Ceres Tag: An Evaluation for the Prevention, Interruption and Reduction of Livestock Theft

FINAL REPORT | August 2022

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Executive Summary

Crime victimisation amongst farmers is extremely high, particularly for property and acquisitive crimes. One of the most common crimes farmers and landholders experience is the theft of livestock. Ceres Tag is a livestock information platform that uses a unique wearable smart ear tag to generate data on animals to monitor health, welfare, and traceability provenance.

The purpose of this study was to evaluate the application of the Ceres Tag smart animal ear tag for improving farm security, and specifically to determine the efficacy of this technology for the purpose of preventing, interrupting, and reducing the theft of livestock. It was hypothesised that Ceres Tag may combat livestock theft by offering opportunities for intervention at three key stages: rapid intervention/prevention; tracking stolen livestock; and recovering stolen livestock. To test this, a mock-theft of livestock was staged along with a coordinated law enforcement response.

The key findings are summarised below:

- The results indicate that Ceres Tag offers a promising technological tool through which farmers and landholders may prevent the theft of livestock, while offering law enforcement officers a significantly improved capacity to intervene in livestock-theft and recover stolen livestock.
- Ceres Tag prompted a 'high activity alert', indicating to the farmer the livestock were being significantly agitated, within 12 minutes of the mock theft commencing.
- Drawing on Ceres Tag data, the NSW Police were able to track and interrupt the livestock theft within 25 minutes.
- Drawing on Ceres Tag data, the NSW Police were able to track and interrupt the theft of the livestock on three separate occasions over a 90-minute period.
- From the thieves' arrival at their destination, drawing on Ceres Tag data, the NSW Police were able to recover the stolen livestock within 20 minutes.
- Ceres Tag offers the opportunity to increase the risk of criminal behaviour, in an often-riskless rural space, providing for guardianship through technological innovation and target-hardening livestock.
- Ceres Tag provides farmers with evidence and greater certainty of a crime occurring and dramatically reduces the time it takes to report the crime to the police.
- With this timely report police are positioned for rapid intervention and, through the data provided by Ceres Tag, are better equipped to respond to, investigate and solve crimes of livestock theft.

Acronyms

GNSS	Global navigation satellite system
GPS	Global positions system
HAA	High Activity Alert
HDMA	High Distance Movement Alert
NSWPF	NSW Police Force
PEA	Paddock Escape Alert
POI	Person of interest
RCI	Rural Crime Investigator
RCPT	Rural Crime Prevention Team
VOI	Vehicle of interest

The Problem of Livestock-Theft

Crime victimisation amongst farmers is extremely high, particularly for property and acquisitive crimes (see Barclay 2015; 2016). For example, the NSW Farm Crime Survey found that 80 percent of farmers have been a victim of farm crime over their lifetime (Mulrooney, 2021). One of the most common crimes farmers and landholders experience is the theft of livestock. 44 percent of those responding to the NSW Farm Crime Survey had experienced livestock theft (see also Harkness, 2021 for survey results from Victoria). The impact of crime on Australian farmers and other rural property owners is significant psychologically and financially, and there are direct and broader social and economic implications which can impact the entire rural community and the wider agricultural industry (Anderson & McCall, 2005).

In terms of economic loss, considering livestock theft alone, NSW Police Force figures indicate that between 2015 and 2020, an average of 1,800 cattle and 16,700 sheep were stolen each year across the state at a cost of nearly $4 million (annually) to farmers. If we add the value of stud livestock, loss of animal by-products like wool or milk, and loss of future breeding potential, the annual monetary impact on NSW primary producers could realistically be over $60 million per annum. Looking to cattle theft nationally, PricewaterhouseCoopers estimate an average of 31,000 stolen cattle per year across Australia at an average cost of $50 million (PwC, 2022).

Additionally, the violation of an intruder entering private land and stealing property has a substantial bearing on a person's emotional state and sense of safety and security, especially when considering that many of these offences occur in isolated rural spaces where a police response will not be immediate. Given this, it is perhaps not surprising that research also indicates prominent levels of worry about crime amongst farmers which may have an impact on an individual's quality of life through stress, physiological effects, and negative psychological well-being (Mulrooney, 2021).

Notably, there are other economic and social costs as productive farmers may leave the sector all together owing to the personal stress and anxiety associated with victimisation and the loss of a valuable livestock line which may have been built up over many years or generations. These costs are borne by farmers already facing serious challenges from droughts, flooding, bush fires, climate change and mental health impacts. Of course, these crimes can have an additional flow-on effects, impacting pricing, distribution, and the availability of produce. Intricately connected to this we can consider the implications of trespassing on to farms for the purpose of theft, introducing issues of biosecurity and, subsequently, food security more broadly.

Despite significant rates of victimisation, livestock theft often goes unreported. As such, estimates of the incidence of such offending are especially conservative given this 'dark figure' of farm crime. Research points to a number of interconnected reasons farmers do not report crime, including: discovering the theft too late and having no indication of when the event occurred; perceptions of barriers to investigating crime in rural spaces, such as a lack of evidence or proof; and a lack of confidence in the police to able to solve the crime (see Mulrooney, 2021; Harkness, 2021). Related to this, the distance, remoteness, and considerable size of rural properties often limit the regularity with which farmers check their livestock, meaning the farmer is often unaware that offending has occurred. Consequently, the time lag between the theft of livestock and the reporting of the theft can be lengthy, if reported at all, leaving little evidence and therefore a reduced capacity for police to intervene

Ceres Tag and Mapipedia Software

The purpose of this study was to evaluate the application of the Ceres Tag smart animal ear tag for improving farm security, and specifically to determine the efficacy of this technology for the purpose of preventing, interrupting, and reducing the theft of livestock.

Ceres Tag is a livestock information platform that uses a unique wearable smart ear tag to generate data on animals to monitor health, welfare, and traceability provenance. It does this in two ways. The first is activity monitoring. Ceres Tag activity monitoring is an algorithm that has been developed utilising an accelerometer within the tag. The accelerometer samples the pattern of behaviour over a rolling six-day period to determine a base line activity level, which is then expressed on a scale of 1 -7 with 1 meaning low activity and 7 meaning extremely high activity. The tag continuously utilises machine learning to update and inform this metric.

The continual comparison to the baseline level allows unusual changes to the 'normal' activity to be identified and alert the producer of a potential problem with that individual animal. The Ceres Tag high activity alert is triggered if an animal's average activity level greatly exceeds their average activity relative to the previous 6-days of monitoring. Importantly, alerts associated with the accelerometer are pushed out by the tag every 10 minutes. Additionally, the Ceres Tag mortality alert is triggered if no activity has been observed on the tag for a period of 60 minutes. Once triggered, the tag will continue to send alerts every 12 hours.

Ceres Tag's second main feature is the ability to monitor animal location. The tag uses global navigation satellite system (GNSS) technology to provide a position approximately six-hourly (dependent on the receiver's environment and satellite sky view) via the Globalstar network. The location system used within the tags is uncorrected GNSS, meaning the tag's position can be within +\- 10 meters of the animal's true location. All data is transmitted directly to the 'cloud' via a constellation of low earth orbit (LEO) satellites. This ensures data can be securely collected without any other infrastructure. Once received via satellite, all data is transferred and stored securely in Ceres Tag's cloud-based data platform.

This cloud stored data can be accessed through farm management software platforms, allowing data to be combined, visualised, and analysed in powerful, meaningful ways and shared with other third parties as desired by the user. The Ceres Tag software partner used in this research was Mapipedia. Mapipedia uses the latest web technologies to automatically import data from Ceres Tags and allow data to be viewed on any device. Data can be visualised on maps with animations, filters, user defined zones (such as paddocks), user defined points of interest (such as water sources and so on) and more.

Most importantly, bespoke alerts such as notifying the farmer if livestock breach a pre-determined geo-fence (GNSS data) or if livestock have abnormally high activity (accelerometer data) may be programmed. Based on these alerts, users are notified about incidents and emergencies via email, SMS, WhatsApp or via the web app when events that are important to the user occur: for example, perimeter breaches (such as due to theft or damaged fences), animals in distress, animals in potential flood zones based on weather forecasts, and more. Historical data may be analysed to gain a better understanding of different animal behaviours, land usage and, in this case, theft events and so on.

Research Questions

Drawing on this technology and its associated data, we hypothesised that Ceres Tag may combat livestock theft by offering opportunities for intervention at three key stages: rapid intervention/prevention of livestock theft; tracking stolen livestock; and recovering stolen livestock.

Key Stage	Opportunity
Stage 1: Rapid Intervention /Prevention	Thieves commence theft of livestock. Ceres Tag is evaluated on the data it may provide the farmer/landholder to enable a quick reponse to the theft event.
Stage 2: Tracking Stolen Livestock	Thieves proceed to drive stolen livestock from the site of theft in Armidale to the Tamworth Regional Livelivestock Exchange. Ceres Tag is evaluated on the data it may provide and enable police to track and stop the thieves on route to their destination.
Stage 3: Recovering Stolen Livestock	Thieves arrive at the Tamworth Regional Livelivestock Exchange. Ceres Tag is evaluated on the data it may provide and enable police to recover the stolen livestock.

In this trial, we sought to answer five key research questions:

Rapid Intervention/Prevention of Livestock Theft

1. Does Ceres Tag provide near real-time data which may indicate livestock are being disturbed/stressed?
   If so, what is this data and how does it differentiate to that under 'normal' conditions?
2. Does Ceres Tag alert/notify of a breach of boundary by livestock?
   If so, what factors determine the time it takes to receive this notification?.

Tracking Stolen Livestock

3. Does Ceres Tag provide data on livestock movement and location once a boundary has been breached?
   If so, can this data be used to track livestock in near real-time while in transit?

Recovering Stolen Livestock

4. Can data from Ceres Tag be used to track livestock to the destination and recover?

Policing Stolen Livestock

5. Based on these results, can Ceres Tag improve the capacity of the police to prevent and respond to livestock theft? If so, how?


CERES
TAG

The Mock Theft Trial

To answer these research questions, researchers and law enforcement coordinated by the Centre for Rural Criminology undertook a proof of concept 'mock' theft trial (AUTHORITY No: ARA21-081). The 'mock' theft occurred at the University of New England in New South Wales, Australia. 20 sheep were fitted with Ceres Tags affixed on collars around their neck. Collars were employed as it was deemed unnecessary to affix the tags to the ears of the sheep for a short trial. The use of collars had no implications on the data pertinent to the research questions above given the attachment location which maintained adequate sky view of the tags' solar panels.

Ceres Tags were deployed on sheep via individual restraint in the sheep yard race. After collar deployment, animals were monitored for 30 minutes to ensure there were no immediate adverse reactions to the collar deployment.

After this point animals were inspected every second day to ensure they were in good health throughout the study period. To develop a baseline and better understand the consistency and content of the data and alerts being reported, the sheep were monitored for eight weeks prior to the mock theft.

Prior to the theft event, a virtual perimeter, known as a geofence, was constructed in Mapipedia software around the boundary of the paddock following the fence line. This boundary was needed to enable a threshold location to initiate boundary breaches known as paddock escape alerts (PEA) when animals are outside the designated area.

Alerts were also set for high accelerometer activity (HAA). HAA alerts send messages to contacts when sheep activity is above the normal value for that animal. An additional alert of high distance movement (HDMA) was programmed into the tag software. In this case, when animals travelled a distance greater 1000 metres (or another set distance measurement) away from the previous recorded GNSS position, an alert was triggered.

Actors in the mock trial were divided into three groups, each with their own role in the project: the thieves; the farmer/landholder; and the police. The thieves stole the sheep, the farmer monitored Ceres Tag data and alerts, and the police followed standard police protocols to intercept and recover stolen sheep using the data coming from the tags.

Figure 1 (Opposite) Ceres Tags on Collars; Figure 2 (Above) Participants in the Mock Theft Trial

The Thieves

To begin Stage 1 (rapid intervention/prevention of stolen livestock) of the trial, the thieves entered the paddock and began to move the sheep into the loading yards and on to a trailer.

While the real-world conditions of theft will vary considerably, in this trial the conditions were skewed towards that of the thief. For example, the paddock and accompanying geo-fence was located at the roadside, the thieves had access to an all-terrain vehicle (ATV) to muster sheep, and there were loading yards present.

Once the sheep were loaded, the theft vehicle and trailer breached the geo-fence and drove 200 metres from the loading yard prior to beginning Stage 2 of the trial (tracking stolen livestock). The thieves waited for the first PEA before commencing the journey to their destination. This was done to isolate stage two and to see how much data could be collected by the police/ actioned over the duration of the trip to the final destination (recovery). After the first PEA, the thieves drove from Armidale to the Tamworth Regional Livestock Exchange, approximately 113 kilometres away (1.5 hours by road).

Once the thieves arrived at their destination Stage 3 (recovering stolen livestock) of the trial began, and the experimenters timed and waited for the police to recover the livestock. Through the journey, the thieves tracked their movement using GPS for comparison with Ceres Tag alerts and tag activity.

Figure 3 Sheep collared with Ceres Tags

Figure 4 Thieves mustering livestock near the loading yards

The Farmer

The farmer's role was to act upon the information provided by the tags. HAA, PEA and HDMA were sent to the farmers phone via SMS messaging as well as by email (see Figure 5, 6 and Table 1 for examples of alerts sent during the trial). Each alert prompted the farmer to make a decision. A HAA for six tags came in 12 minutes after the theft commenced. An HAA alert, across a number of tags, should indicate a problem and incline the farmer to check on the livestock. Thus, if the farmer acted upon this HAA in this trial, intervention could have occurred within twelve minutes of livestock disturbance.

In this case, the HAA prompted the farmer to look at the Mapipedia online platform which presents the GNSS data and alerts in greater detail. Upon reviewing the online platform, the farmer was able to see that two tags 'pinged' on the outside of the boundary geo fence.

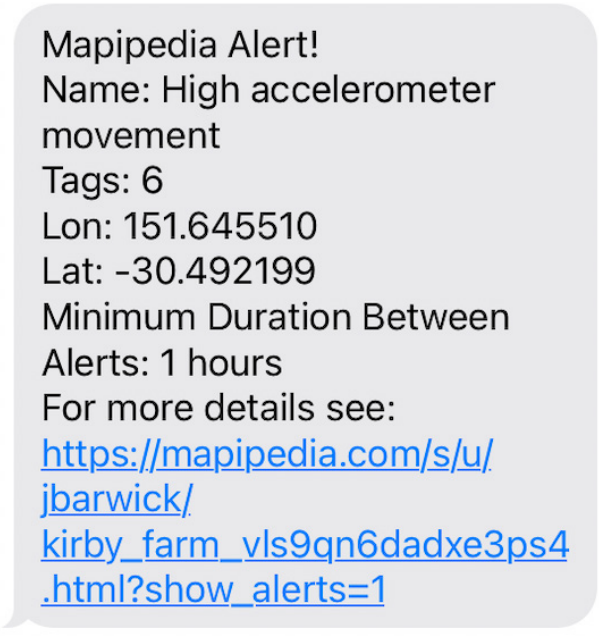

Figure 5 Mapipedia alerts send via SMS

However, SMS/email PEA alerts are not sent until the livestock have moved beyond a 20m buffer outside the geofence. Once again, to isolate Stage 2, the research team chose to require both a HAA and PEA alter to trigger the farmer to call the police for assistance (Stage 2). Therefore, a decision was made not to contact the police until a formal PEA SMS alert was received by the farmer.

Once the thieves had breached the geofence, an SMS alert for a boundary breach (PEA) took 33 minutes to be received by the farmer. At this point, the farmer called the police and reported the HAA and PEA and requested the support of the police. To avoid intervention with the public during the live mock-theft trial, the Rural Crime Investigators (RCI) were provided with a vehicle description (a white utility vehicle). No other information was provided to the officers.

After calling the police, the farmer emailed them a publicly accessible link to their Mapipedia platform. As such, from here the police had full access to the Ceres Tag data for the purposes of tracking (stage 2) and recovering (stage 3) the stolen livestock.

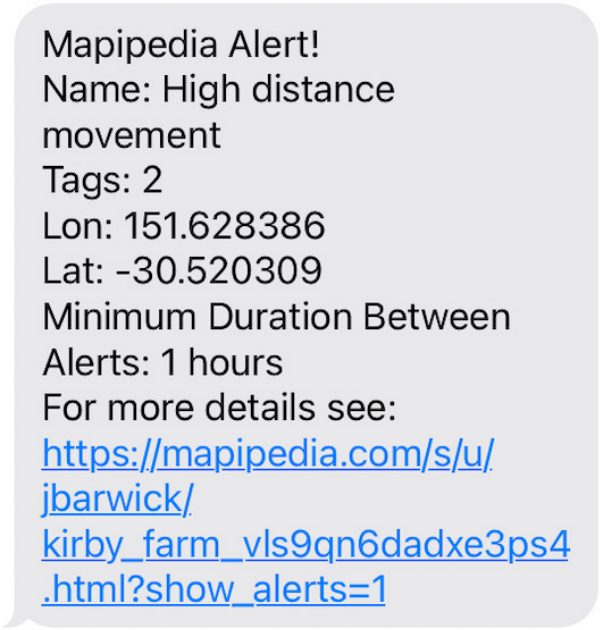

Figure 6 Mapipedia alerts send via SMS

The Police

The NSW Police Rural Crime investigators (RCIs) were aware that the mock theft would occur. Together they liaised with local law enforcement to respond to the theft. The police behaved only as they would normally and reacted entirely on the initial information provided by the farmer and the data coming from the Ceres Tag and accessed by them through the Mapipedia software (GNSS

Figure 7 Rural Crime Investigator intervening in livestock theft

Index	Alert Name	Tags	Date
1	High distance movement	16	29 Mar 2022 16:38
2	Paddock escape	17	29 Mar 2022 16:22
3	High distance movement	16	29 Mar 2022 15:35
4	Paddock escape	17	29 Mar 2022 15:19
5	High distance movement	13	29 Mar 2022 14:31
6	Paddock escape	13	29 Mar 2022 14:15
7	High distance movement	9	29 Mar 2022 13:27
8	Paddock escape	11	29 Mar 2022 13:10
9	High distance movement	5	29 Mar 2022 12:22
10	Paddock escape	8	29 Mar 2022 12:06
11	High accelerometer movement	1	29 Mar 2022 11:32
12	High distance movement	2	29 Mar 2022 11:18
13	Paddock escape	1	29 Mar 2022 11:02
14	High accelerometer movement	6	29 Mar 2022 10:17

Table 1 Ceres Tag Alerts in Mapipedia during duration of trial

data + programmed alerts). Using this data, the police made a series of decisions based on standard operating procedures, with the goal of intercepting the thieves and/or recovering the livestock at their destination.

The Rural Crime Prevention Team (NSW Police Force) received the livestock-theft report from the farmer at 11:05am. Examining the data received thus far in Mapipedia, the police dispatched RCI's to the area of the theft to look for person/s (POI) or vehicle/s of interest (VOI) and/or animals (being transported). No leads were found at this stage. At 11:14am the police noted the last GNSS data from the Ceres Tag may have indicated the VOI was heading for a nearby highway (the New England Highway), and that it was unlikely the thieves would travel through town. Police in surrounding areas were notified to "keep a look out" for vehicles carting livestock.

At 11:18am the Ceres Tag sent a HDMA alert. The accompanying GNSS information had the livestock moving south from Armidale along the New England Highway, confirming the earlier hypothesis of the police that this might likely be the direction taken by the thieves. As the RCI's entered a nearby town, Uralla, they began to look at service stations and other obvious places the thieves could have stopped, paying attention to any alternate routes where the thieves could have turned off as well. The RCI's observed a VOI facing west on East Street alongside a Puma service station. The RCI's pulled over the VOI to inspect their livestock transportation documentation and enquire about the livestock. The stolen livestock was successfully tracked, and the thieves intercepted at 11:30am, 25 minutes from the police receiving the report of the crime.

At this point, the RCI's divorced themselves from the interaction and reset the scenario, awaiting further data for action.

The RCI's informed officers in the surrounding areas to examine local maps as the thieves could have now turned off the New England Highway, travelling in a westerly or easterly direction from Uralla. The RCI's continued along the New England Highway, as this was the last location data was available from.

At 11:48am the RCI's received GNSS location data indicating the thieves were travelling south of Kentucky and, as such, were most likely to still be travelling along the New England Highway. The RCI's radioed ahead to officers based in Kootingal (11:53am) and at 12:13pm the VOI was sighted at the top of Moonbi Range. The officer set up at the Moonbi RBT site on the highway and the VOI was intercepted for a second time at 12:21pm.

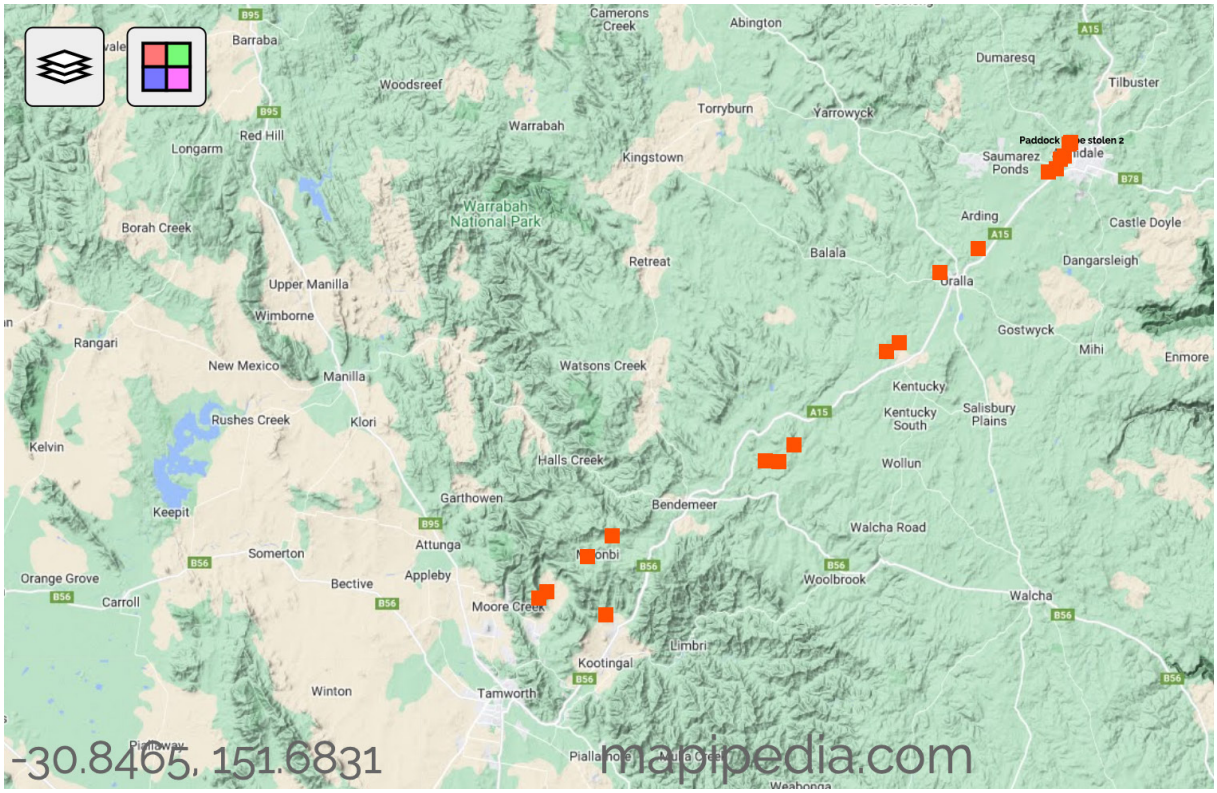

Figure 8 GNSS Location Data from Ceres Tag as seen in Mapipedia

Figure 9 Rural Crime Investigator inspecting livestock transportation documentation of VOI

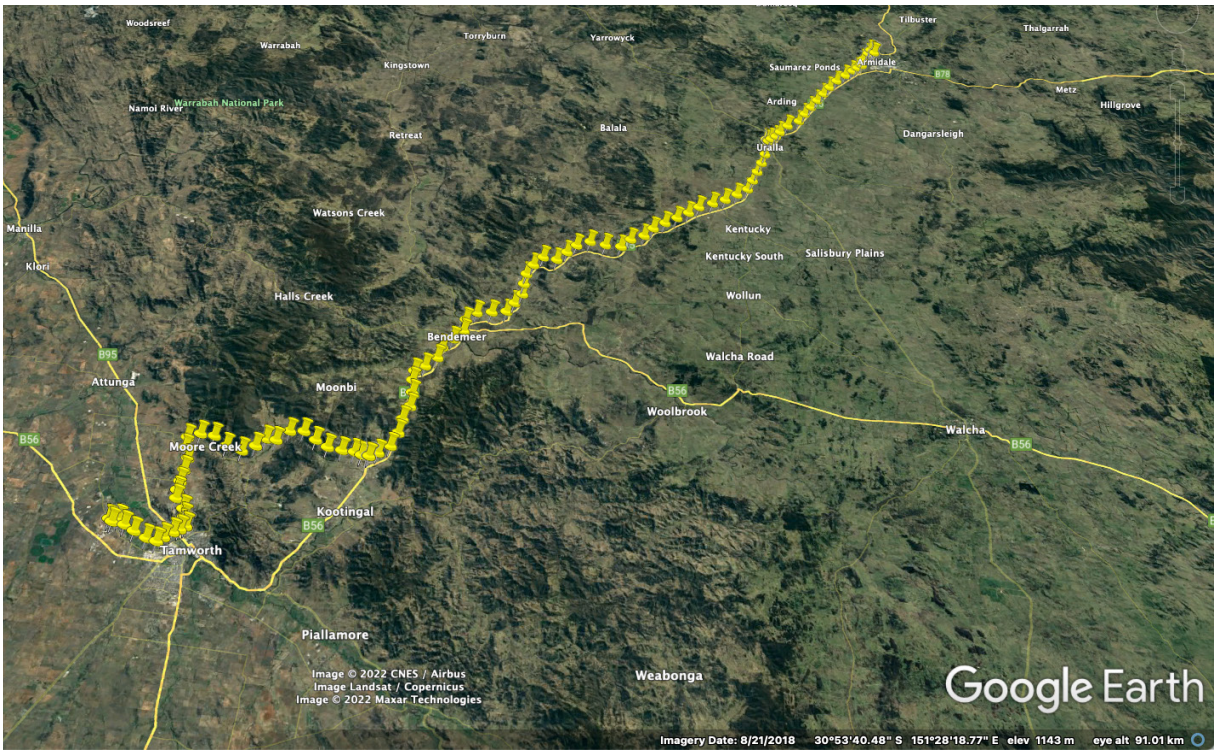

Figure 10 GPS Data of the route taken by the livestock thieves

Once again, the RCI's divorced themselves from the interaction and reset the scenario until they received further data from Ceres Tag. Another HDMA came in at 12:22pm indicating the thieves were still moving. At 12:27pm, GNSS location data indicated the VOI was at Moonbi Gap road, 2.46km west of Moonbi. Drawing on this data, the RCIs then considered the time it would take to travel from Moonbi to nearby Tamworth and estimated the likely location of the VOI. The RCI's in pursuit then contacted the Tamworth RCI's and asked them to do the same and to be on high alert. At 12:48pm, the Tamworth RCI's sighted the VOI and intercepted the thieves for a third time. Once again, the RCI's divorced themselves from the interaction and reset the scenario until they received further data.

The thieves arrived at their destination, the Tamworth Livestock Exchange, at 1:04pm. At 1:13pm, a number of GNSS pings indicated the thieves were near Armstrong and Phoenix Streets in Tamworth suggesting they may be stopped. Tamworth RCI's were instructed to make their way to the location. At 1:24pm, the RCI's intercepted the VOI parked at the entrance of Thomas Food International, near the Tamworth Livestock Exchange.

At this point, the livestock was successfully recovered by the NSW Police Force Rural Crime Prevention Team. From the thieves' arrival at their destination, it took the NSW Police 20 minutes to recover the livestock.

Answering the Research Questions: Results by Stage

Table 2 Summary of key 'time' results by stage

Scenario	Data	Alert	Time
Stage 1: Rapid intervention/prevention	Accelerometer	High activity alert	12 minutes
Stage 2: Tracking stolen livestock	GNSS location data	Paddock escape alert/ high distance movement alert	25 minutes
Stage 3: Recovering stolen livestock	GNSS location data	Paddock escape alert/ high distance movement alert	20 minutes
Total trial time	Accelerometer/ GNSS location data	High activity alert/Paddock escape alert/high distance movement alert	175 minutes

Rapid Intervention/Prevention of Livestock Theft

1. *Does Ceres Tag provide near real-time data which may indicate livestock are being disturbed/ stressed? If so, what is this data and how does it differentiate to that under 'normal' conditions?*

By providing farmers with movement and location data and associated alerts, Ceres Tag provides the capacity to intervene in the theft of livestock in near real time. Specifically, accelerometer data and accompanying HAA alerts, which are provided every 10 minutes, may indicate that livestock are being disturbed by a thief attempting to muster and load them.

Importantly, as the accelerometer samples the pattern of movement behaviour over a rolling six-day period, to determine individualised base line activity level, such alerts are reliable and should be taken seriously by the farmer. For example, in the mock trial, the six HAA received in the 12th minute should prompt the farmer to check on the livestock (see Table 2).

This may provide the opportunity for rapid intervention/prevention and or the gathering of evidence to pass along to the police (e.g., vehicle description; video recording etc.).

2. *Does Ceres Tag alert/notify of a breach of boundary by livestock?*

Alerts notifying a breach of boundary (PEA) may indicate livestock are being stolen. With these timely notifications, farmers are provided an opportunity to respond to theft with significantly reduced delay and inform police who can react in a timely manner, allowing for interruption/ prevention of the criminal event and/or the preservation of evidence.

Where interruption/prevention is not possible, the notification of boundary breach, especially in combination with any HAA, should prompt the farmer to check on their livestock thereby greatly reducing the time to reporting. This provides the police with a much greater ability to track and recover the livestock as well as gather evidence which may otherwise be destroyed or rendered useless overtime. In this case, following the HAA the farmer checked the GNSS data in Mapipedia and was able to see two tags pinged outside the geofence.

Additionally, a PEA was received in 33 minutes, prompting the farmer to phone the police who were then able to track the thieves and intervene in the theft within 25 minutes (see Table 2).

Figure 11 (Opposite) Sheep collared with Ceres Tag near loading yards

If so, what factors determine the time it takes to receive this notification?

The time it takes to report a PEA (or GNSS data more broadly) depends on the total number of tags. In this mock theft trial, 20 tags were used.

When the data sent by each tag over a two-week period is reviewed, the timeliness of information flowing from the tags can be estimated. Over the 14 days in question, the highest number of times GNSS data was transmitted over a day was 111 times with the lowest number being 89 times. This provides an average of 101 data transmissions per day.

While the times of these transmissions may vary, users should expect to receive data 4.21 times per hour or every 14.25 minutes if using 20 tags. This number will increase or decrease depending on the total number of tags.

In this trial, as outlined above, upon receiving the HAA the farmer noted two tags pinged outside the geofence. However, as the as the livestock had yet to move beyond the 20m geofence buffer, a formal sms/email PEA was not sent. In a real-world scenario the combination of this data with the HAA should promt the farmers to check on the stock, at the very least.

In terms of receiving a PEA, as GNSS data was sent and received just prior to the 20m paddock buffer being breached, a formal PEA took 33 minutes to be received by the farmer.

Tracking and Interrupting Stolen Livestock

3. *Does Ceres Tag provide data on livestock movement and location once a boundary has been breached? If so, can this data be used to track livestock in near real-time while in transit?*

In instances where livestock theft does occur, GNSS location data and associated alerts may be utilised to track livestock which has been stolen and to build investigations. Law enforcement agents may draw on the data provided by Ceres Tag to follow the transportation of the stolen livestock to its destination.

This data may also allow for targeted interruption of the stolen livestock on route to its destination. In this mock trial, the RCI's were able to track and interrupt the theft of the livestock on three separate occasions over a 90-minute period, with the first intervention occurring withing 25 minutes of the police being notified of the theft (see Table 2).

In the event the police are unable to intervene, this location data may also be used to gather evidence. For example, by knowing the route travelled by the thieves, as well as any stops along the way, CCTV footage of the VOI/POI's, whether from services stations, houses, dashcams and so on may be collected for evidence. Such evidence may be useful when prosecuting offenders.

Recovering Stolen Livestock

4. *Can data from Ceres Tag be used to track livestock to the destination and recover?*

GNSS data and related alerts may be used to ascertain when the stolen livestock has stopped moving and, subsequently, to coordinate an intervention for recovery at the destination. As GNSS pings began to conglomerate, this data allowed the RCIs to ascertain that the thieves had stopped, as well as where they had stopped, and to recover the stolen livestock 20 minutes after the thieves arrived at their destination (see Table 2).

Policing Livestock-Theft

5. *Based on these results, can Ceres Tag improve the capacity of the police to intervene in livestock theft and/or recover stolen livestock?*

The RCIs reported their response and investigative decisions in this trial were made solely based on the data provided by Ceres Tag via the Mapipedia Software, along with local and industry based policing knowledge (e.g., likely points of interest; main highways travelled etc.).

As above, the timely reporting of the theft from the farmer allowed the police to respond to the theft rapidly, which differs significantly from the current real-world norm. Additionally, the data allowed the officers to determine the travel/direction of the thieves and intervene in the theft on numerous

occasions. The data also provided the RCI's with the knowledge that the vehicle had stopped at a particular location, allowing them to recover the stolen livestock.

In debriefing following the trial, the RCI's also highlighted a number of specific investigatory benefits. For instance, they noted the data allowed them to coordinate a police response by radioing forward and establishing checkpoints. The examination of the data after the fact was useful in identifying the route of travel and any points in which the thieves were stationary. Through this the police may gather evidence such as CCTV footage of the route (e.g., houses; businesses; dash-cams) and/or of the POI's, as well as financial records if they used key cards etc. The RCI's also noted that being rapidly alerted to the theft could also allow them to employ other tools such as point to point stationary speed cameras, which can set real time triggers if the registration is known, and automatic number plate recognition (ANPR) technology in Highway Police vehicles.

The RCI's also indicated that, in the unlikely event that the tags are cut, evidence of possession would allow for the application of crime scene/ search warrants at the location and, if tags are found on site, DNA/fingerprint examination due to timeliness of recovery.

Limitations

While the Ceres Tag performed very positively with respect to facilitating rapid intervention/prevention, tracking and interrupting stolen livestock, and recovering stolen livestock, there are few limitations which must be considered.

One obvious limitation is the possible removal of the tag by thieves. However, there are some important caveats here. First, the tag is made of polymer coated stainless steel which makes removal much more difficult than traditional tags in terms of effort and time. Difficulty/time, as outlined below, is an important factor in the decision to steal livestock. Time introduces greater opportunity for intervention, and therefore risk to the thief, particularly if the animals are being agitated and HAA alerts are being sent. As such, would-be thieves are less likely to be comfortable spending time removing individual tags with bolt cutters or other devices and may be dissuaded/ prevented from stealing the livestock.

Additionally, there is a higher chance of damage to the animal's ear from the forced removal of a Ceres Tag. If such damage is readily noticeable, it may be more difficult for the thieves to move the livestock onto market and/or is likely to raise suspicion. Nevertheless, if the thief successfully removes the tag and or kills and field dresses the animal, a Ceres Tag Mortality alert will be triggered if no activity has been observed by the tag for a period of 60 minutes.

Another limitation is that the flow/magnitude of data is dependent upon the total number of tags. As noted above, with the 20 tags included in this study data transmissions were received on average every 14.21 minutes. This means that if the 20 tagged cattle are stolen and breach the geofence, the farmer should be alerted on average within 14.21 minutes. In reality, this varies with some alerts coming closer together and others further apart. For example, some tags transmit data within several minutes of one another, leaving a larger time gap for subsequent communications.

This trial has evidenced that 20 tags may allow for rapid intervention/prevention of livestock theft, the tracking and interruption of stolen livestock, and the recovery of stolen livestock.

However, less tags would mean less data and therefore greater limitations on law enforcement capacity to succeed in stage 2 of the trial, tracking and interruption, as the ability to track and intervene in transit is heavily dependent on the flow of GNSS location data. Stage 1, rapid intervention, would be possible with very few tags, particularly if the farmer responds to the HAA. Stage 3 of the trial, recovery, would also be successful with few tags. However, again, the time to recovery would be increased as law enforcement must wait for location data/ confirmation the livestock has stopped moving. Naturally, the more tags the more data and thus the better opportunity to prevent, track, intervene and recover due to the data reporting times of tags throughout a 24-hour period. Yet, even few Ceres Tags appear to significantly increase the capacity to secure livestock.

There are also limitations pertinent to the study itself. Namely, while the farmer and police acted on the data coming from the tags, the mock-theft was staged and controlled in phases necessary to evaluate the tag and 'test' for particular capacities including rapid intervention/prevention, tracking and interrupting and recovery. In a real-world scenario a number of variables could impact the outcomes. For example, in this case the theft event occurred during the day. Conversely, if the theft event were to occur at night the farmer may be delayed in responding to notifications and the police may have greater difficulty in tracking the thieves due to visibility etc. Additionally, the police utilised in this trial are experts in crimes which impact upon the agricultural, pastoral and aquacultural industries and therefore have significant industry knowledge and experience relevant to responding to rural crimes such as livestock theft. Ideally, future research should seek to understand and evaluate Ceres Tag in a non-controlled environment, including understanding real-world use from the perspective of farmers and landholders as they adopt Ceres Tag.

So What? Understanding and Responding to Livestock-Theft

Turning up the Risk

Rational choice theory suggests that offenders evaluate perceived risks, gains, needs, apprehension possibilities, punishment possibilities, and specific factors regarding the situation and target. Offenders then rationalise whether the reward is worth the general risk or if the fear of being caught and punished outweighs the perceived gains. Routine Activity Theory suggests that crime occurs when a motivated offender meets a suitable target. A motivated offender refers to the temptation of those who are inclined to commit crimes, while a target refers to the characteristics of an object, property, or person which engender provocation or perceived opportunity. The choice and attractiveness of a target depends on its value, visibility, accessibility, transportability, and the absence of a capable guardian. For example, an offender will target high market value items which are easily identifiable, accessible, and transportable, and of which there is minimal risk of being caught. While the actual decision to commit a crime is weighed by considerations such as offender background factors, previous experience, and learning, evaluated solutions, perceived solutions, and readiness, we can readily apply this more broadly to the rural environment and livestock theft more specifically.

Livestock theft is a high-reward and low-risk crime for motivated offenders, particularly those with cultural and industry-based knowledge (e.g., how to muster and load cattle). Cattle are economically lucrative, and increasingly so, and the vast wide-open expanse combined with a scarcity of formal (police) or informal (citizens) guardianship means little likelihood of being caught or punished, and difficulties with implementing physical crime prevention measures (i.e., target hardening). A guardian is someone or something capable of preventing a crime, either actively or through mere presence, including, for example, police, security guards and neighbours and also includes physical measures such as locks, signage, and alarms. With respect to formal guardianship, the sheer distances between settlements and properties are much greater than in urbanised environments, and local policing presences are much sparser. Considering informal guardianship, one mechanism to increase the risk of offending is through natural surveillance based on the notion that a busy city-street is apt to be a safe street as people are around to witness and intervene in crime, thus deterring such behaviour. Yet, in the rural environment, the risk/reward calculation made by a potential offender is often skewed to them favourably as there are a myriad of valuable assets on farms yet eyes and ears in the paddock are few and far between resulting in an absence of both formal and informal 'guardianship'.

Regarding physical measures, culturally may be more relaxed attitudes to security and there are practical and technological limitations which inhibit the ability of farmers to target harden. For example, it is not always practical to lock gates which are used regularly in the course of work and, often, by a number of individuals. Likewise, technological innovations now regularly employed in urban environments, such as CCTV, may be limited by connectivity and the vastness of space needing to be covered. When taken together, the rational choice for offenders is to steal livestock given the attractiveness and suitability of targets.

There is no shortage of motivated offenders who possess the practical and cultural knowledge necessary to undertake these crimes and they are well aware of the current limitations on farm crime prevention and thus tempted and provoked by the perceived criminal opportunities. In terms of social density in rural communities, while strong social bonds have been shown to mitigate crime, for example through increased informal social controls, others have highlighted that these same tight-knit acquaintanceship networks may facilitate crime and criminal networks; this, again, is particularly relevant when we consider the likelihood of offenders having some level of industry and socio-cultural knowledge in undertaken these offences.

Together, these elements combine to create a criminogenic environment that is dependent upon local characteristics (i.e., the presence of livestock) yet is vastly different than an urban environment in terms of types of offending, opportunities for offending and in preventing and responding to crime. This, however, is not to suggest that crime prevention theory, tools and techniques cannot be applied on farms, only that we must consider the characteristics of rural spaces and, more

specifically, the ways in which locational context and cultural geography impact upon the types and incidences of crime, the ability for prevention, intervention, and response, as well as access to related services.

Ceres Tag is one such tailored intervention that offers a solution to many of the problems with preventing crime in rural spaces identified above. Ceres Tag offers the opportunity to increase the risk of criminal behaviour, in an often-riskless space. More specifically, the tag provides for guardianship through technological innovation and serves to target-harden livestock. Theoretically, would-be offenders are less likely to steal livestock tagged with Ceres Tag and more likely to move on to a softer target owing to perceptions of risk around being caught. Connected to this, while not measured in this trial, Ceres Tag may also offer the opportunity for proactive prevention by increasing the offenders perceived risk of detection. Specifically, in addition to extending guardianship and target hardening through surveillance, the tag also provides opportunities for territorial reinforcement; promoted by clarifying boundaries and defining ownership. For example, this can be reinforced in several ways, but one example is with signage which communicates to offenders that the livestock in question is tagged with Ceres Tag and, as such, property owners will be alerted to theft, and thieves tracked etc., thereby introducing risk into a would-be offender's decision-making process to steal livestock tagged with Ceres Tag.

Figure 12 Ceres Tag sign

Increasing Timely Reporting

Farm crime research has consistently identified a significant 'dark figure' of rural crime (Mulrooney, 2021). Specifically, many farmers indicate being repeated victims of crime but also that they do not regularly report that victimisation to the police. This is a fundamental problem in combatting livestock theft. Most obviously, if police are unaware of crimes they are unable to respond. However, a lack of reporting also weakens the available intelligence for police decision making. For example, if four farmers within a particular radius have been victims of theft over a given month, the police may not be able to solve the individual crime but with such intelligence they may identify opportunities for proactive intervention. Without this information, the police remain unaware and in the dark.

Farmers give many reasons for their lack of reporting, including: a lack of confidence in the police capacity to solve the crime; a lack of evidence or proof; inability to prove property has been stolen and uncertainty over whether a crime has occurred. Ceres Tag addresses these issues and that of underreporting more broadly. First and foremost, the time it takes for farmers to become aware of stolen livestock can range from days to months. With Ceres Tag farmers are notified of an 'issue' nearly immediately with HAA and PEA notifications. This provides the farmers with evidence and greater certainty of a crime occurring and dramatically reduces the time it takes to report the crime to the police. With this timely report police are better positioned to respond t the theft of livestock.

Improving Police Capability and Community Confidence

Research has identified that the relationship between farmers and the police is strained (Mulrooney, 2021; Harkness, 2021). This is, in part, the product of the environment in which rural crime takes place, outlined above, which often leaves the police attempting to solve crimes such as livestock theft with very little in terms of evidence. At the same time, farmers are left frustrated by the unlikelihood of a positive outcome or solution, and they often experience this scenario repeatedly. Given this, it is no surprise that farmers tend to express low satisfaction in the police generally and a lack of confidence in the police capacity to solve the crime of livestock theft. While this has been improved by the introduction of the NSW Police Force RCPT in the state of NSW (see Mulrooney, 2021), the police themselves identify limitations on being able to respond to crimes which may have occurred long before they were ever notified and/or have little in the way of evidence from which to begin an investigation.

Ceres Tag may not only provide farmers with a greater sense of security and peace of mind, but improvements in the ability of the police to prevent and intervene in livestock theft may contribute to an increased confidence in the police to respond to livestock theft and, by extension, an increased likelihood of reporting crime to the police.

Preventing, Interrupting and Reducing Livestock Theft

In this mock trial, the Ceres Tags performed positively across all three stages of intervention tested. Specifically, Ceres Tag provides the opportunity for rapid intervention/prevention into the theft of livestock, thanks in large part to accelerometer data and subsequent HAA. Additionally, PEA informs the farmers of any paddock breaches. Evidently, rapid intervention is possible and, at the very least, the time to awareness of theft and reporting has been reduced to minutes from what has historically been days, weeks and even months.

The trial was also able to confirm the capacity of the Ceres Tag to track stolen livestock and interrupt on route. The GNSS location data provided by the Ceres Tag, along with associated alerts, allowed the RCPT to coordinate a law enforcement response to track and interrupt the theft of the stolen livestock on three separate occasions. Finally, GNSS location and associated alerts allowed law enforcement to determine whether or not the stolen livestock was in transit or had stopped and subsequently to coordinate an intervention for recovery at the determined location.

When taken together, Ceres Tag offers a promising technological tool through which farmers and landholders may prevent the theft of livestock while also offering law enforcement officers a significantly improved capacity to interrupt in livestock-theft and recover stolen livestock.

As such, the widespread application of Ceres Tag could be a significant ‘game changer’ in the livestock theft space and for farm security more broadly. This technology greatly shifts the risk of rural offending, making the act much more difficult to complete, while also significantly improving our capacity to prevent and rapidly intervene in livestock theft, track and interrupt the theft of stolen livestock, recover stolen livestock, and the ability of the police to solve such crimes more broadly.

Figure 13 (Page 25) Mock theft trial underway; Photo credit Matthew Cawood

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