two fence posts that were 42.6 m apart, and (3) two fence posts that were 30 m apart. (Figure 2a). Each reference object had been measured in the field prior to the study. The video recorded at an altitude varying between 15 and 30 magl was used to determine the identity of each individual cow and calf on the orthomosaics (Figure 2b-c).

At each sampling point, we measured the distance between each calf and its dam as well as the distances between each calf and all 11 other cows in the herd. Thus, each temporal sample of cow-calf proximity comprised 12 distance measurements of calf-dam pairs and 122 distance

measurements of calves and non-related cows. We analyzed these data according to kinship (i.e., Calf-Dam vs. Calf-Other) and by time period (i.e., Day vs. Eve).

Figure 2a-c.

2.4 Validating Distance Estimates

To validate the procedure for calculating the image scale and the image-based distance estimation method, we compared the estimated and actual lengths of reference objects visible within the images. This analysis was performed on a sample of 11 orthomosaics in which two reference objects are visible. The 11 orthomosaics were selected by stratified sampling from the set of 76 orthomosaics generated from each of the sampling periods, such that two orthomosaics were selected from each of the six sampling periods, except for Day2-D, for which only one

orthomosaic was generated. For each of the 11 orthomosaics, we calculated the image scale using one of the reference objects in the image and used it to estimate the length of the other reference object (Figure 3). In each orthomosaic, the measurement of the reference object was repeated three times and the average used as the object length. We used a 2-tailed paired t-test to test our null hypothesis that the mean difference between the estimated and true distances is equal to zero and a Ryan-Joiner normality test to determine if the differences were normally distributed.

Figure 3.

2.5 Cow-Calf Proximity Analysis

Our analyses showed that the factors related to cow-calf proximity include: the day of study (days 1–4), the time period of the study (Day or Eve), and the relationship between the cow and the calf (whether the cow is the mother of the calf or is unrelated to it). Analysis of variance (ANOVA), showed that cow-calf proximity varied among days ($P = 0.0156$); thus, to remove the effect of day in further analyses, the data were standardized by day such that the mean was equal to zero and the standard deviation was equal to one. The standardized data were used in a mixed

model analysis (to account for the pseudo replication inherent in using the same animals at each sampling point) to examine the effect of time period, relationship, and the interaction between period and the relationship. We constructed the mixed model with cow-calf distance as the response variable, time period and relationship as fixed effects and individual calf as a random effect. All tests were done using JMP 13 statistical software (© SAS Institute Inc., Cary, NC, USA)

3. Results

3.1 Distance Estimation

In each of the 11 orthomosaics used to validate the distance measurement method, the measurement of the reference object was repeated three times and the average of these three measurements was used as the object length. Based on the sample of 11 orthomosaics used to test the accuracy of the distance estimation method used in this work, the mean difference between the estimated length of a reference object and its true length measured in the field was 0.4 ± 1.0 m (mean $\pm$ standard deviation) ($n = 11$). The maximum difference was 1.8 m. The estimation errors were normally distributed ($P > 0.100$) and the mean difference ($n = 11$) between the estimated and true length (i.e., the length estimation error) was not statistically different from zero ($P = 0.887$).

3.2 Cow-Calf Proximity

Time of day (i.e., Day vs. Eve) had a significant effect on cow-calf proximity ($F_{1,849} = 101.79$, $P < 0.001$) as did cow-calf kinship ($F_{1,849} = 26.75$, $P < 0.001$). There was no statistically significant interaction between the two factors ($F_{1,849} = 1.35$, $P = 0.245$). The mean cow-calf distance ($n = 576$) in the daytime was 39.8 ± 15 m (mean $\pm$ standard deviation) and in the evening ($n = 288$)

was 84.3 ± 24 m (Figure 4). The mean distance ($n = 72$) of the Calf-Dam group was 43.8 ± 24 m (mean $\pm$ standard deviation) and the mean distance ($n = 792$) of the Calf-Other group was 55.6 ± 28 m (mean $\pm$ standard deviation). Overall cow-calf distances ranged from 0.5–303 m.

Figure 4.

4. Discussion

4.1 Accuracy of Inter-individual Distance Measurements

Based on the work of Hirata et al. (2003), we assert that cow-calf proximity studies require a distance measurement method that is capable of measuring distances up to 100 m with an accuracy of ± 2 m or better. These criteria come from a study performed in a 1.1 ha paddock that found that dams were usually within 2 m of their calves for nursing activities and within 25–

50 m while grazing, and that cow-calf distances also ranged from < 20 m up to 100 m (Hirata *et al.* 2003). Furthermore, to be effective under field conditions, where cattle may be walking or foraging, it must be possible to acquire distance estimates in less than 5 minutes (Anderson *et al.* 2013).

We determined that the mean error of our distance estimate was not significantly different from zero at a significance level of 0.05. Thus, we conclude that our distance estimates are unbiased. Our statistical tests also showed that the error distribution of our distance measurements is approximately normal with a standard deviation of 1 m. Therefore, the error of our distance estimates are expected to be within ± 1.96 m of the true value 95% of the time.

It is notoriously challenging to compare published methods for estimating cow/calf distances (Anderson *et al.* 2013) and some authors simply fail to validate and/or report the estimation error of their methods (Patisson *et al.* 2010; Stricklin 1983). The positional accuracy of our method, however, is superior to the ± 7.8 m horizontal positioning accuracy (95% likelihood) of the United States' Global Positioning System (GPS) Standard Positioning Service (SPS) used by civilian GPS receivers (Government of the United States of America, Department of Defense 2008), as well as with GPS-collar based and visual estimation methods published in the literature. Anderson *et al.* (2013) reviewed the accuracy of GPS collars used in 99 free-ranging cattle studies from 1997–2012: the accuracy of GPS collars with non-biased positional estimates ranged from ± 5 –8 m and those with biased estimates ranged from 1–12 m. Hirata *et al.* (2003) claimed an accuracy of ± 5 –10 m for cow-calf distances estimated visually by multiple observers using field markers for positional references.

Additionally, most GPS receivers required 5 minutes or more to achieve a stable position fix, whereas walking or foraging cattle will require a faster fix rate (< 5 minutes) (Anderson *et al.*

2013). Image based methods, such as the one presented here, have a nearly instantaneous fix rate (i.e., instantaneous image capture), and thus, image-based methods may be preferable in studies on cattle moving across a landscape. Harris et al. (2007) presented an orthomosaic-based method to estimate inter-individual distances within a herd of cattle that exhibited an accuracy similar to that of our method (average ± 2 m, maximum ± 5 m), however, their method relied on imagery collected by hand-held video-cameras, which would not be easily applied over large spaces. The UAV-based image acquisition used in this work permits the acquisition of data by field technicians positioned far from the animals. This means that the method can scale to much larger field sites and will be less likely to result in an observer effect than work that relies on human camera operators. Furthermore, UAV-based image capture enables the operators to remain in a safe location during the entire study, rather than walking among the animals in the herd.

To meet the challenges of high-spatial accuracy and fast acquisition times, radio-frequency (e.g., radar) based methods have been suggested. For example, Gygax et al. (2007) presented data collected using radar collars that exhibited a positional error of less than ± 0.5 m, although it is not clear if this is a statement of a mean error rate, or a probabilistic interval. Not only are radio-frequency devices expensive and, thus, cost prohibitive for extensive deployment in field studies, their power requirements limit them to short-term use. On the other hand, the UAV-based method presented here has the potential to be rapidly deployed and capable of supporting longer-term observation periods with minimal cost.

4.2 Quality of the Orthomosaics

The accuracy of the distance estimation method developed in this study relies on the creation of high-quality orthomosaics. In this study, we observed two types of errors that degraded

orthomosaic quality. First, some animals' body shapes are distorted (e.g., stretched or twisted). These distortions challenged the analyst to determine the centre of the penning tag, a situation that reduced the accuracy of the distance estimates. However, this problem was uncommon: 19 of the 76 orthomosaics had only one distorted animal (out of the 24 animals present), eight had two distorted animals, and five had three. Furthermore, we suspect that positioning errors caused by distorted animal shapes were small relative to the cow-calf distances. Second, in some orthomosaics the same animal would appear twice, while in others an animal might not appear at all. This issue was even less common than distortion of animal shape, occurring in only two of the 76 orthomosaics. Other researchers have noted similar distortions when creating orthomosaics of landscapes that include visible animals (Hodgson et al. 2017; Whitehead et al. 2014b, Seymour et al. 2017). We suspect that the distortion, duplication or elimination of animals from our orthomosaics was a result either of cattle moving quickly, relative to the interval between successive image captures, or of insufficient overlap in the images. Flying the UAV faster and increasing the degree of overlap between photos would likely reduce the number of distorted animals, since there would be less time for animals to move between capture of neighbouring images.

4.3 Utility of UAV-acquired Imagery for Studying Cattle Behaviour

Operating UAVs for studying cattle behaviour is financially feasible and requires little expertise. The DJI Phantom 4 quadcopter used in this study offers automated flight paths and automated photo capture. Many UAVs have these capabilities, which can be used to produce a series of consistent overlapping photos that can be photogrammetrically processed by commercially available photogrammetry software, (such as the Agisoft Photoscan, used in this study). These software packages are relatively easy to use as they provide automated, high-throughput

processing that only requires the user to provide image files to be processed, along with selecting the desired product (e.g., orthomosaic) (Whitehead et al. 2014b).

Though UAVs may initially appear to provide a strong visual and auditory stimulus, we observed that our cattle were rapidly habituated. At first exposure, our cattle watched the UAVs flying overhead at an altitude 10 m, but after three days of habituation, they showed no response to the UAVs. Many species show little or no behavioural response to UAVs (reviewed by Christie et al. 2016), except when the UAV is flown very close to an individual (e.g., Ditmer et al. 2015). A recent study demonstrated that free-roaming cattle do not seem to be disturbed by UAVs flying at an altitude of 100 magl (Mulero-Pázmány et al. 2015) and Whitehead *et al.* (2014b) reported the same for cattle in a feedlot. Even at a closer altitude of 25 magl, UAVs had no effect on the feeding behaviour of cattle in both habituated and non-habituated groups (Nyamuryekung'e et al. 2016).

4.4 Application of Cow-Calf Affiliations

We examined the effects of time-of-day and kinship on cow-calf distance. In both the evening and daytime periods, calves were closer to their dams than to other cows in the herd. This was expected since calves require nursing from their dams and is consistent with observations made in previous cow-calf affiliation studies (Swain and Bishop-Hurley 2007; Hirata et al. 2003).

All cow-calf pairs, regardless of their relationship (i.e., Calf-Dam or Calf-Other), were closer together in the Day period than in the Eve period; average cow-calf distance in the evening was twice as large as in the daytime. This strong diurnal variation in cow-calf distances may largely be attributed to the behaviour of the dams. Beef cattle exhibit a “hiding” predator-avoidance strategy in which dams leave their calves behind during maintenance activities (grazing,

ruminating, and resting) and then return to the calf for nursing activities (grooming and milking) (von Keyserlingk and Weary 2007). In species that employ this “hiding” strategy, young animals generally reduce their activity to minimize predator risk (in contrast to species employing a “following” strategy, in which young always stay close to their mothers) (Fisher et al. 2002; Carl and Robbins 1988). In the UAV-acquired video, we noticed that cows spent more time grazing and walking in the evening than in the daytime; in the latter, they seemed to spend more time lying down. Since this study was carried out during almost the hottest time of the year in Lethbridge, we suspect that this strong diurnal variation in behaviour may be due to the lack of shade in the pasture, which would make daytime foraging uncomfortable. However, our anecdotal observations do not provide sufficiently reliable evidence to fully explain the diurnal variation.

5. Conclusion

We have developed, validated, and demonstrated the use of a novel, efficient and non-invasive method to quantify the spatial proximity of cattle in a field setting, using UAV-based image acquisition and photogrammetric processing and analysis. Orthomosaic-generated UAV-acquired imagery allows for the study of spatial relationships among cattle in their environmental and social context. Orthomosaics provide high-resolution images of animals in the herd relative to its resources (e.g., grazing and watering sites). Environmental conditions provide useful information as they affect the spatial distribution of cattle (Handcock et al. 2009; Harris et al. 2007; Sowell et al. 1999). Our orthoimages clearly show the position of each animal in the entire herd, from which dyadic relationships and social structure can be studied.

Our technique of using two simultaneously operated UAVs potentially offers an integrative approach to studying social behaviour, in which both (1) behavioural scoring of individual activity (e.g., grazing, lying) and dyadic interactions (e.g., fighting, allogrooming) and (2) spatial data can be collected simultaneously in 15-min scans. For example, we observed individual activity (e.g., resting, foraging and ruminating) and dyadic interactions (e.g., grooming, head-butting, chasing) in videos collected by our UAV flown at 15–30 magl. This temporal resolution of behavioural observation would be sufficient for future studies; the literature reports sampling rates for recording behavioural and spatial data that range from 5–15-min intervals (Sueur et al. 2018; Val-Laillet et al 2009; Harris et al. 2007). On two of the eight sampling periods poor flying conditions due to inclement weather limited data collection. Beyond wind or rain, we speculate that dense forest canopies may further serve to diminish the practicality of this technique; in pasture settings, however, many of which have little or no tree cover, the effect of canopy will be negligible.

Consumer-grade UAVs are affordable and offer user-friendly capabilities; in addition, commercially-available photogrammetric software offers high-throughput and semi-automated processing. Our UAV-based method of estimating inter-individual distances in cattle can be used to further our understanding of the role of spatial proximity in the social behaviour of cattle. The knowledge gained would ultimately be beneficial for cattle industry managers who are trying to develop and implement best practices.

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Table 1. Number of aerial imaging flights (samples) performed during the eight sampling periods of the study period.

Sampling Period	Number of Samples
Day1-D	7
Day1-E	0
Day2-D	17
Day2-E	12
Day3-D	13
Day3-E	0
Day4-D	14
Day4-E	13
Total	76

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Figure Captions

Figure 1a-d. Video screenshots of the cattle herd in the research pasture collected from a DJI Phantom 4 quadcopter at an altitude of 100 magl (a-c). Multiple photos of the herd were integrated into an orthomosaic of the entire herd (d).

Figure 2a-c. An example of an orthomosaic used to determine cow-calf distances. Two fence posts that were 42.6 m apart was used a reference to calculate the scale of the orthomosaic (a). Two photos obtained from taking a screenshot from the UAV flying at an altitude of 15 magl are shown (b and c) around the orthomosaic (a). Photos screenshotted from the low-flying UAV were used to identify each individual in the orthomosaic. The magenta, blue, and green arrows show that the cattle in the orthomosaic can be identified using the photos obtained from the low-flying UAV.

Figure 3. An orthomosaic used to test the accuracy of the distance measurements made on the ImageJ program. In this example, reference 1 is a feeding trough that was used to calculate the image scale. The distance of reference 2, the length between two distinct fence posts, was then estimated; this estimation F

Figure 4. The distribution of cow-calf proximities. Proximities of each of the 144 animal pairs were averaged across each sampling period and were plotted by relationship and time of day.