

Final report for Biosecurity R&D Fund¹ research project: *Using interactive technologies to identify and map invasive cacti in the southern rangelands of WA*

Proponent: Goldfields Nullarbor Rangelands Biosecurity Association

Date of report: 22nd December 2017

1 Project information

1.1 Contact details

Project manager	Name: Ross Wood Phone: 0439 918 492 Email: ceo@gnrba.com.au
Best contact person post-project (where different to above)	Name: As above Phone: Email:
Start date	1 st July 2015
Finish date	31 st December 2017

1.2 Project objective

The aim of the project was to utilise innovative technologies- (thermal imaging; NDVI) to identify locations of cacti, leading to a more targeted approach to eradication. By managing this invasive weed, through identification then eradication, the region will be able to continue to build long term sustainability plans both on private land and public. This will have benefits for current and future pastoralists, tourists and government.

1.3 Project summary

The Goldfields Nullarbor Rangelands Biosecurity Association (GNRBA) has recently completed a Royalties for Regions and GNRBA funded project. Its aim was to utilise innovative technologies (thermal imaging and NDVI) to identify locations of cacti in the WA Goldfields region, leading to a more targeted approach to eradication of these declared weeds. By finding new, more innovative ways of managing this invasive weed, through identification then eradication, it is expected that the region will be able to continue to build long term sustainability plans both on private land and public. This will have benefits for current and future pastoralists, tourists and government.

The imminent spread of invasive cacti species is threatening the ecosystem and its inhabitants in parts of the southern rangelands of WA. If the cacti are not detected early and managed, and are left to spread, native flora and fauna in the ecosystem will be greatly impacted, along with any future production on private land and surrounding landscapes.

¹ The Biosecurity R&D Fund is part of the Boosting Biosecurity Defences project, supported by Royalties for Regions and the Department of Primary Industries and Regional Development (DPIRD).

Currently practices to identify and manage invasive cacti are labour intensive and expensive. There is also high risk of many plants not being found (therefore not treated) where the terrain is difficult to penetrate from the ground. It was therefore crucial that an enhanced, proactive approach be investigated that was cost effective and sustainable over time. This project has provided the opportunity for findings to be shared within the Kalgoorlie and Nullarbor region, and far beyond, for example, to the Gascoyne region of WA and the North West Local Land Services region of NSW.

Objective

The aim of the project was to utilise innovative technologies- (thermal imaging; NDVI) to identify locations of cacti, leading to a more targeted approach to eradication. By managing this invasive weed, through identification then eradication, the region will be able to continue to build long term sustainability plans both on private land and public. This will have benefits for current and future pastoralists, tourists and government. Findings from the project will also be able to be extended to other regions.

Methodology

The methodology followed by contractors, Precision Agronomics Australia, was extensive and complex. It involved flying 3 different types of Unmanned Aerial Vehicles (UAV's) with Near Infra-red cameras attached, over sites of known specific cacti infestations (Hudson Pear and Coral cactus species) at a range of different altitudes to map their locations. Images captured were then interpreted, and algorithms developed, to differentiate cacti plants from the rest of the scrub in the images. Maps were then developed that can be used on the ground to seek and destroy cacti plants. Part of the methodology included many ground truthing activities to ensure that images being captured and resulting algorithms were correctly reflecting what was found at the sites.

An extensive communications strategy was developed and implemented to ensure learnings from this project were communicated widely and effectively, including a Participatory Surveillance strategy to ensure ongoing vigilance and clear pathways to reporting of sightings of the declared weed now and in the future.

Key Findings

The Coral Cactus infestation was mapped relatively easily using a near infrared camera flying at 20m altitude. The Hudson Pear infestation was much harder to map due to the more complex vegetation and the occurrence of similar looking non-cactus plant species. The resulting algorithm was slow to implement and had a large proportion of type 1 errors. However, further refinement of the model using size and shape constraints, and software configuration to run in parallel, could be easily implemented to improve these outputs.

Awareness of the issues surrounding cacti in the region has built dramatically over the life of this project, due to this and other projects focussing on the eradication of this weed, led by the GNRBA. One of the pastoralists was quoted as saying, "I had no idea how bad this weed was out there until GNRBA brought it to my attention. We have to do what we can to make sure this weed doesn't end up on pastoral land." The Participatory Surveillance strategy will be an ideal vehicle to direct reported sightings and enquiries to the Dept of Primary Industries and Regional Development (DPIRD) where infestations can be logged, treated and monitored. Such a strategy embraces the power of anyone living or passing through the region, to be aware of the issue and know how to help address it in a proactive, collaborative manner.

Future audience

Through this project it has become evident that the problem of cacti as a weed of concern is more widespread than previously thought. This was particularly evident when November 2017 was purported in WA as 'Cacti Month' to build awareness around this growing, and often ignored, problem. Therefore, it is expected that this research innovation's relevance

and usage will be widespread, and certainly not limited geographically. This project has also presented questions around this technology and it's usage with weeds other than cacti. Such opportunities will likely be explored by others, based on this research.

The potential of this research is therefore exponential, and only limited by communication of the project and its findings.

Acknowledgements

The project proponents, GNRBA, would like to acknowledge the expertise, passion and guidance of the following people who assisted in this ground breaking research:

- Frank D'Emden, Precision Agronomics Australia
- Alberto Dri, Luminis Analytics
- Ajmal Mian, University of WA
- Tamrika Lanoiselet, DPIRD
- Sandy Lloyd, DPIRD
- Justin Stevens, Mt Vettors Station
- Darren Rowtcliff, Tarmoola Station
- Shire of Menzies
- Shire of Coolgardie
- Shire of Leonora.

2 Project performance

2.1 Did the project deliver all milestones?

Yes

2.2 Performance against outcomes

Outcome within project - 1: Strategic approach, through data collection and mapping, to the identification and management of invasive cacti in the southern Rangelands.

Due to the technical nature of this project, Precision Agronomics Australia (PAA) was contracted to provide the 'strategic approach, through data collection and mapping, to the identification and management of invasive cacti in the southern Rangelands'. The subsequent report is attached.

All activities were conducted to achieve this project outcome, with four sites of 80ha's identified and all being flown over by a UAV and images taken, as stated in Milestone 2. As is the case with the exploration of any new innovation, there is an element of trial and error in order to reach the best outcome, as there are so many unknown's at the beginning when planning a project. On studying the sites in greater detail with the contractors, it was agreed by all parties to focus on the data collection and analytics (Milestone 3 and 5) at just two of the sites – Tarmoola Station for the Coral Cactus and Coolgardie for the Hudson Pear – as these sites were going to provide the best result for the next stages of the project, given there were many more live plants that could be used for the project at these two locations and both provided alternate landscape variables indicative of the country (see PAA Final Report). The Menzies site also presented with difficulties due to the proximity to the Menzies airstrip. This tactic proved very successful in enabling a more informed 'deep dive' of the potential of this technology than would have been, had the project tried to spread itself across 4 sites and vast distances.

In summary, from the PAA report:

- Two locations representing typical infestations of Coral Cactus and Hudson Pear at Tarmoola Station and Coolgardie respectively were mapped using three types of UAVs at a range of different altitudes. Image analysis techniques were then applied to the orthomosaics from each site in an attempt to automate the detection of each species.
- The Coral Cactus infestation at Tarmoola Station was mapped relatively easily using a near infrared camera flying at 20m altitude.
- The Hudson Pear Cactus infestation at Coolgardie was much harder to map due to the more complex vegetation and the occurrence of similar looking non-cactus plant species. The resulting algorithm was slow to implement and had a large proportion of type 1 errors, however further refinement of the model using size and shape constraints, and software configuration to run in parallel, could be easily implemented to improve these outputs.
- It was determined that multirotor UAVs would provide a more stable platform to enable the acquisition of sharper imagery than the fixed-wing UAV. Multirotor UAVs are also more commonly available as consumer or 'prosumer' devices which is likely to be required if the rangelands and pastoralist community are to adopt the technology as a means to target cactus control efforts. The downside of multirotor UAVs is that they are less efficient at capturing imagery over large areas which is an important consideration in the rangelands.
- There are trade-offs between the resolution of the imagery, type of camera, flight times and imagery processing times. These are all reflected in the accuracy of the image analysis.
- Cameras with near-infrared and red-edge detection capabilities can provide additional image data that improves image analysis, however these cameras tend to have a lower resolution and are more expensive. The imagery from near-infrared and red edge cameras also takes longer to process (often at least twice as long) due to the larger volumes of data contained in the images.
- Infra-red thermal sensors were installed at the Coolgardie site to obtain plant canopy temperature data from a Hudson Pear cacti and a neighbouring native Acacia species, to test whether cacti plants that are obscured from an aerial (UAV) view by shrub and tree canopies could be distinguished from surrounding vegetation using thermal cameras.

Outcome within project - 2: Demonstration of use and affordability of technologies to address biosecurity issues in rangeland environments (Public and private benefit, both in the southern Rangelands and beyond)

The PAA report contains details regarding the possible usage of this technology to address biosecurity issues around Hudson Pear and Coral cacti infestations in the Goldfields Nullarbor region and likely usage in similar landscapes.

Affordability of this technology can really only be estimated, although it is clear that these technologies will likely reduce in cost over time as UAV's and suitable cameras become cheaper. An approximate estimation of costs (based on the minimum requirements) are as follows:

- DJI Inspire UAV (\$3500 AU)
- Multispectral camera (\$3500 US)
- Software for the image stitching and orthomosaic development (\$8700 USD for a perpetual license, \$3500 USD for an annual license or \$350 USD/month)
- High-spec computer for the image processing (\$12,000 AU).

NB DPIRD is planning to conduct some economic analysis work on invasive cacti using information from this project in March/April 2018, which is expected to add value to this research and support ongoing decision-making about cacti management in the rangelands.

Outcome within project - 3: Demonstration of collaborating parties working together towards a common outcome and promoting a common, positive message to the wider community.

Throughout the project there was extensive collaboration between many parties, which in many cases led to further linkages outside the project. Centrally, this project linked GNRBA, its members and staff with experts in the field of

- Precision agronomics (specifically UAV technology) through Precision Agronomics Australia, which led to benefits beyond the project through activities such as usage of UAV's in areas other than mapping of cacti
- Image interpretation and data analysis with staff at University of Western Australia and one of their consultants. This work provided an insight into the rangelands and its landscape which may then be used to further advantage, such as the impact variable nature of cacti plants at different times of year and stages of maturity

Beyond those contracted to deliver services, there were extensive examples of parties working together. These included

- WA Dept. of Biodiversity, Conservation and Attractions (formerly WA Dept. of Parks and Wildlife) through their attendance at some of the ground truthing visits, along with participating in the GNRBA bus tour where the two of the cacti sites were visited. Many informal conversations were had regarding the nature of the cacti infestations on Govt. owned land and ways to identify, manage and treat the plants.
- Kalgoorlie Boulder Urban Landcare Group (KBULG) CEO attended the bus tour and also worked with GNRBA on another project, the Williamstown Cacti Mechanical Removal project - a joint collaboration between KCGM (Kalgoorlie Consolidated Gold Mines), CKB (City of Kalgoorlie-Boulder); GNRBA (Goldfields Nullarbor Rangelands Biosecurity Association); DPaW (Dept. of Parks and Wildlife); DAFWA (Dept. of Agriculture and Food WA); and BC&M (Boulder Contracting and Maintenance). Many informal conversations were had regarding cacti infestations within the KBULG region and how to identify, manage and treat the plants.
- Local Shires were liaised with constantly as the project progressed, to keep them informed of findings. The Bus Tour group was hosted by both the Menzies and Leonora Shires where the project activities were discussed and personnel of all groups were able to interact and share experiences and build networks to strengthen future linkages.
- The local printed media and local ABC radio worked with GNRBA to promote the work of this project to bring it to the attention of the wider public. Both look to GNRBA to seek the most up to date and honest appraisal of biosecurity work in the region.
- A pastoralist from Winning Station in the Gascoyne, who has found cacti on her property, heard of this project and after contact with GNRBA, visited the PAA offices in Midland to learn how to use the equipment with a view to seeking funds to get footage of her cacti infestation. As stated in the PAA Final Report, she also intends to share her knowledge further in the Gascoyne region, which GNRBA are more than happy to assist with further information where required.

Outcome beyond project 1: reduce the spread of cacti on public land therefore reducing the likelihood of cacti spreading into privately owned land, benefiting pastoralists and farmers

This project and GNRBA's activities have catapulted the issue of cacti infestations on public land onto the radar far and wide, and offered a possible solution of ways to find as many cacti as possible on public land so they can be treated before reaching pastoral land (mostly under leasehold). It is now the responsibility of the managers of this public land to utilise this information to treat the known infestations (which is already being actively pursued by some local shires) and find any other problem areas. GNRBA is confident that this work is being done and will continue to be done, however, there will need to be vigilance to ensure further outbreaks do not occur.

One of the significant outcomes of this project has been the use of this technology to more easily identify the location of outliers at known infestations to reduce the likelihood of the cacti currently in public land, spreading into private lease holds (noting most of the land is pastoral leasehold so is Govt. owned, but managed by pastoralists under tenure arrangements). It is often the case that these outliers are the hub, or 'nursery' of infestations whose 'offspring' are carried by birds and other animals, waterways or wind to create their own problem areas. Given these areas are often a distance from these main hubs, often the offshoot locations are the ones found and treated, leaving the hub/nursery sites untouched and continuing to wreak havoc.

This project has also highlighted the issue of cacti infestations to pastoralists, so they are now more aware of the need to keep vigilant and report and/or treat any plants they find, either on the properties they lease, or in land adjoining theirs. This also extends to the broader public either residing in the area or passing through.

Outcome beyond project 2: reduce the spread of cacti on public land benefiting public and private stakeholders

The initiation of this project by GNRBA and the highlighting of this issue to a broader audience, has made cacti, and the management of this weed, a more central topic of conversation across many of the collaborating parties and across the whole of the Goldfields and Nullarbor region. Where it was once not something discussed actively or just seen as something the local shires had to contend with on their own, it is now well and truly seen as a regional issue and this project has presented stakeholders with an innovative solution to assist them in the fight against invasive cacti and a strong network of organisations that can work together, such as through Goldfields Voluntary Regional Organisation of Councils (GVROC). GNRBA is confident that managers of the public land will continue to work hard to find and eradicate cacti, and will be able to provide further information and networks to them to help them continue this work.

A significant factor in the ongoing fight against the cacti whilst it is still mainly found on public land, beyond the life of this project, will be through the implemented Participatory Surveillance system whereby the public will be able to be more engaged in awareness and reporting of any cacti sighted. The more eyes on public land looking for and reporting these plants the better and this strategy provides a strong and clear pathway for any members of the public in the region to do so. This information is then fed straight back to the Dept. of Primary Industries and Regional Development, whose role it is to log the sightings and advise the relevant bodies of the issue.

Outcome beyond project 3: strengthened relationships between collaborating parties and others, nurturing and guiding future collaborations towards shared objectives, which will benefit all stakeholders operating in the southern rangelands now and in the future.

The benefits gained during the project will likely be continued beyond the project, which can be partly attributed to this project. Future activities and/or projects will continue to be sought and/or supported by the GNRBA where it falls within its charter. For example, on the bus tour, the Tarmoola site was visited and the trial release of the Cochineal bug was inspected. This led to discussion regarding the need for a project to assist in the spread of the bug to other known infestations. On return from the bus tour, GNRBA immediately applied for funds from State NRM to do this, and was successful. This project is currently under negotiation and development.

The pathway between the public and Govt. (state and local) agencies may also be strengthened through the more visible means for the public to report sightings of cacti and weeds in general. The material distributed through the project will have a long lasting impact as new people continue to travel through the area and venture into public lands for professional and/or recreational purposes. The material will also provide an ongoing reminder to those residing in the area, to continue to be vigilant.

Outcome beyond project 4: demonstrating leadership in biosecurity through taking a proactive approach to the prevention, early detection and management of invasive plants, such as cacti, in the southern rangelands

GNRBA is viewed as a leader in the area of biosecurity both regionally and the broader rangelands areas of WA. It is through projects such as these, which delve into areas not otherwise occupied by biosecurity groups that sets a pillar of leadership and a vision for identifying possible future hazards for its members. Cacti is not currently an issue for pastoralists – the ratepayers of the GNRBA. However, it is through the leadership and vision of the group that identified cacti as a huge threat to the viability of pastoralism, should this weed be left untreated and creep into the pastoral country. One can only imagine the detrimental effect these plants would have to livestock on pastoral properties, not to mention the impact on native animals and wildlife.

This project (along with other projects developed by the GNRBA) has been a vehicle to enhance collaboration of many organisations and businesses, providing a central focus of significance to all parties. It has also brought technologies and providers with specific skills and knowledge, into the region.

The GNRBA Innovation Conference has been held for the past three years and has hosted between 55 and 90 attendees at each event. Cacti has been discussed and information shared at each of the events, further demonstrating leadership of biosecurity to members and others outside the organisation. In 2016, boxes of the cochineal bug infested cacti were present, to bring the cacti to the people so understanding of the issue could be further highlighted with real, tangible evidence. This conference will continue to be held and the prevention, early detection and management of cacti will be part of the information sharing.

Given GNRBA's reputation of leadership, the website will continue to be seen as a valuable source of information, so those in other parts of the Southern Rangelands will continue to be able to visit the GNRBA website for further information, as will any members of the public.

2.3 List of key project outputs or products

Key output or product	Purpose (use) and potential users?	How accessible to potential users?
“GNRBA Cactus Identification Project - Final Report” by Precision Agronomics Australia, Nov 2017	Outlines technological approach taken and results; Potentially of interest to anyone wanting to map/target weeds on a larger scale/in difficult terrain, or anyone interested in the rapidly developing technology itself.	Attached to this final report; Available at GNRBA office (27 Charlotte St, Kalgoorlie) and on GNRBA website www.gnrba.com.au GNRBA email contact: admin@gnrba.com.au
<p>Final versions of the maps of the two research sites flown with cacti infestations circled; These maps are the tool that land managers would use to physically locate cacti infestations for direct control; Available digitally or as printed version; GPS coordinates direct the search to within 4m on-ground.</p> <p>These ‘end-product’ maps are intended to be digitally ‘small’ enough for a land manager to be able to use on-ground with a standard consumer-level mobile device - in conjunction with GPS functionality</p> <ul style="list-style-type: none"> • Map of site 1 (Tarmoola Station/Leonora) - 20ha of low open shrubland with Coral cactus infestations circled. • Map of site 2 (Kangaroo Hills Timber Reserve/Coolgardie) - 20ha of tall open woodland/low open shrubland with Brown-spined Hudson pear infestations circled. 	These maps are firstly useful for strategic cacti control by the relevant land managers on the two sites themselves. More broadly, they are useful to demonstrate to others the practical end product (and future potential) of the research approach of UAV image capture and analysis to map/target weeds on a larger scale or in difficult terrain.	<p>Hard copy maps are included in above Precision Agronomics Australia (PAA) final report; Digital and hard copy versions available at GNRBA office (contact details above).</p> <p>Maps (with other research project information) will also be presented or distributed via existing GNRBA networks and events as relevant, and potential value discussed.</p>
<p>Short (1.11min) YouTube video showing some of the research activities; centred around a UAV being set and flown at one of the research sites.</p> <p>YouTube title ‘GNRBA R4R research project (cactus identification)’</p>	General promotional material - provides a taste of what the project was about.	<p>YouTube link: https://www.youtube.com/watch?v=IQD4pk2Y82E</p> <p>Link on GNRBA website: www.gnrba.com.au</p>
Case study on the research project titled ‘Smart technology targets cactus control’; 2-page summary available electronically or printed.	General promotional material about research project.	Available at GNRBA office and on GNRBA website (see above) and distributed via existing GNRBA networks and events.

Key output or product (cont.)	Purpose (use) and potential users?	How is accessible to potential users?
<p>Existing DPIRD information materials relevant to research project - reprinted and/or distributed/promoted by GNRBA as part of project communication strategy:</p> <ul style="list-style-type: none"> • My Weed Watcher laminated posters (A3 & A2) • Wanted dead or alive cacti laminated posters (A3 and A2) • Wanted dead or alive' cacti rip off pads • Weeds of Western Australia Facebook link https://www.facebook.com/groups/WeedsOfWesternAustralia/ 	<p>General promotional material about the problem of invasive cacti, how to identify them, and how to report cacti if sighted.</p>	<p>Available at GNRBA office and distributed via existing GNRBA networks and events as relevant.</p> <p>Facebook page link promoted in GNRBA newsletter.</p>
<p>Raw digital images captured from UAV flights at each of the two research sites.</p> <ul style="list-style-type: none"> • Images from site 1 (Tarmoola Station/Leonora) - 20ha of low open shrubland with typical infestations Coral cactus. • Images of site 2 (Kangaroo Hills Timber Reserve/Coolgardie) - 20ha of tall open woodland/low open shrubland with typical infestations of Brown-spined Hudson pear. 	<p>Requires high-powered computer hardware and specialised software to run, and are small areas in the rangelands context; Unlikely to be useful for other applications, but wanted to record that GNRBA has access to the data should any other use come up in future.</p>	<p>Accessible via Precision Agronomics Australia.</p> <p>Contact Frank D'Emden frank.demden@precisionag.com.au</p>
<p>Algorithms – At the project end, there were two 'final image recognition algorithms developed to enable differentiation of Coral cactus in low open shrubland and Hudson pear in tall open woodland/low open shrubland from surrounding vegetation. The final algorithm for each site was specific to that vegetation/ecology, and a particular UAV type, camera type and altitude.</p>	<p>These algorithms - as at the end point of the project - are likely to be out of date almost immediately, as they are designed to inherently adjust and improve with every new data set applied, and because image analysis and artificial intelligence technologies are in a phase of rapid evolution.</p>	<p>Accessible via Precision Agronomics Australia.</p> <p>Contact Frank D'Emden frank.demden@precisionag.com.au</p>

2.4 Did the project deliver on time/on schedule?

- Yes

3. Project budget

3.1 Final acquittal statement attached?

- Yes

3.2 Were there any unspent funds at the project end?

- No

3.3 Was there any variation to planned budget allocation?

- No

4. Stakeholders

4.1 Stakeholder input into project

Jenny Crisp, Development Officer, Biosecurity and Regulation, Agriculture and Food, Department of Primary Industries and Regional Development was contacted informally on the phone or by email at times throughout the project to discuss particular aspects of the project or to clarify any expectations of the project.

4.2 Collaborator contributions

All organisations listed as collaborators contributed as was outlined in the project plan, although some staff changes occurred during the life of the project (RNRM, DPaW, DAFWA/DPIRD)

Collaborator	Contributions agreed in project plan?	Actual contributions (relative to agreed)
Goldfields Nullarbor Rangelands Biosecurity Association; Ross Wood, Executive Officer	\$15,000 In-kind operational and logistics management	\$15,000 cash provided to the project Gnrba provided in-kind support through guidance and interactions with PAA, Luminis and UWA including ground truthing; arranging pastoralists and agency liaison; project liaison; map relevance feedback; mentoring of participants; impromptu communications of project;
Rangelands NRM; Jane Bradley, Program Manager	In-kind Communications and promotion	Jane Bradley replaced by Kieran Massie Distribution of material through their networks across Rangelands ie RNRM newsletter and email updates Attendance at Annual Conferences Sharing of project informally across Rangelands region
Dept of Agriculture and Food WA; Mac Jensen, Leader - Southern Rangelands Invasive Species	In-kind operational planning support	Mac Jensen left DPIRD mid project. Not replaced locally. Prior to his leaving, provided support to Gnrba CEO with additional local cacti knowledge and liaison with DPIRD

Dept of Parks and Wildlife; Ian Keally, Regional Manager Kalgoorlie	In-kind mapping and logistics support	Ian Keally replaced by Nigel Wessels. Assistance to GNRBA CEO for logistical support and ground truthing when operating on Crown Land eg Coolgardie site; advice regarding weed status and Crown Land landscapes
Pastoralists - Kalgoorlie Pastoral Alliance P/L; Ross Wood, Executive Officer	In-kind local knowledge and accommodation, attendance at workshop and training	Pastoralists conferred with on local sightings and landscape; attended training workshops; ground truthing on Tarmoola Stn. Accommodation not required

5. Use of research findings

5.1 Was any Intellectual Property (IP) generated in the course of the project?

Yes - The two final image recognition algorithms for image analysis of the two species (Coral cactus in low open shrubland and Hudson pear in tall open woodland/low open shrubland) were developed within the project, using existing software and existing knowledge in the fields of image analysis and artificial intelligence (including neural network processing). These algorithms though - as at the end point of the project - are likely to be out of date almost immediately as they are inherently designed to adjust and improve with every new data set applied (there was already interest in using the Hudson pear algorithm for a NSW data set). Also, the fields of image analysis and artificial intelligence are in very rapid evolution with the demands of emerging technologies such as autonomous vehicles and automated security/surveillance, and it is expected current technology will be very quickly superseded.

5.2 Who will use the findings from your research?

The following table outlines who is likely to use the findings and/or materials from our research, and how they would use it.

Potential user of research	How would they use it?	*Steps taken to inform potential users of research findings
Local Shires – Menzies, Leonora, Coolgardie, Laverton, Wiluna (including any of their information centres)	Investigate possibilities of using this technology to seek and/or monitor sites in own shires in order to more cost effectively manage cacti infestations. Display Participatory Surveillance materials in offices, libraries, toilet blocks, schools, hospitals etc Include information in own communication networks ie newsletters & websites	Send PAA report and follow up with explanation of possible value/relevance to their shire Distribute posters, pads, case studies – includes face to face explanation of materials, project intent and follow up avenues, such as GNRBA website & Weeds Facebook page
DPIRD & DBCA	Investigate possibilities of using this technology to seek and/or monitor sites in own departments in order to more cost effectively manage cacti infestations. Display Participatory Surveillance materials in offices Include information in own communication networks ie newsletters & websites	Send PAA report and follow up with explanation of possible value/relevance to their departments Distribute posters, pads, case studies – includes face to face explanation of materials, project intent and follow up avenues, such as GNRBA website & Weeds Facebook page

GNRBA & other biosecurity organisations	<p>Investigate possibilities of using this technology to seek and/or monitor sites in own regions in order to more cost effectively manage cacti infestations. This could also stimulate thinking around the potential for this technology to be modified for other invasive cacti species (or other weeds)</p> <p>Display Participatory Surveillance materials in offices</p> <p>Include information in own communication networks ie newsletters & websites</p>	<p>Send PAA report and follow up with explanation of possible value/relevance to their organisations</p> <p>Distribute (local groups only) posters, pads, case studies – includes face to face explanation of materials, project intent and follow up avenues, such as GNRBA website & Weeds Facebook page. Advise other groups of materials which can be provided on request at that group's cost for postage</p>
Rangelands NRM	<p>Investigate possibilities of using this technology to assist groups to seek and/or monitor sites in the rangelands, in order to more cost effectively manage cacti infestations. This could also stimulate thinking around the potential for this technology to be modified for other invasive cacti species (or other weeds)</p> <p>Display Participatory Surveillance materials in offices</p> <p>Include information in own communication networks ie newsletters & websites</p>	<p>Send PAA report and follow up with explanation of possible value/relevance to their organisations</p> <p>Advise of materials available (posters, pads, case studies) and provide explanation of project intent and follow up avenues, such as GNRBA website & Weeds Facebook page.</p>
Pastoralists	<p>Read any of the outputs of the project and contact GNRBA for advice on next steps if they wish to investigate further on own leaseholds</p>	<p>Article in GNRBA newsletter summarising project and avenues for follow up.</p> <p>Reminder at events in the future</p>
Indigenous communities	<p>Investigate possibilities of using this technology to assist groups to seek and/or monitor sites in the rangelands, in order to more cost effectively manage cacti infestations. This could also stimulate thinking around the potential for this technology to be modified for other invasive cacti species (or other weeds)</p> <p>Display Participatory Surveillance materials in community facilities</p>	<p>Advise of materials available (posters, pads, case studies) and provide explanation of project intent and follow up avenues, such as GNRBA website & Weeds Facebook page.</p>
General public (including interstate), including roadhouse staff & visitors	<p>To inform others and/or report any sightings or find further information on what is being done to manage cacti in the region</p>	<p>Distribute (local groups only ie roadhouses) posters, pads, case studies</p> <p>Provide PAA report on request to distribute through Society of Precision Agriculture Australia contacts</p> <p>Word of mouth for general public/tourists through travelling networks and social media</p>

*Some of these steps will not be implemented until approval of final report by the funding body, such as distribution of the PAA report

5.3 What are the next steps for your research?

In the immediate future (pending available funds), the model for the GNRBA going forward might look like:

- Land managers identify cacti infestations of concern and approach the GNRBA.
- GNRBA support land managers with small contracts to strategically fly the site (particularly looking for outliers in relation to hub/core) and produce a map of the infestation/s.
- *Or* - there could be efficiencies in GNRBA purchasing a drone, training a local pilot and sending digital images for external analysis and map production. The speed of technological advances in UAVs and their capacity though, could outdate the purchase in a fairly short timeframe.
- Land managers commit to controlling mapped infestation in a targeted way.

The more sites/vegetation systems that are successfully mapped in this way, the more transferable the algorithm will be to a broader range of vegetation systems. Should opportunities arise for further mapping in the GNRBA region arise, not only will declared weed management in the region be supported, but further technology development will also be supported, as outlined in recommendations 1, 2 and 3 from the PAA final report below.

- ✓ Recommendation 1 - Continue to develop the Hudson Pear neural network algorithm to reduce the proportion of type I errors and processing time to acceptable levels.
- ✓ Recommendation 2 - Collect image datasets from other infestations of Coral Cactus and Hudson Pear to test the effectiveness of the algorithms in different vegetation assemblages. A conscious effort was made to balance the image analysis efforts between constructing useful algorithms for identifying the two types of cactus, and a procedure would enable relatively easy refinement of the model to different vegetation assemblages. Further work to automate these procedures and create a user interface would create a valuable resource for biosecurity organisations.
- ✓ Recommendation 3 - Refine the image analysis procedures to a point where they can be used by an experienced QGIS user. The neural network algorithms are currently implemented in a Linux operating system environment. Further development is required to enable the algorithms to be implemented through a user-friendly Windows-based operating system.

Technological advances in the realms of UAVs, miniaturised imaging devices and graphics processors are expected to continue at a fast pace. The fields of image analysis and artificial intelligence are also rapidly evolving with the demands of emerging technologies such as autonomous vehicles and automated security/surveillance. Increases in the availability of low cost data storage and computing power means increased capacity to analyse large amounts of data and run image recognition applications by more users.

6. Communications

6.1 What communications have taken place (or will take place?)

Communications was a large of this project as it was clear to GNRBA that there was limited awareness of the severity and spread of invasive cacti and the threat it poses to pastoral land if left to spread from current infestations, some known and others not. Given people's preferences for varying types of communication mediums, a range of materials were produced. The following activities were carried out as per attached Communications Strategy developed as part of the project:

- Two media releases were written and provided to local papers. Copies are attached. Kalgoorlie Miner printed an article (attached) based on this project.

- Article in Kalgoorlie Miner (not sure what paper that was?) July 2015 - 'Funds for dog baits, cacti'.
- ABC Rural radio interview (Frank D'Emden interviewed by Tara Delandgrafft) 22nd September 2015 - 'Western Australian pastoralists pinpoint prickly pear using drones'.
- Presentation and demonstration at GNRBA Kalgoorlie Innovation Conference 22nd Sept 2015 by Frank D'Emden of Precision Agronomics Australia, which included an introduction by GNRBA Executive Officer, Ross Wood.
- Presentation at Carnarvon Rangelands Biosecurity Association Innovation Conference 11th November 2015 by Frank D'Emden of Precision Agronomics Australia.
- Article in the Kalgoorlie Miner newspaper 14th March 2016 - 'Pastoralists use drones to hunt down rogue cacti'.
- A 2-page Case Study summarising the project approach and outcomes was professionally written, designed and made available in printed form and will be added to the website on approval of this report, outlining the project. The printed case study will be made available to local shires, local Govt. departments, interested community groups, GNRBA members and at any events held by GNRBA in the future. Copies can be made available to anyone else on request.
- A Participatory Surveillance strategy was also developed to ensure there was a clear path for any member of the public to report sightings of cacti (not necessarily restricted to Hudson Pear and Coral cacti). Posters were accessed and printed that will be distributed to locations such as local shire and roadhouses, along with 'rip off sheets' on pads that people can take with them on the road to reference if they see cacti in their travels. This has a QR code, phone number and website to contact if people wish to report any sightings. These materials were provided by DPIRD. It was decided that it was sensible to utilise current material available rather than create our own, so there are common messages and pathways throughout the state for the public to report sightings. GNRBA will assist in the distribution of these materials throughout the Goldfields and Nullarbor which will assist in spreading the message of vigilant surveillance to help protect the rangelands and our industries. The Weeds of WA Facebook page will also be promoted through GNRBA channels such as the newsletter, as this is reported to be one of the most effective and timely platforms for the reporting of weeds. All reporting through this Participatory Surveillance strategy goes straight through the DPIRD for any actions required, as is appropriate in management of weeds in WA.

6.2 Please provide photos

Photos provided

- Frank D'Emden (Precision Agronomics Australia) shows pastoralist Darren Rowtcliff (Tarmoola Station) the workings of UAV equipment in March 2016
- Ajmal Mian (UWA), Frank D'Emden (Precision Agronomics Australia) and Alberto Dri (Luminis Analytics) discuss the project in December 2016

Appendix 1: Completed project milestones

Milestone	Due Date	Payment on milestone	Status
1. Signed contract returned to WAAA with tax invoice for initial payment	1 July 2015	\$31,700 (20%)	Completed; payment made
2. Identification of 4 most appropriate sites (80ha each) completed	31 Dec 2015	\$60,000	Completed; 4 sites identified
3. Data collection using UAV's and infrared camera technology completed	31 May 2016	\$58,800	Completed; data collected 4 sites; refined to 2 sites to gather more detailed data
1. Annual progress report to WAAA	31 Jul 2016	-	Not required; close to previous report
2. Collate data and develop report and maps	31 Dec 2016		Data collated; report and maps completed
3. Communication Strategy developed and implemented (2 workshops, including training in use of technology, Participatory Surveillance system implemented, 2 media releases, 1 case study, 1 video)	30 May 2017	-	Completed all items (participatory surveillance implemented Dec 17)
4. Annual progress report to WAAA	31 Jul 2017	-	Completed
Pre-payment for final report milestone requested by R Wood; Approval given by J Crisp Sept 2017 (with verbal or emailed summary interim report)	30 Nov 2017	\$8,000 (5%)	Invoice submitted Verbal report provided
5. Deliver final report to WAAA	31 Dec 2017	\$8,000 (5%)	Completed