final report

Project code: P.PSH 0835

Prepared by: Mark Trotter, Amy Cosby, Jaime Manning, Michael Thomson, Tieneke Trotter, Patrick Graz, Elle Fogarty, Alexandra Lobb and Alan Smart
CQUniversity and ACIL Allen

Date published: 3 May 2018

PUBLISHED BY
Meat and Livestock Australia Limited
Locked Bag 1961
NORTH SYDNEY NSW 2059

Demonstrating the value of animal location and behaviour data in the red meat value chain

This is an MLA Donor Company funded project.

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

Abstract

This report brings together the results of several research activities aimed at exploring and uncovering the value that might be derived for graziers if they could remotely monitor the location behaviour and state (LBS) of the animals under their management.

The deployment of sensors on a number of properties provided industry participants with hands on experience with the information that can be provided by LBS systems. These producers reported a range of potential applications and benefits.

On-line surveys and detailed producer interviews explored the potential applications and benefits that graziers might gain from the development of commercial LBS systems. A diverse range of applications were reported. There were a small number of applications that had large value but much of the financial benefit would come about through the cumulative impact of a number of applications with smaller revenue gains and cost savings. The value of non-financial benefits of LBS systems should not be underestimated. Many producers articulated the benefits that would come in terms of “peace of mind” from implementing these systems.

The national economic impact of LBS systems across the red meat sector could be significant, with the benefits from producers involved in the study scaled up across the beef and sheep industries resulting in substantial gains. However, these economic impacts can only be realised if the hardware can be provided at appropriate cost, producers actually adopt the technology and the benefits estimated can be achieved.

Despite significant private sector activity, there is still no system that Australian producers can easily buy off the shelf and implement on an extensive grazing property. Further hardware developments are required by the various technology entities currently in the market to realise this. Unless there is complete market failure, fully publicly funded hardware developments are unnecessary where co-investment schemes remain viable. One exception to this would be the development of research grade hardware which might be shared across the livestock science community to provide recommendations to commercial developers around sensor duty cycling and algorithm development.

Further research could explore the way in which LBS systems might impact on animal welfare and social license as well as biosecurity. More novel ways of obtaining the LBS information through off-animal sensors also warrants investigation. Research into the development of robust and reliable algorithms that turn data from LBS systems into information that producers can make profit driving decisions from is essential.

A key next step will be establishing long term evaluation sites that support the testing of commercial systems along with collecting physical, behavioural and high resolution sensor data to improve sensor design and algorithm development. Collaboration across commercial developers, domain experts and data analysts will be essential.

There is potential for LBS systems to impact positively on the way livestock are managed across the industry and bring significant economic and non-financial value. The challenge will be taking the ideas and concepts developed in this project and turning them into a tangible reality for all graziers.

Executive summary

This report brings together the results of several research activities aimed at exploring and uncovering the value that might be derived for livestock managers if they could remotely monitor the location behaviour and state (LBS) of the animals under their management.

Industry partner sensor deployment, analysis and evaluation

GPS tracking devices were deployed on a small number of animals in larger herds or flocks across seven extensive grazing operations. Five case studies explored the impact in relation to livestock management and two explored value in other parts of the industry. Producer and industry partners collaborated with the research team to analyse the data and convert it into meaningful information which demonstrated how these systems might be used to bring value to these operations.

i. GPS tracking on “Shepherds Hill” Kingston SA demonstrated the potential value of LBS data to improve the understanding of landscape utilisation. The information also began to provide some clues around spatial soil nutrient patterns and how these might provide an opportunity for refined fertiliser application. Analysing the LBS data revealed how patterns of behaviour relating to Phalaris toxicity issues might allow better management of this disease once real-time systems are available.

ii. The deployment of sensors on Australian Country Choices “Brindley Park” Roma Qld revealed individual animal variation in behaviour. Although the number of animals was limited, there appeared to be some relationship between animal behaviour, live-weight gain and carcase characteristics. The trial has resulted in significant interest at ACC in the potential for LBS data to provide more refined management of animals whilst in the backgrounding phase.

iii. Tracking of sheep on “Warialda” Arthur River WA demonstrated changes in behaviour associated with spatial and temporal variability in the feed-base. Objectively measuring this variation may allow better feed-base management to increase live-weight and reduce overgrazing. A more immediate application for LBS data was found in its ability to detect and therefore prevent livestock theft, a significant issue for that region.

iv. The sensor data from “Rosebank” Longreach Qld revealed the watering behaviour of sheep that are vulnerable to perishing. Live LBS systems would provide opportunities for rapid response to prevent losses. The spatial grazing patterns confirmed the need for additional water infrastructure to optimise landscape utilisation.

v. Spatial and temporal variation in individual animal grazing patterns were observed between sheep on “Stonyhurst” near Christchurch in NZ. The GPS data very clearly demonstrated the tendency for sheep to graze the mid slope and camp at the top. Opportunities around site specific fertiliser management and selection of animals for grazing distribution were considered to be possibilities for turning this data into profit making decisions.

vi. In an investigation of how LBS data might impact on the supply chain of animal health products, GPS collars and accelerometer ear tags were deployed on animals involved in a Buffalo Fly chemical ear tag efficacy trial run by Landmark. This leading provider of agricultural products and services was convinced that LBS data will help producers better manage animal health inputs.

vii. The value of LBS data was also explored in the context of animals grazing on Travelling Stock Routes (TSR). The management of TSR's is difficult with competing interests of animal managers, the sustainability of the landscape and animal welfare difficult to balance. The deployment demonstrated the value that could be obtained from these systems and has inspired further investment in the technology.

Across all the case studies a number of key applications were commonly reported with the understanding of long term spatial landscape utilisation considered universally valuable. Other applications of potential value involved the detection of important animal health and behaviour issues.

Each industry participant had unique issues that they considered important and for which they considered a live LBS system could provide alerts from which they could derive financial benefit. Producers also articulated the potential non-financial value around "peace-of-mind" which LBS systems might provide them. The value of LBS systems to provide an impact into social perceptions of animal welfare was also commonly reported.

Understanding the value of location, behaviour and state information

Online surveys and in-depth producer interviews were undertaken to explore the financial benefits associated with the various applications of LBS information. The results suggest that sheep and beef producers from across the major production zones (Pastoral and a combination of Sheep-wheat and High-rainfall) could benefit with increases in revenue and cost savings potentially achievable. Both whole of herd or flock deployment (where every animal is monitored), as well sentinel deployment (where only a small proportion of animals are monitored) were considered.

The value of LBS systems for pastoral beef producers

Producers from the Pastoral Beef zone reported on average 4.2 individual applications that would impact through increased revenue and 2.2 applications that would reduce costs. One of the key applications that was consistently reported and had high value for this segment was the use of LBS information to refine mustering activities. This application alone was estimated to save an average 3.84% of costs across the five of the six producers interviewed.

Across all applications, pastoral beef producers articulated average benefits of 6.8% in increased revenue and 3.8% in cost savings. The prevented revenue losses from catastrophic or unusual events (CUE) averaged only 0.2%.

Using LBS data to detect predation events, cow pregnancy status, basic animal location, genetic matching (cow/calf) and bull activity were commonly articulated as having value but with lower financial benefits. Less commonly reported applications with larger benefits included monitoring and managing landscape utilisation, water related behaviours and the detection of calving. Monitoring and managing landscape utilisation could have substantial financial benefit, however most producers were not confident in articulating a specific value.

Sentinel deployment (5-10% of animals monitored) more than halved the potential revenue benefits (2.7%) and reduced the cost savings to 0.6%. Most of the loss in cost savings was due to the inability to locate every animal which impacted on mustering efficiency. A key issue with the value of potential revenue benefits under a sentinel system is that these predominantly come from landscape monitoring and management and as such require more skill to implement.

The value of LBS systems for beef producers in the high-rainfall/sheep-wheat zone

Beef producers interviewed from this zone reported an average of 3.3 applications that would increase revenue and 2.5 application that would reduce costs. The four producers interviewed in this segment articulated average revenue benefits of 6.0% and cost savings of 4.7%. The prevented revenue losses from CUEs averaged 1.6%.

The largest value application of interest was based around the detection of water related behaviours to save both costs in checking troughs and prevent losses from animal perishing when water systems failed. The detection of calving and lambing events as well as the use of LBS data to inform grazing rotations were also thought to have significant value. The detection of stock theft, disease, plant toxicity issues, cow pregnancy status and use of LBS data for monitoring and managing landscape utilisation were also considered to have financial benefits.

The value estimates for deployment of sentinel systems were 2.6% for revenue increases, 0.6% for cost savings and 0.0% for CUE's. The revenue benefits were dominated by the value gained through better timing grazing rotations. Like monitoring and managing landscape utilisation this application requires an increased level of skill to implement.

High rainfall & sheep wheat zone sheep

The eight sheep producers interviewed reported an average of 3.0 applications that would increase revenue and 2.9 applications that would impact by reducing costs. The average estimate of cost savings was 2.6% and revenue saved through prevention of CUEs was 0.9%. The average potential revenue gain was estimated at 11.1%. This high figure was dominated by one particular application, the genetic matching of ewes and lambs which was reported by five of the eight to have an average benefit of 9.76%. Removing this one application reduced the revenue benefits to 5.0% which is similar to the beef segments.

Other applications which held potential benefits included: the detection of lambing, disease, stock theft, water related behaviours, pregnancy status, plant toxicity, ram activity and location for mustering efficiency. Larger benefits were articulated by a smaller number of producers relating to using LBS data to inform grazing rotations, monitoring and managing landscape utilisation and refining fertiliser application. These largely feedbase related applications were of interest to many but the exact value was unclear and it was apparent that an increased level of skill was required to extract the potential value.

Big wins or small cumulative gains?

Apart from the two key applications (mustering efficiency in the pastoral beef and genetic matching in sheep), and in general, producers articulated that the benefits from LBS information would come from the cumulative effect of a number of smaller increases in revenue and cost savings.

The non-financial benefits of certain applications cannot be underestimated. Producer frequently referred to the "peace of mind" that they believed LBS system would provide.

What is the likely economic impact on the red-meat industry?

Modelling of the potential benefit of whole of herd/flock deployment as limited by likely adoption rates (and not including the costs of LBS systems) suggest total accumulated benefits of between $280 million (minimum) and $808 million (maximum) for the beef industry over a 10 year period. The accumulated benefits for sheep would be $204 million (minimum) to $501 million (maximum) over a 10 year period.

Considering the minimum (realistic) scenario for the beef industry, benefit cost ratio's (BCR) of 1.1 (at sensor cost (SC) $50/year) and 5.3 (SC of $10/year) for whole of herd deployment at a national level were estimated. The same criteria for sentinel deployment (5% of animal monitored) suggests BCR's of 1.3 (SC of $150/year) and 3.8 (SC $50/year) might be achieved.

Considering the minimum (realistic) scenario for the sheep industry (in the High-rainfall/Sheep-wheat zone) BCR's of 1.4 (SC of $10/year) for a full flock deployment and 1.2 (SC of $50/year) for sentinel deployments suggest some value. Increased sensor cost scenarios ($50 for whole of flock) and ($150 for sentinel) are clearly not a viable option under the proposed adoption profile.

The economic value outside of the on-farm financial benefits reported by producers involved in this study could also be significant. Two areas of particular industry level impact are biosecurity and animal welfare/social license. Further research into how LBS system might impact on these areas is required to confirm the economic benefits likely to flow from improved biosecurity and social license outcomes.

Where is the industry up to in delivering location, behaviour and state information to producers?

A review of all known technology providers reported in the literature, press releases or with a web presence was undertaken (full details are provided in Appendix 2). The results suggest that there are few if any service providers that are currently in a position to provide the LBS information required to realise the gains articulated by producers throughout this project. However, technology development is a fast moving sector and several entities are moving towards delivery of systems in the near future.

Further research, what needs to happen from here?

There is already relatively large private sector investment into the hardware required to realise the gains described by producers throughout this project. However, the specific needs of Australian producers, the challenges of extensive landscapes and the way in which graziers anticipate drawing value from these systems may not be well understood by all technology developers. Better linkages between hardware developers and producers could be fostered through specific forums.

As hardware solutions become available there may well to be a tendency for rapid uptake by some segments of the industry. This needs to be tempered by the understanding that the true value of this technology is realised when the hardware systems reliably perform over several years. This means that long term testing and evaluation of LBS systems will be required and may best be undertaken by independent agencies.

Research into novel ways of deploying systems such as non-ear tag solutions and systems that use hybrid or sentinel deployments should be pursued in line with achieving the high value benefits identified in this report. Research into a new generation of systems that can provide LBS information without requiring on animal sensors is also warranted.

Most importantly, the interpretation of data into meaningful and decision actionable information is critical to the success of LBS systems. This project has identified numerous valuable applications that will require algorithm development to convert the location and movement data from the various sensors into maps or alerts that producers can base profit driving decisions from. In some cases the development of algorithms will be simple, in others the integration of domain expert knowledge with hardware builders, and algorithm developers will be required to provide robust and reliable outputs for producers.

Several key areas of application of LBS system require further research before a full understanding of the value they may bring is evident. The value that can be achieved through the various feed-base related applications, particularly landscape utilisation needs to be explored. The potential value around the application of LBS system to inform and interact with consumers in the context of animal welfare and social license also needs attention.

Conclusions

The potential for location, behaviour and state systems for livestock is significant. Producers have articulated a diverse range of applications that translate into financial and non-financial benefits that will impact across the red-meat industry.

The key challenges at the moment are the development of commercial hardware systems that can provide the data, and then algorithm development to provide the required information to producers to enable the various revenue gains and cost savings described.

These systems need to be appropriately priced and provide a reliable and robust solution that delivers the information to producers in a form and in a time frame that enables the appropriate intervention. LBS systems alone will never make money, it's the decisions and actions of the producer in response to the information they provide which makes all the difference.

Table of contents

1 Introduction and broad overview of activities

1.1 Background

The potential for LBS in commercial grazing systems has long been anticipated by many in the industry. There is a wide spread belief that measuring and monitoring individual animal behaviour could provide a number of opportunities to refine management decisions. In many cases the best the industry can do at present is model the likely behaviour and biological state of animals. These new and emerging systems could turn what is currently modelled, into data from objective measurement, or at a minimum, provide new and more reliable inputs for improved modelling processes.

This report brings together the results of several research activities aimed at exploring and uncovering the value that might be derived for livestock managers if they could remotely monitor the location, behaviour and state (LBS) of the animals under their management.

There have been a number of reports exploring the value of precision livestock technologies which have outlined the value of location and behaviour information. However, many have focused their investigation on the value of one or two applications, whereas there has been a growing realisation amongst researchers and producers that this sort of information may well have benefits across a range of applications.

This means that the development of a sensing solution that provides key attributes about the location, behaviour and state of an animal may have its value in more than one single "big hit application". In contrast, it may well be the cumulative value of several "1-percenters" that provide sufficient value to enable producers to justify investment.

In addition to exploring the financial benefits of having location and behavioural state (LBS) data this project has also sought to report the likely non-financial benefits that might be brought about by the provision of this sort of information.

1.2 Objectives

The report provides the outcomes of a project designed to deliver against five objectives:

1. Establish a series of demonstrations of producers using location behaviour and state (LBS) information in grazing systems;
2. Document the range of applications for which producers perceive value can be derived from LBS information;
3. Provide a sector wide economic analysis of the financial value of LBS information;
4. Review the current and potential technologies that can provide LBS information; and
5. Provide direction and recommendations for future investment into research and economic analysis of LBS information.

1.3 Broad overview of methods

This project involved coordinating four distinct research activities with significant interactions between each.

The first activity involved the deployment of research grade on-animal sensors onto a range of commercial operations to explore how the data generated might bring value to the industry participants involved. Five of the case studies explored the application of location, behaviour and state (LBS) information in the context of producer benefits. A further two cases studies explored the benefits that LBS information may bring in other areas of the red-meat industry, such as product suppliers and travelling stock routes.

The second research activity involved surveying producers and industry participants to determine what applications might be derived from LBS systems and identify how they would bring value to producers. This section involved an online survey, detailed producer interviews and a desktop review and information collation exercise.

Using information gleaned from the previous activities a sector wide analysis of the value of LBS data was undertaken. This provided an evaluation of the potential value that the development of adoptable LBS systems could bring to the red meat industry across the major production segments.

The final activity involved a desktop analysis of the current state of the sensor development. A review of all technology developers providing details into the public domain was undertaken to determine where the industry was up to in delivering a working LBS system to producers.

1.4 The context in which this research was undertaken

Rather than looking specifically at the applications of the “next generation of smart ears tags” this project has, wherever possible, attempted to focus on the key information that would allow producers to gain value from LBS information in their production system.

The critical information that producers are most interested in is the location (where is my animal?), the behaviour (what is it doing?) and its state (is it in a normal biological state or is there a problem?). Of course, just focussing on these characteristics without limiting them to what can actually be practically measured or estimated would simply provide an unrealistic wish list. And so this study has focussed on the location, behaviour and state (LBS) information that is likely to be achievable within the near future given the current state of technology development.

Whilst the “next generation smart ear tag” is one of the best candidates for delivery of much of the required information at the moment, there are numerous other on and off animal sensors that could provide at least some of the LBS information that producers could use to gain the benefits described later in the report.

Despite the aim of focussing on the LBS information (and not the hardware) it was nonetheless necessary to provide a context in which people in the industry could think about, and then articulate the potential benefits that this information could provide them. As such, much of the communication with producers and industry used the “next generation smart ear tag” as the key piece of hardware around which they could base their thinking and responses. This provided them with a familiar point of reference (in terms of hardware) from which they could develop value propositions to report as potential financial and non-financial benefits.

Whilst this report focuses on the value of LBS information to producers, it doesn’t intend to suggest that this information is the silver bullet that will answer all problems. In many situations it is highly likely that the integration of LBS information with other sensor data will provide either a more complete picture of a problem, or enable far deeper insights into a situation around which a producer is seeking to make revenue increasing or cost saving decisions. Several of the case studies in this report explore the value of integrating LBS information with other data including climate, live weight, carcase characteristics and satellite imagery. These case studies begin to reveal the value of integrating LBS information with other relevant data streams.

2 Industry partner sensor deployment, analysis and evaluation

2.1 Background

Location, behaviour and state (LBS) systems have been extensively used in research for several decades now (Swain et al., 2011). Many trials have been undertaken on commercial properties but they largely (and rightly) focus on the research outcome around which the deployment was based. The producers involved in these trials have often learnt a lot, but have not necessarily been able to ask the questions they wanted of the data and systems.

Now that commercial technology developers are beginning to offer solutions that can be implemented, producers are keen to use them. However, the technology developers are not necessarily informed as to what the producers actually need, and the producers themselves aren't certain of how they could take advantage of these systems.

This part of the project endeavoured to place the industry participant in the driving seat in terms of what they were looking to get from the data at the same time as leaving the door open for discovery of new and unexpected benefits that LBS systems might offer.

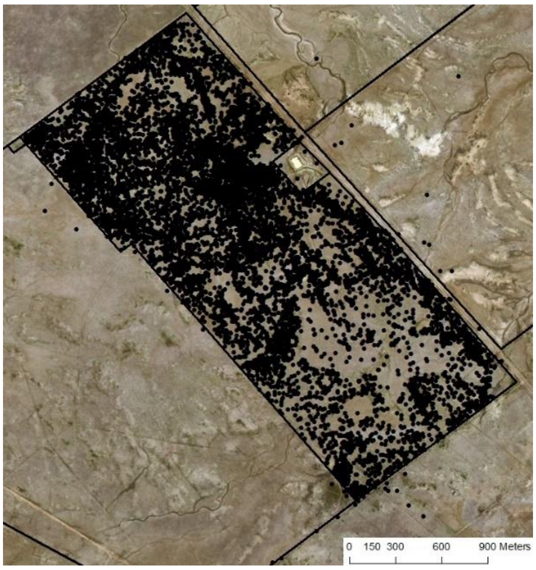
2.2 Materials and methods

GPS collars were deployed onto nine livestock management operations across Australia and one in New Zealand. They were deliberately stratified across a range of enterprise types and climatic zones to provide the most diverse range of outcomes possible.

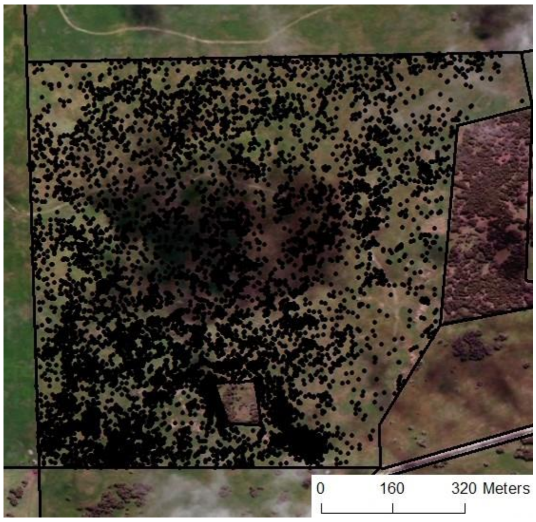
Two deployments were undertaken to explore the value of LBS data in situations outside the normal on-farm management application. These were a deployment to investigate the value of LBS information for suppliers of animal products and a deployment to explore the value for livestock being managed on a travelling stock route (TSR).

At the time of reporting two deployments were still underway and could not be included as data from GPS units had not been downloaded. Delays for these two producers were the result of animal ethics approval, internal property issues and seasonal conditions.

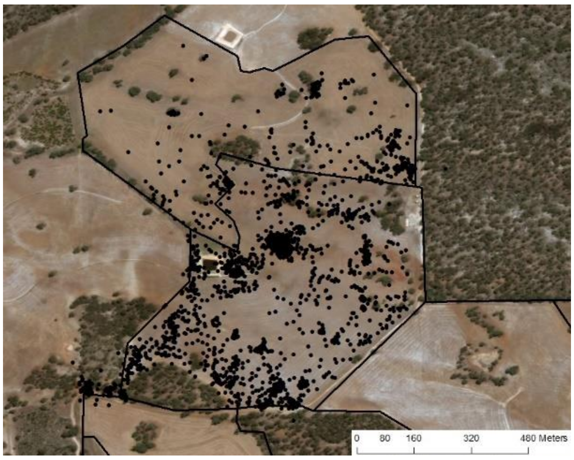
Raw data from each site consisted of time stamped readings of latitude and longitude, a summary of the scale of data from a single animal from each case study can be seen in Figure 1.



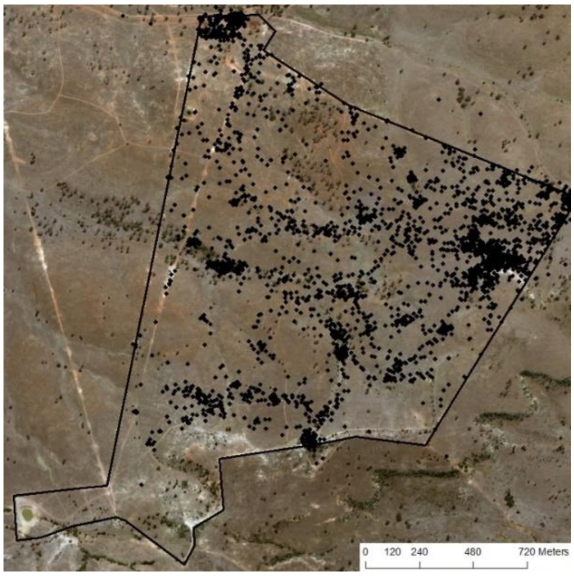
(a) "Rosebank" Longreach Qld



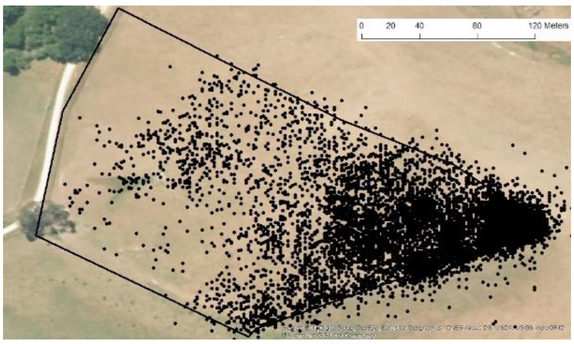
(b) "Shepherds Hill" Kingston SA



(c) "Warialda" Arthur River WA

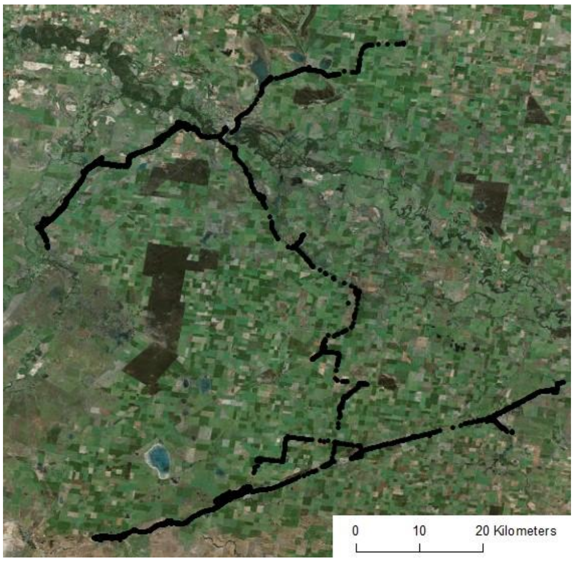


(d) "Brindley Park" Qld



(e) "Stonyhurst" NZ

(f) Detecting Buffalo Fly - supply chain value - Landmark



(g) Value for managing livestock on traveling stock routes

Figure 1 Raw GPS data from a single animal and paddock from each case study operation

2.2.1 Animal ethics approval

Animal Ethics for this research was approved by the CQUniversity Ethics Committee under application AEC20728. Some activities also required additional specific approval which are reported in the methods for each case study.

2.2.2 Data processing and analysis applied across all deployments

The raw data from each case study property was initially processed using a standard suite of analytical techniques and a preliminary report provided to each producer. Following discussion with the producer around these initial results a variety of custom analytical procedures were applied depending on the exact questions of interest to each partner. Basic details of specific analytical techniques are reported in each case study. The more general processing and analytical techniques applied are reported below.

Data cleaning

CSV files were imported into R 3.4.2 (R Development Core Team 2017) and all readings with a Latitude and Longitude of 0 were removed. Such readings are often obtained during the activation of the loggers inside a building. Duplicate timestamps were also removed.

Further examination of the standard import had shown estimates of speed and distance to be unreliable as a result of internal processing errors within the GPS. These readings were subsequently dropped from the data as a standard procedure - the parameters were later recalculated - and only the index number, coordinates, date, time and estimated precision error (EHPE) were retained. Date and time were consolidated into a single timestamp field, standardised on GMT+0.

Where a GPS log covered multiple paddocks, the log was split based on the time that the animal entered and left each paddock. All points between these timestamps were retained as a basic data set and stored as a single track, although some points might fall outside the paddock. This way points belonging to tracks in adjoining paddocks were separated.

Data processing

Each basic data set was sub-selected to include only those points that fell within the boundaries of the paddock, and the movement parameters were re-calculated using the library Move (version 3.0.2). In addition, the local date and time as well as the hour of the day (based on local time) were determined for each location. The movement parameters were then used to determine an average speed of movement at each location, using 5 consecutive readings (including 2 readings before and 2 after a given location). The activity level of an animal was then derived for each location using the average speed: Avg. Speed > 0.1 - animal is active Avg. Speed < 0.1 - animal is inactive. Activity levels were then assessed against the hour of the day as well as against the date. The latter permitted an assessment of activity in relation to weather information. A 0.25ha grid covering individual paddocks was generated using QGIS, and the number of locations classified as active and inactive for each grid cell were obtained.

Reporting and analysis in collaboration with participants

Participants were first sent a report outlining all the results for individual animals tracked throughout the trial period. Over several discussions with participant producers the results were refined down and reanalysed under their direction to provide the information in a format that expressed the key findings they believed had been demonstrated through the study.

Assessment of the financial benefits reported by producers

Each producer was involved in an extended telephone or in person interview to explore the financial benefits in terms of increases in revenue and reduction in costs that might be achieved from the implementation of a live system. The full details of the process used can be found in the methods section of part 3 of this report (3.3.2). The top three applications were reported for each producer. In some cases these did not relate to the actual applications explored in the project. Most commonly this was due to the inability of the available research grade sensors to collect the required data or due to seasonal conditions or timing of issue precluding the collection of data within the time allocated for the project.

Some producers also commented on the usefulness of “sentinel systems”. In this context a sentinel system is defined as the deployment of sensors on a small proportion of the flock or herd to provide an indication of the behaviour of the herd as a whole. This concept is explain later in the report in more detail as the specific value of sentinel against whole of her/flock is investigated.

2.2.3 Reporting format and presentation

The write-up of each deployment has been deliberately provided in case study format as opposed to a more traditional scientific report. This partly reflects the nature of the co-development of this work but it is also anticipated that this will engage other producers in the outcomes when published.

2.3 GPS tracking of stock informs fertiliser management and disease prevention

2.3.1 Participants

Jack England, “Shepherds Hill” Kingston South Australia

2.3.2 Highlights

Data supplied by GPS tracking has provided farmer Jack England of “Shepherds Hill”, Kingston, SA, with new insights into fertiliser management practices and Phalaris toxicity prevention of sheep.

GPS tracking collars deployed on his farm have demonstrated the ability of the technology to objectively measure the grazing and camping locations of sheep.

“Tracking data from the GPS collars clearly showed us how sheep were using the paddock, where they were and weren’t grazing,” Mr England said.

These insights have helped Mr England understand some of the trends in soil nutrient distribution occurring across the paddocks, which helped inform changes to his fertiliser application strategy.

The GPS tracking data also demonstrated how Phalaris toxicity was affecting a flock and validated some of the actions he has undertaken to manage this issue, such as reducing flock size to allow better individual sheep water access.

2.3.3 Background

“Shepherd’s Hill” is a 3200-hectare operation running 9000 ewes and a 400-cow breeding herd. The property is managed by Jack England and is located between Kingstown and Lucindale in South Australia.

2.3.4 Trial objectives

The primary objective of the study was to objectively measure paddock utilisation and examine if any relationships with soil nutrient status could be found.

After close examination of the data Mr England was also interested in the ability of the tracking information to detect behaviours associated with a minor outbreak of Phalaris staggers experienced during the trial period.

2.3.5 Materials and methods

Collars were deployed on single sheep in four mobs across several paddocks on the property. This data was processed as per the standard protocol and then specific analysis techniques explored the objectives developed by Mr England. The spatial utilisation maps were compared with a soil phosphorus map which was interpolated from a gridded soil survey. A paddock utilisation index and water point utilisation index were developed from the GPS data and integrated a number of spatial analytical processes.

2.3.6 Results

Validating landscape utilisation for paddock planning

From the GPS tracking data Mr England was able to quantify his gut feeling about paddock utilisation by his sheep (Figure 2).

His knowledge of the stock and paddocks suggested that there was a consistent underutilisation of the north and north-eastern areas of paddocks, due to prevailing winds. The results across many of the paddocks substantiated this hunch and Mr England is now examining how the tracking data might validate his planned paddock splits which are aimed at fixing this issue.

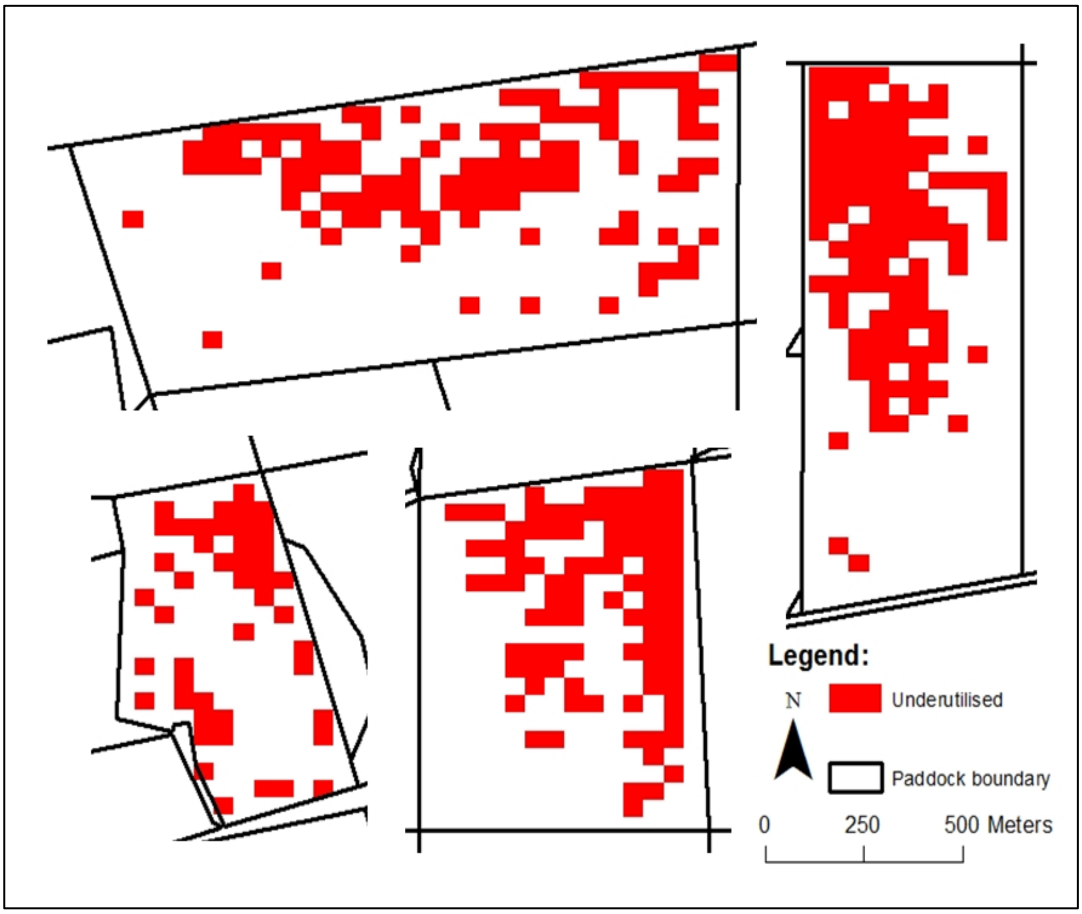


Figure 2 Key areas of underutilisation across several paddocks on "Shepherd's Hill". In most incidences, the Northern parts of the paddocks were consistently underutilised, highlighted by red cells

Understanding nutrient distribution and grazing livestock interactions

The trial also addressed the question of whether the variation in landscape utilisation identified by GPS tracking related to any underlying soil nutrition issues.

When the data was mapped for both grazing/camping density and soil phosphorus (P) levels, some key features were observed (Figure 3i). However, a robust correlation between soil P levels with grazing/camping density could not be found.

This means that using short term grazing density data from a single animal is unlikely to provide a zone map to enable refined fertiliser management. This is not surprising given that only one animal was tracked for a relatively short period of time in a non-growth period. Longer term GPS tracking is required and particularly data from peak pasture growth seasons needs to be examined to determine if it can be used to directly correlate to soil nutrient levels.

Despite this obvious limitation there were several observations made by Mr England that suggests there is value in the data.

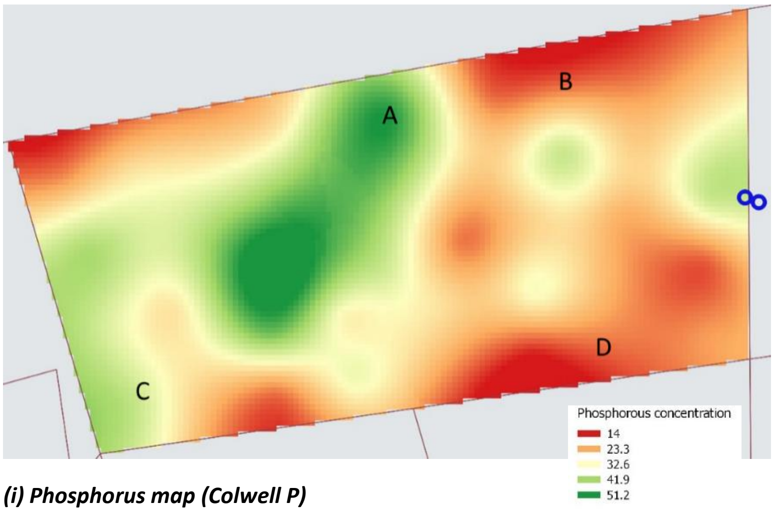
”The areas that were high in phosphorus were basically a standing wall of cardboard - Phalaris that had grown rank - and the sheep hadn’t bothered to graze into that area,” he said (Figure 3-A).

“I think what’s happened, is that we’ve continued to pour fertiliser over these areas at the same rate as the rest of the paddock but nothing is being removed and it’s just building up nutrient levels.”

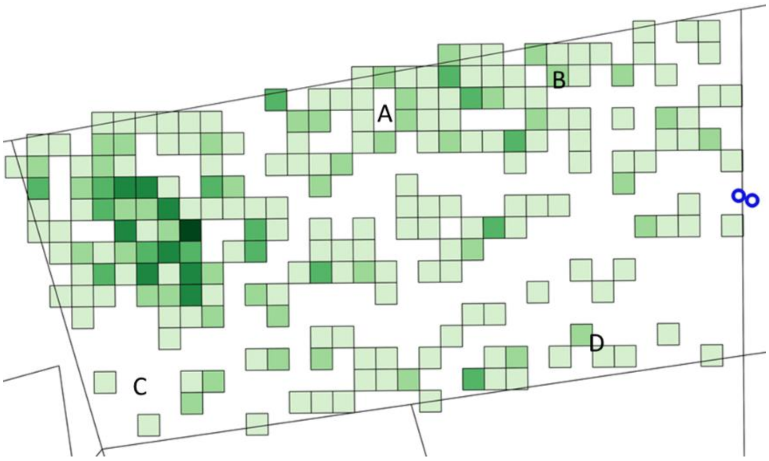
Mr England said an area adjacent to this that does receive grazing pressure (Figure 3-B) has much lower soil P most likely because of more palatable pasture species and subsequent nutrient export.

“The camp areas are pretty well captured by the GPS tracking data,” he said. The camp site shown in Figure 3-C also had an increased level of soil P which is common for these areas as increased faecal matter builds nutrient levels.

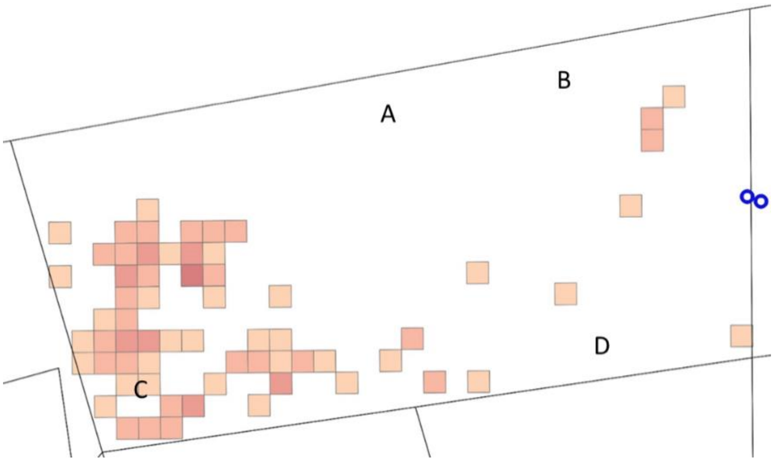
The area that most concerned Jack was the low P zone in Figure 3-D. “This area can grow some really good clover and highly digestible feed - you can see the sheep working it. It’s also got the lowest P levels and I think we need to top this area up to make the most of it.”



(i) Phosphorus map (Colwell P)



(ii) Grazing density map for peak morning grazing period. Darker green cells show areas of higher utilisation



(iii) Camping density map (high density use areas only) darker red cells show areas of higher utilisation

A – High P and low Grazing density. Large amounts of unpalatable phalaris. Sheep avoid.

B – Low P and medium grazing density. Lower biomass present.

C – Medium P and low grazing density. High camping. Visible camp site (note faecal matter in foreground).

D – Low P and medium/high grazing density. Very low biomass, grows clover but overgrazed

Figure 3 (i) Soil Phosphorus map of paddock generated by point samples on a 1 hectare grid; (ii) Grazing density map for selected grazing period (peak morning grazing) and activity threshold (speed above 0.10m/s); (iii) Camping density map for high use areas only; and pictures of selected sites across the paddock (A-D).

Understanding livestock, water and disease interactions

During the trial period Mr England experienced some issues with Phalaris toxicity which played out in a large mob of sheep and caused some behavioural issues around water point use and grazing distribution. As a consequence a number of sheep were lost.

The data was examined with a view to understanding whether there was a behavioural change associated with the disease and Mr England's management response which was to reduce the mob size. Mr England also wanted to know if the data could have provided a warning of the issues that occurred so that when a real-time data delivery system is developed he could use it to stay remotely informed about these issues to back up his regular observations.

The behavioural data from a single sheep was examined for changes in two key indicators: water point utilisation (how much time was spent within 50 m of the trough); and paddock utilisation (how much of the paddock the sheep utilised on a daily basis). Results are shown in Figure 4. Both indicators (water and paddock utilisation indices) were combined to produce an "alert indicator" which could be integrated into a real-time location, behaviour and state (LBS) system to provide the sort of warning that Mr England is interested in.

"Alerts to prevent the fouling of water by cast animals, and when water is not being consumed due to high salt levels despite a clean appearance, will also be most useful," he said.

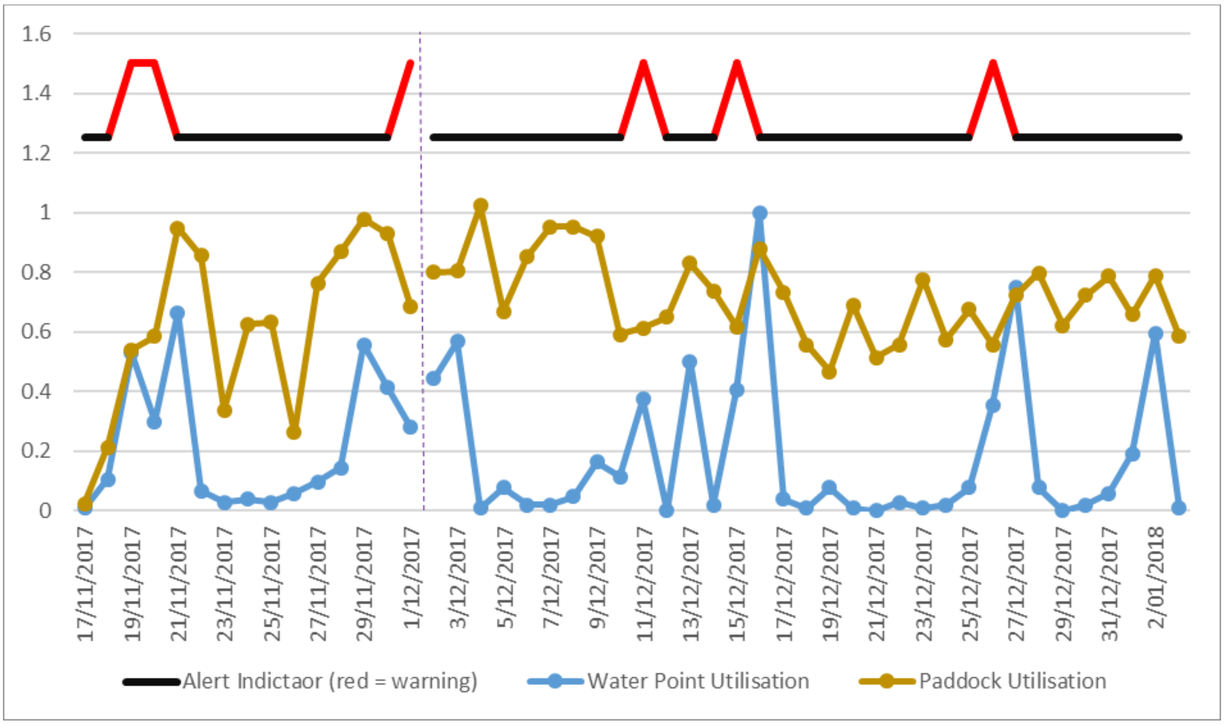


Figure 4 Water point utilisation index (blue) and paddock utilisation index (gold) for a single sheep. The date of management intervention is shown by the purple line. The "Alert indicator" is a preliminary indicator that combines both the water point utilisation and paddock utilisation indices and applies thresholds to each which would then in the case of a real-time system send a warning (at the red peaks) to the manager. It is worth noting that after the initial intervention (purple line) several other alert states were reported.

One of the key issues that Jack wanted to understand was how well the mob changed their behaviour after the management intervention. His primary interest was around achieving an increase in grazing distribution and getting animals to move out and away from the water point. By comparing the results before and after the intervention the GPS data could be used to validate that at least a short term increase in grazing distribution was achieved.

One of the key issues that Mr England wanted to understand was how well the mob changed their behaviour after the management intervention, in order to achieve an increase in grazing distribution by moving stock away from the water point. By comparing the results before and after the intervention the GPS data could be used to validate that at least a short term increase in grazing distribution was achieved (Figure 5).

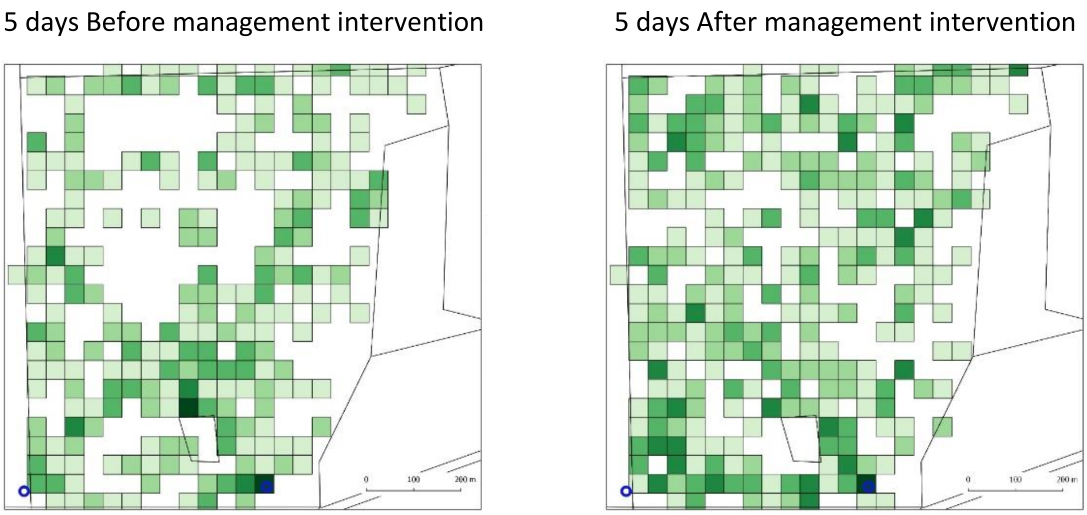


Figure 5 Grazing distribution increases as a result of management intervention following adverse impacts from Phalaris staggers. Presence of green cell shows use, darker green cells show higher utilisation.

2.3.7 Implications of having real-time LBS information

Financial

As well as the value provided by the top 3 applications described by Mr England (Table 1), there were some additional specific uses that were of interest, such as using the data to help manage Phalaris toxicity and better design paddocks. When all the different applications were considered Mr England could see cumulative value added to his operation of a potential estimated benefit of a 5.45% increase in annual revenue and decrease in costs by 0.6%.

Table 1 Top 3 applications by value in terms of annualised value that could be derived from real-time LBS data for "Shepherd's Hill" for a whole of flock deployment.

Rank	Application	Estimated annualised value	How would this work?
1	Refining fertiliser application	2.6% increase in revenue	Zone up using data, soil test and then apply different fertiliser rates
2	Genetic matching (dam/offspring)	0.8% increase in revenue	Identify and cull bottom 25% of ewes based on lamb performance
3	Calving/lambing detection	0.5% increase in revenue and 0.2% reduction in costs	Get alerts to dystocia and take action to intervene, save some cows and calves. Reduced time checking cows.

Mr England has progressed to developing and implementing a variable rate fertiliser strategy for the paddock examined in this study, based primarily on the soil nutrient testing results he obtained through grid sampling.

Those areas high in P now receive 40% less and an increased capital allocation of up to 200 kg/ha of single super being applied to the low P zones.

“Soil testing is great but it’s expensive to do a full paddock,” he said. “If we can work out how to zone up using this sort of tracking data then we could target the soils tests, save a lot of money in the process and then make more out of the paddock, there’s a lot of value in that.”

Genetic matching

The ability to mother up ewes and lambs and identify how productive each ewe is in terms of the offspring profitability also holds significant value for Mr England. Identifying and culling the bottom 25% of ewes would increase the genetic potential and productivity of his flock considerably.

Calving detection

A simple application that can bring value would be the provision of alerts around calving activity of cows.

“There’s probably around eight calves a year we could save if I knew that the heifer or cow was in trouble,” he said. “Each year we expect to get 1-3 cows with paralyses caused by a large calf or lengthy birth process. I expect we could save half of these animals with earlier intervention.”

Other financial benefits

Mr England also identified a number of applications of a real-time LBS system on his operation, which could all add to his bottom line. These included: small savings in mustering efficiency from knowing he has gathered all of the animals; detection of infectious diseases; pregnancy status alerts, ram and bull mating activity (break down alerts); detection of plant toxicity issues (particularly staggers); on-farm biosecurity issues; and detection of shy feeders around supplement.

Non-financial

An added benefit is the potential value of these systems for welfare management which impacts through to social license. “It would mean you are on top of these issues straight away [meaning health and disease] which is great for our industry,” he said.

Whole of herd/flock versus sentinel deployments

When considering the potential value of a sentinel system against a whole of herd/flock deployment, the estimated benefits fell from 5.5% to 2.9% for revenue gains and from 0.6% to 0.2% for cost savings.

There is still reasonable value in the deployment of sentinel systems and Mr England is comfortable that even with the small numbers of sheep tracked in this study, valuable information was gained.

2.3.8 Where to from here?

Mr England is continuing to use the GPS tracking devices to collect data and plans to undertake more comprehensive data collection over the coming growing season. He also has a submission under review to the Landcare Smarter Farming program involving the use of GPS tracking for sustainability issues.

2.4 How GPS tracking of animal behaviour can drive profit at Australian Country Choice

2.4.1 Participants

Joel Bentley, Australian Country Choice Innovation Officer and Ben Dwyer Australian Cattle and Beef Holdings CEO

2.4.2 Highlights

GPS tracking of cattle from grazing through to slaughter has shown that relationships between animal behaviour, live-weight gain, cost of production and even meat quality could deliver significant profitability gains.

"The tracking data showed us some amazing detail on the animal behaviour, and then when we compared it to the production data there were even more surprises," said Joel Bentley, Innovation Officer with Australian Country Choice (ACC).

The pilot study only examined a small group of animals and so the results need to be treated with caution, however there were some very interesting trends that became apparent.

The study showed that, in general those animals that walked more during backgrounding ended up having a higher live-weight gain for the same period.

According to the GPS data, one animal that was tracked demonstrated a more erratic behaviour pattern than the others. This animal had the lowest weight gain and had to be lot-fed for an additional 20 days to meet weight specifications.

"Compared to the others, that animal cost us more to produce and you can start to see why from the GPS data," Mr Bentley said. "We only tracked 6 animals in this pilot-study, but it has sparked so much interest, we've got to get this done across more animals now."

2.4.3 Background

ACC is one of the largest vertically integrated red-meat supply chains in the world. For more than 40 years ACC has supplied exclusively to Coles Supermarkets and a number of export customers. ACC currently has a long-term contract in place with Coles as the principal northern supplier and processor of beef products.

In conjunction with its joint venture business, Australian Cattle and Beef Holdings (ACBH), ACC manages 54 Queensland properties, totalling 662,500 hectares. These properties accommodate around 15,000 breeding beef cows, 54,000 young growing beef cattle and 46,000 young beef cattle in feedlots, to provide 240,000 head of cattle each year to the processing facility.

This large vertically integrated business model provides numerous opportunities for livestock location, behaviour and state (LBS) data to impact on production efficiency.

2.4.4 Trial objectives

ACC's primary objective was to explore variability in individual animal behaviour. The key point of interest was to determine if all animals graze and behave in a similar way within the group, or if there are differences that might relate to productivity measures.

2.4.5 Materials and methods

GPS tracking collars were fitted to 6 animals from a variety of sources that were inducted into a backgrounding pasture paddock for a period of 21 days before being moved to a feedlot for finishing. Data was collected in both the pasture and feedlot phases, but the focus of this report is on the backgrounding activity.

The standard data analysis was undertaken in addition to the correlation of live-weight gain and final carcase characteristics with behaviour data from GPS. A conceptual Erratic Behaviour Index (EBI) was developed based on the observed characteristics of the animals and their productivity measures. Grazing density maps were derived for the backgrounding paddock.

With regard to the correlation of behaviour with live-weight gain and carcase characteristics, the limited number of animals tracked during the study means that the data needs to be treated with caution, but it has raised many questions and hinted at the value that might be extracted from commercially deployable monitoring systems in the future.

Figure 6 ACC cattle fitted with GPS tracking collars prior to being moved into a backgrounding paddock. A variety of types of animals within the same mob where fitted with collars to explore if there would be any individual animal differences.

2.4.6 Results

Individual variation in activity during backgrounding

There were some particular differences between individual animals in both the backgrounding and feedlot phases. The diurnal activity of the animals during backgrounding reveals distinct behavioural patterns which differ between animals and appeared to have some relationship with live-weight gain and cost of production.

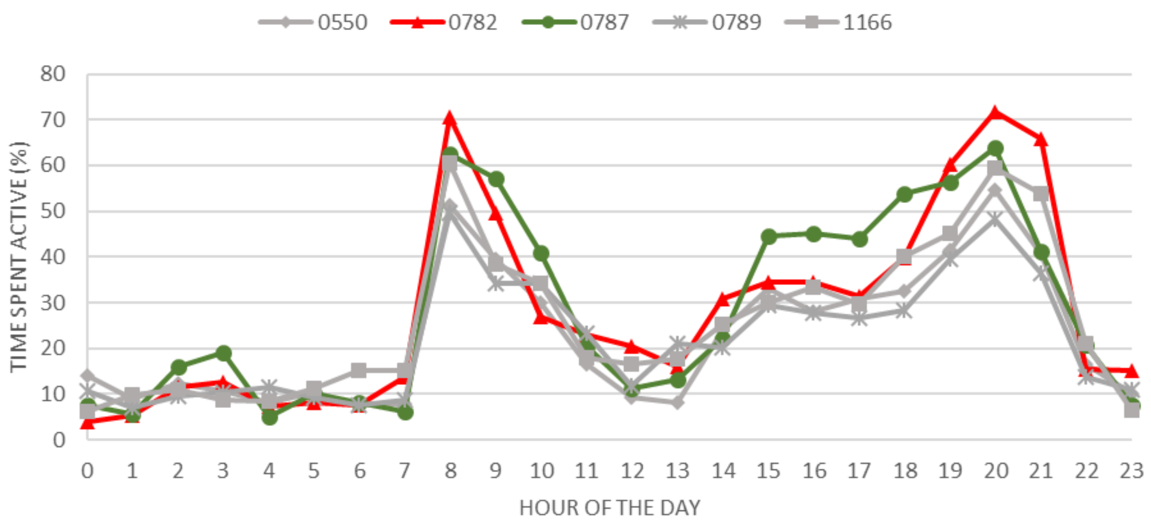


Figure 7 A diurnal activity graph for 5 of the animals during backgrounding. Two distinct behavioural patterns can be seen. The first (animal 0787 – green circle line) shows a higher activity time over the peak afternoon grazing period, this animal had the highest weight gain during backgrounding. The second (animal 0782 – red triangle) shows extremely high levels of activity during the morning and late afternoon periods, this animal had the lowest weight gain during backgrounding and the highest cost of production of all.

The numbers sampled were too low for a formal evaluation of the relationship between production and movement and behaviour data, however some interesting trends where observed. In this small group there does appear to be a relationship between live-weight gain during backgrounding and activity in the paddock, with a higher average daily gain (ADG) being related to increased average daily distance travelled (ADDT) (Figure 8).

One key outlier (the square – animal 0782) was identified, this animal had the lowest average daily gain (ADG) during backgrounding but also had moderately high paddock activity. A closer examination of this animal revealed that its behaviour was different to the others and may be more erratic.

There also appears to be a relationship between ADDT and the final carcase pH (risk for dark colour) (Figure 9). There is additional activity within the feedlot phase that may explain this (animals with high ADDT in backgrounding have low feedlot activity).

These results suggest that further investigation is worthwhile to explore the potential for early identification of animals which may either not perform well further down the production chain or be at risk of carcase compliance issues.

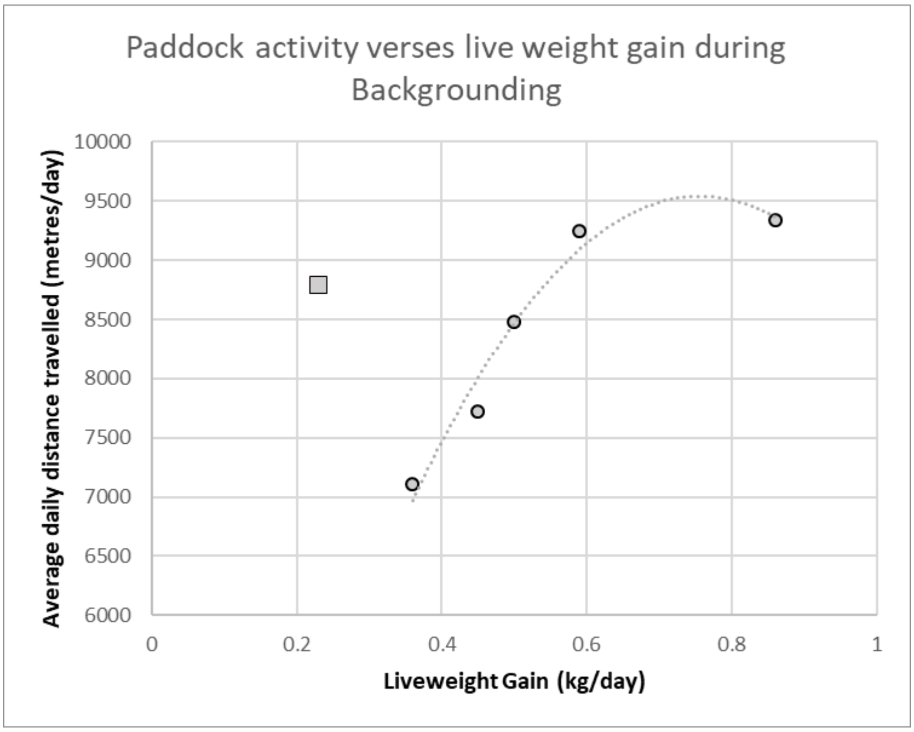


Figure 8 The relationship between paddock activity and live-weight gain during the backgrounding phase. The outlier (square) is animal 782 which demonstrated more erratic behaviour.

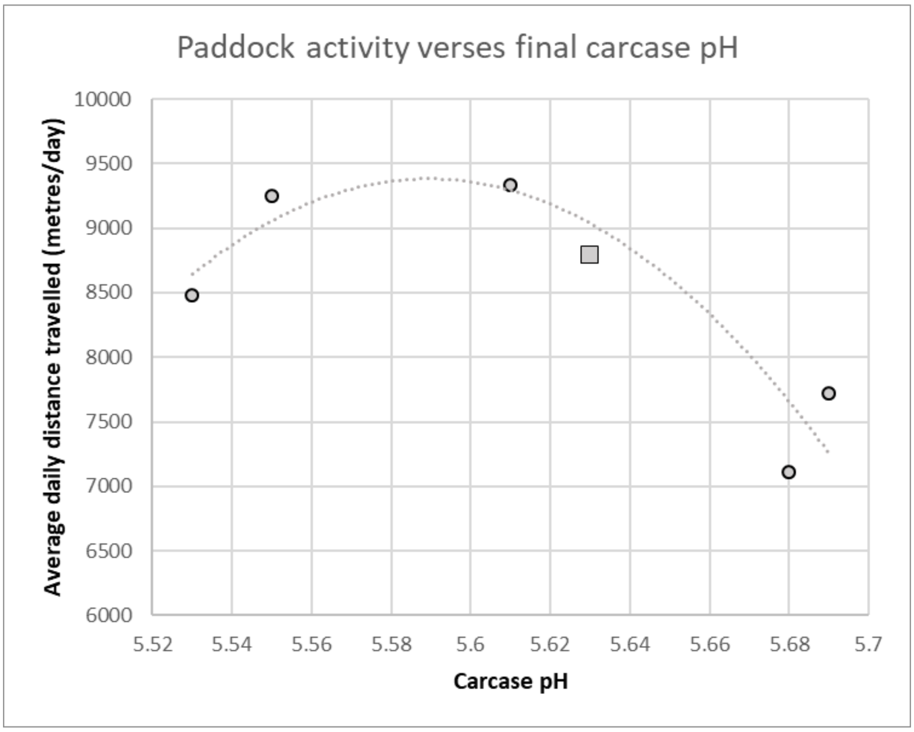


Figure 9 The relationship between carcase pH and paddock activity during the backgrounding phase. Animals at higher risk of cutting dark had the lowest average daily distance travelled during their pasture production phase. The outlier (animal 782) is back in range of other animals but did spend an additional 20 days in feedlot to achieve this.

2.4.7 Implications of having a live system

Financial benefits

ACC and ACBH are large integrated value chains and numerous applications were identified that would increase production efficiency across breeding, backgrounding and feedlot operations. On the more extensively grazed operations the top three benefits related to detection of watering behaviours, getting clean musters of paddocks and detecting bull activity.

Table 2 The top 3 benefits and estimates of value across the breeding and backgrounding operations

Rank	Application	Estimated annualised value	How would this work?
1	Water related behaviour	4.0% increase in revenue	Having optimal water in front of animals is critical. Poor water translates into reduced body condition which ultimately limits branding rates.
2	Mustering efficiency	2.8% increase in revenue	Getting a clean muster of a paddock means that pasture regrowth is optimised increasing overall production.
3	Bull/Ram activity	1.0% reduction in costs	Saving in bull to cow rates run as any breakdowns detected and fixed rather than running the extras.

Detection of behaviours associated with water and feed-base

Ben Dwyer, CEO of ACBH, said that having optimal water in front of animals was critical.

“If you have a situation in which either water quantity or quality becomes an issue for cattle even for a short period of time, it can really have a flow on effect through the system,” Mr Dwyer said.

“That time when cows are off their water means they aren’t putting on body condition, and this ultimately reduces branding rates [through reduced body condition score at joining].”

Mr Dwyer said that having live data coming back in from animals would allow managers to identify water-related issues and have them fixed much faster than they are currently. Optimising feed-base management

Another application that could increase revenue would be monitoring stock during musters to ensure an absolutely clean muster of every paddock every time. This would mean improved regrowth of pastures as there are no strays left behind to graze those particularly productive areas. The extra feed produced would have a significant impact on overall production.

One of the key opportunities identified by Mr Dwyer was around using real-time data to optimise feed-base management.

"Currently we take a visual stock take of the grass and then assess the animal behaviour as an indicator of when we need to be moving animals around paddocks," he said.

Mr Dwyer believes that the integration of an automated feed-base measurement system with behavioural indicators from a tracking device on an animal could enable them to see trends well ahead of when the animals start to lose weight.

"There's a six-week lag between what we see in terms of changes in live-weight and the grass and animal grazing behaviour interaction that have resulted in that change in animal production."

Mr Dwyer said spatial landscape utilisation maps (Figure 10) could also help identify which areas were being overgrazed, enabling targeted spelling of paddocks which would in-turn lead to increased pasture re-growth rates.

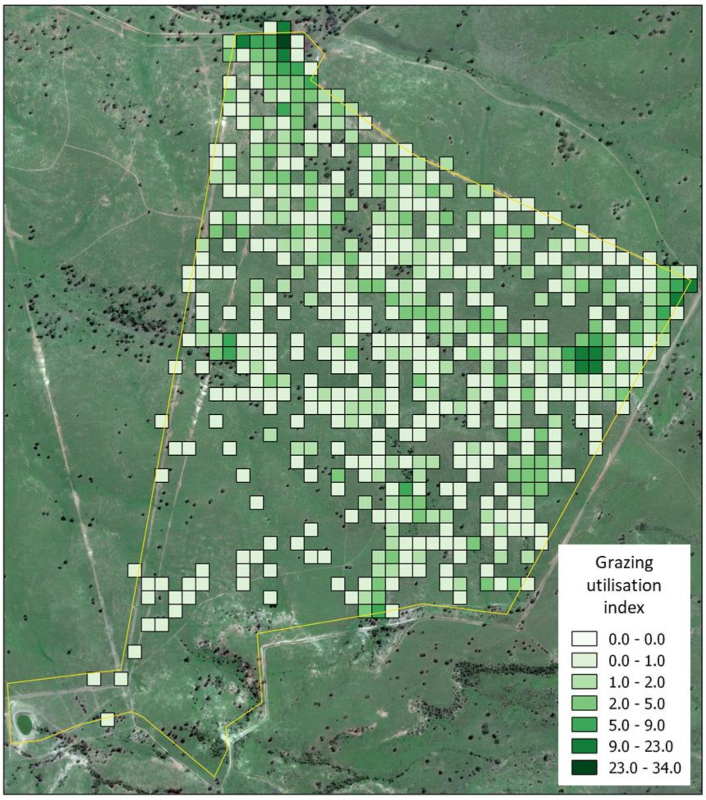


Figure 10 Spatial landscape grazing utilisation density map for one paddock. ACBH CEO Ben Dwyer suggests that having this information in real-time or near real-time could help manage overgrazing and increase pasture re-growth rates to optimise overall productivity.

Monitoring the activity of bulls

The top cost-saving application was identified as live monitoring of bull activity during the mating season. Mr Dwyer said that having alerts for bulls that may be injured or have stopped mating would potentially allow them to reduce the number of bulls they buy. Currently, higher than normal rates are used to cover off on these issues.

Mr Bentley believes that knowledge of exact bull location would have a massive impact on the bottom line.

"If we knew exactly where every bull was and what it was doing, this would have massive impact. We are really careful around the management of venereal diseases, and if we know a bull has got out of an allocated mob or has been left behind after we have removed them all, then it would really help us keep on top of this."

Early identification of animals that may not perform

One of the key production drivers at ACC is the identification and management of poorly performing animals.

"The case study data we collected showed one animal that was a really bad performer in terms of live-weight gain in the pasture phase," Mr Bentley said. "We had to feed that animal for a further 20 days in the feedlot compared to the others to get it up to spec, so that animal has cost us a lot more to produce."

Mr Bentley said that having live data coming in on each animal on a day-by-day basis (Figure 11) there may be ways in which they could identify the problem and then either manage the herd or individual animals to optimise their productivity.

"One of the biggest challenges we have is that cattle are coming in from all over Queensland and NSW from a range of different environments," he said. "I suspect that some of the behaviour differences we see are a result of animals being taken from one sort of environment and asked to perform in another, this tracking data could really help us understand how to better manage this."

Figure 11 A comparison of one animal (0782) against the average of all other animals for a Restlessness Index (RI). Animal 0782 shows several days during backgrounding when it breached the 1 standard deviation threshold which in the case of a live system providing daily updates could be used to trigger warnings to managers to investigate further.

Benefits from inventory management over a vertically integrated value chain

Given the size of ACC, an important potential benefit of real-time stock monitoring would be inventory management of cattle. Knowing exactly where each animal is and in what condition is critically important to maintaining a constant supply of animals through the production system.

2.4.8 Where to from here?

"This has really sparked our curiosity," Mr Bentley said. "It's only six head that we've tracked and looked at, but you've got to wonder what else we might find. Now we've just got to expand this out over several hundred animals."

ACC and CQUniversity are currently exploring opportunities for further collaborative projects to expand on this preliminary work. They are currently looking at studies that will explore the relationships between carcase traits and animal movements with larger numbers, as well as using the technologies to evaluate new pasture improvement strategies.

2.6 Detecting stock theft could make tracking data pay

2.6.1 Participants

Brad, Tracey, Emily and Sophie Wooldridge, “Warialda” Arthur River Western Australia

2.6.2 Highlights

GPS tracking could be a powerful tool for the industry to fight the scourge of stock theft, according to WA farmer Brad Wooldridge.

It’s just one of a range of benefits identified by Mr Wooldridge during a trial of the technology on his property “Warialda”, from improved flock genetics through to significant gains in feed-base management.

“It’s not about the data itself, it’s about how you interpret it,” Mr Wooldridge said.

The research team worked with the Wooldridge family to develop a number of data analysis techniques to turn the raw “GPS dots on a map” into meaningful information that, if provided in a real-time system, could revolutionise sheep management on their properties.

One of the key findings of the project was the value around improved feed-base management and prevention of stock theft that could be achieved through sentinel systems, where only a small proportion of the flock is tracked. This means value could be achieved at a much lower cost than having to tag every animal once real-time systems become available.

“Of course I want a cheap enough ear tag that I could use to track every animal, but I can also see how I could get the information I want just by having a handful of sheep being tracked,” Mr Wooldridge said.

2.6.3 Background

“Warialda” is a mixed farming operation managed by the Wooldridge family near Arthur River in Southern WA. The property is managed in combination with another property at Albany on the south coast of WA.

Together they run a sheep flock of around 3000 ewes, turning off 2500 lambs into the domestic market.

Sheep graze a combination of annual pastures, crop stubble and perennial pastures.

2.6.4 Trial objectives

The trials at “Warialda” were designed around three distinct applications. The first two involved using GPS to understand how animals were utilising paddocks and the variability that might be found over: 1. Time (temporal variation); and 2. Space in grazing patterns (spatial variation). The third was more pragmatic, with a simulation trial undertaken to determine if the technology could be used to detect and therefore prevent stock theft.

2.6.5 Materials and methods

GPS collars were deployed on 6 sheep from a mob of 400 for a period of one month grazing in numerous paddocks on “Warialda”.

The raw data was subject to the normal processing and analysis protocol outlined, before specific analytical processes were undertaken to provide data that addressed each of the specific questions posed by the producer.

A simulated stock theft event was undertaken in which the sheep where subject to activities associated with them being deliberately stolen from a paddock.

2.6.6 Results

The results of the tracking project were explored over the three key applications that Brad was interested in: behaviour changes associated with the feed-base, spatial patterns of landscape utilisation and detection of stock theft.

Behavioural changes associated with feed-base variation

Mr Wooldridge was interested in the use of GPS data to better manage the timing of grazing rotations.

”The way in which animals move and behave can change as the pasture quantity and quality changes,” he said. “If we can see these changes in the tracking data and then get the right interpretation of this, then the sheep can start telling us when they should be moved on.”

Figure 12 One of the sheep tracked with GPS on “Warialda”

Data was examined from five days immediately before and after a paddock shift (Figure 13). There is a large variation between the two periods in the way the animals are grazing. Mr Wooldridge said the shift to a new paddock coincided with a small amount of rain which drove some development of green pick. The sheep then spent a lot more time moving around the new paddock chasing this fresh feed.

“This is exactly what I wanted to see,” Mr Wooldridge said. “If I can get this data as a live feed, even just a summary at the end of each day, I reckon I can use this to make some much better decisions around rotating sheep and even supplementary feeding them”. “This would be particularly helpful for the Albany block” suggested Mr Wooldridge.

Mr Wooldridge believes this would deliver significant productivity gains in the form of increased growth rates from avoiding leaving sheep in an a paddock with too little feed, as well as from avoiding overgrazing and the subsequent reduced pasture re-growth rates.

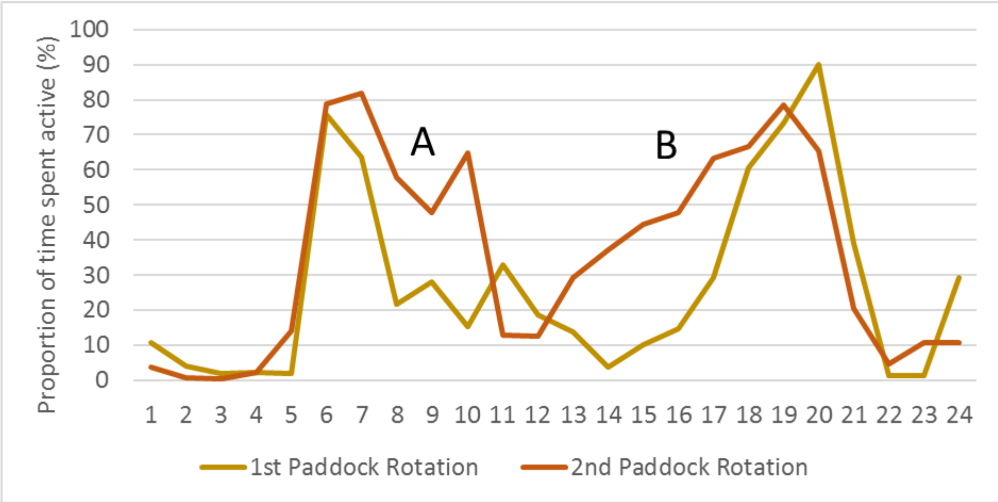


Figure 13 Comparison of diurnal activity for sheep in two different paddock rotations (over 24 hour period). The peak morning (A) and afternoon (B) activity times are significantly longer in the second paddock. The difference in the feed-base between the two paddocks was thought to be the major contributor to this variation.

Relationships between spatial landscape utilisation and remote sensing of the feedbase

To explore the potential for integrating satellite remote sensing and livestock tracking data, Normalised Difference Vegetation Index (NDVI) imagery from *Pastures From Space©* was extracted for the period coincident with the animals having access to two paddocks with differing feed-base conditions. Timing of the study was not ideal for this analysis as late summer relates to the lowest feed available with only minimal variation between the two areas.

Although marginal, an observable difference can be seen between the grazing intensity across two paddocks (Figure 14), with the lower grazing density being associated with a lower NDVI. Conversely, the higher grazing density was associated with areas reporting a higher NDVI.

“We obviously need to redo this again when we are in a winter growing phase, but I think there is some very useful information in this,” Mr Wooldridge said. “If we can understand how the sheep are using the country and which areas are and are not growing based on the satellite imagery, then I think we can start answering some big questions about getting better pasture utilisation”.

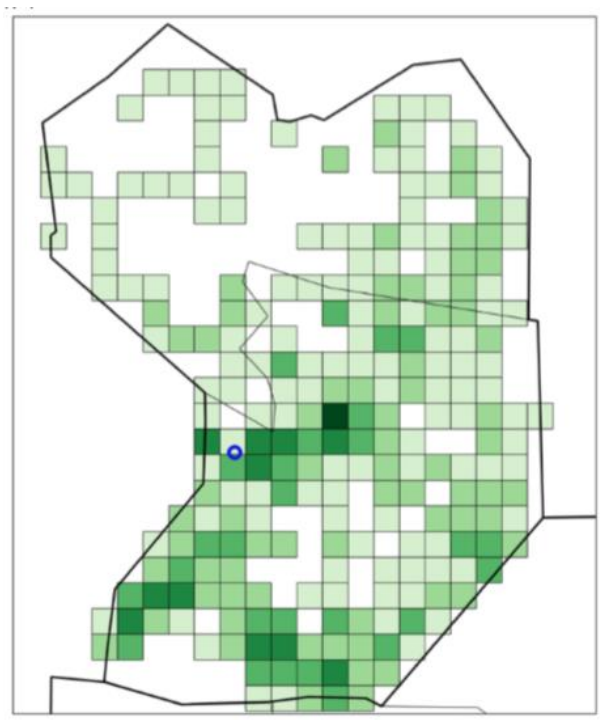


Figure 14 Grazing density map for the period when the mob had access to these two paddocks (gate open). There is a higher utilisation of the southern paddock compared to the north. Additionally, there appears to be a relationship between this grazing density and the NDVI data for the equivalent period (Figure 4).

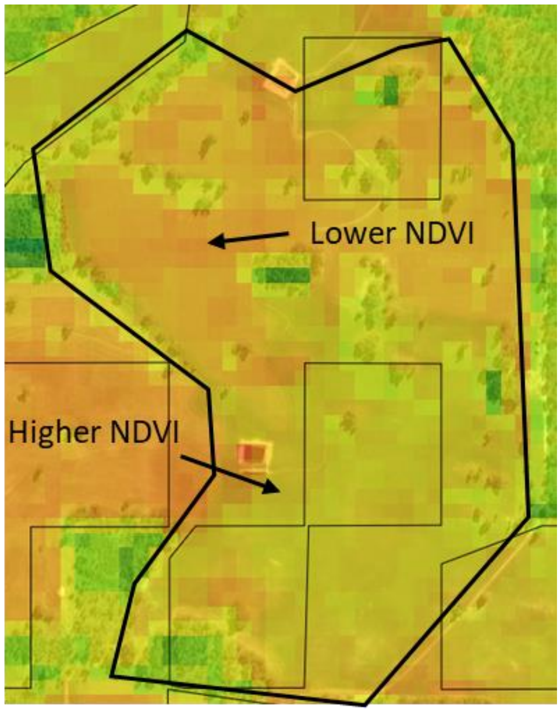


Figure 15 NDVI map derived from Landsat and sourced through Pastures From Space ©. The two paddocks are slightly different in NDVI, with the Southern paddock being marginally higher (green/yellow pixels – NDVI ~ 0.52) compared to the North (yellow/orange pixels – NDVI ~ 0.43). The sheep appear to prefer areas with higher NDVI, which when ground truthed was found to relate to a higher level of green feed (mint weed and clover).

Stock theft detection

Stock theft remains a significant issue in many areas of Australia and is a particular problem in southern WA. In anticipation of having access to a real-time system the Wooldridge family and the research team developed a protocol to simulate stock theft to determine if the data derived from a GPS collar could be used to provide an alert to this event occurring.

"We essentially tried to steal our own sheep!" Mr Wooldridge said. "The first time we did it we might have got away with it too, but the research team went back to the drawing board and redesigned the way the GPS worked so that on the second go round we would have got caught red-handed if we were genuine thieves".

Data from the GPS was used to determine normal behavioural patterns, and when the stock theft simulation was undertaken the difference between the normal activity and the behaviour under duress was sufficient to enable detection of the event (Figure 16).

Whilst the result is positive, more research is required to properly develop and validate a stock theft behavioural model. This includes the configuration of alerts to minimise the number of false positives (orange dots; Figure 16). Further investigation is also required to determine if sentinel deployments could effectively be used to provide this service.

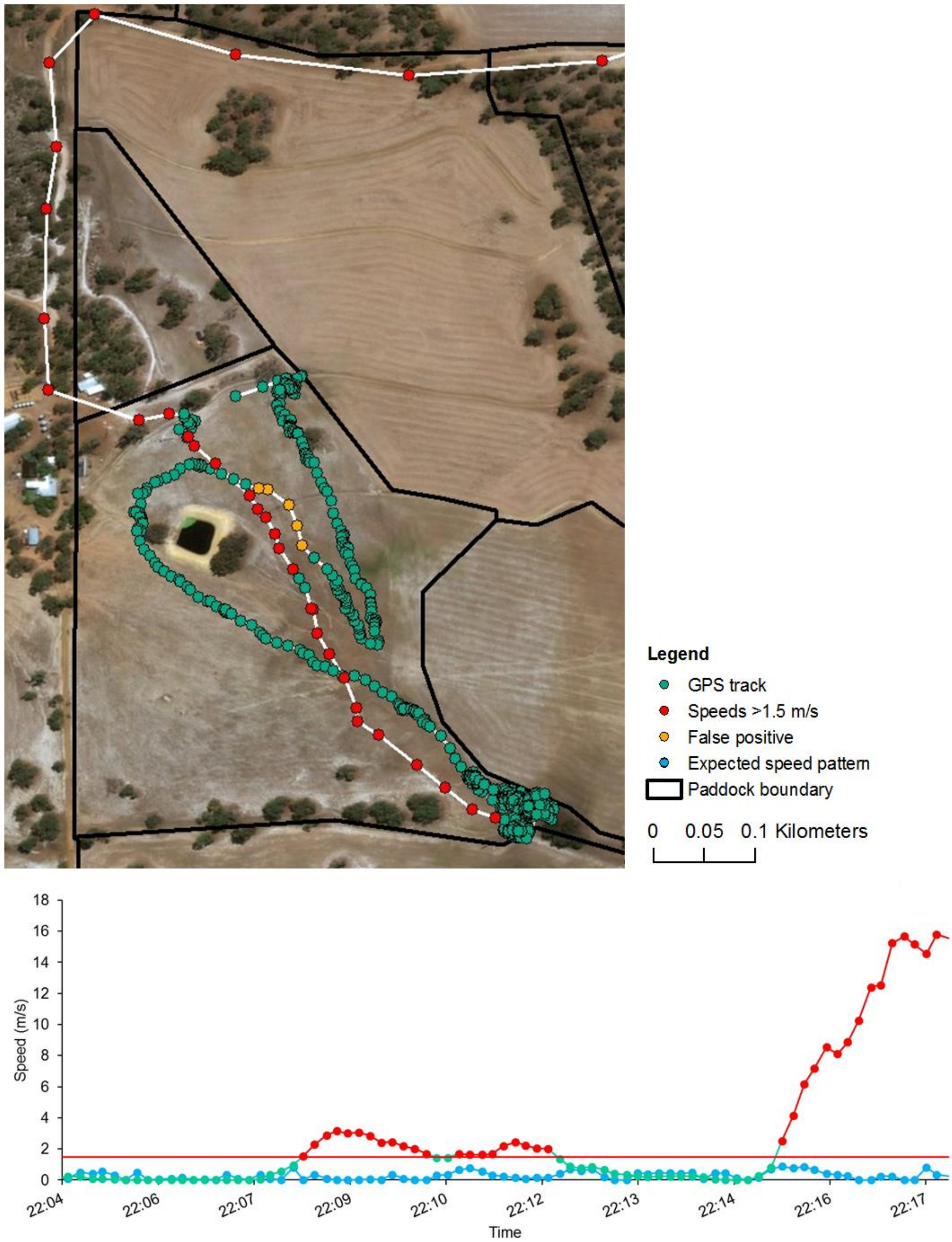


Figure 16 Stock theft detection simulation data. The first section of red dots shows the sheep be moved (mustered) to an area where it was held before being "stolen" off the property. The abnormally high speed (against what was the expected behaviour – blue dots) provides an alert that could be sent to the manager. The orange dots represent a potential false positive, however this can be modelled out as this behaviour is typical of that time of day.

2.6.7 Implications of having a live LBS system

Financial benefits

Mr Wooldridge believes the key financial benefit to come from having a location, behaviour and state (LBS) system will be the ability to mother-up ewes and lambs.

Modelling of the estimates of value suggest that an increase of 13.5% in annual total revenue could be achieved if Mr Wooldridge can identify which ewes are delivering the best lambs and then culling out the lowest performers (Table 3).

Mr Wooldridge reports "There's big variability across the mob, and if I can work out which ewes have raised two lambs and they have gone on to grow at a decent average daily gain (ADG), then I can potentially reduce stocking rates but actually increase the kilograms of meat produced per hectare".

The other significant value Mr Wooldridge identified is in increasing pasture utilisation through improved timing of grazing rotations. The data from the trial demonstrated that LBS information could provide an objective measure of the behavioural changes that Mr Wooldridge is looking for when it comes to making grazing rotation decisions. Mr Wooldridge suggested that integrating this animal behaviour data with information on the pasture quantity and quality from other sensors would allow him to increase revenue by 6.0% by maintaining live-weight gains (Table 3).

The simple application of preventing stock theft will lead to definite revenue gains. Mr Wooldridge has documented the rate and numbers of animals stolen in the past few years, and as such this value estimate of 3.2% (annualised revenue increase) is based on preventing similar future occurrences (Table 3).

The financial benefits from having a sentinel system (5-10% of the flock tracked) are still substantial although the largest value benefit (mothering up) is lost.

Other applications that could be achieved through sentinel tracking include watering behaviour and infectious disease detection. A benefit from a sentinel system would also come about through simply knowing where animals are on the away block.

Table 3 The top 3 benefits in terms of annualised value that could be derived from real-time LBS data for "Warialda" for a whole of flock deployment.

Rank	Application	Estimated annualised value	How would this work?
1	Genetic matching (dam/offspring)	13.5% increase in revenue	Identify top performing ewes and cull bottom performers to increase kg/ha
2	Timing grazing rotations	6.0% increase in revenue	Increased lamb growth rates and ewe condition score by maintaining growth rates
3	Stock theft	3.2% increase in revenue from prevention of losses	Stock theft events prevented as warning systems deter thieves

Non-financial benefits

Peace of mind

"More sleep - less stress," Mr Wooldridge said. He also said that there was a degree of emotional energy involved in worrying about stock theft that could be completely eliminated.

“I just don’t know what’s going on - they could be backing a truck up right now [with reference to stock thieves]”.

Having a LBS system that provides real-time warnings of sheep activity would significantly reduce if not eliminate this worry.

“You could spend your time thinking about more important things,” he said.

Mr Wooldridge indicates that this is also the case for some other issues as well. He added that he is “always on edge when it comes to egg counts and worm control” and suggests that having live LBS could potentially relieve this if it could detect early signs of infestation in the flock.

Welfare and social license

One of the other issues that Mr Wooldridge raised was around monitoring the general welfare status of animals and the wider implication for the industry.

“It’s really important that I don’t have unwell animals on the Albany block,” he said. “If I have people driving past seeing a sheep with a problem then I lose my reputation and that impacts on the whole industry’s social license”.

Engaging the next generation

Mr Wooldridge said the technology would be attractive to the next generation of farmers coming through. He points out that this sort of technology has been available in many other industries but not extensively for the red-meat sector.

2.6.8 Where to from here?

“We aren’t giving these GPS trackers back!” Mr Wooldridge said. The collars will now be deployed on their Albany property on ewes in the coming growing season. He is also looking forward to taking the modelling developed for stock theft detection and integrating it into a live tracking system when one comes to market.

2.7 GPS tracking reveals rapid response opportunity at Rosebank near Longreach

2.7.1 Summary

The simple GPS data collected from animals can be transformed into highly valuable information to help with both immediate decision making, such as knowing if weaners are not accessing water, and long-term decisions around infrastructure design and water placement.

Queensland Agricultural Training Colleges' Executive Director of Production, Andrew Lewis says the trial of collar-mounted sensors on five animals at their property "Rosebank", Longreach, had revealed the potential for productivity gains if a real-time location, behaviour and state (LBS) system were to become available.

Mr Lewis said the top three applications of such a system would be improved mustering efficiency, detection of predation events and detection of watering behaviours.

"We could actually change the whole way in which we muster animals," Mr Lewis said. "Rather than going out and finding them you could wait until they were coming onto water and then work from there."

If a real-time LBS system could be developed to provide an alert to predation, particularly of lambs, Mr Lewis said targeted interventions (shooting the dogs and pigs responsible) could increase lambing percentages and reduce ewes lost. "Pigs can very easily get into the lambs and before you know it you've lost 20-30% of a drop," he said. "And even with the exclusion fences you can still get dogs inside."

2.7.2 Background

"Rosebank" is 5,800 hectares in size and currently runs 2,500 ewes as part of a predominantly Merino flock. This property is managed as a part of the commercial operations of the Queensland Agriculture and Training Colleges which cumulatively manage around 30,000 hectares of country used for livestock across central and southern Queensland.

Seasonal conditions play a significant role in the turn off of lambs with low weaning rates having limited historical production to around 600-700. These are sold through various markets including direct consignment.

At the beginning of the trial property managers identified a number of issues that could be addressed including detection of where predation was occurring and understanding lamb and weaner survival to improve weaning rates. Their focus for participating was understanding the potential for location, behaviour and state (LBS) information to provide better management of weaner sheep which are particularly susceptible to problems around accessing water and at greater risk of perishing.

Figure 17 One of the key issues identified by the managers of Rosebank that LBS data could help with is understanding how sheep interact with water points and particularly the identification of weaners that fail to find and use the water trough.

2.7.3 Trial Objectives

The primary objective of this research trial was to explore how weaner sheep interact with water and determine if there was any way in which LBS data might be used to better manage this at risk group. There was also interest in exploring if there was any relationship between water point location and landscape utilisation. There was an intention to detect predation events however none occurred during the trial period.

2.7.4 Materials and methods

A total of 5 collars were deployed on weaner sheep in a mob of 800.

Data was analysed to explore the objective of animal use of water point by determining if daily visits to water were reported for individual sheep. Landscape utilisation was also mapped to see how this related to water point location.

A Paddock Activity Index (PAI) was developed based on distance travelled, time spent active and area of the paddock utilised. This was graphed and related to the various management activities that were undertaken.

2.7.5 Results

Individual animal use of water

An analytical procedure was developed to evaluate if an individual sheep had visited water on a daily basis through the trial period. A visit to water was characterised as the animal being recorded within 60m radius of the water trough and is demonstrated in Figure 18.

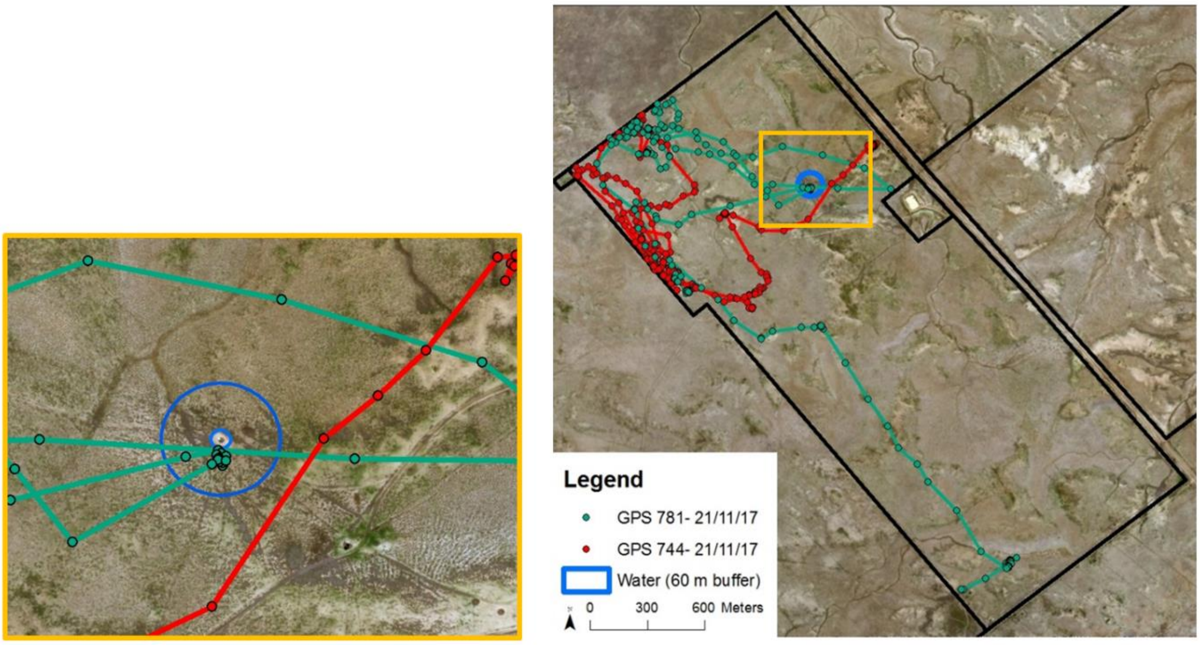


Figure 18 Two animals showing successful (green) and unsuccessful (red) use of the water point within a 24 hour period. Note that the unsuccessful weaner went close to the water point but did not actually use the trough.

The number of days in which individual sheep failed to report water usage is shown in Figure 19.

"This behaviour is really important in weaner sheep," Mr Lewis said. "Sometimes you can have the lead come in but by the time the tail end get there the lead are off and the last sheep turn around before they get a drink."

Animal 474 (red dot) failed to reach the water for three consecutive days when it was first introduced to the paddock. This was of significant concern and if a real-time alert system was available these criteria could have triggered an alert to the manager to investigate further.

Two other points of time showed variation in water use: in one case (B) a management activity (crutching) removed sheep from the paddock; and (C) a rainfall event. The rainfall event would have provided both surface water and increase moisture in the feed-base which would have allowed the animals to survive with access the water trough.

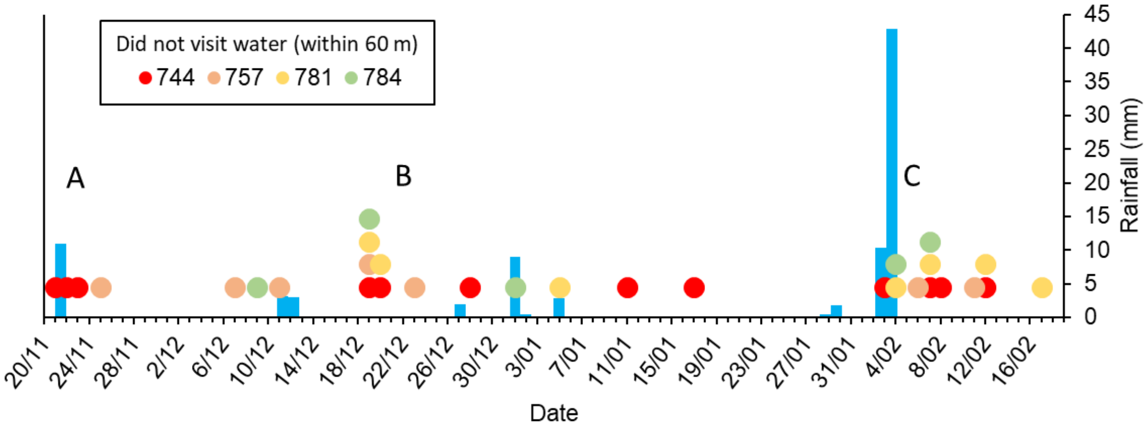


Figure 19 The days on which individual sheep did not visit the water point. There are three key points of interest: (A) Note that sheep 744 failed to visit the water point during a 3 day period early after being put into the paddock. This is of significant concern and if this information was available as a real-time system it would have prompted an alert to the manager to investigate further; (B) All sheep failed to drink, this was a result of a management intervention; (C) Several sheep stop coming to water after the rainfall event as they would have been getting adequate moisture from feed and surface water.

Foraging range and water point location

One of the other key areas of interest was the relationship between foraging range and water point location. The grazing distribution map (Figure 20) demonstrates that there are some distinct areas of under-utilisation. Tony Jesberg (Production Overseer at Rosebank) made comment on these areas identifying that the area just adjacent to the trough (Figure 20 - A) that had low utilisation was unusual in that there was actually feed there but the sheep just didn't want to go into that area.

"It does sit on the corner of two busy roads, it might be that the sheep were just disturbed too much by the traffic". Mr Jesburg and the research team spent some time speculating about how the sheep might be drawn out into this area to increase its utilisation with the idea of locating the supplement feeder there being considered in the future.

"The area of low utilisation at the southern end of the paddock makes more sense" (Figure 20 - B) says Tony. "That's a very different soil type and when those sheep were in there, there was just no feed there so no reason for them to be there".

One of the key applications of the GPS data that Mr Jesburg can see is in better planning water point locations. "We were planning on putting a new water trough into this paddock" he said. "The areas around the southern boundary, on the eastern and western edges [shown in C and D in Figure 20] carry good feed, and you can see them working it in the GPS data, but it's up to a 2km walk for sheep to get there from the current water". Mr Jesburg went on to explain that the proposed water (shown as the PW symbol in Figure 20) will soon allow sheep better access to the areas marked in C and D as well as area B which can grow some feed when it rains.

"This GPS data would truthfully help design where we should be putting troughs" explains Mr Jesburg and he is keen to get the collars out again to see how this would apply in other paddocks.

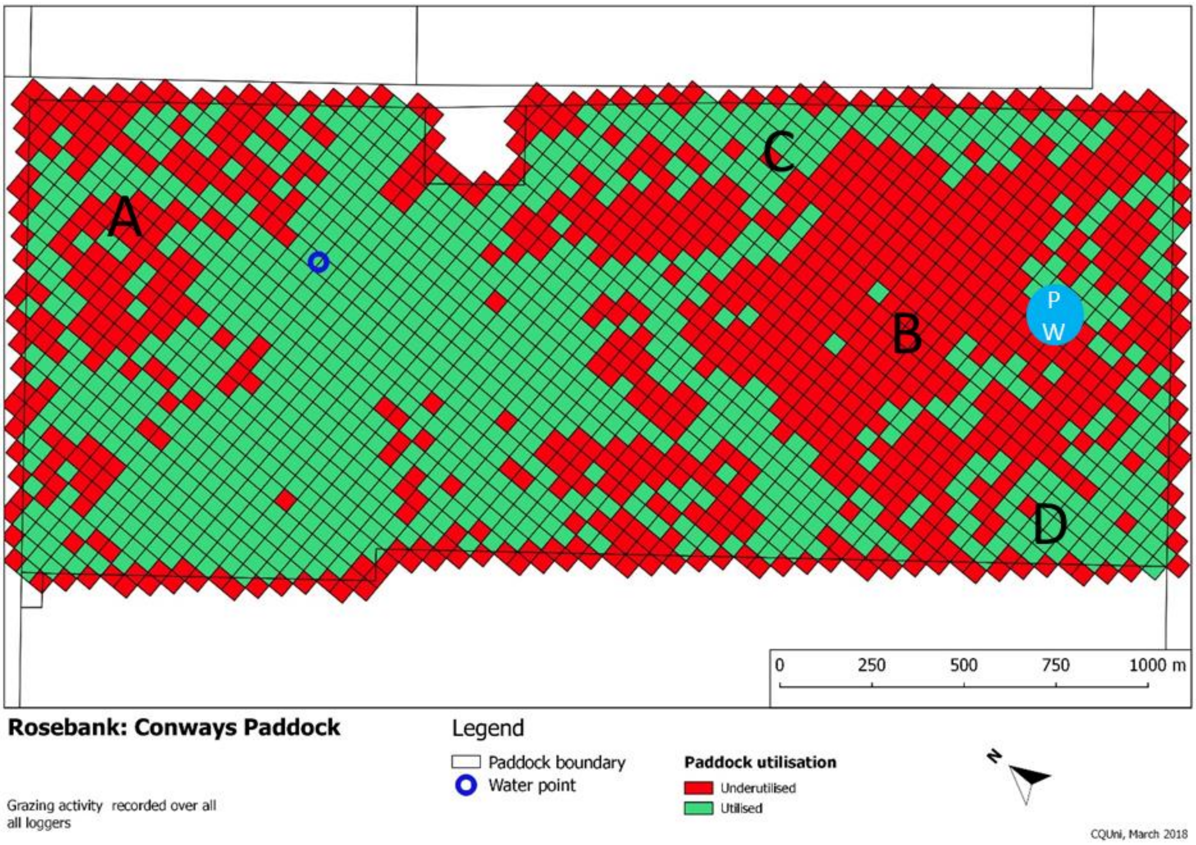


Figure 20 Grazing distribution map for all sheep. There is a clear preference for grazing activity to be recorded around the water point, some of which may actually be travelling behaviour to and from the trough. Area A held good feed but sheep filed to utilise it; area B has very little feed and matching low utilisation; Areas C and D held good feed and where used by sheep but animals had to travel up to 2km to access these areas. The proposed new water point (PW) will provide better access to areas C and D to potentially increase overall paddock production.

Quantifying animal behavioural responses to management actions

One of the most interesting results from the trial undertaken at Longreach were the observable responses by the sheep to management actions. There were several very clear patterns in the daily change in activity that could be attributed to different interventions that were carried out that have big implications once this data starts being delivered in real-time.

After an initial period of normal behaviour, the flock showed a decline in activity (red line - Figure 21). The research team and Rosebank management have come up with two possible explanations for this: the first is that the feed-base was gradually running out; the second is that an increasing parasite load was starting to impact on their ability to graze; it could also be a combination of both these factors.

On the 12th December supplement feeders where added to the paddock which caused sheep to dramatically reduce their activity. On the 20th of December the sheep were taken to yards and drenched and a smaller number returned to the paddock. The significant jump in activity following this treatment suggests that internal parasites may well have been a contributing factor to the decline observed in the deterioration period. However a change in flock structure may have also contributed with part of the group removed from this paddock.

Following this management intervention regular supplementary feeding interventions can be seen in the reduced activity on the days in which it was delivered to the paddock.

The Rosebank management team can see the potential in this data if it could be delivered on a daily basis. The concept of being able to remotely detect increasing parasite loads and better time drenching or know when animals need to be supplementary fed has significant potential.

The ability to confirm that that Intervention activities have actually been effective is also considered very powerful information. However, any behavioural model needs to take into account other management actions (i.e. supplementation) which would impact on the ability of a live LBS system to detect disease states.

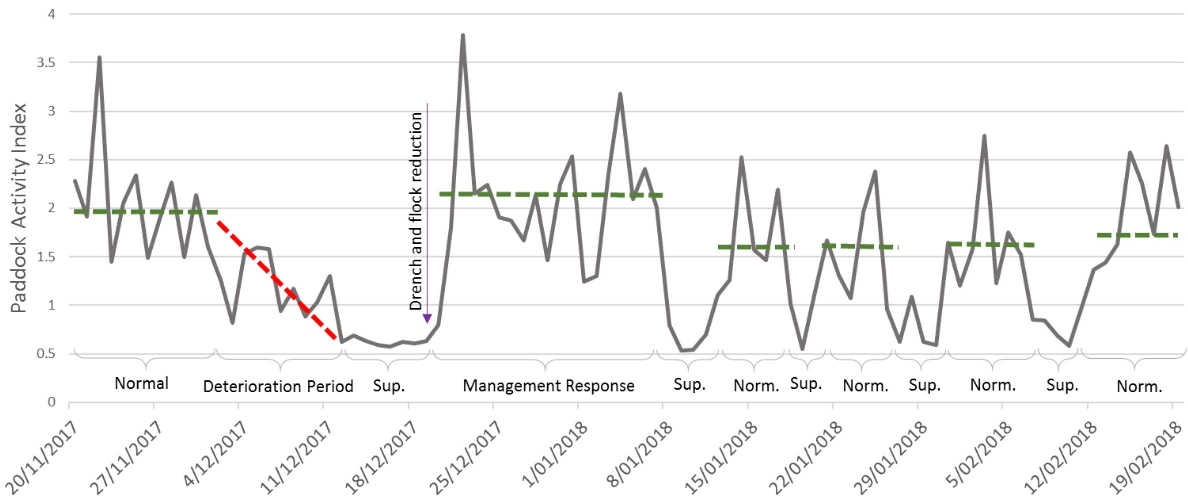


Figure 21 Variation over time in the average Paddock Activity Index (PAI - a combination of sheep movement and landscape utilisation data) for all sheep tracked. There are noticeable differences in the PAI across the different periods of the study. The most interesting feature is the deterioration period which was followed by a supplementation event and a subsequent drench and flock size reduction to which the sheep appear to have had a significant response. Numerous supplementation events after this first drench response period highlight that the data alone cannot be relied upon to provide an alert to disease based deterioration.

2.7.6 The benefits of having a live system

Financial benefits

The simple GPS data collected from animals can be transformed into highly valuable information to help with both immediate decision making, such as knowing if weaners are not accessing water, and long-term decisions around infrastructure design and water placement.

Andrew Lewis (Executive Director of Production) says the trial of collar-mounted sensors on five animals at their property ‘Rosebank’, Longreach, had revealed the potential for productivity gains if a real-time location, behaviour and state (LBS) monitoring system were to become available.

Mr Lewis said the top three applications of such a system in terms of financial benefits would be improved mustering efficiency, detection of predation events and detection of watering behaviours (Table 4).

“We could actually change the whole way in which we muster animals,” Mr Lewis said. “Rather than going out and finding them you could wait until they were coming onto water and then work from there.” If a real-time LBS system could be developed to provide an alert to predation, particularly of lambs, Mr Lewis said targeted interventions (shooting the dogs and pigs responsible) could increase lambing percentages and reduce ewes lost. “Pigs can very easily get into the lambs and before you know it you’ve lost 20-30% of a drop,” he said. “And even with the exclusion fences you can still get dogs inside.”

Table 4 The top 3 benefits in terms of annualised value that could be derived from real-time LBS data for Rosebank

Rank	Application	Estimated annualised value	How would this work?
1	Mustering efficiency	Total costs reduced by 2.0%	Change the way in which mustering is planned and undertaken
2	Predation detection	Avoid lost total revenue of 1.6%	Regular losses due to dogs and occasional large losses due to pigs detected and controlled
3	Water related behaviour	Total costs reduced by 0.5%. Also prevent very occasional losses of 50 lambs in one unusual event.	Detection that all animals have successfully reached and used water point

Non-financial benefits

As a result of the trial the Rosebank management team identified several non-financial benefits of LBS, including using data to better understand animal mortalities.

"We have a lot of unidentified losses - we don't know why they die, but if we had tracking we could work out what the problems were," he said.

There was also value in terms of general welfare monitoring for quantification of ethical management practices.

Mr Lewis said the system would also provide peace of mind from having data available confirming everything was under control.

He said the data from a LBS system would be even more powerful if integrated with other information.

"It would be interesting to see how a combination of sensors would go. Monitoring water consumption at the same time you are tracking animals could have value in really hot weather," he said.

2.7.7 Where to from here?

Rosebank are re-deploying GPS collars across new paddocks in the next few months to gain more data around paddock utilisation to improve water point location planning.

QATC are also exploring the opportunity to invest in an expansion of this project into a Digital Sheep Research Program which would see LBS tracking integrated with numerous other sensors.

2.8 Understanding ewe and lamb interactions could lead to big returns at "Stonyhurst"

2.8.1 Participants

John Douglas-Clifford "Stonyhurst" Cheviot NZ

2.8.2 Highlights

The use of GPS data to monitor ewe and lamb interactions for genetic selection purposes, could lead to increases of up to 10% for both weaning and growth rates, according to leading New Zealand grazier John Douglas Clifford.

The Douglas Clifford family is renowned as among the most innovative producers in New Zealand, running a 500-cow breeding herd and 10,000-head ewe flock at "Stonyhurst" on the South Island.

John Douglas Clifford believes that monitoring which ewe and which lamb are associated after marking could identify the best performing ewes in terms of overall productivity, allowing for culling and decisions which maximise the genetic potential of the flock.

"This would brings us back up to par with other industries like dairy and pork who have had this sort of information for years," he said.

2.8.3 Background

"Stonyhurst" is located about 1.5 hour's drive north of Christchurch on the South Island of New Zealand. The operation is run by the Douglas Clifford family, who have a track record as among the most innovative producers in New Zealand. 'Stonyhurst' carries a 500-cow breeding herd, 10,000-head ewe flock and a 400-hind venison deer herd.

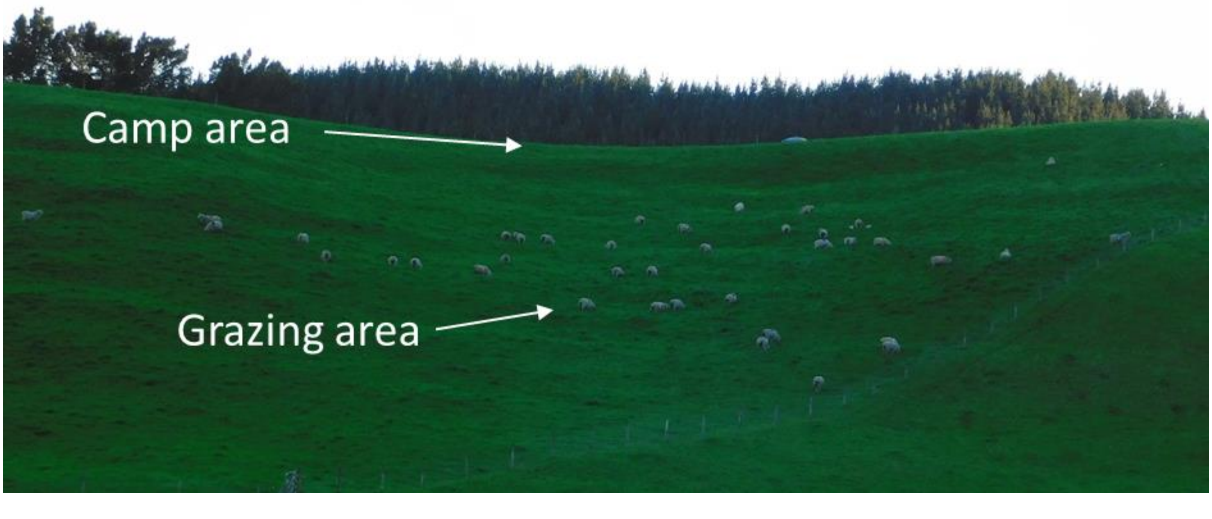


Figure 22 Sheep grazing in the paddock whilst being GPS tracked on Stonyhurst. The camp area was at the top of the hill (just beyond the ridgeline) whilst the main grazing area was lower down the slope.

2.8.4 Trial objectives

The key applications of interest to Stonyhurst management were the ability to quantify spatial grazing landscape utilisation and the potential behavioural indicators that might enable improved management opportunities.

2.8.5 Materials and methods

Six tracking collars were fitted to ewes in a mob of 40 (Figure 22). The standard data analysis techniques were undertaken before some minor additional analysis exploring variation between individual animal in landscape utilisation was further explored. This involved calculating the area of landscape used on a daily basis by each animal using the minimum convex polygom

2.8.6 Results

Grazing distributions and the differences between individual sheep

There was a strong correlation between elevation and the camping and grazing activities of the sheep. Animals showed a strong tendency to camp at the highest point in the paddock and then grazed down towards the bottom of the hill to the water point during active periods (Figure 23). This can also be seen in Figure 22 where the sheep are in an active grazing mode and working the mid and lower slopes of the paddock.

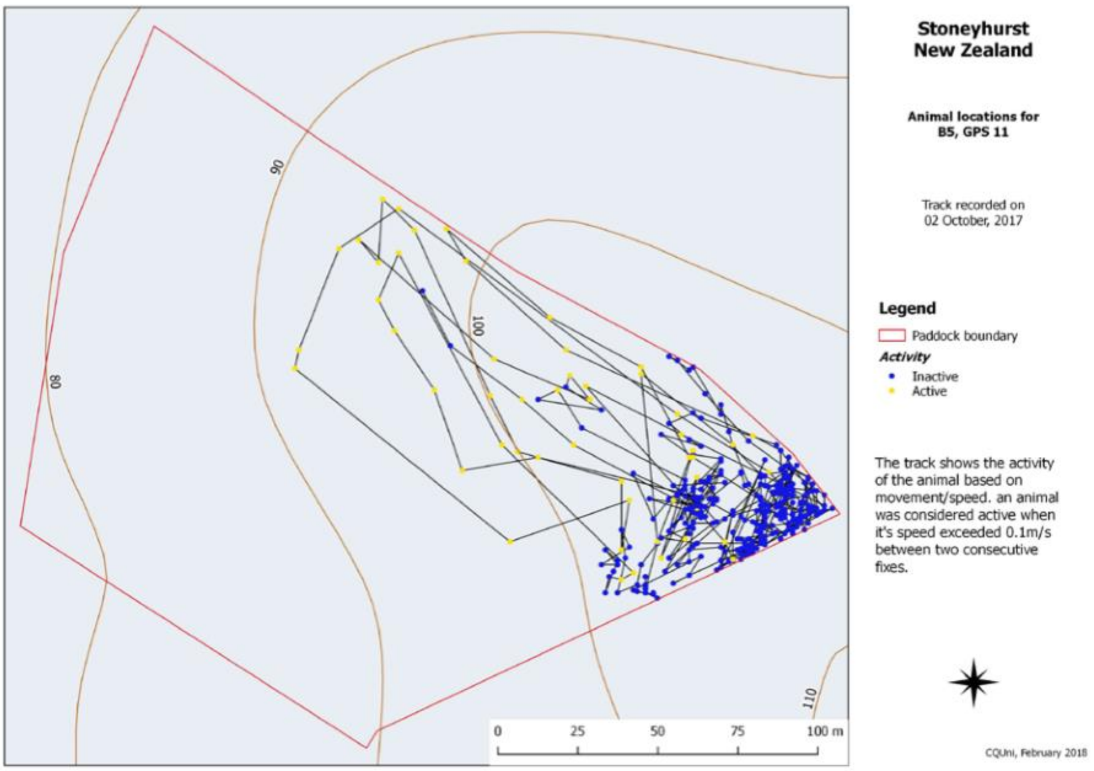
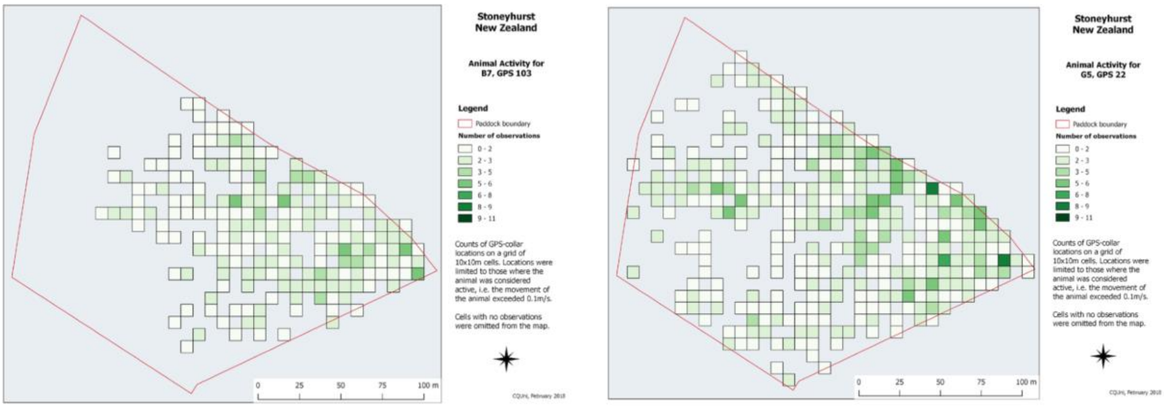


Figure 23 A single day trace of the active and inactive data for a sheep. The data demonstrates the tendency for sheep to camp at the highest point and graze down the hill during active periods.

There was some variation found in the way in which individual sheep used the landscape with some animals demonstrating a much higher tendency to graze further from the camp site (Figure 24). According to John Douglas Clifford, this was of interest because of the potential to select for sheep that use the landscape both productively and sustainably.



A – Low spatial utilisation B – High spatial utilisation

Figure 24 A comparison of two individual sheep showing one animal with relatively low spatial landscape utilisation (A) and another with the highest landscape utilisation (B).

Behavioural variation in the paddock over time

One of the most interesting results from the trial was the variation observed in animal behaviour over time. The individual animals reported in the previous section not only demonstrated variation in landscape utilisation in space, this also varied in time (Figure 25). Whilst both sheep started the trial period with similar areas utilised, Sheep 22 increased the area grazed substantially over time. Whilst the reasons for this is unclear at this stage, Mr Douglas Clifford believes this sort of data could help detect management issues that might be going undiagnosed.

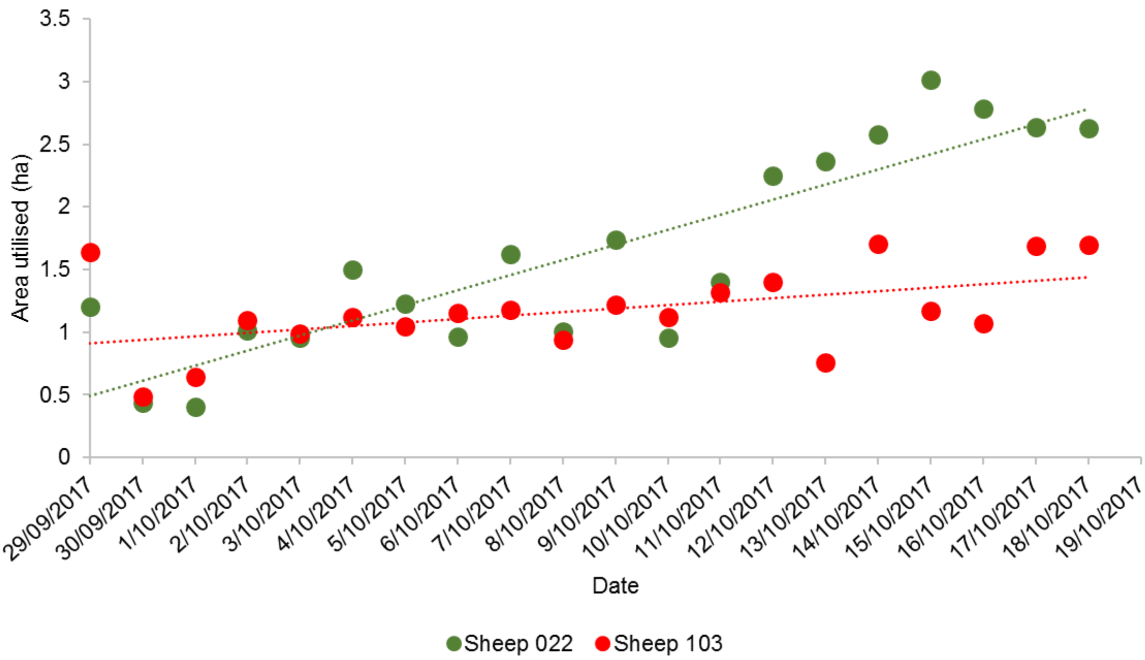


Figure 25 Temporal change in landscape utilisation for two sheep. Animal 103 shows a consistent landscape utilisation pattern whilst animal 022 shows a substantial increase in area used.

2.8.7 Implications of having a live system

Financial benefits

There were numerous potential benefits identified of having location, behaviour and state (LBS) data available in real-time across the flocks and herds on "Stonyhurst". The top three were associated with potential increases in revenue (Table 5).

Table 5 The top 3 benefits in terms of annualised value that could be derived from real-time LBS data for Stonyhurst

Rank	Application	Estimated annualised value	How would this work?
1	Genetic matching (dam/offspring)	Increase in total revenue of 5.9%	Being able to identify the progeny from best ewes and culling non-performers
2	Refining fertiliser application.	Increase in total revenue of 3.5%	Targeting fertiliser to areas where it's needed to increase whole paddock productivity
3	Water related behaviour	Avoid losses in total revenue of 0.5%	Avoiding losses in growth rate when animals occasionally lose water supply (e.g. burst pipe)

Genetic matching of females and offspring

Mr Douglas Clifford said this opportunity offered "the highest value to our operation".

"You can spend $18 per head to do the DNA testing to determine parentage, but for sheep this is prohibitively expensive," he said. "If you could determine which ewe and which lamb are associated after marking, then apart from mismothering problems, you could identify the best performing ewes in terms of overall productivity, both hers and the lambs. This brings us back up to par with other industries like dairy and pork who have had this sort of information for years."

Using this sort of information to inform culling decisions and increase the genetic potential of the entire flock, Mr Douglas Clifford said increases of around 10% in both weaning percentages and growth rates would be possible.

"Location and behaviour data from individual animals could also be used to start selecting for animals that use the landscape and water resources in a way that increases overall pasture productivity", he said. While this would be hard to quantify, he believes it would result in increased production per hectare through this novel form of genetic selection.

Landscape optimisation

One of the key applications that Mr Douglas Clifford was interested in was using GPS tracking data to understand landscape utilisation and determine if this could be used to develop prescription maps for variable rate fertiliser.

"We have all the variable rate fertiliser equipment ready to go, we just need to start thinking about zoning up," he said.

Whilst underlying soil fertility would be a primary driver of any prescription maps, there may be value in understanding where animals are taking nutrients from and targeting these areas for fertiliser top ups. This approach is similar to the site-specific management strategies used in the cropping industries where initial variable rate applications are targeted at fixing any underlying nutrient variation, before switching to a maintenance variable rate approach which uses yield maps to understand high and low nutrient export areas.

Grazing animals don't just export nutrients they also move them around a paddock and this would also need to be taken into account. This isn't a simple application of LBS information but Mr Douglas Clifford believes there could be at least a 5% gain in production over the whole property if it could be realised.

Monitoring water access and drinking behaviours

One of the simplest but most valuable applications of real-time LBS information would be the provision of alerts or warnings around animal interaction with water behaviours.

"There could be quite big gains to be made for us if we could pick up problems early, particularly in the summer months," Mr Douglas Clifford said.

It was not uncommon for a pipe to burst or similar accident resulting in animals being left without water for a period of time before it was discovered, he said, significantly checking the weight gain of growing animals.

"You can very quickly see a 100gram per day reduction in growth rate - over 3000 lambs for 2 days that's a lost income of over $3,000 each time it occurs," he said.

Non-financial

One of the key benefits identified by Mr Douglas Clifford was the value held in being able to quantify the welfare state of animals across "Stonyhurst".

"Welfare monitoring will be essential in the future for marketing and sales," he said. "We want to be able to prove that we are doing the right thing, that's a big thing for our industry."

This would require the ability to detect any issues related to animal welfare and clearly demonstrate that there has been an adequate intervention to fix any problems.

2.8.8 Where to from here?

"Stonyhurst" is planning on implementing a real-time LBS system as soon as one becomes commercially available in a form factor that will work for sheep.

2.9 Sensors deliver early detection of Buffalo Fly

2.9.1 Industry Participants

Phil Jones & Anthony Feez - Landmark

2.9.2 Highlights

Sensor data could allow suppliers to help producers obtain better value from the animal health products they provide.

Sensors were successfully used to detect the infestation of buffalo fly and the effectiveness of control measures.

Phil Jones from Landmark said that "from a supplier's perspective we need to help producers get the best value out of the products we provide". Mr Jones said that working together with a producer to review the information provided by sensors would allow them to optimise the timing of insecticidal ear tag treatments thus maximising effectiveness.

2.9.3 Background

Early results from producer and industry discussion had suggested that there might be an opportunity for LBS data to help the supply chain refine the way in which it delivers products and services to graziers. An opportunity became available to work with Landmark to explore how LBS data might benefit the operation of th supply chain. Landmark is a leading distributer of insecticidal ear tags for the control of buffalo fly. In this collaborative trial, GPS collars and accelerometer ear tags were deployed on cattle involved in an efficacy trial of Y-Tex's range of insecticidal ear tags.

2.9.4 Trial objectives

The trial was designed to explore how location, behaviour and state (LBS) data might bring value to the suppliers of animal health products and services to producers. Whilst the objective of the sensor deployment itself was to determine if Bufflao fly infestations could be detected it was the potential benefits to the supply chain that were of interest.

2.9.5 Materials and methods

GPS tracking collars and accelerometer ear tags were deployed on treated (3) and untreated cattle (3) involved in an efficacy trial of Y-Tex insecticidal ear tags used to treat for Buffalo fly. The trial was based on "Belmont", Rockhampton (currently run by AgForce) and undertaken as part of a network of similar trials across commercial herds in Queensland. The cattle used were from a commercial seed stock producer leasing the property. The deployment of sensors on these animals required an additional animal ethics approval which was integrated into the ear tag efficacy trial (Approved by the CQU animal ethics committee - approval number 20920).

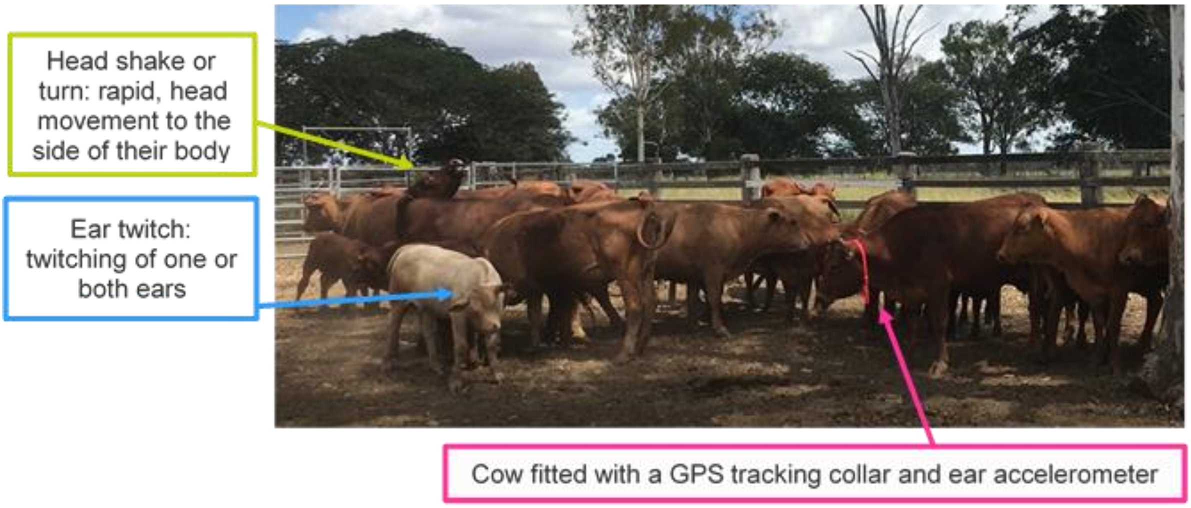


Figure 26 Untreated cattle fitted with GPS collars and accelerometer ear tags showing visible signs of irritation from Buffalo Fly. Head shaking and ear twitching behaviours were used to inform the accelerometer derived Fly Agitation Index (FAI)

The accelerometer ear tag collected fine scale head movement data; and the GPS tracking collar was used to examine spatial and temporal behavioural and location changes.

2.9.6 Results

Fly Agitation Index

Accelerometer data was used to calculate a Fly Agitation Index (FAI) - a measure of how much head-throwing activity the animals expressed. A comparison of two animals and the derived FAI is shown in Figure 27. One animal was fitted with an insecticidal ear tag (orange line) for the duration of the trial which provided effective control of Buffalo fly as highlighted by a consistently low FAI. The untreated animal (no insecticidal ear tag; blue line) was not treated until the 14th February (trial day no) when observations suggested that the fly burden was having a significant impact on animal wellbeing. After treatment this animal showed a similar low FAI to that of the animal with an insecticidal ear tag.

The key outcome of this study suggests that sensor data could provide remote warnings of the degree of Buffalo fly infestation. This would mean producers could better monitor emerging infestations and time the application of treatments to optimise their efficacy.

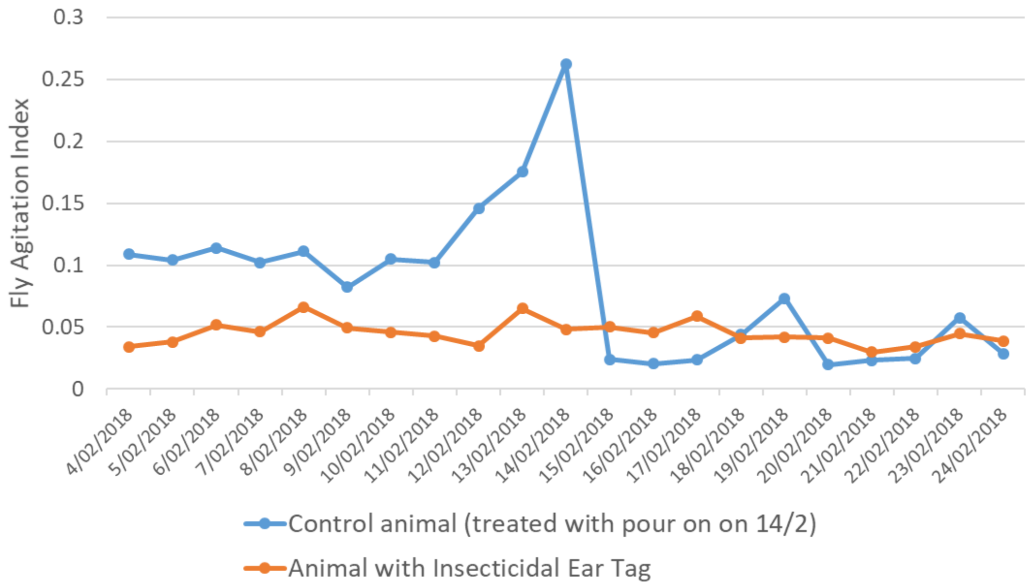


Figure 27 The variation in time for two animals and the Fly Agitation Index derived from an accelerometer ear tag sensor. The orange line represents an animal with an insecticidal ear tag showing consistent low agitation levels. The blue line represents an animal that was not treated until the 14th February when Buffalo fly infestation became a welfare concern. After treatment this animal returns a similar FAI level as shown by the animal wearing an insecticidal ear tag.

Paddock Movement Index

GPS tracking data was used to examine the behavioural responses of the untreated group before and after treatment.

The initial hypothesis was that there would be an increase in grazing time and landscape distribution after the untreated were treated, as animals would be less time agitated by flies and spend more time performing maintenance behaviours, such as grazing and resting.

However, the results showed that there was actually a decrease in the Paddock Movement Index (PMI) after treatment (green line; Figure 28). It may be that animals were actually moving more prior to the treatment in an effort to get away from flies (red line; Figure 28). Therefore, the lower PMI after treatment is likely more representative of the normal and desirable grazing activity.

The limited number of animals in this trial meant that these results can only be considered indicative and further replicated research needs to follow up this pilot study.

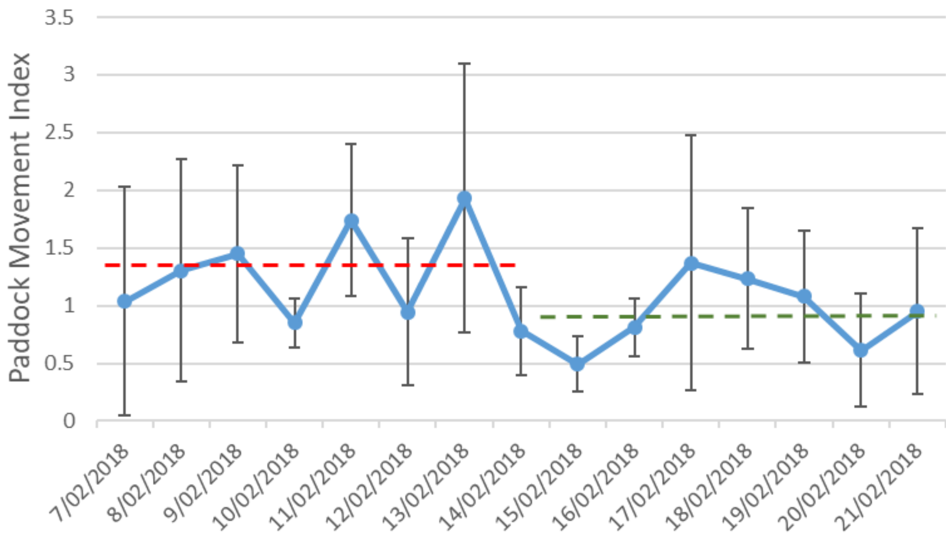


Figure 28 The behavioural response of untreated cattle before and after treatment with a commercial pour-on insecticide. The Paddock Movement Index is derived from GPS data of individual animal's distance travelled, time spent active and area of the paddock utilised

2.9.7 Implications of having a live system

Landmark's Phil Jones believes there is value in having automated on-animal sensors feeding live data back to producers.

"From a supplier's perspective we need to help producers get the best value out of the products we provide," he said.

Mr Jones believes that producers would benefit from knowing exactly when their animals were being affected by Buffalo fly and to what degree.

The current recommendations for the implementation of control strategies are based on economic thresholds of fly counts (300 per animal), but this relies on the ability of the manager to actually find the animals and make regular observations.

"It's possible that this sort of data coming in live to a producer could help them keep track animals in areas where it's impossible to check them on a regular basis," Mr Jones said.

This could translate into a much more refined and strategic approach to Buffalo fly management whereby chemical tags are deployed only when they are needed, allowing them to have a prolonged effect later in the season.

"Not putting out tags too early is critical, if you go too soon then you can run out of efficacy later in the season," Mr Jones said.

Another important value proposition for suppliers is the ability of producers to quantify the impact of the treatments they are implementing.

"There is a lot of anecdotal evidence around the effectiveness of certain treatments but with this sort of information you can actually see the impact that a treatment has on things like agitation and time spent grazing," he said.

Can sensor data impact on the supply chain?

The critical result of this study is that there appears that there could be an opportunity for suppliers of products and services to refine the way in which they interact with producers to bring significant benefits to the industry as a whole.

Mr Jones said that working together with a producer to review the information provided by sensors would allow them to optimise the timing of insecticidal ear tag treatments thus maximising effectiveness.

Where to from here?

Landmark and CQUniversity are currently discussing the potential for further trials to explore how this system might be implemented.

2.10 Sensors for managing livestock on Travelling Stock Routes

2.10.1 Participants

Tom White, Team Leader Upper District for Riverine Local Land Services.

2.10.2 Highlights

GPS tracking of livestock on Travelling Stock Routes (TSRs) in the Riverina region of NSW has demonstrated how this technology could provide better outcomes for animals, producers, biosecurity and the environmental sustainability of the routes themselves.

Team Leader Upper District for Riverina Local Land Services, Tom White, said, “TSR managers faced a tough task balancing the feed and water needs of animals with maintaining the feedbase and ground cover along the network. These factors have been optimised at the same time as taking into account the upcoming temperatures which can limit the ability of stock to travel”.

“Having seen the detail that we can get from GPS tracking, it’s really clear that there is enormous potential for these sorts of system to improve the management of TSRs,” Mr White said.

LLS and CQUniversity are currently discussing the possibility of developing an integrated system that provides real-time GPS tracking data along with biomass/groundcover and climate forecasts to take this research to the next level.

2.10.3 Background

TSRs cover 2 million hectares of NSW, with more than 500,000 hectares managed by Local Land Services (LLS). TSRs are a valuable resource for livestock management as they provide a feed source during times of drought. They have also been recognised as having significant biodiversity value. The challenge for LLS is managing this resource to provide a sustainable feed-base for livestock while maintaining the remnant vegetation and biodiversity in these areas.

2.10.4 Trial objectives

The objective of this study was to explore how location, behaviour and state (LBS) data could assist in the management of livestock on TSRs. Two key areas of interest were identified early in the study: the first was based on the relationship between animal movement and temperature; the second focussed on validating the actual distances travelled against the targeted distances set to optimise grazing pressure and maintain ground cover.

2.10.5 Materials and methods

A single cow (with calf) was fitted with a GPS collar (Figure 29) and monitored for a period of 86 days as it was managed on a TSR in the Riverine LLS region.

Figure 29 Cow fitted with GPS collar amongst the herd travelling on the TSR

2.10.6 Results

Quantifying distances travelled

GPS tracking provided the LLS with an objective measure of the areas utilised by this herd of cattle whilst grazing on the TSRs under their management (Figure 30). The daily distances travelled could be compared against the planned TSR usage to assess compliance.

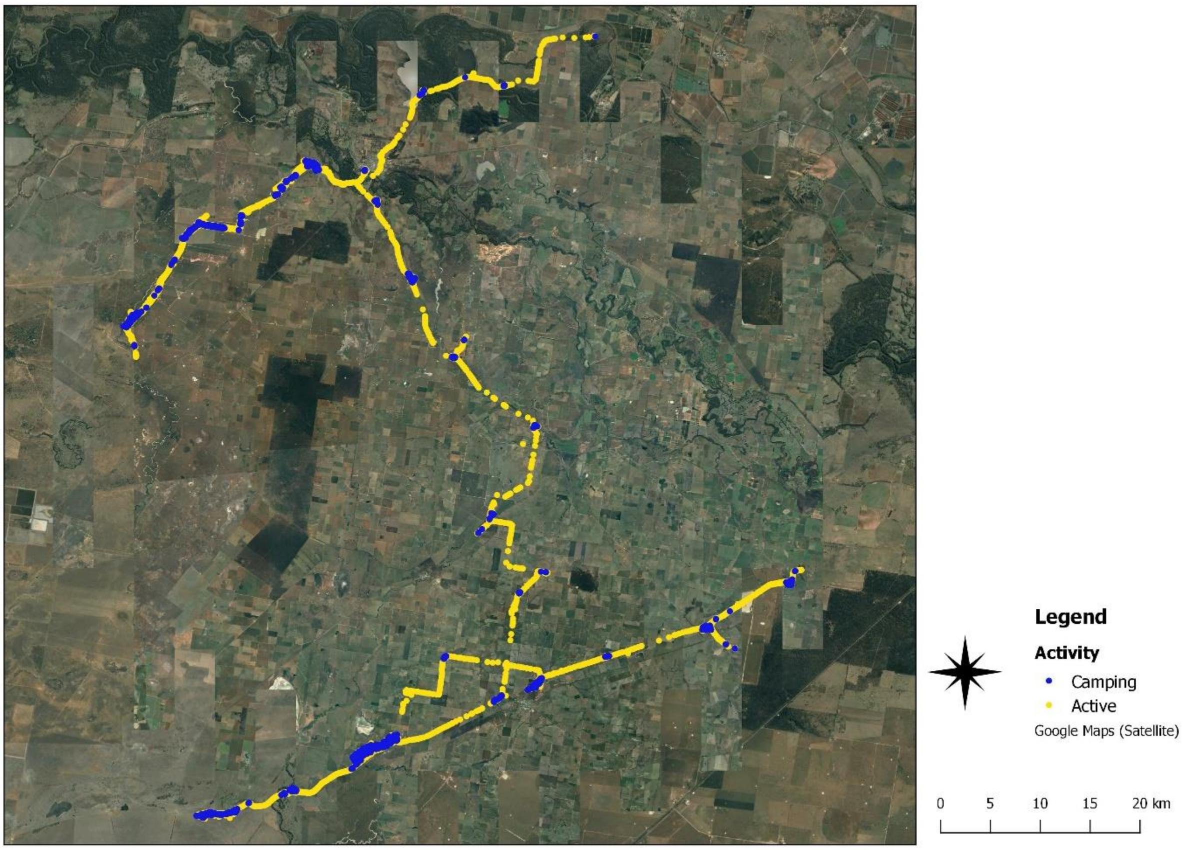


Figure 30 The total area utilised over the 86 day period, including periods when this cow was active (yellow) and camping (blue).

The average daily distance travelled by the tracked cow was 11.3 km, with most days ranging between 7.5 km and 17.5 km. Only a few days exceeded 20 km (Figure 31).

Of particular interest was the diurnal activity recorded for the cow. This pattern showed a distinct difference to the normal behavioural pattern of a cow in a paddock, which would show a peak morning and afternoon grazing activity pattern (Figure 32). This animal demonstrated a high speed in the morning (from 6am) before gradually slowing down. This pattern is typical of animals being managed on the road as they are pushed along but quite different from a normal behaviour pattern demonstrated by a cow in a paddock.

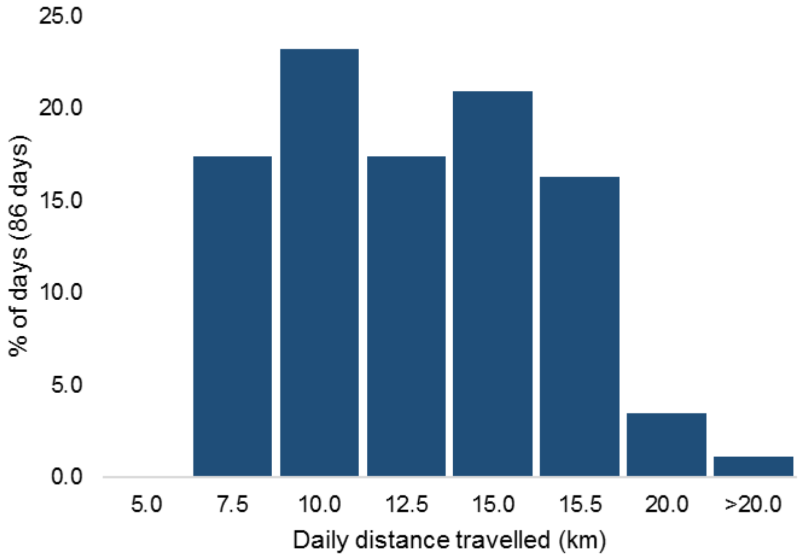


Figure 31 The distribution of daily distance travelled over the 86 days on the TSR. An average daily distance travelled was 11.35 km.

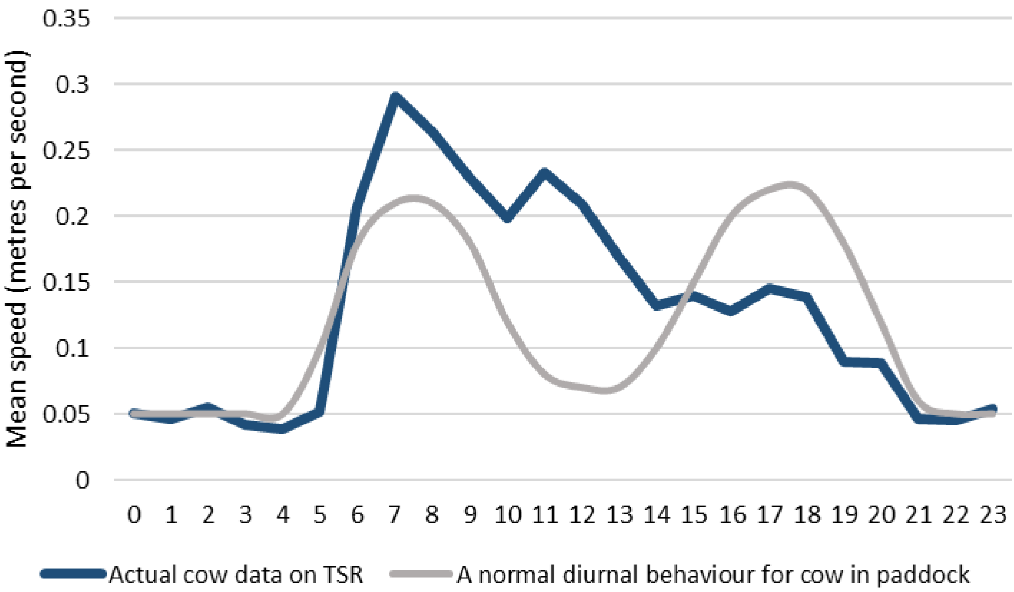


Figure 32 Diurnal activity for a cow over a 24 hour period whilst being managed on the TSR (blue line). Note that this is quite different from the normal diurnal pattern reported for animals under normal paddock management (grey line).

Understanding the relationship between temperature and animal movements

Of particular interest to the LLS team was the relationship between animal movement and maximum daily temperature. Historical management of TSRs has been less flexible and expected animal movement to be achieved in spite of environmental conditions. The current management strategy involves being more flexible and taking into account the impact that high temperatures can have on livestock and their ability and willingness to move.

During time on the TSR, this cow experienced reduced daily movements on all but one of the hottest days (>40°C; Figure 33 A-D). For the majority of these >40°C days, distance travelled was reduced to <15 km.

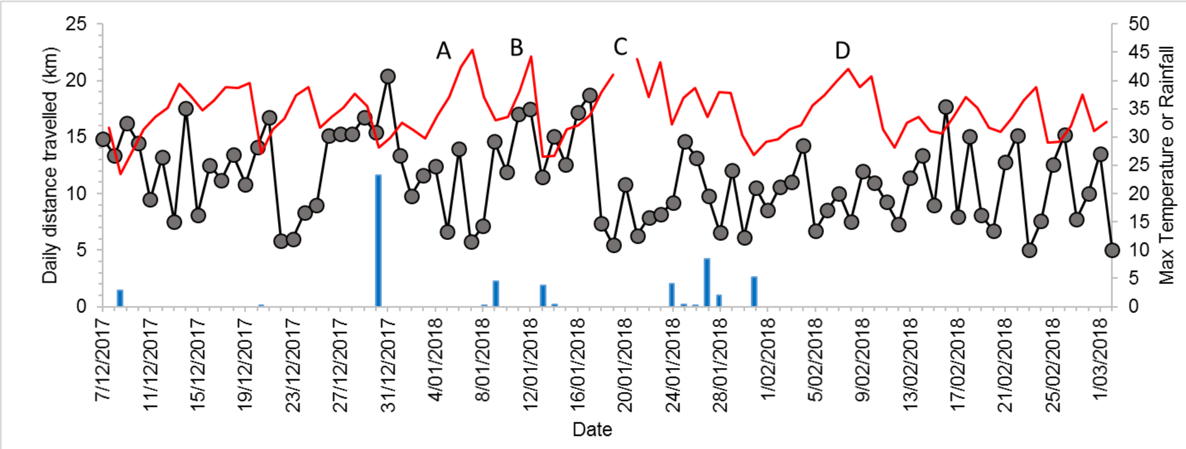


Figure 33 Daily distance travelled and climatic data (maximum temperature (red) and rainfall (blue)) during the period that this cow was on the TSR. Four periods of time were found to exceed a temperature threshold of 40°c (A-D). For periods A, C and D animal movement in terms of distance travelled was reduced to under 15 km on these extreme days. For period B, distance travelled was more than 15 km.

2.10.7 Implications of having real-time LBS information

Team Leader Upper District for Riverina Local Land Services, Tom White, said having this sort of information available in real-time would be invaluable.

"We are trying to balance the needs of animals on the road, particularly feed and water with the sustainability of the TSRs," he said.

"If we can get information on where these animals are and then start to integrate it with forecast temperatures, water point location, status and the groundcover and feed available, we will be able to be far more flexible in how the TSRs can be used."

Mr White said that being able to manage animals around expected heatwaves, where they can access water and the need to avoid overgrazing the TSRs was a significant challenge. Such a system would also provide benefits for biosecurity.

"The capacity to monitor the locations of animals, where they have been, and for what duration, cannot be overvalued should the need arise from a biosecurity point of view," he said. "We hope it never happens but if something occurred where we needed to know where animals may have strayed, camped or wandered, then the LBS data would remove any confusion or contradiction."

Mr White emphatically believes that having LBS data would provide better outcomes for the animals, the producer and the long term viability of the TSRs.

2.10.8 Where to from here?

The Riverina LLS and CQU are currently developing a project proposal, which will take the concepts established in this project from theory to reality. The proposed project will develop a real-time monitoring system that integrates GPS tracking devices and the appropriate telemetry (satellite) with feed-base, water point and forecast temperature data to optimise livestock management on the travelling stock route.

2.11 Discussion and conclusions

All producers and industry participants involved in the deployment of sensors articulated that there was significant value in the information collected. What was surprising was that most participants believed there was significant value in the historical data and that they were going to continue to deploy the store-on-board collars into the future. Several of the producers have decided to invest their own time into learning how to download and process data so that they can resource this themselves.

This contrasts with the original purpose of the study which was to examine the value of the data in anticipation of the development of real-time or near real-time monitoring systems. It was initially thought that the historical data would provide a sample of what could be achieved. It was not expected that producers would be keen to continue the use of the research devices.

Obviously the group of producers involved in this project represent the very leading edge of thinkers and adopters however it does highlight the value that the industry can see in this information.

2.11.1 The key applications explored by industry participants

There were several themes that kept coming up amongst the producer and industry participants involved in the deployment of sensors. There was universal interest in the application of LBS data to explore and understand landscape utilisation. All of the producers involved believed there was an opportunity to improve their landscape and feedbase management to optimise production.

For some producers, the pathway to achieving increased profitability from this opportunity was at least somewhat apparent. The use of refined fertiliser management and paddock splitting on “Shepherds Hill” was already happening with the LBS data assisting in understanding and implementing the interventions. The roll out of strategically placed water points on “Rosebank” is another example of management action targeted at influencing grazing distribution.

For other producers the actions required to take advantage of the measured spatial variability in landscape utilisation was more complicated and less clear. The tracking of sheep on “Warialda” had revealed the value of this data but longer term deployments where considered necessary before profit making decisions could be articulated.

Another commonly reported applications related to the management of grazing rotations and the use of animal behaviour as a key indicator of the need to move animals to new pasture. Many of the producers looking for trends in feedbase and animal behaviour in the data strongly believed that there was significant value in being able to better time these management decisions.

One important caveat on these feedbase related benefits is that in most cases, whilst producers believed there was large value in the use of LBS data to manage spatial and temporal feedbase variation, they were not confident in articulating the financial benefits. They strongly believed they could gain significant value from LBS systems and in many cases more than many other applications but they stressed that until they couldn’t really be sure until they had started implementing the systems.

The other key area that the producers and industry partners where interested in was the application of LBS data for detection of events that occur to animals which they can’t easily observe themselves. This is the key behaviour and state information that producers believe that, if delivered in real-time or near-real-time, could assist them greatly. They key feature of this broad area was the diversity in applications. For "Shepherds Hill" it was phalaris toxicity, for ACC it was the detection of "restlessness" or an inability to settle into normal grazing, for "Warialda" it was stock theft, for "Rosebank" and "Stonyhurst" it was water related behaviours, for Landmark it was detection of pest incursion and for cattle on the TSR's it was the relationship between movement and temperature. The key point from this is that producers and industry have a wide range of applications from which they believe value can be derived if a LBS system can be developed to provide the right information in the right time frame.

The importance of non-financial benefits

While the producers involved in the study are very clearly driven by profitability, it's by no means the only point of value they could see. "Peace of mind" was a regular phrase used to describe the key non-economic benefits. There appeared to be a general consensus that the provision of LBS data in real-time (or near-real-time) could have a significant impact well beyond the time taken to check that livestock are not experiencing a problem.

There is a distinct feeling amongst the participants that this information will "free-up brain space". By this they mean that the things they would normally worry about might be left to the monitoring system. For example the worry of knowing if a gate was closed or a water trough was being used would be replaced with more strategic thinking around planning activities or taking advantage of opportunities as they come up. This simple benefit may be worth further research but might also be a difficult area to objectively measure.

It never ends…

It's worth noting that the applications and benefits reported and summarised by participants here in this report are not the final picture. Even as this report is being written the producer and industry partners are continuing to provide more in-depth insights. One producer recently went back through the activity data and related it to their supplementary feeding program. From this, they have decided to test and evaluate a new sup-feeding management strategy. The value of LBS to producers is significant and at least in some cases it can take some time to uncover the hidden gems.

2.11.2 The key applications: a researchers perspective

Whilst managing the numerous case studies involved in this project the research team were able to make some general observations on key applications that were apparent when viewing the bigger picture across multiple properties.

Animal welfare and social license

The majority of producers involved in the study believed that there was value in LBS information applied to animal welfare. This value came in two main forms: the first was the ability of the producer to be alerted to problems and enable timely intervention; the second was the ability of the industry to portray itself as welfare focussed and demonstrate this through objective sensor based monitoring. The producers were quick to point out that the benefits from the latter were hard if not impossible to quantify at an individual property level but had wider industry significance.

What was apparent to the research team was that there were numerous components of animal welfare which might be addressed by LBS systems. The five freedoms are commonly used as a framework for welfare assessment. Examples of how the LBS sensors might relate to each freedom follow, this is not an endorsement of the five freedoms model but does demonstrate how LBS data might provide an in-depth and objective measure across a well-known welfare framework.

1. Freedom from hunger and thirst: The "Rosebank" case study explicitly explored animal water interactions (Figure 18). Animal relationships with feedbase were explored in the "Warialda" case study (Figure 13).
2. Freedom from discomfort: although not specifically explored in any of the case studies this can be related to the camping activity reported from "Shepherds Hill" where animals were able to select their optimum resting area (Figure 3 (iii)). It could also be related to the movement of animals on TSR's during extreme temperatures (Figure 33).
3. Freedom from pain injury and distress: Several examples of how LBS data might be used to asses this were reported including: the detection of possible worm related disease state in sheep on "Rosebank" (Figure 21); the problems with phalaris toxicity on "Shepherds Hill" (Figure 4); and the Fly Agitation Index (Figure 27) developed in the Landmark case study.
4. Freedom to express (most) normal behaviour: This is probably the most well represented freedom in terms of the ability for LBS data to provide some measure. The diurnal patterns of behaviour evident in the ACC cattle (Figure 7) and the "Warialda" sheep (Figure 13) is typical of animals expressing a normal behavioural pattern.
5. Freedom from fear and distress: this is perhaps the most difficult freedom to relate to LBS information. The closest example of an animal that was potentially displaying some mental distress can be seen in the outlier (animal 782) as observed in Figure 11. This animal showed more restless behaviour. Taking this further, an animal in genuinely fearful and distressed state would likely display an exaggerated degree of this sort behaviour which could be measured using LBS data.

The critical issue may not be so much can we detect animal welfare, as how the industry uses this information to engage with the broader community to maintain support. LBS systems could provide significant benefits for social license but more research, targeted at understanding how consumers might interact with this data is required.

Biosecurity

Several producers involved in the deployment of sensors could see the benefits from the perspective of biosecurity for their own operation. However, it is the application of LBS data on a much larger scale that has obvious benefits for the industry as a whole. The potential to track any animal's location and its history of transport between farms and across states would have clear benefits in the case of exotic disease outbreak. There are also likely to be potential benefits from early detection of both exotic and endemic diseases. The challenge for this concept is the development of a hardware system that is at least as reliable as the current RFID NLIS based system. Most of the hardware solutions available at the moment do not meet this requirement (see section 5). As such, whilst this concept shouldn't be ignored, any attempt to formalise it needs to take into account the reality of the current hardware limitations. It is also worth considering the social impact that the use of LBS data for biosecurity and integrity might have, producers are notoriously sceptical when it comes to oversight of their operations. Any move to increase the sensing capabilities of the current NLIS would have to be carefully pitched to the industry to prevent backlash.

Market compliance and assurance

There were several points at which the research team observed the potential for the data collected from LBS systems to impact on the specifications set for markets. The most obvious example was observed in cattle being managed on the ACC property prior to sale. These animals had to be handled in a particular way to meet MSA specifications. In particular the co-mingling threshold prior to transport for slaughter was examined. The GPS tracking data could be very clearly used to validate that these animals had met this criteria.

Whilst simply meeting management criteria is useful, it is also possible to go on and assess the animal's actual response. Further research could explore how individual animal reaction and behaviour might be directly related to market compliance. This would be particularly beneficial for dark cutting which has a significant impact across much of the industry.

Enabling on farm research

Several of the producers involved in the project articulated the potential benefits that might be gleaned from using LBS data as part of on farm experiments. For some producers this might be as simple as undertaking observational studies where the cause of animal mortalities can be quantified as the animal can actually be found to enable a diagnosis through post-mortem.

For other producers more complex experimental designs have been considered. This is not dissimilar to the way in which yield monitoring technology in the grains industry has allowed an expansion of on-farm trials. One case study property "Shepherds Hill" is already planning to undertake more GPS tracking to enable a pre-and-post evaluation of the impact of paddock splitting on landscape utilisation. The ACC team are also considering the integration of GPS tracking into on-farm research trials o pasture renovation techniques.

Although LBS data does not provide the full picture of productivity (it really needs to be integrated with live weight gain and/or body condition score to do this) it does shed light on areas that many producers are keen to better understand and provides objective data where a "gut feeling" is currently the standard.

2.11.3 Whole of herd/flock verses sentinel deployment

The interest amongst producers in retaining the research grade store-on-board collars has been previously mentioned. This wasn't expected, and the interest in the sentinel deployment of real-time systems was probably underestimated at least at the beginning of the study. Throughout the project it became apparent that the producers involved could obtain significant value from even a very small number of tracking devices and could see this value translating through to commercial systems. The take home message is that even collar based systems deployed on only a few animals are likely to have benefits, at least for some of the leading producers in the industry.

2.12 Key messages

- All producers and industry partners involved in deploying sensors on their livestock could see a range of benefits from LBS data.
- The most universally valued benefits related to feedbase issues, particularly understanding landscape utilisation and timing of grazing rotations. There appears to be big potential gains to be made through this. However this needs to be treated with some caution as there is more uncertainty around the value of these applications.
- The producers articulated a range of applications that could be achieved in terms of using LBS data from live or real-time systems. These included detection of watering behaviours,

stock theft, plant toxicity issues, disease detection and parasite infestation. Each producer had their own unique value proposition around which they considered LBS useful.

- Producers continue to use the simple store-on-board GPS collars to collect data. There appears to be value for both sentinel and whole of herd/flock deployment amongst these leading producers.
- Whilst financial impact is critically important, the producers could also articulate a range of non-financial benefits that related to “peace of mind” which also had value.

3 Where is the value in tracking the location, behaviour and state of livestock?

3.1 Introduction

This section of the report provides the results of an engagement process across several activities designed to provide information on how the industry might benefit from location, behaviour and state (LBS) information.

While there is a general perception that there is significant value to be derived from LBS systems in the red meat industry there have been few studies which specifically explore how producers would most benefit from them. Some studies have looked into specific use cases: for example mustering efficiency and bull activity in Northern beef (Swain et al., 2013); and disease detection in southern sheep systems (Henry et al., 2013). However they haven't explored how these systems could provide benefit across a range of applications.

This study aims to explore how LBS data might provide a broad range of benefits and determine if the value comes from specific use case or if investment by producers will be justified by small benefits from a range of applications.

3.1.1 Broad objective

The broad objective of this section was to examine the range of potential applications that producers considered to be of value. There were several key questions developed to address this:

1. What are the applications of LBS data that producers consider have value?
2. Are there differences between industry segments in terms of their valuation of each of the applications identified?
3. What are perceived to be the highest value applications reported across the industry?

3.1.2 Broad methodology

To obtain the desired information three activities were undertaken:

1. An online survey of producer perceptions of the relative value of different applications;
2. In-depth interviews of selected producers to develop case studies of the financial and non-financial benefits of individual application of LBS information; and
3. A collation process in which all information gleaned throughout the study was brought together to identify where the value might be drawn from LBS information.

3.2 Online survey of applications of location, behaviour and state information

3.2.1 Introduction

An online survey was designed to capture information on the potential applications of LBS data from as many producers as possible across Australia.

3.2.2 Materials and methods

Respondents were recruited to participate in the online survey through direct email campaigns, agricultural industry newsletters and Facebook advertisements. A short animated video was created to simply illustrate how LBS data could be collected and used on farms in Australia to encourage people to participate in the survey.

The online survey asked respondents to first indicate their role within an agricultural operation. They were then provided with a short explanation of the proposed capabilities of an ear tag which could give producers LBS data. They were told to assume the technology was available for use now and asked to rank 17 possible applications of LBS data from 1 (most important) to 17 (least important). Participants were also given the opportunity to suggest any other applications of LBS data they believe would provide value to their operation. The final section of the survey asked respondents to answer several demographic questions e.g. postcode, type of operation and age.

Respondents were also given the option to leave their name and contact details if they were willing to participate in a telephone interview to discuss in more depth the potential financial benefits that could be obtained from LBS data. The online survey and telephone interview process was approved by the CQUniversity Human Research Ethics Committee (approval no. 20826).

3.2.3 Results and Discussion

Respondent details

The sixty producer respondents to the online survey had an even age distribution (Figure 35). It might have been expected that the respondents would skew to younger ages but there were sufficient older producers to balance this. Throughout this project it became apparent that there is a large cohort of older producers that are particularly interested in this technology. Some of them would fall into the category of early adopters (of any innovation) but most have a specific interest in LBS systems.

The majority of respondents had larger properties (Figure 36) however it’s worth noting that some very small land holders (under 40 hectares) also participated. There may be a unique opportunity for LBS systems in the small block holder segment (sometimes seen as a risk to the industry) that could provide broader industry benefits. The location of respondents to the survey is displayed in Figure 34 revealing a large geographic spread.

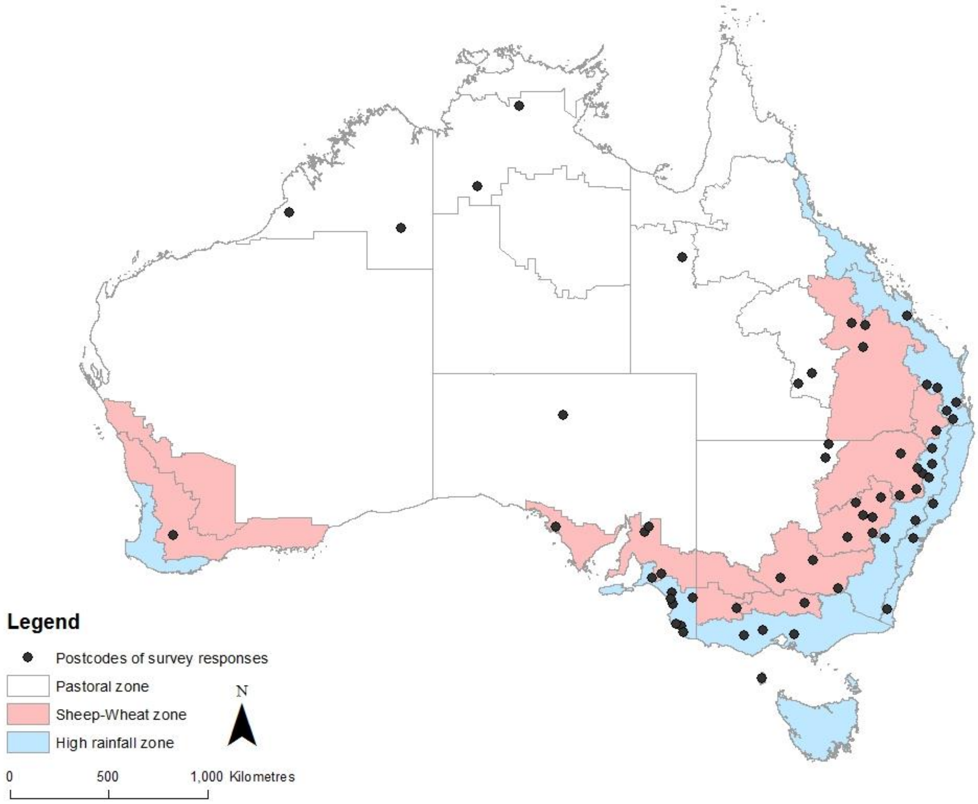


Figure 34 Distribution of producer respondents to the online survey

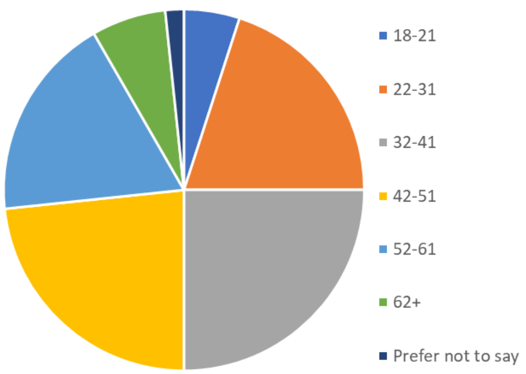


Figure 35 Distribution of respondent ages. There was a fairly even spread with as many older producers as younger

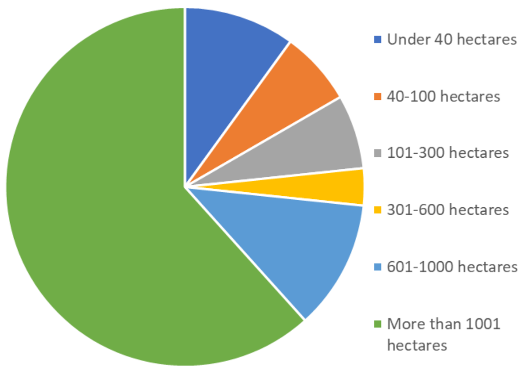


Figure 36 Distribution of respondent property sizes. The majority of respondents were managing more than 1000 hectares

Results from all respondents to online survey

Water related behaviour was the application believed to be most valuable to farmers with over half of all respondents ranking it within their top 5. This was followed by welfare monitoring, mustering efficiency, timing of grazing rotations and health alerts for critical injuries (Table 6). There were noticeable trends in preference for applications across the different production systems and so the results were segmented by zone and industry.

Table 6 Ranking of all applications across all respondents and then the breakdown across zones and industries

Application	All respondents (%) n= 60	Pastoral beef (%) n=9	HRWS* Beef (%) n=21	HRWS* sheep (%) n=12	HRWS* beef/sheep (%) n=18
Water related behaviour	53	44	67	42	56
Welfare monitoring	45	22	38	83	39
Mustering efficiency	42	89	33	50	33
Timing grazing rotations	40	89	29	42	33
Health alerts for critical injuries	38	11	48	33	44
Calving and lambing detection	35	11	57	0	39
Landscape utilisation	33	67	29	17	33
Pregnancy status	30	22	38	8	33
Disease detection	27	11	19	25	61
Refining supplementary feeding	25	44	14	25	33
Stock theft	25	22	38	50	0
Predation detection	20	11	5	33	28
Genetic matching (dam/offspring)	20	22	14	42	6
Oestrus detection	18	22	29	8	11
Poisoning detection	17	0	14	25	22
Refining fertiliser application	13	0	19	8	17
Genetic matching (male/female)	10	11	10	8	11

* HRWS = High Rainfall Wheat Sheep Zone

Additional items reported by producers

Respondents were provided with an opportunity to report additional applications. Several were reported and included: “during supplementary feeding to detect bullies and/or shy feeders”; “detecting whether animals are in correct paddocks/on-farm”; “use animals as yield monitors and to calculate feed efficiency and pasture production”; “virtual fencing”; “identifying lambing sites”; “landscape exclusion for environmental management”; and “management information e.g. animal weights, health treatments, joining history, calving/lambing records” [presumably relating this to LBS data].

Results for zone and industry segments

Pastoral zone beef producers reported mustering efficiency as the top ranked application. Following this were three feedbase related applications (timing of grazing rotations, landscape utilisation and refinement of supplement feeding). Detection of behaviours associated with water came in lower than expected for this segment (Table 7). Given the interest in remote water monitoring systems

(RWMS) in this zone this application was expected to rank higher however producers may feel that this application is adequately served through these existing systems.

Beef producers from the High-Rainfall/Sheep-Wheat (HRSW) zone ranked water related behaviour as their highest priority with 83% listing it amongst their top 5 applications (Table 8). Other applications of interest included calving detection and health alerts for critical injury.

Sheep producers from the HRWS zone reported welfare monitoring as the highest ranked application (Table 9). It is unclear exactly how sheep producers perceived the definition of "welfare monitoring" and may have used this as a coverall term for all disease and injury related applications. The mustering efficiency application also ranked highly amongst sheep producers along with detection of stock theft.

Not surprisingly, the application reported by the beef-sheep segment show a mix of the highly ranked application from both sheep and beef alone (Table 10). However one noticeable addition is the top ranked application of disease detection. This may be due to the fact that sheep producers considered this as being addressed under the welfare detection application.

Table 7 Top 5 ranked applications by pastoral zone beef producers (n=9)

Rank	Application	%
1	Mustering efficiency	89
2	Timing grazing rotations	89
3	Landscape utilisation	67
4	Refining supplementary feeding	44
5	Water related behaviour	44

Table 8 Top 6 ranked applications by High Rainfall/Wheat Sheep zone beef producers (n=21)

Rank	Application	%
1	Water related behaviour	67
2	Calving and lambing detection	57
3	Health alerts for critical injuries	48
4	Pregnancy status	38
5	Welfare monitoring	38
6	Stock theft	38

Table 9 Top 6 ranked applications by High Rainfall/Wheat Sheep zone sheep producers (n=12)

Rank	Application	%
1	Welfare monitoring	83

2	Stock theft	50
3	Mustering efficiency	50
4	Genetic matching (ewe/lamb)	42
5	Timing grazing rotations	42
6	Water related behaviour	42

Table 10 Top 5 ranked applications by High Rainfall/Wheat Sheep zone beef-sheep producers (N=18)

Rank	Application	%
1	Disease detection	61
2	Water related behaviour	56
3	Health alerts for critical injuries	44
4	Welfare monitoring	39
5	Calving and lambing detection	39

Results for non-producer respondents

Whilst the focus of the survey was on the potential applications that producers were interested in, the survey was open to other participants in the red meat industry. A total of eight respondents fell into this category. Their responses are shown in Table 11. The low numbers in this section preclude further analysis of this data, although it is worth noting that these results do not differ significantly from the information provided by producers.

Table 11 Responses to survey by non-producers, these included researchers, consultants, supply chain participants.

Rank	Application	%
1	Mustering efficiency	63
2	Water related behaviour	50
3	Predation detection	50
4	Health alerts for critical injuries	38
5	Welfare monitoring	38
6	Refining supplementary feeding	38
7	Landscape utilisation	38
8	Timing grazing rotations	38

3.3 In-depth interviews of selected case study producers

3.3.1 Introduction

The original plan in this project was to obtain details from the producers involved in the on-farm demonstrations of location, behaviour and state (LBS) data and then determine exactly how they could gain benefits from these systems and what the financial impact might be on their business. Early on in the project it became apparent that there was a large amount of diversity in how producers perceived they could gain benefit from a LBS system. To capture as much of this diversity as possible, the interview footprint was expanded to include as many producers as possible from as many different regions and production system types. Producers that completed the online survey were asked whether they were happy to be contact to participate in a telephone interview regarding the financial impact of LBS systems.

3.3.2 Materials and methods

To capture the information required to determine the financial impact of different applications of LBS data, a set of semi-structured questions was developed and responses recorded during a telephone interview. The questions asked producers for information on the production statistics of their operation and then collected detailed information on what they perceived to be the relevance and value for the range of different applications of LBS systems. A total of 19 producer interviews were completed and analysed.

The contextualisation of responses

Producers were asked to provide responses to the questions based on what they considered to be an average year, rather than the most recent, which may have been affected by seasonal conditions. All producers understood the importance of this and were able to work within this framework.

To provide a better context to the producers, they were provided a basic introduction to the research and then asked to respond to the questions based on having a smart ear tag device that could detect the location, quantify basic behaviour and detect relevant biological states as inferred from behaviour. This was an open discussion and importantly set the scene for the responses provided by the respondent. Before proceeding, the interviewers were comfortable that the respondent had a basic grasp of the capabilities of a LBS system that included sensor capabilities and the ability to deliver information back to the producer.

Importantly, when the producer was asked to articulate a financial value around each application it was reinforced that the benefit should come from the LBS system and could not be achieved by another means available at the moment. This was particularly relevant for any potential revenue gains articulated.

Understanding the enterprise

Baseline data from each producer was gathered to enable the later calculation of percentage gains in revenue or reductions in costs from each application of a LBS system.

Estimating production and total revenue

The production and revenue data for each operation was relatively easy to gather with producers able to clearly articulate the average number and classes of stock sold and market channels. Prices for these stock classes were then derived from the MLA market tool (https://www.mla.com.au/prices-markets/market-reports-prices/) over an average of the last three years for the relevant sale yard or market channel. For some specialist markets a producer nominated average price was applied. The purpose of using three year average data was to smooth out the relatively high prices received across most red-meat commodities in the past 1-2 years.

Estimating operating costs

In contrast to production data, producers struggled to estimate the costs of production of their operations. Early interviews suggested an alternative approach was required and as a consequence a general cost of production as a percentage of revenue was applied across all operations surveyed. This did vary according to zone with pastoral properties being allocated a nominal operating cost of 60% and wheat sheep and high rainfall operations allocated a nominal operating cost of 70%. These operating figures include all business costs along with depreciation but deliberately exclude both employed labour and operator and family labour (dealt with below). These estimates were drawn from averages across the ABARES survey data for the past three years.

Because the technology under review has a high relevance to labour use and efficiency this item was treated as a separate line item and costs estimated from the total full-time equivalent (FTE) working on the property as reported by the producer. A cash cost for each FTE labour unit was estimated by applying the *Pastoral Award* (2010) Farm and Livestock Hand Level 5 Award with on-costs and superannuation of 29%. This meant that all labour used on the properties was valued equally at approximately $26 per hour or $196 per day.

Estimating benefits

Producers were asked to provide an estimate of the value of the benefit, across a number of potential applications of LBS data. The potential benefits were divided into three categories: estimated annual cost savings; estimated annual revenue gains; and finally the revenue savings achieved by preventing or containing a catastrophic or unusual event (CUE).

One of the key features of the semi-structure interview process was that producers were able to articulate the benefits of the LBS by any means possible as long as we could bring it back to an annual estimate of value to the business. This could be expressed in many ways including labour time, direct spending, and kg of red-meat or stocking rate. This meant that some producers articulated financial benefits for similar value pathways by very different means. Some of these are discussed in more detail below.

Estimating annual cost savings

Cost savings for each application varied considerably and could be made up of more than one component. For example in pastoral beef operations the cost savings achieved through improved mustering efficiency was frequently made up of labour savings expressed in either days or hours along with helicopter cost savings. Producers were more easily able to articulate the potential for cost saving when compared to annual revenue gains.

Estimated annual revenue gains

The way in which producers estimated annual revenue varied considerably. Some producers would articulate productivity gains in terms of increased weaning rates and others would describe proportional gains in stocking rates, prices received or kg of red-meat produced per hectare. There was enormous variation in value pathways but each articulated benefit was discussed so that an annualised benefit could be drawn from it to calculate a percentage gain against the current revenue state.

Estimated revenue loss prevention from Catastrophic or Unusual Events (CUEs)

One key feature of the questionnaire was the attempt to capture information around the value and impact of catastrophic or unusual events (CUE's). These events do not occur on an annual basis but have a significant impact on the operation when they do. Common examples reported by producers included stock theft events, significant disease outbreaks, fire and perishing of animals due to lack of water.

Producers were asked to provide details of the total impact of these events which was almost universally related to either lost revenue of stock to be sold or the loss of breeding animals. Where breeding animals were lost these were valued at the same rate as cull sales.

Producers were also asked to provide a frequency of impact, this was expressed as an occurrence per years (e.g. 1 in 5 year event, 1 in 10 year event or 1 in 50 year event etc.). This frequency was then used to annualise the value of total revenue lost. For example if a producer suggested that losing 50 lambs (valued at $100 each) due to a phalaris toxicity outbreak occurred on average 1 in 10 years then the total value of the revenue loss (50 x $100 = $5000) was multiplied by the frequency (1 year / 10 years = 0.1) to provide an annualised revenue value ($5000 x 0.1 = $500 per year).

All impacts relating to CUE's were valued through to a proportion of revenue. This essentially expressed the impact of saving that revenue which might normally be expected to be lost at the rate proportional to its occurrence.

This is a relatively simple way of calculating value and whilst other complex means could have been applied, this provides the most readily understandable way of standardising the value across properties and applications.

Taking into account the costs associated with estimates of increased revenue

When a producer nominated a pathway to increased revenue from a certain application of LBS information that related to a general increase in productivity there was a necessary adjustment made to accommodate the fact that extra costs would in many cases be associated with this increase. This would particularly be the case for increases in stocking rates where variable costs (e.g. vaccines, transport etc.) would increase on a per head basis. To accommodate this a nominal value of half the operating costs was applied (35% for properties in high rainfall/wheat sheep and 30% for pastoral) to discount the estimated revenue increase.

For some revenue increases there was no extra costs applied. In these cases, the extra costs of production were not relevant. For example when LBS data led to increased prices received through better market compliance or improved timing of sale of animals.

Very occasionally, a producer would articulate that a large potential benefit might be associated with a certain application but also expressed that large capital costs would be associated with taking advantage of it. This was discussed with the producer and the benefit downscaled to accommodate this as best as possible. This most commonly occurred with monitoring and managing landscape utilisation where intervention required increased fencing and water infrastructure.

Additional operating costs were not levied against the benefits accrued for CUE's. This is because in most cases the value around these events was expressed in terms of getting the operation back up to the normal level of production and in most cases the costs of production would have already been spent.

Comparing whole of herd deployment with a sentinel deployment of sensors

One of the points of interest that came up early in the project was based around the value of tracking all animals in a herd or flock verses only a handful which would act as sentinel animals to provide a sample of information from the larger group. To investigate this, producers were first asked to report any benefits associated with a whole of herd/flock deployment after which they were asked to provide an estimate of the proportion of the value that they could achieve if they had only 5-10% of the animals monitored. Producers were provided with the option of attributing between 0 and 100% of the value originally described in the whole of herd/flock deployment mode.

The producers perspective on estimating benefits

For many producers the semi structured interview process allowed them the flexibility to articulate the potential benefits of the technology in a way which they felt comfortable that they were providing realistic information. However, as some producers discussed some of the more complex applications or pathways to value, many did comment that they were less certain about the accuracy of their estimates. This was particularly the case for the higher level feed-base management applications, especially for monitoring and managing landscape utilisation.

3.3.3 Results

The results from the detailed interviews were summarised across two broad zone and industry categories. The two zones used were the pastoral zone and the second was a combination of the Sheep-wheat zone and High-rainfall zone. In the wheat/sheep and high rainfall zone summaries of both the beef and sheep industries were reported and in the pastoral zone, beef only.

Table 12 numbers of producers interviewed in each zone and industry

Zone	industry	Number of case studies
Pastoral	Beef	7
High-rainfall/Sheep-wheat	Beef	4
High-rainfall/Sheep-wheat	Sheep	8

The following results are presented in some detail and where possible the estimates of value articulated by producers have been elaborated with specific information recorded during interviews. This detail is provided so that those considering research and development in this field can explore the pathways to value that producers articulated as well as the basic value proposition.

Pastoral beef production systems – whole of herd deployment

Producers interviewed from the pastoral zone running beef cattle reported on average 4.2 applications for which they could articulate a revenue increase. The same group reported only 2.2 applications that would result in cost reductions. There were few (mean = 0.5) applications reported for which producers could articulate a benefit in terms of revenue savings from preventing a catastrophic or unusual event (CUE).

On average the pastoral beef producers interviewed reported revenue gains of 6.8%. Total revenue gains ranged from 0 to 15.8%. The highest (15.8%) was associated with a producer (Case study (CS) 5 -Table 13) that reported a high level benefit from understanding landscape utilisation. One producer (CS 2 - Table 13) could articulate no revenue benefits but estimated larger cost savings (11.7%). The estimated benefits from detecting and then preventing the adverse impact on revenue (CUE) were small compared to the proposed annual revenue gains and cost savings.

The restriction back to a sentinel deployment reduced the number of applications for which producers could articulate an economic benefit. The average revenue gain drops from 6.8% to 2.7%. For one case study (CS 2 - Table 14) the scenario in which only a small proportion of the herd could be tracked meant there were no-longer any benefits that could be articulated.

Table 13 Summary details across all estimated benefits and cost savings for tags on all animals. Count is the number of individual applications that a producer could articulate a financial benefit or cost saving for. Percent (%) is the total value of that revenue gain, cost saving or revenue loss avoidance across all applications.

	Revenue gains		Cost savings		CUE	
Case study	**count**	**%**	**count**	**%**	**count**	**%**
1	6	7.5	2	2.5	-	0.0
2	-	0.0	2	11.7	-	0.0
3	6	2.7	4	1.7	2	1.0
4	1	4.1	2	1.6	1	0.2
5	5	15.8	2	4.3	-	0.0
6	7	10.6	1	1.0	-	0.0
mean	**4.2**	**6.8**	**2.2**	**3.8**	**0.5**	**0.2**
SD	2.7	5.3	0.9	3.7	0.8	0.4

Table 14 Summary details across all estimated benefits and cost savings for sentinel deployments on 5-10% of animals. Count is the number of individual applications that a producer could articulate a financial benefit or cost saving for. Percent (%) is the total value of that revenue gain, cost saving or revenue loss avoidance across all applications.

	Revenue		Costs		CUE	
Case study	**count**	**%**	**count**	**%**	**count**	**%**
1	1	2.0	0	0.0	0	0.0
2	0	0.0	0	0.0	0	0.0
3	5	2.1	1	0.5	0	0.0
4	0	0.0	1	0.2	1	0.2
5	1	10.7	2	1.9	0	0.0
6	3	1.6	1	1.0	0	0.0
mean	**1.7**	**2.7**	**0.8**	**0.6**	**0.2**	**0.0**
SD	1.8	3.7	0.7	0.7	0.4	0.1

Breaking the data down to explore the value of individual applications across the pastoral beef case studies shows several important trends.

Consistent and large benefits

Mustering efficiency

The most universally valuable benefit of LBS data from the perspective of pastoral beef producers is its application in mustering animals with nearly all reporting a cost saving (mean = 3.84%). These cost savings were predominantly derived from labour and helicopter or fixed wing hours with ground vehicle and fuel use having a smaller impact. One producer identified a key revenue gain achieved through clean musters which could subsequently increase pasture regrowth rates and in turn have a positive impact on live weight gain (2.76%). It's worth noting that one producer reported cost savings of up 11% and described how this application was key to their interest in LBS data.

Predation detection

The next most universally articulated benefit of LBS data was for detection of predation events with 4 of the 6 producers reporting potential revenue gains ranging from 0.40 to 4.11%. In all cases these revenue gains related to increased calf survival. One producer articulated benefits from reduced pricing downgrades due to carcase and skin damage from dog attack. Most producers suggested that direct intervention in terms of targeting wild dogs during the event would not be possible but that knowing where the predation events were occurring would allow them to target baiting programs that would then be more effective. This means that a real-time solution for predation detection in the pastoral may not be necessary for producers to gain value.

Pregnancy status

The provision of information around the pregnancy status of cattle in the pastoral zone was deemed valuable by 4 of the 6 producers interviewed. Two producers reported cost savings that involved a reduction in labour used in the yards or paddock to assess reproductive status. Two producers articulated revenue benefits from increased calving rates through improved management of non-performing cows.

Consistent but medium or low benefits

Basic animal location

Although only attributed small benefit values (mean cost saving 0.31% and mean unusual event of 0.27%) the provision of basic animal location data was considered valuable by many respondents. Each had a different reason for this although simply saving time in finding cattle that had strayed through boundaries after storms or fence faults was common. Knowing where animals were during catastrophic events (fire and flood) was articulated as a key benefit with one producer reporting an incident in which fire caused significant cattle losses and believed they could have saved many animals had they known exactly where they were, "we could have got the helicopters up and moved them".

One producer who did not articulate a financial benefit suggested that there is value in this for basic record keeping "Just knowing which animals were in which paddock, accurate records of cows in paddocks, we don't have this data now". The discussions undertaken with producers suggest that there is a significant non-financial value in this application. It was commonly articulated that a greater peace of mind would be achieved by having this information.

Genetic matching (dam/offspring)

Producers providing estimates of value around genetic matching commonly attributed it to the improvement in productivity achievable through increases in genetic gain and culling cows with poorly performing calves. This reflects the fact that the manual process of genetic matching of cows and calves is rarely undertaken amongst these producers with only one respondent articulating a labour saving (0.31%) from not having to do this manually (either by yard sorting or in the paddock).

Bull activity

The results show that 2 producers articulated a benefit around identifying bulls that had broken down during joining with a range of 0.47 to 1.97% in increased revenue estimated from this application. One producer estimated a cost saving of 0.97% relating to a reduction in bull purchases as they believed they could more actively manage break downs and reduce the extra bulls purchased to cover for these occurrences. Two other producers who could not directly provide an estimate of financial benefit suggested that they would be interested to see how active their bulls were "he might have passed a confirmation test but we would cull him if he's not working" commented one. Further research could validate the proportion of bulls that breakdown during a season and the dynamics of bull behaviour in a multi-sire herd to provide a better understanding the value of this application.

Less commonly reported with large benefits

These applications were reported less than half of the producers but had estimated benefits of more than ~2% in terms of revenue, costs, CUE's or a combination of these.

Landscape utilisation

Only one producer was comfortable articulating a potential financial benefit (revenue increase of ~10%) associated with understanding and managing landscape utilisation. However, every producer commented that they saw value in this information. Several producers referred to the benefit of having objective data on how animals used the landscape to better design water points and fencing infrastructure and place supplement to modify grazing pressure. One commented "If you had map data of grazing patterns you would action it, at the moment it's not obvious and in your face so you don't [referring to fence and water placement as the action]". Whilst there might well be value in this application it is obvious that producers aren't confident in how they will turn this information into increased revenue on their own property. The reporting of this application is complex, for some producers the value was obvious but unquantifiable for others they simply felt that they needed to see it on their own property before making a judgement.

Water related behaviour.

Whilst only two producers could articulate financial value, several more suggested that they would benefit. There was one producer who relied on a remote water monitoring system (RWMS) and was satisfied with that. Another producer also had a RWMS but identified issues with small groups of vulnerable animals regularly walking away from water and dying, they pointed out that the RWMS could not detect this issue. It's worth noting that both producers suggested that this was a regular issue and not a catastrophic or unusual event.

Calving detection

Only one producer was able to articulate a financial benefit around calving detection. In several cases producers expressed that their inability to intervene given the large distances was the reason they could not see a financial benefit. A number of producers articulated benefits for the wider industry from knowing birth dates and rates of dystocia and calf loss.

Less commonly reported with medium or low benefits

Stock theft

Two producers articulated financial benefits through the prevention of stock theft events that regularly occur on their property. One producer provided some insight into this with the comment "There is quite a bit of tension around this issue, we lose animals into the neighbours and don't get them back". This suggests that there is some non-financial benefit in terms of the maintenance of neighbour relationships in these communities.

Disease detection

Producers articulated benefits around detection of specific diseases such as botulism and 3-day sickness. Botulism detection was important despite vaccination programs, as one producer suggested that they still had occasional problems with this disease. Detection of Buffalo Fly was also listed as a key issue. The management interventions to bring about the value for each disease (or pest) varied according to the specific symptoms and impact. However, most producers indicated that early detection would allow earlier intervention to prevent further animals becoming affected and reduce loss of production. In that case of 3-day sickness avoiding moving the herd during an outbreak was suggested as valuable.

Poisoning detection

Detection of plant toxicity issues was reported by several producers as having value. The key management strategy around this was detection of early symptoms or mortalities to enable intervention. One producer articulated there was value in having constant remote monitoring of stock available as opposed to the occasional visual inspection providing only limited information. There is considerable interest in this issue as many producers are not sure why they lose some animals and if they could confirm plant toxicity issues they could address the specific cause. This would be partly achieved by simply finding the dead animals to allow inspection/post mortem but sensor based disease diagnosis would be the preferred option.

Timing of grazing rotations

Not all producers were in a position where paddock rotation and management of stocking rate could be achieved. Two producers that were, suggested potential revenue gains ranging from 0.28% to 2.55%. These producers believe they could use the data to interpret the behavioural patterns of livestock to better inform them of when they should be making rotations. Both suggested that the observations they currently make by physical inspection could be more thoroughly achieved through LBS monitoring.

Refining supplementary feeding

Only one producer articulated a financial benefit around the timing of supplementary feeding with a small increase in weight gain through improved timing of putting out urea, although other producers did suggest this application may have value. This producer described the process by which they currently make this decision which was through animal observation. They articulated a compelling argument around how they could interpret behavioural information from an LBS system to improve their observations and then timing of supplement.

Welfare monitoring

Only one producer articulated a financial benefit in terms of cost savings (0.25%). This producer articulated that the benefit came from linking this information to market access and it was actually a time saving in filling out paper work. Other producers suggested that there was value in this for the industry as a whole, one specifically stating "In the future welfare monitoring will be quite critical. We are supposed to be compliant with animal welfare management issues. This technology would allow us to demonstrate that we are compliant". In general producers seemed to believe there was value in being able to monitor the general welfare status of animals but struggled to articulate that in terms of financial returns to their own property.

Applications for which no financial benefit was articulated but for which producers expressed interest

Health alerts for critical injury

Although no producers could put a value on this application several commented that they would use any knowledge derived to intervene when any animal was suffering. Comments included: "If you knew you had an animal that's broken a leg you can put it out of its misery"; "This would be very beneficial. It would allow us to locate animals in pain and shoot them to fix the suffering"; and "This would be valuable but we have no access to vets and so it would just allow us to put an animal out of its misery". Other producers expressed concern about their ability to intervene given the distances involved.

Oestrus detection

No financial benefits were articulated for oestrus detection although two producers expressed interest in specific use cases for this. One commented that "This would be valuable when we have a not normal season, particularly if the season is late, we would be looking at cycling of cows and determine sup feeding requirements". Others commented that this might be of value to the wider industry.

Applications with no value

Not surprisingly, refining fertiliser application was not considered relevant for this group, little fertiliser is used in this segment. Detection of shy feeders was also not considered relevant.

Pastoral beef production systems – sentinel deployment

When considering the value of a sentinel system whereby only 5-10% of the herd could be monitored many of the higher value applications dropped off. Not surprisingly, the value around mustering efficiency drops away (from mean of 3.84% to 1.15%) as producers could no longer see the full benefits if they couldn't locate each animal. Two producers believed that they could still use the data from a small number of animals to infer the location of groups and gain at least some value from reduced costs in mustering events. Similar results and justifications were found for basic animal location data and detection of behaviours associated with water. Its worth highlighting that research into how sentinel devices might assist in mustering efficiency would be worthwhile to quantify the benefits likely to be gained through this more affordable technical solution.

The value around detecting water issues was mainly focussed on being alerted to issues with vulnerable animals, particularly weaners. Although not explored in this study there may be a case for temporary deployment of sentinel LBS systems on smaller numbers of these vulnerable animals which could maintain the benefits described in the whole of herd deployment.

Perhaps the most clearly valuable application for a sentinel system would be the deployment on bulls to detect mating activity during joining season. In this situation producers described how they would use the smaller number of monitoring devices on bulls to maintain the benefit described under a whole of herd deployment.

Although only reported by a single producer the use of LBS data for monitoring and managing landscape utilisation did not suffer from the limited deployment of LBS systems. The producer described how they believed a small number of animals could be strategically tracked to provide an understanding of whole of herd spatial grazing patterns.

A handful of applications still had some value under a sentinel deployment but producers were not always confident in these estimates. Predation alerts, infectious disease, poisoning alerts, timing of grazing rotations and refining supplementary feeding are all candidates but there would need to be confirmation that these issues could be detected before value is confirmed.

Table 15 Summary of financial benefits: Pastoral beef – whole of herd deployment

	Increase in Annual Revenue				Reduction in Annual Costs				Annualised revenue losses prevented from CUE			
	Count	Mean (%)	Min (%)	Max (%)	Count	Mean (%)	Min (%)	Max (%)	Count	Mean (%)	Min (%)	Max (%)
Mustering efficiency	1	2.76			5	3.84	0.50	11.23				
Water related behaviour	2	2.10	0.23	3.98								
Basic animal location					3	0.31	0.10	0.65	2	0.27	0.22	0.31
Stock theft	2	0.56	0.55	0.58								
Predation alert	4	1.52	0.40	4.11								
Bull/ram activity	2	1.22	0.47	1.97	1	0.97						
Detecting shy feeders												
Health alerts for critical injuries												
Oestrus detection												
Pregnancy status	2	1.78	1.59	1.97	2	0.57	0.51	0.63				
Calving and lambing detection	1	1.97										
Disease detection	2	0.43	0.12	0.74					1	0.67		
Poisoning detection	2	0.69	0.23	1.16								
Welfare monitoring					1	0.25						

Genetic matching (dam/offspring)	3	0.83	0.74	0.88	1	0.31						
Landscape utilisation	1	10.73										
Refining fertiliser application												
Timing grazing rotations	2	1.41	0.28	2.55								
Refining supplementary feeding	1	0.29										

Table 16 Summary of financial benefits: Pastoral beef - sentinel deployment

	Increase in Annual Revenue				**Reduction in Annual Costs**				**Annualised revenue losses prevented from CUE**			
	Count	Mean (%)	Min (%)	Max (%)	Count	Mean (%)	Min (%)	Max (%)	Count	Mean (%)	Min (%)	Max (%)
Mustering efficiency					2	1.15	0.50	1.80				
Water related behaviour	2	0.51	0.23	0.80								
Basic animal location					2	0.15	0.13	0.17	1	0.22		
Stock theft												
Predation alert	1	0.98										
Bull/ram activity	2	1.22	0.47	1.97	1	0.97						
Detecting shy feeders												

Health alerts for critical injuries		
Oestrus detection		
Pregnancy status		
Calving and lambing detection		
Disease detection	1	0.74
Poisoning detection	1	0.11
Welfare monitoring		
Genetic matching (dam/offspring)		
Landscape utilisation	1	10.7
Refining fertiliser application		
Timing grazing rotations	1	0.11
Refining supplementary feeding	1	0.29

High rainfall & sheep-wheat (HRSW) zone beef producers

Case study beef producers from the HRWS zone reported average revenue gains of 5.7%, cost savings of 3.0% and CUE's of 1.6%. These producers identified an average of 3.3 applications that would impact revenue and 2.5 applications that would translate to cost savings. The restriction back to a sentinel deployment halved the potential revenue gains (from 5.7% to 2.6%) but had a much greater impact on the applications that influence cost savings with a reduction from 3.0% to 0.6%. Nearly all of the value from applications relating to CUEs were lost under a sentinel deployment.

Table 17 HRSW beef whole of herd deployment

	Revenue gains		Cost savings		CUE	
Case study	count	%	count	%	count	%
1	3	7.4	1	0.3	0	0.0
2	4	5.1	4	10.6	3	6.1
3	3	3.4	3	6.1	1	0.3
4	4	8.0	2	1.8	1	0.1
mean	**3.3**	**6.0**	**2.5**	**4.7**	**1.3**	**1.6**
SD	0.5	1.8	1.1	4.0	1.1	2.6

Table 18 HRSW beef sentinel deployment

	Revenue gains		Cost savings		CUE	
Case study	count	%	count	%	count	%
1	0	0.0	0	0.0	0	0.0
2	2	3.9	1	0.5	0	0.0
3	1	2.0	2	0.3	0	0.0
4	1	4.7	1	1.7	1	0.1
mean	**1.0**	**2.6**	**1.0**	**0.6**	**0.3**	**0.0**
SD	0.7	1.8	0.7	0.6	0.4	0.1

Consistent and large benefits

Water related behaviour.

The highest value application for HRSW beef was based around monitoring water related behaviours which was consistent with the findings reported in the survey. This has both a cost saving element (mean value 5.39%) and in one case an increased revenue through prevention of CUE (5.66%) based around perishing cattle where troughs had failed. The cost savings were associated with reduced labour and vehicle expenses associated with regular checking of stock water. One operation had a higher level of cost savings (9.10%) which can be explained by the fact they managed a number of geographically diverse properties which required travel between each to complete the current water checking program. This producer used a remote water monitoring system (RWMS) but was still interested in the watering behaviour of individual animals, with reference to a LBS system they stated "you could see each individual animal is drinking as opposed to water meters, you can't be sure [that each animal has had adequate access to water]". The case study reporting the large value around a CUE had recently experienced an event where 300 animals had nearly perished and were only saved through a neighbour accidentally finding and reporting the problem. In discussion with producers it was apparent that those reliant on artificial water systems (troughs, pipes and troughs) were more interested in this application. One key issue with these results is the lower number of participants interview in this group. It maybe that further survey would decrease this relatively high benefit, however its worth noting that the result is not dissimilar to the online survey results.

Calving and lambing detection

Producers reported significant value around the detection of calving activities both in terms of additional revenue (mean 1.06%) but predominantly through cost savings (3.23%). The cost savings came through reduced labour and to a lesser extent vehicle costs used to check calving cows. The labour costing for this application probably underestimates the value that producers would place on it as one producer put it succinctly "It's a long 6 weeks driving around looking for calving heifers". This reflects the higher degree of human energy expended during peak seasonal activities like calving.

Timing of grazing rotations

Whilst only two producers articulated a financial value relating LBS data to improved timing of paddock rotations (ranging between 1.95% and 4.74% increase in revenue) the balance did consider it worthwhile and strongly linking it with landscape utilisation. One producer specifically commented "Understanding how animals are interacting with the pasture would allow us to run closer to the line [under verses overgrazing] and make better decisions, increase the accuracy at which I graze [referencing optimising animal intake and pasture regrowth]".

Consistent but medium or low benefits

Pregnancy status

Most of the producers were interested in this application but had very different value paths. For one producer the ability to detect the pregnancy status of cows after the bull had been removed meant they could sell cows still cycling earlier into the market and gain a price premium. Another suggested that having more detailed and integrated data on the reproductive performance of cows (number of days in oestrus, date of joining and date of calving) would allow them to select for genetically superior females which would lift overall productivity.

Poisoning detection

Three of the four producer case studies nominated plant toxicity and resultant metabolic disorders as impacting on both annual revenue (mean 1.66%) and from annualised revenue associated with CUEs (0.26%). The two key disease states reported were bloat and endophyte toxicity. One producer reported a recent case where they had lost 40 steers in a paddock of 70 from endophyte toxicity, and although they considered this a relative rare event it had none the less resulted in a significant income loss in that year and influenced their response.

Less commonly reported with large benefits

Stock theft

Stock theft detection was reported as having value by two producers. One described a case of preventing losses which impacted through to a CUE value of 0.29%. The other producer provided a more novel value proposition. They believed that the threat of stock theft meant they were currently under utilising the feed-base of paddocks adjacent to roads on their property. They rarely left animals in these paddocks for a longer period of time for fear of theft as they were more easily observed and accessed by potential thieves. This meant that these paddocks were underutilised. This was a significant issue for this producer and they believed they could increase productivity gains leading to a 1.95% increase in revenue.

Landscape utilisation

Only one producer articulated a benefit related to monitoring and managing the utilisation of the landscape at a 1.95% increase in revenue. This producer believed they could make this impact through feed-base management and the targeted deployment of temporary electric fencing to optimise spatial landscape utilisation. Several more producers believed there was value but could not articulate a specific financial benefit. One producer who did not articulate a financial value believed they could make an impact through the targeted placement of supplement to attract animals into unused areas once they understood where they were currently grazing. Another suggested that this information would assist with water point placement to optimise feedbase management.

Disease detection

Only two producers reported potential revenue gains from disease detection. One producer was particularly interested in lameness detection and believed they could increase production by preventing live weight losses in these animals (3.13% increase in revenue) if they could detect it earlier and intervene. The other producer articulated a minor benefit in terms of cost saving from not having to check animals as often if a near-real time LBS system could provide adequate warnings for fly and tick infestations.

Less commonly reported with medium or low benefits

One producer articulated a benefit in terms of costs saving from not having to check on bulls during the joining period.

A minor cost saving in terms of time in the yards to mother up (genetic matching) was articulated by one producer. One producer articulated benefits from basic animal location data based on the regular loss of strayed animals (revenue 0.97%).

There were two producers who articulated very minor financial benefits from predation detection. One related to detecting and then intervening by shooting the dog (0.49% revenue gain from saved calves). The other related to the cost of fence repair after dogs had run cattle through them.

Applications for which no financial benefit was articulated but for which producer expressed interest

One producer was interested in oestrus detection as they ran an artificial insemination program. This producer explains "This would enable an increase in conception rates from AI which would then allow a reduction in bull numbers [through less backup bulls] at the same time as increasing genetic gains through the better AI genetics. Value is difficult to ascertain as reduction in bulls is offset by an increase in AI costs”.

Applications with no articulated value

The applications for which this group of producers could not articulate a financial benefit includes welfare monitoring, refining fertiliser application, refining supplementary feeding and the detection of shy feeders.

High rainfall & sheep-wheat (HRSW) zone beef producers – sentinel deployment

The application of a sentinel system in which only a small proportion of the herd or flock would be tracked saw a large decrease in the financial value compared to whole of herd deployment. The only application (with more than one producer reporting it) that maintained its value from whole of herd through to the sentinel deployment was in the management of the timing of grazing rotations. Landscape utilisation maintained its value although only reported by one producer. Other applications that producers considered achievable through sentinel deployment included detecting issues around watering behaviour, stock theft, bull activity and some minor disease and plant poisoning issues.

Table 19 Summary of financial benefits: HRWS zone Beef – Whole of herd deployment

	Increase in Annual Revenue				**Reduction in Annual Costs**				**Annualised revenue losses prevented from CUE**			
	Count	Mean (%)	Min (%)	Max (%)	Count	Mean (%)	Min (%)	Max (%)	Count	Mean (%)	Min (%)	Max (%)
Mustering efficiency					2	0.33	0.25	0.41				
Water related behaviour					2	5.39	1.68	9.10	1	5.66		
Basic animal location	1	0.97										
Stock theft	1	1.95							1	0.29		
Predation alert	1	0.49							1	0.10		
Bull/ram activity					1	0.47						
Detecting shy feeders												
Health alerts for critical injuries	1	0.85										
Oestrus detection												
Pregnancy status	2	1.20	1.04	1.39	1	0.26						
Calving and lambing detection	2	1.06	1.04	1.09	2	3.23	0.62	5.84				
Disease detection	1	3.13			1	0.06						
Poisoning detection	2	1.66	0.19	3.13					2	0.26	0.14	0.38
Welfare monitoring												

Genetic matching (dam/offspring)					1	0.16						
Landscape utilisation	1	1.95										
Refining fertiliser application												
Timing grazing rotations	2	3.35	1.95	4.74								
Refining supplementary feeding												

Table 20 Summary of financial benefits: HRSW zone beef – Sentinel deployment

	Increase in Annual Revenue				**Reduction in Annual Costs**				**Annualised revenue losses prevented from CUE**			
	Count	Mean (%)	Min (%)	Max (%)	Count	Mean (%)	Min (%)	Max (%)	Count	Mean (%)	Min (%)	Max (%)
Mustering efficiency					1	0.25						
Water related behaviour					1	1.68						
Basic animal location												
Stock theft	1	1.95										
Predation alert												
Bull/ram activity					1	0.47						
Detecting shy feeders												

Health alerts for critical injuries										
Oestrus detection										
Pregnancy status										
Calving and lambing detection										
Disease detection					1	0.06				
Poisoning detection									1	0.14
Welfare monitoring										
Genetic matching (dam/offspring)										
Landscape utilisation	1	1.95								
Refining fertiliser application										
Timing grazing rotations	2	3.35	1.95	4.74						
Refining supplementary feeding										

High rainfall & sheep-wheat (HRSW) zone sheep producers

Case study sheep producers reported an average of 3.0 applications which could have an impact by increasing revenue. This same group reported a similar number of applications (mean 2.9) that could have an impact by reducing costs. Sheep producers reported a high average number of application which could benefit them through preventing catastrophic or unusual events (CUEs) with a mean of 2.1.

Sheep producers reported a mean value of 11.1% in terms of overall revenue gains with a minimum of 3.2% and a maximum of 22.4%. Three producers reported quite high total revenue gains between 18.1% and 22.4%. Sentinel deployment reduced the average estimated benefit to 2.0% a significant drop from the whole of flock deployment (11.1%). Cost savings dropped from 3.2% to 1.1% under a sentinel system.

Table 21 Summary of average applications and individual total value: HRWS zone sheep - Whole of flock deployment

	Revenue		**Costs**		**CUE**	
Case study	count	%	count	%	count	%
1	3	5.3	2	6.5	4	0.8
2	3	18.1	2	1.8	2	0.0
3	2	22.4	1	0.3	-	0.0
4	5	3.9	4	0.6	4	1.1
5	5	10.2	3	0.2	-	0.0
6	3	20.3	5	1.8	5	4.4
7	2	3.2	2	2.8	1	0.6
8	1	5.2	4	6.6	1	0.3
mean	**3.0**	**11.1**	**2.9**	**2.6**	**2.1**	**0.9**
SD	1.3	7.5	1.3	2.4	1.8	1.4

Table 22 HRWS zone sheep – Sentinel deployment

	Revenue		**Costs**		**CUE**	
Case study	count	%	count	%	count	%
1	-	0.0%	2	6.5%	4	0.8%
2	-	0.0%	1	0.8%	-	0.0%
3	1	5.6%	1	0.2%	-	0.0%
4	1	2.6%	3	0.2%	1	0.3%
5	3	2.1%	-	0.0%	-	0.0%
6	1	6.0%	1	0.2%	3	3.8%
7	-	0.0%	1	2.3%	1	0.6%

8	-	0.0%	-	0.0%	-	0.0%
mean	**0.8**	**2.0%**	**1.1**	**1.3%**	**1.1**	**0.7%**
SD	1.0	2.4%	0.9	2.1%	1.5	1.2%

Consistent and large benefits

Genetic matching (dam/offspring)

Many of the sheep producers articulated large benefits around genetic matching of ewes with lambs with an average of 9.76% in increased revenue reported by 5 of the 8. The primary pathway to these revenue gains was through identification of ewe productivity in terms of offspring performance. By objectively measuring lamb productivity producers could start culling underperforming ewes and increasing the genetic potential of their flock. Many producers had similar comments regarding increasing production per land area unit "This is so important to us, the maternal line and being able to wean twins, good mothering ability. This means increased kg of meat and wool per hectare”.

Lambing detection

Being able to detect lambing events was seen as a key application of LBS data by many producers. Some producers articulated revenue gains (mean 2.17%) through intervening in difficult births to save either the lamb or ewe or both. Many producers identified costs savings (mean 0.81%) achieved through reduced time spent checking on ewes over the lambing season.

Consistent but medium or low benefits

Disease detection

Many producers articulated benefits around infectious disease detection, particularly related to the provision of animal state information for worms, footrot and lice. Three producers estimated average revenue gains of 1.24% and four estimated average benefits of 0.39% derived from preventing high sheep mortality due to disease (primarily worms). One producer described the importance of this to their operation in terms of both an immediate benefit and longer term worm management "knowing when sheep are developing infection we could detect and control and then prevent re-infection of the pastures which comes back to bight us in the following year".

Stock theft

Four producers reported stock theft as a key issue and articulated financial benefits in terms of preventing revenue losses of 0.99% from the CUE of losing animals. Of all the applications investigated in this study detecting and preventing stock theft would have the highest degree of impact in terms of non-financial value. As one producer puts it "Its demoralising, the anguish it causes when animals you’ve worked hard to grow are taken". Although only being valued in terms of the animals lost through occasional theft events this application would have a significant impact in terms of the emotional energy producers invest in worrying about livestock and for many would provide significant peace of mind.

Mustering efficiency

Although only providing a small benefit in terms of cost savings (mean 0.25%) many producers reported value in being able to locate animals to improve mustering efficiency. For some producers the added benefit of ensuring clean paddock musters had flow on effects in terms of disease management. A clean paddock muster meant that disease breaks were guaranteed through avoidance of reinfestation, particularly with regards to worms.

Water related behaviour.

Two producers articulated value in terms of cost savings (mean 1.5%) from reduced labour requirements to check water troughs and the knowledge that sheep had adequately watered. Several other producers who could not articulate a value believed it may assist them in detecting issues such as drinking water quality. Two producers articulated benefits in terms of preventing the death of sheep due to breakdowns in the water infrastructure (CUE mean 0.20%).

Pregnancy status

Two producers believed that they may be able to reduce some scanning costs (0.39%) if they knew which ewes had been mated and which were still cycling after the rams had been removed. Two producers believed they could better manage ewes that were not pregnant after joining had finished to increase revenue (mean 1.24%) either through re-joining or early sale as culls.

Poisoning detection

Although only being reported to provide a small financial value from prevention of lost revenue by detection of CUEs (mean 0.15%) four producers articulated a benefit from the detection of plant poisoning events. The specific causes of these problems were diverse and included: poisoning from endophyte toxicity, St John's Wort and Gastrolobium; and physical (fatal) damage from grass seeds. One producer articulated that the value proposition around this would be that it could potentially pick up a suite of minor problems. The impacts of this application may have more value from a non-financial benefit, one producer reported "We lost 110 of the best young breeding ewes last year when they were in a paddock in which an outbreak of staggers occurred, I was away and the hired hand hadn't checked them, this is on top of the weight gain lost on the ones that didn't die". This producer went on to describe the worry that he experiences around this issue and that a real-time LBS would provide significant impact in terms of peace of mind.

Less commonly reported with large benefits

Timing grazing rotations

The producers reporting this application provided a diverse range of ways in which it could have an impact on increasing revenue and decreasing costs. Two producers articulated benefits around improving the timing of rotations to better manage animal feed intake and feed-base residuals (mean 3.10%). One producer articulated labour savings from less time spent checking paddocks (0.86%) whilst another suggested costs savings would flow through reduced supplement use due to better feed-base management (2.27%).

Refining fertiliser application

Two producers articulated value around using LBS data to better inform fertiliser application (mean revenue increase 2.93%). Both producers articulated a similar pathway to value by using the tracking data to better understand high and low grazing areas before developing zonal fertiliser management strategies. In both cases the producers suggested that this process may require more than simple LBS data with the integration of other data from remote sensing potentially necessary.

Landscape utilisation

Only one producer reported potential revenue increases around monitoring and managing landscape utilisation up to 11.18%. This producer suggests "This is a big thing, knowing where they are feeding highlights where you should fence, we could split paddocks to improve utilisation". Like other estimates based around this application the producer was not certain around this value estimate.

Ram activity

Whilst only two producers reported estimates of value around ram activity both suggested cost savings (ranging from 0.77 to 6.16%) in terms of reduced ram purchases could be achieved. This was based on being able to monitor ram activity and where necessary replacing a non-active animal with a substitute. One producer commented "This is the biggest thing for us. We've had situations where a ram simply hasn’t been out working, he stayed at the bottom of the paddock and served a handful of ewes, that cost us 120 lambs at least".

Less commonly reported with medium or low benefits

A number of applications were only occasionally reported and had lower perceived value, these included: basic animal location; predation detection; detection of shy feeders; health alerts for critical injuries; refining supplementary feeding. Where these application were reported by producers they were often considered important to that particular operation and may have more application across a larger industry sample.

Applications for which no financial benefit was articulated but for which producer expressed interest

Welfare monitoring

Several producers commented on the potential value of welfare monitoring with regard to industry perception in the wider community. One producer stated “If there was a welfare score and we could be paid on it then we would embrace it”. This largely explains the inability of producers to provide an estimate of value in terms revenue gains or cost savings, as at this stage producers can’t see a direct economic value back to their own operation.

Oestrus detection

One producer considered oestrus detection to potentially have some financial value. "This would be really valuable for young stock, particularly the merino ewe hogget. We would prefer to mate her on the 2nd or 3rd cycle when the most eggs are being shed. We would work a whole farm plan around this to take advantage of the increase lambing percentage results".

Table 23 Summary of financial benefits: HRWS zone sheep – Whole of flock deployment

	Increase in Annual Revenue				Reduction in Annual Costs				Annualised revenue losses prevented from CUE			
	Count	Mean (%)	Min (%)	Max (%)	Count	Mean (%)	Min (%)	Max (%)	Count	Mean (%)	Min (%)	Max (%)
Mustering efficiency					5	0.25	0.06	0.38				
Water related behaviour	1	0.47			2	1.25	0.01	2.49	2	0.20	0.15	0.25
Basic animal location					1	0.23			1	0.38		
Stock theft									4	0.99	0.04	3.18
Predation detection									1	0.17		
Bull/ram activity					2	3.46	0.77	6.16				
Detecting shy feeders	2	0.36	0.18	0.54								
Health alerts for critical injuries	2	0.25	0.02	0.48	1	0.12						
Oestrus detection												
Pregnancy status	2	1.24	0.09	2.40	2	0.39	0.25	0.54				
Calving and lambing detection	4	2.17	0.16	5.22	5	0.81	0.04	1.82	1	0.22		
Disease detection	3	1.24	0.18	3.22	1	0.14			4	0.39	0.30	0.50
Poisoning detection									4	0.15	0.00	0.40
Welfare monitoring												

Genetic matching (dam/offspring)	5	9.76	0.81	17.40								
Landscape utilisation	1	11.18										
Refining fertiliser application	2	2.93	2.61	3.25								
Timing grazing rotations	2	3.10	0.25	5.96	2	1.56	0.86	2.27				
Refining supplementary feeding					2	0.73	0.06	1.40				

Table 24 Summary of financial benefits: HRSW zone sheep – Sentinel deployment

	Increase in Annual Revenue				**Reduction in Annual Costs**				**Annualised revenue losses prevented from CUE**			
	Count	Mean (%)	Min (%)	Max (%)	Count	Mean (%)	Min (%)	Max (%)	Count	Mean (%)	Min (%)	Max (%)
Mustering efficiency					3	0.24	0.15	0.38				
Water related behaviour	1	0.23			1	0.01			2	0.20	0.15	0.25
Basic animal location					1	0.23						
Stock theft									3	1.31	0.14	3.18
Predation detection									1	0.17		
Bull/ram activity					2	3.46	0.77	6.16				
Detecting shy feeders												

Health alerts for critical injuries												
Oestrus detection												
Pregnancy status												
Calving and lambing detection												
Disease detection									2	0.44	0.38	0.50
Poisoning detection									1	0.15		
Welfare monitoring												
Genetic matching (dam/offspring)												
Landscape utilisation	1	5.59										
Refining fertiliser application	2	2.12	1.63	2.61								
Timing grazing rotations	2	3.10	0.25	5.96	1	2.27						
Refining supplementary feeding					1	0.04						

3.3.4 Considering the non-financial benefits

One of the limitations of the survey and interview process used in this study is that it doesn't specifically quantify the extent of non-financial value the producers feel they could achieve through LBS systems.

As a simple exercise the two researchers involved in interviewing the producers for the case studies were asked to rank the importance of applications based on the value that the perceived producers had placed on each in terms of the "peace of mind" it provided or the "emotional energy" expended in dealing with the outcomes of an adverse event. This was undertaken across the entire group after all interviews were completed and not on an individual producer basis.

Although this is a relatively rudimentary analysis the top five ranked applications highlight the key issues for which producer's perceived significant non-financial benefit.

Table 25 The top five application which might provide the most peace of mind and reduce emotional energy expended.

Rank	Application
1	**Water related behaviour**
1	**Welfare monitoring**
2	**Basic animal location**
3	**Stock theft**
3	**Predation detection**

One aspect of the potential value of LBS systems that was not explored was based around the value that producers put on their time. During peak activity times (e.g. lambing, calving joining and shearing) the value of a producers time potentially increases significantly as they struggle to complete all their tasks within the hours available. There was potentially more value associated with time savings from applications which were effective within these peak activity times. This is worth considering in future investigations.

3.4 Collation of all applications and value pathways reported throughout the study

As part of the project a record was kept and updated to report all the possible applications being reported from producers, industry participants and from scientific literature and publically available records.

The full details of all potential applications of LBS systems can be found in Appendix 1.

3.4.1 The adoptability of LBS applications

One of the key issues not considered in this study is the adoptability of the various applications. Although not a formal part of this project, it is worth considering the likely adoption rates of the various applications as this impacts significantly on the likely industry wide benefits.

This information was also used to shape some of the assumptions used in section 4 where the industry wide value was explored. Adoption rates being a necessary component of the modelling undertaken.

As part of this process of collating the details around potential applications a simple rating of the ease of adoptability and ease of path to value was defined. These are subjective ratings but do provide a guide to important factors relating to the likely adoption rates of LBS systems. These ratings are detailed in the table in Appendix 1.

Applications which are simple to implement and which require little interpretation of data for the producer to realise the financial value will inevitably have a higher adoption rate. At the other end of the spectrum, those applications which might be more difficult to implement, particularly those that require more interpretation of the information provided and those that require a high degree of additional management skill will likely have a lower adoption rate.

Highly adoptable applications

An example of an application with a high ease of adoptability and ease of path to value is mustering efficiency. In this situation, knowing where animals are in real-time requires little data interpretation, at worst, if the sample interval of the location data is low (say 30 minutes) the producer might need to estimate the likely movement path to locate the animal from the last known position. This application therefore has relatively high ease of adoptability. At the same time, the path to value is easily realised by the producer, locating animals remotely means less hours in the saddle and less helicopter time. There is little additional skill required to obtain value from the system. Thus, this application also has a high ease of path to value.

Applications which can be easily adopted and for which the path to value is apparent are likely to have a faster adoption rate and higher final adoption. In many ways these sort of applications might be considered analogous to the adoption of GPS guidance systems in the cropping industry. Guidance systems allow producers to easily steer their tractors to reduce driver fatigue and minimise overlap of inputs. The systems were simple to adopt and the path to value was easily observed through reduced inputs and fatigue. As a consequence guidance systems were rapidly adopted over the past 20 years and are currently used on over 86% of farms (Umbers, 2017).

Low adoptability applications

In contrast to mustering efficiency, an application such as monitoring and managing landscape utilisation is both more difficult to adopt, and realise value from. Considerably more data interpretation and in-depth understanding of the animal landscape interaction is required by the producer. The science behind this application is in its infancy and the path to value for many producers is not clear. For those producers who can see a path to value, there is also relatively high level of skill required to realise it. As an example, one producer explained how they could use the LBS data to guide the design of fencing to intensify management. However, simply subdividing paddocks will not be enough to realise the value, this producer will also need to maintain an increased level of grazing management to realise the benefits.

Applications which are both difficult to adopt and for which the path to value is not clear or which require additional skills are likely to have both a lower rate of adoption and final adoption. Like the GPS guidance example provided above the grains industry also provides an example of a technology which has had limited adoption. The current reported rate of adoption of site specific fertiliser management in the grains industry is less than 8% (Umbers, 2017). Like the landscape utilisation application discussed above this innovation requires cropping producers to interpret a number of data sources (e.g. yield maps and soil tests) and then apply their agronomic knowledge to gain a benefit. It is both relatively difficult to adopt and the path to value requires skilled decision making.

The key message from this section is that the adoptability of the various applications cannot be ignored and the experience in other industries suggests that the more complex the innovation and the higher degree of skill required to extract value results in reduced producer uptake.

Staged adoption

However, the very fact that the one piece of hardware (potentially a smart ear tag) can provide benefits with a range of adoptability may be at least in part the key to adoption of more complex applications. If the device can provide sufficient value to enable producers to engage based on easily adoptable applications, they could later be introduced to higher level applications in a deliberate and considered way that ensured their skills developed at the same time.

Could LBS data actually impact on adoption of other innovations?

There is some speculation amongst leading researchers and industry representatives that the provision of LBS data to producers may engage them with other currently available innovations they are yet to adopt.

One hypothetical scenario in which this might occur is based around a producer who initially adopts a live LBS system to monitor basic animal behaviours (water, stock theft etc.). However, this producer is also provided with temporal and spatial grazing behaviour information. Through this the producer is made aware of the variation in grazing time and animal activity which is strongly linked to feed-base management. A strategy could be developed to transition this producer from a passive observer of grazing activity to a more active manager focussed on maintaining appropriate biomass thresholds through a feed budgeting platform.

In a similar vein a producer with lower level skills in endemic disease management skills might be made more aware of the value of regular testing and intervention through monitoring the pre and post treatment activity of their livestock.

While there is little evidence that this will occur, it should be considered in the development of future research programs.

3.4.2 Conclusion

The key message from this section is that despite their being potential value in many applications there is likely to be significant barriers to the widespread adoption of some. This area in particular requires further research to confirm the subjective results presented above and where possible find ways of bridging the gap between the benefit and the issues that might impede producers realising it.

3.5 General discussion and conclusions

The following discussion focusses on exploring the similarities and differences found between the industry segments in terms of the value on offer from LBS systems. It also attempts to provide some prioritisation in terms of the value and importance of the various applications to the industry as a whole.

3.5.1 General value of LBS information to industry segments – are there any big winners?

Before discussing the most valuable applications, it is worth considering the differences observed between the industry segments. When all estimates of value were averaged for each producer the Pastoral Beef and HRWS Beef segments were relatively similar both in terms of the total estimated revenue increases and cost savings. How each segment achieved this though was quite different.

The largest variation observed across the sectors was the difference between the estimated revenue benefits between sheep and the beef cattle segments. HRWS sheep producers reported an average of 11.1% in potential revenue gains. There was one particular application which influenced this relatively high average. Genetic matching of ewes and lambs had a mean estimated value of 9.76% (increased revenue) and was reported by a large proportion of producers. Removing revenue benefits estimated for genetic matching in the HRWS sheep segment more than halved the mean value (from 11.1% to 5.0%) and brought the value back into line with the other segments.

Table 26 The average benefits reported across zone and industry segments. Also included is an adjusted mean revenue value if genetic matching was excluded from the sheep industry.

Segment	Mean revenue (%)	Mean Costs (%)	CUE prevention (%)
Pastoral beef	6.8	3.8	0.2
HRWS Beef	6.0	4.7	1.6
HRWS Sheep	11.1	2.6	0.9
HRWS Sheep (excluding Genetic matching)	5.0	2.6	0.9

The results suggest that all segments of the industry could benefit from the development of LBS systems that provide information on the key value generating applications. Apart from the high value of genetic matching in the sheep industry the total value across all segments is relatively similar.

Producers generally suggested that higher percentage revenue gains could be achieved rather than a percentage reduction in costs.

One key finding is that the economic value around the prevention of catastrophic or unusual events (CUEs) is only a small part of the overall financial value compared to the revenue gains and cost savings. Many of the events that were reported by producers in this category also carried commentary around the non-financial benefit of having peace of mind in knowing that these issues could be monitored. Thus, the value to the industry is more than the financial benefits articulated and this really needs to be considered in the development of LBS systems.

3.5.2 What are the most important applications that will have impact across the entire industry?

By compiling the results across the online survey and detailed producer interviews it is possible to identify applications that will have a widespread and significant impact on the red-meat industry, applications that might have a more specific impact in particular sectors and those with lower level impacts (Table 27). This list and ranking is not definitive but does act as a guide as to what applications when developed will provide the most value to the industry.

Table 27 A summation of the applications and their value across all segments

Category	Application
High financial value and consistently reported by producers across more than one sector	Water related behaviour* Calving and lambing detection
High financial value but not consistently reported by producers	Timing of grazing rotations Landscape utilisation
High financial value but limited to one sector	Genetic matching (dam/offspring) Mustering efficiency
Applications with medium financial value	Stock theft detection and prevention* Disease detection Predation detection* Pregnancy status Refining fertiliser application Bull/ram activity
Applications with lower financial value	Poisoning detection Basic animal location* Refining supplementary feeding
Applications for which producers did not articulate significant financial value but should still be pursued	Oestrus detection Welfare monitoring*

	Health alert for critical injuries Detecting shy feeders

* Applications determined to have a high value in terms of providing producers with "Peace of Mind".

3.5.3 Is there any value in sentinel deployment and if so, do the applications change in value?

The deployment of sentinel systems reduced the potential value that producers could articulate for LBS data when compared to monitoring the whole herd or flock. The value around revenue gains was roughly halved and mean cost savings fell to less than a quarter of the savings articulated under a whole of herd/flock deployment.

Critically though, producers largely still believed there was some value to be gained from the deployment of sensing devices to collect LBS data from 5-10% of their herd and/or flock.

Equally relevant to this, is that these benefits will potentially be achievable at a much lower costs and in a time frame sooner than when whole of herd/flock tracking might be achieved. One of the challenges of achieving this value through sentinel deployment is that the relevant applications are potentially different to those reported for a whole of herd deployment.

Table 28 Average benefits reported across zone and industry segments. Also included is an adjusted mean revenue value if genetic matching was excluded from the sheep industry.

Segment	Mean revenue (%)	Mean Costs (%)	CUE prevention (%)
Pastoral beef	2.7	0.6	0.0
HRWS Beef	2.6	0.6	0.0
HRWS Sheep	2.0	0.3	0.9

One of the key issues with the sentinel deployment will be deriving value from the limited number of animals being monitored. Whilst those producers who could articulate value from more complex applications such as landscape utilisation and timing of grazing rotations could still see how they could apply this in a sentinel system they represent a relatively highly skilled cohort. The challenge for the industry will be increasing the skill of producers to enable them to make the necessary management decisions to take advantage of the data.

Perhaps the more likely candidate for widespread adoption of sentinel devices will be the application of monitoring the activity of rams and bulls. This application has some value over all market segments and may be the best way for producers with lower level feedbase management skills to take advantage and begin to adopt the technology.

Producers believe that the detecting water related behaviour, disease, stock theft and predation was still possible in some situations. Further research is required to determine exactly how effective a sentinel system might be in providing the required information to producers to ensure they can achieve the required financial benefit.

One of the more interesting results was the idea that having small numbers of animals tracked might allow you to still get some benefit in terms of mustering efficiency. A handful of producers believed that they could use the sentinel animals to gain a better understanding of animal behaviour and then optimise their mustering activities around this. This is quite valuable as it means that producers from the pastoral zone could start using these systems earlier to at least gain some financial benefit which may lead to increased adoption rates.

Table 29 A summation of applications and there value across all industry segments when deployed as a sentinel system. Note that some of the applications have changed in value because the effectiveness of the sentinel system is less than that of the whole of herd/flock system and therefore less financial benefit can be achieved.

Category	Application
High (relative) financial value and relevant to more than one sector	Landscape utilisation Timing of grazing rotations Bull and ram activity
High (relative) financial value but limited to one sector	Refining fertiliser application
Applications with medium financial value	Stock theft detection* Mustering efficiency Water related behaviour* Disease detection Predation detection*

3.6 Key messages

- Producers articulated a diverse range of potential applications from LBS systems that would provide either financial benefit or bring non-financial value to their business. Furthermore, there was diversity in the “path to value”, the way in which producers would achieve a benefit within each application.
- There were two key applications: genetic matching of ewes and lambs (sheep) and mustering efficiency (pastoral beef) with large estimated benefits for the specific sectors in which they had relevance.
- Outside the two “big wins”, and in general, producers articulated that the financial benefits from LBS data would come from a range of applications and in most cases it was the cumulative effect of a number of smaller increases in revenue and cost savings that would provide a substantive benefit.
- As a whole producers suggested that there was more benefit to be had from increases in revenue than cost savings or from the prevention of catastrophic or unusual events (CUE’s).

However, the ability to achieve these increases in revenue may be limited by uncertainty and the increased level of skill required to turn the information provided by LBS systems into effective management decisions.

- Whilst the financial value around the use of LBS systems to prevent CUE’s was quite small, producers were primarily interested in this from a “peace of mind” perspective. The non-financial value that these systems might bring should not be underestimated and warrants further investigation.
- The benefits that could be gained from sentinel systems were less than half that of whole of herd/flock deployments. However, significant consideration needs to be given to pursuing a better understanding of how these system might best beused. The cost of deployment may well be lower and the time frame in which these systems are likely to be technically available, much less, making them a candidate for a more rapid adoption.
- Whilst sentinel systems look promising, the benefits need further specific exploration as the total value was often dominated by applications with more difficult value paths, particularly landscape utilisation. Specific applications such as bull/ram management as well as monitoring of vulnerable animals needs to be considered. How sentinel deployments might be used to capture some of the broader value needs further research.
- The adoptability of applications needs further consideration, some will be easily applied and require little additional skill to realise the benefits. Others will require further technical development, be more difficult to apply or require increased skills in other allied areas and will subsequently be slower to be adopted. This will have a major impact on the likely total industry benefit.

4 What would be the national industry impact of location, behaviour and state information?

4.1 Productivity benefits

4.1.1 Overview of approach

This section addresses benefits accruing to livestock enterprises from the use of sensors to monitor animal location, behaviour and state.

Economic value can arise from use and non-use benefits. Use benefits can be tangible, such those associated with increasing revenues or reducing costs, or they can be intangible, such as improvements in environmental values. Non-use values are generally intangible such as animal welfare benefits or a positive state of mind on the part of farm managers.

The benefits that have been examined in this report are:

- productivity benefits from the use of animal monitoring systems
- benefits associated with managing biosecurity
- benefits associated with animal welfare

Benefits for the first two areas use values for which some economic value has been quantified. Benefits for the third area are a mixture of use and non-use values for which economic value has not been quantified.

The analysis was undertaken in two parts. The first part estimated the productivity impacts from the application of LBS monitoring systems and the total net benefits, net present values (NPVs) and benefit cost ratios (BCRs). The second part examined the impacts on biosecurity and animal welfare. The latter cases are discussed in section 4.3.

The process is summarised in Figure 37

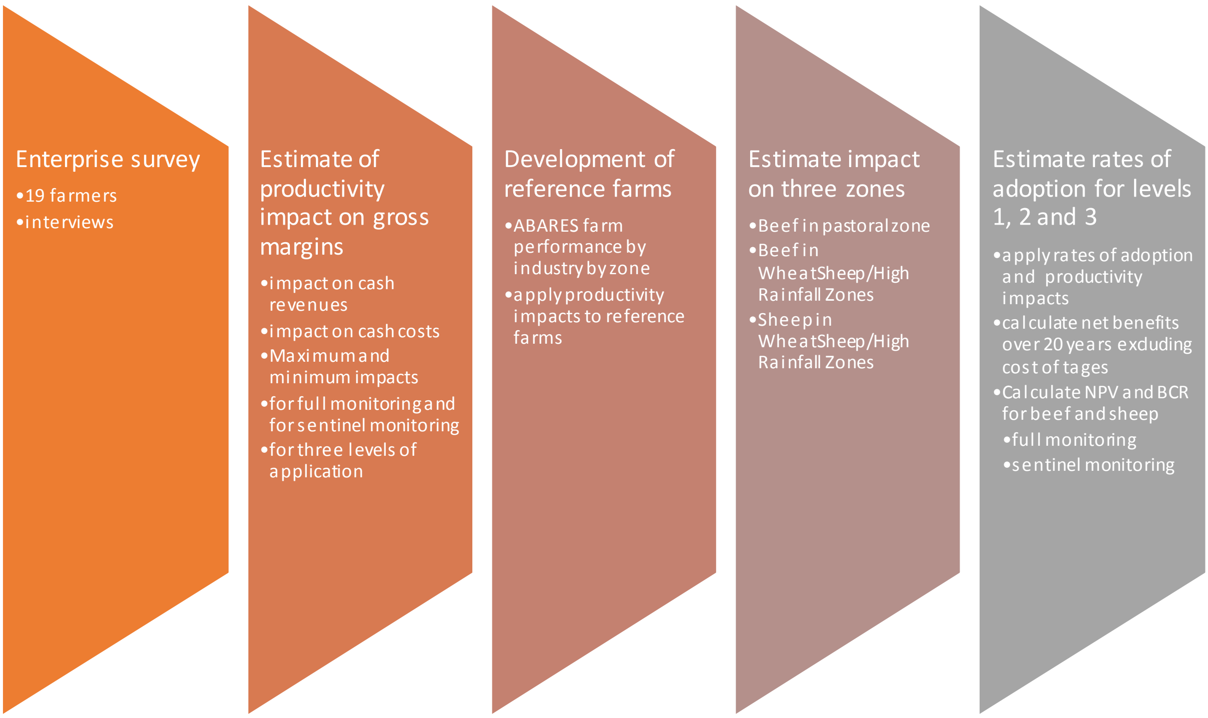


Figure 37 Summary of process for economic analysis

4.1.2 Survey

Central Queensland University undertook a survey of 19 farmer in the beef and sheep industries in three agricultural zones across Australia (see section 3). The survey posed questions to farmers on what the impact of LBS data might have on farm incomes or costs. The impacts were divided into three levels:

- Level 1 – basic applications for which adoption is simple and path to value easily achieved;
- Level 2 – more advanced applications associated with animal state, calving activities and health, these require more technical development, skill and/or might be difficult to implement; and
- Level 3 – advanced applications relating to feedbase that require more skill and/or infrastructure to realise benefits.

The areas of benefit explored in the questionnaire are provided in Table 30 Survey questions and categorisation into adoption levels. The impacts were expressed as percentages of changes in cash income or costs. The incomes and costs were expressed as total farm income in order to be able to apply them to average farms in three zones as reported from the Australian Bureau of Agricultural and Resource Economics (ABARES) farm survey file titled "Performance for broad acre farms by industry and zone"[1].

Table 30 Survey questions and categorisation into adoption levels

Level 1	Level 2	Level 3
Mustering efficiency	Oestrus detection	Landscape utilisation.
Water related behaviours	Pregnancy status	Refining fertiliser application
Basic animal location	Calving and lambing detection	Timing grazing rotations
Stock theft	Disease detection	Refining supplementary feeding
Predation alert	Poisoning detection	
Bull/ram activity	Welfare monitoring	
	Genetic matching (dam/offspring)	
Detecting shy feeders		
Health alerts for critical injury		

4.1.3 Agricultural Zones

The survey data was sorted into three agricultural zones for the purposes of the economic analysis: 1. Pastoral Zone; 2. Wheat-Sheep Zone; and 3. High Rainfall Zone.

[1] Performance for broadacre farms by industry and zone.xlsx

The zones are shown in Figure 38 below. These zones correspond to data provided in the annual farm survey conducted by ABARES. The farm survey provides average cash returns and costs for farms in these zones by enterprise.

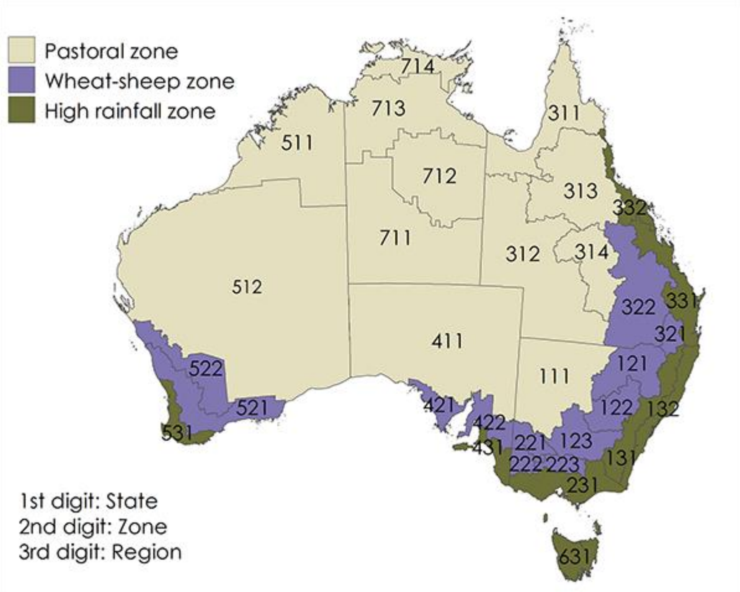


Figure 38 ABARES zones of agricultural production

4.1.4 Reference farms

To organise the baseline economic data Reference Farms were developed for beef and sheep enterprises.

The Wheat-Sheep and High Rainfall zones were combined as the survey undertaken for this study did not reveal any significant differences in productivity impacts between these two zones.

Reference farms were established for beef and sheep enterprises:

- Beef enterprises were categorised into Pastoral and High-rainfall/sheep-wheat Zones.
- Sheep enterprises were categorised into the High-rainfall/sheep-wheat Zone.

A net benefit was estimated for each reference farm for full monitoring (whole of herd) and for sentinel monitoring. Full monitoring involves attaching sensors to all livestock while sentinel monitoring involves attaching tags to five percent of animals.

The results were converted to an average benefit per head for each reference farm. These data were then used as indicators for beef in the Pastoral and High-rainfall/sheep-wheat Zones and for sheep in the High-rainfall/sheep-wheat zones.

4.1.5 Estimating likely minimum and maximum benefits

An extensive examination of how benefits reported by participants might be best translated into whole of industry impacts was undertaken and after consideration a basic approach that relied heavily on the producer reports was nominated.

Minimum and maximum likely industry impacts were calculated based on the likely upper and lower levels of financial benefit that were articulated throughout the producer case studies.

The minimum likely industry impact was calculated for each reference farm based on the reported benefits (cost reductions, annual revenue gains and annualised prevented revenue losses from

CUEs) averaged across all participants within the group. This process brought the total benefit for the reference farm back into line with the average benefit reported for each property. This minimum likely benefit scenario could also be considered a “realistic” situation.

The maximum likely industry impact assumed that the average benefit reported by those producers able to articulate a financial benefit (not all producers) was achievable across the industry. This reflects the scenario where every producer could take advantage of all the various benefits articulated by participants at the average rate at which they reported them. It should be noted that this is not the maximum rate at which each application was reported unless only one producer articulated this benefit. This maximum likely benefit scenario can also be considered an “optimistic” situation in which producers can gain the most benefit from LBS systems.

Table 31 An example of how the minimum and maximum likely industry impacts were calculated for each application

Producer	Application benefit (e.g. Revenue gain from disease detection)
1	4%
2	2%
3	0%
4	0%
Minimum likely industry impact	**= 1.5% [i.e. (4%+2%+0%+0%) / all 4 participants]**
Maximum likely industry impact	**= 3% [i.e. 4% + 2% / 2 participants reporting value]**

4.1.6 Adoption rates of various applications

To reflect the likely variation final adoption rates of the various applications each was assigned to one of three groups. Level 1 applications were considered to be easily adopted with a simple path to value for producers. These were estimated to have a final adoption rate of 80 per cent after 20 years. Level 2 applications were considered to have a medium level of adoptability with some minor difficulties in adoption and or path to value. These were considered to have a final adoption rate of 50 per cent after 20 years. The final group consisted of the feedbase related applications for which producers expressed high but uncertain value. These applications are more difficult to implement and/or generally require a higher degree of skill before the value can be extracted. These were considered to have the lowest final adoption rate of 10 per cent after 20 years.

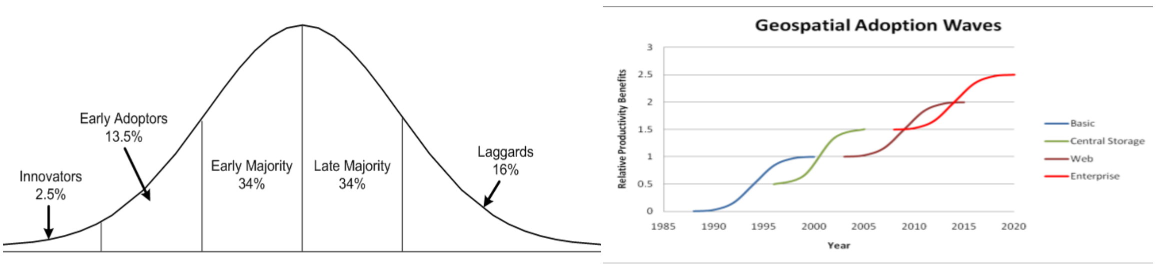
Wider economic impacts depend on levels of adoption of specific applications across industry sectors. The direct impact on a sector is the productivity impact of an application multiplied by the level of adoption.

$$\begin{aligned} & Direct\ impact\ on\ a\ sector \\ & \qquad = specific\ net\ productivity\ impact \\ & \qquad \times the\ level\ of\ adoption\ accross\ the\ sector \end{aligned}$$

A typical adoption profile is shown in the left hand chart in Figure 39. This curve is based on work done by Rogers (2003) and illustrates the early to mid-level adoption phase followed by the late adopters. If the curve is redrawn to show increases in productivity over time the curve becomes an S shaped curve as shown on the right hand side of the diagram.

It is necessary to assess at what stage the adoption phases are for each application. In practice geospatial systems frequently come in waves as different technologies combine to produce new products or services.

For example the four adoption curves depicted on the right hand side show each wave of adoption building on a previous wave to produce higher levels of productivity with each wave. The first wave represents the introduction of basic GIS services in an organization. The second wave involves the central storage of these systems so that more than one person in the organization can use the GIS. The third stage represents the migration to web based application and the final stage represents migration to enterprise based applications.



***Source:* Rogers (2003), ACIL Tasman and ConsultingWhere (2010).**

Figure 39 Adoption curves

Estimates of the productivity impacts for an application and the level of adoption are combined to provide productivity shocks for a sector. This data is then entered into the benefit cost analysis.

4.1.7 Reference farm details

A total of 12 reference farm scenarios were developed to provide input into the economic analysis. These reflected the results of the farm surveys discussed above and included Minimum and Maximum Scenarios. These are summarised in Table 32. The reference farms were based on the zones classified in the annual farm survey conducted by the Australian Bureau of Agricultural and Resource Economics. These were divided into Pastoral and High-rainfall/sheep-wheat zones.

Table 32 Reference farm scenarios developed for the industry wide analysis

Enterprise	Zone	Monitoring level	Scenario
Beef	Pastoral	Full	Max
Beef	Pastoral	Full	Min
Beef	Wheat-Sheep/High Rainfall	Full	Max
Beef	Wheat-Sheep/High Rainfall	Full	Min
Beef	Pastoral	Sentinel	Max
Beef	Pastoral	Sentinel	Min

Beef	Wheat-Sheep/High Rainfall	Sentinel	Max
Beef	Wheat-Sheep/High Rainfall	Sentinel	Min
Sheep	Wheat-Sheep/High Rainfall	Full	Max
Sheep	Wheat-Sheep/High Rainfall	Full	Min
Sheep	Wheat-Sheep/High Rainfall	Sentinel	Max
Sheep	Wheat-Sheep/High Rainfall	Sentinel	Min

The reference farms were then used to estimate the level of benefits from three levels of application of the LBS technologies assuming 100 per cent adoption of all three levels of technology. Each reference farm is discussed in turn below. The data was obtained from the following reference file: "Performance for broad acre farms by industry and zone.xlsx" (submitted with final report).

4.1.8 Breaking down survey results across adoption levels

These percentage improvements in revenues or costs have been entered in to an economic model to create budgets for reference farms as discussed in the previous section.

Beef in the Pastoral Zone

The results of the Survey for Beef in the Pastoral Zone for the three levels of application are summarised in Table 33.

Table 33 Beef in Pastoral Zone

	Category	Revenue impact	Cost impact	CUE impact
Level 1	Full Monitoring Maximum	8.17%	5.11%	0.27%
	Full Monitoring Minimum	2.77%	3.46%	0.01%
	Sentinel Maximum	2.71%	2.27%	0.22%
	Sentinel Minimum	0.74%	0.64%	0.00%
Level 2	Full Monitoring Maximum	13.87%	6.24%	0.93%
	Full Monitoring Minimum	4.48%	3.74%	0.01%
	Sentinel Maximum	3.56%	2.27%	0.22%
	Sentinel Minimum	0.88%	0.64%	0.00%

Level 3	Full Monitoring Maximum	26.20%	6.24%	0.93%
	Full Monitoring Minimum	8.54%	3.74%	0.01%
	Sentinel Maximum	14.69%	2.27%	0.22%
	Sentinel Minimum	2.74%	0.64%	0.00%

Beef in the high-rainfall/sheep-wheat zones

The results of the Survey for the three levels of application for beef in the high-rainfall/sheep-wheat zones are shown in Table 34.

Table 34 Beef in the high-rainfall/sheep-wheat zones

	Category	Revenue impact	Cost impact	CUE impact
Level 1	Full Monitoring Maximum	4.26%	6.19%	6.05%
	Full Monitoring Minimum	0.94%	2.98%	1.51%
	Sentinel Maximum	1.95%	2.39%	0.00%
	Sentinel Minimum	0.49%	0.60%	0.00%
Level 2	Full Monitoring Maximum	11.34%	9.90%	6.31%
	Full Monitoring Minimum	3.70%	4.70%	1.64%
	Sentinel Maximum	1.95%	2.45%	0.14%
	Sentinel Minimum	0.49%	0.61%	0.03%
Level 3	Full Monitoring Maximum	16.64%	9.90%	6.31%
	Full Monitoring Minimum	5.86%	4.70%	1.64%
	Sentinel Maximum	7.25%	2.45%	0.14%
	Sentinel Minimum	2.65%	0.61%	0.03%

Sheep in the high-rainfall/sheep-wheat Zones

The results of the survey for the three levels of application for beef in the high-rainfall/sheep-wheat zones are shown in Table 35.

Table 35 Sheep in the high-rainfall/sheep-wheat zones

	Category	Revenue impact	Cost impact	CUE impact
Level 1	Full Monitoring Maximum	1.08%	5.31%	1.75%
	Full Monitoring Minimum	0.21%	1.38%	0.61%

	Sentinel Maximum	0.23%	3.95%	1.68%
	Sentinel Minimum	0.03%	0.99%	0.56%
Level 2	Full Monitoring Maximum	15.49%	6.66%	2.51%
	Full Monitoring Minimum	8.17%	2.00%	0.99%
	Sentinel Maximum	0.23%	3.95%	2.26%
	Sentinel Minimum	0.03%	0.99%	0.71%
Level 3	Full Monitoring Maximum	32.71%	8.95%	2.51%
	Full Monitoring Minimum	11.08%	2.57%	0.99%
	Sentinel Maximum	11.05%	6.26%	2.26%
	Sentinel Minimum	2.03%	1.28%	0.71%

4.1.9 Beef Reference Farms

Costs of animal monitoring services

For the purposes of modelling a single annual monitoring service charge has been assumed to apply for all three levels of service regardless of the number of applications applied. As discussed earlier two levels of service charge have been assumed. The lower level represents a base case and the higher level represents a sensitivity test.

The tables show reference farm economics assuming 100 per cent adoption of all three levels.

Beef – Pastoral zone - Full monitoring

Monitoring service charge - $10 per animal per year

The reference farm for beef in the Pastoral Zone with Full Monitoring for the Maximum and Minimum Scenarios is shown in Table 36. The most relevant statistic is the net benefits per head which shows a net benefit of $82 per head with full adoption of all three levels of tracking technologies and services under the Maximum Scenario and $22 per head under the Minimum Scenario.

Table 36 Beef in the pastoral zone – full monitoring

	Maximum		**Minimum**	
	Total	**Per Head**	**Total**	**Per Head**
Total Head	4225		4225	
Revenue	$ 1,268,185.00	$ 300.16	$ 1,268,185.00	$ 300.16
Cost	$ 767,131.77	$ 181.57	$ 767,131.77	$ 181.57
Gross Margin	$ 501,053.23	$ 118.59	$ 501,053.23	$ 118.59
Level 1				
Increase in Revenue	$ 106,988.14	$ 25.32	$ 35,247.47	$ 8.34
Reduction in Cost	$ 39,227.01	$ 9.28	$ 26,532.11	$ 6.28
Total Benefit of Level 1	$ 146,215.15	$ 34.61	$ 61,779.58	$ 14.62
Level 2				
Increase in Revenue	$ 80,779.81	$ 19.12	$ 21,683.09	$ 5.13
Reduction in Cost	$ 8,673.17	$ 2.05	$ 2,173.26	$ 0.51
Total Benefit of Level 2	$ 89,452.98	$ 21.17	$ 23,856.35	$ 5.65
Level 3				
Increase in Revenue	$ 156,282.45	$ 36.99	$ 51,484.21	$ 12.19
Reduction in Cost	$ -	$ -	$ -	$ -
Total Benefit of Level 3	$ 156,282.45	$ 36.99	$ 51,484.21	$ 12.19
Total Potential Benefit	$ 391,950.59	$ 92.77	$ 137,120.14	$ 32.45
Total Cost of Monitoring Service	$ 42,250.00	$ 10.00	$ 42,250.00	$ 10.00
Net Increase in Gross Margin	**$ 349,700.59**	**$ 82.77**	**$ 94,870.14**	**$ 22.45**

Monitoring service charge - $50 per animal per year

The reference farm for beef in the Pastoral Zone with Full Monitoring for the Maximum and minimum scenarios is shown in Table 37. The most relevant statistic is the net benefits per head which shows a net benefit of $42 per head with full adoption of all three levels of tracking technologies and services under the Maximum Scenario and minus $18 per head under the minimum scenario.

Table 37 Beef in the Pastoral zone – Full monitoring

	Maximum		**Minimum**	
	Total	**Per Head**	**Total**	**Per Head**
Total Head	4225		4225	
Revenue	$ 1,268,185.00	$ 300.16	$ 1,268,185.00	$ 300.16
Cost	$ 767,131.77	$ 181.57	$ 767,131.77	$ 181.57
Gross Margin	$ 501,053.23	$ 118.59	$ 501,053.23	$ 118.59
Level 1				
Increase in Revenue	$ 106,988.14	$ 25.32	$ 35,247.47	$ 8.34
Reduction in Cost	$ 39,227.01	$ 9.28	$ 26,532.11	$ 6.28
Total Benefit of Level 1	$ 146,215.15	$ 34.61	$ 61,779.58	$ 14.62
Level 2				
Increase in Revenue	$ 80,779.81	$ 19.12	$ 21,683.09	$ 5.13
Reduction in Cost	$ 8,673.17	$ 2.05	$ 2,173.26	$ 0.51
Total Benefit of Level 2	$ 89,452.98	$ 21.17	$ 23,856.35	$ 5.65
Level 3				
Increase in Revenue	$ 156,282.45	$ 36.99	$ 51,484.21	$ 12.19
Reduction in Cost	$ -	$ -	$ -	$ -
Total Benefit of Level 3	$ 156,282.45	$ 36.99	$ 51,484.21	$ 12.19
Total Potential Benefit	$ 391,950.59	$ 92.77	$ 137,120.14	$ 32.45
Total Cost of Monitoring Service	$ 211,250.00	$ 50.00	$ 211,250.00	$ 50.00

	Maximum		Minimum	
	Total	Per Head	Total	Per Head
Net Increase in Gross Margin	**$ 180,700.59**	**$ 42.77**	**$ -74,129.86**	**$ -17.55**

Beef – High-rainfall/sheep-wheat zones – Full monitoring

Monitoring service charge - $10 per animal per year

The reference farm for beef in the High-rainfall/sheep-wheat zone for Full monitoring for the Maximum scenario is shown in Table 38. The reference farm represents the total of the average farm in each zone and is therefore larger than an average farm in either zone.

The most relevant statistic is the net benefits per head which shows a net benefit of $146 per head with full adoption of all three levels of tracking technologies under the Maximum Scenario and $46 per head under the Minimum Scenario.

There is a significant range between the maximum and minimum scenarios for beef enterprises in the wheat-sheep/high rainfall zone.

Table 38 Beef reference farm in the High-rainfall/sheep-wheat zones – full monitoring

	Maximum		Minimum	
	Total both zones	Per Head	Total both zones	Per Head
Total Head	604		604	
Revenue	$ 320,152.48	$ 530.37	$ 320,152.48	$ 530.37
Cost	$ 206,832.86	$ 342.64	$ 206,832.86	$ 342.64
Gross Margin	$ 113,319.61	$ 187.73	$ 113,319.61	$ 187.73
Level 1				
Increase in Revenue	$ 33,024.33	$ 54.71	$ 7,855.89	$ 13.01
Reduction in Cost	$ 12,793.41	$ 21.19	$ 6,155.01	$ 10.20
Total Benefit of Level 1	$ 45,817.74	$ 75.90	$ 14,010.90	$ 23.21
Level 2				
Increase in Revenue	$ 23,478.40	$ 38.89	$ 9,231.25	$ 15.29
Reduction in Cost	$ 7,688.04	$ 12.74	$ 3,562.61	$ 5.90
Total Benefit of Level 2	$ 31,166.44	$ 51.63	$ 12,793.87	$ 21.19
Level 3				
Increase in Revenue	$ 16,959.19	$ 28.09	$ 6,918.85	$ 11.46
Reduction in Cost	$ -	$ -	$ -	$ -
Total Benefit of Level 3	$ 16,959.19	$ 28.09	$ 6,918.85	$ 11.46

	Maximum				Minimum			
	Total both zones		Per Head		Total both zones		Per Head	
Total Potential Benefit	$	93,943.37	$	155.63	$	33,723.62	$	55.87
Total Cost of Monitoring Service	$	6,036.41	$	10.00	$	6,036.41	$	10.00
Net Increase in Gross Margin	**$**	**87,906.96**	**$**	**145.63**	**$**	**27,687.21**	**$**	**45.87**

Note: the reference farm for the High-rainfall/sheep-wheat Zones is based on a weighted average of the two zones. Source: ABARES 2018.

Monitoring service charge - $50 per animal per year

The reference farm Beef in the High-rainfall/sheep-wheat Zone for Full Monitoring for the Maximum Scenario is shown in Table 39 The reference farm represents the total of the average farm in each Zone and is therefore larger than an average farm in either zone.

The most relevant statistic is the net benefits per head which shows a net benefit of $106 per head with full adoption of all three levels of tracking technologies under the Maximum Scenario and $6 per head under the Minimum Scenario.

There is a significant range between the maximum and minimum scenarios for beef enterprises in the Wheat-Sheep/High Rainfall zone.

Table 39 Beef reference farm in the High-rainfall/sheep-wheat zones – full monitoring

	Maximum				Minimum			
	Total both zones		Per Head		Total both zones		Per Head	
Total Head		604				604		
Revenue	$	320,152.48	$	530.37	$	320,152.48	$	530.37
Cost	$	206,832.86	$	342.64	$	206,832.86	$	342.64
Gross Margin	$	113,319.61	$	187.73	$	113,319.61	$	187.73
Level 1								
Increase in Revenue	$	33,024.33	$	54.71	$	7,855.89	$	13.01
Reduction in Cost	$	12,793.41	$	21.19	$	6,155.01	$	10.20
Total Benefit of Level 1	$	45,817.74	$	75.90	$	14,010.90	$	23.21
Level 2								
Increase in Revenue	$	23,478.40	$	38.89	$	9,231.25	$	15.29

	Maximum		Minimum	
	Total both zones	**Per Head**	**Total both zones**	**Per Head**
Reduction in Cost	$ 7,688.04	$ 12.74	$ 3,562.61	$ 5.90
Total Benefit of Level 2	$ 31,166.44	$ 51.63	$ 12,793.87	$ 21.19
Level 3				
Increase in Revenue	$ 16,959.19	$ 28.09	$ 6,918.85	$ 11.46
Reduction in Cost	$ -	$ -	$ -	$ -
Total Benefit of Level 3	$ 16,959.19	$ 28.09	$ 6,918.85	$ 11.46
Total Potential Benefit	$ 93,943.37	$ 155.63	$ 33,723.62	$ 55.87
Total Cost of Monitoring Service	$ 30,182.05	$ 50.00	$ 30,182.05	$ 50.00
Net Increase in Gross Margin	**$ 63,761.32**	**$ 105.63**	**$ 3,541.58**	**$ 5.87**

Note: the reference farm for the High-rainfall/sheep-wheat Zones is based on a weighted average of the two zones. Source: ABARES 2018.

Beef – Pastoral Zone - Sentinel

Monitoring service charge - $50 per sensor per year

The reference farm for Beef in the Pastoral Zone with Sentinel Monitoring for the Maximum Scenario is shown in Table 40. The most relevant statistic is the net benefits per head which shows a net benefit of $46 per head with full adoption of all three levels of tracking technologies and services under the Maximum Scenario and $7 per head under the Minimum Scenario.

Table 40 Beef reference farm in the Pastoral zone – Sentinel

	Maximum		**Minimum**	
	Total both zones	**Per Head**	**Total both zones**	**Per Head**
Total Head	4225		4225	
Revenue	$ 1,268,185.00	$ 300.16	$ 1,268,185.00	$ 300.16
Cost	$ 767,131.77	$ 181.57	$ 767,131.77	$ 181.57
Gross Margin	$ 501,053.23	$ 118.59	$ 501,053.23	$ 118.59
Level 1				
Increase in Revenue	$ 37,203.45	$ 8.81	$ 9,434.67	$ 2.23
Reduction in Cost	$ 17,400.40	$ 4.12	$ 4,942.46	$ 1.17
Total Benefit of Level 1	$ 54,603.85	$ 12.92	$ 14,377.13	$ 3.40
Level 2				
Increase in Revenue	$ 10,782.35	$ 2.55	$ 1,797.06	$ 0.43
Reduction in Cost	$ -	$ -	$ -	$ -
Total Benefit of Level 2	$ 10,782.35	$ 2.55	$ 1,797.06	$ 0.43
Level 3				
Increase in Revenue	$ 141,135.52	$ 33.40	$ 23,543.72	$ 5.57
Reduction in Cost	$ -	$ -	$ -	$ -
Total Benefit of Level 3	$ 141,135.52	$ 33.40	$ 23,543.72	$ 5.57
Total Potential Benefit	$ 206,521.73	$ 48.88	$ 39,717.91	$ 9.40
Total Cost of Monitoring Service	$ 10,562.50	$ 2.50	$ 10,562.50	$ 2.50
Net Increase in Gross Margin	**$ 195,959.23**	**$ 46.38**	**$ 29,155.41**	**$ 6.90**

Note: the reference farm for the High-rainfall/sheep-wheat Zones is based on a weighted average of the two zones. Source: ABARES 2018.

Monitoring service charge - $150 per sensor per year

The reference farm for Beef in the Pastoral Zone with Sentinel Monitoring for the Maximum Scenario is shown in Table 41. The most relevant statistic is the net benefits per head which shows a net benefit of $41 per head with full adoption of all three levels of tracking technologies and services under the Maximum Scenario and $2 per head under the Minimum Scenario.

Table 41 Beef reference farm in the Pastoral zone – Sentinel

	Maximum		**Minimum**	
	Total both zones	**Per Head**	**Total both zones**	**Per Head**
Total Head	4225		4225	
Revenue	$ 1,268,185.00	$ 300.16	$ 1,268,185.00	$ 300.16
Cost	$ 767,131.77	$ 181.57	$ 767,131.77	$ 181.57
Gross Margin	$ 501,053.23	$ 118.59	$ 501,053.23	$ 118.59
Level 1				
Increase in Revenue	$ 37,203.45	$ 8.81	$ 9,434.67	$ 2.23
Reduction in Cost	$ 17,400.40	$ 4.12	$ 4,942.46	$ 1.17
Total Benefit of Level 1	$ 54,603.85	$ 12.92	$ 14,377.13	$ 3.40
Level 2				
Increase in Revenue	$ 10,782.35	$ 2.55	$ 1,797.06	$ 0.43
Reduction in Cost	$ -	$ -	$ -	$ -
Total Benefit of Level 2	$ 10,782.35	$ 2.55	$ 1,797.06	$ 0.43
Level 3				
Increase in Revenue	$ 141,135.52	$ 33.40	$ 23,543.72	$ 5.57
Reduction in Cost	$ -	$ -	$ -	$ -
Total Benefit of Level 3	$ 141,135.52	$ 33.40	$ 23,543.72	$ 5.57
Total Potential Benefit	$ 206,521.73	$ 48.88	$ 39,717.91	$ 9.40
Total Cost of Monitoring Service	$ 31,687.50	$ 7.50	$ 31,687.50	$ 7.50

	Maximum		Minimum	
	Total both zones	Per Head	Total both zones	Per Head
Net Increase in Gross Margin	**$ 174,834.23**	**$ 41.38**	**$ 8,030.41**	**$ 1.90**

Note: the reference farm for the High-rainfall/sheep-wheat Zones is based on a weighted average of the two zones. Source: ABARES 2018.

Beef – High-rainfall/sheep-wheat Zones - Sentinel

Monitoring service charge - $50 per animal per year

The reference farm for full monitoring for the maximum effort is shown in Table 42. The most relevant statistic is the net benefits per head which shows a net benefit of $45 per head with full adoption of all three levels of tracking technologies and services under the Maximum Scenario and $14 per head under the Minimum Scenario.

Table 42 Beef in the High-rainfall/sheep-wheat zones – Sentinel

	Maximum		Minimum	
	Total both zones	Per Head	Total both zones	Per Head
Total Head	604		604	
Revenue	$ 320,152.48	$ 530.37	$ 320,152.48	$ 530.37
Cost	$ 206,832.86	$ 342.64	$ 206,832.86	$ 342.64
Gross Margin	$ 113,319.61	$ 187.73	$ 113,319.61	$ 187.73
Level 1				
Increase in Revenue	$ 6,242.97	$ 10.34	$ 1,560.74	$ 2.59
Reduction in Cost	$ 4,948.47	$ 8.20	$ 1,237.12	$ 2.05
Total Benefit of Level 1	$ 11,191.44	$ 18.54	$ 2,797.86	$ 4.63
Level 2				
Increase in Revenue	$ 445.22	$ 0.74	$ 111.30	$ 0.18
Reduction in Cost	$ 127.37	$ 0.21	$ 31.84	$ 0.05
Total Benefit of Level 2	$ 572.58	$ 0.95	$ 143.15	$ 0.24
Level 3				
Increase in Revenue	$ 16,959.19	$ 28.09	$ 6,918.85	$ 11.46
Reduction in Cost	$ -	$ -	$ -	$ -

	Maximum		Minimum	
	Total both zones	Per Head	Total both zones	Per Head
Total Benefit of Level 3	$ 16,959.19	$ 28.09	$ 6,918.85	$ 11.46
Total Potential Benefit	$ 28,723.22	$ 47.58	$ 9,859.86	$ 16.33
Total Cost of Monitoring Service	$ 1,509.10	$ 2.50	$ 1,509.10	$ 2.50
Net Increase in Gross Margin	**$ 27,214.12**	**$ 45.08**	**$ 8,350.76**	**$ 13.83**

Note: the reference farm for the High-rainfall/sheep-wheat Zones is based on a weighted average of the two zones. Source: ABARES 2018.

Monitoring service charge - $150 per animal per year

The reference farm for full monitoring for the maximum effort is shown in Table 43. The most relevant statistic is the net benefits per head which shows a net benefit of $40 per head with full adoption of all three levels of tracking technologies and services under the Maximum Scenario and $8 per head under the Minimum Scenario.

Table 43 Beef in the High-rainfall/sheep-wheat zones – Sentinel

	Maximum		Minimum	
	Total both zones	Per Head	Total both zones	Per Head
Total Head	604		604	
Revenue	$ 320,152.48	$ 530.37	$ 320,152.48	$ 530.37
Cost	$ 206,832.86	$ 342.64	$ 206,832.86	$ 342.64
Gross Margin	$ 113,319.61	$ 187.73	$ 113,319.61	$ 187.73
Level 1				
Increase in Revenue	$ 6,242.97	$ 10.34	$ 1,560.74	$ 2.59
Reduction in Cost	$ 4,948.47	$ 8.20	$ 1,237.12	$ 2.05
Total Benefit of Level 1	$ 11,191.44	$ 18.54	$ 2,797.86	$ 4.63
Level 2				
Increase in Revenue	$ 445.22	$ 0.74	$ 111.30	$ 0.18
Reduction in Cost	$ 127.37	$ 0.21	$ 31.84	$ 0.05

	Maximum		Minimum	
	Total both zones	Per Head	Total both zones	Per Head
Total Benefit of Level 2	$ 572.58	$ 0.95	$ 143.15	$ 0.24
Level 3				
Increase in Revenue	$ 16,959.19	$ 28.09	$ 6,918.85	$ 11.46
Reduction in Cost	$ -	$ -	$ -	$ -
Total Benefit of Level 3	$ 16,959.19	$ 28.09	$ 6,918.85	$ 11.46
Total Potential Benefit	$ 28,723.22	$ 47.58	$ 9,859.86	$ 16.33
Total Cost of Tags Service	$ 4,527.31	$ 7.50	$ 4,527.31	$ 7.50
Net Increase in Gross Margin	**$ 24,195.91**	**$ 40.08**	**$ 5,332.55**	**$ 8.83**

Note: the reference farm for the High-rainfall/sheep-wheat Zones is based on a weighted average of the two zones.
Source: UCQ, (ABARES, 2018)

4.1.10 Sheep reference farms

Sheep – High-rainfall/sheep-wheat Zones – Full monitoring

Monitoring service charge - $10 per animal per year

The reference farm for Sheep in the High-rainfall/sheep-wheat Zones with full monitoring for the Maximum Scenario is shown in Table 44. The most relevant statistic is the net benefits per head which shows a net benefit of $34 per head with full adoption of all three levels of tracking technologies and services under the Maximum Scenario and $5 per head under the Minimum Scenario.

Table 44 Sheep in the High-rainfall/sheep-wheat Zone – full monitoring

	Maximum		Minimum	
	Total	Per head	Total	Per head
Total Head	2,799		2799	
Revenue	$ 304,461.74	$ 108.77	$ 304,461.74	$ 108.77
Cost	$ 191,239.92	$ 68.32	$ 191,239.92	$ 68.32
Gross Margin	$ 113,221.83	$ 40.45	$ 113,221.83	$ 40.45
Level 1				

	Maximum				Minimum			
	Total		Per head		Total		Per head	
Increase in Revenue	$	8,593.13	$	3.07	$	2,512.02	$	0.90
Reduction in Cost	$	10,153.88	$	3.63	$	2,634.23	$	0.94
Total Benefit of Level 1	$	18,747.01	$	6.70	$	5,146.24	$	1.84
Level 2								
Increase in Revenue	$	46,200.95	$	16.51	$	25,369.46	$	9.06
Reduction in Cost	$	2,577.73	$	0.92	$	1,193.20	$	0.43
Total Benefit of Level 2	$	48,778.69	$	17.43	$	26,562.67	$	9.49
Level 3								
Increase in Revenue	$	52,414.78	$	18.73	$	8,848.91	$	3.16
Reduction in Cost	$	4,383.05	$	1.57	$	1,095.76	$	0.39
Total Benefit of Level 3	$	56,797.83	$	20.29	$	9,944.67	$	3.55
Total Potential Benefit	$	124,323.52	$	44.42	$	41,653.59	$	14.88
Total Cost of Monitoring Service	$	27,990.51	$	10.00	$	27,990.51	$	10.00
Net Increase in Gross Margin	**$**	**96,333.01**	**$**	**34.42**	**$**	**13,663.07**	**$**	**4.88**

Note: the reference farm for the High-rainfall/sheep-wheat Zones is based on a weighted average of the two zones. Source: ABARES 2018.

Monitoring service charge - $50 per animal per year

The reference farm for Sheep in the High-rainfall/sheep-wheat Zones with full monitoring for the Maximum Scenario is shown in Table 45. The most relevant statistic is the net benefits per head which shows a net benefit of -$6 per head with full adoption of all three levels of tracking technologies and services under the Maximum Scenario and -$35 per head under the Minimum Scenario.

Table 45 Sheep in the High-rainfall/sheep-wheat Zone – full monitoring

	Maximum		**Minimum**	
	Total	Per head	Total	Per head
Total Head	2,799		2799	
Revenue	$ 304,461.74	$ 108.77	$ 304,461.74	$ 108.77
Cost	$ 191,239.92	$ 68.32	$ 191,239.92	$ 68.32
Gross Margin	$ 113,221.83	$ 40.45	$ 113,221.83	$ 40.45
Level 1				
Increase in Revenue	$ 8,593.13	$ 3.07	$ 2,512.02	$ 0.90
Reduction in Cost	$ 10,153.88	$ 3.63	$ 2,634.23	$ 0.94
Total Benefit of Level 1	$ 18,747.01	$ 6.70	$ 5,146.24	$ 1.84
Level 2				
Increase in Revenue	$ 46,200.95	$ 16.51	$ 25,369.46	$ 9.06
Reduction in Cost	$ 2,577.73	$ 0.92	$ 1,193.20	$ 0.43
Total Benefit of Level 2	$ 48,778.69	$ 17.43	$ 26,562.67	$ 9.49
Level 3				
Increase in Revenue	$ 52,414.78	$ 18.73	$ 8,848.91	$ 3.16
Reduction in Cost	$ 4,383.05	$ 1.57	$ 1,095.76	$ 0.39
Total Benefit of Level 3	$ 56,797.83	$ 20.29	$ 9,944.67	$ 3.55
Total Potential Benefit	$ 124,323.52	$ 44.42	$ 41,653.59	$ 14.88
Total Cost of Tags Service	$ 139,952.57	$ 50.00	$ 139,952.57	$ 50.00
Net Increase in Gross Margin	**$ -15,629.05**	**$ -5.58**	**$ -98,298.99**	**$ -35.12**

Note: the reference farm for the High-rainfall/sheep-wheat Zones is based on a weighted average of the two zones. Source: ABARES 2018.

Sheep – High-rainfall/sheep-wheat Zones – Sentinel

Monitoring service charge - $50 per animal per year

The reference farm for Sheep in the Wheat- Sheep/High Rainfall Zones with Sentinel monitoring for the Maximum Scenario is shown in Table 46. The net benefits per head which is of $16 per head with full adoption of all three levels of tracking technologies and services for the Maximum Scenario and $1 per head for the Minimum Scenario.

Table 46 Sheep in the High-rainfall/sheep-wheat Zone – Sentinel

	Maximum		**Minimum**	
	Total	**Per head**	**Total**	**Per head**
Total Head	2799		2799	
Revenue	$ 304,461.74	$ 108.77	$ 304,461.74	$ 108.77
Cost	$ 191,239.92	$ 68.32	$ 191,239.92	$ 68.32
Gross Margin	$ 113,221.83	$ 40.45	$ 113,221.83	$ 40.45
Level 1				
Increase in Revenue	$ 5,818.36	$ 2.08	$ 1,797.62	$ 0.64
Reduction in Cost	$ 7,549.25	$ 2.70	$ 1,888.94	$ 0.67
Total Benefit of Level 1	$ 13,367.61	$ 4.78	$ 3,686.56	$ 1.32
Level 2				
Increase in Revenue	$ 1,783.26	$ 0.64	$ 445.82	$ 0.16
Reduction in Cost	$ -	$ -	$ -	$ -
Total Benefit of Level 2	$ 1,783.26	$ 0.64	$ 445.82	$ 0.16
Level 3				
Increase in Revenue	$ 32,921.89	$ 11.76	$ 6,103.08	$ 2.18
Reduction in Cost	$ 4,414.48	$ 1.58	$ 551.81	$ 0.20
Total Benefit of Level 3	$ 37,336.38	$ 13.34	$ 6,654.89	$ 2.38
Total Potential Benefit	$ 52,487.25	$ 18.75	$ 10,787.26	$ 3.85
Total Cost of Monitoring Service	$ 6,997.63	$ 2.50	$ 6,997.63	$ 2.50
Net Increase in Gross Margin	**$ 45,489.62**	**$ 16.25**	**$ 3,789.64**	**$ 1.35**

Note: the reference farm for the High-rainfall/sheep-wheat Zones is based on a weighted average of the two zones. Source: ABARES 2018.

Monitoring service charge - $150 per animal per year

The reference farm for Sheep in the Wheat- Sheep/High Rainfall Zones with Sentinel monitoring for the Maximum Scenario is shown in Table 47. The net benefits per head which is of $11 per head with full adoption of all three levels of tracking technologies and services for the Maximum Scenario and minus $4 per head for the Minimum Scenario.

Table 47 Sheep in the High-rainfall/sheep-wheat Zone – Sentinel

	Maximum		Minimum	
	Total	**Per head**	**Total**	**Per head**
Total Head	2799		2799	
Revenue	$ 304,461.74	$ 108.77	$ 304,461.74	$ 108.77
Cost	$ 191,239.92	$ 68.32	$ 191,239.92	$ 68.32
Gross Margin	$ 113,221.83	$ 40.45	$ 113,221.83	$ 40.45
Level 1				
Increase in Revenue	$ 5,818.36	$ 2.08	$ 1,797.62	$ 0.64
Reduction in Cost	$ 7,549.25	$ 2.70	$ 1,888.94	$ 0.67
Total Benefit of Level 1	$ 13,367.61	$ 4.78	$ 3,686.56	$ 1.32
Level 2				
Increase in Revenue	$ 1,783.26	$ 0.64	$ 445.82	$ 0.16
Reduction in Cost	$ -	$ -	$ -	$ -
Total Benefit of Level 2	$ 1,783.26	$ 0.64	$ 445.82	$ 0.16
Level 3				
Increase in Revenue	$ 32,921.89	$ 11.76	$ 6,103.08	$ 2.18
Reduction in Cost	$ 4,414.48	$ 1.58	$ 551.81	$ 0.20
Total Benefit of Level 3	$ 37,336.38	$ 13.34	$ 6,654.89	$ 2.38
Total Potential Benefit	$ 52,487.25	$ 18.75	$ 10,787.26	$ 3.85
Total Cost of Monitoring Service	$ 20,992.89	$ 7.50	$ 20,992.89	$ 7.50
Net Increase in Gross Margin	**$ 31,494.37**	**$ 11.25**	**$ -10,205.62**	**$ -3.65**

Note: the reference farm for the High-rainfall/sheep-wheat Zones is based on a weighted average of the two zones. Source: ABARES 2018.

Conclusion

All reference farms show a positive impact on gross margin from the use of LBS systems except for three:

- Beef in the Pastoral Zone with full monitoring, $50 per device annual charge and the Minimum Scenario;
- Sheep in the High-rainfall/sheep-wheat Zone with sentinel monitoring, $50 per device annual charge for both the Minimum and Maximum Scenarios; and
- Sheep in the High-rainfall/sheep-wheat Zone with sentinel monitoring, $150 per device annual charge and the Minimum Scenario.

4.2 Australia Wide economic benefits and costs

4.2.1 Scaling up

Information on the number of cattle in each of the zones for 2015-16 was made available from ABARES[2]. The results are summarised in Table 48.

Table 48 Head of livestock for Australia and zones 2015-16

	Total beef cattle	Total sheep and lambs
Pastoral	7,950,436	5,371,317
Wheat-sheep	7,176,109	39,782,340
High-rainfall	7,179,730	22,389,434
Australia total	22,306,275	67,543,092

Source: ABARE file: Beef cattle and sheep numbers state by zone 2015-16.xlsx

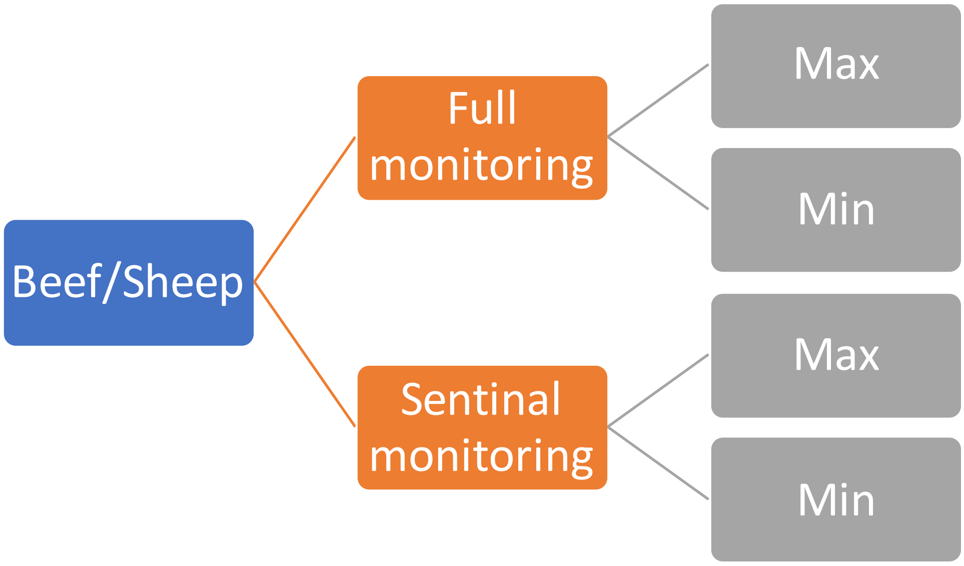
The benefits were then scaled up as follows:

- $Benefits\ to\ beef\ in\ pastoral\ zone = benefit\ per\ head\ in\ the\ pastoral\ zone\ x\ total\ number\ of\ cattle\ in\ the\ pastoral\ zone$
- $Benefits\ to\ sheep = weighted\ average\ benefit\ per\ head\ in\ the\ WheatSheep\ High\ Rainfall\ Zones\ x\ total\ number\ of\ sheep\ in\ the\ WheatSheep\ High\ Rainfall\ Zones$

The economic characteristics of farms across the zones will of course vary significantly and the use of an average reference farm figure masks the variance across each zone. However, the zonal data is the only consistent data set available that applies each zone across Australia as a whole. The benefits calculated therefore represent only a broad indication of the total possible benefits for Australia.

The results are expressed as net benefits (excluding an annual charge for animal monitoring services) and were then summarised for the beef and sheep industry for full monitoring and for sentinel monitoring. In each case a maximum and minimum estimate was provided. The structure of the results is shown in Figure 40.

[2] Beef cattle and sheep numbers state by zone 2015-16.xlsx



Note: Results have been prepared for both beef and sheep.

Figure 40 Structure of results

4.2.2 Total benefits

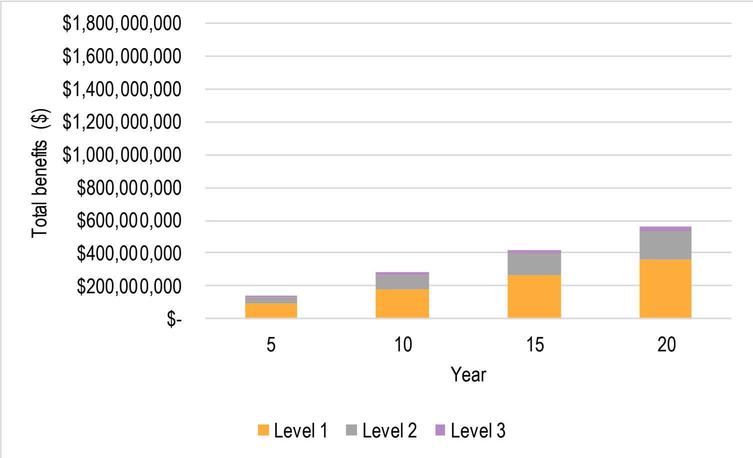
The impact on the total gross margins has been estimated for the beef and sheep industries across the three zones. The results for the beef industry have been derived by combining the results for beef in the pastoral zone and beef in the high-rainfall/sheep-wheat zones. The results are net of additional on-farm costs but do not include deductions for the annual service charge per monitoring device.

Beef industry full herd monitoring

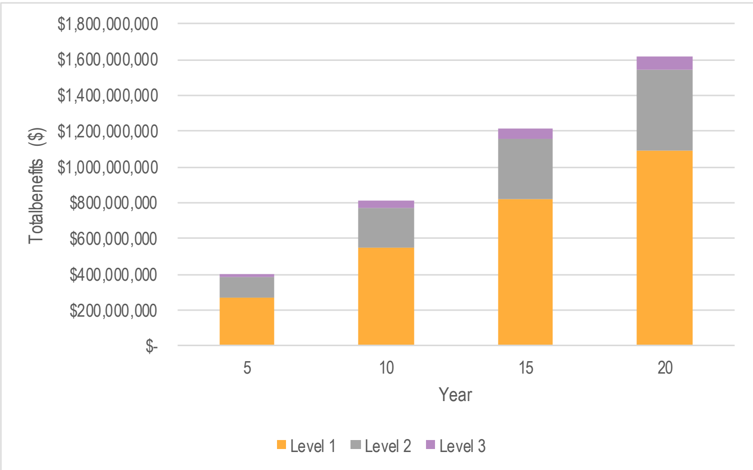
The Australia wide results for beef in the Pastoral Wheat/Sheep/High Rainfall Zones are shown in Figure 41. The results are presented for the Minimum and Maximum Scenarios. The results show Australia wide benefits of $560 million by year 20 under the Minimum Scenario and $1,616 million under the Maximum Scenario.

The largest contribution comes from Level 1 activities that represents around $359 million in year 20 under the Minimum Scenario and $1,091 million under the Maximum Scenario. The small contribution to total benefits from Level 3 activities is mainly attributable a lower level of adoption of Level 3 activities assumed for the modelling.

Minimum Scenario



Maximum Scenario



Note: The results combine beef in the pastoral and High-rainfall/sheep-wheat zones

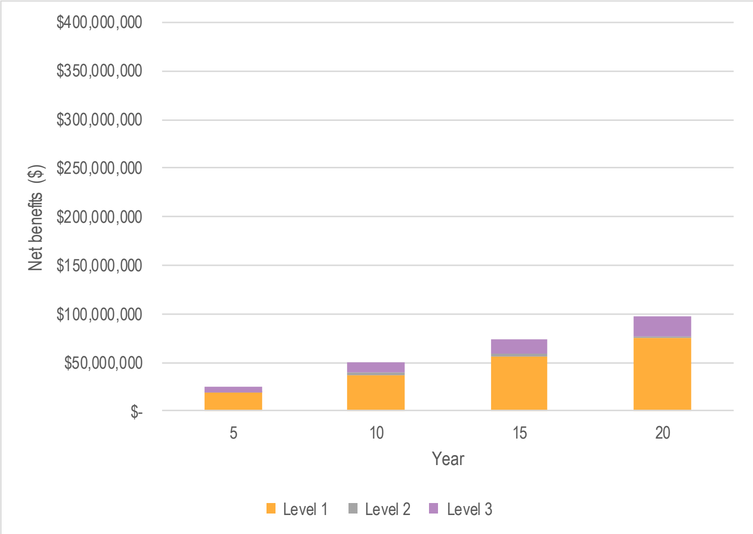
Figure 41 Results for beef – full monitoring

Beef industry – sentinel monitoring

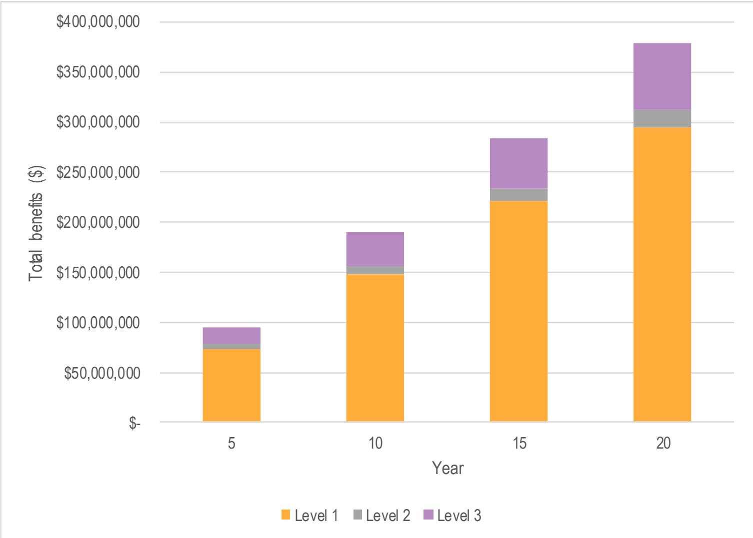
The Australia wide results for beef in the Pastoral Wheat/Sheep/High Rainfall Zones are shown in Figure 42. The results are presented for the Maximum and Minimum Scenarios. The results show Australia wide benefits by year 20 of $97 million by year 20 under the Minimum Scenario and $378 million under the Maximum Scenario.

The largest contribution comes from Level 1 activities that represents around $97 million in year 20 under the Minimum Scenario and $378 million under the Maximum Scenario. This is largely driven by the adoption assumptions for Level 1 activities reaching 80 per cent by 2020 compared to 50 per cent adoption for Level 2 and 10 per cent adoption for Level 3 activities.

Minimum Scenario



Maximum Scenario



Note: The results combine beef in the pastoral and High-rainfall/sheep-wheat zones.

Figure 42 Total benefits Beef – sentinel monitoring

Sheep industry – full monitoring

The Australia wide results for sheep in the High-rainfall/Sheep-wheat Zones are shown in Figure 43. The results show Australia wide benefits by year 20 of $408 million by year 20 under the Minimum Scenario and $1,001 million under the Maximum Scenario.

The largest contribution comes from Level 2 activities that represents around $295 million in year 20 under the Minimum Scenario and $541 million under the Maximum Scenario.

Figure 43 Total benefits - Sheep Industry – Full Monitoring

Sheep industry – Sentinel monitoring

The Australia wide results for sheep in the Pastoral Wheat/Sheep/High Rainfall Zones are shown in Figure 44. The results show Australia wide benefits by year 20 of $85 million by year 20 under the Minimum Scenario and just $340 million under the Maximum Scenario.

The largest contribution comes from Level 1 activities that represent around $66 million in year 20 under the Minimum Scenario and $238 million under the Maximum Scenario.

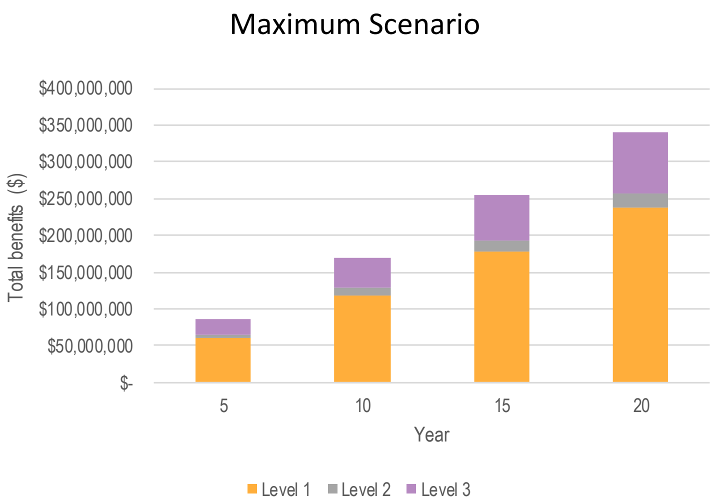


Figure 44 Total Benefits Sheep industry – Sentinel Monitoring

4.2.3 Overall economic impact

The above results are total benefits (after deducting additional operating costs) but do not deduct the cost of sensor devices or monitoring services. Separate calculations have been made that allow for the latter and these are presented in terms of a Net Present Value (NPV) and Benefit Cost Ratio (BCR) calculated over 20 years with a real discount rate of 7 per cent[3].

Net present value

The NPV and BCR results have been calculated for a total of 8 options as follows:

- Maximum and Minimum Benefit Scenarios
- Two levels of monitoring service charges for Full Monitoring - $10 per device and $50 per device
- Two levels of monitoring service charges for Sentinel Monitoring - $50 per device and $150 per device

[3] This is the standard discount rate used by Treasury.

Beef

The net present values for the beef industry across the zones for Australia are summarised in Table 49 Net present values for beef over 20 years.

The NPV for full monitoring ranges between $2,004 million and $6,656 million at $10 per animal per year and between $149 million and $4,801 million at $50 per animal per year.

The NPV for sentinel monitoring ranges between $321 million and $1,553 million at $50 per sensor per year and $89 million and $1,322 million at $150 per sensor per year.

Table 49 Net present values for beef over 20 years

	Full monitoring		Sentinel	
Productivity impact	Monitoring service costs	NPV	Monitoring service costs	NPV
	$ per head per year	$m	$ per head per year	$m
Max	10	6,656	50	1,553
Min	10	2,004	50	321
Max	50	4,801	150	1,322
Min	50	149	150	89

Note: The net present values allow for the cost of sensors and monitoring services which have been assumed to be incurred on an annual basis. A discount rate of 7 per cent was used for the calculation of the NPV.

Sheep

The net present values for the sheep industry across the zones for Australia are summarised in Table 50.

The table shows that the NPV for full monitoring ranges between $507 million and $3,117 million at $10 per animal per year and between minus $4,664 million and minus $2,054 million at $50 per animal per year. This shows that for the sheep industry in the High-rainfall/sheep-wheat Zones that an annual animal cost of $50 per animal per year for full monitoring is not economically viable for the productivity improvements identified for this report.

The NPV for sentinel monitoring ranges between $52 million and $1,176 million at $50 per sensor per year and minus $594 million and $529 million at $150 per sensor per year. The results for Sentinel monitoring are also marginal at a sensor charge of $150 per device per year.

Table 50 Net present value for sheep over 20 years

	Full monitoring		Sentinel	
Productivity impact	Monitoring service costs	NPV	Monitoring service costs	NPV
	$ per head	$m	$ per head	$m
Max	10	3,117	50	1,176
Min	10	507	50	52
Max	50	-2,054	150	529
Min	50	-4,664	150	-594

Note: The net present values allow for the cost of sensors and monitoring services which have been assumed to be incurred on an annual basis. A discount rate of 7 per cent was used for the calculation of the NPV.

Source: ACIL Allen Consulting.

Benefit cost ratio

Beef

The benefit cost ratios for the beef sector for all the zones examined across Australia are summarised in Table 51.

The table shows that the BCR for full monitoring lies between 5.3 and 15.4 at $10 per animal per year and between 1.1 and 3.1 at $50 per animal per year.

The BCR for sentinel monitoring ranges between 3.8 and 14.4 at $50 per sensor per year and 1.3 and 4.8 at $150 per sensor per year.

Table 51 Benefit cost ratio for beef over 20 years

	Full Monitoring		Sentinel	
Productivity impact	Monitoring service costs $ per head	BCR	Monitoring service costs $ per head	BCR
Max	10	15.4	50	14.4
Min	10	5.3	50	3.8
Max	50	3.1	150	4.8
Min	50	1.1	150	1.3

Note: The net present values allow for the cost of sensors and monitoring services which have been assumed to be incurred on an annual basis. A discount rate of 7 per cent was used for the calculation of the NPV

Sheep

The benefit cost ratios for the sheep sector for all the zones examined across Australia are summarised in Table 52.

The table shows that the BCR for full monitoring ranges between 1.4 and 3.4 at $10 per animal per year and between 0.3 and 0.7 at $50 per animal per year. The latter reflects an uneconomic outcome for the $50 per animal per year charge for the Sheep full monitoring option.

The BCR for sentinel monitoring ranges between 1.2 and 4.6 at $50 per sesnor per year and 0.4 and 1.5 at $150 per sensor per year. The BCR for the Minimum Scenario for the $150 per sesnor per year is also less than one reflecting the fact that this charge is marginal for the Minimum Scenario productivity impacts.

Apart from the exceptions noted above, all the results show positive BCRs.

Table 52 Benefit cost ratio for sheep over 20 years

	Full monitoring		Sentinel	
Productivity impact	Monitoring service costs $ per head	BCR	Monitoring service costs $ per head	BCR
Max	10	3.4	50	4.6
Min	10	1.4	50	1.2
Max	50	0.7	150	1.5
Min	50	0.3	150	0.4

Note: The net present values allow for the cost of sensors and monitoring services which have been assumed to be incurred on an annual basis. A discount rate of 7 per cent was used for the calculation of the NPV.

4.2.4 Comparison of results with Meat Industry Strategic Plan

The Meat Industry Strategic Plan 2020 (MISP) sets out whole-of-industry strategic priorities for Australia's red meat industry comprising the production, processing and live export sectors (RMAC, 2017). Improving productivity and profitability in red meat and livestock enterprises is one of four strategic priorities that relate directly to the measures being tested in the use and application of LBS systems for livestock.

The actions identified in advancing this priority are:

- Production efficiency in farms and feedlots;
- Decision support in farms and feedlots;
- Increasing livestock productivity through new research;
- Processing productivity;
- Increasing productivity and access to labour;
- Live export productivity; and
- Improving livestock performance in export operations.

The MISP cites benefits from these activities to be $2.11 billion in accumulated benefits with a BCR of 7.1.

Comparison with total benefits calculated in this report

Livestock monitoring relates directly to the first of these objectives. The accumulated benefits by 2030 identified in this report would relate approximately to the benefits identified in year 10 of the economic results cited above. These results reveal the following projected outcomes by year 10:

Accumulated benefits for the beef industry ranging from:

- $280 million to $808 million for the Full Monitoring Scenario
- $50 million to $189 million for the Sentinel Monitoring Scenario

Accumulated benefits for the sheep industry ranging from:

- $204 million to $501 million for the Full Monitoring Scenario
- $43 million to $170 million for the Sentinel Monitoring Scenario

This suggests that tracking animal location and behaviour could contribute between $484 million and $1309 million with full monitoring. This would represent between 23 per cent and 62 per cent of the MISP benefits estimate.

The results for sentinel monitoring could contribute between $93 million and $359 million which would represent between 4 per cent and 17 per cent of the MISP benefits estimate.

Benefit cost ratios

The MISP quotes a BCR of 7:1 for investment in productivity improvements in farms and feedlots by 2030. The BCRs reported above are not strictly comparable as they relate to on-farm monitoring only and do not include feedlots. However, the BCR for beef with full monitoring at a service cost of $10 per animal per year lie above and below 7:1 (5.3 to 15.4). The BCRs for beef with full monitoring and with monitoring costs of $50 per animal per year lie below of 7:1 (1.1 to 3.3).

A similar outcome arises with sentinel monitoring for both $50 per sensor per year and $150 per sensor per year.

The BCRs for the sheep industry for full monitoring range fall below 7:1 and are between 1.4 and 3.4 for a $10 per animal per year price and between 1.2 and 4.6 for sentinel monitoring with a monitoring cost of $50 per animal per year. BCR results of less than 1 arise for sheep with full monitoring with a monitoring price of $50 per sensor per year and for sheep with sentinel monitoring at $150 per sesnor per year for the minimum scenario

4.3 Economic benefits in other areas of the red meat industry

In addition to the financial benefits of LBS systems modelled for producers in terms of on farm value, two other areas were considered to be potentially impacted by this innovation. A more general discussion follows of the potential value for LBS to impact on biosecurity and animal welfare follows.

4.3.1 Biosecurity

Managing biosecurity is critical to maintaining the productivity of Australian agriculture and is especially important to the red meat sector. It is critical both for the management of disease risk on-farm and off-farm as part of the red meat supply chain. Freedom from many of the world's major pests and animal diseases provides Australian agricultural industries with a significant trade advantage and is important to maintaining access to valuable export markets.

Australia has a strong biosecurity system that involves cooperation between Australian, state and territory government's, the farming sector and the community. At the national level a National Biosecurity Committee (NBC) provides strategic leadership across state and territory governments and industry sectors to oversee and guide national approaches as set out in the Intergovernmental Agreement on Biosecurity (IGAB).

Animal Health Australia (AHA) is a national organisation whose role is to keep Australia free of emergency animal diseases, improve animal health and foster the resilience and integrity of the animal health system. The SAFEMEAT program is a partnership between the peak meat industry bodies and the Australian, state and territory governments. SAFEMEAT overseas and promotes sound management systems to deliver safe and hygienic meat products. The SAFEMEAT priorities include:

- standards and regulations;
- emergency disease management;
- animal diseases;
- residues;

- pathogens; and
- systems development and management;

Key initiatives of SAFEMEAT include:

- targeted residue monitoring programs;
- the National Livestock Identification System (NLIS);
- a system of National Vendor Declarations (NVDs) about the health of livestock; and
- strategies for animal disease issues.

Monitoring animal behaviour and movement is an important subset of activities on farm to support many of these initiatives. It has the potential to enhance the effectiveness of the NLIS and NVDs, facilitate early identification of disease and health issues in animals, improve the effectiveness of responses to residue issues and trace-back and in the longer-term support post farm gate supply chain management. In the longer term improved behaviour monitoring data will lead to better decisions and management of the red meat supply chain both on and off farm.

In 2007 AHA and Plant Health Australia undertook a survey or producers to track trends in attitudes towards farm biosecurity[4]. In 2017, 56 per cent of all producers surveyed related controlling diseases, pests and weeds to biosecurity an increase from 47 per cent in those who reported this in 2013.

47 per cent of livestock producers monitored their stock daily. Most producers were willing to share monitoring records with departments of agriculture, agronomists, neighbours and vets. However, this trend was at odds with a separate response from producers reporting decrease in the number of producers who reported that they monitored their livestock (from 30 per cent to 17 per cent.).

In response to questions on the benefits of implementing biosecurity measures the main responses the survey found:

- Freedom from diseases, pests and weeds was the main benefit, reported by 54% of producers.
- The next most reported benefit was “protect livelihood/income” at 37%.
- Continued or improved market access was steady at 15%, while “not losing income” increased from 7% to 11%.

It is clear from this survey that the awareness of the importance of biosecurity is growing in the farming community but the response to the importance of stock monitoring for biosecurity purposes was mixed. Given the importance of biosecurity to Australia’s trade access as well as to farm income security, policy makers and the livestock industry face a challenge improving monitoring and trace-back of animal diseases. Technologies that make monitoring of animal behaviour such as those discussed in this report would have an important role to play in improving this situation.

The value of biosecurity activities can be measured in different ways. One approach is to estimate the value of the costs avoided from incursions of pests and diseases from mitigation activates. These avoided costs include:

- direct production losses (for example, reductions in the productivity of livestock and output quality);
- additional expenditures on control measures and damage mitigation (for example, additional chemical inputs or stock trace-back); and

[4] Animal Health Australia - https://www.animalhealthaustralia.com.au/our-publications/farm-biosecurity-producer-survey/ sourced on 29 April 2017

- export market losses (for example, because of trade bans or the loss of price premiums as products are diverted to lower value markets where the pest, disease or weed is endemic).

ABARE (2015) reported that without biosecurity mitigation activities:

- annual profits of beef, dairy and sheep enterprises in Australia would be 8 to 12 per cent lower;
- annual profits of pig enterprises would be 15 per cent lower; and
- annual profits of cropping enterprises would be 7 per cent lower

It is difficult to scale these findings up to a national level because of the non-uniform nature of the farming enterprises examined among other reasons. For the purposes of making a lower bound estimate of the value of biosecurity measures in Australia, ACIL Allen drew on another study prepared by ABARES estimating the costs of an outbreak of Foot and Mouth Disease (FMD) in Australia (Buetre et al, 2013).

The study estimated the direct production losses, the eradication costs and the impact of trade sanctions that would arise from large and small outbreaks of FMD. The findings are summarised in Table 53. The table also provides estimates of the probability of an outbreak of FMD with and without biosecurity measures from the previously cited ABARES report (Hafi et al., 2015).

Table 53 *Estimate of the average annual value of biosecurity in present value terms - outbreaks of FMD*

	Cost of FMD event ($b)	Probability without biosecurity	Average annual cost without biosecurity ($b)	Probability with biosecurity	Average annual cost with biosecurity ($b)	Net reduction in average annual cost FMD ($b)
Large scale outbreak	52.21	0.16	8.35	0.01	0.52	7.83
Small scale outbreak in Victoria	6.00	0.16	0.96	0.01	0.06	0.90
Small scale outbreak in QLD	5.64	0.16	0.90	0.01	0.06	0.85

Source: (Buetre et al, 2013) (Hafi et al., 2015)

While the calculations are general estimates for specific States they do provide an indication of the value of biosecurity measures against FMD. Taking a conservative approach, the calculation suggests that a lower bound estimate of the average annual value of biosecurity against an outbreak of FMD could be around $850 million.

A more recent study of the economic consequences of a scrapie outbreak in Australia was undertaken by ABARES in a report published in September 2017 (HafiH H, Eather J, Garner G., 2017). Scrapie is a progressive neurodegenerative disease affecting sheep and goats. Signs of scrapie are generally visible two to five years after infection and the disease is always fatal. The signs include nervousness and aggression, scratching and rubbing, lack of coordination, tremors, weight loss, head pressing and “star-gazing”.

Monitoring of animal movements and behaviour using LBS collars would not report all of these symptoms but it could send warning signs of aberrant behaviour. Transmission can occur through direct contact with or between sheep flocks. Monitoring could also assist in keeping uninfected and uninfected flock separate to prevent disease spreading.

The study modelled the impact of three scenarios for an outbreak. The results from the modelling were:

Eradicable scrapie epidemic

- 3-months Cost of scrapie to trade: lost revenue from export market closures
- $75 million in present value terms for sheep meat and beef ban ($5 million in control costs plus $70 million from trade disruptions)

Managed Spread

- 3-months Cost of scrapie to trade: export market closures plus lost income resulting from increased animal mortality and reduced productivity
- $49 million to $80 million in present value terms

Uncontrolled Spread

- 3-months Cost of scrapie to trade: export market closures + lost income resulting from higher animal mortality and lower productivity
- $83 million in present value terms. This is in addition to export ban impacts that would be more severe in this case.

ABARES estimated the economic returns from investing in control measures using estimated avoided losses for the eradication and managed spread scenario. Successful eradication would result in avoidance of the losses associated with the managed spread. It estimated that eradication would potentially yield a benefit cost ratio of between 5:1 and 10:1.

The benefit of managing and slowing disease spread is in avoided losses associated with an uncontrolled spread over a managed spread. In this case management measures were estimated to yield a benefit cost ratio of approximately 6:1.

It is evident from these studies, that the cost of biosecurity to the Australian red meat industry is in the millions of dollars and the benefit cost ratio of managing is well in excess of one. Monitoring of livestock using LBS systems would only be a part of the solution to managing biosecurity risk but it would have an important role to play and deliver benefits over and above the benefits identified in Section 4.2.

The growing awareness of the importance of on-farm activities for managing biosecurity is evidence of the future need for systems and processes to assist in managing these risks on farm. Data that can be made available to farmers on stock behaviour and movement will be an important component of this challenge. It has the potential to contribute digital data to control and monitoring systems. However, the full benefits will only be realised when the data is translated into management decisions.

The importance of digital data to management decisions in health and disease monitoring on farms has been reported in the Autumn Quarter edition of the Farm Policy Journal (Farm Policy Journal, Autumn 2018). The Journal reports a cross sectoral boost in productivity and Gross Value of Production for animal health and disease monitoring from this report is shown in Table 54.

Table 54 Boost to Gross Value of production from animal health and disease monitoring from biosecurity platforms

Sector	Productivity improvement	Percentage increase in GVP	Increase in GVP
	%	%	$million
Beef	5	2.43	254.7
Sheep meat	10	4.55	136.1

Source: (Heath, Autumn 2017)

The study also found benefits from increased process automation using digital systems which delivers labour savings where sensors replace subjective human judgement in areas such as animal health monitoring and regulatory and market compliance. Animal behaviour and monitoring would be a component of providing digital information in the longer term. The economic benefits from increased process automation from the report are also summarised in Table 55.

Table 55 Boost to Gross Value of production from digital platforms

Sector	Productivity improvement (%)	Percentage increase in GVP (%)	Increase in GVP ($m)
Beef	3.17	1.54	161.3
Sheep meat	2.93	1.33	39.9

Source: (Heath, Autumn 2017)

In summary the value of monitoring livestock behaviour and movements is likely to be an important component of longer term efforts to manage biosecurity risks both on and off farm. The potential to use LBS systems to track animals through the supply chain has not yet been fully explored but has the potential to add depth and digital data to management of the SAFEMEAT program and the NLIS and NDV processes. If the benefits cited above are a guide it is likely that the value of such monitoring systems is likely to be in the tens of millions of dollars.

4.3.2 Animal welfare

Public awareness of animal welfare in Australia have risen in certain livestock industries in recent years. Public concern over live sheep and cattle exports, layer cages, mulesing and containment pens for sows have become issues of public debate and in some cases government intervention.

According to recent research, these concerns are not the major drivers of consumer purchasing decisions and attitudes to livestock welfare are only one determinant of purchasing behaviour. However, there is some evidence that public attitudes to animal welfare in livestock industries may become a threat to the social licence to operate (Coleman, Jan 2018). Social licence to operate can been defined as:

"The latitude that society allows to its citizens to exploit resources for the private purposes" (Martin P, Shepheard M, 2011)

Failure to observe the obligations inherent in the social licence can lead to community opposition, action by animal welfare groups, legal action and/or government intervention. In some circumstances it can lead to the development of industry codes of practice and in some cases changes in industry practices. Examples of animal welfare group action include the "Save Babe" campaign that was concerned with containment of Sows in furrowing crates or to the anti-mulesing campaign in 2014 mounted by PETA. The latter led to some wool growers adopting the use of anaesthetic during mulesing operations. The PETA campaign also led to a temporary ban imposed by some countries of Australian wool.

Research reported in 2017 showed that the community is prepared to engage in activities that may affect the livestock industries (Coleman G, Toukhsati S, 2016). Table 56 show the changes in frequencies with which respondents reported being engaged in community behaviours between 2005 and 2014.

Table 56 Percentage of community behaviours in opposition to the livestock industries

	Letter to a politician	Called radio talkback	Attended a public rally	Signed a petition	Donated money to an animal welfare organisation	Volunteered service to an animal welfare organisation	Spoken to family and friends	Written to a newspaper
2005	4.5%	1.6%	3.1%	25.6%	35.6%	3.0%	30.1%	2.2%
2014	9.4%	2.3%	7.3%	36.3%	46.6%	11.7%	55.3%	4.0%

Source: (Coleman, Jan 2018)

Other research indicates that engaging with the community in a cooperative manner rather than working against the community in a defensive manner is the most successful means of addressing threats to social licence (Coleman, Jan 2018).

To this end, evidence that livestock operators are closely monitoring animal location and behavioural data may be an important factor in future in addressing community concerns over animal welfare and the social licence to operate.

There has been limited economic studies undertaken on the value of animal welfare (Hudson, 2010). Hansson (2014) identifies both use and non-use values.

Use values include being able to continue the business and maintaining product quality and the work environment. Non-use values include avoidance of suffering on behalf of the animals, the farmer feeling good about the enterprise, ethical considerations (Hanson H Lagerkvist C, 2015).

There are numerous frameworks for assessment of animal welfare, the best known is the "Five Freedoms" model:

- freedom from hunger and thirst;
- freedom from discomfort;
- freedom from pain, injury or disease;
- freedom to express normal behaviour; and
- freedom from fear and distress (Economics at large, 2012).

By and large these freedoms are public goods which by definition are not priced and therefore difficult to value without extensive willingness to pay surveys.

Despite the difficulties in valuing animal welfare benefits that might arise as from the use of LBS systems to monitor animal behaviour and movements it is evident that farm animal welfare can become a community concern that might affect the red meat industries licence to operate. While the benefits are likely to be more in the form of public goods, community and government concerns over animal welfare issues could ultimately result in additional costs for industry in compliance or regulation. For this reason, it is considered that the benefits are positive for the future licence to operate by the industry.

As discussed in previous sections of this report more research is required into exactly how consumers and the broader community will best interact with information from LBS systems. The outcomes of this sort of research would bring more clarity to the potential dollar value of using LBS systems for monitoring animal welfare.

4.4 Key messages

- For pastoral beef production systems (with whole of herd monitoring) the reference farm suggests that a positive impact on gross margin would be achieved for the maximum (optimistic) scenarios under a sensor cost of $10 to $50. There is still a positive impact for the minimum (realistic) scenario at a sensor cost of $10 however at a monitoring cost of $50 there is financial gain. For sentinel deployment the benefits across all scenarios are positive however at $150 service cost per unit the gain is marginal.
- For beef producers in the High-rainfall/Sheep-wheat zone all scenario's tested for the reference farm under a whole herd deployment were positive, however the returns when the device service charge was $50 per year were marginal. Sentinel deployments also showed positive results however the returns at a service cost of $150 per device were more marginal.
- The reference farm for the sheep producers showed a positive impact on gross margin under both maximum and minimum scenarios for whole of flock deployment. The sentinel deployment was positive at a monitoring costs of $50 per device, however the deployment of sentinel devices at a cost of $150 did not provide an economic benefit under the minimum scenario.
- Modelling of the potential benefit of whole of herd/flock deployment as limited by likely adoption rates (and not including the costs of LBS systems) suggest total accumulated benefits of between $280 million (minimum) and $808 million (maximum) for the beef industry over a 10 year period. The accumulated benefits for sheep would be $204 million (minimum) to $501 million (maximum) over a 10 year period.
- Considering the minimum (realistic) scenario only for the beef industry, benefit cost ratio's (BCR) of 1.1 (@ sensor cost (SC) $50/year) and 5.3 (@ SC of $10/year) at a national level (Pastoral and High-rainfall/Sheep-wheat combined) for whole of herd deployment. The same criteria for sentinel deployment suggests BCR's of 1.3 (@ SC of $150/year) and 3.8 (@ SC $50/year).
- Considering the minimum (realistic) scenario only for sheep in the High-rainfall/Sheep-wheat zone BCR's of 1.4 (@ SC of $10/year) for a full flock deployment and 1.2 (@ SC of $50/year) for sentinel deployments suggest reasonable value. Increased sensor cost scenarios ($50 for whole of flock) and ($150 for sentinel) are clearly not a viable option under the proposed adoption profile.
- The value outside of the on-farm financial benefits reported by producers involved in this study could also be significant. Two areas of particular industry level impact are biosecurity and animal welfare/social license. Further research into how LBS system might impact on these areas is required to confirm the economic benefits likely to flow from improved biosecurity and social license outcomes.

5 Where is the tech-industry up to in delivering location, behaviour and state information to producers?

5.1 Introduction

A review of all technologies reported in the literature, press releases or with a web presence was undertaken to determine what (if any) commercial solutions were available to producers at the moment.

A full list of the systems and their basic characteristics is provided in Appendix 2. The details reported for these commercial systems are drawn from publicly available resources and as such are likely to be subject to change quite quickly as the technologies develop. A further caveat is that some technology companies may be making claims around their technologies which are yet to be realised.

The following section provides some broad information around the technologies and sensor capabilities being applied in this field. It is not exhaustive and like the commercially developed systems is likely to change quickly as new technologies evolve.

5.2 The basic components of animal monitoring systems

Most of the research and commercially available animal monitoring systems have four basic components: the on-animal sensor and energy source; a communications system to transfer data; a data management and analytics system; and an information transfer or visualisation system for the manager to observe and make decisions from.

The on animal component remains one of the most challenging parts. This device needs to house the critical sensor equipment, sometimes a data processor, a radio communication system and maintain an energy supply to these. The energy supply is often a battery with some sort of power generation system, which in most cases is based on solar energy. All of this needs to be housed in a rugged, waterproof and lightweight form factor that can be worn by an animal, which will at best ignore it and at worst inadvertently damage it through normal activities like rubbing against trees, fences and troughs.

5.3 The on-animal sensor component

Current commercial systems can be divided into two categories based on their functionality. The first are those systems providing location as well as behaviour and state; the second are those that provide only behaviour and state information. Both categories use similar sensors for behaviour and state but getting location information uses additional sensing systems.

5.3.1 Positioning systems

Those systems providing location, behaviour and state (LBS) information, largely use two different types of positioning systems: either the Global Navigation Satellite System (GNSS) or a radio beacon trilateration system (RBT).

Global Navigation Satellite Systems

GNSS is a term used to cover all the satellite based navigation systems including the Global Positioning System (GPS), along with other systems from countries such as Russia (GLONASS), China (BeiDou), Japan (QZSS) and the European system (Galileo).

GNSS works by receiving radio signals from satellites and then calculating its position by trilateration (from the time of flight of 4 or more radio signals). It is useful as positioning can be achieved almost anywhere on the earth, subject to the receiver having a clear view of the sky (satellites). However, one of the key challenges is that GNSS uses a relatively large amount of energy and thus can quickly drain a power source. This commonly limits the number of locations that can be recorded by animal tracking systems and tracking duration.

Radio Beacon Trilateration

Radio Beacon Trilateration (RBT) works in almost the opposite way to GNSS. A radio signal is propagated by an emitter and received by a number of antennas that are strategically located. The position of the device is calculated from either the time of flight or the signal strength (which is reduced the further you are away from the antenna). Practically, these systems can be used as part of short range radio communication systems (e.g., Smartbow WiFi system) or longer range systems (e.g., LoRa and Monitoringgle's system). Drone based systems have also been proposed, where UAVs form mobile antenna's enabling a more nimble and portable solution. One of the advantages of RBT systems is that it takes only a relatively small amount of energy to transmit the radio signal and so the battery and energy generation in the on animal device becomes less critical. The disadvantage of these systems is that they must be set up using strategically located radio receivers. In small areas this is relatively affordable (e.g. Smartbows WiFi system), but in large areas this becomes expensive.

Relative positioning systems

Other positioning systems can provide relative rather than absolute location. For example, proximity systems provide the relative location between sensors, and can be useful for some basic animal to paddock relationships. For example, the Herddog system downloads ear tag data at water points and allows producers to know the animal is within that area.

Inertia Monitoring Units (IMU) consist of three sensors: accelerometer, gyrometer and magnetometer. Together these can be used to calculate relative locations through a process call "ded reckoning" (or sometimes "dead reckoning"). There are no records of this process being used in livestock monitoring.

5.3.2 Behaviour and state sensing systems

Behaviour is what an animal is doing and relates to the various activities that it undertakes on a daily basis. These might include grazing, standing, lying, ruminating and a variety of other normal behaviours. State refers to a more in-depth understanding of the biological situation in which an animal finds itself. These terms are often used interchangeably but there are subtle differences that are important to understand. In many cases behaviour information is used to model or infer the state of the animal.

A good example of the difference between behaviour and state can be found in how oestrus detection sensors currently work in the dairy industry. There are now several collar and ear tag options that provide producers with key information for detecting oestrus. These devices generally monitor the increased activity of a cow (the behaviour) which might consist of increased walking and mounting activity. From this behaviour data, the systems infer the biological state of the animal that it is in oestrus. Similarly, the cessation or reduction of rumination (a behaviour) is often used to infer that the animal is in a compromised health state.

In the same way as behaviour sensors can be used to infer state, location sensors can also be used to infer behaviour and then state. A simple example of this is when livestock fail to use any water sources in a paddock for several days (which can be detected by absolute or relative location), and therefore their behaviour (of failing to access water) suggests they will be in a compromised state in terms of hydration. There are a number of different sensors which have been used to detect behaviour, infer state or more directly measure the biological state of animals.

Movement or motion sensors

The most commonly used sensor in research and commercial animal monitoring systems is the accelerometer. This device measures the changes in acceleration as it moves. It can also be used to detect the relative position as the earth's gravitational force is constantly pulling down. The addition of other allied sensors such as gyrometers and magnetometers can provide additional advanced functionality but this is not widely applied.

Temperature and biological state sensors

Subcutaneous and rumen temperature sensors have been widely explored in the research and lessor extent commercial systems. Ear tag based temperature sensors have either a separate probe which extends down the ear canal of the animal (e.g. Fever tag) or now more commonly a temperature sensor on the back of the ear tag that is in contact with the ear (e.g. Herddog). These sensors enable the animal's state to be evaluated, by using abnormal temperature readings to indicate a compromised animal.

There have been numerous research and commercial grade rumen sensors made available on the market. Most measure key metabolic attributes like rumen pH and a range of metabolites.

5.3.3 What's coming in the future?

A review of the literature will show a range of new sensors being integrated into on animal sensors. Audio sensing, along with photodiode sensing hold particular potential to help with refining measures of biological state.

5.4 Data transfer and communication component

There are numerous communication systems in use in both research and the commercial animal monitoring systems. However, all rely on some form of radio protocol. Some systems use Bluetooth protocols to down load data when in near proximity to antenna's (e.g. Herddogg). Other systems use Wifi frequencies (Smartbow) or their own proprietary protocol (e.g. Taggle). The most commonly used radio protocol in many of the systems currently under development is the LoRaWAN (Long Range Wide Area Network – or LoRa for short). This is a low power protocol for transfer of small packets of data.

5.5 Data management and analytics component

Depending on the system and application there are a number of ways in which the data management and analytics is managed. For some, like the RBT positioning systems the calculation of location is done off animal on a server (e.g. Taggle). For GPS positing systems, the calculation of location is predominantly undertaken on the device and then this location data is sent. When it comes to the analysis of animal behaviour sensors there are some real challenges around managing the data volume. If the raw data from an accelerometer sensor, which can conceivably be run up to 500 hertz (500 readings per second) was to be sent directly from the on-animal device it would soon drain the energy source as the sheer volume would mean near constant transmission would be required. Whilst some solutions to this involve duty cycling the accelerometer to collect and send a small sample of raw data, most researchers and commercial developers appear to be favouring an embedded processing approach. Embedded processing involves taking the raw accelerometer signals and using an algorithm to process the data down to a series of behavioural indicators that can be sent in a much smaller data package making it a much more energy efficient process.

Even with the reduction of data through embedded processing the likely volumes of information created by on-animal sensing systems is likely to be enormous and far exceed what has been collected on farm in the past. Consideration needs to be given to management systems that can handle the data in ways in which the processioning and storage is optimised whilst also optimising the availability of the information to producers to enable them to make the decisions essential to converting this information into revenue increases or cost reductions. There are a number of developing fields of research in distributed data processing and storage and these need exploration to optimise the solution for extensive grazing systems.

Once the location, behaviour and/or state data is received on a server (be it in the field or in the cloud) a detailed analysis of the information is undertaken. Much of the analysis in current commercial systems (particularly those behaviour/state systems used in dairy) is based on proprietary algorithms. However, it appears that in most cases the systems work by establishing a baseline of activity and then look to identify anomalies. Whilst this approach has proven useful in dairy more complex modelling systems may be required in extensive grazing situations where environmental conditions are less controlled. The development of algorithms that provide producers with the key information they require to make profit driving decisions will be a key area of future research that needs to be pursued. This could foreseeably be undertaken in advance of the roll out of commercial systems as the sensor requirements for detection of key issues (be they specific disease states or management issues) could also be assessed. By providing commercial developers of technology with guidance around the type of sensors, duty cycling requirements (how often to sample) and specific algorithms it is likely that the value proposition for these sensor systems will be enhanced.

5.6 Information transfer or visualisation component

One of the most critical components of LBS systems is the way in which it provides the information to producers. This is possibly one of the least well developed areas in terms of understanding producer requirements. The systems currently in use in the dairy industry predominantly rely on a web interface with either app based notifications or sms alerts for critical information. However it is delivered, the information required by producers needs to be succinct and avoid overwhelming them with irrelevant detail. A further discussion of this topic can be found below which addresses the gap in activity in this area.

5.7 Does it have to be an on-animal sensing system?

Short answer, no. There are a range of other options out there that can provide at least some information on the location, behaviour and state of grazing livestock.

The use of remotely sensed imagery holds significant potential. An image, whether traditional multispectral or integrating thermal technology can provide significant information around the location of animals and if repeated in time can be used to derive behaviour in a similar way to GPS. The development of unmanned aerial vehicles with long flight times along with nano-satellites could provide this information.

Other technologies such as terrestrial radar tracking of objects could also come into play and is being explored in other industries. The development of autonomous robotics platforms that follow the herd will also contribute to the provision of LBS information.

In many ways attaching a sensor to an animal is one of the more rudimentary techniques for obtaining the key bits of information we are interested in. However, for the moment at least, it appears to be one of the most technically viable, despite the challenges it poses.

5.8 What might be missing?

Whilst many of the commercial systems currently available and in development are taking into account many of the factors that will be required for the successful deployment of their systems in extensive grazing environments there is one key attribute that is not commonly reported.

The way in which the information is delivered to the producer depends very much on the applications they are interested in. For some applications real-time data is required, and it is needed in areas where current connectivity options may not be suitable. Yet, for many applications, real-time information is simply not required. Hence, profit driving decisions can be made with data provided on a less frequent or daily basis.

For mustering in a pastoral beef operation producers may need a real-time feed of the most up to date locations of animals in the paddock. This will require a data link direct to a screen being held by the stock person in the field. Obviously, there are ways around this, for example someone providing directions over a UHF (Ultra High Frequency) radio but ultimately producers will want this information with them wherever they are working in the paddock.

Many commercial developers are pursuing systems that will connect the “cow to cloud”, however few appear to be thinking about the required “server to saddle” connectivity that the end user will need. Much of this is entirely achievable using satellite communications for even the remotest areas but the review would suggest that this is yet to be fully considered by many of the commercial developers.

6 Further research, what needs to happen from here?

One of the key objectives of this study was to identify opportunities for future investment into research and economic analysis of location, behaviour and state (LBS) systems and information. The various activities undertaken within this project have highlighted numerous areas which require better understanding or technical development for the industry to realise the benefits articulated by the many industry participants involved.

6.1 Hardware and sensor development

There is a relatively large amount of activity amongst commercial technology providers as demonstrated by the 15 companies reportedly developing systems with location, behaviour and state (LBS) capabilities and the further 14 companies developing behaviour and state monitoring systems (Appendix 2). However, there is little hardware currently available at the time of writing this report that a producer can actually go out, buy off the shelf and easily setup on their property.

Unless there is a complete market failure, it would be difficult to justify a purely public investment into the commercial development of hardware. There are good reasons to use leverage opportunities where private sector funding is matched in some way with public sector investment. The development of hardware solutions to provide the LBS data for extensive grazing industries is not simple and the inducement provided by at least some financial support will assist in engaging technology developers with this challenge.

There are two areas of research and development that should be considered for public funding. The first is the development and evaluation of new and novel sensor systems (e.g. hear rate, metabolite sensors, and audio). Once tested and evaluated these sensors could be integrated into the commercial platforms currently under development.

The second is the development of a sensor system that enables researchers to collect high resolution data to inform the development of sensors, duty cycle protocols and algorithms. At the moment researchers use a range of off-the shelf sensor systems which do not necessarily meet their specific needs.

The development of affordable research grade sensor systems would allow domain experts to determine the optimal settings for detection of key issues or applications and pass this knowledge on to commercial developers. This would significantly enhance the speed of development of LBS systems as a whole and potentially improve the value proposition.

This area of research has relevance to a number of livestock and animal based sectors (beef, sheep, dairy, goats, pigs and horses) and as such investment could be pursued in a cross-industry approach. The development of such a system might be best considered in a shared resource approach where multiple organisations collaborate under an “open source” agreement to ensure the developments are made available to all researchers.

6.1.1 Hardware producers need to fully understand the path to value

Hardware developers need to consider how the device they are producing will impact through a value pathway for producers. In many instances technology companies are focussed on only a few applications or industry segments and have not considered the potential for their device to impact more broadly. This could have significant benefit for them in terms of opening up market opportunities. However, they also need to carefully consider how the sensors and form factor of their system might limit the applicability of their device.

One key activity that may be of value is exposing technology developers to a wide range of producers as early as possible to shape the way in which they engineer their solution. This could take the form of an annual symposium in which technology developers provide updates on the current state of their hardware development and producers reciprocate by providing feedback on the value of implementing LBS information. The inclusion of domain experts (e.g. researchers with experience in specific issues such as disease, reproduction, behaviour or feedbase management) and data management and analysis researchers could also prove valuable.

6.1.2 Issues with ear tag deployments

One of the key issues specifically facing the developers of ear tag solutions will be the retention of these devices. Current NLIS ear tags already have issues with retention rates and the addition of sensors and communications systems will only increase weight and the likelihood of loss. Research efforts could be focussed on the long term testing of emerging ear tag solutions to the point where retention rates over several years can be assessed. Furthermore, alternative attachment form factors would also warrant investigation. While the collar based systems are often looked down upon, several producers involved in this study believed they could provide a suitable solution in the context of sentinel deployments. Research into collar based systems that are easier to attach to animals may be warranted if reliable alternatives can't be found.

6.1.3 Considering sentinel and hybrid deployments

At the same time as technology developers are focussed on creating devices for whole of herd or flock development, it may also be worth them considering sentinel deployments as a way of entering a market at a higher price point and with a more robust and reliable technology. Research into how more benefits might be gained from sentinel systems is warranted. In addition to this, the rollout of hybrid systems where most animals have a base level sensor system (e.g. accelerometers) and small numbers have more advanced sensors (e.g. GPS) although already being applied (e.g. Cattlewatch) could be further explored for specific value paths.

6.1.4 Research into the next generation of systems to provide LBS information

While much of the effort in this area is based around the development of on-animal sensors, research into the next generation of solutions to provide the key LBS information is warranted. Of most use would be a LBS system that did not require an on-animal hardware component. There are several candidate technologies but all need significant development.

6.2 Data interpretation and delivery

One of the key areas that will benefit from additional research is the interpretation of the sensor data to provide decision actionable information to producers. This project has demonstrated how basic positional data from GPS or movement data from accelerometers might be interpreted to provide alerts to producers around key issues such as water use and behaviour (Figure 19), plant toxicity (Figure 4), animal restlessness (Figure 11), disease (Figure 21 & Figure 27) and stock theft (Figure 16). However, the development of robust behavioural algorithms that can be relied upon to accurately detect and report issues whilst avoiding false positives is significantly more difficult than the simple historical analysis undertaken here.

6.2.1 Considering the hardware requirements for algorithm development

One of the critical steps in this is determining which sensor systems are needed to provide the required data to input into the models. In some situations low power accelerometers will provide the key behaviour and state information and location data may not be required at all. In other situations location data may be essential to both the detection of the problem and to enable the intervention (by finding the animal). It is at this point that there is an unavoidable interaction with the hardware development. Hardware developers need to be aware of the likely requirements of the algorithm developers. The reverse is also true, algorithm developers need to better understand the likely limitations of the hardware and work within these. There is also a critical link between algorithm developers and domain experts. Domain experts are those with specific knowledge in their field of expertise that can be applied in the development of algorithms targeting the issues they have experience in. There is a widespread belief amongst technology developers that machine learning and big data analysis will be able to provide the required predicative algorithms, however this has yet to be proven. Until these analytical processes are developed that can cope with the complex biological system that is extensive grazing, it is likely that collaboration across hardware developers, algorithm developers and domain experts will provide a more efficient and reliable algorithms.

6.2.2 Important behavioural algorithms to be developed

A broad prioritisation of the highest value and most widely applicable applications has been reported in Table 27. There is a definite need for research into the development of modelling to support data interpretation for the most valuable applications reported by producers.

The key challenge with many of these is the variation between animals and production systems that is likely to influence the development of robust detection algorithms. For some, there may be relatively unique and somewhat consistent behaviours or symptoms for which the sensor data can be easily interpreted. As an example, oestrus detection is already widely used in the dairy industry and is generally reliably based on the temporal variation in base line activity. For other applications which represent a grouping of a variety of specific issues (e.g. disease detection) there may be a wide ranging variety of behaviours and symptoms for which the interpreting sensor data may be more difficult.

As part of this process, the timeliness of delivery of the information to the producer needs to be considered. The response required to a disease such as worms in sheep can be relatively slow (days) compared to what is required for bloat in cattle (hours or minute). This needs to influence the way in which commercial platforms develop the communications systems that both collect the data (the "cow to cloud") and deliver it to producers (the "server to saddle").

This area of research and development is perhaps one of the best candidates for collaborative research between the array of commercial entities seeking to deliver hardware solutions and the domain experts and data analysis experts available within the research community.

6.2.3 Quantifying the feedbase related applications

This project has demonstrated that producers believe there may be large value in the applications relating to feedbase management, particularly the monitoring and managing of spatial landscape utilisation. However, there is also significant uncertainty when it comes to the likely value that can be gained.

Further research could explore and quantify the benefits from longer term monitoring of animals and the evaluation of intervention strategies that might be enabled by LBS information. There needs to be a clear picture of what value LBS information might bring and what could be achieved through other more affordable or readily available technologies such as remote sensing alone or in combination with animal sensing information.

6.3 Using LBS information for animal welfare and social license

Many producers articulated the value of LBS data for improved animal welfare outcomes, proposing that the systems would enable them to more rapidly intervene. They also believed that there was value in being able to demonstrate that they were managing their animals in a way which met animal welfare standards. Many believed that this may provide a tool to engage with the community and maintain social license.

One of the key issues with this is that it is unclear as to how the community may engage and respond to the concept of, or specific information from LBS systems. On one end of the spectrum the community may be satisfied with simply knowing that producers are using the latest technology to care for their animals (i.e. the shared values approach). Alternatively, future community support may only be maintained by making the data publicly available or accredited by a trusted agent. These are research questions which need to be addressed before the full value of using LBS for animal welfare and social license can be truly understood.

One of the key concerns that also needs to be addressed is the issue of producers being made aware of welfare issues with individual animals, but the not being in a position to intervene. This was raised as a potential problem by a handful of producers and is a particular issue for those involved in extensive properties or animals of low individual value. The community perception around producers knowing that there is a problem but not actively intervening needs to be addressed.

6.4 Research into likely adoption issues and opportunities

There needs to be a lot more development in terms of hardware before adoption truly needs to be considered as an issue. However, it is worth considering some of the likely future constraints and opportunities LBS systems may provide.

One of the key issues which may emerge is the skill set required by the producers to both implement and utilize LBS systems to the degree to which they gain the value they are seeking. Digital literacy skills amongst producers are known to limit the adoption of some technologies. As LBS systems start to evolve and become available in the market it may be worth considering research into how producers not comfortable with technology might be encouraged to trial it and for those using the device for simple applications, how they might be convinced to try more advanced applications.

One minor concern that may need to be addressed is the perception that the data being collected may be used against a producer. As these system begin to roll out it may be necessary to explore ways of mediating this perceived issue.

A further development of this would be the potential for LBS system to increase the adoption of existing innovations with lagging uptake. This has been discussed previously (see section 3.4.1) and does warrant further investigation as these systems evolve. Research could potentially explore how LBS might be best leveraged into or leverage from existing extension programs.

7 Conclusions and next steps

This study has demonstrated that the potential for location, behaviour and state (LBS) systems for livestock management in extensive grazing systems is significant. Producers have articulated a diverse range of applications that translate into financial and non-financial benefits that will impact across the red meat industry.

7.1 Conclusions

What was learnt from industry participants using LBS systems and interacting with the data?

- The producer case studies demonstrated how LBS data could be used to provide information on a range of critical issues. These included: detection of watering behaviours, stock theft, plant toxicity issues, disease detection and parasite infestation. Each producer had their own unique value proposition around which they considered LBS data useful.
- The most universally valued benefits related to feedbase applications, particularly understanding landscape utilisation and timing of grazing rotations. There appear to be big potential gains to be made through this. However, this needs to be treated with some caution as there is more uncertainty around the value of these applications and higher level skills may be required to realise benefits.
- Non-financial benefits were also identified as critically important in many of the industry case study projects. Of particular value was the "peace of mind" that would come from knowing that there was no adverse event occurring and impacting on the grazing animals.
- Taking a synoptic view of the results across all case studies undertaken in this project there are several key applications that have broader implications for the red-meat industry. Using LBS to monitor animal welfare for improved social license outcomes, applications around biosecurity, market compliance and assurance, and enabling on-farm research. All of these could impact significantly and deserve further investigation.
- Many of the industry partners could see value in the long term historical data collected using the simple research grade store-on-board devices. Somewhat surprisingly, some have gone on to retain them and continue to use them beyond the life of this project to enable their own investigations.

How will commercially available LBS systems provide a benefit to producers?

- Wider surveys of industry participants (both online and in-depth interviews) revealed that producers foresee a diverse range of applications of LBS systems once they are available for commercial deployment.
- The producer interviews suggested that there were two key industry and region specific applications that could have a relatively large financial value. These were: genetic matching of ewes and lambs for the sheep industry; and mustering efficiency for the pastoral beef industry.
- Other than these two applications with significant value, the producers interviewed suggested that, in general, the financial benefits would come through the accumulation of value across the combination of a number of smaller increases in revenue or cost savings.
- Pastoral beef industry producers reported an average of 4.2 individual applications that would impact through increasing revenue by an average of 6.8%. On average producers reported 2.2

applications that would reduce costs by 3.8%. The cost savings were dominated by improvements in mustering efficiency.

- Beef producers from the high-rainfall/sheep-wheat zone reported an average of 3.3 applications that would increase revenue by an average of 6.0%. On average, producers in this segment reported 2.5 applications that would impact on cost savings by 4.7%.
- Sheep producers from the high-rainfall/sheep-wheat zone reported an average of 3.0 applications that would increase revenue by 11.1%. On average, sheep producers reported 2.9 applications that would reduce costs by 2.6%. The relatively larger revenue increase was dominated by the genetic matching application.
- As a whole, producers suggested that there was more value to be gained from increases in revenue than cost savings or from the prevention of catastrophic or unusual events. However, there was more uncertainty around achieving these purported increases in revenue and potential higher level skill requirements to turn the information provided by LBS systems into revenue driving management decisions.
- Preventing catastrophic or unusual events (e.g. disease outbreak, fire or stock theft) provided only small financial benefit but had it primary value in providing "peace of mind" to producers.
- The financial value of sentinel systems (where only a small number of animals are monitored) was less than half that of the benefit from whole of her/flock deployment. However, the investment costs of sentinel deployments may be so much lower that serious consideration needs to be given to these as a first step in rolling out LBS systems.
- The adoptability of LBS systems and specific applications needs further consideration. Some require little additional skill and the benefit can be realised by most producers. Others will require additional skills and may be applicable to a much smaller proportion of livestock managers. This is particularly the case for the feedbase related applications.

What would be the economic impact of LBS systems?

- Economic modelling of the potential benefits of whole of herd/flock deployment as limited by likely adoption rates (and not including the costs of LBS systems) suggest total accumulated benefits of between $280 million (minimum) and $808 million (maximum) for the beef industry over a 10 year period. The accumulated benefits for sheep would be $204 million (minimum) to $501 million (maximum) over a 10 year period.
- Considering the minimum (realistic) scenario for the beef industry, benefit cost ratio's (BCR) of 1.1 (at sensor cost (SC) $50/year) and 5.3 (SC of $10/year) for whole of herd deployment at a national level were estimated. The same criteria for sentinel deployment (5% of animal monitored) suggests BCR's of 1.3 (SC of $150/year) and 3.8 (SC $50/year) might be achieved.
- Considering the minimum (realistic) scenario for the sheep industry (in the High-rainfall/Sheep-wheat zone) BCR's of 1.4 (SC of $10/year) for a full flock deployment and 1.2 (SC of $50/year) for sentinel deployments suggest some value. Increased sensor cost scenarios ($50 for whole of flock) and ($150 for sentinel) are clearly not a viable option under the proposed adoption profile.
- The economic value outside of the on-farm financial benefits reported by producers involved in this study could also be significant. Two areas of potentially high industry level impact are biosecurity and animal welfare/social license. Further research into how LBS system might

impact on these areas is required to confirm the economic benefits likely to flow from improved biosecurity and social license outcomes.

Where is the technology sector up to in delivering LBS systems to the red-meat industry

- A total of 15 commercial entities were found that were developing sensor systems that provided location, behaviour and state information. A further 14 commercial entities were developing systems focussed on behaviour and state alone (not location).
- Most of the commercial entities are focussed on more intensive animal production systems with limitations around the applicability of their technology to larger extensive grazing livestock operations.
- There are few, if any, service providers that are currently in a position to provide the LBS information required to realise the gains articulated by producers throughout this project. However, technology development is a fast moving sector and several entities suggest delivery of systems in the near future is likely.

What are the future research and development opportunities?

- Whilst there is a large private sector investment into technology, the specific needs of Australian producers and the way in which they anticipate drawing value from these systems may not be well understood by all developers. Better linkages between hardware developers and producers could be fostered through specific forums.
- As hardware solutions become available there may well to be a tendency for rapid uptake by some segments of the industry. This needs to be tempered by the understanding that the true value of this technology is realised when the hardware systems reliably perform over several years. This means that long term testing and evaluation of LBS systems will be required and may best be supported by independent agencies.
- Research into novel ways of deploying systems such as non-ear tag solutions and systems that use hybrid or sentinel deployments should be pursued in line with achieving the high value benefits identified in this report. Research into a new generation of systems that can provide LBS information without requiring on animal sensors is also warranted.
- Most importantly, the interpretation of data into meaningful and decision actionable information is critical to the success of LBS systems. This project has identified numerous valuable applications that will require algorithm development to convert the location and movement data from the various sensors into maps or alerts that producers can base profit driving decisions from.
- There is a lot of interest amongst the research community in providing guidance to hardware developers around the application of sensors to specific issues. One key resource that is missing is a readily useable research grade animal monitoring system which collects data in a way that allows domain experts to provide suitable recommendations.
- Several key areas of application of LBS system require further research before a full understanding of the value they may bring is evident. The value that can be achieved through the various feed-base related applications, particularly landscape utilisation needs to be explored.

- The potential value around the application of LBS system to inform and interact with consumers in the context of animal welfare and social license should also be explored.

7.2 Next steps…

The future directions for research provides a broad scope for likely directions for further investment. Some more immediate actions that could assist in speeding LBS systems to commercial reality and providing long term benefits to producer from them include:

- Development of workshops/symposia to bring hardware developers, data analysts, domain experts and producers together to assist in bridging the gaps in understanding that exist between these parties.
- Continued support for commercial entities seeking to develop hardware and software solutions through leveraging schemes. There has historically been a significant attrition rate amongst technology developers entering this market. If this trend continues, the more commercial entities endeavouring to enter the market may mean at least a handful will be successful. This support should be conditional on these entities providing justification as to how their technological solution will operate in extensive grazing conditions (and not be limited to small areas).
- Ongoing support of research into the development of algorithms relevant to extensive Australian grazing systems. Publicly funded research with published outcomes could speed the integration of key algorithms into commercial systems. Specific research into the key issues described in this report is warranted (water related behaviours, calving/lambing alerts, stock theft and disease detection etc.). However, in some cases sensor and algorithm development might be overlaid onto other research as and when it is funded.
- The research community is keen to support the commercial development of LBS systems however they are currently limited to using either commercial devices (with predetermined limitations around sensor type or duty cycle) or rudimentary store-on-board systems (which are not optimised for on-animal deployment). The development of an open source sensor platform that enabled researchers to collect large amounts of data in a similar form factor to what commercial systems are proposing (i.e. an ear tag) would allow them to provide guidance on the best sensors, duty cycle and algorithms to detect key issues.
- Establishment of long term testing and evaluation sites as commercial products enter the market. These sites could be on-farm or research stations, but must allow testing of devices under real commercial conditions over extended periods of time (i.e. more than 3 years). Where possible, these should be matched with observational/physical data collection and high resolution sensor systems to allow refinement of commercial sensors and algorithms. These studies need to focus on the system as a whole, including data transfer, analysis and delivery back to the manager. Some caution is warranted here as rushing unsupported technology onto farms may result in producer disenchantment. Support from independent and experienced field staff (researchers/technicians) may help overcome this.
- Support for research into validating the potential value of LBS data to improve feedbase related applications should be pursued. These had some of the greatest potential financial benefit but producers reported more uncertainty around achieving this. Research using existing LBS

technology (simple store-on-board devices as used in the case studies in this project) could provide a short term solution to this.

- Further social and economic research into the role that LBS systems might play in animal welfare and social license. An understanding of how consumer and key influencers will interact either directly with LBS data or how they will perceive the value of LBS systems being used by producers is essential. The danger here is that LBS systems are promoted as having large positive impacts on social license when in some cases the reverse may be true. This issue needs clarification.

8 Bibliography

ABARES. (2018). Performance for broadacre farms by industry and zone.xlsx. Canberra: Australian Bureay of Agricultural and Resource Economics.

Abell, K. M., Theurer, M. E., Larson, R. L., White, B. J., Hardin, D. K. & Randle, R. F. 2017. Predicting bull behavior events in a multiple-sire pasture with video analysis, accelerometers, and classification algorithms. *Computers and Electronics in Agriculture,* 136**,** 221-227.

Barwick, J., Lamb, D., Dobos, R., Schneider, D., Welch, M. & Trotter, M. 2018. Predicting Lameness in Sheep Activity Using Tri-Axial Acceleration Signals. *Animals,* 8**,** 12.

Buetre et al. (2013). *Potential socio economic impacts of an outbreak of foot-and-mouth disease in Australia.* Canberra: Australian Bureau of Agricultural and Resource Economics and Science.

Coleman G, Toukhsati S. (2016). *Consumer attitudes and behaviour relvant to the red meat industry.* Sydney: Meat and Livestock Australia.

Coleman, G. (2018). Public animal welfare discussions and outlooks in Australia. *Animal Frontiers*, 12-19.

Dobos, R., Dickson, S., Bailey, D. W. & Trotter, M. 2014. The use of GNSS technology to identify lambing behaviour in pregnant grazing Merino ewes *Animal Production Science,* 54**,** 1722-1727.

Economics at large. (2012). *The economics of animal welfare, Paper number 1, Thinking like and economist.* Melbourne: Economists at Large.

Falzon, G., Schneider, D., Trotter, M. & Lamb, D. W. 2013. Correlating movement patterns of merino sheep to faecal egg counts using global positioning system tracking collars and functional data analysis. *Small Ruminant Research,* 111**,** 171-174.

Farm Policy Journal. (Autumn 2018). Accelerating Precision Agriculture to Decision Agriculture. *Farm Policy Journal*, 1-77.

Fogarty, E. S., Manning, J. K., Trotter, M. G., Schneider, D. A., Thomson, P. C., Bush, R. D., et al. 2015. GNSS technology and its application for improved reproductive management in extensive sheep systems. *Animal Production Science,* 55**,** 1272–1280.

Hafi et al. (2015). *The value of Australia's biosecurity system at the farm gate.* Canberra: Australian Bureau of Agricultural and Resource Economics and Science.

Hafi et al. (2015). The value of Australia's biosecurity system at the farm gate: an analysis of avoided trade and on- farm impacts. ABARES Research Report.

Hafi H, Eather J, Garner G. (2017). Economic consequesnces of a crapie outbreak in Australia. Canberra: Australian Bureay of Agricultural and Resources Economics.

Hanson H Lagerkvist C. (2015). Identifying use and non use values of animal welfare, evidence from Swedish dairy agriculture. Food policy, 35-42.

Heath, R. (Autumn 2017). An analysis of the potential of digital agriculture for the Australian economy. Farm Policy Journal, Australian Farm Institute.

Henry, D., Shovelton, J., de Fegely, C., Manning, R., Beattie, L. & Trotter, M. 2013. Potential for information technologies to improve decision making for the southern livestock industries. North Sydney NSW Meat & Livestock Australia Ltd.

Hudson, D. (2010). Discussion: the economics of animal welfare. *Journal of agricultural and applied economics*, 454-455.

Jukan, A., Masip-Bruin, X. & Amla, N. 2017. Smart Computing and Sensing Technologies for Animal Welfare: A Systematic Review. *ACM Computing Surveys (CSUR),* 50**,** 10.

Manning, J. K., Fogarty, E. S., Trotter, M. G., Schneider, D. A., Thomson, P. C., Bush, R. D., et al. 2014. A pilot study into the use of global navigation satellite system technology to quantify the behavioural responses of sheep during simulated dog predation events. *Animal Production Science,* 54**,** 1676-1681.

Martin P, Shepheard M. (2011). What is meanbt by the social licence. *Defencing the social licence of farming: issues, challenges and new directions for agricultue*, CSIRO publishing.

RMAC. (2017). *Meat Industry Strategic Plan.* Canberra: Meat Industry Advisory Council.

Roberts, J., Trotter, M., Schneider, D., Lamb, D., Hinch, G. & Dobos, R. 2015. Daily grazing time of free-ranging cattle as an indicator of available feed. *7th European Conference on Precision Livestock Farming.* EC-PLF, Milan.

Rojers, E. (1983). *Diffusion of innovations.* New York: The Free Press.

Swain, D., Friend, M., Bishop-Hurley, G., Handcock, R. & Wark, T. 2011. Tracking livestock using global positioning systems–are we still lost? *Animal Production Science,* 51**,** 167-175.

Swain, D., Gregg, D., Bishop-Hurley, G., Trotter, M. & Petty, S. 2013. On property benefits of Precision Livestock Management. North Sydney NSW, Australia: Meat and Livestock Australia.

Trotter, M. G., Lamb, D. W., Hinch, G. N. & Guppy, C. N. 2010. Global Navigation Satellite Systems (GNSS) livestock tracking: system development and data interpretation. *Animal Production Science,* 50**,** 616–623.

Umbers, A. 2017. GRDC Farm Practices Survey Report 2016. Kingston ACT Grains Research Development Corporation.

Williams, L. R., Bishop-Hurley, G. J., Anderson, A. E. & Swain, D. L. Application of accelerometers to record drinking behaviour of beef cattle. *Animal Production Science*.

9 Appendices

9.1 Appendix 1

Application	Explanation	How would this work?	How would it bring value to the producer?	Would there be benefit in other areas of the value chain?	Real-time, near real time or post processed. Office or paddock data.	Whole of mob (WOM) or sentinel deployment (SD) system	Current state of required algorithm or modelling development	Adoptability	Ease of path to value
Basic location	Remotely checking animals are in correct paddocks or on farm	Location data identifies animals are in nominated paddocks. Alerts if animals leave paddocks or farm.	1. Producers currently check the location of livestock periodically, would save some of this time; 2. When animals escape notification means faster intervention; 3. Prevents loss of animals straying away from farm into neighbours, clarifies straying verses deliberate theft; 4. Prevents animals straying into sensitive areas (e.g. recently sprayed paddocks or grazing exclusion zones) 5. Basic paddock utilisation records	Biosecurity and integrity	Herd/flock level location data at day scale (in-office). Real-time alerts optimal for paddock/farm egress (in field).	WOM prefereable but some value from SD if subgroups tracked	Developed (geo-fencing)	High	High
Mustering efficiency	Animal location for mustering efficiencies	Location data allows producers to find animals in extensive areas or difficult terrain.	1. Reduced use of aerial resources (helicopter and fixed wing); 2. Reduced labour as less staff required to find stock;	Behaviour during mustering and time since mustering	Real-time or near-time and in field data required in most cases	WOM for clean musters but SD would provide some assistance	Developed, basic location data only. Some modelling might be required if location not	High	High

Application	Explanation	How would this work?	How would it bring value to the producer?	Would there be benefit in other areas of the value chain?	Real-time, near real time or post processed. Office or paddock data.	Whole of mob (WOM) or sentinel deployment (SD) system	Current state of required algorithm or modelling development	Adoptability	Ease of path to value
			3. Opportunistic stock mustering as they approach water/gates; 4. Reduced impact on animals as less time being held in mobs whilst mustering 5. Clean muster means all animals removed, no re-muster costs; 6. Clean muster means reduced occurrence of infectious disease on pastures (life cycle breaks); 7. Clean muster means better marketing of stock (animals not left to go beyond spec). 8. Better OHS as less time in difficult terrain	might impact on compliance ?			recorded frequently		
Water related behaviour	Detecting behaviours that indicate animals have run out of water (e.g. hanging around a broken trough) and monitoring whether animals have had a drink water (e.g.	Location data provides producers with the knowledge that a group of animals that are hanging around water for a prolonged period, or individual animals that have not been near water for a prolonged period	1. Reduced labour as less time spent checking water availability. 2.Reduced mortality of animals due to lack of water (especially weaner animals) 3. Reduced weight loss in animals due to lack of water.	Welfare/social license	Real-time and in paddock alerts preffered. Minimum end of day report allowing fix next day	WOM required for vulnerable animals (weaners). SD may be sufficient for non-vulnerable animals	Proximity to water troughdemonstrated in this project. Actual drinking behaviour (from collar) demonstrated (Williams et al.)	High	High

Application	Explanation	How would this work?	How would it bring value to the producer?	Would there be benefit in other areas of the value chain?	Real-time, near real time or post processed. Office or paddock data.	Whole of mob (WOM) or sentinel deployment (SD) system	Current state of required algorithm or modelling development	Adoptability	Ease of path to value
	approached water trough in last 24 hours).	of time and an alert is sent to producers.							
Health alerts for critical injuries	Detecting and locating an animal that has suffered an injury (e.g. broken leg)	Alert sent to producer indicating that animal is exhibiting behaviour indicating it is critically injured and location data allowing producer to easily find animal.	1.Reduce suffering of animal as producer is able to put it down. 2. Allow high animal values (e.g. stud bulls) to receive treatment quickly.	Welfare/social license	Real-time infield data preffered	WOM data required if trying to detect the occasional individual with problem	Some preliminary work on lameness would suggest gate change could be detected (Barwick et al., 2018). Severe case would show cessation of movement easily detected	Medium	High
Disease detection	Detecting animals that are suffering from increased parasite load, viral or bacterial infection	Alert sent to producer indicating that animal is exhibiting behaviour indicating it is in a diseased state and location data allowing producer to easily find animal.	1. Allow animals to receive treatment quickly to prevent production loss. 2. Prevent/lower rates of mortality by responding to outbreaks quickly. 3. Reduce costs associated with faecal egg counts/routine health treatments when not required.	Biosecurity and welfare/social license	End of day data for most diseases. Some particular diseases might warrant real-time	WOM likely required if trying to detect individual animals. SD may be possible if behavioural change detection defines disease	Some diseases have very clear symptoms (e.g. Buffalo fly as demonstrated in this study) which may allow dyagnosis. Others may be more subtle. Producers believe they could interpret activity data to provide	Medium	Medium

Application	Explanation	How would this work?	How would it bring value to the producer?	Would there be benefit in other areas of the value chain?	Real-time, near real time or post processed. Office or paddock data.	Whole of mob (WOM) or sentinel deployment (SD) system	Current state of required algorithm or modelling development	Adoptability	Ease of path to value
							warnings. Activty to disease state has been demonstrated in feedlots (REDI system) and sheep (Falzon et al., 2013)		
Poisoning detection	Detection of animals suffering from plant related poisoning such as ryegrass staggers or bloat.	Alert sent to producer indicating that animal is exhibiting behaviour indicating potential poisoning and location data allowing producer to easily find animal.	1. Allow animals to receive treatment quickly to prevent production loss. 2. Prevent/lower rates of mortality by responding to outbreaks quickly. 3. Allow producers to identify areas of poisonous plants and remove to prevent further loss.		Real-time in field data required.	WOB for individual diagnosis. This study suggests that SD may work for some disease (see case study on Shepherd Hills)	Limited literature	Medium	Medium
Welfare monitoring	General quantification of animal welfare status.	Alert will be sent to producer with animal location and welfare state if compromised. More complex system could inegtrate multiple	1. Demonstrates producer care for animals which maintains social license 2. Information can be used for accreditation schemes (e.g. EU) and to access markets. 2. Peace of mind for producers.	Improved market access. Maintain social license	End of day for producer application. Potentially used at animal processing	All animals required to detect individual behaviour.	Reviews exist (Jukan et al., 2017). This is complex would require measures acros multiple characteristics of	Low	Medium

Application	Explanation	How would this work?	How would it bring value to the producer?	Would there be benefit in other areas of the value chain?	Real-time, near real time or post processed. Office or paddock data.	Whole of mob (WOM) or sentinel deployment (SD) system	Current state of required algorithm or modelling development	Adoptability	Ease of path to value
		domains to provide welfare index					the animal state and environment		
Oestrus detection	Detection of behaviour indicating that females are cycling and ready for artificial insemination or mating or have reached puberty	Alert will be sent to producer indicating animal is on heat.	1. Producers with an AI program will be able to increase conception rates. 2. Identify females with superior reproductive performance. 3. Cull female animals that are not cycling. 4. Detect age of puberty of females		End of day but may need crush side real time	WOM required	Oestrus detection demonstrated in dairy. Proofo of concept in sheep (Fogarty et al., 2015).	High	Medium
Pregnancy status / maternal status	Detection of the pregnancy status of cows/ewes after bulls/rams removed through identification of animals expressing oestrus.	Alert will be sent to producer indicating animal is on heat and therefore not pregnant. Behavioural detection of cow feeding calf	1. Allow producers to cull female animals earlier that are not pregnant. 2. Reduce costs associated with pregnancy testing (note: the system will not be able to identify an animal that is not cycling and not pregnant).		Near real time in field data.	WOM required		Medium	Medium

Application	Explanation	How would this work?	How would it bring value to the producer?	Would there be benefit in other areas of the value chain?	Real-time, near real time or post processed. Office or paddock data.	Whole of mob (WOM) or sentinel deployment (SD) system	Current state of required algorithm or modelling development	Adoptability	Ease of path to value
Calving and lambing detection	Detection and location of birth events including alerts for difficult births.	Alert sent to producer indicating that animal is exhibiting behaviour indicating it is having difficulty giving birth and location data allowing producer to easily find animal.	1. Reduced mortality of female and/or offspring due to difficult births (through intervention) 2. Reduced labour as less time spent checking livestock. 3. Peace of mind.	Welfare/social license	Real-time data with in field alerts	WOM required	Proof of concept in sheep (Dobos et al., 2014).	Medium	Medium
Genetic matching (dam/offspring)	Determining which calf/lamb belongs to which cow or ewe	Proximity between ewe and lamb (after lamb tagged) (same for cattle)	1. Allow producers to select ewes based on productivity in terms of offspring performance. 2. Saves time in yards for beef producers		End of season data. Office data.	WOM	Proximity has been proven using a number of methods. Will not detect genetic match for mismothered stock	Medium	Medium
Genetic matching (male/female)	Determining which male has mated which female.	Proximity between ewe and ram or bull and cow	1. Ability to more accurately predict calving dates and record sires 2. May aid in identifying non perofrming bulls/rams		End of season data. Office.	WOM	Proximity proven using a number of methods	Low	medium

Application	**Explanation**	**How would this work?**	**How would it bring value to the producer?**	**Would there be benefit in other areas of the value chain?**	**Real-time, near real time or post processed. Office or paddock data.**	**Whole of mob (WOM) or sentinel deployment (SD) system**	**Current state of required algorithm or modelling development**	**Adoptability**	**Ease of path to value**
Landscape utilisation	Determining which areas of the paddock are being used and not used by animals.	Producers will be able to analyse processed data to observe where and how long livestock have spent grazing specific areas of the paddock.	1. Producers will be able to plan infrastructure e.g. fences, water points to allow more efficient pasture utilisation. 2. Producers will be able to make better decisions as to the appropriate stocking rate.	Environmental sustainability e.g. reduce overgrazing	Office data. May be long term (>12 months of data) or short term (days) depending on application	SD would likely work	Variosu publications show methods for this (Trotter et al., 2010).	Low	Low
Refining fertiliser application	Creating zones of high and low grazing production to better manage fertiliser applications	1. Producers will be able to analyse processed data to observe where and how long livestock have spent camping at specific areas of the paddock.	1. Producers will be able to used data to develop zonal fertiliser management strategies.	Environmental sustainability e.g. reduce run off	Long term data. Office.	Sentinel approach will provide some benefits	Novel. Unknown how important animal data will be for this application	Low	Low
Timing grazing rotations	Detecting grazing behaviour changes to enable refined grazing management decisions	An alert will be sent to producers alerting them that livestock are exhibiting behaviour indicating they are running out of feed.	1. Producers will be able to better manage animal feed take by knowing when they need to move their stock to a new paddock or start to supplementary feed. 2. Reduce labour required to check paddocks to ensure there is enough feed for animals.	Environmental sustainability e.g. reduce overgrazing	End of day summary. In some situations real time alert may be useful	SD would work	Relatively novel. Proof of concept established but unclear how prtable (Roberts et al., 2015).	Low	Low

Application	Explanation	How would this work?	How would it bring value to the producer?	Would there be benefit in other areas of the value chain?	Real-time, near real time or post processed. Office or paddock data.	Whole of mob (WOM) or sentinel deployment (SD) system	Current state of required algorithm or modelling development	Adoptability	Ease of path to value
Refining supplementary feeding	Detection of animal behaviours that indicate supplementary feeding is required	An alert will be sent to producers alerting them that livestock are exhibiting behaviour indicating they are running out of feed.	1. In pastoral areas producers could time urea application more accurately. 2. In pastoral areas reduce labour checking stock. 3. More timely supplementary feeding may use livestock do not lose weight due to insufficient feed intake.	Supply chain benefits for producers of supplement	Near real time processed data.	SD may work	Novel. Producers articulate that they observe behaviour but little published on sensor use.	Medium	Low
Stock theft	Detecting stock theft as it occurs in the paddock.	Producers will be sent an alert notifying them that their stock are being mustered and/or trucked and the last location they were tracked.	1. Reduce stock theft events and assist police to catch thieves 2. Knowledge that animals are being tracked may deter stock thieves. 3. Peace of mind 4. Identification of actual theft events as opposed to animals straying away from farm into neighbours, clarifies straying verses deliberate theft.	Integrity systems	Real time in field data	SD may work	Some commercial systems claim stock theft but unclear if it's a behavioural trigger or collar removal	High	High
Predation detection	Wild dog or other predation events.	Producers will be sent an alert notifying them that their stock are	1. Producers in some circumstances will be able to stop the attack reducing stock mortality and injury.	Welfare	Real time in field data (for alert). But value in	Unclear, WOM will work but SD might.	Proof of concept completed	Medium	High

Application	Explanation	How would this work?	How would it bring value to the producer?	Would there be benefit in other areas of the value chain?	Real-time, near real time or post processed. Office or paddock data.	Whole of mob (WOM) or sentinel deployment (SD) system	Current state of required algorithm or modelling development	Adoptability	Ease of path to value
		currently being attacked.	2. Producers will be able to react to predation event more quickly treating and/or destroying stock. 3. Producers will be able to monitor an area and possibly destroy predators through targetted baiting		longer term data for targetted baiting (Northern Aus)		(Manning et al., 2014).		
Detecting shy feeders	Detecting animals which when introduced to feedlot or when supplementary feeding (lambs and cattle) are not eating and/or are bullied and therefore not able to access feed.	Producers will be able to observe data which outlines which animals are not spending enough time where supplementary feed is placed.	1. Producers will be able to draft shy feeders into another paddock/pen to ensure they are receiving enough supplement. 2. Producers will be better able to manage the tail of their livestock and increase productivity of these animals.	Welfare	Near real time processed data.	All animals required to detect individual behaviour.	Novel	Medium	High
Bull/Ram activity	Detecting whether male animals are serving female animals	An alert will be sent to producers with the location of a bull/ram whose behaviour indicates it is not working.	1. Producers may be able to reduce the number of bull/rams used as they are confident all are working (this will not assist with bulls who are infertile as opposed to not serving female animals).		Real time in field data	Sentinel approach. All male animals will need to be tracked.	Several commcercial systems claim to do this. (Abell et al., 2017)	High	High

Application	Explanation	How would this work?	How would it bring value to the producer?	Would there be benefit in other areas of the value chain?	Real-time, near real time or post processed. Office or paddock data.	Whole of mob (WOM) or sentinel deployment (SD) system	Current state of required algorithm or modelling development	Adoptability	Ease of path to value
			2. Increased conception rates by replacing any non active males						
Calculating feed efficiency	Determining how much pasture an animal has consumed against its weight gain	Sensor measures bite rate or audio sensor measure sound of pasture tearing	Could be used by seed stock producers to breed more feed efficient animals		Office data.	Individual animal monitoring required	CSIRO collar built for this. Unclear as to current state of commercialisation	Low	Low

9.2 Appendix 2

Detailed information on current technology developers working in the on-animal sensing space. This information has been collated from publicly available information. At the time of compilation these details where up to date, however there are likely to be current changes that each entity has not made public.

(Acronyms/abbreviations - DNP: Detail Not Provided; GPS: Global Positioning System ; IMU: Inertia Monitoring Unit; LoRA: Long Range Radio communication)

Company name and web site	Location (s)	Stated objective (s)	Form factor	Sensor(s)	Telemetry (cow to cloud)	Data Delivery mode to farmer	Can I buy it now?	Applicability to		
								Intensive livestock (dairy or feedlot)	Extensive Grazing beef	Extensive Grazing sheep
Sensors providing Location, Behaviour and State capabilities										
CattleWatch www.cattlewatch.co.za and www.cattle-watch.com	Israel and South Africa	Geofencing, stock theft, disease detection, pregnancy, oestrus	Hybrid – collar base station with peripheral ear tags	GPS collar with accelerom-eter ear tags	Mobile network and iridium satellite. Possibly LoRa now	Web interface	Yes (but actually getting system seems difficult)	✓	✓	✓ (ear tags)

Company name and web site	Location (s)	Stated objective (s)	Form factor	Sensor(s)	Telemetry (cow to cloud)	Data Delivery mode to farmer	Can I buy it now?	Applicability to		
								Intensive livestock (dairy or feedlot)	Extensive Grazing beef	Extensive Grazing sheep
Ceres Monitoring www.cerestag.com/	Brisbane, Australia	Various	Ear tag	GPS and IMU	LoRa and/or satellite	Proposed to be accessed through existing farm management software	No	✓	✓	?
CSIRO eGrazor https://www.csiro.au/en/Research/AF/Areas/Animal-Science/Premium-livestock-breeds/eGrazor---measuring-cattle-pasture-intake	Armidale/ Brisbane, Australia	Detection of feed intake	Collar	GPS and IMU	Unclear but appears to be LoRa	DNP	Unknown	✓	✓	?
Digital Animal https://digitanimal.com	Spain	General monitoring and grazing locations	Collar	GPS (possibly IMU)	Sigfox (proprietary LoRa)	Web and mobile interface	Yes	✓	✓	✓

Company name and web site	Location (s)	Stated objective (s)	Form factor	Sensor(s)	Telemetry (cow to cloud)	Data Delivery mode to farmer	Can I buy it now?	Applicability to		
								Intensive livestock (dairy or feedlot)	Extensive Grazing beef	Extensive Grazing sheep
HotStock (HotGroup) www.hoteye.co.za/index.php/en/	South Africa	Monitoring of animal location – some animal health	Collar	GPS	Local mobile network	Web interface with SMS alerts	Unknown if still supplying	✓	✓	✓
ioMonitoring www.iotag.com.au/	Australia	Monitoring of animal location and rangeland use	Collar but ear tag in development	GPS	LoRa radio	Local base station transmits to web based app for viewing	No, but demo available soon	✓	✓	?
LESS Industries http://www.lessindustries.com	Argentina, Chile, Australia	Geofencing, health, theft	Collar	GPS and IMU	LoRa radio	Web Interface	Yes but only demo	✓	✓	? (they claim yes)

Company name and web site	**Location (s)**	**Stated objective (s)**	**Form factor**	**Sensor(s)**	**Telemetry (cow to cloud)**	**Data Delivery mode to farmer**	**Can I buy it now?**	**Applicability to**		
								Intensive livestock (dairy or feedlot)	**Extensive Grazing beef**	**Extensive Grazing sheep**
mOOvement www.moovement.co/	Australia	Location, oestrus detection, grazing patterns, bull performance	Collar and ear tag in development	GPS and IMU	LoRa radio	Web interface and mobile app	No	✓	✓	? (form factor not released)
Redi www.precisionanimalsolutions.com/	Kansas, USA	Animal health in feedlot	Ear tag (uses Smartbow)	Uses Smartbow tag (below)	Wifi triangulation	Web interface	Yes	✓	✗	✗
SmartBow http://smartbow.com/en/	Austria	Location, health and rumination	Ear tag	Location (no specifics given), temperature and accelerometer	Wifi triangulation	Web interface	Yes	✓	✗	✗

Company name and web site	Location (s)	Stated objective (s)	Form factor	Sensor(s)	Telemetry (cow to cloud)	Data Delivery mode to farmer	Can I buy it now?	Applicability to		
								Intensive livestock (dairy or feedlot)	Extensive Grazing beef	Extensive Grazing sheep
Austraian Wool Innovation Smarttags https://www.wool.com/on-farm-research-and-development/sheep-health-welfare-and-productivity/smart-tags/	Sydney	Ewe-lamb and ewe-ram interaction	Ear tag	Accelerometer and proximity. Location through RBT	INP	INP	No	✓	✓	✓
Smart Paddock http://smartpaddock.com/	Australia	Search for potential health issues	Ear tags	GPS, movement, temperature and heart rate	DNP	Web app and mobile app SMS alerts	No	✓	✓	✓
Vence http://vence.io/	California, USA	Virtual fencing and general animal monitoring	Ear tag	Location (not specified)	DNP	DNP	No	✓	✓	? (form factor not released)

Company name and web site	**Location (s)**	**Stated objective (s)**	**Form factor**	**Sensor(s)**	**Telemetry (cow to cloud)**	**Data Delivery mode to farmer**	**Can I buy it now?**	**Applicability to**		
								Intensive livestock (dairy or feedlot)	**Extensive Grazing beef**	**Extensive Grazing sheep**
Halter https://www.halter.co.nz/	Auckland NZ	Virtual fencing and animal monitoring	Collar	Location (not specified)			Unkown	✓	?	?
Agersens www.agersens.com	Melbourne, Australia	Virtual fencing and animal monitoring	Collar	GPS and IMU	LoRA	Web interface	No, but launching soon	✓	✓	✗ (Form factor too large)

Sensors providing behaviour and state information (no location other than proximity to radio reciever)										
SCR (Allflex) SenseTime www.scrdairy.com	Israel	Reproductive, health, nutritional and wellbeing status	Collar and ear tags	Accelerometer or possibly IMU	IEEE 802.15.4 (similar to ZigBee)	Web interface and mobile application	Yes for collar no for ear tag in Australia	✓	? A beef cattle version has been released but the radio footprint is still quite small	?
CowManager www.cowmanager.com	Netherlands	Reproductive and health status	Ear tag	Accelerometer or possibly IMU	DNP	Web interface and mobile application	Yes	✓	✗	✗
CowLAR https://cowlar.com/	USA and Pakistan	Temperature, activity and behaviour	Headstall	IMU and temperature	Short range radio to node. Mobile network from node to scloud	Web interface with SMS alerts	Unknown	✓	✗	✗

eCow www.ecow.co.uk/	UK	Monitoring of animal health	Rumen bolus	Temperature and pH	Proximal radio not specified	Web interface for all data with some local data available	Unknown	✓	✗	✗
FeverMonitorings www.fevertags.com	Texas, USA	Monitoring of animal health	Ear tag	Temperature sensor in ear canal	WiFi connection direct from sensor to cloud	Wifi connection from cloud to desktop or mobile wireless gateway	Unknown	✓	✗	✗
HerdDogg https://herddogg.com/	USA	Monitoring of animal health	Ear tag	Temperature sensor and unknown activity sensor	Various configuration - Mainly short-range Bluetooth	Web interface available on mobile device.	No, first demo's out now	✓	✓	✓
LiveCare http://www.livecare.xyz/new/	San Francisco, USA	Monitoring animal health	Rumen bolus	Temperature and an optional pH sensor	Local radio network (not specified)	Mobile app	Unkown	✓	✗	✗

MooCall www.moocall.com	UK with a branch in Australia	Oestrus detection	Collar on bull and ear tag on heifers	Proximity sensors on collar and ear tags, activity sensor in collar	Data sent to cloud from collar only, method not specified	Mobile app and alerts to mobile	Yes	✓	✓	✗
Moow Smart (In development) http://www.maformdesign.com/references-1/2016/10/13/moow-rumen-sensor-for-cubilog	Budapest, Hungary	Monitoring of animal health	Rumen bolus	pH and temperature	WiFi to connect to reader	Mobile App	No	✓	✗	✗
Nedap www.nedap.com	Netherlands	Monitoring of animal health	Collar or leg tag	Location (possibly by wifi triangulation) and activity sensors (not specified)	Local network (not specified)	Web interface on PC, tablet or smart phone	Yes	✓	✗	✗

Quantified Ag https://quantifiedag.com/	USA	Monitoring of animal health	Ear tags	Temperature sensor and accelerometer	1.5 to 3 km tag range within unspecified local network, data sent to cloud	Internet accessible dashboard for PC or mobile device	Yes	✓	✗	✗
smaXtec www.smaxtec.com/en/	Austria incl. Australia	Monitoring of animal health, drinking behaviour and oestrus and calving detection	Rumen bolus	Temperature, and a premium version monitors rumen pH	Local wifi network with option of extenders	Web interface and smaXtec messenger alerts	Yes (?)	✓	✗	✗
WellCow http://wellcow.co.uk/bolus/	UK	Monitoring of animal health	Rumen bolus	Temperature and pH every 15 minutes	Wirelessly to a receiver	PC or laptop access only (method not specified)	Yes	✓	✗	✗

Livestock Labs https://www.embedivet.com/	Australia	Health, fertility and production	Implant	Accelerometer, heart-rate, blood oxygen, temperature	Blue tooth (and long range radio DNP)	Mobile app	No	✓	✗	✗