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Automating welfare measurements and interventions for Northern Australia beef cattle

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Abstract

This project delivered a proof-of-concept study which was conducted to determine the capability of an auto-drafting system to automatically separate calves from cows in-paddock. The project encompassed three phases: (i) a systematic literature review on the use of automated livestock management system (ALMS) technologies to record animal welfare in extensive beef production, (ii) development of an in-paddock calf segregation system, and (iii) reporting on current calf management practices, producer perceptions and evaluation of an auto-drafting system.

The results of the study identified great potential for an ALMS to successfully operate in remote locations with 83% of calves effectively drafted from cows. The study also indicated that calves that used the system within 15 days of birth had 13 times more entries per week than calves that were older at first use. Overall calf use was low and alternative training programs, attractants and infrastructure modifications are required to increase calf use.

Producers saw great benefit in the technology to improve the way animals are monitored and managed. However, they also identified various challenges that need to be overcome to minimise barriers to adoption and maximise wider industry use. In particular, ensuring that the benefits to be derived will outweigh the investment necessary.

Further studies evaluating the costs and benefits of various management and productivity applications are required. These studies will determine the value that auto-drafting can deliver through labour savings, improved productivity, increased returns and enhanced animal health and welfare.

Executive summary

This report details the methodology used and progress made towards developing a proof-of-concept auto-drafting system to automatically separate calves from cows in-paddock. The project encompassed three phases: (i) conducting a systematic literature review into the use of automated livestock management systems (ALMS) to record animal welfare in extensive beef production enterprises, (ii) development of an in-paddock calf segregation system to automatically draft calves from cows, and (iii) reporting of producer views on current calf management practices, perceptions of auto-drafting and evaluation of the operational auto-drafting system.

It is reported that calf husbandry practices in northern Australian extensive beef operations occur at a later age than is the case for beef calves raised throughout other regions of Australia. This is because calves in these regions are not generally yarded until they are older than six months of age. The rationale for this project was to develop an automated method of separating calves from cows in-paddock to provide producers with access to calves at a younger age than traditional practices allow.

A systematic literature review was first conducted to report on published studies in which technologies have been used to monitor animal welfare. The review focussed on automated livestock management technologies relevant to commercial beef cattle operations, including auto-drafting, proximity loggers, radio frequency identification (RFID), Taggle locating devices and walk-over-weighing (WoW). A total of 65 peer-reviewed articles reporting on 68 separate studies published from the year 2000 onwards were reviewed. The general details of each study were assessed and the outcomes of the study were aligned with Mellor's five domains of animal welfare (Mellor 2017). The studies were classified according to focus area with the majority relating to behaviour recording, followed by methods for validation. Only three studies had a primary focus to determine welfare state. The objective of most of these studies aligned with Mellor's nutrition domain followed by inferring behavioural state.

Of those studies included in the review, there were very few where ALMS technologies were specifically used to infer welfare state, and none that used auto-drafting in extensively managed beef cattle. The review however, identified great potential for technologies to be used to monitor animal well-being under the domains of nutrition, environment, health and behaviour as proposed by Mellor (2017). It also showed that multiple sensors provide the greatest insight into an animal's welfare relative to all five domains. Future investigations should consider the application of other on-animal sensors, such as GPS, accelerometers and pedometers.

The second component of the study was the development and assessment of an ALMS comprising a WoW platform and auto-drafting infrastructure for its efficiency and accuracy to draft calves from cows. Due to limited information on the design and operation of existing remote auto-drafting technology, a purpose built ALMS system was developed with greater flexibility and control than commercially available systems. The system was refined as a result of a series of studies, with a dietary supplementation study (Corbet *et al.* 2019a; Corbet *et al.* 2019b) demonstrating correct drafting of 99.9% of heifers. A similar approach was applied to a group of 42 cows and their calves. Calf use of the ALMS was monitored over a period of eight months to report on factors that influenced how frequently the calves used the system. The average age when calves first used the

system was 34.6 ± 36.6 days, which ranged from three calves using the system on the day they were born through to one calf taking 154 days to first use the system. The age at which a calf first used the ALMS had a greater effect on future use than the age of the calf per se. Calves that used the ALMS within 15 days of age (classified as Early first age users) were 13 times more likely to use the system than calves that were between 16 to 50 days old (classified as Mid first age users), or older than 51 days (classified as Late first age users) at the time of first entry into the unit. The average time separation between a calf following a cow through the system was 26 seconds for 70% of calves; this information directly influences the settings used to initiate the drafting gate.

It was expected that calves would learn to use the ALMS by following their mothers. However, for most calves this did not occur. Training sessions, using a manual muster of the whole herd to the compound, were conducted eight times over a six week period to familiarise the calves with the system before the drafting gate was initiated. A further five training events were conducted to familiarise the cattle with the drafting gate. However, calf use remained low with an average of 15 calves using the system per day. The accuracy of the drafting gate was tested when cows and calves were manually mustered to the ALMS compound, resulting in 83% of calves being successfully drafted from cows.

The results of the study indicate the importance of training calves to use the ALMS from an early age to enhance future use, and that cows will not necessarily train their calves to use the system without manual intervention. The system successfully drafted the majority of calves from cows when mustered to the ALMS compound. This indicates that such an approach would provide producers with an option to automatically draft calves from cows in-paddock, which could represent a weaning situation where calves could be removed from their mothers in-paddock and either trucked or walked from there to another paddock or yards. Implementing this application could provide labour savings by not having to muster cattle to a set of main yards, as well as productivity and animal welfare benefits as cattle would not need to be walked for kilometres or held off pasture while being held in yards. These findings also provided confidence that improvements in drafting calves from cows could be made through adjustments to the infrastructure and software.

The third component involved running three different activities to engage with producers including one-on-one interviews with seven producers, an online survey attracting 61 respondents and a technology demonstration attended by 31 participants with ten of those also completing an additional online evaluation survey. The engagement activities aimed to understand current calf management practices and report on producer's perceptions and evaluations of auto-drafting. Involving producers in the research process was an important component to ensure that all future developments will be useful in a commercial setting, which will thus facilitate adoption by industry.

Almost 60% of surveyed producers were interested in installing auto-drafting, and six of ten producers reported their interest had increased after seeing the demonstration. Producers stated that the capacity of the system to monitor body weight for informing management decisions such as identifying cattle ready for market and supplementation, along with the ability to automatically draft calves to be weaned, provided the most significant perceived potential benefits. Cost and requirement for multiple watering source within a paddock were perceived as the greatest barriers to installing an auto-drafting system. Collaborative networks between researchers and producers were established, promoting a shared-values research model where researchers and producers can work together to develop industry relevant technology.

The results obtained in this proof-of-concept study provide confidence that automated drafting can be implemented in remote locations. It paves the way for more detailed studies focussed on investigating the necessary refinements identified in this study. Followed by a cost benefit analysis of the technology for various management applications, including health and welfare monitoring and management. There are still advancements to be made to improve the current system and eventually develop a completely automated paddock-based calf separating system for untagged calves. Methods of attracting and training calves to use the system efficiently is a high priority, both for auto-drafting applications as well as WoW. Improvements to the drafting gate infrastructure are also warranted, primarily to decrease the noise of the compressor and the gate making contact with the metal frame and ease the sudden movement of the gate that caused cattle to baulk. Additionally, varied and/or alternate applications identified by industry should also be considered for future research investment.

Adoption by industry will happen only after producers develop confidence in the technology they are purchasing. This might be achieved through additional feasibility and validation studies and economic analysis. Developing a producer-informed model, where producers are partners in the research, will enable the delivery of industry relevant outcomes and promote the distribution of information throughout the producer network. This approach encourages transparency throughout the research-extension-adoption process, thereby providing industry with the information they need to make informed decisions about the technology they are adopting and result in efficient implementation under various commercial settings.

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1 Background

The different welfare standards that exist for calves in Australia exposes the northern beef industry to the risk of attack from animal rights lobby groups. National standards currently require castration to be performed on calves less than 6 months of age, however, in northern Australia there is an exception for calves that are mustered for the first time after this age, with the average age of first muster around 7 months old (Petherick 2005). It is illegal in some states to perform castration on calves older than 6 months, thus, exposing the issue of compromised calf welfare standards in regions of Australia where cattle are managed in an extensive setting.

Public perception of animal welfare can have devastating short- and long-term effects on animal-based industries. For example, the month-long ban on live cattle export trade to Indonesia affected beef producers across Australia, with economic effects felt by northern Australia cattle farmers several years later (Everingham and O'Brien 2014). Additionally, consumers are increasingly interested in knowing that their food has been produced using welfare friendly practices (Cembalo *et al.* 2016), and are willing to pay greater price premiums as a result (Kehlbacher *et al.* 2012). Providing information to consumers and society that national welfare standards are being met on a daily basis in our farming practices has the potential to increase confidence in red meat products, promote integrity within the supply chain, and ensure market security.

Research has shown that castrating beef calves at 3 months of age results in less stress and shorter recovery times than calves castrated at 6 months of age (Petherick *et al.* 2015), while most surgical procedures can be performed on calves less than 6 months of age without the need for pain relieving treatments (Animal Health Australia 2014). Additionally, calves castrated at younger ages are easier to physically handle, have less health-related complications afterwards and the procedures are simpler to conduct than with older calves. Thus, there are proven benefits for both the producer and animal by performing husbandry procedures earlier than current practice in northern Australia, potentially resulting in labour efficiencies, increased animal welfare and productivity gains.

Northern Australian beef producers face several welfare monitoring challenges. The expansive area, harsh climatic conditions and a small labour force and infrastructure inputs lead to issues in the way animal welfare is monitored. Automated livestock management systems (ALMS) are combinations of technology and infrastructure that can automatically monitor and manage cattle, including walk-over-weighing (WoW) technology and auto-drafting capabilities. The technology presents potential benefits to improve animal management, labour efficiency and animal welfare. One particular benefit proposed from an auto-drafting ALMS is the potential to draft calves from their mothers to perform husbandry practices at younger ages than what is currently reported, which would improve welfare outcomes for the calf and ease of handling by the producer; this potential application presents an opportunity to proactively address the issue of calf welfare and prevent negative publicity about the way beef calves are managed in extensive systems.

Auto-drafting is an emerging technology that has been adopted by both the dairy and sheep industries (Bowen *et al.* 2009; Edwards *et al.* 2015). The system operates by using a RFID reader to identify individual animals as they walk across a platform and automatically draft them based on certain criteria, such as weight, targeted supplementation, or oestrous detection for artificial insemination programs. The integration of auto-drafting into a walk-over-weigh system increases the value proposition of the technology by delivering multiple production parameters, such as individual animal monitoring, weight tracking, estimated calf birth date and parentage information. Auto-drafting systems have successfully been used to apportion sheep supplementation (Bowen *et al.* 2008) and manage pre-partum ewe nutrition (Wishart *et al.* 2015). In the New Zealand dairy industry, auto-drafting was identified as the greatest labour saving benefit to the producer of all technologies implemented on-farm (Edwards *et al.* 2015). There is potential for auto-drafting to be implemented in the northern Australian beef industry to provide labour saving benefits whilst also improving the welfare of extensively managed beef cattle, however, testing of this technology is required to determine if the perceived benefits translate into real on-farm value.

There are several auto-drafting units currently available. Those available commercially are designed to be operated in a fixed location with access to mains power, generally with the operator within close proximity to make drafting decisions at that point in time (e.g. TruTest). The Precision Pastoral Management System (PPMS) incorporates a remotely operated drafting system within a walk-over-weighing system. While the system operates remotely via solar power, the location is fixed, preventing the drafting system being utilised in more than one location. The PPMS development project recently concluded with very little literature available on the actual success of the project or details of the algorithms developed. To date, the results of the PPMS Company endeavours related to separating calves from cows has not been published. Therefore, there is limited published information available on remotely separating cows from calves in-paddock. The benefits of auto-drafting technology for calf management extend to providing producers with reliable and accurate data to make informed decisions, which has the potential to lead to higher welfare standards than current industry practice.

The adoption of technology in the agricultural sector has traditionally been low (Llewellyn 2007). Factors such as the complexity of the technology, being able to observe outcomes, cost and the producers own opinions, motivations and perceptions of the technology, as well as their attitude towards risk and change affect how readily a technology will be adopted (Guerin and Guerin 1994). Post-adoption, success of implementation relates to how well the technology meets expectations, producers income, farm size and farming sector (Khanal *et al.* 2019). As ALMS are a relatively new technology for the extensive beef industry, research is needed to identify producer's perceptions towards the technology and understand where producers see the greatest benefits and barriers. This is crucial to inform future research to ensure future developments will be appealing to commercial enterprises and in turn promote adoption by the wider industry.

This project explores exactly how auto-drafting technology might be integrated into extensive livestock grazing systems and the likely benefits for production and welfare that might result from adoption on-farm. The project comprises three components, being a systematic literature review reporting on the use of ALMS technology to record cattle welfare; the development and testing of an auto-drafting integrated ALMS to separate calves from cows in-paddock, and; engagement with producers to understand their current management practices, particularly related to calves, and report on their perceptions and evaluation of auto-drafting.

2 Project objectives

1. Develop a practical on-farm auto-drafting system to facilitate the adoption of earlier calf husbandry practices by remotely segregating untagged calves from the herd whilst in their paddock environment.
2. Produce a systematic literature review to assess the use of ALMS in validating animal welfare parameters against national standards.
3. Develop a remote calf segregation system using auto-drafting to improve welfare surveillance and herd management practices. This includes finding the most appropriate method to identify calves that are not tagged with NLIS.
4. Conduct focus groups to obtain information on current husbandry practices and challenges with calf welfare to inform research findings, and the evaluation of the drafting system once operational.
5. Produce a progress report detailing the outcomes of the focus groups and the installation and initial performance of the auto-drafting system.
6. Produce a final report detailing the refinement of the auto-drafting technology, findings of the field study, as well as the findings of the focus group, fully evaluating the refined paddock-based auto-drafting system.

3 Systematic Literature Review

3.1 Introduction

Extensively managed beef cattle in Australia face many welfare challenges, with low input systems dominated by harsh climates, poor fertility soils and vast landscapes affected by flooding and drought that make regular animal surveillance extremely difficult on some properties (Petherick 2005). Cattle grazing rangelands across the world face these issues. While there are welfare issues that affect all kinds of cattle management systems, such as castration and dehorning, there are also issues unique to specific cattle management systems (Bailey 2016). For example, whereas intensively reared dairy cattle are restricted in grazing time and space, they enjoy closer individual monitoring (and timely husbandry intervention), whilst extensively managed beef cattle enjoy greater freedom under more natural conditions, as experienced by their wild ancestors, but are not closely monitored by their stock people. There are opportunities to apply techniques and technologies that have been developed and tested in intensive livestock operations to extensive cattle production systems, given appropriate testing and validation.

Consumers and society are increasingly becoming aware of the ethical issues associated with practices used by livestock producers and are seeking improvements in animal welfare (European Commission 2007; de Jonge and van Trijp 2013). Producers are also looking for technologies that can automatically record animal welfare status (Trotter *et al.* 2018). Correspondingly producers and researchers are searching for methods to increase transparency in husbandry practices to improve and document the way animal health issues are identified and resolved.

The first step in disease detection is identifying when an animal's behaviour has changed; abnormal behaviour is the first sign that an animal's health is compromised (Broom and Fraser 2007). In extensive livestock systems where animal activity is not monitored daily, behavioural changes can occur without notice. When animals are routinely monitored, even sub-clinical diseases can be detected from subtle behavioural changes without any physical symptoms being observed (Theurer *et al.* 2013; Caja *et al.* 2016). Early illness and disease detection leads to improved health and productivity through timely treatment and management whilst decreasing the chances of disease spread and helping ensure productivity and good health after leaving the farm (Neethirajan 2017). Currently, animal welfare assessments on extensive systems are conducted periodically, often during times when food and water are provided or animals are confined for management purposes. Such practices comply with the five freedoms of animal welfare, however, the assessments are infrequent, only comprising a small portion of the animal's life, and are largely determined by human convenience (i.e., what is easy and convenient to measure). There is a need for continual monitoring of welfare indicators in modern livestock production systems to objectively reassure the public that animals are generally in an optimal welfare state.

The five freedoms model of animal welfare was developed by the British Farm Animal Welfare Council in 1979 to promote a duty of care for agricultural animals (Farm Animal Welfare Council 1979), by enforcing a code to provide all animals with the freedom from: (i) thirst, hunger or malnutrition (ii) discomfort and exposure, (iii) pain, injury and disease, (iv) fear and distress, and (v) the freedom to express normal behaviour. Since their conception these freedoms have formed the foundation of basic provisions for all animals, including companion animals, those used in research and teaching, wildlife, zoos and domesticated livestock. While this model is well accepted across the world, the freedoms have been criticised for their negative focus and unobtainable targets, as an animal in "good" welfare state is considered to be completely free from negative experiences, yet this is physiologically and practically unobtainable and sets unrealistic expectations (Mellor 2016). A new framework has been proposed that considers positive and rewarding situations to maximise animal welfare, whilst also taking into account an animal's mental state (Figure 1; Mellor 2017). The five domains model of animal welfare was originally intended as a system to evaluate the welfare of animals used in research, teaching and testing, however, the model is now widely applied to all animals just as the five freedoms.

	1. Nutrition		**2. Environment**		**3. Health**		**4. Behaviour**	
Physical/functional Domains	*Restrictions on:*	*Opportunity to:*	*Unavoidable or imposed:*	*Available:*	*Presence of:*	*Little or no:*	*Normal behaviour restricted by:*	*Normal behaviour promoted by:*
	Water Food quantity, quality and variety	Drink enough water; Eat enough food, with variety and balanced nutrition	Thermal extremes; Close confinement; Inappropriate lighting; Environment pollutants	Thermally tolerable; Space to move freely; Appropriate lighting; Fresh air	Disease; Injury; Functional impairment	Disease; Injury; Functional impairment	Barren, unstimulating environment; Social interaction; Limits on avoidance, escape or defensive activity; Limits on sleep/rest	Environmental enrichment; Social interaction; Reproduction opportunities; Rearing young; Play; Opportunity for rest/sleep
Affective Domain	**5. Mental State**							
	Negative	*Positive*	*Negative*	*Positive*	*Negative*	*Positive*	*Negative*	*Positive*
	Thirst; Hunger; Malnutrition	Pleasures of drinking, different tastes/ smells	Discomfort e.g. thermal, physical pain, respiratory	Comfort e.g. thermal, physical, respiratory	Pain; Illness; Physical exhaustion	Good health and fitness	Anger, frustration, boredom, loneliness, isolation, helplessness Anxiety, fear	Calmness, in control; Social interaction; Maternally rewarded; Excitation, playfulness; Secure, protected

Fig. 1. The five domains model of animal welfare [adapted from Mellor (2017)]

Some segments of livestock agriculture have implemented new technologies to monitor animals more than others. The dairy industry uses new technologies sooner and more often than extensive cattle operations, because electrical power and connectivity are more available and easier to manage (Rutter 2017). The most successful adoptions of technology in the sheep industry have been multi-functional devices that facilitate management and track productivity, such as electronic identification, walk over weighing and automatic drafting gates (Rutter 2017).

A suite of technologies, including radio frequency identification device (RFID), walk over weighing, automatic drafting gates, proximity loggers and location tracking, are known as automatic livestock management systems (ALMS) because of their capability to routinely record individual animal data remotely. Along with recording production data, ALMS technologies have the potential to simultaneously record indicators of welfare (Leigo *et al.* 2012; Brown *et al.* 2015; Swain *et al.* 2015; Bailey 2016). For example, tracking data can provide information on behavioural time budgets, distance travelled and energy expenditure, with the potential to use deviations in these patterns to identify health concerns (Bailey *et al.* 2018). Walk over weighing monitors changes in live weight, which can be used to indicate health and diet concerns; water meters quantify water availability and GPS tracking and accelerometers can indicate a calving event and predation. The objectives of this component are to conduct a systematic literature review to (i) quantify the use of ALMS technology in existing original research publications with reference to welfare monitoring, and (ii) identify the welfare indicators from existing ALMS research that are applicable to the five domains of animal welfare.

3.2 Methods

The methodology of this review is similar to Fogarty *et al.* (2018). The electronic databases Scopus, Web of Science, ScienceDirect and ProQuest were searched between August and September 2018 for articles related to on-farm technology use in beef production systems. Search terms associated with cattle were combined with search terms relating to each technology using the Boolean operator 'AND'. The search terms for cattle were: 'beef', 'bovine', 'calf', 'cattle' and 'cow'. The terms 'heifer' and 'steer' returned too many irrelevant results and were excluded from the search. The five cattle terms that were used successfully returned articles containing 'heifer' and 'steer', which obviated the need to include them. The technology related search terms were: 'contact log*', 'proximity log*', 'walk over weigh*', 'auto* draft*', 'taggle*', 'radio frequency identification' and 'RFID'. ScienceDirect was unable to process wildcards such as asterisks to represent all possible versions of words (e.g. 'proximity log*' to infer 'proximity logger' or 'proximity logging'), thus all possible technology options were written in full.

The following criteria were required for articles to be included in the review: (i) written in English; (ii) used live cattle as the main subject; (iii) applied one or more ALMS technologies to cattle on-farm (supply chain, product traceability and transport studies were excluded); and (iv) published after the year 2000. Only peer reviewed original research journal articles were included, thus books, book chapters, review articles and conference proceedings were not included. Articles were deemed unobtainable if copies could not be retrieved via electronic searchers (e.g. Google), affiliated networks such as author websites or social media platforms (e.g., ResearchGate), or interlibrary loan services. Simulation studies were excluded, unless the algorithm developed on live animals was also tested on a separate set of data collected from live animals using that technology. Due to a large volume of records obtained relating to RFID, results were further refined to only include studies relating specifically to beef cattle. Both dairy and beef cattle were included for other technologies as the studies involved activities common to both systems e.g. inter-species interaction (Bohm *et al.* 2009). Additionally, articles using more than one technology were not duplicated across technologies but reported according to the main technology used, for example, Menzies *et al.* (2018a) used walk-over-weighing to determine parturition date in cattle, thus meeting the search criteria for both walk-over-weighing and RFID technology, but was categorised as walk-over-weighing as that was the main focus of the study.

3.2.1 Data collection

The type of technology used, author, title and year of publication were recorded for all articles meeting the specified criteria. Geographic region of the study (Africa, Asia, Europe, Oceania, North America or South America) was recorded, climate was classified as either tropical, arid/semi-arid, temperate or cold (Peel *et al.* 2007). Study year was reported as the first year that the study commenced. If more than one study was reported in a single article it was classified as a separate study and analysed independently of the related study. If the study location was not reported the first authors address was used, and likewise, if the year of study was not defined the year of publication was used, realising that this would not be the actual year the study took place. The study type was defined as 'grazing' or intensive' as per Williams *et al.* (2017), where extensive referred to cattle grazing pasture outdoors, while intensive referred to studies based within confined environments such as a pen, barn, feedlot or dairy production system.

The breed of animal (i.e., *Bos indicus, Bos taurus or Bos indicus x Bos taurus*), the class of animal (cow, bull, heifer, steer, calf) and the sex were recorded for each study. No more than two classes of animals were recorded per study. All studies were assessed for the time period that technology was used by recording (i) the number of deployments; (ii) the total length of recording, and (iii) the average deployment length. As per Fogarty *et al.* (2018), the deployment durations were classified into clusters of weeks using 2 weekly increments (e.g. 1-2 weeks, 2-4 weeks) followed by 2 monthly increments (e.g. 1-2 months, 2-4 months), with 4 weeks representing 1 month.

Data recorded from each device type varied among the technologies. For proximity loggers, total number of devices used, maximum herd size, and proportion of the herd fitted with a device was recorded. If the latter was not specifically stated, the value was derived as a proportion of the total number of animals with devices divided by animals in the herd. The make and model of the device and the attachment method were also recorded as well as the specific device settings, including the UHF setting, approximate proximity recording radius and separation time. Details of logged data, including the frequency and duration of contacts recorded per logger, were not analysed as there were not enough studies reporting the results of this information to make valid comparisons.

The manufacturer of walk-over-weighing and auto-drafting equipment, and the direction of movement (either one way, indicating a separate entry and exit, or two-way, where animals exit the compound via the entry) were recorded. In addition, the type of inducement used to encourage animals to use the system and the number of records obtained per animal per day were noted. The success rate was defined as the number of legitimate records divided by all records.

For RFID studies, the manufacturer of the receiver system, the type of inducement used to encourage animals to approach the RFID reader, the type of RFID attachment (ear, rumen bolus), the number of records obtained per animal per day, the average duration spent at the reader per day and the number of RFID reading units per animal were used in the analysis.

For all technologies, continuous data were reported as the average ± standard deviation. For categorical data, counts and frequencies were reported. The inclusion of other technologies or species in the study were also noted.

The objectives of each study were classified into one or two of the following foci: behaviour; health, methods validations, environmental management, sensor validation, and welfare, according to the definitions listed in Table 1. The main implications of each study were assigned into one or two of the five domains of animal welfare (i.e., nutrition, environment, health, behaviour and mental state) proposed by Mellor (2017). The keywords used to categorise each study into one of the five domains are listed in Table 2. As there were only three studies that reported welfare implications from their research, all experiments were evaluated for the potential to relate to a welfare domain from the outcomes. For example, a study by Menzies *et al.* (2018b) used walk-over-weighing with water as an inducement to determine parturition date and was assigned to Domain 3 (Health) because recording animal weight provided an indication of its body condition. In addition, Menzies et al. (2018b) was assigned to Domain 1 (Nutrition) as the technology was used to record watering events.

Table 1. A description of the focal areas used to categorise each study (adapted from Fogarty et al. (2018))

Focus	***Description***
Behaviour	Studies using technology to record all aspects of cattle behaviour, including drinking and feeding events
Health	Use of technology to identify the onset and occurrence of disease, including clinical and sub-clinical disease, or provide an indication of good health
Methods validation	Studies developing or evaluating methods to interpret and analyse data from technology that are validated against other reliable sources (e.g. visual observations)
Environmental management	Applying technology to measure cattle impacts on the environment, including measuring methane emissions
Sensor validation	Studies testing, developing and refining technology hardware and platforms
Welfare	Studies applying technology to record a specific aspect of animal welfare

Table 2. Keywords used to assign studies to the five domains of animal welfare (adapted from Fogarty et al. (Unpublished))

Domain	***Potential keywords***	
1. Nutrition	- Feeding (e.g. grazing, foraging, chewing) - Food quality	- Metabolisable energy - Water/drinking
2. Environment	- Exposure - Weather/temperature - Resting - Lying	- Thermal stress - Housing conditions - Space available/stocking rate
3. Health	- Disease - Pain	- Body condition score - Live weight changes
4. Behaviour	- Behaviour - Reference to performing particular behaviours e.g. grazing	- Reproduction behaviours e.g. oestrus, mating - Inter- and intra-species interaction
5. Mental state	- Affective state - Emotion	- Fear - Distress

3.3 Results

The use of these search terms resulted in a total 771 unique articles being assessed, with the majority of these related to RFID (81.7%, n = 630), followed by proximity loggers (13.0%, n = 100), walk-over-weighing (3.2%, n = 25), auto-drafting (1.4%, n = 11) and Taggle (0.6%, n = 5). A large portion of articles did not relate to cattle (71.2%, n = 549), and of those a further 17 articles did not relate to any technology and were excluded. Of the 205 articles relating to both cattle and technology, 45.2% (n = 61) were excluded due to document type (e.g., books, review articles and conference proceedings), 23.7% (n = 32) did not include the ALMS technologies as the main focus of the paper (studies using RFID purely for identification purposes and not for data collection were excluded), 20.0% (n = 27) of articles did not meet the study type criteria, either they were based on simulation, supply chain or survey, 9.6% (n = 13) were RFID studies based in the dairy industry and 1.5% (n = 2) were not written in English. All articles meeting the required specifications were retrieved from electronic databases and Inter-Library loan services.

A total of 70 articles were accepted for this review based on the previously described criteria. A further three articles, however, were discarded as these did not apply the technology to live animals, in one study the complete methodology was not reported and was deemed incomplete, and in another study did not use the technology for automated recording, leaving 65 articles remaining for review. In three studies, two separate experiments were reported, thus the total number of studies reviewed was 68 (Table 3). There were no studies using Taggle technology that met the required search criteria. The year of publication per technology was summarised in categories of 5-yearly intervals (Fig. 2).

Table 3. Details of the publications reviewed according to the main technology used

Article and Technology[a]	Continent[b]	Climate[c]	Study year[d]	Management[e]	Cattle species[f]	Cattle class[d]	Focus[g]	Domain[h]
Auto-drafting								
Jago *et al.* (2004)	Oceania	Temp.	2002	I	i x t	Cow	M, B	4
Lyons *et al.* (2014)	Oceania	Temp.	2011	I	t	Cow	B	4, 1
Scott *et al.* (2016)	Oceania	Temp.	2012	I	t	Cow	B	4, 1
Proximity loggers								
Böhm *et al.* (2009)	Europe	Temp.	2006	E	t	Cow	B	4, 5
Bolt *et al.* (2017)	Europe	Temp.	2013	I	t	Calf	H, B	4, 3
Boyland *et al.* (2013)	Europe	Temp.	n.r	E	t	Cow	B	4
Boyland *et al.* (2016)	Europe	Temp.	2013	E	t	Cow	H, B	4, 3
Corbet *et al.* (2018)	Oceania	Temp.	2017	E	t	Cow	M	4
Cowie *et al.* (2016)	Europe	s/arid	2010	E	t	Cow	M	4
Drewe *et al.* (2012)	Europe	Temp.	2009	I	t	Cow	M	4
Drewe *et al.* (2013)	Europe	Temp.	2009	E	t	Cow	M	4
Duncan *et al.* (2012)	Europe	Temp.	2009	E	t	Cow	B	4
Lavelle *et al.* (2016)	Nth Am	Cold	2012	E	t	Cow	M	4
O'Neill *et al.* (2014)	Oceania	Temp.	2005	E	i x t	Cow	B	4
Patison *et al.* (2010)	Oceania	Temp.	2008	I	t	Steer	M, B	4
Patison *et al.* (2015)	Oceania	Temp.	2009	E	t	Steer	H	4, 3
Swain and Bishop-Hurley (2007)	Oceania	Temp.	2004	E	i x t	Cow	H, B	4, 3
Swain *et al.* (2015)	Oceania	Temp.	2011	I	t	Cow	H, W	4, 3
Watson-Haigh *et al.* (2012)	Oceania	Temp.	2009	E	i, i x t	Heifer	M, B	4
RFID								
Alemu *et al.* (2017)*	Nth Am	s/arid	2015	I	t	Heifer	B, E	1, 3
Brew *et al.* (2011)	Nth Am	Temp.	2006	I	t	Bull, steer, heifer	B	1
Brown-Brandl and Eigenberg (2011)	Nth Am	Cold	n.r	I	i x t	Steer	M, B	1
Camacho *et al.* (2014)	Nth Am	Cold	2012	I	t	Cow	B, H	1, 3
Champion and Matthews (2007)	Oceania	Temp.	n.r	I	t	Cow	W, B	1
Corbet *et al.* (2018)	Oceania	Temp.	2017	E	t	Cow	M, B	4
Cottle *et al.* (2015)	Oceania	Temp.	n.r	I	t	Heifer	M, E	1, 3
Curtis *et al.* (2017)	Nth Am	Temp.	n.r	I	t	Steer	H, B	2
Dogan and Yavuz (2018)	Europe	Temp.	2016	I	i x t	Steer	S, H	3
Ghirardi *et al.* (2006)	Europe	Arid	n.r	I	t	Calf	S	4
Gibb *et al.* (2000)	Nth Am	s/arid	n.r	I	t	Steer	B, H	1
Gibb *et al.* (2001)	Nth Am	s/arid	n.r	I	t	Calf	B	1
Gibb *et al.* (2008)	Nth Am	s/arid	n.r	I	i	Steer	B	1
Hammer *et al.* (2016)	Europe	Temp.	n.r	I	t	Heifer	S	4

Article and Technology[a]	Continent[b]	Climate[c]	Study year[d]	Management[e]	Cattle species[f]	Cattle class[d]	Focus[g]	Domain[h]
Hammond *et al.* (2015)	Europe	Temp.	n.r	I	t	Heifer	M, E	4
Lees *et al.* (2018a)	Oceania	Temp.	n.r	I	t	Steer	H, B	2
Lees *et al.* (2018b)	Oceania	Temp.	n.r	I	i x t	Steer	H, M	2
Meléndez *et al.* (2017)	Nth Am	s/arid	n.r	I	t	Calf	W, B	3
Mendes *et al.* (2011)	Nth Am	Temp.	n.r	I	i x t	Heifer	M, B	1
Menzies *et al.* (2018a)	Oceania	Temp.	2015	E	i x t	Cow	M, B	4, 5
Montanholi *et al.* (2010)	Nth Am	Cold	n.r	I	t	Steer	B	1
Moya *et al.* (2015)	Nth Am	Temp.	n.r	I	t	Heifer	M, B	3, 1
Nkrumah *et al.* (2005)	Nth Am	Temp.	n.r	I	t	Steer	B	1
Oliveira *et al.* (2018)*	Sth Am	Temp.	n.r	I	i x t	Heifer	M, B	1
Paz *et al.* (2018)	Nth Am	Cold	2009	I	i x t	Heifer	H, B	1
Prados *et al.* (2017)	Sth Am	Temp.	n.r	I	i	Bull	H	1
Prezotto *et al.* (2017)	Nth Am	Cold	n.r	I	t	Steer	B	1
Roberts *et al.* (2012)	Nth Am	Cold	2005	E	i x t	n.r	M	4
Salim *et al.* (2014)	Nth Am	Cold	n.r	I	t	Steer	B	1
Schwartzkopf-Genswein *et al.* (2003)	Nth Am	s/arid	n.r	I	i	Steer	B	1, 2
Schwartzkopf-Genswein *et al.* (2004)	Nth Am	s/arid	1999	I	t	Steer	B	1
Schwartzkopf-Genswein *et al.* (2011)	Nth Am	s/arid	1999	I	t	Calf	B	1
Small *et al.* (2008)	Nth Am	Cold	2005	I	t	Heifer	B	2
Smith *et al.* (2016)	Nth Am	Temp.	n.r	E	t	Calf	B, M	1
Velazco *et al.* (2016)*	Oceania	Temp.	n.r	I	t	Cow, steer	M, E	4
Walter *et al.* (2016)	Nth Am	Arid	2012	I	t	Steer	B	1
Wolfger *et al.* (2015a)	Nth Am	Cold	2010	I	i x t	Steer	H, B	3, 1
Wolfger *et al.* (2016)	Nth Am	s/arid	2010	I	t	Heifer	B	1
Yuri Regis *et al.* (2017)	Nth Am	Cold	n.r	I	t	Steer	H, B	1, 3
Walk-over-weighing								
Aldridge *et al.* (2017)	Oceania	Temp.	n.r	I	t	Cow	M, B	1, 3
Dickinson *et al.* (2013)	Oceania	Temp.	2013	E	t	Cow	H, B	1, 3
González *et al.* (2014)	Oceania	Tropical	2013	E	t	Steer	B	1, 3
Menzies *et al.* (2018b)	Oceania	Temp.	n.r	I	i x t	Cow	H, B	3
Ortega *et al.* (2017)	Europe	Temp.	2003	I	t	Cow	H	3
Smith *et al.* (2017)	Oceania	Temp.	2015	E	t	Cow	B	3, 1
Song *et al.* (2018)	Europe	Temp.	2015	I	t	Cow	H	3

[a] * denotes two studies were reported
[b] Nth Am = North America, Sth Am = South America
[c] As per Peel *et al.* (2007), temp. = Temperate, s/arid = arid/semi-arid
[d] n.r = not reported
[e] *i = Bos indicus, t = Bos taurus, i x t = Bos indicus cross Bos taurus*
[f] I = intensive, E = extensive
[g] As per Table 1
[h] As per Table 2

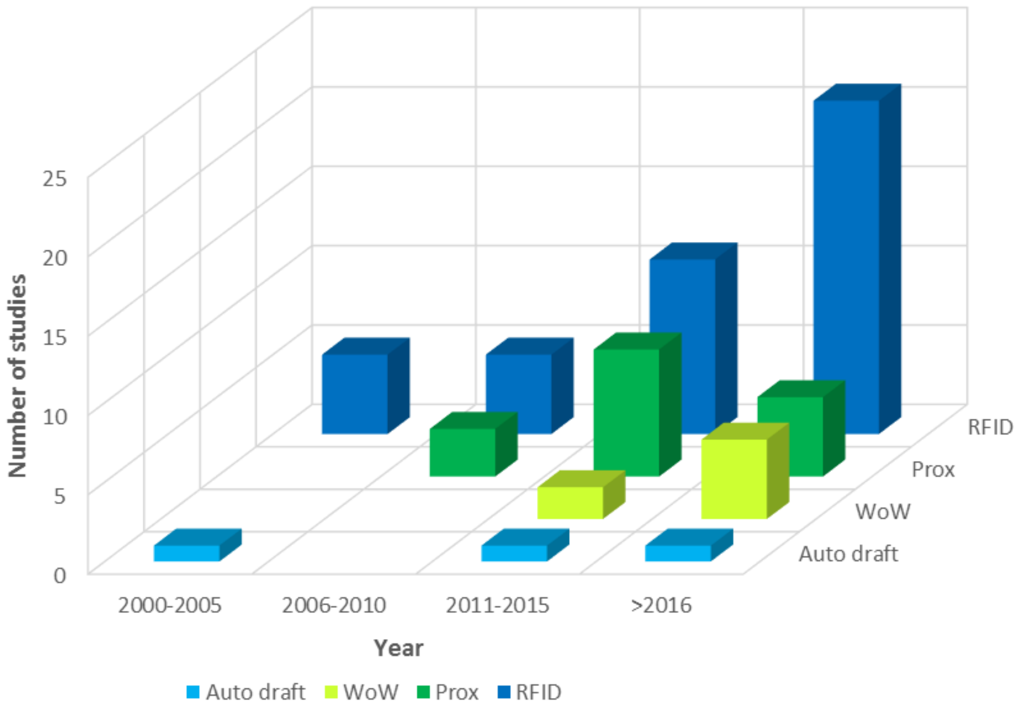


Fig. 2. The number of publications reviewed according to the year published and main technology used, where the technology acronyms relate to: Auto draft = auto-drafting, WoW = walk over weighing, Prox = proximity loggers, and RFID = radio frequency identification.

3.3.1 Climate and study site details

Studies were conducted on four continents, with the majority being conducted in North America (42.6%, n = 29), followed by Oceania (32.4%, n = 22) and Europe (20.6%, n = 14), with only a small percentage recorded in South America (4.4%, n = 3). With six studies, the study location was not reported, thus the first authors location was used. A summary of the location per technology is depicted in Fig. 3. The majority of studies were conducted in temperate environments (63.2%, n = 43), followed by arid/semi-arid (19.1%, n = 3), cold (16.2%, n = 11) and only a small percent in a tropical climate (1.5%, n = 1).

Approximately 30% of studies (n = 19) were conducted in extensive grazing environments, with the rest conducted in intensive management systems. All of the extensive studies were conducted outside with access to pasture, with the majority of intensive studies conducted in outdoor pens or feedlots (61.2%, n = 30). In a small number of intensive studies cattle were provided access to pasture (14.3%, n = 7), approximately 10% (n = 5) were conducted in barns or indoors, approximately 10% (n = 5) were allowed access to both indoor and outdoor environments while two studies did not report the environment where the cattle were housed.

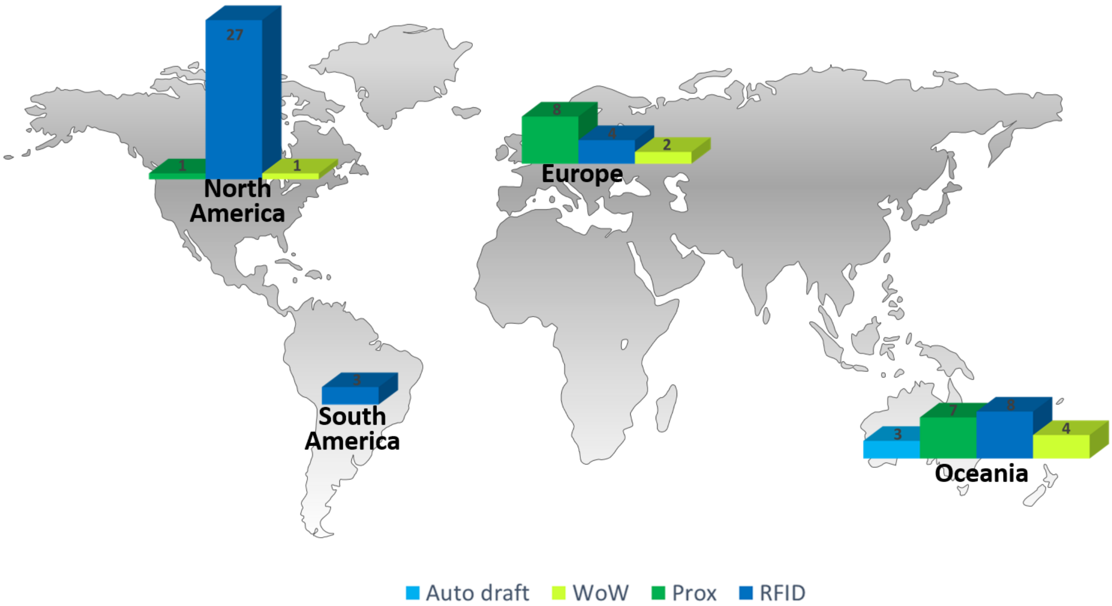


Fig. 3. The distribution of reviewed studies across the world according to technology, where the technology acronyms relate to: Auto draft = auto-drafting, WoW = walk over weighing, Prox = proximity loggers, and RFID = radio frequency identification (map sourced from fppt.com (2018)).

The average study duration was 180 days (±396) for all technologies, with auto-drafting having the shortest period (13.6 days ± 7.02), followed by RFID (140.2 days ± 297.6), proximity loggers (143.14 days ± 228.0) and walk-over-weighing with the longest deployment length (491.9 days ± 943.63). In the longest study, walk-over-weighing technology was used to collect data during an 8-year period (Smith *et al.* 2017). The study duration using each technology is depicted in Fig. 4. In approximately 70% of studies (n = 48), data was collected during only one deployment, with the average number of deployments being 2.05 ± 2.75 across all technologies, a minimum of one and a maximum of 19.

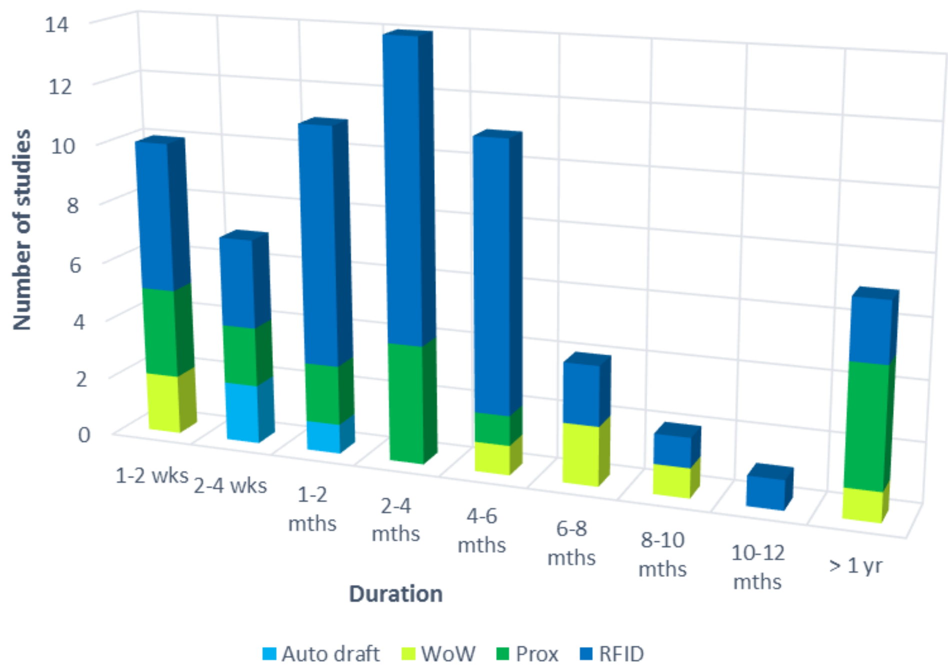


Fig. 4. The duration of studies reviewed per technology, where the technology acronyms relate to: Auto draft = auto-drafting, WoW = walk over weighing, Prox = proximity loggers, and RFID = radio frequency identification.

3.3.2 Animals

Of the studies where details on the number and type of animals used were reported, there was a total of 10,732 animals with an average of 157.8 (±536.8) animals per study. *Bos taurus* cattle were used in the majority of studies (63.9%, n = 46), *Bos taurus x* Bos *indicus* cattle were used in 15 studies (20.8%), straight bred *Bos indicus* cattle were used in seven studies (9.7%) and four studies did not report the sub species or breed of cattle used (5.6%). Adult female cattle were used in the majority of studies (32.1%, n = 26), followed by steers (27.2%, n = 22), heifers (i.e., female cattle that have not yet had a calf, 18.8%, n = 15), calves (i.e., less than 1 year of age, 12.3%, n = 10) and bulls (6.2%, n = 5). With three studies, the class of animal used was not reported. Of all the cattle classes reported, 42 studies used female cattle, 32 studies used male cattle and five studies used mixed sex animals; two studies did not specify the sex of cattle used.

3.3.3 Technologies

3.3.3.1 Auto-drafting

Of the three auto-drafting studies reviewed, automatic drafting gates were used prior to or post milking in an automatic milking system, with three-way drafting options. Only one study reported the average number of records per animal per day (5.52 ± 0.53) and the rate of successful drafts (between 97.9%-99.4%). For two studies, the manufacturer of the drafting gates was reported, while this information was not reported in the third study.

3.3.3.2 Walk-over-weighing

Animals attempted to enter the walk-over-weighing units on an average of 1.74 (±0.96) times per day, with a complete set of data collection occurring 71% of the times the animals attempted to enter the units. TruTest was the most common manufacturer (n = 3) of data collection equipment used in studies, with the equipment used in the remaining studies not being used by the other studies (Afimilk, AllScales, Insentec and Precision Pastoral). For all units, there was only one-directional traffic flow through the unit, with the exception of the Precision Pastoral unit, which allowed bi-directional flow by using the same exit and entry gate. The four intensive studies used post-milking as the inducement for animals to enter the walk-over-weighing unit, while in all three extensive studies water was used as the inducement.

3.3.3.3 Proximity loggers

In all proximity logger studies, Sirtrack manufactured collars were used, and each reported the same model if the logger version was listed (n = 5). The majority of studies applied loggers to the entire herd under study (56.2%, n = 9), while the other five studies applied collars on a range of animals, from 10% to 91% of the herd. In five studies, there was also collars placed on animals of species other than cattle during the deployments to record inter-species interactions, including badgers (n = 3), deer (n = 1), racoons (n = 1), domestic pigs (n = 1), wild boars (n = 1), and opossums (n = 1). For all studies, the approximate detection distance of the loggers was listed, which ranged from 0.88 to 7 m. Only nine studies reported of the actual UHF setting from the logger.

3.3.3.4 Radio Frequency Identification

In approximately 80% of RFID studies, the technology was used to record the frequency and duration of supplementary feeding events (n = 33). In a smaller proportion of the studies, the RFID technology was used to automatically record the frequency cattle accessed water (7%, n = 3), one study used manual herding to direct animals to walk past a RFID reader and in two studies there was no recording of the location or source of the RFID reader. In a further three studies, the technology was evaluated with no use of an attractant, such as food or water, to get the animal near the RFID reader.

In 36 studies, the RFID was enclosed in an ear tag while in the remaining six studies the RFID was enclosed within a rumen bolus. With the ear tag studies, seven different RFID reading units were listed, with the majority using GrowSafe Feed systems (48.6%), followed by Insentec group housing feeding systems (20%) and GreenFeed respiration chambers to measure methane emissions (11.4%). A smaller portion of the studies used TruTest (5.7%), Intergado (5.7%) and a custom-built design (5.7%) unit. Only one study used Texas Instruments RFID feed system. Of the rumen bolus studies, Smartstock and Texas Instruments manufactured technology were used in two studies each, while there were five studies that used units from different technology manufacturers, including Allflex, Datamars, MaGiiX, Rumitag and UDEA Wireless Technologies.

Thirty-three studies reported the number of RFID reading units allocated to animals. Of those studies, the majority (50%, n=17) used one unit to five or less animals and approximately 21% (n=7) of studies used one unit for six to 10 animals. A smaller proportion had a larger reader unit to animal ratio, with 9% of studies reporting one unit for 11-15 animals, another 9% reporting one unit for 16-20 animals and a further 9% reported one RFID reader to more than 20 animals. The frequency of visits by individual animals recorded by the RFID readers was reported in 24 studies; the average number of visits per day was 13.6, with a minimum of 0.6 (equivalent to one visit every 2 days) up to a maximum of 56.3 visits per day. The average duration per visit was reported in 22 studies, with animals spending on average 92.4 minutes per day in the vicinity of the reader. The shortest recorded average duration was 3.3 minutes, up to the longest average duration of 213 minutes. Only two studies using RFID ear tags reported the actual reading range of the RFID reader to record data from the ear tag, which was 45.7-50 cm. The reported reading range was much larger for the rumen bolus technology, ranging from less than 0.08 m up to 90 m. However, only three studies reported a reading range value for boluses.

3.3.4 Study focus and welfare implications

Over 50% of studies aligned with two focus areas, with the majority of studies using precision technologies to record behaviour (47.6%, n = 49), followed by methods validation (23.3%, n = 24) and animal health (18.4%, n = 19). In a smaller proportion of studies, technology was used to study environmental management (4.9%, n = 5); all of these studies used RFID and methane emission recording units. In three studies, there was a focus on sensor development and application (2.9%), while in only three studies technology was used to record welfare state (2.9%). The range of focus areas per technology is depicted in Fig. 5.

Approximately 20% of studies (n=20) were assigned two welfare domains. In most studies, technology was used to document the provision of nutrients (38.2%, n = 34). In the majority of these studies, there was a reliance on RFID to evaluate access to feed (82.4%, n = 28), followed by walk-over-weighing (11.8%, n = 4) and auto-drafting (5.9%, n = 2) (Fig. 6). Inferring an animal's behavioural state was the second most common welfare domain (30.3%, n = 27). Approximately 73% of proximity logger studies categorised behavioural state (n = 16). Similarly, 60% of auto-drafting studies (n = 3) and 16% of RFID studies (n = 8) classified cattle behaviour into different states. Animal health status, including indicators of disease, was inferred from approximately 24% of studies (n = 21), and the conditions of an animal's environment and effect of exposure to the resulting conditions was inferred in approximately 6% of the studies (n = 5). An animals' mental state was inferred in two studies where technology as used to specifically record interaction of a cow with her calf and monitoring of the state of maternal care. No other mental states were inferred, primarily due to the difficulty of using technology to record behavioural responses in the same detail that would occur with visual observations.

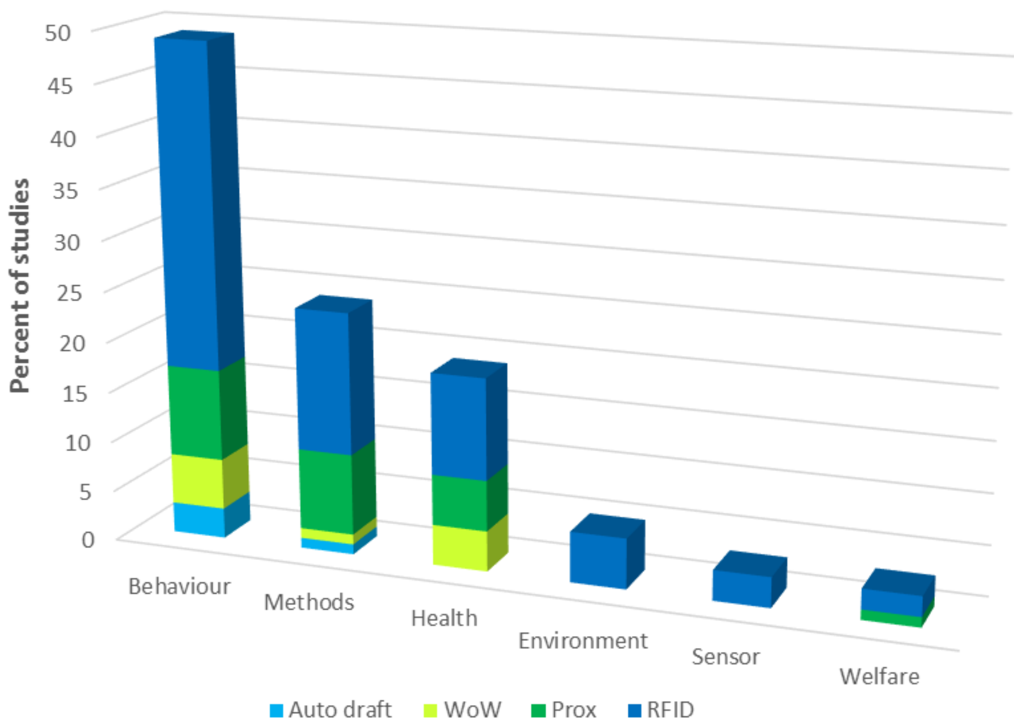


Fig. 5. Main focus of the studies reviewed per technology as a percent of all studies reviewed, where the technology acronyms relate to: Auto draft = auto-drafting, WoW = walk over weighing, Prox = proximity loggers, and RFID = radio frequency identification; Descriptions of the focus areas are defined in Table 1

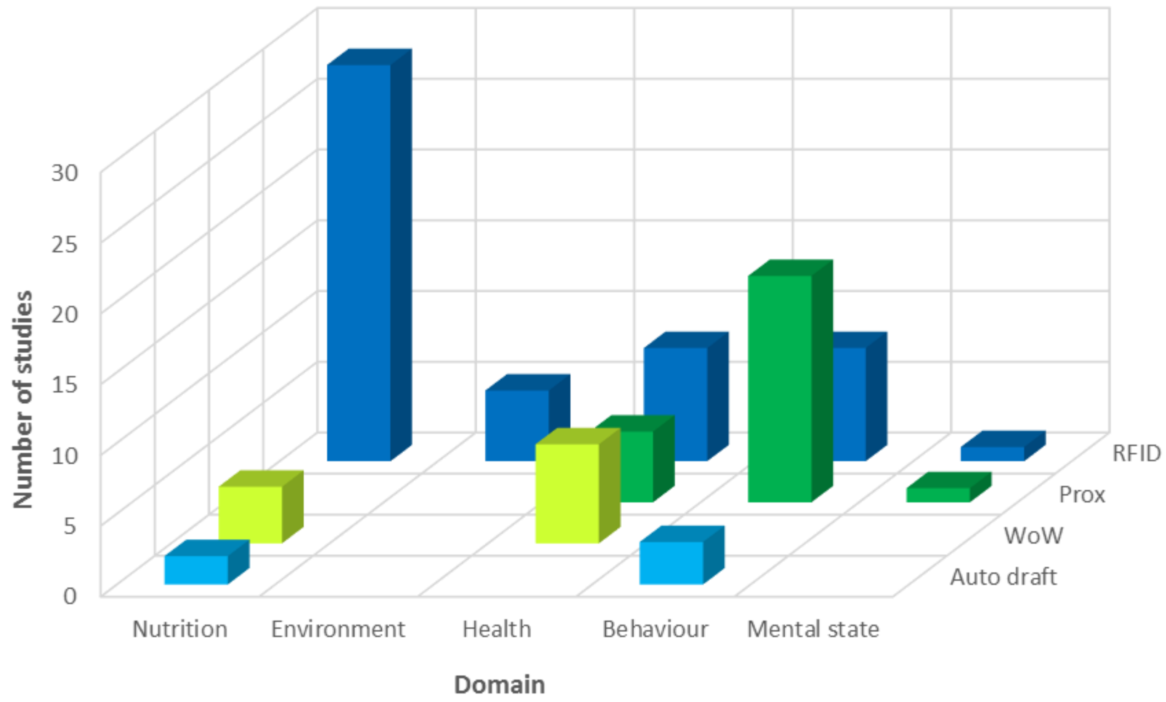


Fig. 6. Number of studies assigned to each of the five welfare Domains per technology, where the technology acronyms relate to: Auto draft = auto-drafting, WoW = walk over weighing, Prox = proximity loggers, and RFID = radio frequency identification; Descriptions of the Domains are defined in Table 2

3.4 Discussion

3.4.1 Technology use to monitor welfare

The potential advantages of using technology to monitor and record animal welfare has been widely discussed (Leigo *et al.* 2012; Rutter 2014; Brown *et al.* 2015; Bailey 2016), yet there are very few studies in which technology has actually been used to record welfare in extensive beef operations. In only three of the studies reviewed was there information about welfare implications from the research conducted, yet the information recorded in the remaining 65 studies have welfare implications that were not specifically stated. For example, using proximity loggers to record the social interactions of cattle during a breeding season, O'Neill *et al.* (2014) recorded the normal behaviour of cattle associating during the mating season, thereby inferring a positive behavioural welfare state (Domain 4) as they were expressing a natural behaviour exhibited by healthy animals, however, as the focus of this study was directly recording social behaviour associated with oestrus, welfare was not considered as an outcome from this study. By using the five domains model of animal welfare and specific keywords related to these domains, it was possible to infer welfare implications from all studies. Inferring welfare state using the five domains model is subject to the author's interpretation, and although a systematic and consistent approach was consciously followed, discrepancies may occur if the study was repeated.

Clearly, the use of technology has the potential to more precisely monitor cattle behaviour and performance and correspondingly welfare. Little research has been conducted, however, to precisely examine the capacity of technology to assess welfare. Until recently, most livestock studies using proximity loggers, GPS tracking and accelerometers have stored their data on the devices, which prevents the equipment from monitoring the animals in real or near real time (Bailey *et al.* 2018). Although real time tracking technology has been available, it has been too economically expensive to be considered for use in industry. Recent developments in technology may provide opportunities for the development of cost-effective methods of real-time cattle tracking and near-real time monitoring of behaviour with accelerometers (Bailey *et al.* 2018).

In intensive operations, the location of animals is not as important as in extensive operations. Animals that are identified as having a welfare problem can be detected more quickly in an intensive operation, but in an extensive system detecting animals with welfare problems can be difficult and time consuming (i.e., impractical in many extensive beef production enterprises). With walk over weigh systems and RFID feeding systems, the location of the associated pen or paddock is obvious. In extensive rangeland systems, real time tracking (Taggle and developing GPS systems) would be invaluable in detecting when individual animals are ill or if their welfare was compromised (Bailey *et al.* 2018).

3.4.2 Trends in technology use

In general, use of technology is increasing, with both RFID and walk-over-weighing studies doubling in the past 8 years (Fig. 2). These technologies are highly relevant to commercial applications, requiring only a simple RFID ear tag to encode individual animal identification. The use of proximity loggers has decreased slightly in the past 5 years, possibly due to other technologies having the capacity to record temporal associations, such as RFID and walk-over-weighing. Historically there has been less focus on analysing the social interactions of animals (Whitehead 2008). In the studies reviewed for this project, there was an obvious importance of social associations on health and productivity. Studies using technology to monitor social interactions will continue, especially if the relationship with welfare outcomes are validated.

Similar to Rutter (2017), this review identified that most applications of technology have been in dairies and feedlots, and correspondingly, the majority of studies used *Bos taurus* cattle. In approximately 30% of studies *Bos indicus* or *Bos indicus* cross cattle were used. While it is appropriate to translate technology advances in intensive industries to extensive production systems, studies are required to identify how technology-based monitoring data differ between intensive and extensive management systems, as well as assessing the capacity of network connectivity in different regions. Similarly, cattle breed may affect the data recorded by technology, for example, ear tag mounted sensors may record different movement patterns of a *Bos taurus* animal’s ear compared with a *Bos indicus* animal’s ear, due to the differences in ear shape, size and physiology between the two species.

3.4.3 Nutrition

The major focus of RFID studies was on monitoring individual animal intake of feed or water using an automatic RFID receiver within a feeding unit. Intake is an important component of the nutrition domain of animal welfare. These units have the capacity to record the frequency that individuals enter the feeding unit and the duration they spend within the unit, with some studies also reporting the kilograms of feed or supplement consumed. In several studies, observation methods were used by researchers to validate the accuracy of these units. Mendes *et al.* (2011) reported that the sensitivity and specificity of GrowSafe units to detect an animal's presence at the feed bunk was 86.4% and 99.6%, respectively. This is in comparison to Oliveira *et al.* (2018) who reported the sensitivity and specificity of Intergado units to be 99.25% and 98.98%, respectively, for automatic feed units and 98.74% and 98.56% for watering units. Findings in both studies confirm the reliability of the technology to record individual feed intake in intensive beef operations, such as feedlots and dairies, but the value of this technology is very limited in extensive rangeland beef production systems.

Walk-over-weighing and/or auto-drafting units at a water source can be used to provide information on the frequency that animals access a water source, which was reported to occur on average once per day in extensive beef production enterprises (González *et al.* 2014; Aldridge *et al.* 2017; Menzies *et al.* 2018a). By monitoring individual animal records over time, deviations in the frequency of use that are unexplained by changes in the external environment (e.g., rain events decreasing the need to access water as frequently) can potentially indicate if managers should check the cattle and assess their capacity to access water sources.

3.4.4 Environment

The combination of RFID and feed intake monitoring was the only technology reviewed where the effect of an animal's environment (e.g., heat stress) could be inferred from the data. Schwartzkopf-Genswein *et al.* (2003) relied solely on RFID recorded feeding behaviour to assess the effect of environmental conditions, determining a negative relationship between ambient temperatures and feeding duration, with Charolais steers more sensitive to temperature fluctuations than Holstein steers. Curtis *et al.* (2017) used a combination of automatic feed recording units and rumen temperature boluses to determine the effect of weather on feed intake. Changes in ambient temperature were recorded in the rumen within 1 hour, however, the authors found the black globe temperature humidity index (which combines the effects of incoming radiation from all possible sources, including the sun, ground and objects) was the greatest predictor of feed intake as a result of changes in the environment 5 days prior. Another study using boluses to record rumen temperature in feedlots (Lees *et al.* 2018a), reported that shade reduced rumen temperature of *Bos taurus* cattle, but no differences were found between shaded and unshaded *Bos indicus* cattle. A further study by Lees *et al.* (2018b), reported there was no correlation between surface temperature and rumen temperature in feedlot conditions during a typical Australian summer, thus confirming that rumen temperatures differ from the external environment, most likely due to the unique metabolic and microbiome processes that exist within the rumen (Czerkawski 2008). These studies highlight that using a combination of sensors provides a more precise assessment of an animal's response to its environment rather than a single technology in isolation. Further studies using these technologies to infer an animal's welfare with respect to its environment are warranted.

3.4.5 Health

Feed intake, changes in body weight, and ambient, rumen and/or ear temperature were potential indicators of compromised wellbeing. The potential to monitor these aspects of animal health remotely has significant implications for productivity and the entire red meat value chain. With the ability to remotely detect illness and monitor animal health, there is the opportunity to address welfare concerns and enhance biosecurity surveillance and intervention strategies. The use of RFID technology has been applied to a range of health issues that occur in intensive industries. Two studies used changes in automatically collected feed intake data to detect cases of bovine respiratory disease in feedlot cattle based on changes in feeding behaviour, with clinical cases detected between 3 and 7 days prior to physical symptoms being observed (Moya *et al.* 2015; Wolfger *et al.* 2015b). A study using rumen temperature boluses challenged heifers with an E.coli infection and was able to detect a 2 °C rumen temperature increase associated with the bacteria challenge. Rumen temperatures were reported when heifers approached a RFID reader at a water trough (Small *et al.* 2008). Results of these studies indicate changes in feeding behaviour caused by illness can be detected when an animal accesses a feeder using RFID technology in an intensive production system. In contrast, monitoring changes in feeding behaviour as an indicator of welfare is a challenge in extensive systems, because intake cannot be directly measured. In addition, rumen temperature is not a practical technique for extensive systems because animals with compromised health may not pass a RFID and rumen temperature at water on a regular basis. There are, however, other means by which behavioural changes can be assessed as an indicator of health. Walk-over-weighing systems can be used to provide regular animal live weight data in real or near real-time allowing producers to make informed management decisions based on changes in body weight. Dickinson *et al.* (2013) reported remotely recorded weights and weights collected from static scales were positively correlated and differed by an average of 10.1 kg ± 17.1 kg. Erroneous weights can, however, be recorded when two animals step onto the platform at the same time or when animals move through the unit too quickly for the RFID tag to be read (Menzies *et al.* 2018a). Assessing the average of weights over a weekly period can improve the correlation between remote and static weights (Dickinson *et al.* 2013), and provide more accurate assessments of animal health from changes in body weight.

Proximity loggers were used most commonly to study health by recording inter-species contacts to predict bovine tuberculosis spread between cattle and wildlife (e.g., badger, racoon, wild boar, red deer and opossum). The logger data provide a way of recording when two animals come close enough for disease transmission to occur, and the continuous recording capacity allows for interaction events to be recorded when visual observations are impractical (e.g., at night or for wildlife that are not frequently sighted). In all studies there were infrequent direct contacts between wildlife and cattle (Böhm *et al.* 2009; Drewe *et al.* 2013; Cowie *et al.* 2016; Lavelle *et al.* 2016), thus confirming that indirect contact may be a greater source of disease spread.

There is the potential for proximity loggers to detect if animals are stressed and their health is adversely based on trends in social interactions. For example, Swain *et al.* (2015) documented changes in social associations at calving, where associations decreased around the time of parturition as the cow isolated themselves from the herd. These associations gradually increased during the following days as the cow re-joined the herd with her calf, however, if an animal experiences dystocia and fails to return to the herd within a standard timeframe real-time data could potentially be used as an alert that calving assistance is needed. This information could equally be applied to situations of impaired well-being, where a cow decreases their association patterns with the rest of the herd unexplainably.

Other technologies may also be useful for remotely monitoring cattle health. In a study investigating the timing of analgesia prior to castration, behavioural responses to pain were detected by pedometers recording the frequency of foot stamping. Although pedometers could monitor impacts of analgesic treatments on foot stamping, pedometers were not able to measure differences in feeding behaviour among treatment groups (Meléndez *et al.* 2017). The results of these studies support the notion that a multi-sensor approach to behavioural recording provides the most precise indication of an animals actual welfare state (Theurer *et al.* 2013). Technology provides an opportunity to improve the way cattle behaviour is recorded and interpreted. Examples described in this review provide some of the potential applications of technology to improve animal management and welfare, however, conducting validation studies and refining hardware, algorithms and software for relevant commercial application is essential and requires time and resources (Bailey *et al.* 2018).

3.4.6 Behaviour

The use of proximity loggers to record social interaction has clear implications for recording an individual animal's expression of normal behaviour and freedom to interact with preferred peers. A study by Patison *et al.* (2010) investigated the social behaviour of steers when paired with either familiar or unfamiliar peers and found that social interaction patterns remained different between familiar and unfamiliar steers even after there were no longer visually observed differences. Familiar steers had more interactions than unfamiliar pairs. Proximity logging devices can also be used to record data used to assess the effects of restricted social interaction or regrouping, as well as assessing the effect of group composition (Patison *et al.* 2010; Patison *et al.* 2015; Patison 2018). Regrouping is known to elicit social stress (Syme and Syme 1979), which was confirmed by Patison (2018) using proximity loggers to record the social interactions of heifers that were regrouped with none, one or four unfamiliar heifers. The frequency and duration of overall group social interaction decreased with an increasing number of unfamiliar heifers, and an acute response to regrouping was detected in blood cortisol concentrations, however, the result varied among individuals.

The strongest bond between two animals is that between a mother and offspring, thus proximity loggers are well suited for studying maternal relationships as well as social events that occur within close proximity, such as reproduction. Swain and Bishop-Hurley (2007) first used proximity loggers in a commercial beef herd to assess the interactions between cows and calves and confirmed the general observation that a cow devotes more time with her own calf than any other cow or calf in the herd. Similarly, proximity loggers were used to determine the changes in associations that occur following parturition, with cows choosing to associate more with other cows that had suckling calves than those pre-calving (Swain *et al.* 2015). These studies provide an understanding of the basic foundations of cattle social systems, which can then be applied to other behavioural data sets to determine abnormal behavioural patterns. Similarly, remote RFID readers such as auto-drafting and walk-over-weighing have the potential to provide a range of behavioural indicators that extends the technology's benefits beyond monitoring body weight to include applications such as health monitoring, by assessing behavioural data relative to a normal baseline.

3.4.7 Mental state

Caution is advised when assessing an animal's mental state using the five domains model of welfare. First, it requires an animal's internal and external states to be identified and credible scientific support is needed to confirm the inferred mental state (Mellor 2017). The five domains model of animal welfare provides a structured and systematic framework to assess situational animal well-being, and while technology can be used to assess an animals' internal state or environment, inferring mental state is a greater level of inference, especially when this aspect can be difficult to assess using visual observations. For this reason, there were only two studies where a positive mental state was inferred, where cows were maternally rewarded by being able to raise their calves naturally (Swain and Bishop-Hurley 2007; Menzies *et al.* 2018a).

The use of walk-over-weighing and auto-drafting in extensive systems has the potential to promote positive mental states. Cattle are infrequently mustered (gathered) to yards in extensive systems, with some herds only being mustered once or twice per year. A large proportion of cattle, therefore, have few experiences with human handling, which can be quite stressful for some animals, particularly those with a nervous temperament (Hemsworth 2003). Additionally, cattle are required to walk kilometres to the cattle handling facilities, where they will not be able to graze until the husbandry procedures have been completed (Petherick 2005). Installing a remote monitoring technology within a paddock can potentially reduce the frequency of mustering events, thereby enhancing an animal's mental state by modifying management practices and decreasing the number of times they are removed from paddocks for extended periods of time.

3.4.8 Future

This review focussed on commercially relevant ALMS technologies, however, the selected technologies were not a comprehensive list. Several other technologies were identified during the review that were used in combination with the sensors selected, including image analysis (n = 4), GPS (n = 2), accelerometers (n = 1), and pedometers (n = 1). These technologies have great potential to be used for welfare monitoring with results of studies already indicating the usefulness in detecting lameness (accelerometer; Barwick 2017) and parturition in sheep (GPS; Dobos *et al.* 2014). Similar to the technologies reviewed, there have been novel developments for more commercially relevant devices to be developed due to improvements in size, attachment method, battery power and real-time or near-real time data transfer (Bailey *et al.* 2018).

The technologies with the greatest potential for commercial adoption provide multiple values such as productivity recording, easy application, and long retention times. In Australia, cattle are required by law to be fitted with a NLIS RFID tag when they are moved from one location to another, and correspondingly technologies using RFID have had some commercial success. The use of technology however, doesn't negate the importance for physically sighting animals and assessing their environmental setting. Changes in animal behaviour monitored with technologies are indicators only, not a diagnostic test. Thus, technology use is intended to be complimentary to traditional methods of surveillance. Technology has the potential to provide producers with the capacity to maximise their efficiency by conducting regular surveillance using an informed approach and reliable information (e.g., timing and location) to respond to indications of compromised welfare as they arise.

It is clear from the review that certain technologies can be used to identify specific welfare attributes and further that a multi-sensor approach has the potential to provide the most accurate representation of an animals actual welfare state (Theurer *et al.* 2013).The review also demonstrated the value of auto-drafting, which has only been used in the Oceania region in intensive dairy industries. While the technology itself cannot be used to detect welfare state, it provides a system to improve the way animals are managed. Producers in extensive systems are often limited by traditional mustering regimens, but auto-drafting has the potential to provide year-round access to their cattle, providing a greater opportunity to implement management decisions when these are required. For example, supplementary feed can be provided to individual animals in response to changes in body weight (Petherick 2005). Auto-drafting also provides the opportunity to improve animal welfare by changing management practices that have traditionally relied on seasonal mustering. For example, castration is traditionally performed at the time of a calf's first muster, with ages ranging from young calves to those beyond 7 months of age, however, results of research indicate that castrating beef calves at 3 months of age results in less stress and shorter recovery times than calves castrated at 6 months of age (Petherick *et al.* 2015). Additionally, calves castrated at younger ages are easier to physically handle, have less health-related complications afterwards and the procedures are simpler to conduct than with older calves. Automatically drafting calves will provide producers the opportunity to castrate young calves without mustering all the cattle, which is a potential way of enhancing animal welfare as well as management efficiency.

Consumers are increasingly interested in knowing that their food has been produced using welfare friendly practices (Cembalo *et al.* 2016), and are willing to pay greater price premiums for products where there are such assurances (Kehlbacher *et al.* 2012). Providing information to consumers and society that national welfare standards are being met on a daily basis in farming practices has the potential to increase confidence in red meat products, enhance integrity through the supply chain and ensure market security. To do this requires aligning on-farm records with processes throughout the entire supply chain. There is an increasing amount of research in this area, with 14 studies excluded from this review because they were related to processes elsewhere in the supply chain. It is expected that technology will have a large role in connecting records and activities between all sectors of the red meat value chain.

3.5 Conclusions

This review has highlighted that there are very few studies that have used ALMS technologies to infer welfare state in extensively managed beef cattle, however, the review has also provided evidence that there is great potential to monitor animal well-being relative to the domains of nutrition, environment, health and behaviour proposed by Mellor (2017). The inference of an animal's mental state (Domain 5) using technology is difficult and requires further investigation. Application of multiple sensors has the greatest potential of assigning technology recorded behavioural indicators to all five domains. Future investigations should be focused on the application of other on-animal sensors, such as GPS, accelerometers and pedometers.

Of the technologies reviewed, walk-over-weighing and proximity loggers have the most potential to deliver individual animal welfare indicators in extensive beef production. Social behaviour data recorded from proximity loggers can be translated into domains other than behaviour, such as nutrition and health, thus providing a wide range of welfare applications from a single device. The use of auto-drafting is best suited as a technology to facilitate management practices, rather than detecting animal welfare states directly. Electronic identification systems using RFID technology has been widely used in intensive cattle management systems with many potential welfare benefits. In particular has been the combined use of RFID tags in combination with rumen boluses to measure internal temperature and automated feeding systems to provide potential welfare assessments of Domain 2 environment and Domain 1 nutrition, respectively. Further refinements with this technology may lead to opportunities for recording more reliable data in extensive systems.

4 Developing an in-paddock auto-drafting system – infrastructure development

4.1 Introduction

Auto-drafting has been used both in the dairy and sheep industries (Bowen *et al.* 2009; Wishart *et al.* 2015), and has proven benefits in reducing labour (Edwards *et al.* 2015). The three studies identified in the systematic review were all undertaken in a dairy setting, with no published articles relating to beef cattle. There are industry reports of a cow/calf separator developed by the Queensland Department of Primary Industries in 1996 (Petherick and Hirst 1996). This system used simple non-automated infrastructure surrounding a water source to entice cattle through a separating unit, where cows were required to push through a door on one side while calves accessed a smaller opening on the opposite side (Fig. 7), thereby cows and calves could be self-separated into different pens. The system relied on basic cattle behaviour principles that cows will enter a spear gate that they can see over and calves will use spear gates that they can see under (Cheffins and Hirst 1990). No further information on its development or use can be sourced beyond 1996. This design has potential to be developed further using automated technology to increase operator control, allowing managers the flexibility to make decisions on drafting individuals at desired times.

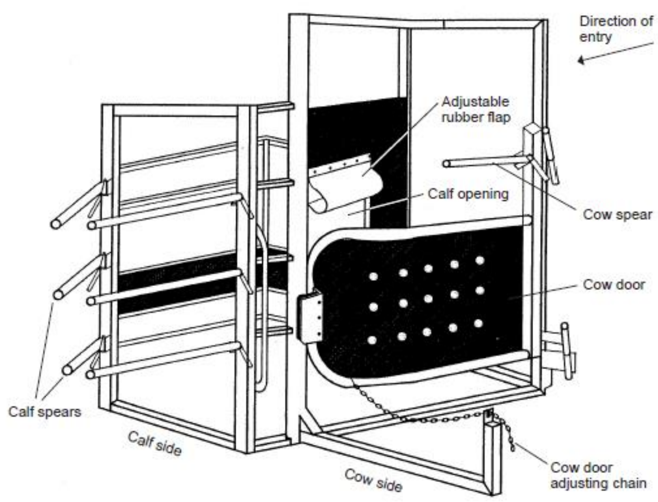


Fig. 7. The cow/calf separator developed by the Queensland Department of Primary Industries in 1996 (Image sourced from Powell and Lapworth (2006))

A project led by the Northern Territory Department of Primary Industries and Fisheries invested in the development of an automated remote management system for extensive beef production. The Precision Pastoral Management System (PPMS) incorporates a remotely operated drafting system within a walk-over-weighing system, with several units being demonstrated on case study properties throughout northern Queensland. After 6 years the project concluded in 2017, and while there were several media reports published about the project, the actual details of the system including electronics, algorithms developed, or statistics have not been published. Without this information, a comprehensive evaluation of the technology cannot be conducted. Future trials therefore, need to publicly report the rigorous methods used to design, develop, implement and evaluate technological innovations. This level of information permits an objective assessment of the systems efficacy.

Therefore, leading to increased adoption by industry of systems shown to be effective for use in beef cattle enterprises.

An important aspect of the theory of technology adoption states that the successful adoption of a technology in one setting generally leads to the successful adoption in other relevant settings (Khanal *et al.* 2019). To maximise the benefits proven within the dairy industry, the technology first needs to be optimised to operate in an extensive beef environment, which means remote locations relying on solar power with cattle that are infrequently handled and unfamiliar with in-paddock yard infrastructure. Overcoming these challenges is an integral part of the technology development and, eventually, successful adoption by industry.

As with all new technologies, research and development moves through several phases where developments are refined, assessed and tested with new innovations incorporated throughout the process. The application of auto-drafting integrated within an ALMS in extensive beef production is relatively new, thus the technology must move through a series of development and evaluation phases to reach a point where animal applications can be tested. This section describes the first process of developing a proof-of-concept automated calf separation system. It includes evaluating the practicalities of operating the auto-drafting infrastructure and assessing operational factors such as power supply and remote connectivity. The second component presented in Section 5 (Developing an in-paddock auto-drafting system – calf separation trial) evaluates the use of auto-drafting to separate cows from calves.

4.2 Methods

Prior to conducting any animal-based trials, the auto-drafting infrastructure was developed and refined to ensure the system would function within an extensive landscape, transmit data wirelessly, allow remote modifications to the software and programming and operate as expected (i.e., the drafting gate would move based on an RFID signal). This component resulted in refinements of the combined infrastructure and electronics to produce a fully functioning auto-drafting system.

The auto-drafting hardware was constructed by Stark Engineering and Hardware Pty Ltd, and the electronics were built by CQUniversity using the DataMuster-developed data transfer and analytics technology and processing platform. For several months, the auto-drafting system was evaluated for its capacity to correctly implement software commands and maintain power and connectivity with on-going refinements made to improve the way the system operated.

4.3 Results

4.3.1 Auto-drafting infrastructure

The auto-drafting infrastructure is located at the front of a walk-over-weigh platform positioned at the entrance to a portable panel enclosure containing an attractant, such as water and/or supplement. Cattle are required to walk over the weigh platform to access the attractant, and while doing so, their electronic identification (EID) and weight are recorded by the DataMuster hub. The cattle are then free to exit the compound via a separate exit fitted with a one-way spear gate to prevent animals entering without having their weight or EID read.

Fig. 8. DataMuster ALMS auto-drafting integrated unit demonstrating a cow being drafted to the left

Fig. 9. ALMS entrance and exit, showing the spear gates at the ALMS exit to prevent animals returning back past the reader and weigh scales

The Data Muster data hub is located on the off-side of the ALMS entrance race, mounted discretely on the solid race wall to avoid being sighted by cattle entering the system. The hub comprises a Wi-Fi modem to transmit data to a personal computer, a Raspberry Pi (a micro-computer) connected to the weigh platform to record weight readings and an electronic identification reader to detect EID tag numbers (Fig. 10).

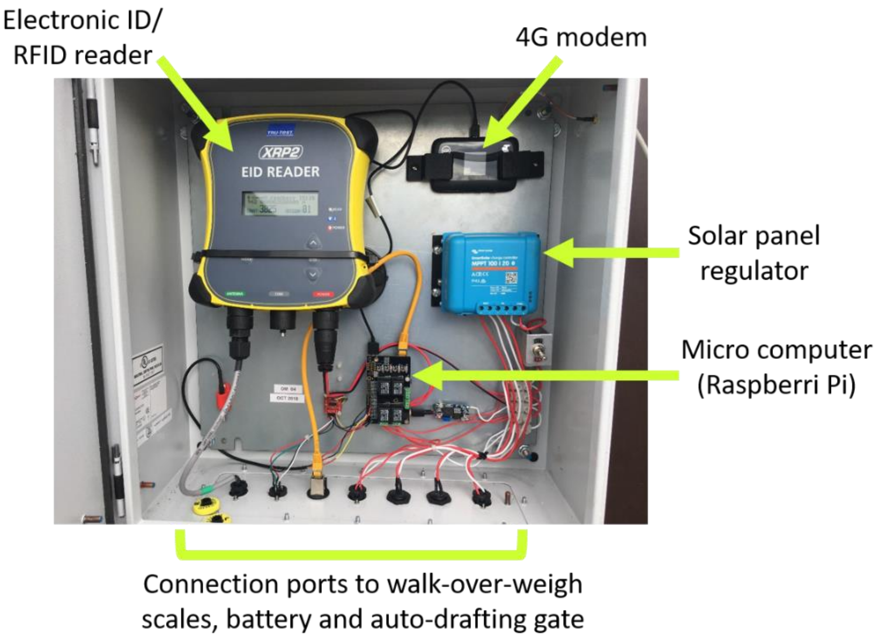


Fig. 10. DataMuster data hub main internal components

The auto-drafting function is based on pre-determined criteria stored in the Pi, being a list of EID's and a draft result, either left, right or straight, which can be entered either physically into the Raspberry Pi or transmitted remotely. The Raspberry Pi processes the draft criteria within 0.001 seconds of an EID being read such that the pneumatic gate changes as soon as an animal has its full body on the weigh platform; the timing of the EID being read is critical for the system to properly operate between EID reads and to minimise the potential for animals to be mis-drafted between gate changes from one direction to the next. The drafting gate will return to a neutral position allowing cattle to travel straight through the race 3 minutes after a left or right direction is actioned, unless a new EID tag is read.

The system undergoes regular evaluations to ensure the data being recorded are accurate. Temperature changes can affect the weight of the weigh platform due to the relative density of steel being affected by temperature, thus the system automatically corrects recorded weights according to the ambient temperature, which is recorded once every hour by the DataMuster hub. Additionally, manure and dirt can gradually accumulate on the weigh platform, which is accounted for by the scales being tarred every day at midnight.

4.3.2 Weight monitoring

Results from previous studies (e.g. Aldridge *et al.* 2017; Menzies *et al.* 2017) indicate erroneous weights can occur due to cattle crossing the weigh platform too fast or multiple animals crossing at the same time, thereby increasing the weight recorded for the EID of a specific animal. For a more accurate data collection, weekly averages can be used based on an animal recording a minimum of three individual weights per week. The DataMuster data processing suite of algorithms filters the data to identify accurate weight records by comparing each recorded weight as compared with the weekly average and only recording those weights that are within a sensible range.

As animals enter the weight platform their ID is recorded by the EID reader and transmitted via Bluetooth to the Raspberry Pi, which is stored along with the weight data. The load on the platform is monitored once every 0.10 seconds, and weights are actively recorded when the load exceeds 25 kg and stops recording when the weight decreases to less than 15 kg.

Following the read cycle, the system undergoes a print process, where the weights are filtered to record an average weight for each animal's EID. The algorithm allows for calculation of how many EID tags were read in the sample of data recorded, starting with when the weight exceeded 25 kg and ending when the weight decreased to less than 15 kg. Based on the number of tags read and whether that EID has a corresponding reference weight, the algorithm is used to process the data in one of four ways (Table 4).

Reference weights can be either a static weight recorded using fixed weigh scales in the cattle handling yards or a previous weekly average, calculated after there have been weights recorded for an individual animal for a minimum of three weights per week. The filtered data are then processed using an iterative mean algorithm to determine the reported weight for that weighing event. This process allows for calculation of the mean and standard deviation of the resultant sample of weights and iteratively removes values outside an expected range. Any values with a standard deviation greater than 15 kg are removed starting with the value furthest from the mean of the sample and repeating this process of elimination until all values are within 15 kg of the mean. If there are more than three points left in the sample at this time the mean weight is recorded, but if no values remain the program returns a "None" message and no weight is recorded for the sample.

The data are transmitted from the Raspberry Pi via Wi-Fi to the CQUniversity server every 5 minutes. If no network is available, the Raspberry Pi will store the data until at least one bar of a 3G network service is attained.

4.3.3 Power

The DataMuster hub is powered by a solar panel connected to a 130 amp deep cycle battery. The hub uses less than 1 amp to function, thus power can be maintained for a minimum of 5 days without any sun. The system will shut down if the power is not adequate and re-start once enough amps have been stored. The pneumatic gates of the auto-drafting unit use a top mounted compressor to operate the swing action, which is powered by the same solar panel and deep cycle battery circuit, but uses an additional 20 amps of power to refill the cylinder with air.

Table 4. Decision process used to record an animal's weight based on the presence or absence of a reference weight stored in the system

Number of EID tags recorded in sample[A]	Reference weight associated with EID[B]	Processing result	Description
0	n/a	No response	Occurs when a weight is recorded with no corresponding EID e.g. if an animal moves too quickly through the ALMS
1	Yes	Filters data to remove values >40kg or <80kg from the reference weight	This range allows extreme deviations caused by parturition[C] and excessive weight gain
1	No	Records the weight 15 points after the EID tag is read	Assumes this point has the greatest likelihood of the entire animal's body being on the weigh platform to record an accurate weight
>1	Yes	Filters data to removes values +40kg or -80kg from the reference weight	Repeats for all EID's within the sample of weights recorded above 15kg
>1	No	Records the weight 15 points after each EID tag is read	Repeats for all EID's within the sample of weights recorded above 15kg

[A]Sample refers to the ALMS data recorded for weights greater than 15 kg until recording ceases for weights of less than 15 kg

[B]Reference weight refers to a static weight recorded from stationary scales in the cattle yards or a previous weekly average weight calculated from three ALMS weights recorded in a week

[C]The expected weight loss from the birth of a calf is about 70 kg

4.3.4 Animal studies

The accuracy and efficiency of the auto-drafting system was tested during a recent study. Corbet *et al.* (2019b) trained a group of 40 weaner heifers to use the system before trialling a segregation phase where half of the heifers were drafted onto supplement (Wilmar BioEthanol Australia Pty Ltd) and the other half were drafted into a pen with water and no supplement. The authors found that training the heifers to use the system presented many challenges and four animals were unable to be trained during the allocated 8-week training period (Corbet *et al.* 2019a). Once these heifers were removed, system usage was 100%. Initiating the drafting gate reduced usage while the heifers familiarised themselves with the gate during additional training sessions. After the study commenced, entry and exit records were analysed to determine the accuracy and efficiency of the system with an overall successful drafting rate of 99.9%. The trial successfully demonstrated the opportunity for an ALMS unit with a combined walk-over-weighing and auto-drafting system to evaluate the effect of supplementation on growing cattle with greater efficiency and precision than traditional methods.

4.4 Summary

Refinements have been made to the system over several months and the system is now operating as expected. There are still some intermittent issues with network connectivity, where the modem loses reception. Data continue to be recorded but are not transmitted. The system has since been refined so that the modem will automatically be re-initiated at midnight, so any data transmission loss would be less than 24 hours. Electronic engineers are currently investigating alternative modems that are not subject to the type of reception issues that have occurred in this study.

The power supplied by the solar panels is subject to the availability of sunlight to re-charge the battery connected to the ALMS. It is rare that there are more than 5 days without sunlight to charge the system, especially in northern Queensland. However, a recent extended period of overcast weather in addition to several auto-drafting training events that caused the compressor to operate more than usual, caused the ALMS unit to deplete its power reserves. It is unlikely that this situation would be replicated under commercial conditions. This issue could be overcome by installing larger solar panels or additional batteries as reserve. However, given the low likelihood of this event occurring the additional expense is not justified. Incorporating an alarm that signals when the battery has depleted to a certain extent (for example 5%) would serve to alert users that the battery power is low allowing them to manage the system accordingly. For example, delaying any auto-drafting training or events that would require animals to be mustered through the system.

Refining the system will continue as long as it is being used in a research context. Trialling the system in a greater number of studies in commercial settings, such as with larger numbers of animals and in different locations with varying environments, will help identify what software features can be refined. Involving producers in these studies will also facilitate identification of where refinements can be made that align directly with producer requirements to maximise end-user benefits.

5 Developing an in-paddock auto-drafting system – calf separation trial

5.1 Introduction

The aim of this component is to automatically separate calves from cows in-paddock. This phase follows-on from the previous section that detailed the infrastructure requirements, software development and validation of the working auto-drafting system to separate animals based on their NLIS ear tag.

There are publications on the processes to train cattle to use walk-over-weighing and the success of these systems (e.g. Menzies and Swain 2018). However, there are no standard guidelines outlining the best approach to train animals for auto-drafting or methods for successful implementation. This proof-of-concept study was designed to investigate how cows and calves respond to the auto-drafter and evaluate different approaches of separating calves from cows in-paddock.

The objectives in this phase were to gather essential information to inform the overall auto-drafting implementation by first obtaining basic information on how calves use the system such as the age when they first use the ALMS, how frequently they enter the walk over weigh unit, and how this changes with age. The other essential component was analysing the temporal sequence of calves following their mothers. This has implications for determining the most appropriate drafting gate settings such as time taken for the gate to swing from one direction to another. Thus, the patterns of cow and calf use through the system were investigated to ascertain how their behavioural patterns change over time and the implications of this for establishing an efficient auto-drafting system. It was hypothesised that as calves get older and become more independent the distance they follow their mothers over the ALMS unit will increase.

The traditional method of identifying an animal as it enters the ALMS is via RFID from a NLIS ear tag however, only a small proportion of commercial properties undertake calf tagging at birth. Thus the majority of properties would have untagged calves using the ALMS system prior to their first muster. One component of this phase is to investigate different methods to draft calves that have not yet been fitted with an ear tag. This will be dependent on the initial success of drafting animals based on their NLIS ear tag.

5.2 Methods

5.2.1 Animals and management

The study was conducted at Belmont Research Station. Forty-two Belmont Red cows and their calves (n = 42) were located in one of two paddocks. There was a single trough for the two paddocks that was enclosed with portable panels. The cattle were required to enter the watering compound via an ALMS unit. The cattle were given access to one paddock at a time, where paddock 1 was 28 hectares and paddock 2 was 22 hectares. This design allowed the cattle to be located in either paddock depending on forage availability, whilst still accessing the same ALMS.

The cows commenced calving in October 2018. During the calving season, the farm manager inspected all cows daily and recorded any calves that had been born in the previous 24 hrs. The calves were tagged, weighed and mother's ID recorded. Daily calf recording continued until late December when the majority of cows had calves (n = 38). Four calves were born after this time, with the last cow calving in mid-January 2019. Post-calving, the cattle were routinely inspected every 3 days. The study was completed on 24 May when the calves were weaned, thus the total length of the study was 32 weeks.

The cows and calves were mustered to the main yards for procedures several times during the study period (Table 5); they were removed from their paddock for a period of several hours on these days.

Table 5. Timing of events when cattle were mustered to the main yards during the study period

Date	Description
17 December 2018	- Static weights recorded - Insecticidal ear tags fitted
28 February 2019	- Static weights recorded - Calves branded and vaccinated
24 May 2019	- Static weights recorded - Calves weaned

The cattle accessed the ALMS through a race, walked over the weigh platform and had their RFID tag and weight recorded simultaneously. The cattle then passed through a one-way spear gate to access the water trough and exited the compound through a separate spear gate. A DataMuster Hub (as described in Section 4) was used to record the RFID number, weights and eventually, initiate the drafting gate based on the previously entered draft criteria for each animal. The drafting gate was powered by a pneumatic cylinder connected to a 12 v solar powered compressor. The gate operated at 10 psi so that an animal was unable to be trapped within the gate.

The cows had been conditioned to use the ALMS without the auto-drafting unit since March 2015. The calves, however, have not been given any specific training prior to or during the data collection period. It was expected that they would learn from their mothers once they were old enough to follow their mothers through the weigh platform. The procedures used in this study were approved by the CQUniversity Animal Ethics Committee (approval number 21218).

5.2.2 Auto-drafting implementation

The auto-drafting infrastructure was introduced to the paddock cattle after all cows had calved to avoid any unnecessary disruptions that may have impacted cow behaviour or mothering up. The existing WoW unit continuously recorded all cattle data as they accessed the ALMS without the auto-drafting unit connected and thus recorded all cow and calf events from before the first calving event.

On 2 February 2019 an auto-drafting unit was installed in front of the existing WoW platform that had been in place since 2015. The unit was attached to the portable panels enclosing the WoW platform (Fig. 11). Issues with the weight and ID data transmitted over the following days were suspected to be caused by the additional metal of the auto-drafting unit resulting in the same 'parasitic effect' as identified in the validation study, where the read range of the RFID reader panel was amplified to span to the entire length of the ALMS. Many animals were thus recording multiple weights only seconds apart. The following week on the 19 February the system was modified to avoid the RFID reader having contact with any metal. The panel was mounted onto a plywood sheet and attached to the portable panel with plastic cable ties (Fig. 11).

Fig. 11. Left: Initial auto-drafting unit attached to the walk-over-weigh platform used by the trial cattle. Right: RFID panel reader mounted on plywood to avoid the read-range extending the entire length of the metal panels

Further issues with the animal data recorded from the ALMS resulted in the WoW system being replaced with a DataMuster hub integrated unit to make future data programming and troubleshooting easier. The unit comprised a consolidated frame containing all the necessary DataMuster hardware and electronics, an integrated weigh platform compatible with the DataMuster developed weighing algorithm and enclosed panels on either side of the weigh platform to avoid cattle in adjacent pens being read by the RFID reader. Thus, also providing a darkened neutral space without reflective metal that may cause the cattle to baulk as they entered (please see Fig. 8 in Section 4).

The new ALMS unit was installed on the 4 March 2019 however, minor technical issues with the read range and recording of accurate weight records were addressed for a week before the system was deemed to be properly operating successfully on 11 March 2019. Even though the system was functioning effectively and efficiently from a data collection perspective the change in infrastructure resulted in a decrease in cattle use. To provide some training with the new infrastructure the cattle were gently mustered through the ALMS on eight separate occasions over a 2-week period until cattle use returned to normal.

A dividing fence was installed on the 1 May 2019 to separate the watering compound into two separate pens (Fig. 12). The fence followed an approximately straight line from the end of the auto-drafting unit to the trough however, this resulted in the two pens being unequal in size. The left draft pen was approximately one third larger than the straight draft pen. Two strands of wire were used to deter cattle jumping over the trough. Each wire was enclosed within an equal length of poly pipe to avoid any calves injuring themselves if they did jump across the trough (Fig. 13).

Fig. 12. Dividing fence installed surrounding the water trough to separate cattle once they had been drafted left or straight

Fig. 13. Poly enclosed wire fitted above the trough to deter any calves jumping over

The drafting gate was initiated on 7 May. Cows were drafted into the larger left pen and calves were drafted straight forward into another pen. Training was provided for the whole herd on six separate occasions over the following 2 weeks by gently mustering the herd to the compound and allowing them to enter the ALMS without pressure to do so being exerted. A small number of cows and calves required additional pressure and this was done by the research team gradually closing in on the group to avoid them withdrawing in other directions. One calf in particular managed to escape from the group and after three attempts was unable to be encouraged across the platform during that particular training event.

An additional RFID reader panel was installed at the exit gate of the left drafting pen (Fig. 14). This would allow the RFID entry data to be compared with all left drafted exits to determine the drafting accuracy. An exit RFID was not installed on the straight draft pen, or calf pen, as it was expected that a single exit reader could be used to determine all exits from the left and extrapolate correct straight drafts from the entry RFID and lack of exit RFID records.

Fig. 14. RFID reader and solar panel being installed at the exit of the left draft pen

After the last training session on the 20 May 2019, there were 3 days provided to record weights and drafting data without any human interference before the herd was mustered to the main yards for the calves to be weaned.

5.2.3 Auto-drafting algorithms to separate calves from calves

Two separate algorithms were tested to determine when the drafting gate was activated. The first algorithm used the same approach as Corbet *et al.* (2019b), where the drafting gate was activated when an RFID ear tag had been recorded. The gate then responded to the next RDIF ear tag being read by closing off access from the other direction or with the gate remaining in the same position as it was when the previous animal passed through the gate. If no RFID had been recorded within 3 minutes the gate would default to a straight position.

The second algorithm relied on the gate closing after the animal in front had begun to step off the weigh platform, thus the algorithm searched for a decrease in 60 kg of weight before initiating the closure of the gate. The aim was for the gate to gradually close behind the cow as her body was fully off the platform, and direct anything that was untagged to be drafted straight.

5.2.4 Data processing and analysis

Data from the DataMuster data hub were transmitted via the 3G communication network to a digital storage space on an atlas server, managed by CQUniversity. The digital storage space, called a GitHub repository, was accessed via the Precision Livestock Management DataMuster MongoDM atlas server based data base, using login credentials and the software package R studio (R Core Team 2017). The raw data were processed using complex algorithms to ensure the resultant data were accurate (for more details on the data processing and algorithms please see Section 4). In this way, a weight is only saved to the database if it is within a physiologically valid weight range for that animal which is achieved by comparing the current weight to the previously recorded weekly average weight. If the weight was the animal's first weight recorded by the system, the last static weight recorded manually at a set of yards was used as the reference weight. This ensured only accurate weights were recorded and avoids erroneous weight recordings, such as two animals being weighed at the same time. If a weight was discarded from the database, or if the animal moved through the ALMS too quickly to have a weight recorded, the animal's RFID, date and time of entry were still recorded. The processed data were stored as a text file, with each entry detailing the date, time, RFID, weight (if recorded) and the identification of the ALMS unit (e.g. BelmontALMS_Pdk66).

The data were first summarised to identify the date each calf was first recorded in the database to determine their age at first crossing. To aid analyses, the age of a calf when it first used the ALMS was summarised into first use categories. A histogram was used to heuristically determine the most appropriate age range per category, with five categories relating to the age that calves first accessed the ALMS unit. These being: Early, within 15 days of birth; Mid, between 16-50 days of age; Late, between 51 and 100 days of age, and; Other, calves that were over 100 days old when they first used the ALMS. Five of the 42 calves were not used in the first use analysis as they were either born after daily calf recording had ceased, were not tagged until branding (n = 4) and thus not recorded by the ALMS until after this time (28 February 2019) or they had a faulty RFID tag (n = 1) that was replaced at branding.

Basic information on calf use was summarised by the number of calf ALMS entries with corresponding weight records to determine calf use over time and compile calf growth paths. The number of RFID entries without a weight record were also analysed to provide an indication of how efficiently the calves were moving through the ALMS. A large number of RFID entries without weights would indicate calves moving through too quickly or at the same time as another animal.

The temporal pattern of a calf following a cow through the ALMS was also analysed. The time difference (in seconds) was calculated for each calf record by subtracting the time the calf's RFID was recorded from the time that the previous cows RFID was recorded. The data were restricted to only compare associations that occurred within 5 minutes of a calf following a cow to ensure the data referred to a meaningful association. A general linear model was used to determine if the frequency of use and temporal patterning were affected by age and first use category based on the week of the trial. Values for averages are presented as mean ± standard deviation, and differences are considered significant at $P<0.05$.

5.3 Results

5.3.1 Calf first use of ALMS

The first calf was born on 9 October 2018. Nineteen were born throughout October, 17 in November, 3 in December and 3 in January, with the last calf born on 5 January 2019 (Fig. 15). There were three calves that used the ALMS on the day they were born, while one calf took 154 days to first use the system Fig. 16. The average calf age at first use was 34.6 ± 36.6 days. Table 6 summarises the number of calves per first use category.

Table 6*Fig. 15.Spread of calf ages based on date of birth*

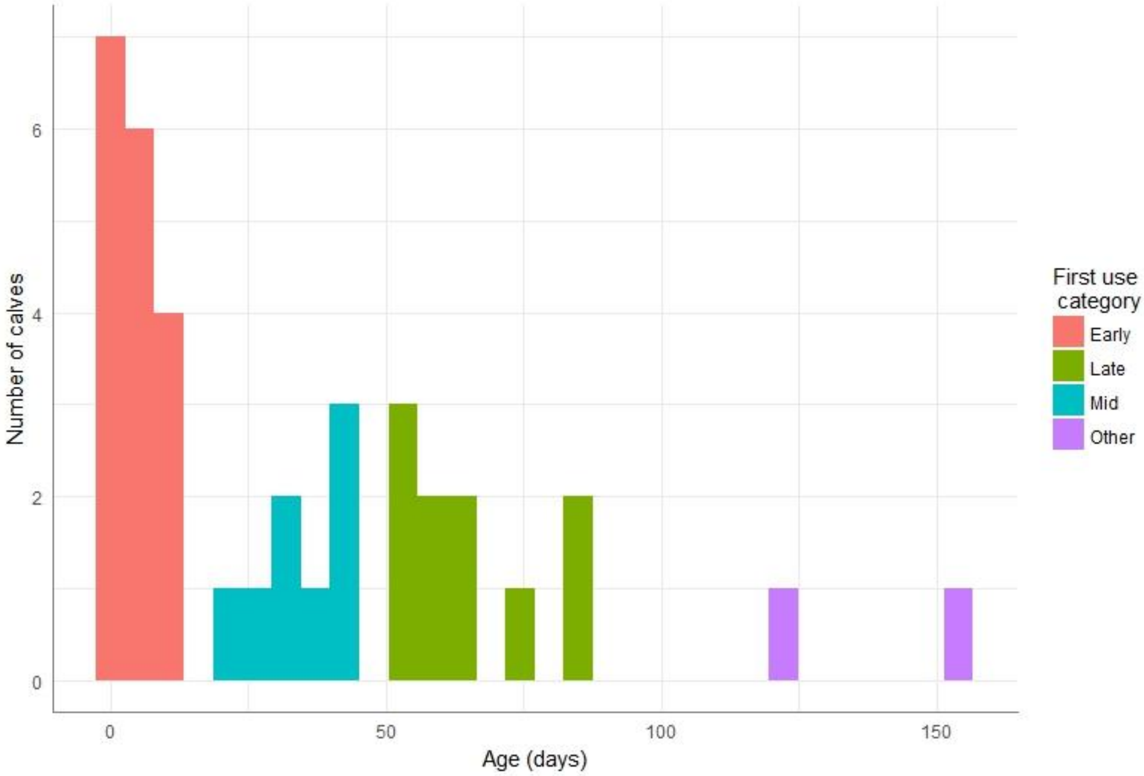


Fig. 16. Age of calves when first recorded by the automated livestock management system (ALMS) coloured by their assigned first use category. 'Early' calves were first recorded by the ALMS within 15 days of birth, 'Mid' calves between 15-50 days of birth, 'Late' between 51 and 100 days of birth and 'Other' calves were first recorded when they were 101+ days old

Table 6. Number of calves per first use category

Age (days)	First use category	Number of calves
0-15	Early	17
16-50	Mid	10
51-100	Late	8
101+	Other	2

5.3.2 Calf frequency of ALMS use

The frequency that calves used the ALMS on a daily basis throughout the experimental period is depicted in Fig. 17. The graph depicts a steady increase over time as calves were born and began using the system. The installation of the auto-drafting unit and changeover from the original WoW platform to a DataMuster data hub integrated weighing unit resulted in some missing data while technical issues were resolved. There was also a decrease in the number of calves using the system while they became familiarised with the new infrastructure.

The training events in February and March resulted in an increase in the number of calves using the system, which decreased in April when no training was provided (Table 7). Initiating the drafting gate and associated training in May saw the calf use increase again, where the number of records reached 12.33 ± 2.84 calf records per day, irrespective of mustering days. The percent of calf use never reached 100%, even though almost all calves were mustered through the system on several occasions. This is a result of the calves rushing through the system when being mustered and more than two animals entering at a time, thus, not all RFID's were recorded at each mustering event (please see 5.3.5 for more details). On average, the calves that accessed the ALMS accessed the ALMS once per day, with a minimum of 0 and a maximum of 4 entries per day (Table 7).

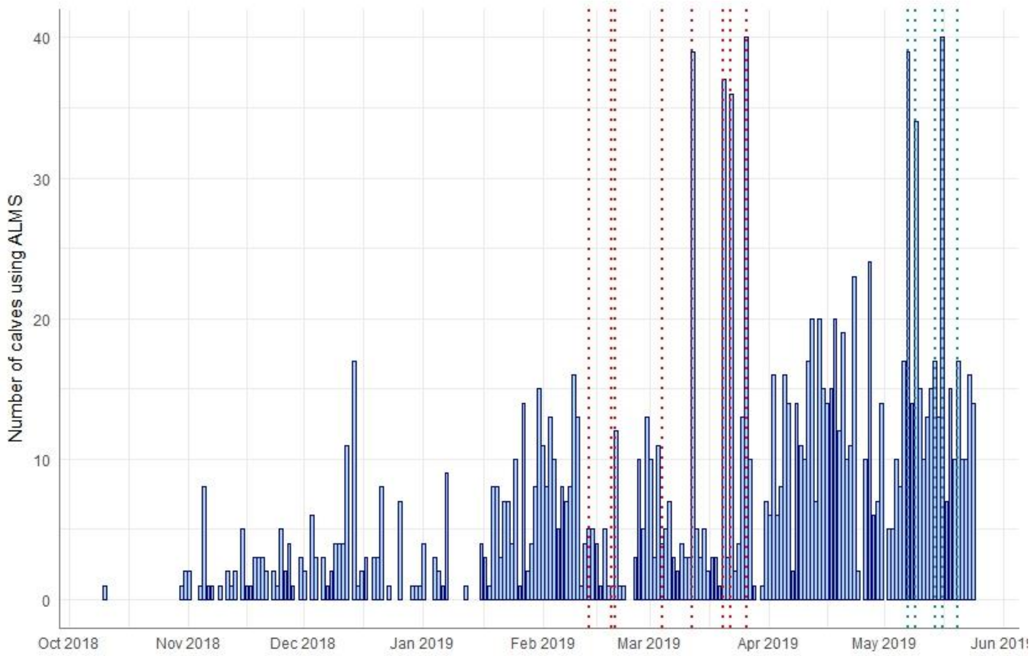


Fig. 17. Number of calves recorded by the ALMS during the trial period. Events where some or all of the herd were mustered through the ALMS are shown by the dotted lines; Red dotted lines represent WoW training while the green dotted lines show auto-drafting training events

Table 7. Number of calves accessing the ALMS per month

Month	Number of ALMS calf records[A]	Number of calves in paddock[B]	Average number of calf visits per day (±s.d)	Number of calves using the ALMS per month (% of all calves[C])	Training events
October 2018	4	19	1.33 (0.58)	3 (16%)	-
November 2018	55	36	2.39 (1.75)	23 (64%)	-
December 2018	88	39	4.00 (3.89)	22 (56%)	-
January 2019	119	42	5.41 (4.09)	22 (52%)	-
February 2019	171	42	6.58 (4.54)	26 (62%)	3
March 2019	270	42	9.00 (12.00)	30 (71%)	5
April 2019	369	42	12.7 (5.89)	29 (69%)	-
May 2019	354	42	15.4 (9.58)	23 (55%)	5
Total	1430	42	8.03 (8.14)[D]	22 (56%)[D]	13

[A]Total of all records per month; this includes calves that accessed the ALMS more than once per day
[B] The cumulative number of calves present at the end of each month
[C]As a proportion of the number of calves present in the paddock for that month
[D]Average for all months

There were issues with calves not accessing the compound regularly and 21 calves were identified as not having accessed the ALMS for 3 days on 16 May. The DataMuster reporting system identifies any animals that have not accessed the ALMS within 3 days and issues an email and SMS alert. It is suggested that these calves may have been accessing water from the river, although a three strand electric fence was installed to deter cattle entering the river area. It is also possible the calves were obtaining their daily fluid intake from their mother's milk. This is a concern as the oldest calf was about 7 months old and would normally be consuming water regularly if given free access. It also presents an issue for their mothers as any increased milk intake would result in a greater demand of her metabolic energy. This result suggests water was not enough of an attractant to get the calves to use the system regularly.

5.3.3 Factors affecting calf ALMS use

A multiple linear regression analysis indicated a positive effect of age when calves first used the ALMS and week of the study ($F(4,59) = 6.98$, $p < 0.01$, $R^2 = 0.32$). The individual predictors were further examined, which indicated all of the first use categories were significant predictors in the model. The results identified that Early calves increased their use on average by 13 times per week. The later the calves initially used the ALMS, the less the frequency of use increased over time with respect to the early group (Table 8). Calves in the Mid category entered the unit about 12 times less per week, which was three entries more than the Late category (Fig. 18). In the Other category, there were only two calves, thus the numbers in this groups were not large enough for a rigorous statistical representation. However, the data for this group showed a trend similar to that for the other categories. There was no effect of week or calf age as an individual predictor of the frequency that calves accessed the ALMS each week ($P > 0.05$).

Table 8. Results for the individual predictors in the linear regression model of calf ALMS use as influenced by calf first use category and week of the study; Effect of Mid, Late and Other categories represent the change per week in ALMS use with respect to the increase in the Early category; CI = confidence interval

Predictor	Estimate	Std. Error	t value	P value	95% CI
Early	13.80	5.00	2.76	0.008	4.97, 22.31
Mid	-11.66	4.36	-2.68	0.010	-18.79, -4.47
Late	-14.87	5.10	-2.92	0.005	-23.75, -7.46
Other	-28.32	9.01	-3.14	0.002	-42.54, -14.93
Week	0.77	0.30	2.56	0.014	0.28, 1.28

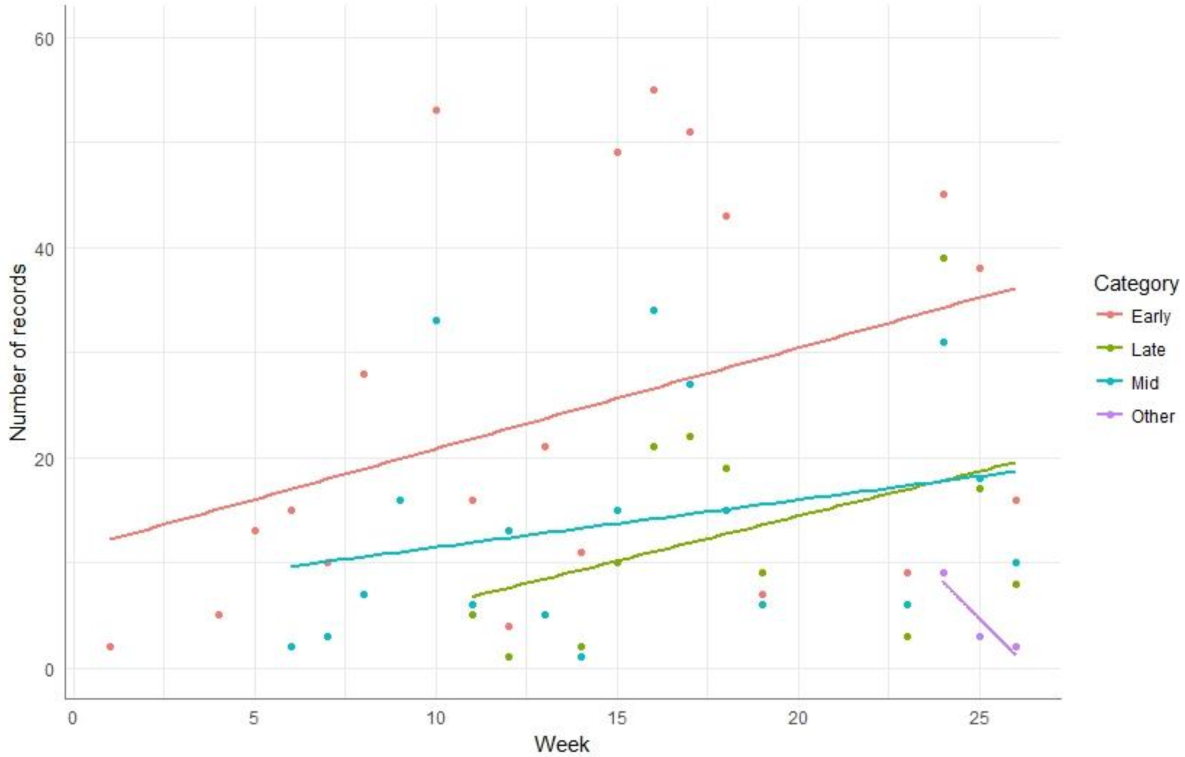


Fig. 18. Number of ALMS calf records per week categorised on the age of first crossing; 'Early' calves were first recorded by the ALMS within 15 days of birth, 'Mid' calves between 15-50 days of birth, 'Late' between 51 and 100 days of birth and 'Other' calves were first recorded when they were 101+ days old; Lines represent the linear trend over time

5.3.4 Calf temporal patterning of ALMS use

The data were restricted so only calf separation times less than 300 seconds were analysed to represent a meaningful association between the calf and the previous cow. There were 1,711 records in the analysis, with an average time difference of 38.04 ± 66.32 s, a minimum time of 0 s and a maximum time of 300 s. The cumulative frequency indicates that 70% of calves had a separation time less than 25 seconds (Fig. 19).

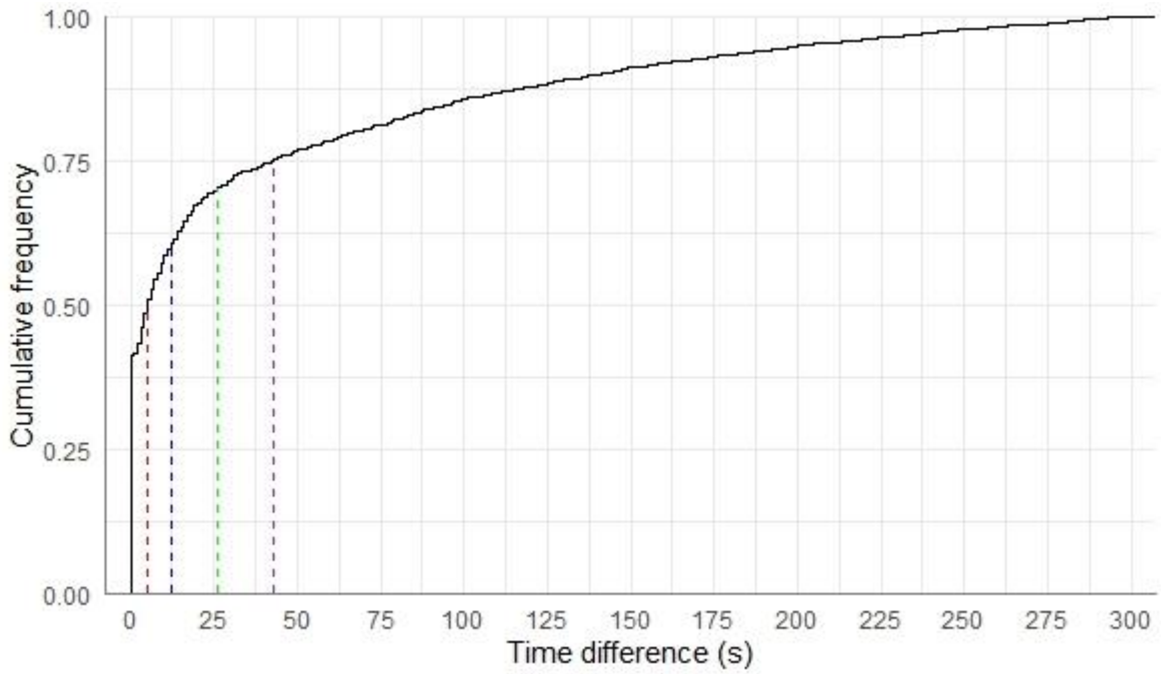


Fig. 19. Cumulative frequency of the separation time between calves following a cow through the ALMS; Dotted lines represent the 50th, 60th, 70th and 75th percentiles for the colours red, blue, green and purple, respectively

The effect of age on the time difference between a calf and the cow it is following through the ALMS is depicted in Fig. 20. The boxplot shows a trend for young calves to have a short time difference from the previous cow, which increases up until approximately 90 days of age before the time decreases again. The influence of outliers increasing the group average can also be observed. Due to the non-normality of the time difference data, a Kruskal-Wallis test was used to assess time differences between age categories ($H(7) = 403.72$, $P < 0.01$). The increased mustering events in the last 2 weeks of the study may have biased the data and decreased the time difference values, as the calves moved through the ALMS more rapidly during mustering than the pace that they would naturally use the system.

The effect of first use category on the time separation between cows and calves accessing the ALMS is depicted in Figure 29. Calves that were the first to use to ALMS had a greater spread in values, however, there were no differences between any categories ($P > 0.05$).

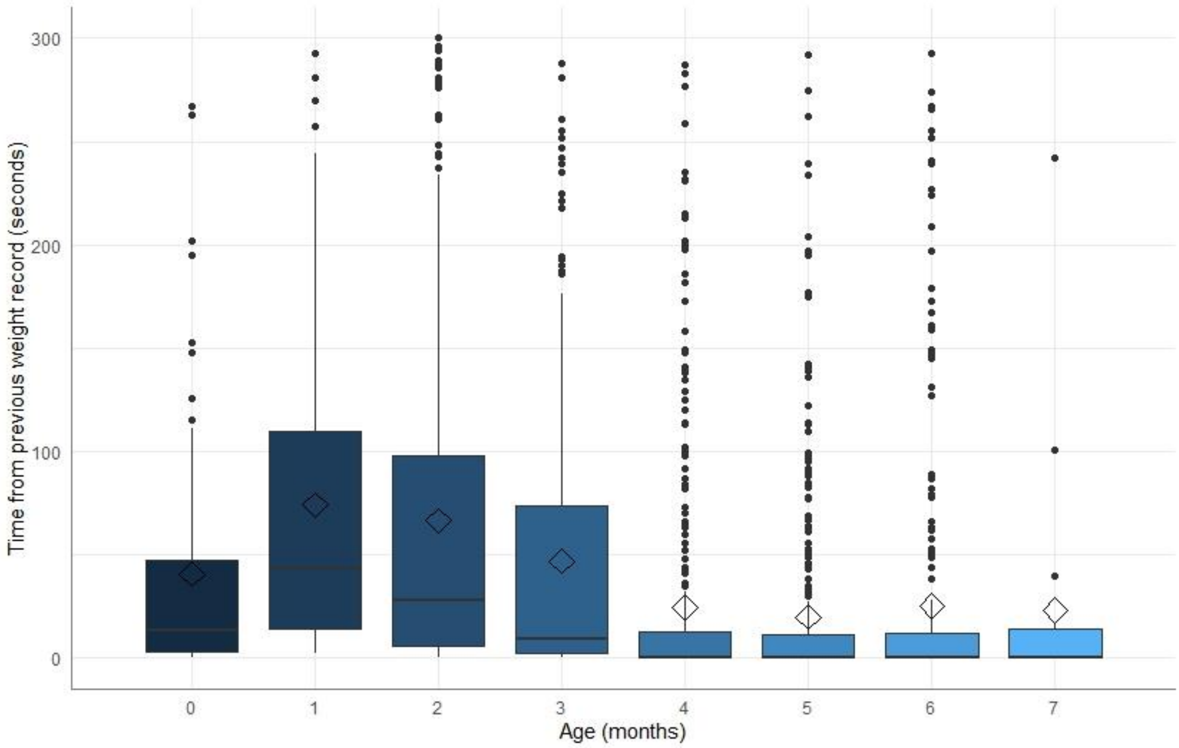


Fig. 20. Effect of calf age on the time difference between a calf following a cow through the ALMS; Diamonds represent the mean per age category

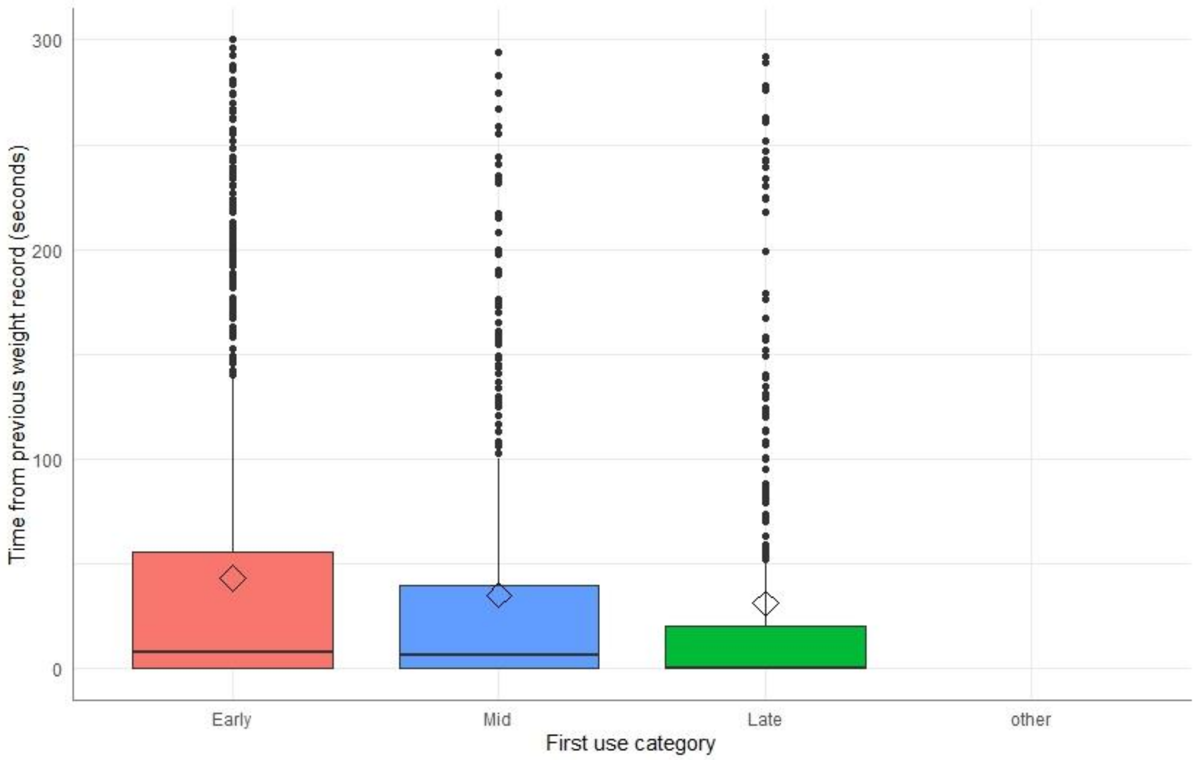


Fig. 21. Effect of calf age when it first accessed the ALMS (first use category) on the time difference between a calf following a cow through the ALMS; 'Early' calves were first recorded by the ALMS within 15 days of birth, 'Mid' calves between 15-50 days of birth, 'Late' between 51 and 100 days of birth and 'Other' calves were first recorded when they were 101+ days old; Diamond represents the mean value for each category

5.3.5 Calf growth

The average weight of a calf when it first used the ALMS was 314.6 ± 225.1 kg, with a minimum of 51 kg and a maximum of 708 kg. It is assumed that the average and maximum values represent both a cow and a calf weight caused by a calf entering the system closely behind its mother, thus recording both the cow and calf weight when the calf's RFID was read. If a calf continued to be recorded at the same time as the cow, a greater than average weekly weight will be recorded over consecutive weeks. This result is indicative of a problem with data filtering that needs to be addressed. Refinements can be made to the algorithm by cross-checking the calf's weight against static reference weights on a regular basis whilst allowing scope for realistic weight gain.

Fig. 22 depicts the unrestricted calf data, where multiple weights were continuously recorded that were greater than 300 kg. The average static weight of calves from the first muster on the 21 December 2018 was 90.8 ± 17.2kg, and their final weight at weaning was 226.0 ± 33.3 kg. To increase the accuracy of the remaining weight analyses, the data were restricted to only analyse weight records that were less than 300 kg, thus ensuring only actual calf weights were included. This resulted in a decrease in number of weight records from 1,108 to 650.

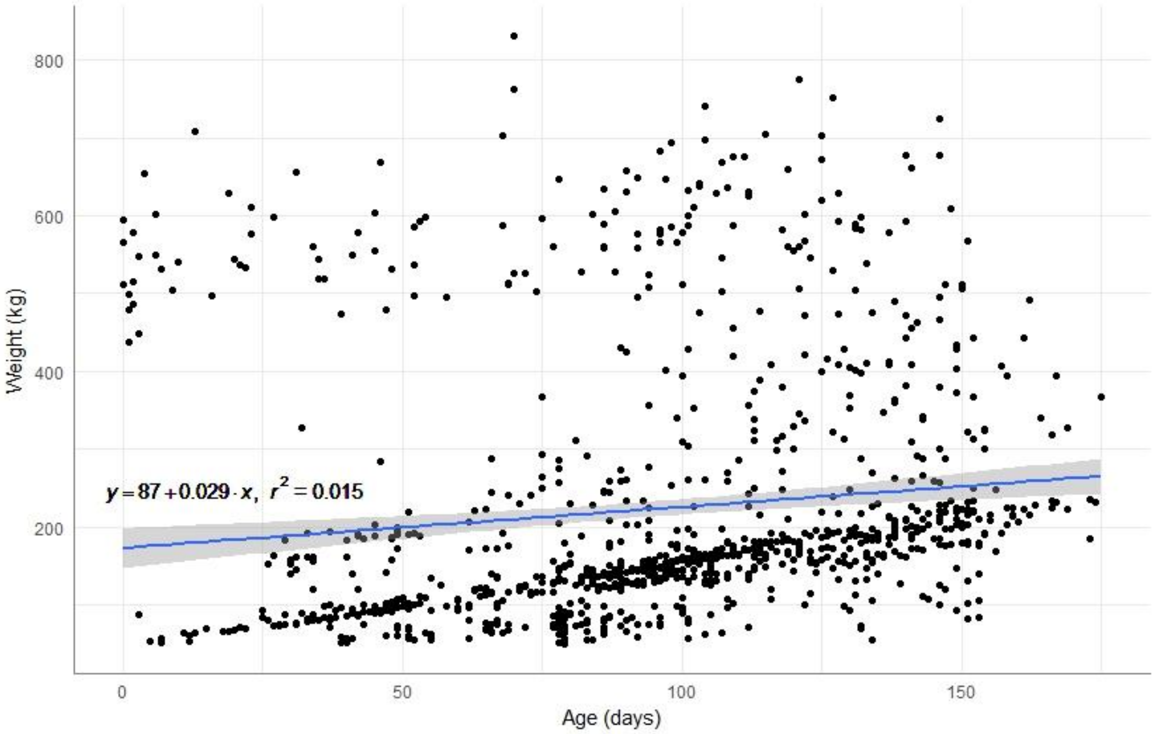


Fig. 22. Effect of age on calf weight with no maximum weight value

A multiple linear regression model identified a collective effect of both calf age, week of trial and first use category on calf weight ($F(5,644) = 25.55$, $P < 0.01$, $R^2 = 0.17$). The individual predictor of age positively affected calf weight, resulting in a 13.2 kg increase for each month of age, ranging between 6.0 to 20.4 kg per month (β = 13.22, SE = 3.66, 95% CI [6.03, 20.40], t = 3.61, P<0.01). The Early first use category also had a positive effect on weight, with Early calves gained 9.6 kg more weight during the trial period than Late calves (β = -9.62, SE = 4.25, 95% CI [-17.97, -1.28], t = -2.26, P < 0.05), and 6.0 kg more than the Mid calves (β = -6.04, SE = 3.58, 95% CI [-13.08, 1.00], t = -1.69, P < 0.10). The individual predictors of week and the first use category "Other" were not significant.

A *post hoc* analysis was conducted to determine the effect of first use category on average daily weight gain. Due to discrepancies in some calves being weighed with their mothers, the static weights recorded at the calves first and last yarding were used to calculate average daily weight gain (ADG) during a 154 day period (from the 21 December 2018 to the 24 May 2019). The average daily weight gain of calves during the study was 0.93 ± 0.13 kg/day, with a minimum of 0.72 kg/day and a maximum of 1.28 kg/day. There was no effect of first use category on ADG (Fig. 23).

The EID files were analysed to determine the frequency that calves were using the ALMS without a weight being read. This was only possible for data collected after 4 March 2019 when the DataMuster data hub was fully operational; the previous TruTest WoW indicator was unable to record EID data if no weight had been recorded. There were 25 days when more EID's were recorded than weights (Table 9), with the majority (n = 54) of EID records corresponding to a weight being recorded. Unmatched EID and weight records occurred more frequently during mustering events, where despite only applying little pressure to encourage the animals to pass over the scales, the cattle still rushed over the scales causing inconsistencies between the two data sets. These results indicate the ALMS accurately recorded an animal's weight with each EID read, except during unnatural circumstances, such as during mustering.

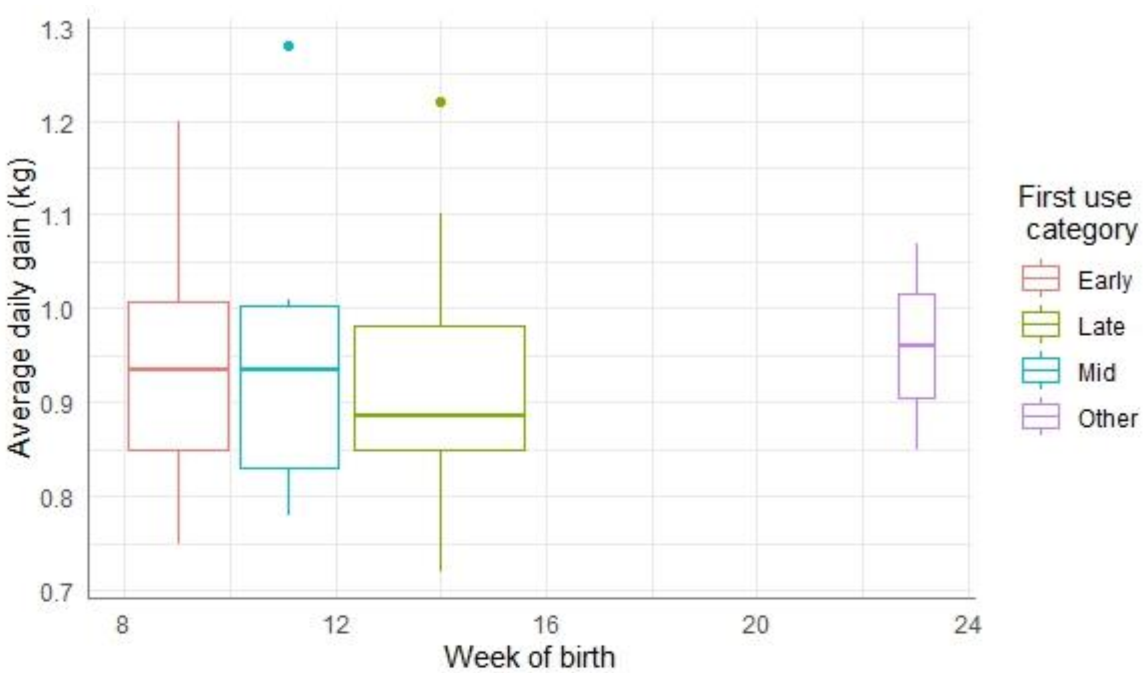


Fig. 23. Boxplot depicting the average daily weight gain of calves based on the week of the trial when they were born; Calves are grouped according to first use category, where 'Early' calves first used the ALMS within 15 days of birth, 'Mid' calves between 15-50 days of birth, 'Late' between 51 and 100 days of birth and 'Other' calves were first recorded when they were 101+ days old

Table 9. Number of times a calf's electronic identification (EID) was recorded without a corresponding weight being recorded, and proportion of these events that were related to days when the cattle were manually mustered through the ALMS

Number of EID files without a weight/day	Number of occurrences	% related to a mustering event
0	54	0
1	14	21
2	4	25
3	2	50
4	3	33
5	1	100

5.3.6 Separating calves from cows

Implementing the drafting gate was delayed due to issues with calves not using the system independently. At the start of the calf separation study, calf use averaged 12.72 ± 8.49 calf visits per day, approximately 30% of all calves. The study commenced in May 2019 to collect as much data as possible prior to weaning.

Two separate algorithms were tested, the first used an RFID tag read to initiate a gate change and the second used a decrease of 60 kg weight to initiate the gate to close. The first algorithm was tested for 13 days and the second only for 2 days.

When the cattle were mustered to the ALMS compound, the success of drafting events was 83% with use of the first algorithm, with 35 calves being separated from cows and seven calves mis-drafted into the cow pen (Fig. 24). This was a result of calves following closely behind their mothers and entering the left pen before the gate closed. In many instances, the gate was beginning to close but the calf's head had already entered the pen. The gate continued to close while the calf was still moving through the entrance, but the pressure on the gate did not cause any harm to the calf and it could continue through the gap. Another cause of a calf being mis-drafted occurred after the gate had closed but the calf took too long to respond, and the following cow's EID was read thus triggering the gate to open, allowing the calf to follow where its mother had gone. There were no instances of a cow being mis-drafted into the calf pen.

Fig. 24. Cows and calves automatically separated into adjoining pens by the ALMS drafting gate

The second algorithm was tested to close the gate more rapidly behind the cow to prevent calves being mis-drafted, as well as attempting to draft calves without RFID tags. This algorithm was tested twice, the first using a weight change of 60 kg to initiate the gate closing, however, this resulted in the gate closing too quickly, especially for cows that were slow exiting the gate or those that hesitated and baulked when the gate swung open; the gate ended up closing around their neck region.

The algorithm was modified to close when the weight on the platform decreased by 90 kg and was tested the following day. While this resulted in the gate closing slightly slower than the previous day, the gate closed too rapidly for cows that didn't use the system confidently and the gate closed on them around the shoulder region. It was also noted that cows that used the system the day before had become even more hesitant and nervous about using the system, thus the new algorithm was detrimental to their previous training and confidence in using the system.

While the exit RFID reader had been calibrated to calculate total mis-drafts, there were issues with the entry records correlating with the exit records. It is suspected that calves were jumping over the trough and exiting the compound with their mother. This system of recording the accuracy of the drafting gate was proven successful by Corbet et al (2019), where metal bars prevented animals jumping the trough. Further development is required to increase the accuracy of the exit reading system for this particular ALMS calibration.

5.4 Summary

Understanding how calves respond to and use an auto-drafting ALMS provides essential information to inform future implementation practices. It was discovered that the age that a calf first uses the ALMS influences how frequently they will use the system in future, and that calf age was not a determinant of future use. The hypothesis that calves would be trained by their mothers to use the ALMS, therefore, was rejected and suggests that implementing training practices when calves are first born may affect the frequency that calves use the system.

The difference in time between a calf following a cow through the ALMS was also expected to increase with age however, the data indicate the time difference decreased with age. The calves that used the ALMS within 15 days of birth had a greater range of separation times than other first use categories. The unexpected decrease with age may be a result of the intensive training provided later in the trial, with the older calves having shorter separation times because the majority of their entries occurred during a mustering event and were therefore more rapid than what would naturally occur. The results imply that an auto-drafting gate needs to close within 26 s from a cow's RFID being read to efficiently draft a calf into a separate pen to separate 70% of calves.

Petherick and Hirst (1996) claim that cattle should remember how to use spear gates for up to 12 months after they have been trained, thus it could be expected that the same would be true for the ALMS infrastructure. The overall rate of calf use was lower than expected, and although it increased gradually over time, the use rate was never greater than 71%. This issue delayed initiating the calf separation phase of this study; activating the drafting gate in the study by Corbet *et al.* (2019b) decreased ALMS use thus we aimed to maximise calf use in the calf separation study before activating the gate, however, calf frequency did not increase to an acceptable level.

Due to issues with calves not using the system independently, the automatic drafting algorithms could not be used to draft a significant portion of the herd into separate cow and calf pens. This also affected the algorithm tested to draft calves without an RFID ear tag. The system could, however, be used to successfully draft 83% of the herd correctly when the cattle were mustered through the ALMS. This provides producers with an option to automatically draft calves from cows in-paddock; this situation could represent a weaning situation, where calves could be removed from their mothers in-paddock and either trucked or walked to another paddock or yards. These findings provide confidence that improvements in drafting calves from cows can be made following adjustments to the infrastructure and software.

Several future developments are suggested:

- Providing a more attractive enticements for calves to use the ALMS. Water was not a strong attractant, especially when calves had access to milk from their mothers. Providing a supplement such as a mineral lick or molasses may be a potential option however, training will also be required to accustom the calves to the supplement. Cows and calves were provided with lucerne hay during auto-drafting training events, but many calves were hesitant to eat the hay as it was unfamiliar to them. However, the extra enticement increased cow use and confidence in using the system. It is thus suggested to introduce the attractant outside of the ALMS compound for a period of time until all calves are familiar with it before offering it exclusively inside the compound in combination with further training.
- Provide an alternative entry to the ALMS compound using creep gates, similar to the calf separator design. This would provide a system where the calves could bypass the ALMS and enter an opening at the entrance to the ALMS that t cows could not access. A producer could trap the cows by closing the exit spears the evening before and close the creep gates when they arrive the next day. It would be expected that the majority of calves would be in the yards with the cows. This design would require further testing to determine the efficiency of such a system Training would be needed to familiarise the calves to the creep

gates. Having calves by-pass the ALMS means their weight and frequency statistics would not be recorded, thus it would be difficult to obtain data on calf growth paths or maternal parentage derived from ALMS sequential data. It would also prolong training if the calves were to experience ALMS's in the future however, this would not be a concern for many production systems where calves are not kept as replacements.

- Initiating the drafting gate caused many cows and calves to baulk at the infrastructure. The swinging gate and compressor created noise and movement that many cattle were fearful of. Changing the pneumatic gate to an electric system may make the gate swing more smoothly and provide for greater control over the speed at which the gate stops. With a pneumatic gate there is no option to control the timing of when the gate stops. However, this could be achieved with a programmable electric system to stop the gate before it makes contact with the metal frame. Therefore, decreasing the noise and motion made by the gate opening and closing.
- Further developments can be made to the gate closing algorithm to draft off untagged animals. The second algorithm worked well for cows that used the system confidently. With increased training and modifications to the infrastructure previously described in this report, this algorithm has potential for success.
- Other methods of identifying calves as they enter the ALMS to make drafting decisions in real-time are possible. For example, image analysis to discriminate calves from cows. Further technological developments are required to implement and test these possibilities including ensuring the system can process the required information in enough time to make a drafting decision, operating within the available battery restrictions and transmitting data within the necessary size limits.

This phase of the study has demonstrated that calves can be automatically drafted from cows in-paddock using manual mustering methods to get cattle to enter the ALMS. Further refinements have the potential to automate this system to draft untagged animals. These results have also provided basic data on the factors that affect calf use over time, which will provide essential background information for refining both technological and software developments. After the system is drafting cattle effectively, different applications can then be tested to determine the real value of auto-drafting for calf welfare, labour benefits and productivity.

6 Understanding current calf husbandry practices and attitudes towards auto-drafting technology in extensive beef production - interviews

6.1 Introduction

Auto-drafting is a new technology that provides potential benefits to improve animal management, labour efficiency and animal welfare. However, testing of the technology is required to determine if these perceived benefits translate to real on-farm value. One particular benefit proposed from auto-drafting is the potential to draft calves from their mothers to perform husbandry practices at younger ages than what is currently reported practice, which would improve welfare outcomes for the calf and ease of handling for the producer.

Producer uptake of precision agriculture technologies has been slow in livestock industries. Factors such as ease of use (Davis 1989), access to professional support (Daberkow and McBride 2003), a lack of decision support tools to convert data into useful information to aid management decisions (Lamb *et al.* 2008), and uncertainty around economic returns (Neethirajan *et al.* 2017) have been reported for the limited uptake. Knowledge on producers' attitudes towards ALMS technologies to monitor welfare is invaluable to not only direct research efforts, but to also customise data management platforms to enhance uptake. Thus, involving producers was considered as an essential component of this study when developing a commercially relevant auto-drafting system.

As auto-drafting technology is currently within a research and development phase, producer knowledge and understanding of the technology is unknown, as well as how well the technology could be applied across a variety of different beef production enterprises. Additionally, each beef property is unique and there are differences in the way cattle, in particular calves, are managed between properties. To develop an auto-drafting system that is suitable for a wide range of properties by gaining information on management practices was an important component of this project. Equally important was the subsequent application of this knowledge to determine how different requirements and benefits could be incorporated and barriers overcome in the system's design.

The aim of this study, therefore, is to obtain information on the current calf husbandry practices of a small group of beef producers in Queensland and determine the perceived benefits to them and industry more broadly of installing emerging technology, in this case an auto-drafter. This study evaluated variations in management practices and attitudes. The information gathered was then used to develop an online survey to be distributed Australia wide and to inform on the practical and theoretical application and development of the auto-drafting technology.

6.2 Methods

Selected producers from beef properties throughout northern Australia were invited to participate in a one-on-interview with researchers to discuss how their individual properties and the wider industry might use auto-drafting, with a specific focus on calf management. The interviews were conducted between November 2018 and March 2019.

The interview questions designed to improve understanding of the basic operations on each producers property, included the number and breed of cattle, type of operation, breeder management and market preferences. Further backgrounding questions explored current calf management practices, such as the number of musters with calves, timing of husbandry practices and weaning criteria (age, weight).

Participants were then asked about what they perceived as the general benefits of and barriers to installing auto-drafting on their property, as well as other benefits and applications for the wider industry. Participants were also asked to consider how auto-drafting could be used to improve calf management.

This research was approved by the CQUniversity Human Research Ethics Committee, approval number 21453.

6.3 Results

Seven producers from Queensland, Northern Territory (NT) and Western Australia (WA) participated in the interviews (Fig. 25), which were conducted either face-to-face, via a web-based platform or telephone, with each interview lasting approximately 1 hour.

Fig. 25. Approximate location of the seven interview respondents within Australia

6.3.1 Property demographics

Property size was correlated with location; properties in Western Australia and Northern Territory averaged a greater property size (215,000 ha) than those in South West Queensland (SWQ, 32,000 ha) and Central Queensland (CQ, 3,760 ha). The number of cattle managed per property were also related to region, with Northern Territory and Western Australian producers having an average of 5,500 animals compared to 3,780 in Central Queensland and 800 in South West Queensland (Fig. 26).

Breed of cattle varied between properties, with two properties reporting single breed herds and four reporting mixed breed enterprises. Of the respondents who mentioned breed of cattle, *Bos indicus* and *Bos indicus* crosses were reported the most with Brahman and Droughtmaster reported for 84%

of all properties, while *Bos taurus* dominant breeds, such as Waygu, Angus and Charolais were reported for 50% of properties.

The livestock markets targeted varied depending on region, with Northern Territory and Western Australian producers marketing cattle through the live export market, while 80% of the Queensland properties targeted more than one livestock market, feedlots (n = 2), direct to abattoir (n = 3), saleyards (n = 2) or to private buyers (n = 1).

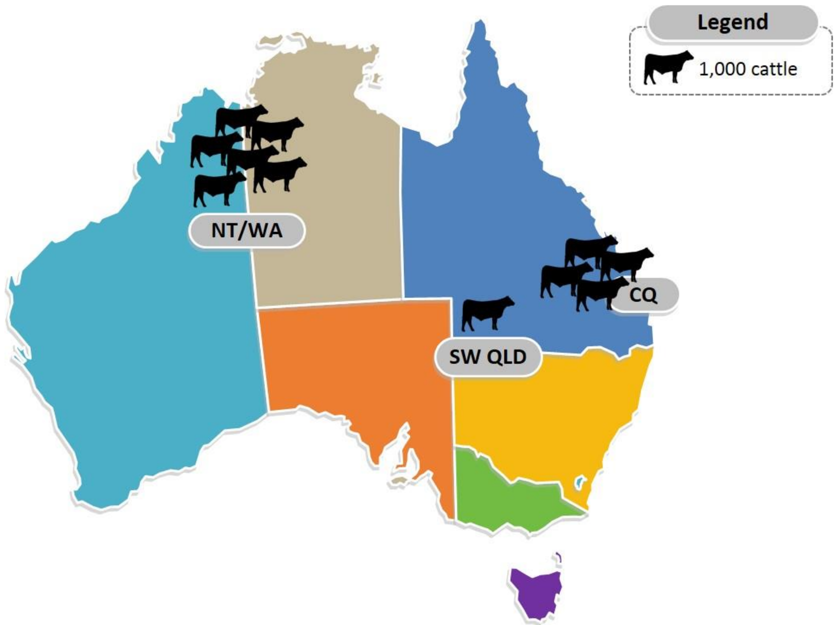


Fig. 26. Average number of cattle per property reported per region, divided into Northern Territory and Western Australia (NT/WA), Central Queensland (CQ) and South-West Queensland (SW QLD)

In relation to breeding practices, 29% of properties implement year round mating practices while the majority (71%) use control mating programs. The average mating period was reported to be 3 months, with three properties having spring-summer calving periods from November onwards, while two properties reported a winter calving period beginning in June and July. Four of the seven properties reported that they pregnancy test their cattle and use this information to inform management practices, such as culling non-pregnant cows, separating cows into management groups based on estimated calving date, and supplementing late calving cows if necessary.

6.3.2 Calf management procedures

The methods used to manage calves varied between properties but was not always related to farming region. The main regional differences in calf management was the number of musters, with Queensland properties reporting four musters per year involving calves, while the Northern Territory and Western Australian properties reported between one and two musters annually. Two properties stated that they solely used helicopters for mustering, three properties reported they used a combination of helicopters and in-paddock mustering methods, such as horses and motorbikes, and two properties relied solely on in-paddock mustering methods. The purpose of the first muster involving calves for all properties was to brand calves.

All properties reported performing similar calf husbandry procedures at the one time, which included fitting NLIS tags, castration and vaccination for botulism and either 5 in 1 or 7 in 1. The timing of calf husbandry procedures varied among properties, with three respondents stating before weaning, two stating at weaning and two stating after weaning.

When asked about the primary factor determining when a calf is ready to be weaned, both Northern Territory and Western Australian respondents stated cow body condition score, while all Central Queensland and South West Queensland respondents that supplied this information stated calf weight as the primary weaning factor. The range of minimum weaning weights per location is shown in Fig. 27.

Fig. 27. Reported minimum weaning weight per property location, based on an average climatic season

6.3.3 Benefits of auto-drafting

Respondents were able to consider the wider applications of auto-drafting for their own and other properties, with a range of benefits mentioned. These benefits were divided into *actions* and *outcomes* from using auto-drafting, where actions relate to management changes that could be implemented with auto-drafting, while outcomes relate to the secondary benefits that could result from performing the actions. A summary of the actions and outcomes are shown in Table 10, with the number of responses related to each of the six different actions being listed in Fig. 28.

The auto-drafting function is contained within automatic livestock management system (ALMS) infrastructure, which refers to the entire infrastructure and data collection and analysis system that contains a weigh platform, electronic identification reader, automatic drafting unit and portable panels surrounding an attractant, such as water and/or supplement. Some of the benefits listed by respondents extended from the specific auto-drafting action to separate animals to other functions of the ALMS, such as recording live weight.

Table 10. Summary of the perceived actions and outcomes gained by installing an in-paddock auto-drafting system that were identified during the interview process; Producers could nominate more than one benefit; Percentage per action refers to the number of responses recorded for that action as a proportion of all actions

ACTIONS	OUTCOMES (number of times outcome was mentioned)
Automatically wean calves from cows in-paddock (29%)	• Optimise the timing of weaning based on calf weight (7) • Wean earlier to improve cow condition (2) • Increase re-breeding success from improved cow condition (1) • Give weaners a better start from decreased handling (1) • Cows experience less stress if they stay in the same paddock post-weaning (1) • Cows experience less stress if they can see their calf during in-paddock husbandry procedures (1)
Using data from the ALMS for decision making (21%)	• Targeted supplementation by drafting lower weight animals into a pen with supplement (2) • Supplement smaller calves (1) • Segregate cows into calving groups based on pregnancy status i.e. early, mid or late (1) • Draft cows based on individual data e.g. cull cows with lighter offspring, lactation status (2) • Monitor offspring performance (e.g. calf weight gain, fertility) (1)
Labour savings from in-paddock auto-drafting (17%)	• Increase muster success (1) • Save on helicopter mustering fees (1) • Save mustering cows and calves to the yards (1) • Decrease the number of musters to yards per year (1) • Potential to automatically apply worm and tick applications in-paddock (1)
Using in-paddock auto-drafting to decrease animal and handler stress (17%)	• Decrease cattle stress from less handling, mustering and time spent in yards (1) • Decrease the calf loss during mustering (1) • Limit the time that calves are away from their mum (1) • Reduce handler stress from mustering and yard work (1) • Improve OH&S from handlers not being in yards with cattle (1) • Reliable data, unbiased data collection (1)
Using live weight data from the ALMS to monitor weight over time (12%)	• Monitor cattle weight as an indicator of pasture availability (3) • Identify animals ready for market (2) • Project weight trends to determine when to sell (1) • Identify weight loss (1)
Other benefits from ALMS data and auto-drafting (4%)	• Determine date of calving (1) • Determine maternal parentage (1)

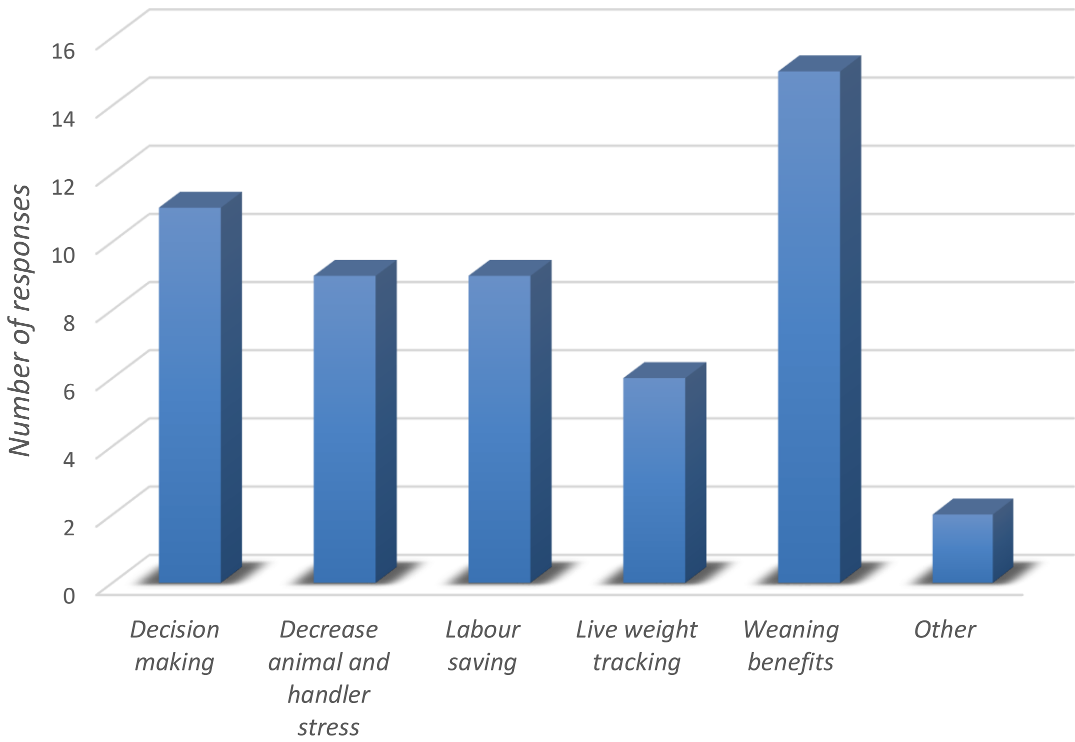


Fig. 28. Total number of responses for each of the six identified actions gained from installing an automatic livestock management system fitted with an auto-drafter

6.3.3.1 Automated weaning

The main auto-drafting benefit identified was related to in-paddock weaning, with four respondents stating this as an advantage for their production system and a total of 15 related outcomes identified from this action. One respondent stated "It's [in paddock weaning would be] fantastic, because getting those calves off as soon as you can is really important, especially where you've got to maintain breeder body weight… Every calf you get off is one breeder that you get a chance to rebreed next year, it's got a lot of value." Another respondent identified the benefits of optimising weaning to benefit cow condition by stating "If you could draft in-paddock a calf that's too big and is pulling off mum, you'd be much better off", which was backed up by another respondent who stated, "Cows do well after the calves come off."

6.3.3.2 Informed decision making

The second greatest benefit identified was using ALMS data to inform decision making, such as knowing when to offer supplement, form calving groups based on estimated calving date and projecting future sales. The additional information on individual animals would provide confidence in decision making and remove some uncertainty about the timing of certain decisions, as summarised by one respondent: "I really like the idea of using weight as a determinant for decision making and for weight loss. I'd like to know how much more [of the] story I can get in a poor season with our cows, if you think they're only losing a couple kilo's a week but they're actually losing 15 kg a week then you can intervene earlier. You can make some fantastic decisions 6 weeks earlier than what you might have seen."

6.3.3.3 Labour savings

Respondents also identified where labour savings could be gained by installing an ALMS, especially around mustering, with helicopters and mustering teams costing one respondent $5,000 per helicopter per day plus fuel. These benefits could potentially assist with the wider industry issue of labour shortages, with respondents commenting "Labour is expensive. We've got good people, however, that could change tomorrow." Another respondent commented "People don't want to live so remotely, it's hot and dusty. It's not like the RM Williams magazine pictures, it's not as glamourous." The benefits from using technology to automatically collect data and implement management decisions in-paddock was viewed favourably by some, for example one respondent stated "The other big advantage I see is the timely and accurate information but also not having to rely on people and vehicles. The [more] that can be done with sensors and sent back the better."

While not yet developed, one respondent could see huge cost savings for their business in developing an automated chemical application based on an animal's weight as it enters the ALMS: "One of the massive things is to tie it [auto-drafting] in with scanning technology that you can assess the size of a cow and apply a dosage rate of tick/worm spray, that's a huge cost for us, $50 k a year… We pay a lot of money and inefficiencies in applying doses per animals based on weight… To standardise things in our production and use chemical more efficiently would be a huge saving."

6.3.3.4 Decrease animal and handler stress

Several respondents could see benefits in using ALMS units to decrease the amount of "hands-on" handling of cattle, resulting in improved welfare outcomes for both cows and calves. One respondent focussed on the benefits for calves at weaning, stating "If you could do that [wean] by minimising stress, it helps them to start better." Another respondent identified the advantages for cows and handlers following weaning, commenting that "[To] take weaners straight out of the paddock, that would be good. Mothers can stay in the paddock. A lot of the time it's a problem to get them back to their paddock, but [with in-paddock auto-drafting] they can jump up and down, it doesn't matter."

Benefits could also be seen in saving cattle being mustered long distances to the yards for husbandry procedures, where they could be held for 2 days and need to be given supplementary food before having to walk back to their paddocks: "We have one set of yards at the wrong end of the property, cows need to walk 10 km plus. In summer it's too far to walk, [we] can't muster and process calves in the one day. We could see benefits to in-paddock weighing rather than bringing them in." This benefit was reflected on another property, where they saw benefits of in-paddock drafting saving smaller calves perishing and needing to be manually raised as orphans following the stress of mustering.

Along with benefits to decrease handling stress, one respondent focused on the potential benefits auto-drafting could provide for human health and safety, identifying the physical risks that come with working in yards with cattle: "When we draft at home there's two blokes on the ground, ones got the gate in the pound and the other opens the right gate so you're on the same level as the cattle. Most of our cows are quiet but there's quite a big risk to get a horn or bump or kick. If you're [drafting remotely] she can't kick, bite or scratch."

6.3.3.5 Live weight tracking

Obtaining reliable and accurate information on an individual's weight was viewed favourably by most respondents, seeing benefit in improving the way management decisions could be made, particularly with respect to animal health and future sales. "It would be an education for us" replied one respondent, "If I know they're going to be putting on weight over the next couple of months, then I'll hold onto them… You can see what the cattle are doing in different circumstances. You can plan your sales based on if they're gaining or losing."

The benefits proposed from knowing regular live weight patterns included picking the lead animals out of a mob of steers destined for sale, spreading out sales by identifying which animals were ready for sale at specific times, optimising the number of decks per sale and not disturbing the cattle not being sold, thus saving them from losing weight during mustering to and from the yards.

6.3.4 Barriers to installing auto-drafting on-property

Respondents identified a range of impediments to installing auto-drafting on their properties, which were refined into four categories: practicality, functionality, animal factors, and environmental factors (Table 11). A summary of the number of responses for each of the four categories is shown in Fig. 29.

6.3.4.1 Animal factors

Animal factors were reported as the greatest issue to implementing a successful auto-drafting system. Training animals to use the system was seen as an impediment for three respondents, with some detailing experiences of similar systems where cattle failed to be trained to the system, with one respondent stating they had heard of animals dying from not being willing to enter a portable fence set up around a watering point as a way of saving mustering. While another acknowledged that training takes time and had heard of a small percentage of cattle unable to be trained, they did not see this as a real issue and highlighted the importance of concentrating training efforts when cattle were young: "… young animals are most impressionable, if you imprint them as weaners then you never have problem with them as cows. The secret with cattle is handling the weaner properly, and I think you'd have very little problem with them going through the auto-drafter later on."

Other animal-based issues included selling animals that were trained, especially in a backgrounding setting where they may only be using the system for several months before being sold. One respondent had heard of others' experiences with animals camping on the weigh platform and not allowing other animals to access water.

6.3.4.2 Practicality

Cost was mentioned the most as an impediment to installing auto-drafting (n=4). Several respondents stated that they would consider installing auto-drafting if the forecast economic benefits were proven: "If I can get a return in 3-5 years I look seriously at it, that's a good investment, but if it takes 7-10 years … it can be a bit dicky." The same respondent roughly calculated it would take in excess of 10 musters to recoup the cost of installing two auto-drafters, as well as the time and cost that would still be required to transport drafted cattle to the yards.

Table 11. Summary of the perceived issues with installing auto-drafting on property that were identified through the interview process; Producers could nominate more than one barrier; Percentage per impediment refers to the number of responses recorded for that barrier as a proportion of all barriers

IMPEDIMENT	DESCRIPTION (number of times impediment was mentioned)
Animal factors (32%)	• Training cattle to use the system; time and efficacy (3) • Selling animals soon after they're trained (1) • Young calves not using the system (2) • Animals blocking up the system and not going through (1)
Practicality (25%)	• Cost (4) • Difficult to implement with large mobs (2) • Requirement to learn a new management software (1)
Environmental factors (25%)	• Surface water deterring animals entering the ALMS (4) • Paddocks with more than one watering point (3)
Functionality (18%)	• The system needs to be portable (2) • Noise of gates and compressor (1) • Unreliable/unavailable network coverage to transmit data (2)

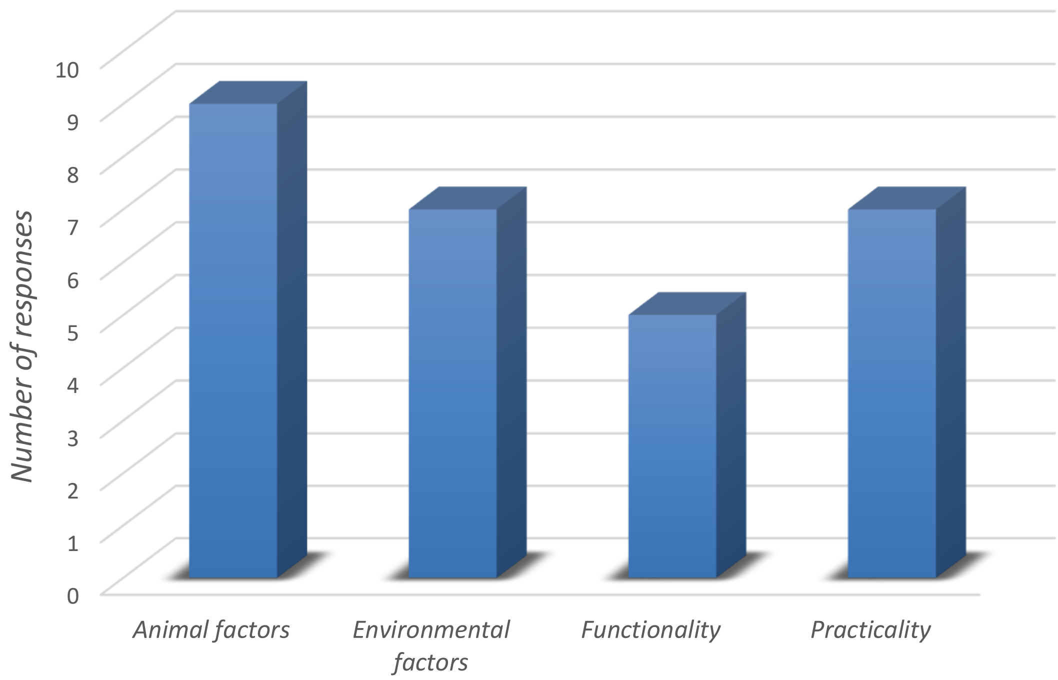


Fig. 29. Total number of responses for each of the four identified categories of impediments for installing an automatic livestock management system fitted with an auto-drafter

Thus, at two musters per year the benefits returned would be borderline between the 5-7 year rate of return rule followed by that particular respondent. Another respondent was more optimistic, commenting that using helicopters for mustering can become quite expensive, while an auto-drafter is a long-term investment: “The auto-drafter’s there forever. If they last 5 years or so, it’s only a few grand per year.” A further respondent highlighted the importance of knowing the economic feasibility of the system before considering installing it on their property: “It depends on the cost as to whether you have 1 or 2 or 10. It depends on cost and returns.” A complete economic evaluation is needed before any financial implications can be realised.

The logistics of managing cattle remotely was also seen as a potential impediment, with some seeing the extra labour required to manage multiple drafting events as more work than their traditional mustering systems. One respondent inferred that it would be cheaper to install new processing yards throughout their property than routinely transport automatically drafted cattle from the ALMS: “You’d need to pick them up in a truck or process them in the paddock, because that would create more work than mustering them and doing it all in the yards. The logistics of gathering those animals from three or five separate places, then having to take them somewhere and process them, you could afford to have processing yards at all of those points.”

6.3.4.3 Environmental factors

The presence of surface water in paddocks was regularly mentioned as a potential issue for installing ALMS units, thus deterring cattle from crossing the weigh platform to access water (n = 4). While respondents recognised there were options to fence off surface water, it would not be feasible in some paddocks: “Natural waters, they’re not going to be practical to fence off and maintain the fences, it’s more cost than what it’s worth.”

Many respondents identified that their current paddock configuration, including the number of watering points per paddock, would not be conducive to installing a single auto-drafting unit (n = 3), with one respondent reporting: “I’ve got a minimum of four waters per paddock. That would be a huge capital outlay.”

6.3.4.4 Functionality

Having a portable system was seen as a top priority for two respondents, where they could maximise their investment by moving the unit in response to cattle, rather than moving cattle in response to the ALMS unit. “You want something portable and put it in the paddock that suits you. That paddock might change to finish the weaners, [then you] might put it in the steer paddock and get all their weights.” Having a portable unit was also seen as a necessity for flood prone areas, where the unit would need to be removed to avoid water damage.

The availability of a communications network to regularly transmit the data was mentioned as a potential issue for one respondent, where there was intermittent network coverage on their property: “Some places you get some telephone signal, some places you don’t... It’s a big thing so that you’re getting all of this information every day, and that varies from paddock to paddock. It is, I believe, getting better, but you can’t count on it getting better.” The issue of communications will be greater for some properties more than others.

6.4 Conclusions

Overall producer attitudes toward the auto-drafting system were positive, with one respondent commenting “If you’d asked me this 10 years ago, I’d say it’s not necessary, but listening to the way you [CQU] run your projects and the ideas coming out of it, we do think it’s really beneficial. I’d love to try one on our place for a few months.”

The sample size, however, was very small and a greater number of interviews are needed for more robust analyses.

The most frequently mentioned benefit from auto-drafting was related to weaning. Not all respondents could see benefit in performing husbandry practices in-paddock, because of logistical factors such as additional infrastructure and required transport. In certain farming areas there were perceived advantages to auto-drafting.

Approximately one quarter of auto-drafting benefits related directly to improving welfare above current practice, such as decreasing the distances calves need to walk to handling yards and reducing the stress from mustering. Other benefits included secondary welfare outcomes, such as monitoring live weight changes and identifying when animals were losing weight so they could be supplemented.

The major issues deterring respondents from evaluating an auto-drafting system on their property were cost, training animals to use the system efficiently and existing paddock water. The former impediments may be overcome in the future as the technology matures, however, environmental factors that can’t be easily controlled pose a greater challenge. Overcoming these barriers will require a case-by-case evaluation of each paddock.

There were only a couple of benefits mentioned that related specifically to monitoring or improving animal welfare, such as decreasing the distances calves need to walk to handling yards and reducing the stress from mustering. There were also other benefits mentioned that were not specifically framed from a welfare perspective, but would have secondary welfare outcomes, such as monitoring live weight changes and supplementing when animals lose weight.

Auto-drafting is a relatively new technology for extensive beef production. Future research needs to provide evidence-based outcomes and detail how challenges can be overcome to gain trust that producer’s expectations will be met. Conducting a full economic analysis is a high research priority, followed by developing detailed and effective animal training guides. The findings from this study will inform both research and extension activities to encourage adoption and successful implementation of auto-drafting technologies.

7 Understanding current calf husbandry practices and attitudes towards auto-drafting technology in extensive beef production – survey

7.1 Introduction

Auto-drafting technology has many perceived benefits for the extensive beef industry. The previous section indicated there was a positive response towards auto-drafting from the small cohort of participants, with a variety of benefits mentioned including in-paddock calf separation for weaning. Participants also identified several barriers to the technology being implemented successfully, however, many of these can potentially be overcome.

The aim of this study is to use the information obtained in the previous section to devise a specific survey for a larger group of beef producers to record information on their current calf husbandry practices and determine the perceived benefits and barriers of installing an auto-drafter on their property.

The previous study deliberately used a small cohort of producers from a range of different locations and operations to gain an understanding of the various on-farm practices and applications of auto-drafting; these responses will be used to inform the questionnaire for a larger range of participants. Conducting detailed interviews first allowed specific survey questions to be formed, thereby ensuring the questions are relevant to the intended data being collected whilst also refining the survey so that only necessary questions were included, and thus reducing the time needed to complete the survey.

Engaging a wider range of producers in this study not only informs the development of an industry relevant auto-drafting system but increases producer knowledge and awareness of the technology, which helps form collaborative networks between producers and researchers, and potentially assists industry uptake of ALMS technologies.

7.2 Methods

A survey was developed based on the responses of a small group of north Australian beef producers during a detailed interview process. The survey questions were designed to provide background information about the respondent's current management system and calf husbandry routine. Questions were included to understand producer's current technology use and their perception of animal welfare practices on-farm. Producers were also asked to provide details on the potential benefits and barriers of installing in-paddock auto-drafting on their property.

Respondents were sought through email lists and advertising on the Agri-tech Innovation and Education Facebook page. Respondents were self-selecting and were able to read information relating to the purpose of the survey, watch a short video on what auto-drafting is and choose to complete the online survey by simply clicking on a link. Within the survey itself, respondents could again watch a short video explaining the basic concepts of auto-drafting. This research was approved by the CQUniversity Human Research Ethics Committee, approval number 21587.

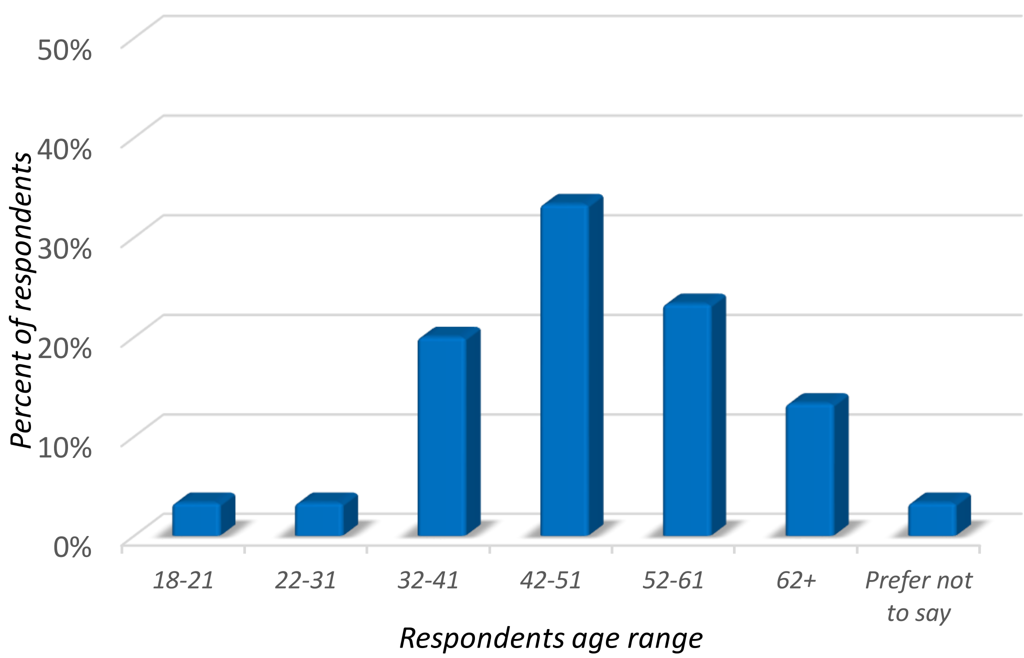
The survey was open to participants from 3 March 2019 and the last participant responded on the 14 June 2019, thus data were collected for a period of 72 days. A total of 61 producers responded to the survey questions. Within 1 month of data collection, an error in the survey logic settings was detected, which prevented respondents access questions relating to their demographics; 31 respondents were affected by this issue. The problem was rectified and the remaining 30 respondents could access all 23 questions. As a result, respondent's location, age, production focus and technology currently used on-farm was not reported for these respondents and their subsequent responses could not be correlated with this information. Not recording this data was unfortunate but unrelated to understanding the calf management practices and producer perceptions of auto-drafting, thus maintaining the validity of the results.

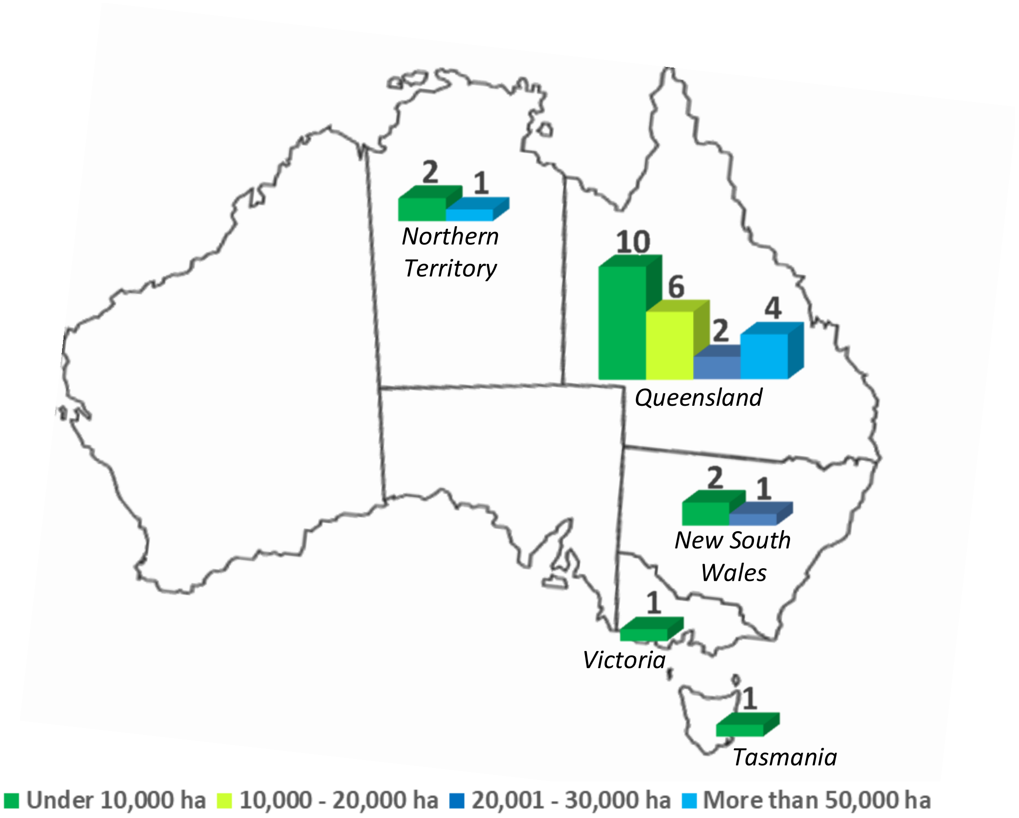
The individual response data were downloaded from the Survey Monkey site as an Excel spreadsheet where it was summarised depending on the type of question. Quantitative data were summarised by the number of responses and expressed as a percent of all respondents. Where responses referred to a quantitative range, the largest value was used to compare data for that question. Qualitative data collected from open-ended questions were summarised using a thematic analysis and similar themes were grouped to present results as a percent of all responses. Where applicable, correlations between data were compared using a Pearson correlation analysis, with differences considered significant at $P<0.05$.

7.3 Results

7.3.1 Respondent demographics

A total of 61 respondents completed the online survey and 30 of those answered the demographic questions. The respondents aged in range from 18 to over 62 (Fig. 30). The majority of respondents were from Queensland (n = 22), followed by three respondents in each of New South Wales and the Northern Territory. There was one respondent in Victoria and one in Tasmania. The size of land





managed according to state is depicted in Fig. 31, where 53% of properties were less than 10,000 ha (n = 16), and almost 20% were 50,000 ha or greater (n = 5).

Fig. 30. Age of respondents who answered the demographic questions (n = 30)

Fig. 31. Property size of respondents that answered the demographic questions according to state (n = 30); Map of Australia accessed from www.abcteach.com

Most respondents (63%) identified one main type of production system (n = 19), while 30% identified two production focuses and 7% stated three different foci. Breeding beef cattle was the main type of production system nominated (67% of respondents), followed by beef backgrounding (29%) and 5% operated beef feedlots.

The number of technology applications used by respondents varied. Five respondents identified only one application of technology, which was either an EID tag reader, a computer or a smart phone, while one respondent reported nine different technology applications. Almost 50% of respondents used five or more technologies on-farm. There was no correlation between respondent's age and number of technology applications used (Pearson correlation, P>0.05).

The type of technology used by respondents is depicted in Fig. 32, where almost all respondents used a smart phone and home computer (90% and 87%, respectively), where a computer could either be a desktop or a laptop. The majority of respondents (70%) also used some form of electronic identification reader to read NLIS ear tags, while 50% used a stock management software, such as Stockbook or Phoenix farm management software. Fewer respondents used some form of telemetry technology, being an automatic water meter (13%) or in-paddock walk-over-weigh scales (7%).

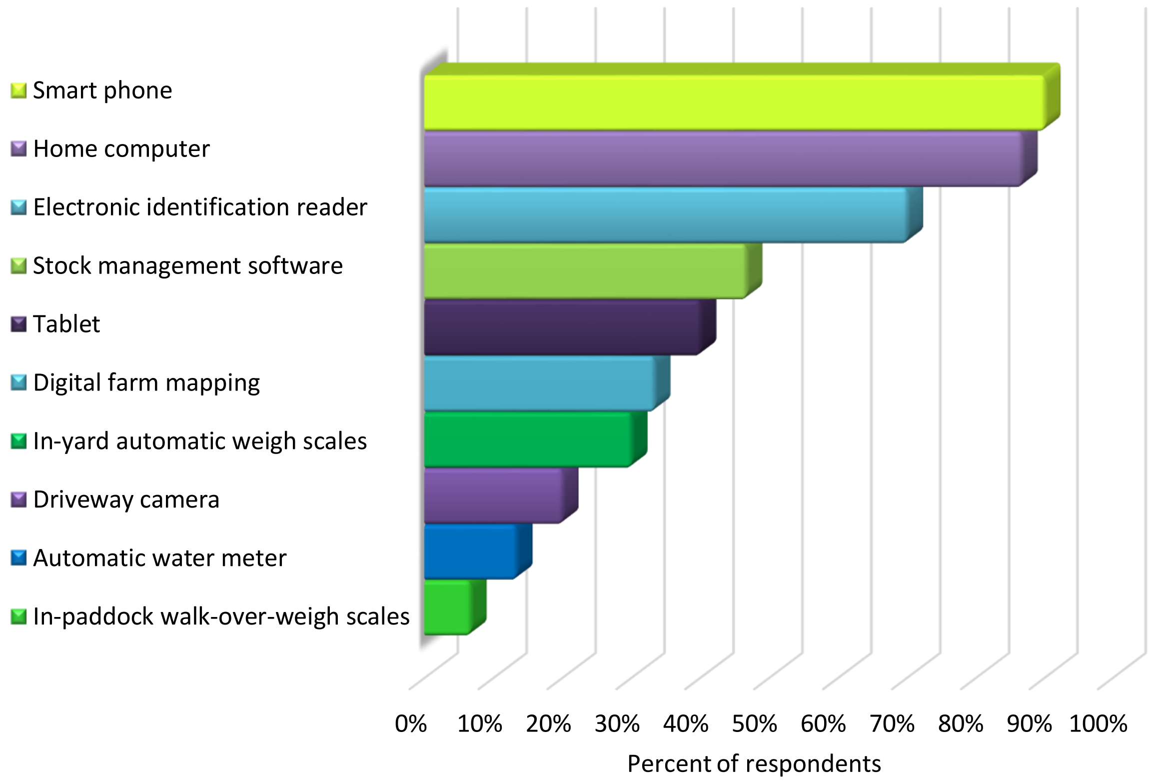


Fig. 32. Technology used by respondents (n = 30)

7.3.2 Calf management practices

Forty-two respondents answered questions related to calf management practices. The majority of respondents (n = 20) mustered twice per year when calves were in the herd, generally one muster for branding and a second muster to wean. Six respondents stated they mustered only once per year while 16 respondents mustered more than twice per year, reporting four (n = 5), five (n = 2) and six (n = 1) musters annually. One respondent indicated they mustered cattle more than 50 times per season, while another stated they separated calves from their mothers at birth to be hand reared.

The majority of respondents (86%) perform calf husbandry practices before weaning, while 10% undertake these procedures at the same time as weaning and 5% perform them after weaning, such as at the completion of weaner training. Eight respondents nominated more than one occasion where they perform calf husbandry procedures, combining either before weaning with after weaning (n = 1), before weaning and at the same time as weaning (n = 4), or at all three occasions (n = 3).

Most respondents (n = 30; 71%) used a single factor to determine when calves were ready to be weaned, while others used a combination of two (n = 9), three (n = 2) or four (n = 1) factors to inform their decision about weaning time. The primary factor used to determine when calves were weaned was cow condition (n = 16), followed closely by calf weight (n = 14) and calf age (n = 11). Other factors, such as weather (n = 2), pasture availability and quality (n = 1), access to paddocks after the wet season (n = 6) and a specific time of year (n = 8) were also used to determine when calves were weaned.

The age and weight of calves reported by respondents at weaning is shown in Fig. 33. Respondents could enter either a weaning age, weaning weight or both weight and age. Of the respondents that entered both age and weight information (n = 28), the average weaning weight was between 200 to 250 kg when calves were 6 months or older. The weaning weight was less for Northern Territory respondents (between 100-150 kg), while Tasmanian beef calves were weaned at the smallest weight and age (50-100 kg at 2-3 months of age), however, the small sample means these data can serve as an indication only and more responses are required to confirm averages for those states.

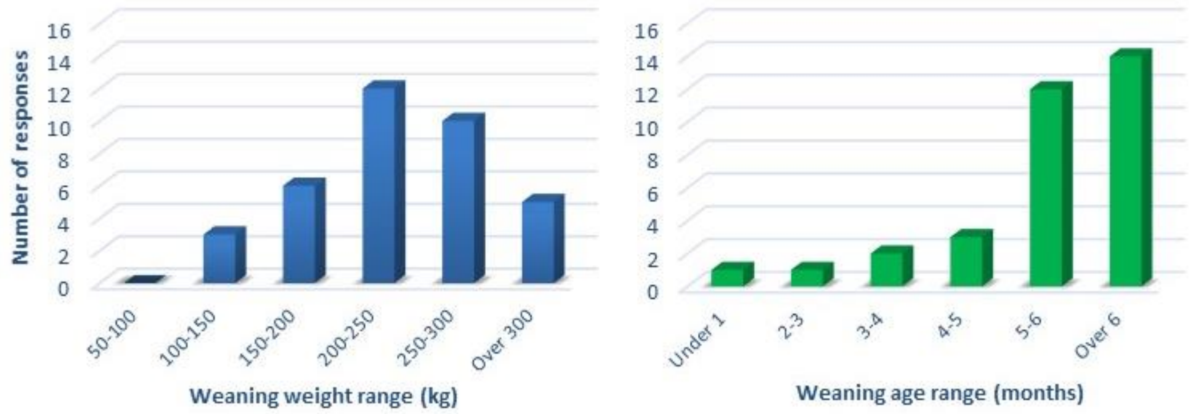


Fig. 33.Age and weight of calves at weaning as reported by survey respondents (n = 37 and 28, respectively)

When asked about calf husbandry practices in relation to animal welfare, 76% of respondents were satisfied or very satisfied, almost 20% were neither satisfied nor dissatisfied, while 5% (n = 2) stated they were dissatisfied. When asked about their perception of society's satisfaction with calf husbandry practices, 61% reported society were either dissatisfied or very dissatisfied, 26% reported those in the general society were neither satisfied nor dissatisfied, while 11% stated they believed those in society were either satisfied or very satisfied.

There was a tendency for respondents that reported their practices to be satisfactory to also report society's perception of husbandry practices to be neutral (n = 17, 81%) or dissatisfied (n = 5, 83%). In general, producers expected society to perceive welfare practices at a lesser welfare standard than themselves (Fig. 34).

It was interesting that one respondent reported they were dissatisfied with their husbandry procedures but reported those in society were very satisfied. This combination went against the trend reported by all other respondents and thus the accuracy of this response is questioned; either the results were reported correctly or the respondent misinterpreted the question.

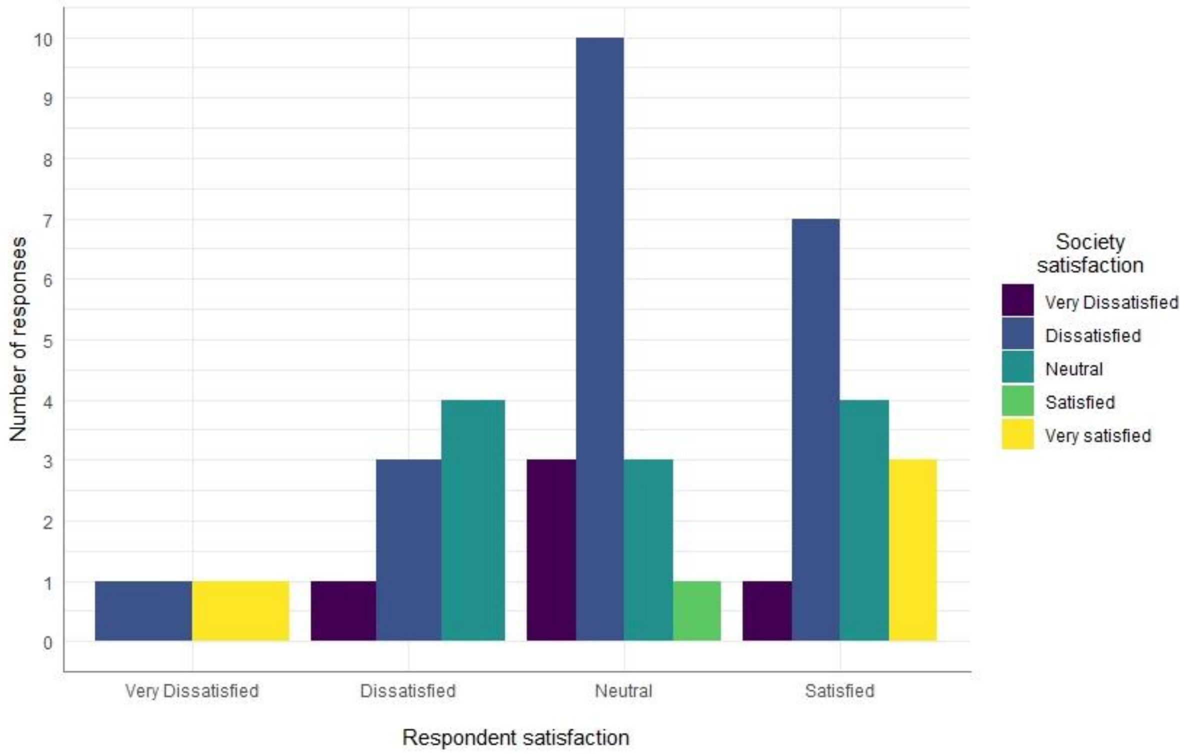


Fig. 34. Relationship between producer and society's perceived satisfaction of the welfare of calf husbandry practices as reported by producers (n = 42)

7.3.3 Perceptions of auto-drafting

Overall, 58% of respondents were interested in installing auto-drafting on their property to sort calves from cows. The following sections report the perceived benefits and barriers of installing a unit on respondent's property.

Benefits

When asked to describe their current level of knowledge on auto-drafting, the majority of respondents reported little (n = 12) or some knowledge (n = 17). There were five respondents that had no previous knowledge of auto-drafting, while four respondents stated they had a lot of knowledge.

The main benefits perceived from installing an auto-drafting unit are depicted in Fig. 35. The top three benefits nominated were drafting calves to wean (n = 19), monitoring animal body weight for sale (n = 19) and drafting cattle that meet market weight specifications (n = 18). Drafting calves to perform in-paddock husbandry procedures was only selected by three respondents.

Eight respondents chose to list additional benefits other than those prescribed. These included drafting cows into separate breeding groups based on cow weight, creating supplementation programs for weaners and cows, removing cattle that were not supposed to be in that paddock and improving the timeliness of removing bulls at the end of the mating period. One respondent mentioned the issue of labour shortages in northern Australia, and they could see benefit in implementing an auto-drafting unit to help with that issue.

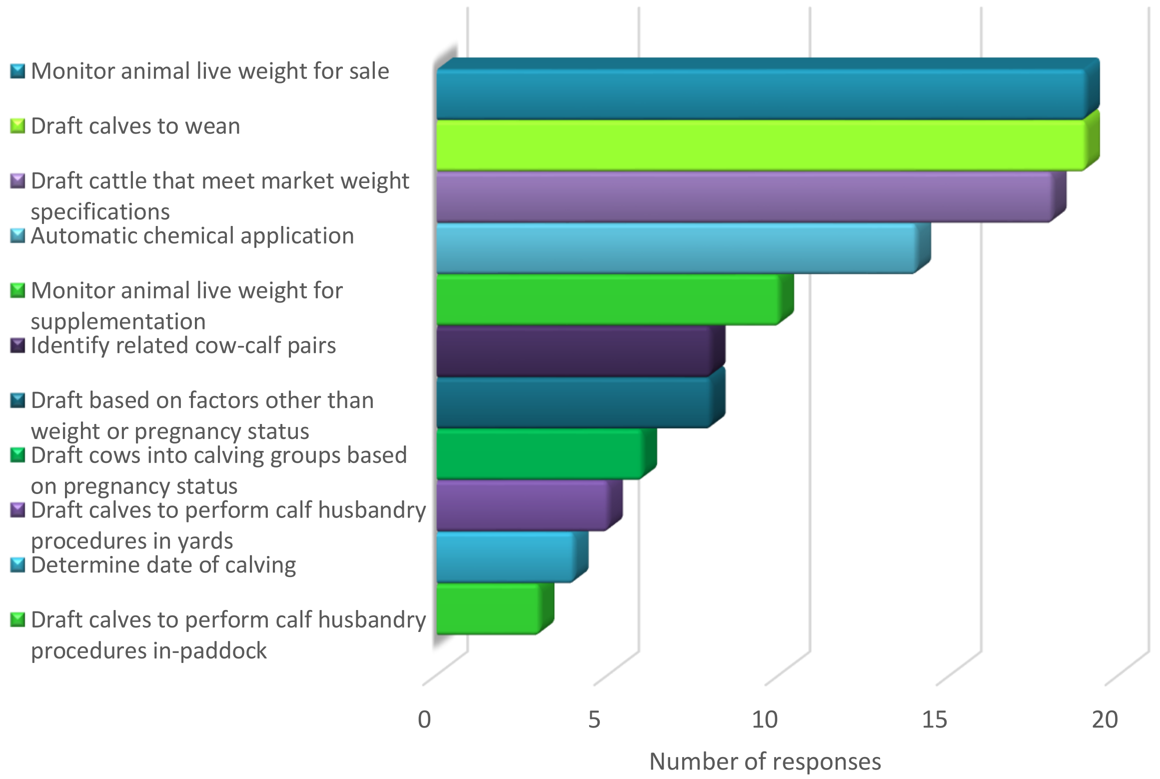


Fig. 35. Top three perceived benefits of installing auto-drafting as reported by survey respondents (n = 42)

Barriers

Cost was the greatest perceived barrier to installing auto-drafting (n = 27), followed by paddocks having more than one watering point (n = 23, Fig. 36). The labour required to move the units between paddocks was also frequently listed as a barrier (n = 14). Issues with flooding (n = 1) and mobs being too large (n = 2) were less of an issue for respondents.

Ten respondents provided additional information to potential barriers on their property, with the main issue listed being the additional infrastructure required to confine, load and transport calves from the paddock. One producer stated that mustering the calves' on-foot away from the compound would be impossible, as the calves would not freely walk away from their mothers. One respondent was concerned about the robustness of the system, especially for cattle with 'wild' temperaments that are not used to infrastructure or handling; they suggested an additional spear gate system to slow animals down as they entered and exited the ALMS might be beneficial.

The issues of cost and more than one watering point were re-iterated as well as some producers that rotationally graze their cattle, with rotations ranging from 45 to 120 days, with a separate watering point in each of the 12 paddocks, thus it would not be feasible to have that many auto-drafting units. Two respondents mentioned welfare issues of separating calves from cows in-paddock, stating wild dogs as a problem in their area and the drafting pen would need to be dog-proof if the mothers were unable to protect their calves. The issue of delaying cattle access to water while they were being trained to use the system was raised, as well as animals blocking access to the system and preventing others from entering; both of which have welfare and productivity implications. One respondent mentioned issues with using virtual data storage to operate an auto-drafting system, stating they would still continue to use their current management system if that was a requirement of any new technology.

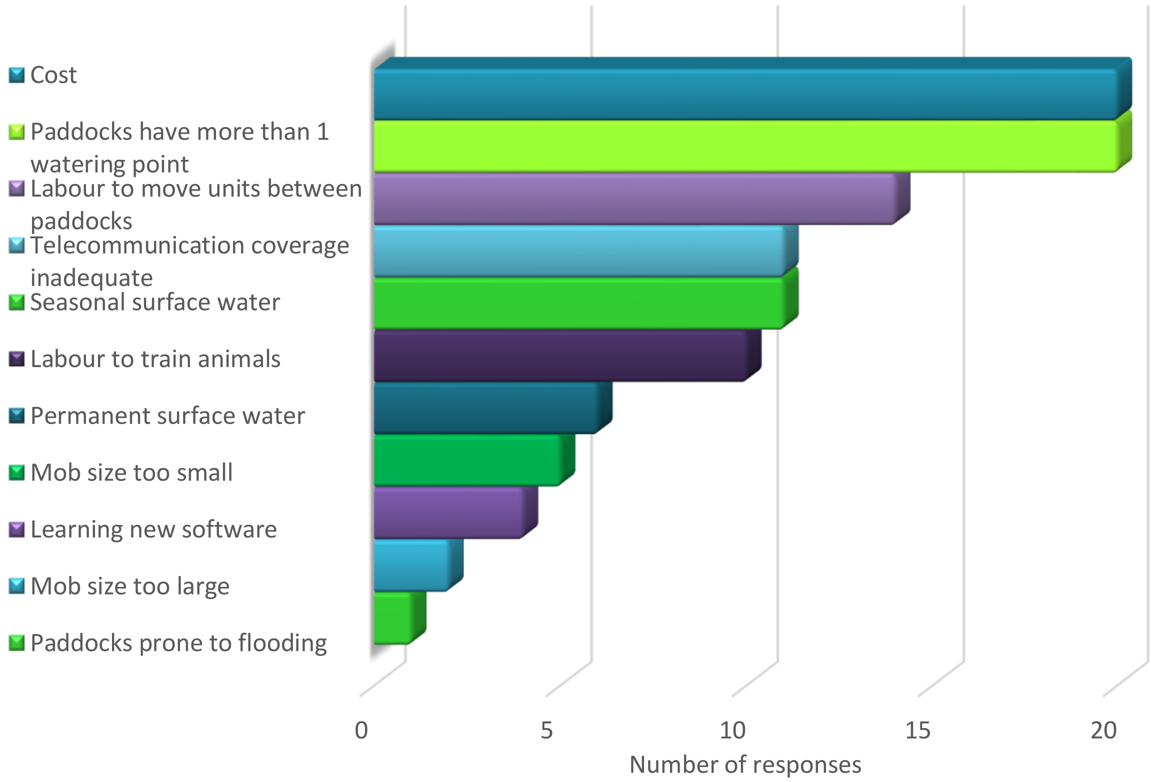


Fig. 36. Top three perceived barriers of installing auto-drafting on-property as reported by survey respondents (n = 42)

Desired auto-drafting features

Respondents were invited to describe what a perfect automated calf management system would look like for their beef cattle operation, with 35 respondents providing additional comments. Nine stated they wouldn't change anything about the CQU DataMuster designed system, with respondents commenting "This system sounds ideal!" and "The above looks good". Four respondents did not add any suggestions for an automated calf management system, while one respondent simply stated, "What I've got now". While only one respondent made this comment, there is anecdotal evidence to suggest that many producers are satisfied with their current management and practices. Three respondents said they would like to see a similar design but at a cheaper cost while two respondents stated the system would be much more practical if additional watering points was not an impediment to its operation. Research scientists at CQU are currently conducting studies to investigate the effectiveness of supplement to attract cattle into an ALMS compound when cattle have access to more than one watering source. These results will help progress towards developing a solution for paddocks with surface water or more than one watering point.

The remaining suggestions put forward by respondents could be classed as either a design feature or an application of auto-drafting that would benefit their operation the most (Table 12). Four of the design suggestions are either already included or could easily be incorporated, such as a separate pen to draft off cattle, a loading ramp and facilities to brand calves, which would only require additional infrastructure to be added to the existing compound. One respondent proposed an integrated animal monitoring system that includes rumination monitoring, oestrous detection and calving detection. This information would provide producers with detailed information on individual cattle to determine their productivity and welfare status, which could be used to make informed management decisions. The technology to record this information already exists, the next action would be to develop an integrated system where this information could be identified by the DataMuster software and translated into user-friendly information for a producer. This suggestion will be possible with future technological developments.

A further suggestion of two respondents was a system that “magically brands, vaccinates and castrates”. This idealistic suggestion would have far reaching benefits for the beef industry, from labour savings to decreased stress on animals during handling, however, it would require the development and integration of robotic technology. As mentioned earlier, to ensure animal welfare is upheld, technology should not replace human observation and monitoring, and until proven possible, handling and procedures.

Many of the application suggestions were reiterated from earlier responses, such as separating steers ready for sale, drafting animals onto dietary supplementations and drafting calves to wean. In relation to drafting, one respondent stated they would like to automatically draft male from female calves. This is possible if animal sex is entered into the DataMuster system at branding to then separate calves in-paddock at weaning. Other applications related to obtaining greater information on their herd’s productivity, such as calculating calving percent, identifying non-performing mothers and determining productivity differences between breeds. These applications are currently possible using manually collected data during yarding events. Further developments are needed to identify this information automatically.

Table 12. Auto-drafting design features and applications sought by respondents

Auto-drafting feature	Respondent’s suggestions (number of responses)
Design	Loading ramp (n=2)
	Separate yard for weaners/drafted cattle (n=2)
	Infrastructure to brand, process and load separated cattle (n=1)
	Permanent and remotely programmable (n=1)
	Entry and exit spear gate system to slow animals down (n=1)
	Integrated animal monitoring system including rumination, heat and calving detection (n=1)
	Automatically brand, vaccinate and castrate (n=2)
Application	Separate cattle that meet a target weight for sale (n=3)
	Draft calves for weaning when they reach a certain age/weight (n=2)
	Separate male from female calves (n=1)
	Draft onto supplement (n=1)
	Determine the productivity of different breeds (n=1)
	Calculate calving % and identify non-performing mothers (n=1)

7.4 Conclusions

The survey provided a valuable method of collecting data on a range of beef producers. The general calf management statistics provides essential data to inform future calf management research and knowledge on current industry practice. The majority of respondents used either a smart phone, computer and/or an electronic NLIS ear tag reader. These technologies are the basic devices used to monitor and manage an ALMS, thus identifying that extension programs need focus on the specific details of learning a new software rather than beginning with basic technology skills.

The general trend is for calves to be mustered twice, one to brand then a second muster to wean, with calves weaned at an approximate 250 kg or at 6 months of age. Calf age and weight were major determinants of when calves were ready to be weaned, along with cow condition. These factors indicate there is a great benefit in using any form of body weight tracking to identify both cow and calf condition, while using the ALMS to determine calf birth date allows a weaning date to be more specific for individual calves.

The interview phase provided in-depth responses to each of the questions that was not obtained during the survey, however, the survey responses confirmed the main results identified in the interview phase. The 61 survey respondents reported similar benefits and barriers to installing auto-drafting on their property, with the main benefits relating to automatically drafting calves to wean and monitoring animal body weight to identify cattle that meet market weight specifications. Cost, additional paddock water sources and labour were stated as the greatest barriers. Neither survey respondents nor interview respondents could see benefit in drafting calves to perform in-paddock husbandry procedures.

There were no direct welfare benefits mentioned by survey respondents, with some actually stating issues where welfare could be compromised, such as delaying access to water and exposing drafted calves to wild dog threats. These issues need to be considered in any future auto-drafting research. The majority of producers were satisfied with their calf husbandry practices with respect to animal welfare, however, they expected society to perceive welfare practices at a lesser standard than their own assessment. This question requires further investigation, both from producer and society perspectives, to determine why the perceived mismatch exists and develop strategies to mitigate these differences. Automated monitoring technology poses great benefit for animal welfare from both a producer and society perspective. Future research needs to consider both productivity and welfare implications from the range of auto-drafting applications proposed.

Overall, almost 60% of survey respondents were interested in installing auto-drafting on their property. This rate was not as great as those interviewed, however, the larger number of respondents provides a more representative value. Given that most respondents only had little or some knowledge on auto-drafting, it would be difficult to determine how beneficial a system would be without having more detailed information. This result highlights that extension strategies need to be developed to inform producers about the technology and current research projects, so they have the knowledge to fully assess the benefits and barriers for their own production system. This will also allow producer input into future research and development.

Many automated calf management design ideas suggested by respondents were similar to the system already implemented, thus highlighting the need for greater communication between research and industry. Other ideas, such as integrating rumination monitors and oestrous detection, are worthy suggestions of future research areas, as are the many varied applications of auto-drafting listed. To date, the supplementation study is the first study to investigate the effectiveness of auto-drafting for productivity; the calf separation trial was a proof-of-concept study to evaluate the infrastructure. Industry stakeholders have stated their interest in the technology and the areas they see greatest benefit, which should now be seriously considered when deciding on future research applications. Conducting robust, detailed studies of auto-drafting applications will provide industry with the evidence they need to make an informed decision about adopting the technology, in combination with a detailed cost: benefit analysis for each application.

8 Evaluation of the operational auto-drafting technology – survey

8.1 Introduction

Engaging with producers to understand their attitudes and perceptions towards ALMS technologies is beneficial to inform research refinements and direction. Building collaborative networks with producers also improves the associations between research and industry, which may assist with increasing uptake of ALMS technologies through partnerships that validate and prove commercial benefits.

In the previous two sections, there was information from producers about their current cattle management practices and the perceived benefits and barriers of installing auto-drafting on their property. These studies relied on producers having existing knowledge of auto-drafting or learning about the details of the technology prior to completing the interview or survey. For many people viewing technology in action provides greater context than watching videos or reading detailed descriptions, and is a proven form of encouraging the adoption of new technologies (Cheffins and Hirst 1990).

A technology demonstration was organised for participants to evaluate the auto-drafting technology in action. This demonstration was combined into a general technology showcase field day provided by CQU, where ALMS technology and other animal sensing technologies were demonstrated to participants. The aim of the field day was to inform producers about the research conducted at CQU and build collaborative networks, with a specific focus on attendees serving as a proxy for industry's evaluation of the auto-drafting technology.

Recording the attendee's feedback on the auto-drafting technology demonstration is an essential component of implementing a producer informed research approach. Attendee responses will build on information recorded during the interview and survey process; by actively viewing the technology, beef producer attendees can gain a greater context for how it could be used on-property, as well as identifying the features that were viewed positively as well as those that were viewed negatively. This feedback will also help gauge the effectiveness of hosting demonstrations to increase industry's interest in ALMS technology, which will further help technology refinements to promote adoption.

8.2 Methods

8.2.1 Belmont Beef Research and Technology Field Day

The field day was held at Belmont Research Station, a 3,260 ha property located 37 kms north of Rockhampton, on Wednesday 29 May 2019. Members of the general public, service providers and producers were invited to the field day in addition to the interview and survey respondents. Email distribution lists and social media sites were used to advertise the event.

Attendees were provided with background information on the establishment of CQUniversity's Precision Livestock Management's research group, their structure and partnerships that facilitate the research, including AgForce, Belmont Research Station and Maynard Cattle Company. Attendees then rotated through four different technology demonstration sites, being:

- DataMuster electronics to record animal’s entering and exiting the property at a loading ramp;
- Animal based sensors to address calf loss;
- Environmental sensors to record water use, water quality and riparian zone management; and
- Auto-drafting for productivity, genetics and improved welfare.

Attendees of the auto-drafting demonstration were asked to provide their contact details if they were willing to provide feedback on the technology.

8.2.2 Auto-drafting demonstration evaluation survey

A link to an online survey was emailed to willing attendees on the 7 June 2019 and a reminder sent on the 19 June 2019. The survey consisted of eight questions, asking attendees about their overall view of the technology, the features they liked and disliked and their interest in installing the technology on their property (if applicable). The evaluation survey was approved by the CQUniversity Human Research Ethics Committee, approval number 21587.

The data were hosted by Survey Monkey, where the results were collated within the online survey platform and downloaded as an Excel spreadsheet. Quantitative data are presented as a percent of all respondents, while qualitative data collected from open-ended questions were summarised using a thematic analysis and similar themes were grouped to present results as a percent of all respondents.

8.3 Results and discussion

There were approximately 31 non-CQUniversity participants at the auto-drafting demonstration. Seventeen attendees provided their contact details to complete an evaluation survey, with ten of those actually completed the survey.

8.3.1 Potential on-farm applications

Respondents identified recording body weight data to inform management decisions as most beneficial applications of auto-drafting to their production system, such as identifying when market specifications have been met and when dietary supplementation is required (Fig. 37). Of the benefits related specifically to the ALMS drafting function, 60% of respondents identified that in-paddock drafting for weaning would be beneficial for their production system. Only 10% of respondents (n = 1) saw benefit in drafting calves in-paddock to perform husbandry procedures.

8.3.2 Assessing auto-drafting features

Each of the respondents listed at least one feature they liked and one feature they did not like about the auto-drafting system. The features viewed favourable by respondents were automated weight recording and the flexible and simple set up, while issues with the infrastructure design, including bulkiness and the slow gate closing mechanism, cost and training required to familiarise cattle to use the system confidently were the main features respondents did not like (Fig. 38).

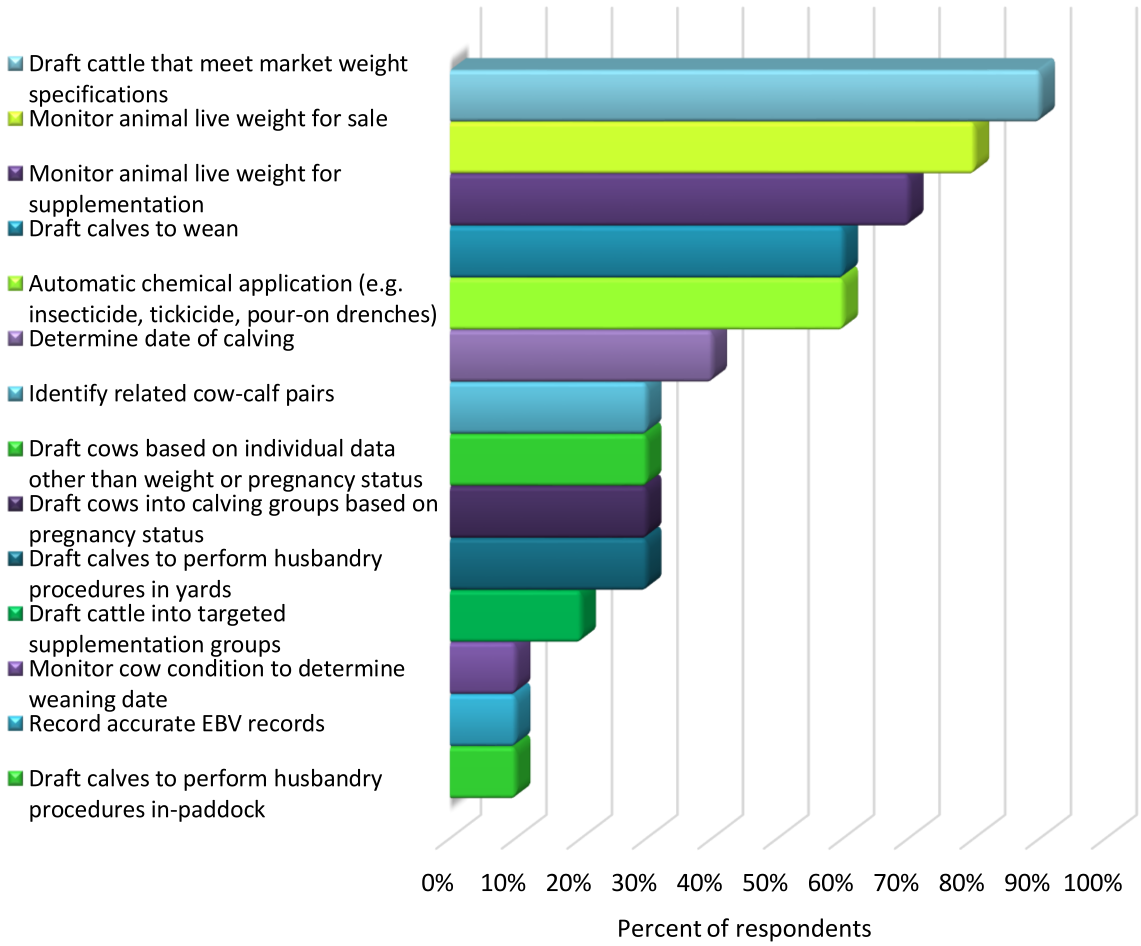
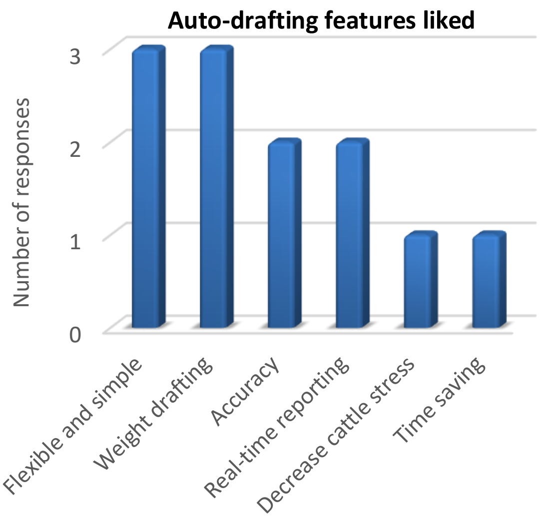


Fig. 37. Proportion of respondents that identified on-farm benefits of the listed potential auto-drafting applications



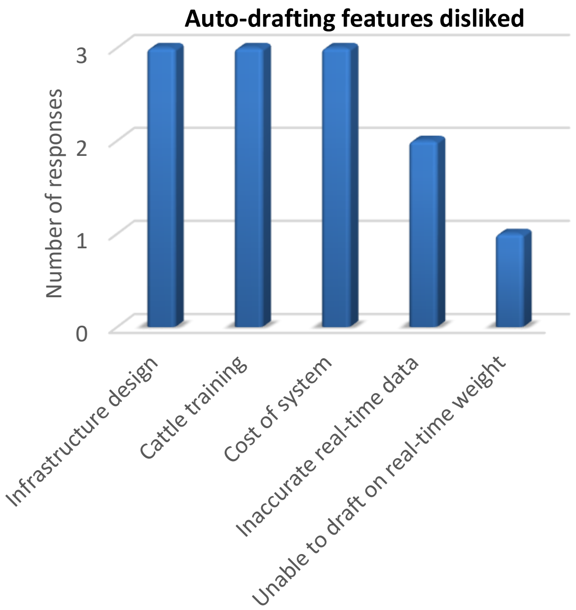


Fig. 38. Left: Number of auto-drafting features liked most by respondents; Right: The number of auto-drafting features disliked by respondents

8.3.3 Field day outcomes

Six respondents (60%) agreed that their interest in installing an auto-drafting system on their property increased after attending the field day. Four respondents (40%) stated their interest in owning a system neither increased nor decreased after the demonstration. All respondents agreed that the field day was a good use of their time and they would attend another field day at Belmont in future.

Survey participants were provided the option to leave comments about the auto-drafting system, or anything related to the field day. Positive feedback was received in relation to the technology and the day in general, with one respondent stating, “A great opportunity to bring industry and researchers together – hope more producers utilise it in the future” and another “The auto-drafter is certainly a real potential for the industry.” This comment was followed by a request to demonstrate the system on a commercial scale using larger number of animals and providing evidence of the results. The ALMS without auto-drafting has been tested on mobs of up to 300 cattle, yet further refinements are needed to optimise the auto-drafter. Using smaller groups of cattle during the research and development phase allows refinements to be implemented quickly whilst minimising the number of animals that are impacted by the changes, for example, cattle may experience low level stress while adapting to a change in the ALMS design, thus using small groups during this phase reduces the amount of cattle that are impacted until a final design has been decided. It is anticipated that with further testing and refinements during the next breeding season, the technology will be ready to be rolled out on commercial properties with larger numbers of cattle the following year.

Additional comments were received about the cost limiting its application on-farm, especially for paddocks with multiple watering points. This is a reality for many producers and highlights the need for a detailed cost: benefit analysis to determine the rate of returns with varying numbers of units on a variety of operating systems. It is envisaged that producers would still return gains from having just one unit strategically located on their property, for example, if they chose to feed supplement calves prior to weaning or identify individuals ready for market, thus producers could identify the greatest benefit for the unit throughout the year to maximise their investment. Further research is needed however to validate these claims.

Positive comments were also received by non-surveyed attendees following the event, either verbally or via email. These attendees had no previous connection with the research group prior to the field day and questionnaires, thereby highlighting the effectiveness of holding demonstrations to promote interest in technology and build collaborative networks. These findings support the claims by Cheffins and Hirst (1990) on the benefits of holding technology demonstrations.

8.4 Conclusions

The auto-drafting field demonstration provided a great opportunity to inform producers, service providers and those related to research and/or beef production on the practicalities of implementing an auto-drafting system. It also provided the opportunity to share information on the rationale behind research projects and updates on results and outcomes. In particular was the opportunity to gain insight into producer opinions of the system, which for some was the first time they had seen the technology in action. Increasing awareness about the technology and openly presenting both successes and challenges promotes transparency in the research process whilst creating a shared-values model where producer's opinions and ideas are incorporated into future developments; this approach has the potential to initiate transformational change within the industry towards technology adoption. One small step in this process is coordinating future field day demonstrations, with the aim of increasing producer involvement at each event and building researcher-producer network connections.

Similar to the interviews and survey conducted in Sections 6 and 7 of this report, the survey respondents placed greater emphasis on the ALMS unit to provide weight related data to inform management decisions rather than using auto-drafting for calf management. Even less emphasis was placed on using an auto-drafting unit to access calves at a younger age to perform husbandry procedures. These results reflect a focus on productivity driving on-farm investment; while this project aimed to evaluate auto-drafting for calf management, the producer focused aspects have increased awareness about the technology and its potential applications, thereby distributing information within the beef production network that may lead to increased uptake and adoption. Ultimately, any activity that increases awareness about the benefits and challenges of all auto-drafting applications has the potential to raise awareness about the potential benefits the technology can provide for welfare monitoring and improvements.

9 Discussion

This report brought together three primary elements to provide a detailed exploration on auto-drafting technology, by first systematically assessing published evidence of the technology use in the literature; developing, validating and testing a functioning system, and; reporting producer perceptions on potential applications, benefits and barriers of auto-drafting technology on-farm.

The systematic literature identified no previous applications of auto-drafting in beef production, with studies only existing in a dairy context. Several publications exist on other methods of auto-drafting in the form of reports and web-based information, such as the cow-calf separator developed by the Department of Primary Industries (Petherick and Hirst 1996) and Precision Pastoral's automated system, however, neither of these publications are peer reviewed and would not have met the search criteria for the systematic literature review.

Auto-drafting has been used successfully in both the dairy and sheep industries. However, there are many things to consider with any attempt to transfer such technology to an extensive beef production system that varies considerably from the more intensified environments. Such considerations include locations that are remote, have no electricity or reliable communication coverage and cattle that aren't familiar with regular handling. These challenges are just some of the issues that need to be considered when designing a system along with capacity to withstand the harsh environment and be readily used by cattle whilst delivering accurate and timely information.

Developing the infrastructure is a continual cyclic process of trial, evaluation and modification. The CQU developed design started looping through this cycle in 2018 leading up to the commencement of this project. Refinements have been made as a part of this process and the system is now fully integrated to incorporate the DataMuster hub that directly links to the weigh platform and drafting gate. Individual animal weights can be recorded with greater precision than ever before and individual weight profiles of animals stepping on and off the scales allow the complete representation of animal movement to be recorded. It is these advancements that will allow the auto-drafting function to be refined with greater accuracy and sensitivity to the location of the animal on the platform without visual imagery.

While the drafting algorithm used in the study by Corbet *et al.* (2019b) effectively drafted the majority of heifers with very few mis-drafts (99.9% accuracy), the same algorithm used in the calf separation study did not result in the same efficiency with just 83% of calves successfully drafted when mustered through the system. Various factors contribute to this lesser rate of success than that of Corbet *et al.* (2019b). Primarily the hesitation of calves to use the system and the need to muster them to the compound rather than allowing them to enter at their own pace. Changing the algorithm so the gate would close behind the animal in front increased the calf drafting efficiency. However, this also led to cows being mis-drafted and caused those that were experienced with the system to become nervous and hesitant. The second algorithm has potential however, further refinements are needed. Principally, to make the infrastructure more seamless and flexible. Changing the pneumatic gate to an electric gate for example, will allow greater control over the speed at which it opens and closes. Thus reducing the amount of noise and sudden movement that was shown to cause the cattle to baulk.

The two separate animal trials showed variation in animal behaviour toward the ALMS system. The older cows used the system seamlessly, albeit many had used the system for several years beforehand. Training the weaners in the study by Corbet *et al.* (2019a) took longer than planned and four animals were removed due to their hesitancy to use the system. However, once these animals were removed usage was 100%. The calves took the longest to train and their level of independent use was disappointing despite having observed their mothers use the system without issue. It may be that the younger the animal the more effort is required to accustom them to an ALMS and that further incentives, other than water are required. . However, a training phase outside of the compound will still be required to ensure they are willing to enter the ALMS to access the alternate attractant.

Previous research (Dickinson *et al.* 2013; Menzies *et al.* 2018b) and experience has shown that proper training leads to increased weight and data recording accuracy. The calmer the animals are as they enter the ALMS system and while passing the RFID reader and traversing the weigh scales, the more precisely they can be identified, weighed and drafted. Future modifications could include a spear gate system at the entrance to the ALMS to slow the animal's transit and prevent more than one accessing the system at any given time. The effectiveness of this will need to be tested but may provide an alternative approach for cattle with nervous temperaments that continue to rush through the system despite sufficient training. More research is needed to determine the most effective training methods for different classes of cattle. This information is essential for industry to evaluate the ability of an ALMS to adapt for each unique operation and to understand the post-purchase requirements so that the benefits from investment might be maximised.

Interacting with industry via interviews, surveys and the field day provided valuable information not previously collected on industry's views of auto-drafting. A large proportion of industry saw great benefit in auto-drafting technology, with almost 60% of those surveyed interested in installing a system on their property. While many producers had only some or little knowledge on auto-drafting, those that viewed the demonstration stated their interest had increased after seeing it in action and interacting with researchers. Whether or not these producers adopt the technology, the project was successful in distributing information on auto-drafting and interacting with producers that can be used to inform future research and progress towards a shared-values research model with greater interaction between producers and researchers.

Producers saw great benefit in using auto-drafting to monitor animal body weight to inform decisions, such as to identify when cattle were ready for sale or to provide dietary supplementations. They also saw great benefit in drafting calves from cows when they were ready to wean. Producers stated the time of weaning was based on cow and/or calf weight, thus ALMS can provide precise information to determine when animals have met these criteria. Cost and issues with multiple water sources were the greatest barriers reported. As a full cost: benefit analysis of auto-drafting has not been completed, it is difficult for many producers to comprehend the economic value a unit might contribute to their business. A study completed by Swain *et al.* (2013) interviewed five case-study properties on the likely benefits of a range of automated management technologies, including an integrated WoW and auto-drafting unit. Three properties estimated between 7.5% to 14.5% reduction in mustering costs by automatically drafting cattle in-paddock, as well as a 7% to 17.5% saving in labour costs. These estimates provide an early indication of the potential on-farm benefits. However, further detailed analyses are required to identify the real value of different auto-drafting applications, both individually and in-combination. Ultimately, auto-drafting technology is not likely to be applicable for all, especially given the varied locations, landscapes and management styles employed by each property. However, with appropriate research there is potential to develop a system that meets the needs of the majority of the industry.

An ALMS is not a plug-and-play off the shelf product. Implementing the system on-farm requires great investment of time and effort, both in the short and long term. Users will need to be aware of the requirements at each phase and have access to the support needed to assist them during each of these phases. Evidence from the adoption of other technology suggests offering full support for purchases of new technology such as providing education, training and one-on-one sessions, increases uptake by 35% compared to users with access to only basic support, such as answering any service related queries (Retana *et al.* 2018). Retana *et al.* (2018) also suggests that users who decrease their level of support after an initial implementation phase continue to use the product 15% more than users with basic support. The results of this study highlight the benefits in providing comprehensive assistance, especially during the initiation phase. A large proportion of technology adoption occurs from information distributed through farmer support networks (i.e. neighbours, service providers). These support networks have different structures to those of typical organisational support networks due to the distribution and relative independence of each farming business. Tending instead to be characterised by key individual influencers who will interact both with other producers and agricultural service providers (Oreszczyn *et al.* 2010). Thus, providing full support services to early adopters in particular will help catalyse the spread of adoption throughout industry, whilst also strengthening producer-researcher relationships to inform future research.

Conducting the interviews and hosting the field day were not only beneficial for the attendees but were equally beneficial for the researchers. The aim of all research conducted within the Precision Livestock Management team at CQU is to develop technology solutions that will benefit industry, ranging from improving labour efficiency, recording data to improve management and productivity, as well as improving welfare outcomes. The research is therefore, intertwined with current and future farming practices. It has been demonstrated that the greatest benefits for industry and research occurs when producers and researchers work alongside each other. This is evidenced by a study correlating producer visits to a research facility and publications (Swain 2017) as well as other research where producers have been included within the research, rather than simply being the subject of the research (Stirling 2006). This approach builds trust in the outcomes and provides in-depth knowledge on producer views. The investment in this style of research limits the number of participants .However, it allows for detailed data to be recorded with wider applications (Oreszczyn *et al.* 2010). This was reflected in the current study where the in-depth interviews provided a richer understanding of producer views than the survey. While the survey confirmed the validity of these results with respect to the wider community. It is envisaged that a shared-values research model, where producers inform research direction and evaluation outcomes, will lead to great advancements in technology development and adoption. With this project, there has been progress towards initiating collaborative partnerships between research and industry. Future projects and activities need to focus on growing and developing new relationships to achieve the shared values vision that will lead to wide-ranging benefits for all.

9.1 Future research

This proof-of-concept study demonstrated that auto-drafting technology can operate successfully in extensive beef production. There is scope to improve the design of the infrastructure and to also evaluate various applications. The following section describes suggested areas of research to provide industry with a comprehensive evaluation of the technology and the costs and benefits of implementation:

- Providing a more attractive enticement for calves to use the ALMS. Water was not a strong attractant, especially when calves had access to milk from their mothers. Providing a supplement such as a mineral lick or molasses may be potential options. However, training will also be required to accustom the calves to the supplement. While cows and calves were provided with lucerne hay during auto-drafting training events many calves were hesitant to eat the hay as it was unfamiliar to them. The extra enticement, however, did increase cow use and confidence in using system. It is suggested therefore that the attractant be introduced outside of the ALMS compound for a period of time until all calves are familiar with it before offering it exclusively inside the compound in combination with further training.
- Provide an alternative entry to the ALMS compound using creep gates, similar to the calf separator design. This would provide a system where the calves could bypass the ALMS and enter an opening at the entrance to the ALMS that the calves but not cows could access as their mothers enter the ALMS. A producer could trap the cows by closing the exit spears the evening before and close the creep gates when they arrive the next day. It would be expected that the majority of calves would be in the yards with the cows. This design would require further testing to determine the efficiency of such a system and training would be needed to familiarise the calves to the creep gates. Having calves by-pass the ALMS means their weight and frequency statistics would not be recorded and thus, it would be difficult to obtain data on calf growth patterns or maternal parentage derived from ALMS sequential data. It would also prolong training if the calves were to experience ALMS's in the future. However, this would not be a concern for many production systems where calves are not kept as replacements.
- Initiating the drafting gate caused many cows and calves to baulk at the infrastructure because the swinging gate and compressor created noise and movement that many cattle were fearful of. Changing the pneumatic gate to an electric system may make the gate swing more smoothly and provide more control over the speed at which the gate stops. With a pneumatic gate there is no option to control the timing of when the gate stops. However, this could be achieved with a programmable electric system to stop the gate before it makes contact with the metal frame therefore, decreasing the noise and motion made by the gate opening and closing.
- Further developments can be made to the gate closing algorithm to draft off untagged animals. The second algorithm worked well for cows that used the system confidently. With increased training and modifications to the infrastructure previously described in this report, this algorithm has potential for successful use.
- Other methods of identifying calves as they enter the ALMS to make drafting decisions in real-time are possible. For example, image analysis to discriminate calves from cows. Further technological developments are required to implement and test these possibilities including

ensuring the system can process the required information in enough time to make a drafting decision, operating within the available battery restrictions and transmitting data within the necessary size limits.

- It should be emphasised that remote animal monitoring technologies such as paddock-based ALMS units, should not replace human observation, but are instead designed to complement and assist management decisions to improve efficiency whilst providing labour saving benefits. Guidelines need to be developed to ensure the welfare of cattle separated by auto-drafting into an enclosed pen are managed appropriately.
- Reporting both producer and society's views on the animal welfare of calf husbandry practices and cattle production systems in general are needed to confirm why society is perceived to have lower satisfaction of animal welfare on-farm and how technology use can influence these perceptions.
- Investigating the effects of social networks on technology adoption in the extensive beef industry. Understanding where producers receive information on new technologies and the factors that influence their adoption will help to identify areas for potential investment. This might include producer-led research, shared values models and extension programs. This information will also inform after sales service programs to understand what type of program to develop and the level of support required.

9.2 Success in meeting project objectives

A short summary of how each of the project objectives have been met is detailed below:

1. *Develop a practical on-farm auto-drafting system to facilitate the adoption of earlier calf husbandry practices by remotely segregating untagged calves from the herd whilst in their paddock environment.*

Conducting this project was the first attempt to automatically draft calves from cows in-paddock. The project had varying degrees of success in automatically separating calves from cows with the greatest achievement being automatic separation of 83% of the calves from cows by manually mustering the herd to the ALMS compound. Issues with training calves to use the ALMS prevented further developments towards automatically drafting calves without an NLIS tag. There needs to be future refinements with of the software and infrastructure including the gate closing mechanism and associated algorithms. In addition, investigating different methods to improve calf training efficiency will further progress towards a fully automated system.

As a result of the literature review detailed in Section 3 of this report, it was discovered that there were no published studies reporting auto-drafting applications in beef, nor were there any published research using ALMS technologies to record welfare. This project is therefore, among the first of its kind and it is not surprising that issues such as refinements to infrastructure and improving calf training efficiency, affected progress toward completing this project.

As a result of conducting this project however, a detailed approach has been established to describe the infrastructure, software, auto-drafting validation and cow/calf separation study which has not previously been reported. The success of automatically separating cows from calves in-paddock following manually mustering of the herd to the ALMS compound may be a sufficient advantage compared with traditional methods for many producers wanting to implement paddock-based weaning or associated applications. Such applications might include dietary supplementation as ascertained in the study by Corbet *et al.* (2019b) or separating cattle based on weight. Many cattle are mustered tens of kilometres to yards, held off feed and water during processing then walked back to a paddock, which has various welfare and productivity implications. Mustering to a single point in a paddock can alleviate some of these issues.

The results obtained in this proof-of-concept study provide confidence that automated drafting can be implemented in remote locations. It paves the way for more detailed studies focussed on investigating the refinements identified in this study and should be followed by a cost: benefit analysis of the technology for various management applications including health and welfare monitoring and management.

2. *Produce a systematic literature review to assess the use of ALMS in validating animal welfare parameters against national standards.*

A systematic literature review was conducted to evaluate the use of automated livestock management systems (ALMS) to record animal welfare parameters and submitted as Milestone 2 on 30 October 2018. The review focussed on technologies relevant to commercial beef cattle production, including auto-drafting, proximity loggers, radio frequency identification (RFID), Taggle locating devices and walk-over-weighing. A total of 65 peer-reviewed articles reporting on 68 separate studies published after the year 2000 were reviewed. In very few studies were direct welfare implications from the research reported. However, the results from the review has identified the potential for these technologies to record welfare parameters using the five domains of animal welfare model proposed by (Mellor 2017). Application of multiple sensors has the greatest potential for technology to record behavioural indicators of animal welfare in all five domains.

3. *Develop a remote calf segregation system using auto-drafting to improve welfare surveillance and herd management practices. This includes finding the most appropriate method to identify calves that are not tagged with NLIS.*

The developed system was successful in automatically drafting calves from cow's in-paddock with the assistance of manually mustering animals to the ALMS compound. This project was a proof-of-concept study to determine the practicalities of applying and developing the infrastructure and to evaluate an auto-drafting system.

Results of this study indicated there is great potential for the auto-drafting system to provide productivity and welfare benefits for current beef production systems through both the evaluation of technology and producer informed research. Productivity related outcomes were commonly reported by producers when asked to consider the benefits of installing auto-drafting on their property. Welfare benefits were less frequently identified as a priority, however, many productivity and health related data obtained from an ALMS have equal welfare connotations that could be extrapolated from the results. For example, live weight monitoring of individual cattle not only allows producers to identify when cattle have reached target market specifications, but also allows causes of weight loss or slower than expected weight gain, such as decreasing pasture availability or illness, to be investigated.. There are many other applications where ALMS data could be used to assist management decisions and individual animal monitoring. However, detailed studies in controlled research conditions as well as commercial scale studies are required to explore the full benefits and practicalities of these.

There are still advancements to be made to develop a completely automated paddock-based calf separating system for untagged calves and further applications as identified by industry should be considered for future research investment. Many producers see benefit in the system for automated weaning but would, still muster for branding. Depending on the eventual design, these producers may therefore view accuracy of drafting a greater priority than drafting untagged animals.

Adoption by industry will result from producers having confidence in the technology they are purchasing. Confidence built as a result of rigorous studies and detailed economic evaluation/information. Developing a producer-informed model, where producers are partners in the research, will help progress towards delivering research outcomes that are relevant to industry and promote the distribution of information throughout the producer network. This approach encourages transparency with the research-extension-adoption process, thereby providing industry stakeholders with the information they need to make informed decisions about the technology they are adopting, thus resulting in efficient implementation under various commercial settings.

4. *Conduct focus groups to obtain information on current husbandry practices and challenges with calf welfare to inform research findings, and the evaluation of the drafting system once operational.*

Due to issues with recruiting enough local producers to form a focus group, the project instead conducted in depth interviews with seven producers, followed by a survey of 61 beef producers and a field day and technology demonstration that attracted 31 people. The resultant industry engagement activities, therefore, had a greater reach than a smaller producer focus group.

The interviews provided in-depth information on current calf management practices and the benefits and barriers of installing auto-drafting on-farm. These results were used to design the survey, with the results of both interviews and survey validating each other. Most producers saw benefit in drafting calves to be weaned and monitoring animal body weight to draft a deck load of cattle that met market specifications. The cost of the system and issues with more than one watering point per paddock were identified as the greatest barriers. These relate to factors external to the design of the system. Overall, almost 60% of survey respondents were interested in installing an auto-drafting system on their property.

The field day was structured on a similar format to those used for previous Beef Australia's Belmont property tour, allowing attendees the opportunity to see a variety of CQU's beef research technologies in action. The auto-drafting demonstration successfully demonstrated the technology to attendees using a small group of trained heifers, whilst informing them on research progress. It also provided an opportunity for researchers and industry to discuss ideas for research into auto-drafting applications. Sixty percent of surveyed attendees stated that their interest in purchasing a system had increased after viewing the demonstration. The success of the event and feedback from attendees has encouraged CQU to make the field day an annual event.

5. *Produce a progress report detailing the outcomes of the focus groups and the installation and initial performance of the auto-drafting system.*

A progress report was submitted on the 21 December 2018. This report detailed the methodology and progress achieved towards developing an auto-drafting system to separate calves from cows in-paddock in each of the three project phases, being: (i) understanding current calf husbandry practices in extensive beef production, (ii) validating the auto-drafting technology to successfully draft targeted individuals, and (iii) developing a calf segregation system to automatically draft untagged calves from the rest of the herd.

At the time of submitting the milestone report, there had been considerable progress: almost 70% of producer interviews conducted and background information on calf behaviour towards the ALMS had continuously been recorded since the cows commenced calving in September. These data were in the process of being analysed to use in combination with the results from the validation study to refine the calf separation trial. The remaining 6 months of the project involved testing various calf segregation options, with the final design demonstrated on-site to a group of producers and their feedback was recorded.

6. *Produce a final report detailing the refinement of the auto-drafting technology, findings of the field study, as well as the findings of the focus group, fully evaluating the refined paddock-based auto-drafting system.*

The final report provides a summary of each of the three main phases, with these being: the systematic literature review; auto-drafting infrastructure design, development and testing to separate calves from cows in-paddock, and; report on producer views on current calf management practices, perceptions of auto-drafting and an evaluation of the operational auto-drafting system.

10 Conclusions

This study was the first component of evaluating the potential for an auto-drafting system to operate within an extensive beef production system. The proof-of-concept phase identified great potential for the system to successfully operate in remote locations and effectively draft 83% of calves from cows. Producers can see great benefit in the technology to improve the way animals are monitored and managed. However, they also identified various barriers that need to be overcome for the wider industry to be able to obtain benefits worth the investment. Interacting with producers was an essential element of conducting a comprehensive evaluation of the technology and this needs to be continued in future.

The outcomes of this study provide evidence that industry are interested in seeing auto-drafting technology developed further. Modifications to infrastructure and further trials evaluating the costs and benefits of the technology for various management and productivity applications are required. Information on individual animal live weight to inform management decisions (i.e. draft animals that reach market specification, access to supplement) was one of the greatest benefits identified by study participants, as well as automatically drafting calves to wean. Few producers saw benefit in drafting calves to perform calf husbandry procedures in paddock. Focusing future research efforts on the applications seen by producers to provide the greatest benefits will provide industry with the information it needs to make decisions about ongoing investment in developing this technology. Successfully implementing the technology to achieve these applications will provide scope to later invest in more unconventional applications, such as in-paddock husbandry procedures.

The following describes the main outcomes of the study:

- A systematic literature review revealed few studies exist using ALMS technologies to infer welfare state in extensively managed beef cattle.
- ALMS technologies have great potential to monitor animal well-being with respect to nutrition, environment, health and behaviour.
- An auto-drafting system successfully drafted 99.9% of heifers into a pen containing dietary supplement.
- Training young cattle to use the ALMS took longer than expected. It is suggested that the younger the animal the more training effort is required with calves not learning to use the system by observing their mothers, and as such ALMS use did not reach 100% for calves.
- In the calf separation study, 83% of calves were successfully drafted into a pen separate to their mothers. There were no cow mis-drafts.
- Modifications to reduce the noise and movement of the drafting gate will likely lead to improvements in cattle use.
- Producer involvement occurred via one-on-one interviews, an online survey and an auto-drafting demonstration held during a field day.
- Almost 60% of surveyed producers were interested in installing auto-drafting, and six of ten producers reported their interest had increased in installing a system after observing the demonstration.

- Producers stated body weight monitoring for management decisions, such as identifying cattle ready for market and supplementation and automatically drafting calves to be weaned were the greatest perceived benefits.
- Cost and multiple watering sources within a paddock were perceived as the greatest barriers to installing auto-drafting.
- Collaborative networks between researchers and producers were established, promoting a shared-values research model where researchers and producers work together to develop industry relevant technology.

11 Key messages

The results from this proof-of-concept study indicate there is considerable potential for the auto-drafting technology to benefit calf management practices in extensive beef production, particularly related to weaning. The system provided an automated way of separating calves from cows in-paddock with 83% accuracy when cows were mustered to the compound containing the auto-drafting infrastructure.

Producer engagement activities with 78 producers reported their perspectives on auto-drafting, with respondents reporting potential on-farm benefits relating to automated weaning, monitoring cattle body weight and identifying when cattle have met market weight specifications. Producers also reported cost and multiple watering points in paddocks as the greatest barrier to adoption. Further studies are needed to conduct a cost: benefit analysis of using auto-drafting to improve calf management practices to allow producers to make more informed decisions about the overall value of the technology for their operation.

Other potential applications of auto-drafting were reported by producers as being beneficial to their operations including automated chemical applications and drafting individuals based on set criteria, such as body weight or pregnancy status. Further research is required to assess the accuracy and efficiency of the system for these applications, as well as conducting a detailed economic evaluation. Further research is needed to develop extension programs that inform industry of technological developments and applications as well as post-adoption support services to facilitate successful implementation.

The results of this project provide a great foundation for further industry endeavours using ALMS to monitor and manage cattle herds with greater efficiency and precision than traditional methods whilst increasing animal welfare standards.

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