Final report

'uSuckled': Detection of maternal behaviours associated with suckling in beef cattle

Project code: B.GBP.0058
Prepared by: Kieren McCosker[1,5], Greg Bishop-Hurley[2], Reza Arablouei[2], Rachel Bender[1],
Georgia Glasson[3], Imtiaz Randhawa[4] and Michael McGowan[4]
[1]Queensland Alliance for Agriculture and Food Innovation, The University of Queensland, Gatton Qld 4343
[2]Commonwealth Scientific and Industrial Research Organisation
[3]Livestock Industries, Northern Territory Department of Industry Tourism and Trade, Katherine NT 0851
[4]School of Veterinary Science, University of Queensland, Gatton Qld 4347
[5]Formally Livestock Industries, Northern Territory Department of Industry Tourism and Trade, Katherine NT 0851

Date published: 30 May 2023

PUBLISHED BY
Meat & Livestock Australia Limited
PO Box 1961
NORTH SYDNEY NSW 2059

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

This study investigated the possibility of remotely detecting suckling behaviour in free-grazing cows using attached remote monitoring devices. The purpose of this study was to test the concept of potentially developing a non-invasive method using dam-based data to estimate the timing of suckling as a potential way of assessing normal suckling behaviour, and identify instances of premature cessation of suckling, indicating self-weaning or mortality events.

At the Katherine Research Station, located in Katherine, NT, remote-monitoring collars and ear tags equipped with GPS loggers accelerometers were fitted to the neck and ear of approximately 30 pregnant Brahman heifers, about one month before their expected calving dates. Ear tags equipped with accelerometer and GPS were also attached to the resulting calves whenever practical after birth.

The data obtained from the cow-calf pairs' sensors were compared with corresponding observations derived from a comprehensive behavioural sampling protocol, including video recordings and direct observations. Machine learning techniques were utilised to identify distinct accelerometer patterns associated with calf suckling and a cow being suckled.

This study contributes valuable insights into the potential of remote technology for monitoring suckling behaviour in beef calves and cows. It highlights the effectiveness of ear tag accelerometers and emphasises the need for further validation. The results suggest that accurately recognizing calf suckling behaviour based on accelerometer readings from ear tags is feasible providing that sufficient labelled data is captured. However, detecting when a cow is being suckled using either a collar or ear tag accelerometer data is not achievable with the dataset generated in this study. Additionally, the findings caution against solely relying on suckling duration as an indicator of milk and energy intake in calf growth. Continued research in this field will contribute to enhancing our understanding of suckling behaviour and improving management practices in beef production.

Executive summary

Background

Losses from pregnancy diagnosis to weaning have been a significant factor contributing to reduced productivity in northern Australia's beef breeding herds. Extensive research employing conventional methods has identified various risk factors associated with calf survival during the first week of life. However, there is an urgent need for research tools that can accurately detect calving events, assess calf viability during critical periods, and be implemented on a commercial scale.

The automated monitoring of livestock has gained significant attention in recent years to investigate production issues, particularly in the context of calf mortality. Suckling, a behaviour that typically occurs within 2-3 hours after birth, is an indicator of calf well-being, as it necessitates key behaviours such as standing, seeking the udder, and attaching to the teats.

Accelerometers have shown effectiveness in recording suckling behaviour in beef calves under paddock conditions, with high accuracy in identifying suckling bouts. Studies have also observed similar discriminatory ability when assessing suckling behaviour in other species like sheep.

Building upon these findings, the aim of this study was to conduct a small, cost-effective, and focused research project to explore the possibility of identifying suckling behaviour in open-grazing beef cattle using remote monitoring devices such as accelerometers attached to cows and calves.

Objectives

By 15 May 2023, the Research Organisation have conducted a small, low-cost focused novel research activity to test a proposed methodology to:

- Detect material behaviours associated with suckling in beef cattle using remote monitoring devices (such as accelerometers, sound monitors and GPS trackers) attached to free-grazing first-lactation cows.
- Describe the association between frequency and duration of suckling and pre-weaning average daily gain of calves.

Methodology

A study involving 30 heifers calving for the first time was conducted at the Katherine Research Station (Katherine, Northern Territory) between Oct. 2021 and Feb. 2022. Approximately one month prior to expected calving, heifers were mustered and equipped with on-animal GPS and accelerometer collars and ear tags. When practical after birth, calves were captured, and accelerometer tags fixed to the ear of the calf. From two weeks prior to the expected date of calving, the heifers were visually observed twice per day to identify calving events. Using the annotated accelerometer data, suckling recognition algorithms were developed and applied to sensor data to infer daily suckling for individual calves. Model based analyses were then conducted to test the strength of association between nursing behaviours and liveweight changes of calves.

Results/key findings

The analyses of sensor (accelerometer) and observational (notes and video) data indicate that accurate recognition of calf suckling behaviour from eartag accelerometer readings is likely possible given sufficient labelled data. However, detecting when a cow is suckled using either collar or eartag accelerometer data does not appear to be feasible given the available labelled data. Additionally, our findings also revealed a lack of association between suckling time and growth rate in calves.

Benefits to industry

The study's findings indicated that the developed model showed promise in accurately differentiating between suckling and non-suckling events in calves only. However, further research is required to expand the application of remote monitoring to include maternal behaviours using sensors attached to cows. Validation of the developed models using larger animal samples and different breeds is necessary.

Future research and recommendations

The potential benefits of advancing this technology are substantial, as a deeper understanding of suckling behaviour can lead to improved cow-calf management practices, enhanced calf growth rates, and increased overall herd productivity. Additionally, the technology has the potential to provide insights into maternal behaviour, which could support the identification of genetic markers for selection purposes. By selectively breeding for favourable maternal behaviours, producers can make further advances in herd genetics and improve calf welfare.

Table of contents

1. Background

Losses from pregnancy diagnosis to weaning have been a significant cause of reduced productivity in northern Australia's beef breeding herds. While well-managed first-lactation cow mobs with low exposure to reproductive disease should only experience a foetal and calf mortality rate of around 17%, reported mortalities exceeding 30% are not uncommon. The complex and multifactorial nature of reproductive wastage has been traditionally investigated through conventional research methods, which have identified various risk factors associated with calf survival in the first week of life (McGowan et al, 2017). However, there is an urgent need for research tools that enable accurate detection of calving events, assess calf viability during critical periods, and can be deployed at a commercial scale. Although recent research activities have aimed to develop or adapt remote technologies to indicate the approximate time of calving, their reliance on invasive intravaginal devices or additional technology fitted to the calf poses methodological challenges. Moreover, these methods can disrupt natural behaviour (Ishiwata et al., 2007), increase the risk of mismothering, and are impractical in large commercial settings.

Suckling, which typically occurs within 2-3 hours after birth, holds the potential for non-invasively approximating the timing of calf births, their viability, and the occurrence of suckling events. Suckling is an indicator of calf well-being, as it requires the calf to exhibit key behaviours such as standing, seeking the udder, and attaching to the teats. If technology existed to combine suckling detection with existing calving alert technology, it becomes possible to capture the time between early labour detection and first suckling, thereby supporting the identification of calves with poor suckling reflex or those exposed to prolonged labour or dystocia events. Furthermore, accurately detecting nursing behaviours can provide insights into the frequency and duration of suckling events and their association with cow performance, including the interval to first oestrus postpartum (Stagg et al 1998) and changes in liveweight due to the energy demands of lactation. This information would offer valuable insights into the key drivers of liveweight production in commercial beef herds in northern Australia.

Accelerometers have demonstrated effectiveness in recording suckling behaviour in beef calves under paddock conditions. Studies have shown that an acceleration signature can identify 98% of observed suckling bouts when sensors are fitted to haltered calves (Kour et al, 2018). Similar discriminatory ability has been observed in suckling behaviour when attached to progeny in other species like sheep (Kuźnicka and Gburzyński, 2017).

The aim of this study was to conduct a small, low-cost focused novel research activity to explore the concept that suckling in open-grazing beef cattle can be identified using remote monitoring devices (such as accelerometers, sound monitors and GPS trackers) attached to cows. While suckling has been remotely indicated using progeny-borne data, this behaviour being described using dam-derived data is currently not described in the literature.

2. Objectives

By 15 May 2023, the Research Organisation have conducted a small, low-cost focused novel research activity to test a proposed methodology to:

- Detect material behaviours associated with suckling in beef cattle using remote monitoring devices (such as accelerometers, sound monitors and GPS trackers) attached to free-grazing first-lactation cows.
- Describe the association between duration and frequency of suckling and pre-weaning average daily gain of calves.

3. Methodology

3.1 Research animals and site

3.1.1 Research site

The study was conducted on the Northern Territory Department of Industry, Tourism and Trade’s Katherine Research Station (-14.4736, 132.3056). The station is located 4km south of Katherine, Northern Territory.

The climate is tropical, characterised by an average annual rainfall of 970mm, which primarily falls between November to March. The Katherine Research Station is 1260ha in area and is subdivided into 27 paddocks of different sizes. Three specific paddocks, Ball, Kearin, and Brodie, were utilised by this study (Figure 1).

These paddocks were chosen as they were well pastured by Urachloa species (Sabi) grasses and their proximity, within a distance of 1 kilometre, to a well-equipped animal processing facility. Moreover, these paddocks were strategically located with gateways (indicated on the map as 'G') to facilitate communication and ensure clear visibility of cow behaviour. Additionally, these paddocks were securely fenced to eliminate the risk of predation or attack by wild or uncontrolled dogs.

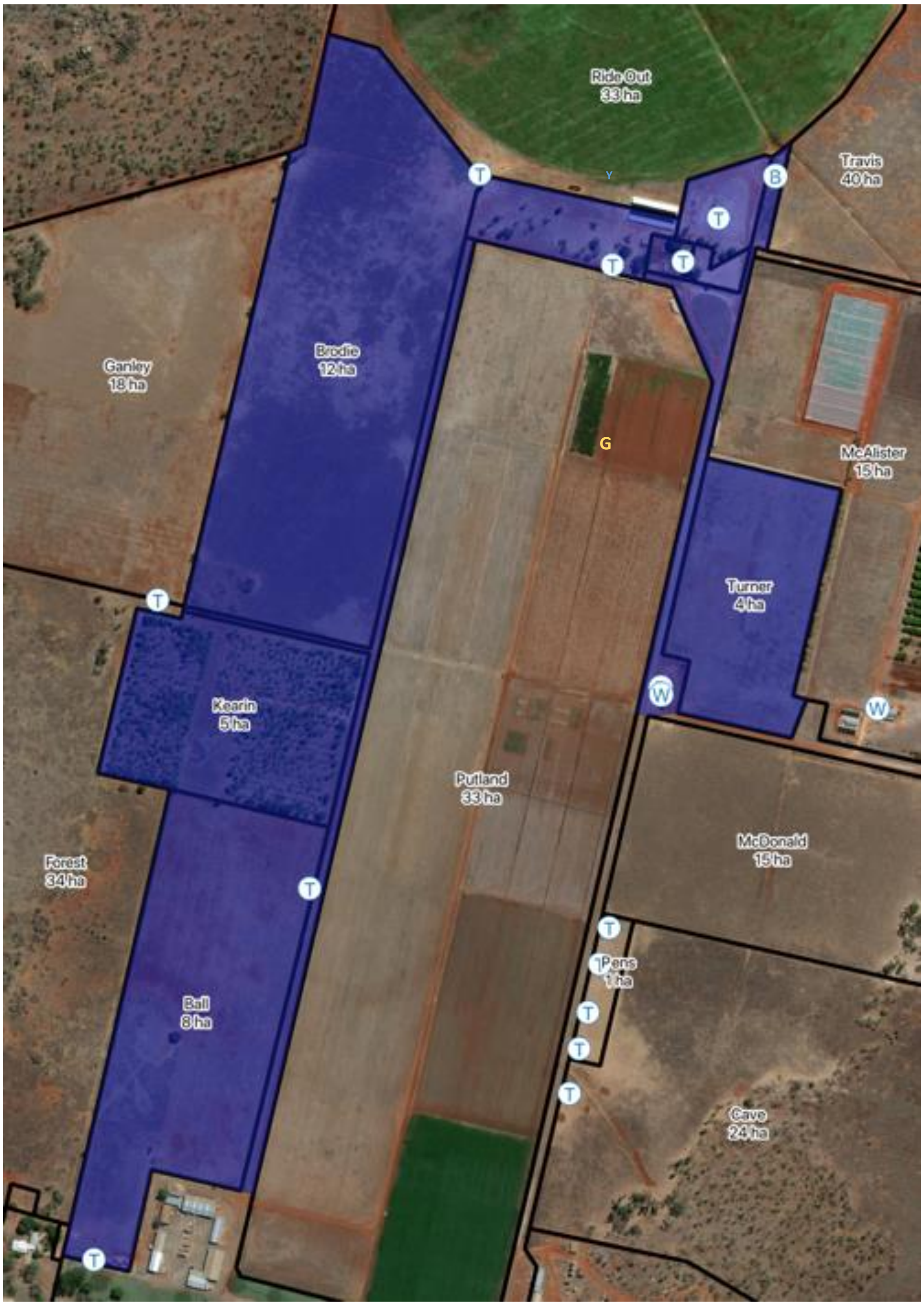


Figure 1. Aerial view of a section of Katherine Research Station, Katherine NT with paddocks and areas that are planned to be utilised by the project highlighted. Legend: T = water point, B=Bore, Y=cattle yards, G=Tower with gateways.

3.1.2 Study animals

This study involved 30 study animals. All methods and procedures employed during this study were approved by The Charles Darwin University Animal Ethics Committee (Animal Ethics Project Number A19021: NT DITT livestock research using common procedures).

This study group consisted of 24 heifers from Beatrice Hill Research Station that had been confirmed to be pregnant through FTAI in March 21 and subsequently relocated to the

Katherine Research Station on 19 Sept 2021. Additionally, 6 yearling heifers were included in the study, having been confirmed as pregnant through natural mating at the Victoria River Research Station before being transferred to the Katherine Research Station in early-September, 2021.

Prior to commencing the trial, a four-week acclimatisation process was conducted on all study animals to minimise any fear of human interaction that could potentially alter their behaviour during observations throughout the study. This process was carried out by skilled staff members at the Katherine Research Station who were experienced in low-stress livestock handling. Its purpose was to allow the cattle to become accustomed and habituated to their new environment as well as improve workability and ensure safety of staff and personnel handling the cattle during the study.

3.1.3 Monitoring animal performance

Once a fortnight, all study animals (cows and calves) were mustered to the cattle yards and measured for liveweight between 29th Oct 2021 and 4 Feb 2022. The KoolCollect crush-side individual animal data recording software was used to record data against each animal's unique electronic ID. The cloud-based data management system was used across the whole research herd and research stations operated by NT DITT and meant that animal history data, including pregnancy status, expected time of calving, mating system and sire if AI was known was accessible at the time of processing for each of the study heifers or their progeny.

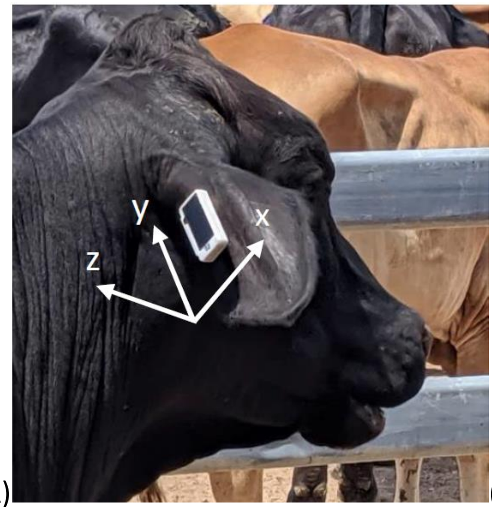
3.2 Recognising suckling and maternal behaviours

3.2.1 Equipping study animals with required technology

The study group was equipped with the required sensors on the 29 Oct 2021. To facilitate this, each heifer was individually restrained in the veterinary crush without capturing their head in the head bail. The kick-gate was latched behind them, and the vulva of each heifer was cleaned. Subsequently, a calf alert transmitter was loaded into a clean and disinfected calf alert applicator, which was then inserted into the vagina of each heifer. The applicator was then carefully manoeuvred to the cervix, where the sensor was deployed. Afterwards, the heifer was rectally palpated to check the position of the sensor.

Following deployment of the calf alert transmitter, the head of the heifer was captured, and the heifer brought to a forward position in the crush using a bar placed behind and ratcheting it forward to provide good access to the head and neck area of the heifer to fit a GNSS eGrazor collar, containing GPS and accelerometer componentry (**Figure 2**). Additionally, a Ceres tag was attached to the heifer's offside (right) ear using the Ceres applicator (**Figure 2**).

The main components of the eartag were microcontroller, accelerometer, satellite communication interface, on-board flash memory, battery (3.2V, 170mAh), and solar panel. The accelerometer detected the immediate acceleration of the eartag along three orthogonal spatial axes as in **Figure 2**. The accelerometer chip produced tri-axial readings at a rate of 50 samples per second (50Hz).


(A)


(B)

Figure 2. A) eGrazor collar and B) Ceres Tag cattle eartag and the orientations of the three axes of the accelerometer.

When practical after birth, typically within 12-24 hours after birth, calves were typically captured in the field, individually identified using visual tags and data captured for body weight, sex and notes on their general appearance. At the same time, a Ceres tag affixed to its offside (right) ear using the Ceres applicator. In addition, a paired BLEAcon device was attached to a medium-sized dog collar, which was then fastened around the neck of the calf (**Figure 3**). To ensure that the BLEAcon device maintained an approximately vertical position when attached to the calf, a chain link weighing approximately 30 grams was secured to the collar using zip ties. This weight would rest at the bottom of the neck, aiding in the desired positioning of the BLEAcon device.

Figure 3. A study calf equipped with a Ceres tag and BLEAcon device.

Figure 4. Photo of transportable tower with 8m mast manufactured by Katherine Research Station staff.

3.2.2 Detection of calving events

Despite substantial investment and efforts made to install a modified Taggle™ Calf Alert system (single receiver only) to alert researchers of calving events and enable assessment of cow and calf behaviour around the time of calving, the technology did not function as expected in this study. The calf alert system, as described by Stephens et al. in 2019, relies on an intravaginal sensor inserted into pregnant cows prior to calving. The expulsion of the transmitter during parturition triggers the detection of increased signal frequency and strength by multiple receivers, indicating a calving event. However, due to technical challenges and delays in establishing connections to real-time data flows, the system did not accurately predict any calving events during the study.

Consequently, diligent and systematic monitoring practices were implemented to identify calving events. Trained personnel conducted frequent visual observations, continuously scanning the grazing areas. They actively looked for newborn calves and visible indications of labour, such as restlessness, isolation, or signs of early stages of parturition.

3.2.3 Collection of sensor data

To facilitate the collection of sensor data, a custom-built portable platform was installed within 1 km of study paddocks (identified as 'G' on Figure 1). This platform housed a solar system capable of generating more than 110 Ah of power per day and had a storage capacity of 660 Ah. The platform featured an 8-meter mast that could pivot for optimal positioning (Figure 4).

At the top of the mast, a cross member was fitted, which hosted a LoRaWAN gateway that supported the capture and transmission of data from eGrazor devices. Additionally, an aerial was connected to the in-field Taggle receiver, which was installed at the base of the mast using coaxial cable.

Since the research site had good mobile coverage, each system had its own independent connection to the mobile network. This ensured reliable communication and data transfer for the collected sensor data.

3.2.4 Observation of animal behaviour

The methodology employed in this study was based on the approach outlined by Hogan *et al.* (2022)[1].

As described above, heifers underwent a desensitisation process to acclimate them to the presence of observers before the onset of calving. The purpose of this acclimatisation period was to further familiarise the heifers with human interaction and minimise the likelihood of altered behaviour when observers were present.

Behavioural sampling was conducted twice daily, including weekends, until all heifers had calved. The sampling sessions were carried out during early morning, typically starting at 6:00 am and mid-afternoon, commencing at 3 pm. Each sampling session typically lasted for 2-3 hours. When all the heifers had calved, the sampling sessions were reduced to once per day during weekdays. Sampling continued until 4 Dec 2021 when calves were approximately one month of age.

To ensure accurate field observations of cow-calf interactions, each cow was assigned a unique and easily identifiable identification number. This identification number was prominently painted on both sides of the cow, ensuring easy identification of cows at a distance.

All behavioural data were collected through video recordings and direct observation. Cow-calf units were filmed using portable digital video cameras with extended battery capacity, and some behaviours were also directly observed. The observer continuously scanned the group, focusing on heifer-calf interactions and calf nursing behaviours. When behaviours of interest were identified, filming commenced and concluded at the end of the behaviour being expressed or when the view of the behaviour was obstructed. This approach ensured that comprehensive data were collected on the targeted behaviours while minimizing any potential bias or data loss.

To capture a broader range of general animal behaviours commonly expressed by cows, footage was also captured when no calves were observed as suckling and cows were observed to be grooming calves, ruminating, and grazing. By documenting this broader range of behaviours, it allowed for more of the data generated by the sensors to be explained and reduce the potential for misclassification of behaviours. To ensure the

[1] Hogan, L.A.; McGowan, M.R.; Johnston, S.D.; Lisle, A.T.; Schooley, K. Suckling Behaviour of Beef Calves during the First Five Days Postpartum. *Ruminants* 2022, 2, 321–340

accurate timestamping of video to support the annotation of sensor data, the video recordings were timestamped using the GPS time, to milliseconds, displayed on either a watch or tablet.

At the end of each day, the recorded video footage was downloaded and organised. The files were renamed using the date, heifer and calf ID numbers, and a brief description of the captured behaviours. This systematic approach facilitated efficient data management and analysis.

3.2.5 Modelling the suckling behaviour of calves and cows being suckled

This research used the recorded behavioural footage to annotate the raw sensor derived data, such as accelerometer output for each axis plane, by retrospectively assigning the displayed behaviours captured on video to the corresponding epochs of time to when they were observed.

The recorded videos of the calves and cows during the experiment were reviewed to annotate the behaviour of the calves and cows, using a CSIRO purpose-built add-on package for VLC media player using seven different behaviours. The synchronisation of the recorded videos was ensured with the logged accelerometer data by tagging both video and accelerometer data streams with the same coordinate universal time (UTC) timestamps acquired via global navigation satellite system (GNSS) receivers.

Video footage was initially annotated using seven different behaviour classifications. For cows, these were: walking, grazing, grazing suckled, ruminating, ruminating – suckled, resting, suckled, active mothering (eg. Licking), mothering – suckled. For calves, these were: suckling, suckling – mothered, grazing, walking, ruminating, resting, mothered, grooming. However, as the focus of this study was primarily on recognizing the suckling behaviour of calves, the analyses performed in this report have collapsed down to binary classification model with behaviours classified as either "not suckling" or "suckling" for calves and 'Suckled' or 'not suckled' for cows.

The labelled accelerometer data was divided into non-overlapping segments of 256 consecutive triaxial accelerometer readings. Since the accelerometer sampling rate is 50Hz, 256 samples correspond to a time window of 5.12 seconds. The values of each 256x3-reading segment and its associated behaviour label was considered as a datapoint. The collection of all datapoints made up the analytical dataset.

Figure 5 is a sketch of the architecture of the end-to-end classification model that was behaviour recognition. The model had two major components, namely feature extraction and behaviour classification. The first component extracts nine features from the raw input triaxial accelerometer readings to compactly represent the information of the input relevant to suckling or suckled behaviour classification in a nine-dimensional feature space. The calculated features are fed into a multilayer perceptron (MLP) that outputs the likelihood of sucking. The employed MLP classifier has one hidden layer that is followed by the rectified linear unit (ReLU) activation function.

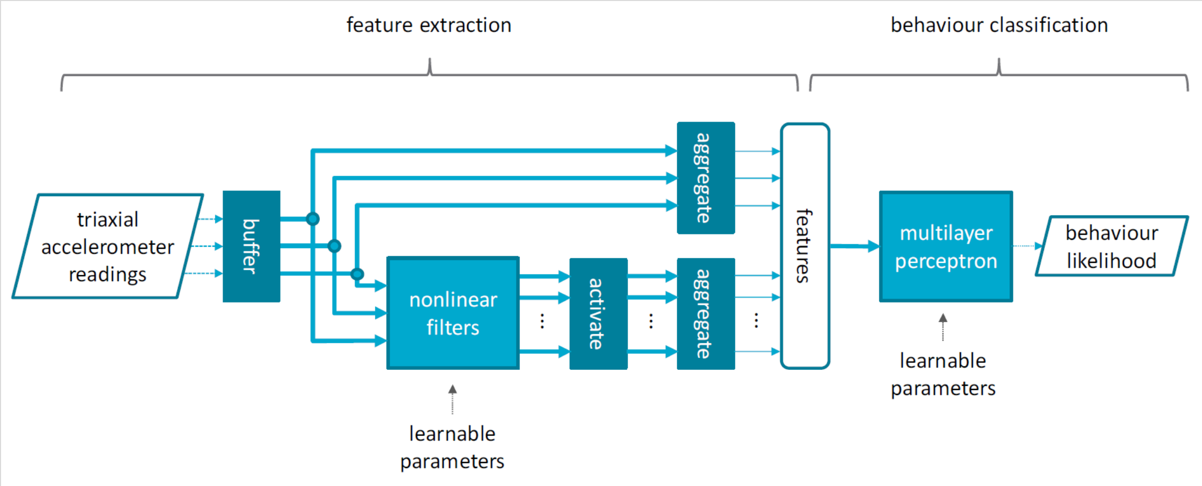


Figure 5. The architecture of the model utilised for the recognition of suckling and suckled from triaxial accelerometer data.

Both feature extraction and behaviour classification components of the suckling or suckled behaviour classification model contain parameters that can be learned from the training data. To estimate the model parameters using the labelled accelerometry data, an end-to-end learning approach was used. The conventional feature-engineering based approaches involved separate feature engineering and classification processes. However, with the end-to-end learning approach, it learnt the parameters of both feature extraction and behaviour classification components of the model from the available training data via joint optimization.

4. Results

4.1 Evaluation of gestation length, calving and calf growth

From the 30 confirmed-pregnant heifers enrolled into the study, 28 birthing events occurred during the observation period, with reproductive wastage occurring in two heifers prior to the observation period. One heifer previously confirmed to be pregnant was diagnosed as not pregnant at the time of equipping the heifers with the calf alert transmitters while another heifer calved prematurely on 7/10/21 with the calf not surviving. The remaining cows calved between 4/11/21 and 5/12/2021. A further two calves died during the study period producing an overall prevalence of loss from confirmed pregnancy of 13% (4/30). A male calf, 4314, at the age of 25 days, was discovered deceased in a water trough. The suspected cause of death is drowning because of being potentially knocked into the water trough and unable to escape. This incident was a very uncommon occurrence and had not been previously observed at the research site. The decision was made to hospitalise a male calf, 5465, at two days of age due to severe dehydration caused by an inability to suckle and the dam's loss of interest in supporting suckling. Following a veterinary consultation, the calf was placed on a drip to rehydrate him. However, with the welfare and best interests of the calf in mind, the decision was made to humanely euthanize the calf, ensuring that further suffering or distress was avoided.

In this study, substantial challenges were incurred with remotely detecting calving events. Six heifers calved while the system was not operating correctly due to delays in establishing connections to real-time data flows. However, when data flows were established, no calving events were accurately predicted by the system due to existing algorithms being based on transmissions being detected by multiple receivers. However, retrospective analyses performed on the raw data from heifers that calved while the system was operating was able to identify the day of calving for 17 of 18 calving events.

Overall, the birthweight of calves averaged 26.5 $\pm$ 1.05 kg and was, on average, 3.7 $\pm$ 2.0 kg greater for males, than females, which trended towards statistical significance (P=0.06). The average change in liveweight over time averaged 0.86kg/d $\pm$ 0.03 kg.day^{-1}. Male calves tended to be approximately 4kg heavier than females, but this association was not found to be statistically significant (P=0.17). However, calves with heavier birthweights were found to maintain the weight advantage over time (P=0.04). Although were not observed to display increased pre-weaning average daily gains (P=0.46).

For the heifers that were confirmed pregnant from fixed-time artificial insemination (n=24), an average gestation length (GL) of 289.6 $\pm$ 1.2 days was observed and ranged between 279 to 301 days. Hence, a 21-day spread of calving (between 4/11/21 and 25/11/21) was observed for conceptions occurring from artificial insemination performed on a single day. Sire (semen from 5 bulls used) was not found to significantly contribute to the observed variance in GL (P=0.92). A 2.5-day greater GL was observed for male calves, when compared to females (Male = 291.6 $\pm$ 3.0 vs. Female = 289.2 $\pm$ 2.6 days; P=0.60).

As the calf alert transmitters used in this study did not provide their location at expulsion, it was not possible to identify the location of expulsion and likely site of calving. Seventeen of the 29 (59%) deployed calving alert devices were located. A map of the locations where transmitters were found within Kearin paddock, Katherine Research Station, is presented as Figure 6.

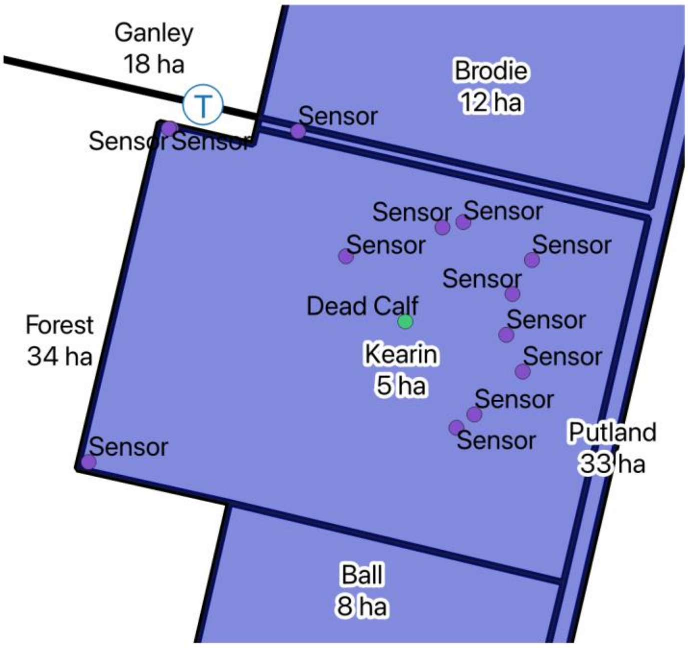


Figure 6. Map of trial paddock (Kearin Paddock) at Katherine Research Station and location where calf alert transmitters have been successfully found.

All of the sensors that have been located were found in Kearin paddock, suggesting that this paddock is where the majority of calving is occurring. The paddock contains an African Mahagony tree plantation trial plot that encompasses approximately ¾ of the paddock. Most of the transmitters (10/14) were found is this area where the timber plantation had recently been thinned and therefore provided sufficient shade as well as reasonable pasture (for bedding) to the calving heifers.

4.2 Recognising suckling behaviour of calves

Accelerometer data from 21 of the 26 ear tags attached to calves soon after birth successfully captured accelerometer data. On average accelerometer data was recorded a rate of 48.7Hz across 35.9 days for calves (Table 1).

Table 1. Summary of accelerometer data derived from ear tags attached to calves.

Ear tag ID	Start Date	End Date	No of days run	No accelerometer values
86	25/11/21	27/11/21	2	12,893,500
88	15/11/21	29/12/21	43.42	181,035,634
97	13/11/21	30/12/21	47.62	211,680,000
102	24/11/21	13/12/21	19.09	78,958,579
105	17/12/21	30/12/21	13.2	60,480,000
110	15/11/21	25/12/21	40.02	129,764,292
142	14/11/21	30/12/21	46.4	211,680,000
146	05/11/21	03/12/21	27.57	54,945,237
147	16/11/21	27/12/21	41.21	172,495,370
149	17/12/21	30/12/21	13.47	60,480,000
164	12/11/21	29/12/21	46.64	200,417,730
168	15/11/21	30/12/21	45.28	211,680,000
173	12/11/21	30/12/21	48.59	211,680,000
0A0E	12/11/21	30/12/21	48.47	211,680,000
0A0F	07/12/21	30/12/21	23.61	120,960,000
0A10	28/11/21	30/12/21	32.6	151,200,000
0A12	15/11/21	30/12/21	45.35	211,680,000
0A13	12/11/21	30/12/21	48.56	211,680,000
0A14	13/11/21	30/12/21	47.56	211,680,000
0A16	17/11/21	30/12/21	43.29	181,440,000
0A1A	14/11/21	13/12/21	28.92	68,318,542
Average			**35.9**	**150,801,375**

The study was successful in recording over 450 minutes cow-calf behaviour data and footage from approximately 96 different suckling events. These data supported the annotation of 1126 accelerometer data points of the input dataset and corresponds to approximately 96 minutes of observation time as each data point represents 5.12 seconds. A summary table containing the frequency of accelerometer points labelled with the eight behaviours is provided as Table 2. A summary table presenting these data when the binary classification of ‘suckling’ and ‘not suckling’ was used is provided as Table 3.

Table 2. Summary table of data points for each calf and each of the eight behaviour classifications.

Calf ID	Suckling	Suckling-mothered	Grazing	Walking	Ruminating	Resting	Mothered	Grooming	Total
666	55	19	0	0	0	36	0	0	**110**
3221	32	0	15	11	0	14	0	0	**72**
3769	39	1	6	0	0	2	0	0	**48**
4260	4	1	0	4	0	52	0	0	**61**
4296	85	1	8	1	0	3	0	0	**98**
5049	21	0	0	5	0	2	0	0	**28**
5051	30	0	48	2	64	66	26	0	**236**
5058	26	0	10	4	0	0	0	0	**40**
5070	50	0	15	6	0	24	0	0	**95**
5071	79	19	0	5	0	0	0	0	**103**
5461	34	0	0	8	0	15	4	0	**61**
5469	0	0	0	0	0	3	0	0	**3**
5482	110	0	10	2	0	39	0	1	**162**
5537	6	2	0	1	0	0	0	0	**9**
Total	**571**	**43**	**112**	**49**	**64**	**256**	**30**	**1**	**1126**

Table 3. Summary table of data points for each calf when binary classification of behaviour was used.

Calf ID	Suckling	Non-suckling	Total
666	74	36	110
3221	32	40	72
3769	40	8	48
4260	5	56	61
4296	86	12	98
5049	21	7	28
5051	30	206	236
5058	26	14	40
5070	50	45	95
5071	98	5	103
5461	34	27	61
5469	0	3	3
5482	110	52	162
5537	8	1	9
Total	**614**	**512**	**1126**

To provide some insight into the dataset, the normalized histogram for each behaviour class and each spatial axis are presented as Figure 7. The histograms are averaged over all respective datapoints. It was observed that the accelerometer readings corresponding to different behaviour have different statistical property. Particularly, the mean values are potentially useful for differentiating the behaviour classes. They reflect the orientation of the ear tag and, by extension, that of the animal's head since they result from the projection of the constant upward acceleration due to the Earth's gravity onto different axes.

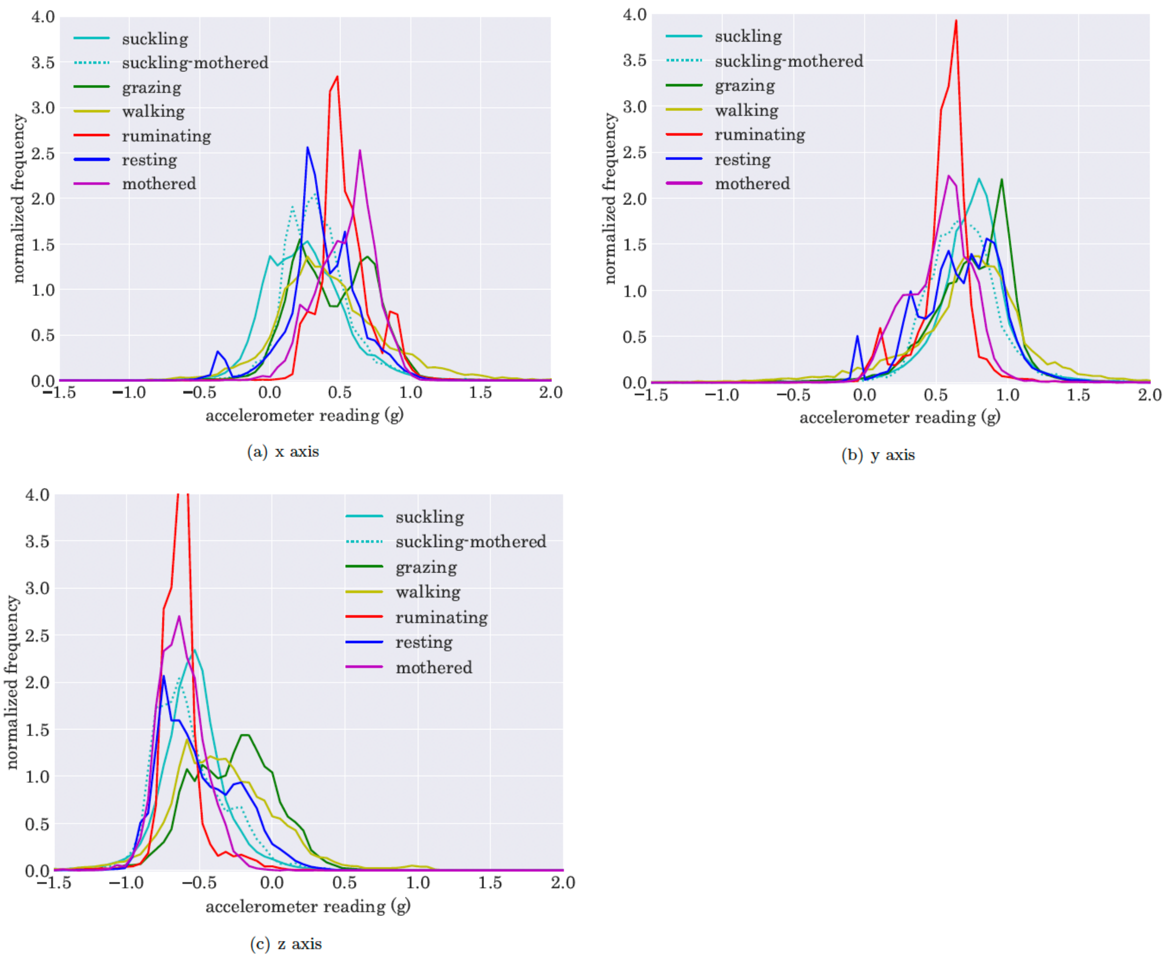


Figure 7. The normalised histograms of the accelerometer readings of all datapoints for each behaviour class and axis [A) x axis B) y axis, C) z axis].

To provide more insight into the data and help identify useful discriminative features, the amplitude spectral density (ASD) of the accelerometer readings for all classes and axes were plotted (Figure 8). The ASD functions were averaged over all respective datapoints. The ASD function is obtained by taking the square root of the power spectral density function and provides information on how the power of the accelerometer readings is distributed across the frequency range of zero to 25 Hz (half of the sampling frequency, also known as the Nyquist frequency) for each class and axis. The power or intensity of the motion captured by the accelerometers can serve as a useful distinguishing factor between different classes. Despite the fluctuations in the curves mainly caused by the limited and noisy data, the ASD functions for the suckling and suckling-mothered classes appear to be similar but distinct from the ASD functions corresponding to other behaviour classes, especially on y-axis.

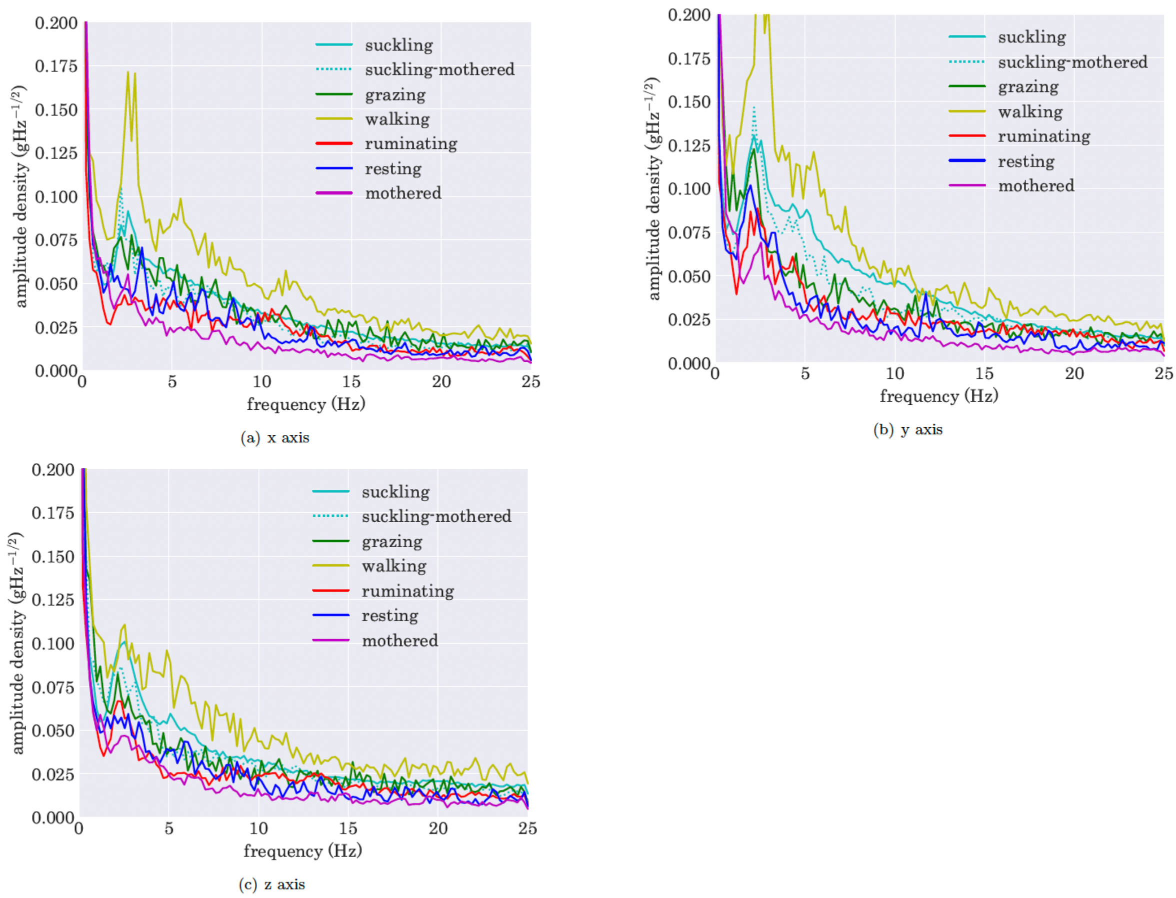


Figure 8. The amplitude spectral density (ASD) of the labelled accelerometer readings for each behaviour class and axis [A) x axis B) y axis, C) z axis], averaged over all datapoints.

Using the methodology described above, a calf suckling recognition algorithm was successfully developed and used to infer the suckling behaviour using ear tag accelerometer data. Due to the small dataset, relative to normal behaviour recognition datasets, the recognition algorithm was limited in its ability to predict the precise timing, duration, and frequency of suckling bouts for each calf though to be unreliable. However, increased confidence was held for the inferences made from consolidating the predictions of suckling behaviour of each calf for a single day. As such, the algorithm was used to infer the suckling time of calves per day over the study period (Figure 9).

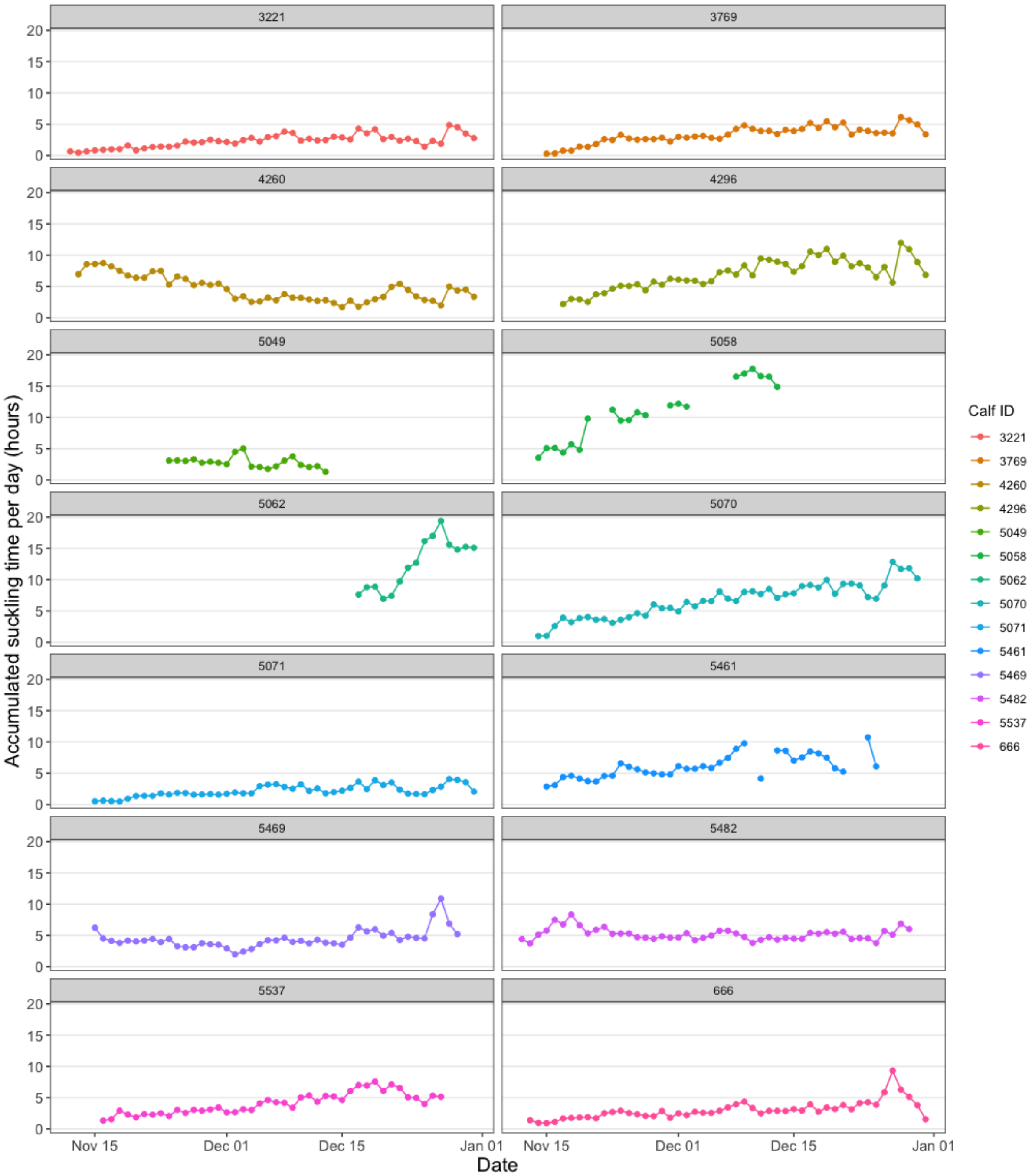


Figure 9. The predicted suckling time per day for each calf during the study period.

The performance of the suckling behaviour recognition algorithm was evaluated using a leave-one-animal-out cross validation scheme. This method of evaluation relies on multiple iterations, with each iteration comparing the outputs from a model utilising all the datapoints associated with all animals but one to the datapoints of the animal left out. Common methodology and metrics were applied to our dataset to evaluate the model performance, such as the receiver operating characteristic (ROC) and precision recall (PR) (Figure 10). Different points on the ROC and PR curves correspond to different values of the decision threshed. The ROC curve depicts the trade-off between the false positive and true positive rates and the PR curve depicts the trade-off between the precision and recall values.

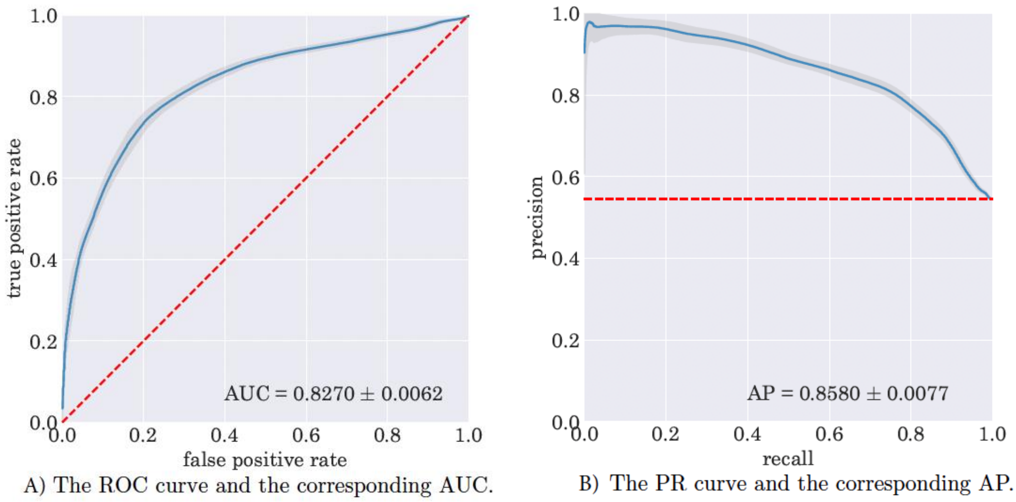


Figure 10. The A) receiver operator character and corresponding area under the curve and B) precision recall curves and corresponding average precision of suckling recognition algorithm.

To illustrate the effect of decision threshold on classification performance, in **Figure 11**, the precision and recall values averaged over 1000 random model parameter initializations versus the decision threshold is presented. The plots suggest that a value of 0.5 to 0.6 can establish a good trade-off between the recall and precision values.

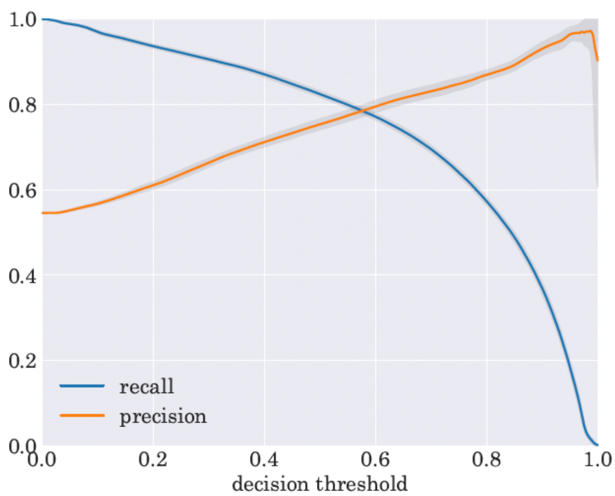


Figure 11. Precision and recall versus the decision threshold**.**

Table 2 presents the values of the performance measures of precision, recall, F1-score, and Mathew's correlation coefficient (MCC) for the decision threshold of 0.5. Table 3 is the corresponding confusion matrix. In this matrix, the rows show the number of datapoints associated with positive or negative class and columns show the number of datapoints predicted to belong to each class. The green numbers are the correct predictions, and the red ones are the incorrect ones.

Table 2: The values of the considered performance measures with the decision threshold of 0.5.

	Precision	**Recall**	**F1score**	**MCC**
suckling	0.7533±0.0128	0.8238±0.0071	0.7869±0.008	0.5075±0.022
not suckling	0.7618±0.0095	0.6761±0.0223	0.7163±0.0156	

Table 3: The confusion matrix with the decision threshold of 0.5.

		Predicted	
		Suckling	Non-suckling
TRUE	Suckling	**506±4**	**108±4**
	Non-suckling	**166±11**	**346±11**

These findings show promise despite the relatively small quantity of labelled data and the algorithm successfully predicted suckling time. This enabled a qualitative assessment of the generalizability of knowledge acquired from the annotated eartag accelerometer data to previously unseen instances. While however, it is important to note that the predicted suckling times for certain calves, such as 5058 and 5062, were unrealistic and not biologically plausible. This discrepancy in model inference for these specific animals can potentially be attributed to poor technology performance and the limited availability of accelerometer data for these individuals throughout the study period.

By excluding these particular animals from the analysis, the results obtained for the remaining calves indicate that the total daily suckling time generally fell within the range of one to five hours per day and up to 10 hours per day for some calves. A possible explanation for this is that results may represent an overestimate and could potentially better reflect nursing time, as they may also encompass ineffective suckling and other related nursing behaviours. Additionally, the predicted daily suckling duration consistently increased over time for all the calves under consideration. It is recommended the to interpret these findings with a degree of caution for the earlier mentioned limitations.

By incorporating significantly larger amounts of annotated data, more sophisticated and accurate algorithms can be developed to recognise calf suckling behaviour using ear tag accelerometer data. Furthermore, it is important to note that the binary classification algorithm developed for suckling behaviour has low computational and memory requirements, making it convenient to implement and run in real time on the eartag itself.

4.3 Recognising when cows were suckled

Overall, 26 of the 28 collars and 25 of the 28 ear tags fitted to pregnant heifers successfully contributed data. An example of the GPS data for a single collar fitted to a cow is provided as Figure 12. On average, each of these collars contributed 6,008,602 GPS positions over a 57.9 day period ie 72.1 positions per minute. The collars also successfully contributed 242,278,484 activity values over the same period, meaning that accelerometer data was successfully captured at 48Hz on average. Accelerometer data from the ear tags was captured on average at 45.2Hz across 38.9 days for cows. A summary table of the GPS and accelerometer data from each collar is provided as Table 4 and from ear tags as Table 5.

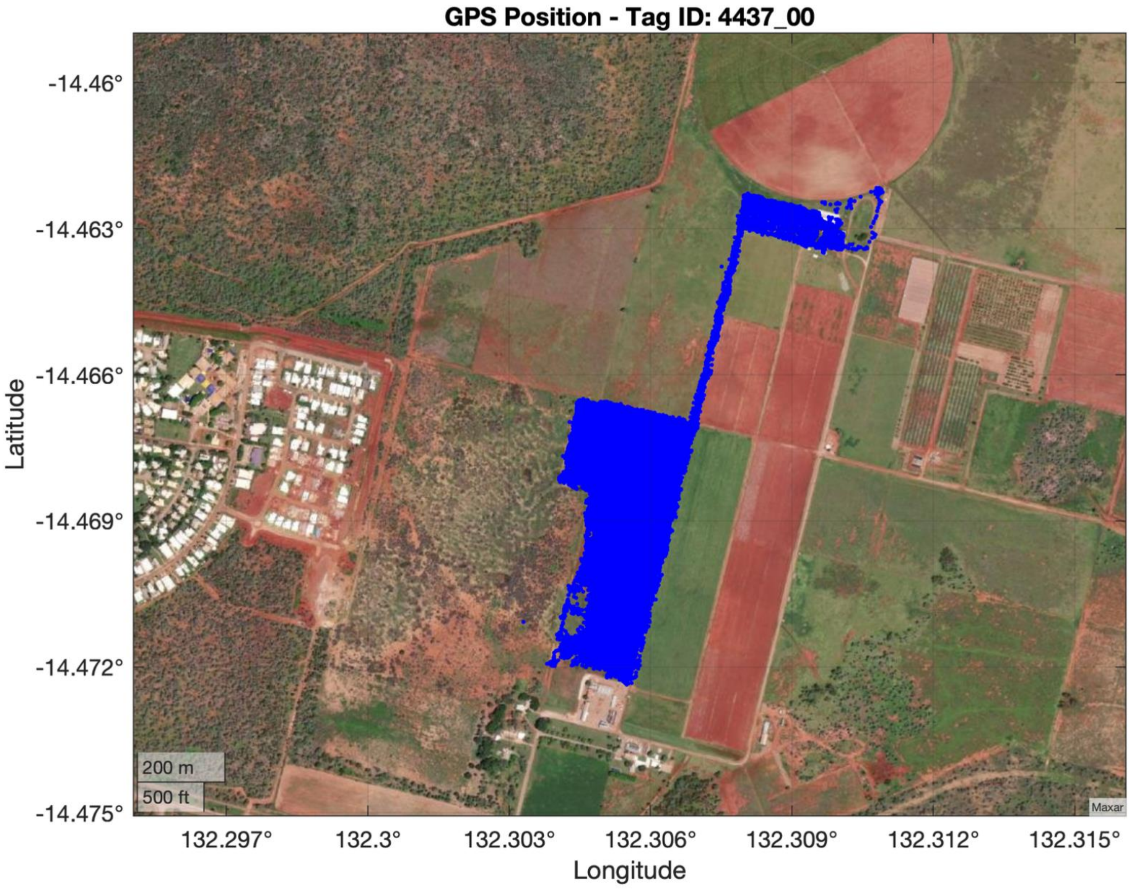


Figure 12. Example mapping of output from a single GPS collar.

Table 4. Summary of collar derived GPS and accelerometer data

CollarID	StartDate	EndDate	NoDaysRun	No GPS fixes	No accelerometer values
4404	29/10/21	30/12/21	63	8,216,977	273,595,184
440C	29/10/21	30/12/21	63	8,202,972	273,641,554
4415	29/10/21	23/12/21	55.96	2,543,217	125,307,853
4418	29/10/21	30/12/21	63	5,808,260	233,128,494
4422	29/10/21	29/12/21	61.28	5,313,114	263,887,848
4425	29/10/21	30/12/21	63	5,930,120	242,184,587
4426	29/10/21	30/12/21	63	8,747,494	273,614,512
4427	29/10/21	30/12/21	63	9,164,699	273,749,270
442B	29/10/21	28/12/21	60.65	5,295,057	264,194,684
4430	29/10/21	30/12/21	63	8,374,523	274,720,381
4431	29/10/21	30/12/21	63	9,186,674	273,489,729
4432	29/10/21	19/11/21	21.62	1,922,975	96,703,777
4433	29/10/21	30/12/21	63	6,706,997	200,566,692
4434	29/10/21	23/12/21	55.95	4,465,166	221,851,785
4436	29/10/21	30/12/21	63	9,155,970	302,400,000
4437	29/10/21	12/05/21	38	3,190,386	161,339,135
443D	29/10/21	15/12/21	47.3	4,141,525	208,686,512
4445	29/10/21	30/12/21	63	8,680,156	302,400,000
4449	29/10/21	30/12/21	63	4,713,245	236,468,786
4464	29/10/21	19/12/21	51.9	5,445,195	241,920,000
444A	29/10/21	29/12/21	61.58	5,375,527	270,937,190
4472	29/10/21	26/12/21	58.64	4,967,844	249,319,060
448E	29/10/21	25/12/21	57.02	4,981,965	251,317,886
44BD	29/10/21	26/12/21	58.84	4,965,250	249,581,581
44BE	29/10/21	28/12/21	60.1	5,528,599	272,160,000
44C0	29/10/21	27/12/21	59.81	5,199,739	262,073,574
		Average	**57.9**	**6,008,602**	**242,278,464**

Table 5. Summary of accelerometer data derived from ear tags attached to cows.

Ear tag ID	Start Date	End Date	No of days run	No accelerometer values
4404	12/11/21	30/12/21	48.54	211,680,000
4415	12/11/21	22/11/21	10.26	19,038,249
4418	12/11/21	30/12/21	48.21	116,773,698
4422	12/11/21	29/12/21	46.79	199,971,489
4425	12/11/21	27/12/21	44.56	428,291
4426	12/11/21	30/12/21	48.32	211,680,000
4427	12/11/21	26/12/21	44.28	180,946,995
4430	12/11/21	30/12/21	48.54	211,680,000
4431	12/11/21	30/12/21	47.68	203,321,565
4432	12/11/21	19/11/21	7.15	31,039,748
4434	12/11/21	24/12/21	41.51	161,054,200
440C	12/11/21	21/12/21	38.66	181,440,000
442B	12/11/21	28/12/21	45.97	163,020,435
4436	12/11/21	30/12/21	48.56	211,680,000
4437	12/11/21	6/12/21	23.54	91,721,303
4445	12/11/21	28/12/21	46.36	170,167,455
4449	12/11/21	28/12/21	46.2	192,834,454
4464	12/11/21	19/12/21	37.21	181,440,000
4472	12/11/21	26/12/21	44.17	182,224,498
443D	12/11/21	15/12/21	32.82	141,187,196
444A	12/11/21	29/12/21	47.16	204,588,299
448E	12/11/21	10/12/21	28.07	121,507,700
44BD	12/11/21	18/11/21	6.56	28,228,350
44BE	12/11/21	26/12/21	43.92	185,242,715
44C0	12/11/21	29/12/21	46.8	197,225,642
		Average	38.9	152,004,891

The study was successful in recording over 450 minutes cow-calf behaviour data and footage from approximately 96 different suckling events. These data supported the annotation of 2469 accelerometer data points of the input suckled dataset and corresponds to approximately 211 minutes of observation time as each data point represents 5.12 seconds. A summary table containing the frequency of accelerometer points labelled with the nine behaviours is provided as Table 6.

Table 6. Summary table of data points for each calf and each of the eight behaviour classifications.

cow ID	Walking	Grazing	Grazing-suckled	ruminating	ruminating-suckled	resting	suckled	mothering	mothering-suckled	Total
2	1	22	0	131	0	86	0	0	0	**240**
3	0	36	23	170	24	28	7	26	0	**314**
4	1	0	0	9	0	9	7	0	0	**26**
5	1	4	0	27	0	1	7	3	3	**46**
8	9	0	0	29	78	25	17	0	1	**159**
9	0	21	0	18	0	15	139	11	1	**205**
10	15	27	0	129	55	23	8	0	20	**277**
14	8	0	0	9	0	30	120	0	0	**167**
15	6	0	9	0	23	7	19	3	0	**67**
16	3	0	0	0	53	20	0	0	0	**76**
19	10	0	0	99	0	13	54	0	19	**195**
20	1	0	0	24	0	36	102	24	66	**253**
23	0	0	0	10	0	26	2	1	19	**58**
24	22	6	0	5	0	4	36	0	1	**74**
25	6	0	0	20	0	5	13	0	0	**44**
26	1	0	0	0	0	14	0	0	0	**15**
28	9	0	0	27	0	31	0	0	0	**67**
29	0	0	0	0	0	33	25	0	12	**70**
30	0	0	0	69	0	47	0	0	0	**116**
Total	**93**	**116**	**32**	**776**	**233**	**453**	**556**	**68**	**142**	**2469**

Examination of the ASD plots (**Figure 13**) suggested that the spectral properties of the accelerometer data for some cow behaviours were not distinguishable from other behaviours, regardless of whether a cow was being suckled or not. As such, the ability to detect when a cow was being suckled using either collar or ear tag accelerometer data did not appear to be feasible with this dataset. Additionally, the annotated data for instances of each behaviour was unbalanced, making it increasingly difficult to have confidence in resulting model predictions.

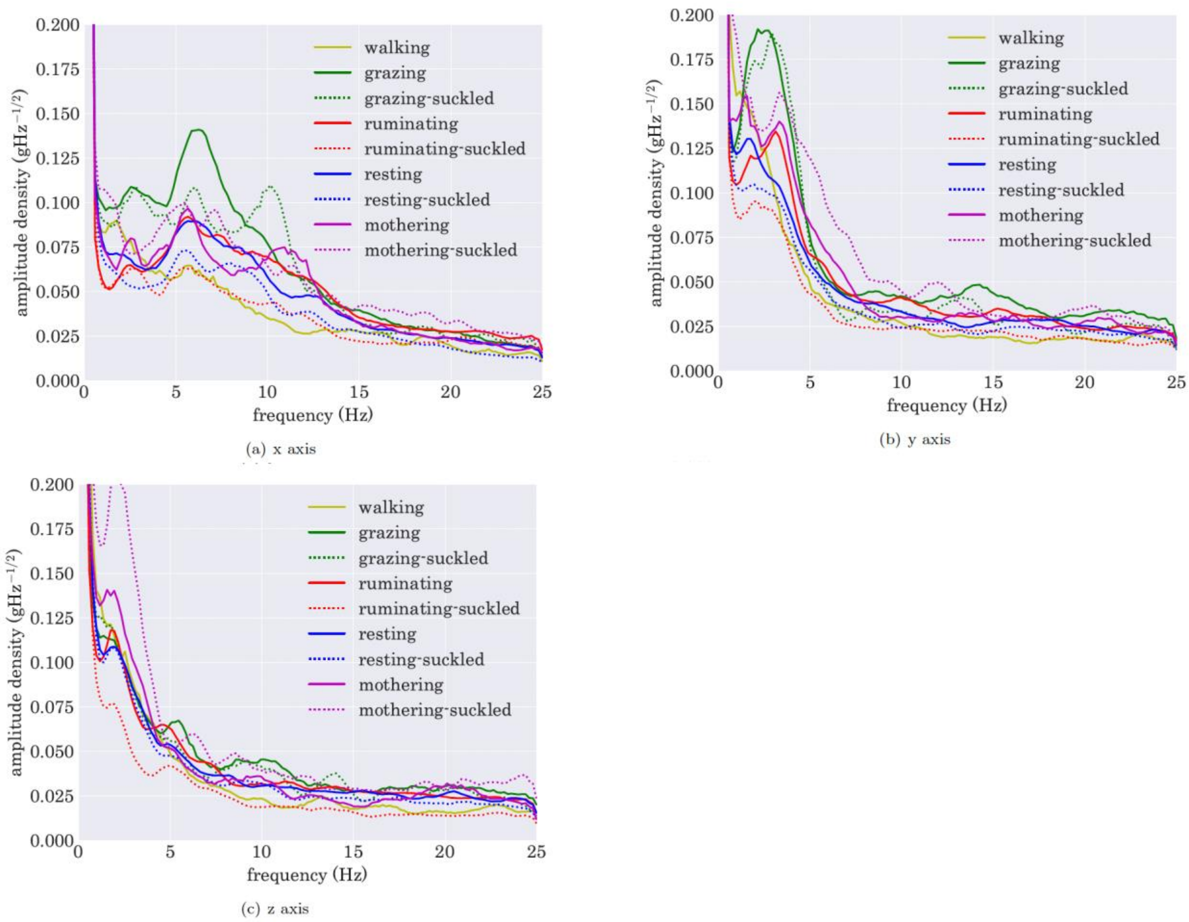


Figure 13. The amplitude spectral density of the labelled cow ear tag accelerometer readings for A) x axis, B) y axis and C) z axis and considered behaviours, averaged over all datapoints.

4.4 Association between suckling behaviour and average daily gain

It was considered important to test the biological plausibility of outputs obtained using the suckling recognition model using ear tag accelerometer data. In the current study, this achieved by assessing the strength of association and relationship between suckling behaviour and calf growth.

As the main outcome of interest in this analysis was daily suckling time, the suckling recognition algorithm was used to produce an estimate of time each calf suckled during each day from their respective ear tag accelerometer data. Figure 14 presents the daily suckling time for each calf over the study period.

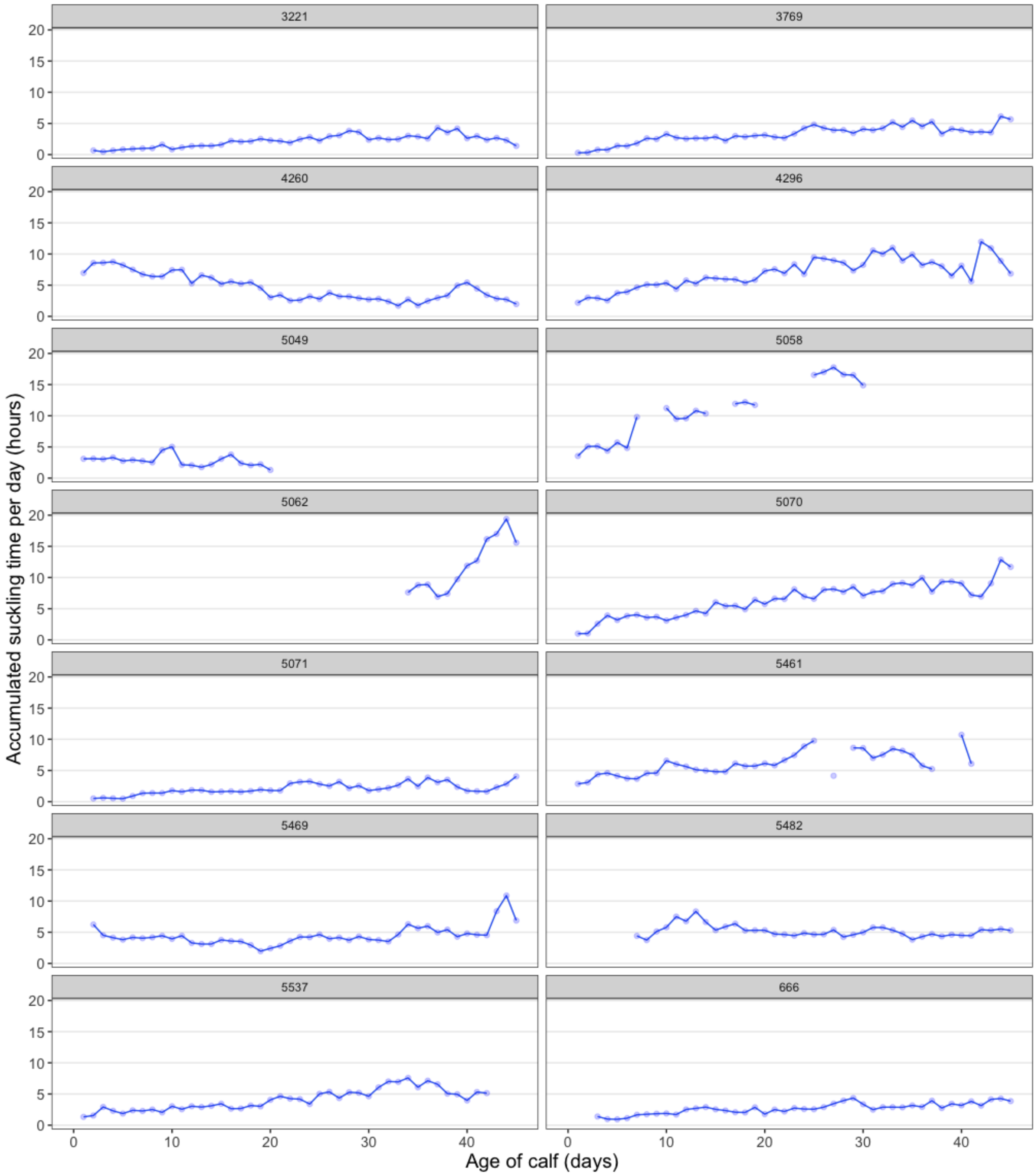


Figure 14. The predicted accumulated suckling time per day.

It should be noted that due to technology failure, calves 5049, 5062 and 5058 did not have data and were removed from further analysis.

The analytical dataset was subjected to a random effects regression analysis with age specified as a fixed effect and dam-calf unit specified as a random effect. This approach was employed as by specifying dam-calf unit as a random effect accounted for the between cow-calf unit variability and allowed an overall evaluation of the suckling behaviour with increasing age. The predictions from this model would represent the baseline average calf or random effect = 0. Additionally, by analysing the random intercept information,

information on the variations in baseline behaviour between calves was able to be obtained and provided a method to rank calves on their sucking activity.

The amount of time spent suckling was estimated to be within the range of two to five hours per day, with older calves tending to spend more time suckling than younger calves. This general trend was generally thought to be consistent with the existing research knowledge and experience. However, the estimated daily time suckling was considered an overestimate of actual and could potentially better reflect nursing time, as they may also encompass ineffective suckling and other related nursing behaviours.

Age was found to have a quadratic relationship with predicted daily nursing time, which was statistically significant ($p<0.001$ and $p=0.001$). Figure 15 shows the predicted average daily nursing time for calves observed in this study over time.

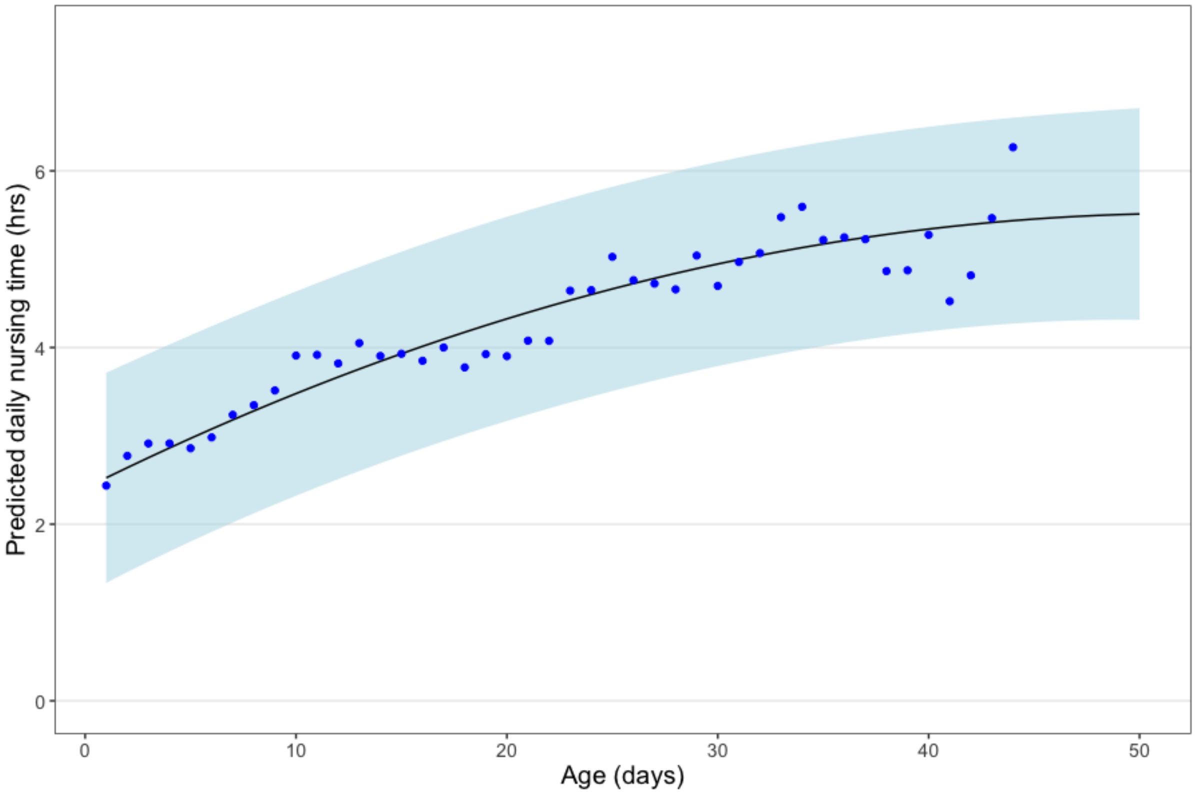


Figure 15. Predicted daily nursing time (hrs) by age of calf, based on least squared means generated from the random intercepts model. Shading represents 95% confidence interval.

Using the random intercept model, the residual variation at the cow-calf unit level (random intercepts) were predicted for each cow-calf unit. The residuals are by definition differences from the overall mean nursing time per day (represented by the horizontal line at zero) and was considered to provide a method to ranking dam-calf units on their suckling activity relative the other study animals. Figure 16 shows the ranking of calves on their overall suckling time.

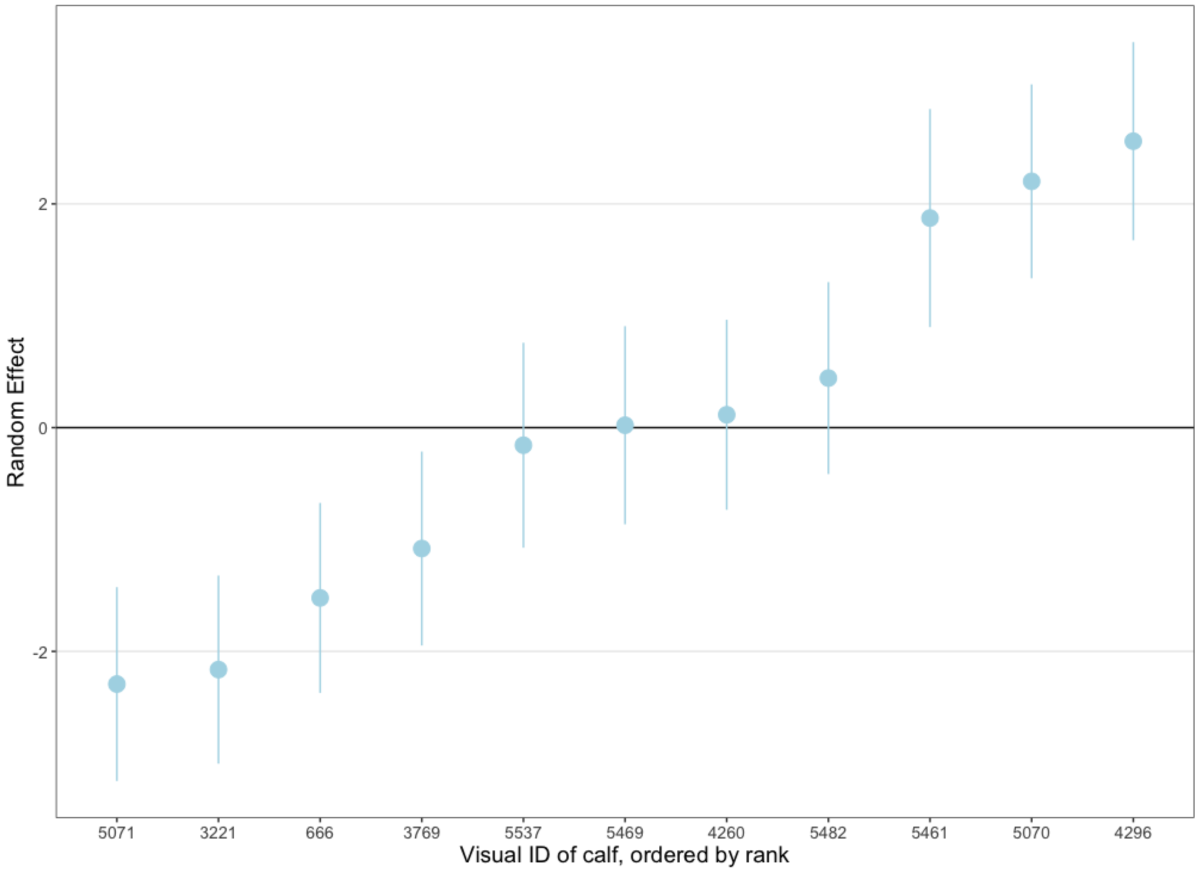


Figure 16. Caterpillar plot of random-intercept predictions (95% confidence interval) by ranking for suckling behaviour.

A routine muster was typically performed once a fortnight when a general health assessment and any adjustments to technology fitted to study animals would occur. At this muster, the liveweight of all animals would be recorded. Shown as Figure 17 is the liveweight of calves over the study period.

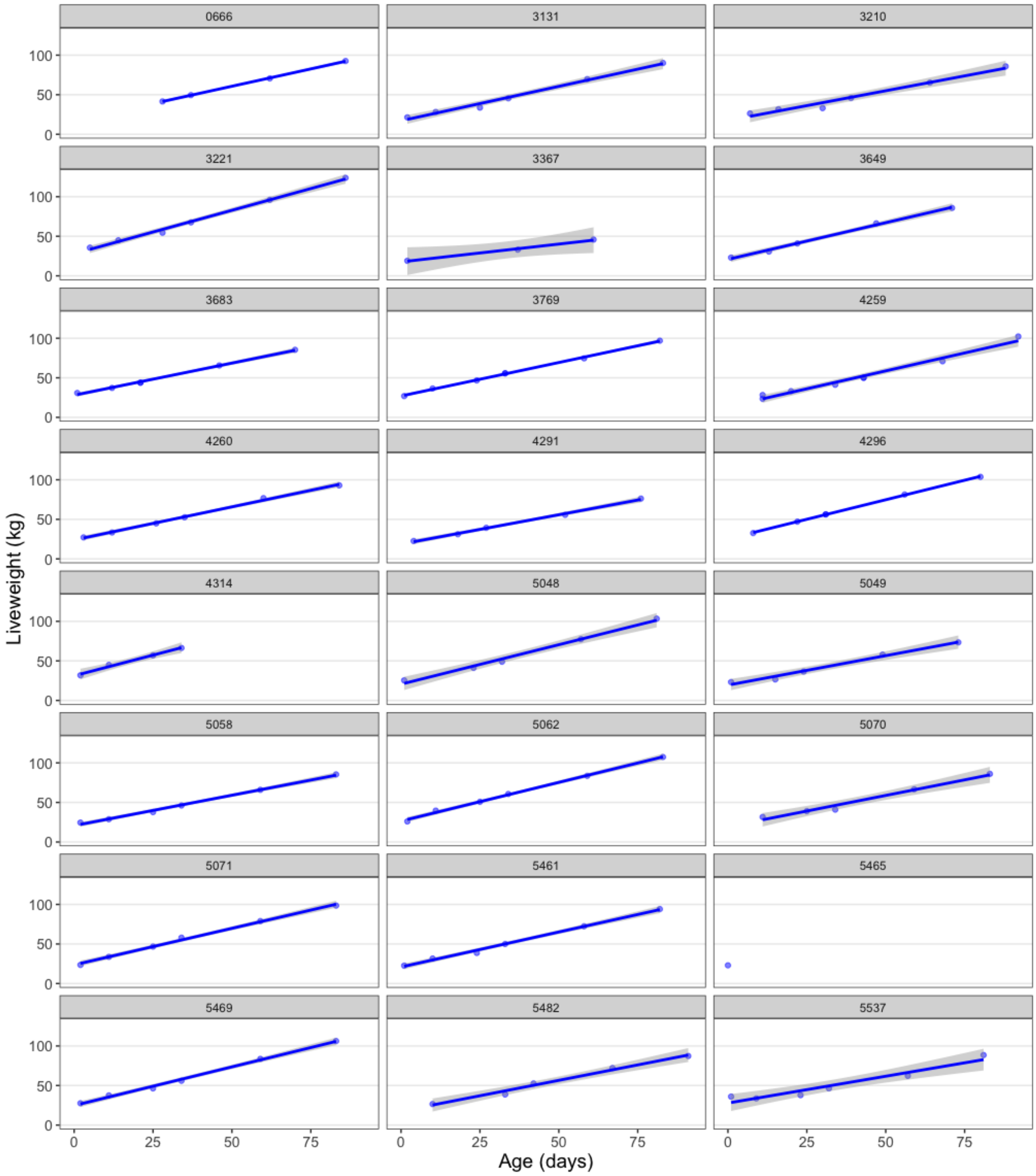


Figure 17. The liveweight of calves over the study period. The slope of the linear regression line was determined provided an estimate of the average daily weight gain for calves.

To calculate the average daily gain (ADG) for each calf, a linear regression model was used. By fitting a regression line to the liveweight-age relationship, the slope of the line was determined, representing the average change in liveweight per unit increase in age and provided an estimated average daily weight gain of the calves. This approach was preferred over using only the initial and final liveweight measurements, as it allowed for all the data measured across time to contribute to the analysis. Allowing the contribution of more measurements throughout the growth period, was considered to reduce the potential for error and provide a more comprehensive assessment of calf growth.

A simple linear regression model was used to assess the strength of association for average daily gain of calves and ranking for suckling activity (Figure 18). While this relationship was not found to be statistically significant (P=0.49), with the direction of effect negative. That is, calves that tended to display increased nursing activity, generally corresponded with reduced pre-weaning average daily gain relative to the rest of the group.

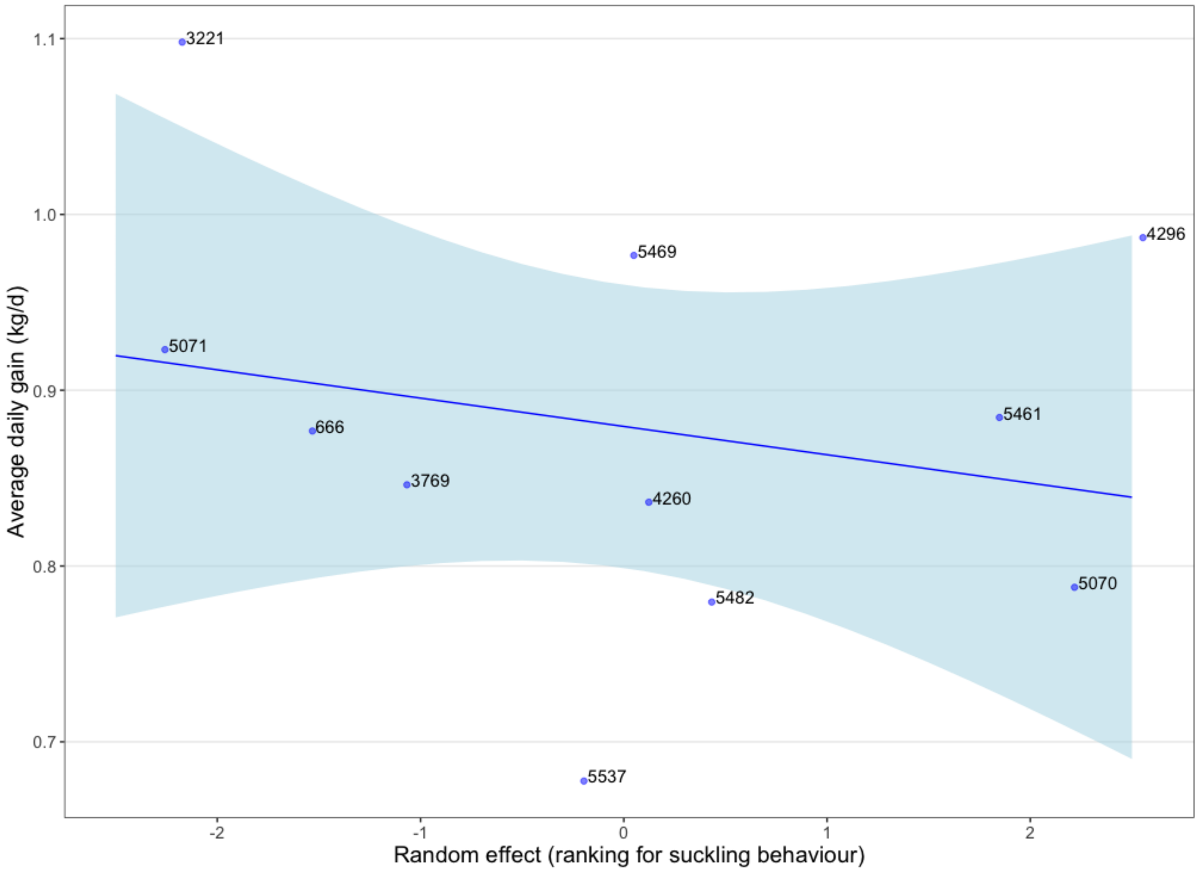


Figure 18. The relationship between average daily gain and ranking for nursing behaviour. The linear regression line of ADG = -0.016RE + 0.88 is displayed, with each data point labelled by Calf ID.

These finding suggest a negative association between suckling activity and growth. This association could potentially be explained by increased suckling activity due to reduced milk availability (Day *et. al.*, 1987; de Passillè, 2001) and the level of hunger of the calf (de Passillè, 2001; de Paula Vieira et al. 2008). Dams with lower levels of milk production were observed to be suckled by calves for longer duration and more frequently (Day *et. al.*, 1987). Consequently, the negative impact on growth may be a result of limited nutrient intake, with the increased suckling behaviour reflecting increased demand.

The lack of association between nursing behaviour and growth is consistent with previous research reported in the literature as they do not consider differences in milk flow rate or suckling vigour (Mendi and Paul, 1989). Research findings have indicated that the duration of suckling behaviour exhibited by calves is not a reliable indicator of milk intake (de Passille, 2001). By extension, it can be inferred that the duration of suckling behaviour is also likely to be an inadequate indicator of calf growth, given the association between calf growth and milk transfer. Similar findings have been reported in studies involving other species. For example, Birgersson and Ekvall (1994), in their investigation of the impact of suckling time on the growth of fawn deer, also reported a lack of association between suckling time and growth. In horses, Cameron et al. (1999) similarly reported no relationship between various measures of suckling and milk and energy transfer. These consistent findings may be attributed to the characterisation of suckling bouts, which typically comprise three phases: pre-stimulation, milk intake, and post-stimulation.

5. Conclusion

In this research study, the potential use of remote technology to analyse suckling behaviour in beef calves and cows was explored. The results of the study indicated promising outcomes, demonstrating the developed model's ability to accurately distinguish between suckling and non-suckling events in calves. However, based on the available labelled data, detecting when a cow is being suckled using either collar or ear tag accelerometer data did not seem to be feasible.

This study is unique in that it is the only known study currently reporting the potential for detecting suckling behaviour solely with sensors attached to ear tags. Unlike previous studies that focused on relationships between suckling behaviour and sensors attached to collars or halters fixed to calves. These findings suggest that ear tag accelerometers can be a viable option for monitoring suckling behaviour of calves. However, further exploration and validation of this approach are needed to confirm its effectiveness and broaden our understanding of the relationship between suckling behaviour and sensor technology.

An analysis of model estimates revealed a significant quadratic relationship between age and predicted daily suckling time. The predictions indicated that suckling time varied within the range of two to five hours per day, with older calves spending more time suckling compared to younger ones. This trend aligns with existing research and practical knowledge in the field. However, it is important to note that the estimated daily suckling time might be an overestimate and could potentially reflect not only effective suckling but also ineffective suckling and other nursing-related behaviours. Further research is needed to refine the estimation and gain a more accurate understanding of the actual nursing time.

Based on output from the suckling recognition model based on accelerometer ear tag data for calves, an analysis revealed a negative trend between suckling activity and growth which was not statistically significant. One possible explanation for this trend reflects poor milk availability from the cow, resulting in increased suckling duration to obtain additional nutrients. However, despite this effort nutrient intake is still reduced and results in reduced growth of the calf. Although, the lack of association between suckling duration and growth aligns with previous research that has also shown a lack of association between suckling time and growth in different species. Studies on fawn deer and horses have reported similar results, emphasizing that suckling duration is not a reliable indicator of milk transfer or energy intake. As such, these results appear to add further evidence that using time spent suckling to infer milk and energy intake is not a useful indicator of maternal investment.

In conclusion, this study contributes valuable insights into the potential of remote technology for monitoring suckling behaviour in beef calves and cows. It highlights the effectiveness of ear tag accelerometers and emphasises the need for further validation and exploration. Additionally, the findings caution against solely relying on suckling duration as an indicator of milk and energy intake in calf growth. Continued research in this field will contribute to enhancing our understanding of suckling behaviour and improving management practices in beef production.

5.1 Benefits to industry

The potential benefits of further developing this technology are substantial. By gaining a deeper understanding of suckling behaviour, researchers and producers can gain insights and knowledge supporting improved of cow-calf management practices, enhance calf growth rates, and overall herd productivity.

Additionally, under research conditions, this technology has the potential to provide valuable insights into the maternal behaviour of cows, which is possibly could support the identification of genetic markers, allowing for its selection. By identifying and selectively breeding for favourable maternal behaviours, producers can make substantial advancements in herd genetics and overall improvements in calf health and welfare.

5.2 Future research and recommendations

Further research is needed to support remote monitoring of maternal behaviours using sensors attached to cows. While the findings of this study showed promise, further research is needed to validate the developed models using larger numbers of animals and represent different breeds.

Furthermore, this study has highlighted the potential challenges associated with the use of commercially available technologies for detecting calving events. Given the considerable variation in Gestation Length (GL) observed in Brahman cattle, as evidenced in this project, further research is recommended to refine and improve these technologies to support observation and information gathering around the immediate time of calving. Enhancing the accuracy and reliability of calving detection in free-grazing cattle through technological advancements would significantly contribute to conducting much-needed research aimed at increasing the overall understanding of calving events, nursing and maternal behaviours around calving and calf loss. It is also crucial for scientists deploying technologies to exercise due diligence and thoroughly test the equipment to ensure its functionality and suitability for their specific application.

6. References

Birgersson, B., & Ekvall, K. (1994). Suckling time and fawn growth in fallow deer (Dama dama). Journal of Zoology, 232(4), 641–650. https://doi.org/10.1111/j.1469-7998.1994.tb04619.x

Cameron, E. Z., Stafford, K. J., Linklater, W. L., & Veltman, C. J. (1999). Suckling behaviour does not measure milk intake in horses, Equus caballus. *Animal Behaviour*, *57*(3), 673–678. https://doi.org/https://doi.org/10.1006/anbe.1998.0997

Day, M. L., Imakawa, K., Clutter, A. C., Wolfe, P. L., Zalesky, D. D., Nielsen, M. K., & Kinder, J. E. (1987). Suckling Behavior of Calves with Dams Varying in Milk Production. *Journal of Animal Science*, *65*(5), 1207–1212. https://doi.org/10.2527/jas1987.6551207x

de Passillé, A. M. (2001). Sucking motivation and related problems in calves. *Applied Animal Behaviour Science*, *72*(3), 175–187. https://doi.org/10.1016/S0168-1591(01)00108-3

de Paula Vieira, A., Guesdon, V., de Passillé, A. M., von Keyserlingk, M. A. G., & Weary, D. M. (2008). Behavioural indicators of hunger in dairy calves. *Applied Animal Behaviour Science*, *109*(2–4), 180–189. https://doi.org/10.1016/J.APPLANIM.2007.03.006

Hogan, L. A., McGowan, M. R., Johnston, S. D., Lisle, A. T., & Schooley, K. (2022). Suckling Behaviour of Beef Calves during the First Five Days Postpartum. *Ruminants 2022, Vol. 2, Pages 321-340*, *2*(3), 321–340. https://doi.org/10.3390/RUMINANTS2030022

Kour, H., Patison, K. P., Corbet, N. J., & Swain, D. L. (2018). Validation of accelerometer use to measure suckling behaviour in Northern Australian beef calves. Applied Animal Behaviour Science, 202, 1–6. https://doi.org/10.1016/j.applanim.2018.01.012

Kuźnicka, E., & Gburzyński, P. (2017). Automatic detection of suckling events in lamb through accelerometer data classification. Computers and Electronics in Agriculture, 138, 137–147. https://doi.org/10.1016/J.COMPAG.2017.04.009

Mendl, M., & Paul, E. S. (1989). Observation of nursing and sucking behaviour as an indicator of milk transfer and parental investment. *Animal Behaviour*, *37*(PART 3), 513–515. https://doi.org/10.1016/0003-3472(89)90100-0

Stagg, K., Spicer, L. J., Sreenan, J. M., Roche, J. F., & Diskin, M. G. (1998). Effect of Calf Isolation on Follicular Wave Dynamics, Gonadotropin and Metabolic Hormone Changes, and Interval to First Ovulation in Beef Cows Fed Either of Two Energy Levels Postpartum. Biology of Reproduction, 59(4), 777–783. https://doi.org/10.1095/biolreprod59.4.777

7. Appendix

1.1 Acknowledgments and contributions

1.1.1 Authors contributions

- **Conceptualisation:** Michael McGowan, Kieren McCosker, Greg Bishop-Hurley
- **Data Curation:** Kieren McCosker, Michael McGowan, Greg Bishop-Hurley, Rachel Bender, Sanchia Gillies and Georgia Glasson
- **Formal Analysis:** Reza Arablouei and Kieren McCosker
- **Funding Acquisition:** Kieren McCosker, Greg Bishop-Hurley, Michael McGowan
- **Methodology:** Kieren McCosker, Greg Bishop-Hurley, Michael McGowan
- **Project Administration:** Kieren McCosker
- **Visualisation:** Kieren McCosker
- **Writing –Draft Preparation:** Kieren McCosker and Imtiaz Randhawa
- **Writing – Review & Editing:** Kieren McCosker, Imtiaz Randhawa, Michael McGowan and Greg Bishop-Hurley

1.1.2 Acknowledgements

The authors of this report would like to gratefully acknowledge the following contributions:

- Meat and Livestock Australia for funding this project.
- Northern Territory Department of industry, Tourism and Resources and the staff at the Katherine Research Station for providing access to necessary resources and support to conduct this study. Dave Hancock’s contributions to the design and fabrication of the portable tower platform utilised during this study is further acknowledged.
- TerraCipher, David and Will Swain, for assistance throughout the project and for accessing and analysing taggle data.
- Taggle staff, Steve Cato and Mark Halliwell, for assistance and advice throughout the project on accessing calf alert transmitterss, installation of taggle receivers and creation of data.
- ComCat (Katherine) who assisted with finding solar power solutions and sourcing equipment.