Livestock mustering with drones

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Executive Summary

This report explores the transformative potential of drone technology in livestock mustering, highlighting its benefits, challenges, and practical applications. Through comprehensive research and multiple field trials across diverse terrains and livestock species, the study demonstrates the efficiency, safety, and economic viability of integrating drones into traditional mustering practices.

Key Findings:

1. **Technological Advancements:**
    - Utilisation of advanced drones such as the DJI Matrice 30T and DJI Mavic 3 Pro, equipped with thermal and zoom cameras, proved effective in locating, starting, and herding livestock.
    - Drones offered enhanced precision and efficiency compared to traditional methods, such as helicopter mustering.
2. **Trial Outcomes:**
    - Nineteen mustering trials conducted across nine properties demonstrated significant reductions in livestock stress and lower operational risks for graziers.
    - Drones were effective in a variety of conditions, showcasing their versatility and reliability.
3. **Economic Benefits:**
    - Economic analysis indicated that drone mustering can be a cost-effective alternative, with potential savings in operational costs and time.
    - The introduction of more affordable drone models, such as the DJI Mavic 3 Enterprise Thermal, increased the return on investment, making drone technology accessible to a broader range of producers.
4. **Regulatory Considerations:**
    - Navigating the regulatory framework for drone operations remains complex and time-consuming.
    - The report advocates for industry and government collaboration to develop practical regulations that support the broader adoption of drone technology, especially for extended and beyond visual line of sight (EVLOS and BVLOS) operations.
5. **Global Insights:**
    - International travel to Asia and the United States, and participation in the Global Focus Program, provided valuable perspectives on global agricultural practices and technological advancements.
    - A drone was amongst the luggage during the Global Focus Program and an opportunity presented itself in Argentina to muster some dairy cows. See video here.
    - Engaging with international stakeholders highlighted the importance of global collaboration in advancing drone mustering practices.

Recommendations:

1. **Industry Adoption:**
    - Implement awareness campaigns and seek government support for regulatory changes.
2. **Research and Development:**
    - Continue research into the benefits of drone mustering and explore new applications for drones in agriculture.
3. **Training and Skill Development:**
    - Develop comprehensive training programmes and offer both online and face-to-face training.
4. **Economic Analysis and Support:**
    - Conduct cost-benefit analyses and advocate for financial incentives to support drone investment.
5. **Regulatory Framework:**
    - Develop practical regulations and provide compliance support.
6. **Collaboration and Networking:**
    - Foster international collaboration and build local networks for knowledge sharing.

The integration of drone technology in livestock mustering presents a significant opportunity to enhance efficiency, safety, and productivity in the agricultural industry. The findings and recommendations in this report provide a roadmap for the successful adoption and implementation of this innovative technology. Continued innovation, supportive regulatory frameworks, and effective training are essential to fully realise the benefits of drones in livestock management.

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Foreword

When I sit and reflect on the three years between being awarded the scholarship and writing this report, I see huge growth. I've mentioned to Jodie Redcliffe (Nuffield Australia CEO) several times that being awarded a Nuffield Scholarship gave me credibility, momentum, and the confidence to attract support from large government and industry organisations to research my topic.

I like to be open about the fact that I was not successful on my first attempt at receiving a Nuffield Scholarship. I made it to the national interviews in 2020, and on the day of the virtual interview, I simply wasn't organised and prepared enough (although I blame daylight savings). When I applied again the next year, I was not only better prepared, but I had also continued over those 12 months to pursue my topic through research and self-funded trials. A Nuffield Scholarship has never been about adding an extra line to my résumé or dropping it at dinner parties for street cred; it has been a genuine opportunity to leverage a powerful network to assist with the awareness and adoption of a solution I believe can bring benefits to our industry.

Early in my research period, I discovered that I could provide more value and insight by refining my original plan. Initially, my ambitions for the scholarship were to explore a broad range of technology in agriculture. However, I soon realised that this broad focus would dilute the potential impact of my research. By honing in specifically on mustering livestock with drones, a relatively novel solution, I found that there was a significant amount of unexplored territory. This refined focus allowed me to delve deeper into the practical applications and benefits of drone technology in livestock management, providing more precise and valuable insights.

Table 1. Travel itinerary

Travel date	Location	Visits/contacts
May 2022	Oakleigh, Upper Pilton, Qld	Trial site
May 2022	Norlands, Julia Creek, Qld	Trial site
June 2022	Abbotsford, Hughenden, Qld	Trial site
June 2022	Malakoff Station, Cloncurry, Qld	Trial site
July 2022	Rodgers Creek Feedlot, Warwick, Qld	Trial site
July 2022	Tumbar Station, Jericho, Qld	Trial site
August 2022	Avington, Blackall, Qld	Trial site
September 2022	Redland Park, McKinlay, Qld	Trial site
April 2023	Hong Kong	Trade Investment QLD, DJI (virtual), manufacturing
April 2023	South Korea	Technology

April 2023	Japan	Trade Investment QLD, technology, manufacturing
September 2023	California, USA	San Francisco, Stamford University, Carissa Koopmann Rivers, Chandler Farms
September 2023	Las Vegas, USA	Commercial UAV Expo
September 2023	Argentina	GFP
September 2023	Ireland	GFP
September 2023	France	GFP
October 2023	Poland	GFP
~~**October 2023**~~	~~Israel~~	~~Technology~~

Acknowledgments

I would like to extend my deepest gratitude to PSP Investments, my primary sponsor, for their unwavering support throughout my Nuffield Scholarship. Their commitment to advancing agricultural innovation has been instrumental in making this research possible. Additionally, I would like to thank Meat & Livestock Australia (MLA) and the Queensland Department of Agriculture and Fisheries (DAF) for their invaluable support, particularly for the domestic trials.

I am grateful to James Walker, Sonya Comiskey, and Jodie Redcliffe from Nuffield Australia for their guidance and encouragement. Your support has been crucial to my journey.

A special thanks to Tim McGrath, who's advanced stockmanship knowledge has greatly enhanced my research. I am also deeply thankful to John McGuren and Darryl Heidke from MLA for their continued belief in and support of my work.

I owe a great debt of gratitude to my parents, who have always encouraged their children to follow their passions, and to my three sisters for their unwavering support.

In this project, SkyKelpie Pty Ltd is referred to as it was the entity through certain aspects of the research was conducted. This context is important as the scholar, Luke Chaplain, carried out the research under the auspices of SkyKelpie. This arrangement was essential for managing tasks such as obtaining regulatory approvals and conducting drone operations. By leveraging the resources and infrastructure of SkyKelpie, the project was able to utilise advanced drone technology and adhere to necessary compliance requirements, ensuring the validity and success of the trials.

I would also like to acknowledge everyone who opened their front gate and allowed me to have a crack at mustering their livestock with a drone. To the new and growing community of SkyKelpie clients, the early adopters who are helping to progress this solution as much as I am, and to anyone who has ever given me encouragement—thank you.

Pioneering a new method in an age-old industry has not always been easy, but it has been a dream come true. There's still have plenty to do, and I am excited about what the future holds.

Abbreviations

UAV	Unmanned Aerial Vehicle
RPAS	Remote Piloted Aircraft System
GPS	Global Positioning System
BVLOS	Beyond Visual Line of Sight
VLOS	Visual Line of Sight
R&D	Research and Development
DAF	Department of Agriculture and Fisheries
MLA	Meat & Livestock Australia

Objectives

This report aims to provide a comprehensive analysis of drone mustering, focusing on its practical applications, regulatory considerations, and potential benefits. By concentrating on specific aspects of UAV technology in livestock management, the research seeks to offer valuable insights and recommendations for industry stakeholders. The key objectives of this study are to:

- Use the latest technology to trial drone mustering on varied terrain and livestock species (cattle, sheep, and goats).
- Analyse the regulatory framework influencing the adoption of drone mustering.
- Explore the economic benefits of drone mustering.
- Develop recommendations for the further development and adoption of drone technology in the livestock sector.

Introduction

There is an opportunity for drones to eclipse traditional methods of helicopter mustering by making it cheaper, safer, and more productive, positively impacting both the environment and animal welfare. While drone mustering is currently practised on Australian livestock operations, the technology used is often quite basic. Consequently, the full potential of this emerging technology has not yet been realised.

The use of drones in livestock mustering has gained significant attention in recent years. Research conducted by the University of New South Wales (UNSW) Canberra, in collaboration with Charles Sturt University, explored the stress levels in sheep when mustered by drones compared to traditional methods. Their findings indicated that drones could reduce stress in sheep, as evidenced by lower heart rates, and improve overall animal welfare (Yaxley et al., 2021). The study also examined effective drone manoeuvres and sought to make the technology more user-friendly for farmers through artificial intelligence enhancements.

A significant portion of the research and trials were conducted in Australia, recognising that aerial mustering is uniquely integral to the country, with over 10 million head of livestock mustered by helicopter each year. The focus on domestic research was crucial, given Australia's distinctive landscapes and the unique opportunities they offer for advancing UAV technology in livestock management. However, the international travel undertaken as part of this scholarship was invaluable. It provided critical insights into emerging technologies and regulatory frameworks in other countries, offering a broader perspective on how these advancements could be adapted and integrated into the Australian context to enhance efficiency and effectiveness in aerial mustering.

It is important to acknowledge that this was not a completely novel solution when conducting this research. Graziers have been experimenting with drone mustering since the technology emerged. This research however is unique, potentially on a global level, with the variety of terrain and livestock species, and ability to measure effectiveness through a stockmanship lens.

This project used the latest in drone hardware and software to demonstrate that drone mustering is a viable solution that will greatly benefit livestock producers and the industry at large. Nineteen different mustering trials on nine separate properties were conducted on various land types and the most common livestock species: sheep, cattle, and goats. By focusing on practical applications across diverse terrains and livestock, this report aims to provide a comprehensive analysis and highlight the significant benefits of advanced drone mustering.

This research builds on foundational studies by offering an in-depth examination of drone mustering's practical implementation. Specifically, it will:

- Trial drone mustering on diverse terrain and livestock species, including cattle, sheep, and goats.
- Analyse the regulatory frameworks affecting drone adoption in livestock management.
- Explore the economic benefits of drone mustering.

- Develop recommendations for further development and adoption of drone technology in the livestock sector.

By addressing these objectives, this report seeks to offer valuable insights and practical guidelines for farmers and industry stakeholders, advancing the understanding and adoption of drone technology in livestock management.

Drone mustering trials

RPAS description

The trials utilised the latest and most appropriate drone technology available at the time. Given the rapid pace of technological advancement, particularly in the drone sector, this technology is expected to become outdated more and more as this report gets older. Continuous innovation is anticipated to bring even more efficient, cost-effective, and capable solutions to the market.

DJI Matrice M30T

The DJI M30T combines the powerful and intelligence of the DJI Matrice 300 RTK into a portable, foldable, and lightweight body. This new all-in-one solution allows organisations and pilots to gain new efficiencies with the new fully remote fleet management system and the autonomous docking and recharging station (sold separately). The future has arrived with DJI's latest transformational technology.

The DJI M30T is integrated with multiple high-performance sensors (12MP Wide Camera, 48MP Zoom Camera, 640 x 512px 30fps Thermal Camera and a 1200m Laser Range Finder) in an IP55 certified lightweight body. The M30T is controlled through the all new DJI RC Plus enterprise remote controller with the newly upgraded DJI Pilot 2 which has undergone significant changes for efficiency and greater flight safety.

Figure 1: DJI M30 RTK (unmodified) (source: DJI)

Command and Control

The DJI RC Plus operates on the four antenna OcuSync 3 standard, (2.4 – 2.4835 GHz and 5.725-5.850 GHz), has a maximum control distance of up to 8 km (CE) and supports Wi-Fi and Bluetooth functions. The remote controller is equipped with a 7-inch bright, dedicated screen that has the DJI Pilot 2 app built in, significantly improving

smoothness and stability. This controller can support RTK with an attached dongle or tether, however Sky Kelpie did not use RTK for this operation.

Figure 2: DJI RC Plus (source: DJI)

DJI Pilot 2 & DJI FlightHub 2

Pilot 2 works seamlessly with the DJI RC Plus. Screen side and customisable buttons are all within reach and enable quick operations, such as adjusting camera views and dropping Pinpoints. Drone and payload controls can be easily accessed with one tap. Clear presentation of flight details and navigational information improves user experience and flight efficiency.

FlightHub 2 is an all-in-one cloud-based drone operations management platform that helps you achieve comprehensive, real-time situational awareness. Access all the information you need to plan drone missions, supervise your fleet, and manage the data you create, now from a secure cloud-based environment. The powerful mapping capability can easily distinguish mustering zones and operations can be viewed live anywhere in the world with the software's livestreaming.

Link of video feed on drone

Figure 3: DJI Pilot 2 & DJI FlightHub 2 (source: DJI)

LP12 Spotlight & Speaker

The LP 12 Searchlight and Broadcasting System takes the DJI M30T to the next level for day and night operations.

With a lightweight design of 270g, a streamline aesthetic, wind-resistant design, sound distance of 200m, and illumination of 100m, this small piece of technology proved to be extremely helpful in certain mustering situations. Through simply connecting the speaker to a computer, we uploaded customs sounds such as helicopter noise, dog bark, human voice and different types of music to aide our mustering operations.

Figure 4: LP Searchlight & Broadcasting System (source: DJI)

DJI Mavic 3 Pro

The DJI Mavic 3 Pro is a multi-rotor drone with a maximum take-off weight of 895g. It has dual IMU and a single barometer and compass for positioning with an approximate position accuracy of 2.5cm. The Mavic 3 Pro also comes with a real-time FPV camera and ten obstacle avoidance vision sensors, that transmit potential obstacle locations and distances (approximated) back to the RP and, unless disabled, will automatically prevent the RPA being flown into a perceived obstacle. The Mavic 3 Pro has a diagonal

wheelbase of 38cm. Quite a dynamic and nimble drone that easily gets under the tree canopy to muster stock. The transmission link on this more affordable drone was at times better than the M30T.

Figure 5: DJI Mavic 3 Pro (source: DJI)

Command and Control

Offering powerful performance, DJI RC Pro is designed for professional-level aerial photography. Thanks to the next-generation processor and increased storage capacity, DJI RC Pro works more stably and smoothly. It comes with the powerful O3+ video transmission technology and adopts the same control sticks as DJI FPV, offering a precise, ultra-smooth control experience.

Figure 6: DJI RC Pro (source: DJI)

Flight Classes

VLOS (visual line of sight)

VLOS conditions means that the drone during the entire flight mission must be clearly visible by the drone operator without any additional aid-equipment such as binoculars, FPV goggles etc. The operator monitors the area and controls the UAV to avoid any collisions or obstacles.

EVLOS (extended visual line of sight)

EVLOS occurs when the drone is flown beyond the pilot's visual line of sight but at least one visual observer is VLOS with the drone or knows the exact location of it. Essentially, the observer must be able to clear the air and ground environment around the drone so careful selection of the observer's location is critical in the planning of any EVLOS operation. Unlike VLOS requirements, the observer can use devices such as binoculars to observe the operating area but must not use these devices as the primary means of keeping the surrounding airspace and ground insight. CASA has divided EVLOS operations into 2 classes:

Class 1

Class 1 is where the pilot and visual observer are at the same location. This allows the pilot to use a first-person view (FPV) system to fly the drone while a visual observer clears the operating air and ground environments more accurately. A FPV system reduces the visual cues and restricts the user's peripheral vision, so for these reasons they cannot be used by the observer or in place of an observer. As the pilot and visual observer are standing next to one another, the increase in planning and operating workload should be easily managed. Communication between the operating crew is not reliant on any communication system as it must be verbal, and they can both view a common display, so knowing the exact location of the RPA is uncomplicated. In the event of a fault with the RPA, it should be possible to quickly bring the RPA back into VLOS operations. Hence class 1 is a great introduction into EVLOS operations and will significantly extend the range of operations depending on the operating location characteristics. Class 1 operations would not be suitable where the observer's view of the ground environment is blocked by buildings, trees or other features.

Class 2

Class 2 is where the pilot and visual observer are in different locations. This allows the drone to be flown at much greater distances from the pilot as multiple observers can be used. It also allows greater flexibility over the observer location, thereby making it easier to position the observer where their view is not obstructed by buildings, trees, etc. However, this could now be the most complex operation with the need for all crewmembers to be highly trained and proficient in their duties. Communication between crewmembers will be performed over a radio or telephone system so there is a higher probability of miscommunication. Although crewmember's situational awareness can be aided by shared displays showing the drone's location, these can be subject to network outages and delays, so their accuracy needs to be constantly confirmed by good crew coordination. Drone faults and failures may now occur at much greater distances from the pilot so the time available to solve these issues may be significantly reduced. A well-thought-out and planned Class 2 EVLOS operation can provide efficiencies and significantly reduce the time taken to complete a task, but it

carries more risks to mitigate than VLOS operations. EVLOS does not allow the drone to be flown in cloud or in visibility below 5000m, but it will also not require expensive detect and avoid systems. The pilot is still responsible for ensuring that the drone is not flown within 30 meters of non-consenting people or over populous areas.

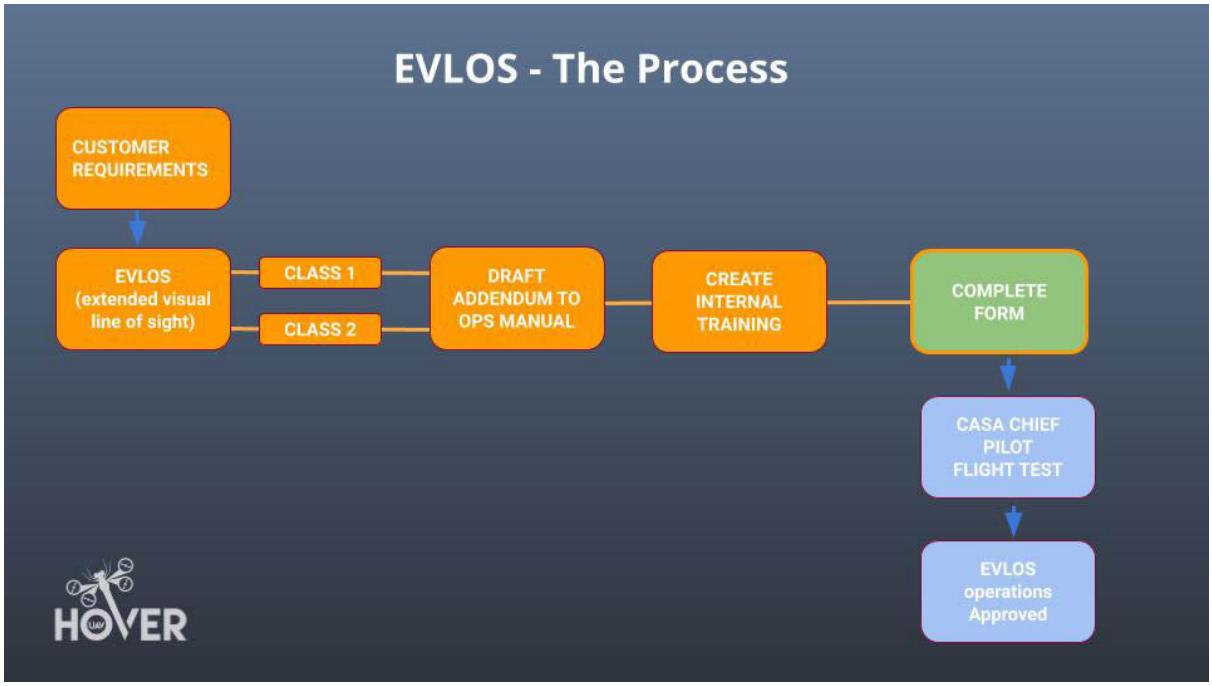

Figure 7: EVLOS - the process (source: Hover UAV, 2018)

BVLOS (beyond visual line of sight)

Beyond Visual Line of Sight (BVLOS), refers to operations where the person or people responsible for operating the drone cannot physically see it during some or all its flight. The process of obtaining permission to fly BVLOS in Australia is complex and time consuming. SkyKelpie successfully acquired approval under its Remote Operators Certificate (ReOC) to fly BVLOS operations at two sites, Malakoff Station and Norlands Station. Some tasks that were required during this difficult process included:

- Develop a concept of operations
- Develop operational area
- Assess the airspace and population within and adjacent to the operational area
- Use the specific operational risk assessment (SORA) process to determine an overall risk level for the operation based on the air and ground risk, and implement strategic mitigations
- Use the overall risk level to determine the level of robustness required for the operational safety objectives that ensure the operation meets the required level of safety
- Create general and site-specific BVLOS operational procedures
- Create training as required (e.g., type of flight or ERP training)
- Submit an application to the National Aviation Authority (NAA) of your country (e.g., CASA)

- Conduct assessments with CASA as required, as this was an in-person flight test

Furthermore, there are licensing requirements for pilots conducting BVLOS operations. Like all operations under a ReOC, pilots must have acquired a Remote Pilots Licence (RePL). In addition to a RePL, pilots flying BVLOS operations must have completed a company training course and hold an Instrument rating (IREX) or be supervised by a pilot who holds an IREX. *(Hover UAV, 2022)*

Figure 8: BVLOS Process (source: Hover UAV, 2022)

Trial sites

Under each trial site is information about the sites and operation that was conducted. There is also a rating for effectiveness of trials which are:

- Grazier's evaluation of trial, from a scale of 1 being not effective at all, to 10 being extremely effective
- Grazier's evaluation of trial, compared to current methods used. From a scale of 1 being not effective at all, to 10 being extremely effective
- SkyKelpie's evaluation of the mustering trial, from a scale of 1 being not effective at all, to 10 being extremely effective

Oakleigh

Location: Upper Pilton, Qld.
Property size: 490ha
Number of paddocks mustered for trials: 2
Size of paddocks mustered: 80ha, 100ha
Land type: Hilly, rocky, timbered, cultivation

Flight class: VLOS
RPAS: Mavic 3

Livestock type: Dry heifers, 18 months old

Oakleigh was the first property SkyKelpie mustered on as part of the trials. Using just the Mavic 3, while the M30T was on order and slightly delayed due to logistical problems with the manufacturer, the compact and nimble drone was ideal for the trial. Not being large paddock sizes, the 28x zoom worked well in locating the cattle. These cattle had never been mustered by a drone before and they moved quite well in the desired direction. The purpose of this muster was to move the animals onto new pastures for land and animal management purposes. The usual method for this practice at Oakleigh is by motor bike which can be quite dangerous given the terrain. Some surveillance of the property was also conducted such as checking dam levels, water troughs and fences.

Effectiveness of trial: 8
Compared to current methods used: 9

SkyKelpie rating: 8

"The country at Oakleigh can be quite dangerous on a bike, so it was amazing to see the drone could achieve the same outcome." – Jamie Ferguson, Manager.

What other purposes do you think drones could serve on your operation other than mustering?

"It would be great for surveillance of many things, crops, erosion and other land management, stock, waters, and fences. After our experience with this trial, I'm absolutely going to buy a drone." – Jamie Ferguson, Manager.

Footage of the Oakleigh trial can be viewed in Appendix 1

Abbotsford

Location: Hughenden, Qld.
Property size: 8,093ha
Number of paddocks mustered for trials: 2
Paddock sizes: Redcliffe Paddock, 1,821ha | Shed Paddock, 2,428ha
Land type: Mitchell grass downs with heavy infestation of prickly acacia

Flight class: VLOS & EVLOS Class 1
RPAS: M30T & Mavic 3

Livestock type: Sheep

- Redcliffe Paddock, 1100 ewes and 850 lambs
- Shed Paddock, 170 ewes

Abbotsford was the first trial site that the M30T was used. The first paddock mustered was Redcliffe. Both drones were used and proved helpful in locating sheep. The drone operator went out with the rest of the mustering crew which was one of the key learnings of this exercise. The operator should have gone out earlier to get their bearings and start to locate the animals before ground crew arrived. There was a mixture of other elements that impeded the drone's effectiveness and therefore gave useful learnings at an early stage of the trials. These included knowledge gaps in technology and the operator's lack of experience with sheep and flight time limitations. Accounting for all these obstacles, the drone was still useful in bringing the sheep together as a mob and checking the paddock to make sure all stock were accounted for.

Shed Paddock was mustered after lunch on the same day using both drones. This was conducted with just two ground staff as we were cleaning up the paddock due to missing approximately 170 ewes when they mustered the week before. The landowners were quite impressed at how quickly the drones were able to scout the paddock and find the missing sheep. Once the sheep were located by the drones, ground staff walked the ewes to the yards.

Effectiveness of trial: Redcliffe Paddock 6/10. Shed Paddock 8.5/10.
Compared to current methods used: Redcliffe Paddock 7/10. Shed Paddock 9/10

SkyKelpie rating: Redcliffe Paddock 5/10. Shed Paddock 8.5/10

"It was helpful to know that Luke could do a sweep behind us to know that we hadn't missed a small mob. It was also helpful near the dam when I couldn't get buggy across a creek with thick trees in it and he could do a sweep and make sure sheep were still coming into the dam." - Anita McNamara, Landholder.

What other purposes do you think drones could serve on your operation other than mustering?

"Land condition scoring, monitoring maremma dogs, especially when they first go out into a paddock, looking for stragglers or small mobs of sheep or cattle in a large paddock." - Anita McNamara, Landholder.

Footage of the Abbotsford trial can be viewed in Appendix 2

Rodgers Creek Feedlot

Location: Warwick, Qld.
Property size: 1,011ha
Number of paddocks mustered for trials: 1 + surveillance of 3
Paddock sizes: Sandalwood, 100ha
Land type: Hilly, rocky, scrubby

Flight class: VLOS
RPAS: M30T

Livestock type: Dry cattle

Being a small paddock, this mustering exercise was achieved under VLOS conditions with one set of batteries. The thermal camera was extremely useful in locating the cattle compared to the wide and zoom cameras due to the foggy and wet conditions. The livestock had never interacted with a drone before and responded well.

It was good to trial at such an intensive operation to discover what other use cases might be applicable to drones. The convenience of mustering small paddocks is certainly an application. Also, asset and livestock surveillance could be a legitimate use case. Checking waters, fences, sick animals and feed rations could save time, labour and provide valuable on-farm data. More drone testing should be trailed on similar operations, but SkyKelpie sees a place for them on intensive operations.

Effectiveness of trial: 9/10

Compared to current methods used: 7/10

SkyKelpie rating: 8/10

"Loved the thermal camera…I definitely would have missed cattle if I didn't use it." Ben Daley, Stockman.

Footage of the Rodgers Creek Feedlot trial can be viewed in Appendix 3

Avington

Location: Blackall, Qld.
Property size: 4,046ha
Number of paddocks mustered for trials: 3
Paddock sizes: Sandalwood, 1,214ha | Leopardwood, 275ha | Horse Paddock, 40ha
Land type: Open Mitchel grass plains, Gidgea channels, Buffel Grass Ridges with forest style timber

Flight class: VLOS
RPAS: M30T

Livestock type: Goats, 3000 head. Same mob in all paddocks, just at different stages.

The trials on Avington produced great results, with encouraging feedback from the landholders. Nat and Amy lean more towards low-stress stock handling, and they were pleased that the drone was able to achieve that. The goats moved off pressure from the drone well. A couple of times the speaker was engaged when the entire mob was moving in the wrong direction. They were quite responsive to the additional noise of the speaker, so it was important the operator didn't overdo it. The zoom camera was extremely useful in monitoring progress and allowed clear insights such as displaced kids and nannies stuck in the fence, without the drone needing to be close and further add stress to the animals. The horse paddock was the final paddock mustered before yarding up. When walking the mob along the fence, the drone handled most of the tail due to labour shortages that day. This was extremely useful as the drone could cover quite a lot of ground quickly and inform the other staff of any problems occurring with the rest of the mob. Goat handling experience of the drone operator was quite limited; but guided by the landholders and using basic stockmanship, the muster was conducted in a professional and timely manner.

Effectiveness of trial: 10/10
Compared to current methods used: 10/10

SkyKelpie rating: 9/10

"It was just as effective as usual mustering methods, but way easier and required less staff. The drone also put less stress on the animals than motorbikes." Natalie Curley, Landholder.

What other purposes do you think drones could serve on your operation other than mustering?

"Checking fences, flooded rivers, pumps, boats. Vermin location. Water checks. All sorts." Natalie Curley, Landholder.

Footage of the Avington trial can be viewed in Appendix 4

Redland Park

Location: McKinlay, Qld.
Property size: 16,187ha
Number of paddocks mustered for trials: 1
Paddock sizes: River Paddock, 1,268ha
Land type: Mitchell Grasslands, Gilliat River Channels

Flight class: VLOS + EVLOS Class 1
RPAS: M30T

Livestock type: 500 cows and calves

This paddock was started at first light, meaning the thermal camera worked extremely well for the first few hours of locating the cattle. Approximately 60 head were located at the back of the paddock and once they were started, they kept moving into water well. While progress of the muster was easily monitored with the zoom camera, the drone would check the channels. At one stage when the drone came back to change batteries, some of the cattle were moving away from the nearby water. Before ground staff on a motorbike reached the lead of the small mob, the drone slowly turned them back and settled them back on the water, much to the landholder's surprise. Once all cattle were mustered together, ground staff walked them to the yards. SkyKelpie was told that was the earliest they have ever experienced that paddock in the yards.

Effectiveness of trial: 10/10
Compared to current methods used: 10/10

SkyKelpie rating: 8/10

"Amazing, the drone blew me away. We don't usually use helicopters, but the river paddock is extremely difficult to muster on the ground. Drone mustering is a real game-changer." – Angus Brodie, Landholder.

What other purposes do you think drones could serve on your operation other than mustering?

"Checking waters/cattle, checking the property during wet season when limited road accessibility, weed management / aerial spraying." Hannah Brodie, Landholder.

Footage of the Redland Park trial can be viewed in Appendix 5

Norlands

Location: Julia Creek, Qld.
Property size: 10,117ha
Number of paddocks mustered for trials: 3
Paddock sizes: Prickly Paddock, 4,000ha | Shed Paddock 428ha | Channel Paddock, 1,400ha
Land type: Mitchell Grasslands, Open downs

Flight class: VLOS, EVLOS Class 1, EVLOS Class 2, BVLOS
RPAS: M30T

Livestock type: Dry cattle

- Prickly Paddock, 300 bullocks
- Shed Paddock, 80 bullocks
- Channel Paddock, 220 steers

It was great to be able to conduct EVLOS and BVLOS on Norlands as it was different land type and livestock to Malakoff, where those flight conditions were also conducted. Norlands has much more open downs, and the cattle are primarily older bullocks which can present more challenges. The cattle moved off the drone very well and congregated nicely into watering points. Three attempts at different locations were made to move cattle that were together as a mob off watering points and on their way to the yards. Two of these attempts were successful using the drone only, although it must be noted that one of those locations was assisted by a fence coming off the water. There was one failed attempt which meant ground staff needed to assist in successfully moving the cattle in the right direction. Attempts to do the same procedure with ground staff alone is historically difficult at this location, so compared against traditional methods, the drone performed well as the cattle responded well to both pressure from ground and air.

Effectiveness of trial: 7.5/10
Compared to current methods used: 9/10

SkyKelpie rating: 7/10

“We don’t have a huge problem finding the cattle on this open country, but the drone certainly made it easier on us. It saved us bouncing over the rough paddocks all the way to the boundaries and I thought the cattle responded quite well.” Patrick Chaplain, Landholder.

What other purposes do you think drones could serve on your operation other than mustering?

“Remote surveillance would be amazing as no one lives on the property. I understand there is remote monitoring technology currently on the market, but surveillance by a drone would give me a very broad view on assets, pasture, and livestock.” Patrick Chaplain, Landholder.

Footage of the Norlands trial can be viewed in Appendix 6

Malakoff Station

Location: Cloncurry, Qld.
Property size: 19,020ha
Number of paddocks mustered for trials: 6
Paddock sizes: Gidyee Paddock, 2,600ha | Top Paddock 5,000ha | River Paddock, 3,800ha | Mountain Bore Paddock, 2,000ha | Telephone Paddock 370ha | Horse Paddock, 230ha
Land type: Mitchell Grasslands, Open downs, timbered, rocky spinifex

Flight class: VLOS, EVLOS Class 1, EVLOS Class 2, BVLOS
RPAS: M30T & Mavic 3

Livestock type: Cows and calves, steers and heifers, weaners

- Gidyee Paddock, 600 steers and heifers
- Top Paddock, 600 cows and calves
- River Paddock, 500 cows and calves
- Mountain Bore Paddock, 500 cows and calves
- Telephone Paddock, 80 dry cows
- Horse Paddock, 12 stragglers, 8 horses

Malakoff was where the largest number of trials were conducted. This was due to the personal connection between SkyKelpie and the landholders and it being the site where BVLOS land approval was established.

Top, River and Mountain Bore paddocks were all breeder paddocks that had similar results. Cattle moved well off the drones and considerable time was saved. Being breeders there were some baby calves too young to walk to the yards. Traditionally

when mustering, baby calves and their mothers are left in the paddock. The zoom camera was successful in determining calves being too small from far enough away that the cow/calf units were not disturbed. Night mustering was conducted in mountain bore paddock which saw all the cattle mobbed together at sunrise, ready to be walked to the yards in the cool of the morning. Top paddock had a laneway to the yards which meant the drone could also drive the cattle to the yards. It's quite common to have trouble yarding up with these larger mobs, but assistance from the drone was hugely beneficial.

Gidyee Paddock is heavily timbered where young cattle are held. With the gidyee being so thick, the drone had to fly directly over all the timber in grids to successfully check for stock. This was more time consuming than utilising the zoom camera like other paddocks, but still greatly beneficial. Starting cattle in the paddock worked well with the drone, although ground staff had some trouble holding the cattle at the water. When they galloped away the drone had some difficulty bending them all around, as they were quite spread out. The drone was certainly useful at bringing the cattle back together, but it would have been more successful if the cattle were more educated or multiple drones were available. Besides a few hiccups, a clean muster was achieved, and it saved the landholder time and money.

The Telephone and Horse paddocks are smaller in size where VLOS operations were possible. These are transactional paddocks where different cattle are held at different times. The M30T was used to bring in fresh weaners from the horse paddock one afternoon with great success. They were brought together as a mob and manoeuvred through a couple of gates which was not an easy task. This demonstrated the power and effectiveness of the drone.

Effectiveness of trial: 8.5/10
Compared to current methods used: 9/10

SkyKelpie rating: 8/10

“It was good to put the drone to the test over different land types. It was hard to get used to how accessible and convenient the drone was…we’re usually forced to be organised and have the chopper booked in advance if we want to aerial muster.” Patrick Chaplain, Landholder.

What other purposes do you think drones could serve on your operation other than mustering?

“Surveillance of the property when it’s wet. Mapping out woody weeds.” Patrick Chaplain, Landholder.

Footage of the Malakoff trial can be viewed in Appendix 7

Tumbar Station

Location: Jericho, Qld.
Property size: 68,796ha
Number of paddocks mustered for trials: 1
Paddock sizes: 271ha
Land type: Sandy Loam, brigalow scrub soil, blade-ploughed 5 years ago

Flight class: VLOS
RPAS: M30T

Livestock type: 600 BrahX Weaner steers

It was a good opportunity to trial at Tumbar with Fred, as he has been a supporter of drone mustering for several years and represents genuine corporate interest in the solution. He was pleasantly surprised with how the cattle reacted to the drone, and how much control he had over them. These weaner steers have never been mustered by a drone before. The land type on Tumbar is well suited to drones as there is a lot of pulled scrub. This presents some safety concerns for ground staff, and efficiencies of musters are not always perfect as the animals usually have the upper hand. A very good result and don't be surprised if you see Georgina Pastoral Company rolling out this solution on their properties in the future.

Effectiveness of trial: 9/10
Compared to current methods used: 9/10
SkyKelpie rating: 9/10

"The drone was easy to operate, and I was surprised with how much control I had over the mob. I'm really impressed and firmly believe drones have a huge future in our industry". - Fred Hughes, Georgina Pastoral Company.

What other purposes do you think drones could serve on your operation other than mustering?

"Water runs, infrastructure planning, weed spraying, fence line/pipeline inspections." Fred Hughes, Georgina Pastoral Company.

Footage of the Tumbar trial can be viewed in Appendix 8

Mustering components

Locating, starting, and bringing the animals together as a mob.

This component is what current aerial helicopter mustering is most used for. The benefits are substantial for graziers and the industry at large. The ability of drones during these trials to locate, start and bring livestock together was exceptional. Locating the animals was made easy by the thermal and zoom cameras, technology that helicopter pilots do not have the luxury of. Starting livestock was a success due to the operator's livestock experience and technological know-how. Most of the livestock during the trials had no experience being mustered by a drone before, so a calm approach was used when placing pressure on them. The process of starting the livestock usually began with curiosity from the animals working out what the airborne device was, followed by moving in the opposite direction as pressure was gradually applied. It is quite a natural response for domesticated livestock to move towards their watering point when pressure is put on them in the paddock, but animals have a mind of their own and do not always follow this process. The drone was effective in guiding them in the desired direction.

There was a small number of occasions where the drone was not able to be in complete control; these situations included stubborn bulls and young cattle with limited education. Cattle with limited education tend not to respond to pressure as well as educated cattle, especially when that form of pressure is new to them. These events were controlled by the assistance of ground staff. Like helicopters when dealing with challenged stock, the ground staff were notified without issue and located the animals successfully. If connectivity in rural Australia improves, software like FlightHub 2 will allow for extremely effective communication between the drone and ground staff.

Footage of the sheep, goats, and cattle trials can be viewed in Appendices 9, 10, and 11, respectively

Driving the animals to and from the processing facility

SkyKelpie experienced success in driving livestock to and from the processing facility. The success of this component will doubtless differ from operation to operation depending on size of mobs, education level of animals, supporting infrastructure and skill level of the drone operator. These trials included several scenarios with different results. As can be expected, this component was more effective with supporting infrastructure such as fences and laneways. To some graziers' surprise, whole mobs were able to be controlled in open paddocks. SkyKelpie did not trial with multiple simultaneous drones but recommends this be considered for several mustering components to save time and increase efficiencies.

Using the drone to assist yarding up was trialled twice. The speaker was engaged at high volume playing the uploaded helicopter noise, which provided a noticeable difference when getting all the cattle in on the first attempt. The ability of the drone to keep the lead moving and making room for the incoming cattle was a significant help. Usually when yarding up a larger mob of cattle from that direction at Malakoff, several attempts are usually needed.

Additional footage of the cattle, goats, and yarding up trials can be viewed in Appendices 12, 13, and 14, respectively

Settling the animals back in the paddock.

It is important to settle animals into a paddock, so they are familiar where the water is (if entering a new paddock) and keeping the young animals paired with their mothers. The drone allowed the operator to have a clear aerial view of the mob and could apply pressure when necessary. The drone operator was able to complete this task on their own, meaning ground staff were free to complete other tasks on the property.

Night mustering

The concept of mustering livestock in the dark (early morning) was possibly the biggest 'lightbulb' moment of this trial. This was trialled on Malakoff Station using the thermal camera on the DJI M30T. It was conducted in three different paddocks on a combination of wet and dry cattle. SkyKelpie questioned if the situational awareness of cattle in the dark would be clear enough to take themselves to their watering point, the point at which they generally congregate when pressure is put on them. It was evident in all three paddocks that the cattle knew where they were going. There is evidence that Cows' eyes are built with an extra reflective layer behind their retinas known as tapetum lucidum, which allows them to detect lower levels of light than animals without one *(Can cows see in the dark? (And how they do it), Fauna Facts 2021)*. For the three-night musters, there was approximately 50% moonlight.

The benefits of night mustering could be a game-changer for the livestock industry. Mustering in the early morning means livestock are being moved in the coolest part of the day. This will have a positive impact on animal welfare and productivity.

Although these initial trials seemed promising, SkyKelpie would encourage further research into this method before declaring it a complete success. Further research/trials may include mustering in complete darkness (no moon), different land types and locations, and different livestock types. There are regulation barriers to this method as night flying in EVLOS and BVLOS conditions requires further permits and licencing.

Footage of the night mustering trial can be viewed in Appendix 15

Educating young cattle

SkyKelpie noticed a difference when working the same mob of freshly weaned young cattle with the drone over a week-long period. At first, they were quite flighty and confused by the drone, and by the end of the week they moved off pressure in a controlled and relaxed manner. Operations wanting to use drones for mustering should 'break in' their weaners with the drone to have a more controlled experience in the paddock.

Asset and stock surveillance

This application was limited by our drone's flight endurance and regulatory requirements, but it was evident that drones have a place for asset and livestock surveillance in agriculture. This was trialled on a more intensive operation in Southeast Queensland during wet conditions. Even through it was a smaller property, it was very convenient that the drone could provide insights on water levels of tanks and feed rations, as the wet conditions made it very difficult to get there by traditional means.

This was also trialled at Malakoff. Flight endurance was a disadvantage as the M30T is more suited to mustering, however the zoom camera proved useful for monitoring from a hover position. The ability of drones to monitor important assets in the northern grazing industry certainly affords multiple benefits.

Footage of the asset and stock surveillance trial can be viewed in Appendix 16

Predator monitoring/detection

This application was only trailed once during this project, but with great success. A sheep grazing property in Northwest Queensland was experiencing an extremely disruptive and stressful week due to a wild dog. The family owned and operated property of 15,378ha has exclusion fencing, meaning once the dog managed to enter the property, it was difficult to leave. While the dog was there it killed several lambs and inflicted noticeable stress on the herd.

Wild dogs are quite active at night, so SkyKelpie decided to search for it at approx. 9pm using the thermal camera on the M30T. The landholders had a calculated idea of the area we might detect the predator, and within minutes of launching the drone the dog was found on the edge of a herd it had bailed up in a corner.

SkyKelpie is not an expert in destroying predators, so cannot give advice on how this may be done, especially at night. From a detection perspective, thermal imagery worked as a useful tool in our trial. Predators can also be detected with the drone in daylight hours, however some animals such as wild dogs will blend into the countryside and the thermal camera is not as effective during the day.

Footage of the predator monitoring/detection trial can be viewed in Appendix 17

Regulatory framework

The regulatory requirements to conduct these trials were extremely complex and time consuming. The difficulty level of navigating this framework was increased due to SkyKelpie's lack of UAV regulatory experience, but this was relevant and constructive as very limited graziers have this knowledge also.

The Landholder Rule *(see Appendix 18)* is a section in the regulations that allows a landholder to fly their own drone on their own land without requiring licencing and permits. This is beneficial to certain applications but has certain conditions that limits the capability of livestock drone mustering.

SkyKelpie recommends industry works towards progression of the 'Landholder rule' for EVLOS and BVLOS operations.

The conduct of mustering/farming activities under the excluded category landowner permissions currently allows operations, with a UAV weighing up to 25 kg, to be conducted in compliance with the drone safety rules and standard RPA operating conditions requiring the RPA operator to hold an operator accreditation *(see Appendix 18).*

The current RPAS regulatory framework restricts the conduct of operations beyond the visual line of sight (BVLOS), including extended visual line of sight (EVLOS), of the remote pilot under the excluded category and therefore requires an RPA operator to hold an operator certification and obtain additional qualifications and implement administration requirements that (from a safety perspective) could be considered grossly disproportionate to the risk being treated, particularly in areas where the air and ground risk would be considered as 'very low'. The additional requirements include, but are not limited to:

a. For EVLOS Class 1:
(1) The RPA operator must hold a Remote Operator's Certificate (ReOC) *(see Appendix 18, Chapter 6)*,
(2) The Remote Pilot (RP) must hold a Remote Pilot's Licence (RePL) *(see Appendix 18, Chapter 7)*

b. For EVLOS Class 2 and BVLOS (in addition to subpara a):
(1) The Remote Pilot must hold or must be under the direct supervision of a person who holds an instrument rating qualification or accepted equivalency *(see Appendix 18, Chapter 5)*

SkyKelpie (in consultation with key stakeholders) are proposing a phased approach to developing and validating a flexible and safe RPAS framework to enable landowners (for mustering/farming purposes) to conduct operations beyond the visual line of sight of the remote pilot under a revised excluded category framework. Achievement of this may include:

a. Developing a standard scenario for excluded landowner beyond visual line of sight operations
b. Defining training and assessment requirements to achieve operator accreditation to conduct excluded landowner BVLOS operations (based on an approved standard scenario)
c. Development of automatic excluded landowner BVLOS area approvals through CASA approved flight safety applications
d. Development of CASA approved documented policy and procedures for the conduct of excluded landowner BVLOS operations
e. Development of a plain English Guides and checklists to assist landowners in applying for operator accreditation to conduct BVLOS operations

These proposed developments would occur in consultation with CASA. SkyKelpie respects and abides by all current regulations when conducting trials and flight operations.

Economic benefits

The economic evaluation of drone mustering, as detailed in *Appendix 19,* highlights several key findings regarding its cost-effectiveness compared to traditional helicopter mustering. The study assumes a scenario where a grazier purchases a drone to replace helicopter mustering services, maintaining the same level of efficacy. The main results are as follows:

1. **Cost Analysis**:
    - **Initial Investment**: The initial outlay for a drone, including the cost of training and licensing, totals $28,823.
    - **Operating Costs**: The operating costs are relatively low, with the drone costing $6 per hour to operate and labour costs at $60 per hour for the drone operator.
    - **Drone Lifespan**: The drone's lifespan is estimated at five years with no salvage value, and the battery life is approximately 250 hours, requiring replacement after 500 recharges.
2. **Scenario Evaluations**:
    - **Three 2000 ha Paddocks**: This scenario did not achieve a net positive value within the five-year period, showing a net present value (NPV) of -$3,677. However, if the initial outlay were reduced to below $25,146, it would become a viable investment.
    - **Three 5000 ha Paddocks**: This scenario proved more profitable, with an NPV of $34,041, a rate of return of 41%, and a payback period of three years.
    - **Maximum Battery Life Utilization**: Utilizing the drone for the total lifespan of three batteries resulted in a highly profitable scenario, with an NPV of $285,497, a 251% rate of return, and a payback period of just one year.
3. **Additional Advantages**:
    - **Operational Efficiency**: Drones offer increased timeliness and flexibility in operations, allowing for pre-mapping of musters and reducing delays caused by contracting helicopters.
    - **Safety and Environmental Benefits**: The use of drones reduces the risk of human fatalities or injuries associated with helicopter mustering and can lead to less stress on livestock by enabling predawn starts.

Appendix 2: Economic Evaluation of Drone Mustering

- **Drone Cost Assumptions**:
    - Drone cost: $24,673
    - Training & license: $4,150
    - Labour costs: $60/hour
    - Operating costs: $6/hour
    - Battery life: 250 hours (500 recharges)
    - Drone lifespan: 5 years

- **Mustering Scenarios**:
  - Scenario 1: Three 2000 ha paddocks, 2 hours mustering each, twice a year over 5 years.
  - Scenario 2: Three 5000 ha paddocks, 5 hours mustering each, twice a year over 5 years.
  - Scenario 3: Using the drone for the total life of three batteries (750 hours).
- **Investment Results**:
  - Three 2000 ha paddocks: NPV of -$3,677, 0% rate of return, >5 years payback period.
  - Three 5000 ha paddocks: NPV of $34,041, 41% rate of return, 3 years payback period.
  - Maximum battery life: NPV of $285,497, 251% rate of return, 1-year payback period.

This comprehensive analysis indicates that drone mustering can offer significant economic benefits under the right conditions, along with improvements in safety and operational efficiency. It should be noted that this analysis was conducted in 2022 and since then more affordable hardware such as the DJI Mavic 3 Enterprise Thermal has been released that would reflect an even better ROI.

Adoption recommendations

With this solution and technology, it is important that livestock operators visually see that it is possible. Whether through live demonstrations or video evidence, the operational requirements will seem less intimidating when the success of livestock drone mustering can be viewed. The results of these trials should contribute positively towards the validation that this solution is both possible and delivers numerous benefits towards grazing operations and the industry at large.

Industry and Government bodies can assist adoption of this solution in numerous ways. Assisting the UAV industry to lobby for more practical regulations would be beneficial. Furthermore, support towards awareness, training, research, and development of home-grown technology would accelerate adoption.

Research gaps

More research and credible scientific evidence on the benefits of livestock drone mustering would greatly impact on future take-up. These benefits include animal welfare, environment, economics and increased productivity.

Operator's skill level

The skill level of the person operating the drone significantly influences the success of livestock drone mustering. Firstly, the operator needs to have a high level of stockmanship. Quality of stockmanship in a person can be subjective, as methods and ideology of how to work livestock varies. It was clear during these trials that drones are just another source of pressure for livestock to move off. To be successful with drones, the operator must understand how to correctly position around the mob and apply and release pressure, so the animals remain agile and responsive to the drone. They also need to strategically outthink the animals and have smart infrastructure and design to support the muster.

Technological skill will be important for the operator, but the technology itself should not be overly complex. The nature of isolation for livestock graziers with limited internet connection and other factors means the skill level with various technologies is lower than people in urban areas. With better connectivity and generation change, this is shifting, but adopting a new solution should not be difficult or confusing.

Training will ensure any gaps in these required skills can be closed. Face-to-face and online tutorials will complement each other for initial and ongoing learning.

Further use cases

Feedback from workshops suggests there is a desire in the industry to explore the variety of other use cases drones can offer on livestock operations. These include:

- Bird and other pest management from cropping areas
- Dingo, pigs and other pest detection
- Woody weed detection
- Multi-drone musters
- Surveillance e.g., waters, fences, stock.

International travel

Asia

During the Nuffield Scholarship, a comprehensive trip to Asia, encompassing Hong Kong, South Korea, and Japan, significantly advanced research on drone mustering by providing broader perspectives on technology development, regulatory frameworks, and potential collaborations.

In Hong Kong, engaging with Trade and Investment Queensland facilitated discussions around the latest advancements in drone technology and potential export opportunities for Queensland's agtech innovations. Interactions with industry experts elucidated the technological capabilities and manufacturing processes in the region, which are crucial for developing cost-effective and efficient drone solutions for livestock management.

South Korea offered insights into how the country has become more efficient and productive across various sectors through the integration of advanced technology. Visits to tech startups and research institutions highlighted South Korea's commitment to innovation and technological advancement. The application of these principles to agriculture demonstrated how efficiency and productivity could be significantly enhanced through the adoption of cutting-edge technology.

Japan provided valuable lessons on the importance of collaboration between different stakeholders, including government bodies, research institutions, and private companies, to drive the adoption of drone technology in agriculture. Meetings with representatives from Trade and Investment Queensland and various agricultural technology firms emphasised the need for precision and efficiency in technology development. These interactions underscored the potential for international collaboration to advance drone mustering practices and improve agricultural productivity.

Overall, the Asian trip underscored the significance of international collaboration and knowledge exchange in advancing drone mustering technology. It reinforced the importance of a supportive regulatory environment and continuous innovation to fully realise the benefits of drones in livestock management.

Figure 9: Virtual meeting with DJI, TIQ and Austrade (source: author)

United States

California

The United States trip began in California, arriving in San Francisco. With commercial interests in drone mustering, the immersion in the startup, business, and innovation culture was invaluable. Visits to co-working spaces provided opportunities to speak with fellow founders, sharing insights and experiences. The walk around Stanford University, known for being a breeding ground for many famous innovators, offered inspiration and a sense of connection to the broader tech community.

The tours of the Apple and Google campuses were particularly insightful, showcasing cutting-edge innovations and providing a glimpse into the operational excellence of these tech giants. A visit to the Computer History Museum further enriched this experience, offering a historical perspective on technological advancements. An autonomous ride in Google's Waymo ride-share service was a highlight, demonstrating the practical applications of advanced AI and autonomous vehicle technology.

Figure 10: Google campus (source: author)

In addition to exploring the tech hubs, visits to two primary producers in California provided practical insights into agricultural practices. The first visit was to Carissa Koopmann Rivers' family-owned ranch, located an hour east of San Francisco. Touring the ranch in a buggy with Carissa and her father, the operation's passion and meticulous management of pastures and livestock were evident.

Figure 11: Carissa Koopmann Rivers' family-owned ranch (source: author)

The second visit was to Chandler Farms in Selma, California, managed by John Chandler. Established in 1889, Chandler Farms grows almonds, citrus, peaches, plums, and raisin and wine grapes. John's extensive background in agriculture, including his work with the California State Senate Committee on Agriculture, provided a deep well of knowledge. Discussions on drone adoption in California highlighted regulatory barriers as a challenge, but also the potential benefits of integrating advanced technology into traditional farming practices. John's expertise and warm hospitality made the visit both informative and enjoyable.

Figure 12: Chandler Farms (source: author)

Las Vegas

The trip to Las Vegas was to attend the Commercial UAV Expo, where a VIP ticket was provided due to operating as a drone company. The Commercial UAV Expo is the leading international trade show and conference focused on the integration and operation of commercial UAS across various industries. The event features over 200 exhibitors and attracts thousands of drone professionals globally, making it a pivotal gathering for those in the drone industry.

Attending the Commercial UAV Expo was highly beneficial for research and networking. The event provided access to the latest advancements in drone technology, including new products, software solutions, and practical applications across different sectors. The conference sessions, led by industry leaders, offered valuable insights into current trends, regulatory updates, and future directions for

commercial UAVs. Networking opportunities with professionals from various industries facilitated discussions on potential collaborations and enterprise opportunities, enhancing the understanding of how drone technology can be further integrated and optimized within agricultural practices.

Figure 13: Commercial UAV Expo (source: author)

Israel

A personal trip to Israel was planned to explore advanced drone technology, leveraging the country's significant advancements in this field. However, the trip was cancelled due to the surprise attack by Hamas on October 7, which led to heightened security concerns and instability in the region.

Global Focus Program

Overview

The Nuffield Australia Global Focus Program (GFP) for September-October 2023 provided scholars with extensive insights into global agricultural practices through visits to Argentina, Ireland, France, and Poland. This journey was designed to expose participants to a variety of agricultural sectors and technologies, enhancing their understanding and knowledge.

Argentina

Buenos Aires:

- The group engaged with agricultural leaders and organisations such as the Buenos Aires Grain Exchange, Sociedad Rural, and Bioceres company.
- Cultural experiences included a cocktail function with the Australian Ambassador and a tour of Rosario port, enriching their understanding of Argentina's agricultural landscape.

Rosario:

- The scholars visited significant agricultural sites and had discussions on livestock genetics and mixed production agriculture, providing valuable insights into local practices.

A drone was amongst the luggage during the Global Focus Program and an opportunity presented itself in Argentina to muster some dairy cows. See Appendix 20.

Ireland

Dublin:

- Meetings with **Ornua**, Bord Bia, and the Department of Agriculture, Food, and the Marine offered a comprehensive view of Ireland's agricultural policies and market strategies.
- The group also attended the **National Ploughing Championships** and visited the **Teagasc** stand, witnessing innovative agricultural technologies and methods.

Kilkenny and Cork:

- Visits to **Teagasc Kilkenny**, Bretts Feed Mill, and O'Shea Farms showcased sustainable agricultural practices.
- Exploring **Farm Zero C** and Pat Collins's farm provided practical insights into sustainability and innovation in agriculture.

France

Paris and Carquefou:

- Discussions on dairy goat genetics at **Capgenes** and biodynamic techniques with **Robin Euvrard** offered an understanding of advanced agricultural genetics and sustainable farming methods.
- Touring a greenhouse for vegetables and flower production highlighted innovative approaches in horticulture.

Foussais and Limoges:

- Visits to **La Pibole** farm and the **Atelier de la Châtaigne** chestnut workshop provided a deep dive into organic farming practices.
- Engagements with local cooperatives demonstrated the effectiveness of community-driven agricultural initiatives.

Poland

Warsaw and Glubczyce:

- The scholars toured **Top Farms Group** operations, focusing on cereal, rape, potatoes, beets, and milk production under a regenerative agriculture regime, gaining insights into large-scale sustainable farming.
- Visits to the **Research Centre for Cultivar Testing** and **Kombinat Rolny Kietrz**, a government farm, showcased advanced research and agricultural practices.

Opole and Kórnik:

- Exploring the soil laboratory **FARMTECH** and local distilleries provided practical knowledge on soil health and sustainable production.
- Presentations on sustainable agriculture and field tours highlighted advanced farming practices and technologies.

The GFP itinerary offered scholars a rich and varied exposure to global agricultural practices, innovations, and regulatory frameworks. This international experience equipped participants with valuable knowledge and perspectives, enabling them to implement advanced and sustainable agricultural methods in their home countries.

Conclusions

The extensive research and trials detailed in this report underscore the transformative potential of drone technology in livestock mustering. The integration of drones into traditional mustering practices has been shown to enhance efficiency, safety, and productivity while also providing significant economic and environmental benefits.

Key Findings

Technological Advancements: The use of advanced drone models such as the DJI Matrice M30T and the DJI Mavic 3 Pro, equipped with high-performance sensors and robust command and control systems, has proven effective in various mustering scenarios. The ability to utilise thermal and zoom cameras has enabled more precise and efficient livestock management, surpassing traditional methods such as helicopter mustering.

Trial Outcomes: Nineteen different mustering trials across nine separate properties demonstrated that drones could effectively locate, start, and herd livestock in diverse terrains and weather conditions. These trials highlighted the practicality of drone mustering, showing significant reductions in stress for livestock and lower operational risks for graziers.

Economic Benefits: Economic analysis indicated that drone mustering could be a cost-effective alternative to helicopter mustering, with potential savings in operational costs and time. The introduction of more affordable drone models, such as the DJI Mavic 3 Enterprise Thermal, further enhances the return on investment, making this technology accessible to a broader range of livestock producers.

Regulatory Considerations: Navigating the regulatory framework for drone operations remains complex and time-consuming. The report advocates for industry and government collaboration to develop more practical regulations that support the broader adoption of drone technology in agriculture, particularly for extended and beyond visual line of sight (EVLOS and BVLOS) operations.

Global Insights: International travel to Asia, the United States, and participation in the Global Focus Program provided valuable perspectives on global agricultural practices and technological advancements. Engaging with international stakeholders and observing innovative applications of technology underscored the importance of global collaboration in advancing drone mustering practices.

Recommendations

1. **Industry Adoption:**
    - Increase awareness and demonstration of successful drone mustering practices through live demonstrations and video evidence.
    - Support from industry and government bodies in lobbying for practical regulatory changes to facilitate wider adoption.
2. **Research and Development:**
    - Continued research into the benefits of drone mustering, focusing on animal welfare, environmental impact, and economic efficiency.
    - Exploration of additional use cases for drones in agriculture, such as pest management, surveillance, and woody weed detection.
3. **Training and Skill Development:**
    - Provide comprehensive training programmes for drone operators, emphasising both stockmanship and technological proficiency.
    - Develop online tutorials and face-to-face workshops to ensure ongoing skill development and operational efficiency.

The findings and recommendations presented in this report highlight the significant potential of drone technology to revolutionise livestock mustering, offering a safer, more efficient, and economically viable solution for the agricultural industry. Continued innovation, supportive regulatory frameworks, and effective training will be essential in fully realising the benefits of this emerging technology.

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Appendices

Appendix 1: Footage of Oakleigh Trial

Footage of the Oakleigh trial can be viewed at the following link: https://www.youtube.com/watch?v=2SCxfz3SQuM

Appendix 2: Footage of Abbotsford Trial

Footage of the Abbotsford trial can be viewed at the following link: https://www.youtube.com/watch?v=_jKJZNprgIE

Appendix 3: Footage of Rodgers Creek Feedlot Trial

Footage of the Rodgers Creek Feedlot trial can be viewed at the following link: https://www.youtube.com/watch?v=uVW0q29LGBc

Appendix 4: Footage of Avington Trial

Footage of the Avington trial can be viewed at the following link: https://www.youtube.com/watch?v=JDGGxBaDm8w

Appendix 5: Footage of Redland Park Trial

Footage of the Redland Park trial can be viewed at the following link: https://www.youtube.com/watch?v=gD7uMway1J0

Appendix 6: Footage of Norlands Trial

Footage of the Norlands trial can be viewed at the following link: https://www.youtube.com/watch?v=0uOdXBuCBoo

Appendix 7: Footage of Malakoff Trial

Footage of the Malakoff trial can be viewed at the following link: https://www.youtube.com/watch?v=1BoWqGaQ5K4

Appendix 8: Footage of Tumbar Trial

Footage of the Tumbar trial can be viewed at the following link: https://www.youtube.com/watch?v=bzl3HDC1ztA

Appendix 9: Footage of Sheep Trial

Footage of the sheep trial can be viewed at the following link: https://youtu.be/_jKJZNprgIE

Appendix 10: Footage of Goats Trial

Footage of the goat's trial can be viewed at the following link: https://youtu.be/bvwN6VrzM0s

Appendix 11: Footage of Cattle Trial

Footage of the cattle trial can be viewed at the following link: https://youtu.be/L9ZV13pzHQg

Appendix 12: Additional Footage of Cattle Trial

Additional footage of the cattle trial can be viewed at the following link: https://youtu.be/4dFmtOlJRuk

Appendix 13: Additional Footage of Goats Trial

Additional footage of the goat's trial can be viewed at the following link: https://youtu.be/eYyiiYhxusk

Appendix 14: Footage of Yarding Up

Footage of yarding up can be viewed at the following link: https://youtu.be/PwjufHszsLU

Appendix 15: Footage of Night Mustering Trial

Footage of the night mustering trial can be viewed at the following link: https://www.youtube.com/watch?v=KPtNNMwmLvM

Appendix 16: Footage of Asset and Stock Surveillance Trial

Footage of the asset and stock surveillance trial can be viewed at the following link: https://www.youtube.com/watch?v=3ZvY9PlCnCE

Appendix 17: Footage of Predator Monitoring/Detection Trial

Footage of the predator monitoring/detection trial can be viewed at the following link: https://www.youtube.com/watch?v=Z_9IL_FfNwE

Appendix 18: Remotely Piloted Aircraft Systems - Licensing and Operations

The document "Remotely Piloted Aircraft Systems - Licensing and Operations" provides guidance on the categorisation of RPAs and general requirements for their use. It outlines licensing and operational requirements for remotely piloted aircraft systems (RPAS). Link: https://www.reocapplication.com/wp-content/uploads/2023/04/101-01-V4.pdf

Appendix 19: Drone Mustering - Economics Factsheet

The "Drone Mustering - Economics Factsheet" evaluates the costs and benefits of using drones for mustering cattle. The analysis includes drone cost assumptions, mustering scenarios, and investment results, highlighting the potential economic advantages of drone mustering over traditional methods. See below.

Appendix 20: Footage of Drone Mustering in Argentina

Footage of the drone mustering trial in Argentina can be viewed at the following link: https://www.youtube.com/watch?v=W2rVo8kDCuk

Drone mustering – costs & benefits

Using drones for mustering cattle is an emerging practice in the beef industry. Skykelpie promotes the use of drones for mustering by addressing regulatory and other barriers. The project is chaired by Luke Chaplain and supported by MLA and DAF.

An economic evaluation was completed to explore the costs and benefits of mustering cattle with a drone. It assumes a drone is purchased by a grazier to replace helicopter mustering (contracted services) and assumes the same efficacy.

Method

Table 1 outlines the drone assumptions. Labour requirements are assumed to remain the same with the helicopter pilot replaced by the drone operator and no changes to ground crew. No contract drone mustering on other properties is included. Table 2 shows the evaluated scenarios.

Table 1: Drone assumptions.

Drone cost	$24,673
Training & licence	$4,150*
Labour costs	$60/hour (drone operator)
Drone lifespan	5 years, no salvage value
Operating costs	$6/hour** (drone)
Flight time per full battery	30 minutes (advertised to be 41 minutes).
Battery life	250 hours (500 recharges)

* Including forgone wages when attending training ($2,400).
** $600 maintenance at 100 hours of flight time. Recharging of batteries is negligible at 10c per hour of flight.

Table 2: Mustering scenarios.

1) Three 2,000 ha paddocks needing 2 hours mustering each. Two musters a year over 5 years.
2) Same as above but three 5,000 ha paddocks (500 head each*) needing 5-hour musters each.
3) Drone used for total life of 3 batteries (750 hrs).

Results

Table 3 shows the investment results for each scenario. The cost reduction is not quite large enough to recoup the full outlay in five years for the three 2000 ha paddocks scenario (net present value of -$3,677). Although, an initial outlay of less than $25,146 would make the investment worthwhile. Alternatively, if the drone replaced at least 69 hours of the helicopter contractors flight time over 5 years, it would also make the investment acceptable.

In comparison, the 'three 2000 ha paddocks' and 'using the drone for the total life of three batteries' scenarios were both expected to be profitable investments with rates of return between 41% and 251% and payback expected within 3 years and 1 year, respectively.

Table 3: Investment analysis.

	Three 2000 ha paddocks	Three 5000 ha paddocks	Max. battery life
Total flight time	60 hrs	150 hrs	750 hrs
Initial outlay	-$28,823	-$28,823	-$28,823
Cost reduction ($/yr)	$5,808	$14,520	$72,600
Net Present Value	-$3,677	$34,041	$285,497
Annual Benefit	-$849	$7,863	$65,943
Rate of Return	0%	41%	251%
Payback period	>5 yrs	3 yrs	1 yr
Breakeven initial outlay	$25,146	$62,864	$314,320
Breakeven flight time	69 hours		

Other advantages

Other potential advantages include: premapping of musters with navigation to allow predawn starts and reduce livestock heat stress, increased timeliness of operations from less contract helicopter delays, increased flexibility in business operations to muster around events such as weather, and reduced risk of human fatalities or injuries from helicopter accidents.